United States
Department of
Agriculture

Forest Service

Pacific Southwest Forest and Range Experiment Station

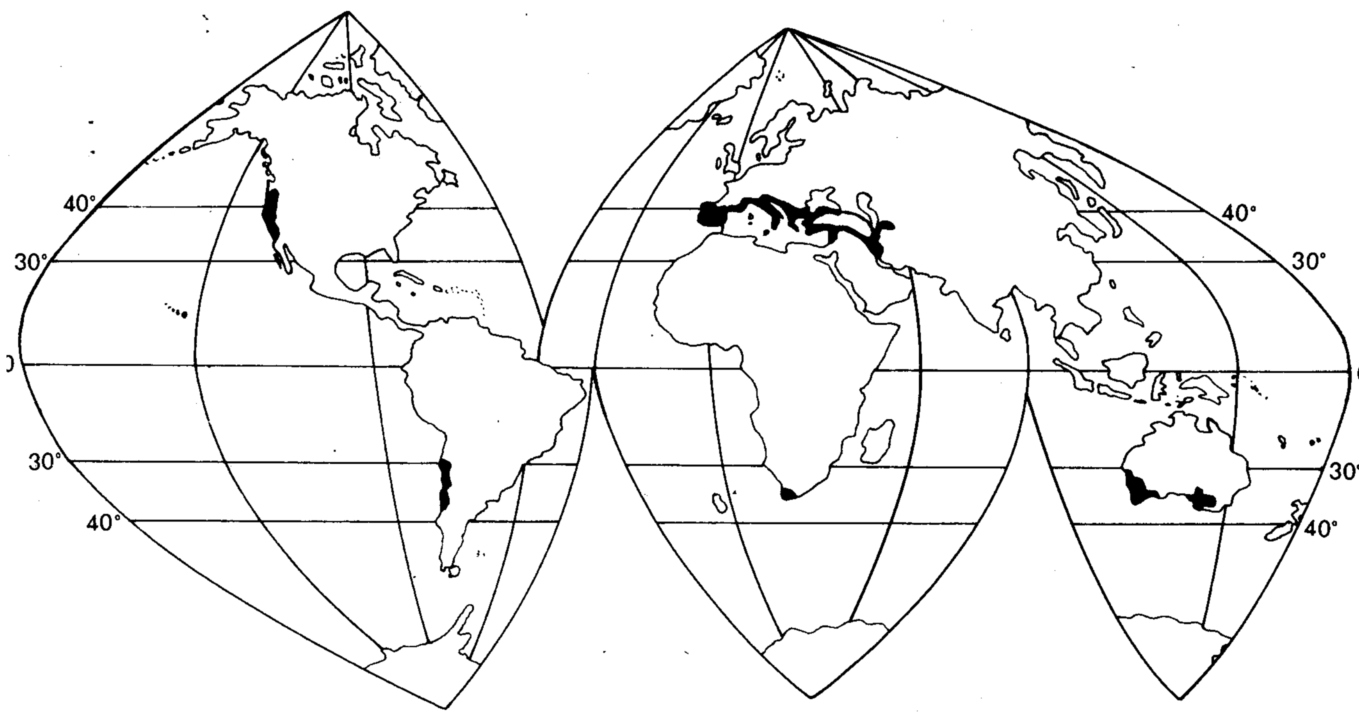
General Technical Report PSW-58

Proceedings of the Symposium on

Dynamics and Management of Mediterranean-Type Ecosystems

June 22-26, 1981, San Diego, California

San Diego State University



Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

June 1982

Proceedings of the Symposium on

Dynamics and Management of Mediterranean-Type Ecosystems

June 22-26, 1981, San Diego, California

San Diego State University

Technical Coordinators:

C. Eugene Conrad
Pacific Southwest Forest and Range Experiment Station

Walter C. Oechel
San Diego State University

CONTENTS

PREFACE

Mediterranean-type ecosystems, which typically have a summer drought, are of worldwide importance. They are present in North and South America, Europe, Africa, and Australia. In California, the regions of Mediterranean climate contain more than 70 percent of the State's population in about 40 percent of its land area. The Mediterranean Rim countries have high population concentrations and ancient cultures. The South African, Australian, and Chilean ecosystems, though less densely populated, have long histories of human impact.

Much of the conceptual development and organization of this Symposium arose from the great need to establish better mechanisms of information exchange between scientists and resource managers. This need is recognized as an international problem. We therefore envisioned a forum for the exchange of information that would meet the following requirements:

- Provide opportunity for researchers and practitioners to talk to each other
- Involve representatives of many nations and many disciplines, and deal with many levels of ecosystem organization
- Generate a published volume of proceedings as a source of information for participants and others.

The first two of these requirements were met during the conferences. Publication of these Proceedings meets the third requirement.

Some of the participants at the conference described themselves as practitioners; others, in about equal numbers, as researchers. These two groups made up more than two-thirds of the participants. Others described themselves as primarily educators, students, environmentalists, or members of the interested public. Of the 377 or more registered participants, about 10 percent were from countries other than the United States.

Numerous sponsoring organizations, listed on the preceding page, contributed money, time, and supplies to the Symposium. Also listed are those persons who shared in organizing and carrying out the meetings. The task could not have been accomplished without the support of these groups. Not included in the list are a great many special people in each of the sponsoring organizations who also made important things happen. These workers were involved all the way from the first ideas for the Symposium to the completion of this publication. It is the anonymous workers who make those who are named look good.

The 5-day Symposium was organized into 15 sessions, a number which made necessary two and even three concurrent sessions at times. Selected product displays were in place during the day and posters were presented at two evening sessions. As much as possible, the sessions were arranged to avoid conflict between closely related subjects in the same time slots. These Proceedings, therefore, do not follow the day-to-day sequence of the program, but are organized according to subject matter.

An examination of the "Perspectives" of scientific and management programs began the Symposium and also introduces these Proceedings. Following are sections on "Vegetation," "Fauna," "Soils," "Hydrology," and "Fire," each drawing the appropriate sessions together. Then a section on "Planning" covers a single session. The final paper for each session was prepared, usually by the coordinator, as a summary and synthesis of the papers presented. "Review and Follow-up" presents remarks made in a concluding session by selected participants, and also includes two additional papers. One describes the Laguna-Morena Demonstration Area, the subject of an afternoon field trip. The second discusses certain problems of particular concern to developing countries. The final section in these Proceedings is the "Poster Presentations," which provides brief summaries of the displays, arranged in alphabetic order.

To expedite the publication of the Proceedings, we asked each author to assume full responsibility for submitting manuscripts in photoready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by sponsoring organizations.

In the opening session, one speaker suggested forming a Mediterranean Ecosystems Institute with international participation. The proposal was widely discussed and favorably received during the week that followed. Presently, efforts are being made toward the establishment of an international steering committee. A first step being planned is the formation of a representative working group that would operate within the framework of an existing international organization. Continued exchange among scientists and practitioners on an international scale through such a group is needed if the best and most appropriate methodologies are to be applied to land resource problems in all Mediterranean climate ecosystems.

Technical Coordinators:
C. Eugene Conrad
Pacific Southwest Forest and
Range Experiment Station
Walter C. Oechel
San Diego State University

ACKNOWLEDGMENTS

Sponsors and Organizers

Chaparral Research and Development Program, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture

In 1977, the Forest Service, U.S. Department of Agriculture, established a research and development program at this Station titled "Vegetation Management Alternatives for Chaparral and Related Ecosystems." This 5-year program, with headquarters at Riverside, California, is an intensive effort to develop, test, and demonstrate a wide range of operations for maintaining or increasing the productivity of chaparral and related ecosystems in southern California.

Systems Ecology Research Group, San Diego State University

The Systems Ecology Research Group was established in 1975 at San Diego State University. Investigators in the Group have specialized in basic ecological research in Mediterranean-type environments. Early research focused on resource use and allocation in the chaparral of California and the mattoral of Chile. Current studies concern mechanisms controlling resource use, organization of plant communities in chaparral ecosystems, and plant succession following fire in chaparral.

California Department of Forestry

The California Department of Forestry is charged with lire protection and resource management responsibilities on the majority of California's non-Federal wildlands. In recognition of the value of vegetation management in meeting these responsibilities, the Department in 1981 began a major new program of vegetation management. The program works with private landowners, providing State cost-sharing to carry out projects based on the degree of public benefits derived.

Co-Sponsors

National Science Foundation
Office of Environment, U.S. Department of Energy
Man and the Biosphere Program, U.S. Department of State
Man and the Biosphere Program, Paris, United Nations Education, Scientific, and Cultural Organization
Society of American Foresters
Southern California Edison Company
Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture
County of Los Angeles Department of Forestry and Fire Warden
Sierra Club

Program Coordinators

Session Coordinators

C. Eugene Conrad, Pacific Southwest Forest and Range Experiment Station, Riverside, California
Leonard F. DeBano, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona
Ted L. Hanes, California State University, Fullerton, California
Jimmie L. Hickman, Southwestern Region (R-3), Forest Service, Albuquerque, New Mexico
Philip C. Miller, San Diego State University, San Diego, California
David J. Parsons, Sequoia and Kings Canyon National Parks, National Park Service, U.S. Department of the Interior, Three Rivers, California
Charles W. Philpot, Pacific Southwest Forest and Range Experiment Station, Riverside, California
Ronald D. Quinn, California State Polytechnic University, Pomona, California
George A. Roby, Pacific Southwest Forest and Range Experiment Station, Riverside, California
Wade G. Wells II, Pacific Southwest Forest and Range Experiment Station, Glendora, California

Field Trip Coordinators

John W. Gray, California Department of Forestry, El Cajon, California
Paul Zedler, San Diego State University, San Diego, California

Display Coordinators

Giles Marion (commercial) and Walter C. Oechel (posters), San Diego State University, San Diego, California

Perspectives

Perspectives

The Purpose, Expectations, and Challenges of the Symposium[1]

Robert Z. Callaham[2]

On behalf of the Forest Service, U.S. Department of Agriculture, and especially its Chaparral Research and Development Program, I welcome you to this Symposium. Let me tell you about its organization and about the purposes, expectations, and challenges of this Symposium as we see them.

Planning for this Symposium began about 3 years ago at the Pacific Southwest Forest and Range Experiment Station. The date for the conference was chosen to coincide with the culmination of our Chaparral Research and Development Program. This R&D program, created in 1977, has a 5-year charter terminating this year. Our scientists and their cooperators have been actively investigating problems and gathering and disseminating information on all aspects of the chaparral ecosystem. In a sense, this Symposium is a high point of the Program.

Cosponsoring the Symposium with the Forest Service is the Systems Ecology Research Group at San Diego State University. Its members too have been actively studying Mediterranean-type ecosystems. Therefore, this conference was planned not only to sum up what has been accomplished through our R&D program, but also to present what has been accomplished by other chaparral scientists and managers around the world.

Almost immediately, other individuals and organizations became involved in planning and financing the Symposium. Financial support has been provided by the U. S. National Science Foundation, the U. S. Department of Energy, the California Department of Forestry, San Diego State University, and the Forest Service. The Man and the Biosphere Program (MAB), at both the international level of the united Nations Economic, Social, and Cultural Organization (UNESCO) in Paris and the U.S. National Program, helped by financing participation by scientists from other countries. Also, many organizations in other countries have provided funding for their representatives to attend this meeting. In a few moments, I would like to recognize this international participation.

Technical support in organizing the Symposium was provided by many groups and individuals. Among the supporters, San Diego State University, and the California Department of Forestry deserve particular thanks. A third group of contributors is helping to carry out the week's activities. Notable among them are the Southern California Society of American Foresters, the Los Angeles County Forester and Fire Warden Department, the Sierra Club, and Southern California Edison Company. The organizers are most grateful to all whose support has made this Symposium a reality.

Each year, the equivalent of many millions of dollars are routinely spent world-wide on management of land and resources in ecosystems dominated by a Mediterranean-type climate. Additional millions are spent world-wide on research to improve and simplify these management efforts. One of the best investments that can be made by people in charge of these research and management efforts is to provide a means for managers and scientists to exchange information and experiences.

This Symposium, it’s Proceedings, and the activities that will follow are designed to facilitate such an exchange. Here, we have brought together individuals and groups who do not routinely interact. Participants will learn about developments in countries with a variety of managerial and research problems. The face-to-face contacts made here should ease your jobs and make your work more effective. We expect that the funds invested by the Symposium organizers and participants will bring substantial returns in the future as participants put into practice what they learn here.

Let's look at the objectives of the Symposium. The primary objective is to provide a mechanism for the exchange of information about Mediterranean-type ecosystems. Our goal is to bring together managers of lands and resources, teachers, scientists, students, and environmentally concerned laymen. Let's take a look at how well we've done. Preregistration indicated we would have about 270 attendees, and 200 are here this morning.

Please help me to estimate the numbers of you who are here as practitioners, meaning land and resource managers, scientists, teachers, students, or lay persons. How many would categorize yourselves as practitioners involved in land or resource management? About 60 percent. How many are scientists or primarily involved with research? About 30 percent. How many of you are primarily teachers? About 4

---

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2] Director, Pacific Southwest Forest and Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.

percent. How many of you would classify yourselves as students? About 3 percent. How many would put themselves in the category of environmentally active or concerned private citizen? About 3 percent.

This is the spectrum of people who have come here to exchange information. Of course, you will want to talk with people in your own category or profession, but the real challenge of the Symposium, and my personal challenge, is for you to interact with people who are not like you. We want to encourage scientists, environmentalists, students, and practioners to get together. Make yourself talk to strangers. The benefits will be great.

Our plan is to make this Symposium unique. Too often at meetings like this, scientists and other specialists speak to each other and fail to communicate with practitioners and laymen. Too seldom do practitioners go to the rostrum and talk about their problems and their successes. Therefore, this Symposium has been designed with these features:

- Plenary sessions where experts from countries around the world can address all of us to broaden our horizons

- Concurrent technical and practical sessions where scientists can discuss the state-of-knowledge, and practitioners can discuss real world situations.

The exchange of information to take place here will also be international. The person sitting next to you may be dealing with your management or research problems, but in a country halfway around-the world. About 38, or 15 percent, of our registrants are from other countries. Let me introduce, by asking them to stand, our visitors from other countries. Registration information tells us that we have participants here from the Mediterranean countries of Spain, Portugal, France, Greece, and Israel. We have visitors from other continents including South Africa, Australia, and Chile, and from Mexico and Canada. Introduce yourselves to these visitors this week. Find out what you have in common with them. You may find that their interests are similar to yours.

Studying the Symposium schedule, you will quickly see that one of our objectives is to encourage a multidisciplinary exchange of information. There are sessions on hydrology, vegetation management, utilization of biomass, soils, and wildlife. I encourage you to use this unique opportunity to catch up on what is happening in fields other than your own in chaparral management.

Interaction will be the key to the success of this Symposium. This should not be a short course where you take, but do not contribute. Planning for an exchange of information among interest groups, among nations, and among disciplines was the greatest challenge faced by the organizers. Carrying out this exchange of information is our greatest challenge to you as participants. Your challenges are to reach a common understanding of what we know, and what we only think we know and to learn who has knowledge or experience and what still needs to be studied or developed.

But let me challenge you further. I want you to identify what needs to be done after this conference in order to improve utilization of available knowledge. From this conference should come suggestions for training courses to meet needs of practitioners in the field. Your suggestions might relate to subject matter for continuing education programs. Those of you who are educators might explore how curricula could be changed to benefit future students. Come forth with your suggestions for guidelines, handbooks, manuals, or audio-visual aids. Our purposes cannot be achieved by this conference alone. Please help us to make this a starting point for a series of on-going activities to spread what we know about the dynamics and management of Mediterranean-type ecosystems.

In closing, I encourage you again to take advantage of the informational resources around you this week: attend the formal sessions, as well as the informal poster sessions tonight and tomorrow night. If you have items you would like to display or literature to hand out, tables are available for that purpose in the hall. If you need a place to carry out discussions among small groups, check with the Conference Control Center. We have reserved several rooms for that purpose.

On behalf of the Forest Service, I thank you for coming. Now it is up to you to make the week worthwhile.

Concerns and Costs of Managing Mediterranean-Type Ecosystems[1]

Douglas R. Leisz[2]

It is a pleasure for me to be here at this Symposium on the Dynamics and Management of Mediterranean-type Ecosystems. I, too, see it as a proper finale for the Chaparral Research and Development Program. During the early 1970's, as Regional Forester, I worked with Bob Harris, who was then Director of the Pacific Southwest Forest and Range Experiment Station, to establish the Chaparral R&D Program. When Bob Callaham became Director of PSW, we continued our efforts.

We were especially interested in seeing the establishment of a chaparral management demonstration area where the tools and techniques used in managing chaparral and related ecosystems could be seen and their effects compared. In 1976, the Laguna-Morena Demonstration Area, which you will visit on Wednesday afternoon, was established for this purpose. In taking on the Mediterranean-type ecosystems of California, and of the world, you researchers and managers have taken on a true challenge and one worthy of your efforts. Both the Demonstration Area and the Chaparral Program have increased our knowledge about managing chaparral and related ecosystems. I am proud to have been involved in their establishment and am proud to be here as the Program draws to a close.

MEDITERRANEAN-TYPE ECOSYSTEMS—THEN AND NOW

We are gathered here to share our collective knowledge on the dynamics and management of Mediterranean-type ecosystems. What, then, is a Mediterranean-type ecosystem? It is one influenced by a Mediterranean climate; that is, it exists in an area with (1) warm-to-hot summers and mild winters; (2) a moderate marine air influence throughout the year; (3) moderate precipitation concentrated during the winter months, with summers that are very dry; and (4) extended periods of sunny weather and few clouds, especially in summer (McCutchan 1977). By this definition, almost all of California's National Forests include some Mediterranean-type ecosystems. About 65 to 75 percent of the area on the four southern National Forests (the Cleveland, Angeles, San Bernardino, and Los Padres) is dominated by the Mediterranean-type climate. Up to 40 percent of the area on the Mendocino and Shasta-Trinity National Forests and 30 percent of the Lassen, Plumas, Sequoia, Sierra, Stanislaus, and Tahoe National Forests is characterized by Mediterranean-type ecosystems.

In its past management efforts, the Forest Service has recognized Mediterranean ecosystems as including brushlands, woodlands, grasslands, and coastal sage scrub, with most of the area being covered by that all-inclusive term "brushland." No one was too concerned about the ecosystems existing on these lands because (1) the areas did not, for the most part, produce commercial timber, and (2) the areas could be expected to burn every 20 to 30 years or so anyway. The money budgeted to these lands came in the form of fire protection--protection mostly for urban areas downstream. Management of the vegetation was oversimplified because the vegetation was seen as being very uniform and, more or less, worthless.

Both of these misconceptions have begun to crumble during the past 5 to 10 years. Although we still use the general terms "brushland" and "chaparral," we have begun to recognize the diversity that actually exists in these vegetation types. We used to characterize chaparral in California as being either chamise chaparral, desert chaparral, mixed chaparral, or mountain chaparral. Now, we recognize that chaparral in southern California alone should be divided into some 10 to 20 types, each characterized by a different species makeup, community dynamics, and relationship to fire. Management schemes for these various chaparral types should reflect their diverse characteristics and requirements.

As our recognition of the diversity present in our Mediterranean ecosystems has increased, so has our recognition of the potential of this resource for satisfying human needs. We all know that the most valuable function that chaparral vegetation serves for us is as a soil stabilizer, but did you know--

--that 1 acre of chaparral shrubs, at 25 tons of biomass/acre, can produce the Btu equivalent of 73 barrels of crude oil?

--that the San Bernardino National Forest recorded 6.8 million visitor-days use in 1980, more than any other National Forest in the United States, even though over 70 percent of the land is non-forested?

--that the foliage of chaparral shrubs serves to clean the air by removing CO_2 and manmade air pollutants?

--that densification of chaparral biomass can generate a number of useful products such as particle board and fireplace logs?

---

[1]Presented by Ralph C. Cisco, Supervisor, Cleveland National Forest, at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Chief, Forest Service, L.S. Department of Agriculture, Washington, D.C.

--that California's Mediterranean–type ecosystems provide habitat for over 400 bird species?

--that cattle and goats will graze on many chaparral shrub species?

--that chaparral shrubs can be used for silage to feed livestock?

These are a few of the products we know can be supplied by chaparral lands and vegetation. There are probably others that we haven't dreamed of yet. One of the most exciting things about the implementation of the Renewable Resource Planning Act of 1974 and other related legislation is that it provides us with the opportunity and direction to study and manage all the potential resources of our National Forests and not just traditional commercial resources. We are required to assign, at least initially, equal consideration to all resources.

But the problem with managing any resource--especially ones owned by a diverse public--is that all demands cannot be simultaneously satisfied. Some land uses such as soil stabilization and air purification will be compatible, but others, such as recreational development and vegetation harvesting for wood products, may not be. Every good has a cost, and included in that cost is the value of other products that must be foregone if that good is produced. To complicate the matter further, public demand for various products changes with time. It is our job as managers of public lands to stay in touch with and respond to these changing needs, concerns, and costs, recognizing that there will always be trade–offs.

ISSUES AND CONCERNS

What are the concerns currently being voiced about the management of Mediterranean–type ecosystems in California? Through the public involvement process required by the Renewable Resources Planning Act of 1974, Region 5 planners have identified the issues and concerns that people consider important. Some of these are

--What role should the National Forests play in affecting water quality and the amount and timing of water yield?

--To what degree should the Forest Service manage chaparral vegetation to produce various goods?

--how should the Forest Service facilitate the development of mineral commodities on the National Forests of California?

--how should prescribed fire be used as a management tool?

--how can coordination be improved between the Forest Service, charged with protecting the National Forests, and the various fire services responsible for protecting privately owned structures within and adjacent to National Forest lands from fire?

--Should seasonal closure continue to be used as a fire prevention tool in southern California?

--How can problems caused by incompatible management activities between National Forests lands and intermingled or adjacent lands be resolved?

Many of these concerns have been around, in one form or another, for a long time. But all of them have been intensified by the increased pressures of California's--especially southern California's--expanding population. Demands for water, clean air, recreation, and wood and fiber production are greater than ever before. As the population moves further into the wildlands, protection of life and property becomes an increasingly difficult task.

MANAGEMENT EMPHASIS

How do we deal with these natural ecosystems that we are only beginning to recognize the diversity and potential of? how do we respond to varied, conflicting, and ever–changing public demands while continuing to protect the resources for which we are responsible? These are difficult questions that must be answered by managers, planners, researchers, and practitioners with increasing amounts of input from the public. They are questions that will he addressed repeatedly during this Symposium.

Amid this environment of change, there are several management strategies that will be receiving new or renewed emphasis within the Forest Service and in President Reagan's administration in general:

1. National, regional, and local planning efforts, with substantial emphasis on public input, will continue.

2. The interdisciplinary approach to natural resource problem solving will be encouraged.

3. More interagency coordination and involvement will be required.

4. More coordination and involvement between various government levels will be required.

5. Increasingly, decisions will be made based on sound economic analyses.

6. The Forest Service and other government agencies will be required to increase efficiency while reducing employee numbers.

These management directions should be viewed not as restrictions but as opportunities to streamline our activities and increase productivity.

SUMMARY

All the ideas I have presented and questions I have raised will be discussed in more detail by other speakers this week. I think you will agree, at least by week's end, that California's Mediterranean-type ecosystems are much more diverse and more valuable than we have considered them to be before. The issues and concerns involved in using the resources are becoming increasingly complex. There will be high costs and difficult trade-offs no matter what management decisions are made. In conclusion, future managers of Mediterranean-type ecosystems will have more definitive information on which to base their decisions; the entire program is well worth your efforts.

Needs and Opportunities in Chaparral Brushlands[1]

Huey Johnson[2]

Chaparral brushlands, a major part of North American Mediterranean Ecosystems, represent one of the globe's last unexplored productive landscapes. This symposium addresses the challenges of a new frontier of knowledge. For this reason I'm honored to be able to open this meeting.

During our exploitative era we've been able to ignore the chaparral resource. A look at our record shows we've freely enjoyed the wealth of our great productive land, taking oil, virgin forests, fisheries, and more and more resources. First, we harvested the accessible resources. Now we enter an era of scarcity and must respond to limits by doing more than just harvesting. We must begin to manage land more intelligently and intensely.

How do California's more than 30 million acres of Mediterranean-type Ecosystems fit this new era of limits? The need for fiber, food, energy, recreation, and esthetic landscapes is obvious. The Mediterranean region of California represents 30 percent to 50 percent of the state and holds well over half our people. These lands are not only underutilized but much of the science of their management is still developing. Yet these lands are the focus of continuing rapid population growth in California and elsewhere.

Just managing the fire environment with increased housing and population is a serious problem. It is costing our state millions in unpredictable and I believe unnecessary expenditures each year.

As a management strategy we should change a problem into an asset. Take energy for instance. The chaparral ecosystem is known for its rapid growth cycle. Initial studies show that 30 tons of biomass can be produced per acre, without irrigation, in 20 or 30 years. Instead of costly wildfires, management can utilize the chaparral energy for both people and jobs. As part of our 20-year plan California is moving aggressively to accomplish this.

Similar opportunities that are currently problems exist in other nations. Take Kenya as an example; while it does not have a Mediterranean-type climate, there are important similarities. It is said to have the world's most rapidly growing population. Yet only 20% of its lands are tillable. Its arid brushlands are essential to its future.

I learned this recently when I called on Mr. Richard Leakey, Kenya's Minister of Resources.

Leakey had traveled the world seeking insight into Kenya's brush problem but found little help. In California, because we've been reacting to a crisis of energy consumption, he found emphasis of "go home and plant trees for oil". Biomass substitutes for oil are important here in the United States. Oil is not Kenya's problem but immediate cooking fuel is. He also attempted to find support for research in the potential of managing and understanding the endemic species of Kenya, many of which are fast-growing and have great promise. But again, no one, including California was helpful. I'm sure this problem could be repeated in many areas of our concern.

Symposiums like this reflect a state of the art of thinking and information. This symposium is the first of its kind that has been successful in drawing both top managers and scientists, in roughly equal numbers, together in a scientific setting. There is another level of important opportunities. We have to take an expanded view--a visionary approach to those needs and the opportunities. What Leakey found in his search is true of this conference. There are several omissions to note. First, the human dimension of the problem environment is lacking. Also missing is the process of translating complex technical information to the public at large. This symposium also needs emphasis on an applied systems approach. The era of single-purpose research and decision-making is behind us. We can no longer consider chaparral without addressing social and political issues and other matters. Ultimately, it is absolutely vital to reach decisionmakers and land managers, to present the visions of an effective assault on the problems of the Mediterranean Ecosystem. The data and knowledge you hold are tools that must be put to work.

I see chaparral and the Mediterranean Ecosystems as a frontier. We all need to expand our view beyond a narrow focus. A true ecosystem approach is needed. In essence this means taking a systems view with all the breadth that implies.

A common data base is an essential major part of managing natural systems. But if we continue with the Mediterranean Ecosystems the way we have with other natural systems, we will not succeed. The basic reason is a lack of coordinated approaches. For instance, in trying to understand California soil data, I've found we lack a comprehensive soil map. Years of soil data have accumulated. Information has been gathered without a common standard to link government and other institutions. Without a standard measure

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Huey D. Johnson, Secretary, the California Resources Agency, Sacramento.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

and shared frame of reference much of the past soil and resource data are useless.

I'm reminded of going through Australia by train some years ago, and changing trains in the middle of the night where one rail line ended and another began. Everyone and everything had to be unloaded and reloaded on the new train because the wheels didn't fit the new track system. Some of our resource data in California has been the same.

Cooperation of individuals and institutions is needed. Not only do we need engineers and technicians but we need sociologists, educators and land use professionals. The systems approach requires informing the public. Public support is needed to successfully compete in a political environment for the support required to properly research, staff and manage the opportunities of the Mediterranean Ecosystems.

It's time we establish an institute on the Mediterranean Ecosystem, (hopefully here in California). Ideally such an institute could be under the United Nations Environmental Programme. Such an institute would address the complex problems of research and management of Mediterranean Ecosystems. It would consider the fuel and fiber potential of this environment as well as the problems of urbanization and people pressures on the land. Such an institute located in this state, ideally cooperative with but independent of government, could coordinate and stimulate understanding and improved management of these lands.

Some may regard the idea of an institute as unreasonable at this time. Cynical people say it is impossible considering budget problems today. But consider what has happened with California's new 20-year plan to upgrade natural systems. This is a time of broad cutbacks in all other departments of government. Yet last week we secured $67 million in new money for this year's beginning program and access to $120 million annually in the future. Progress can be made when a project like investing in the future is sound, when the benefits are obvious.

We should do the same with an Institute on the Mediterranean Ecosystem. The time to start is today--I hope with this symposium.

Applied and Basic Research in Mediterranean-Climate Ecosystems[1]

Harold Mooney[2]

Abstract: Man's impact on ecosystems has become so pervasive that there is now little distinction between basic and applied ecological research. Still, the available research results are often inadequate to translate into management policy. The use of an international network of ecosystem study sites in which researchers and managers collaborate should hasten the development of rational programs to manage the difficult mediterranean-climate ecosystems.

Of all of the world's ecosystems those of mediterranean-climate regions offers the greatest management challenge. In these regions high human populations often abut natural systems which are unusually prone to fire and flood. Rational management policies are hindered by social and political constraints as well as a lack of basic ecological information. It is this latter deficiency which is addressed here.

APPLIED VERSUS BASIC ECOLOGICAL RESEARCH

At present the distinction between applied and basic ecology is rather blurred. Although this merging of approaches has accelerated in recent times it has been true that historically leaders in ecology often have been engaged in research which falls within both realms.

The Ecological Society of America has recently utilized as a working definition of applied ecology, "the study of ecological systems (organisms, populations, communities, ecosystems) influenced by human activity". Such a definition would of course encompass virtually all of ecological research since there are essentially no ecosystems on earth which have not been influenced by the activities of man. This is becoming increasingly so as the impact of man's activities are becoming more pervasive and more global as evidenced by the increase in atmospheric CO_2 concentration, the wide-scale dispersion of toxic compounds such as radioactive nuclides, DDT, and PCB's and the large regional influences of acid rain.

It has only been within the past few decades that man has become aware of the global nature of his impact. Basic ecologists traditionally have been interested in unravelling the interrelationships of organisms with their environment as they have been molded through evolutionary time. Man's activities were viewed as disruptions of these relationships which resulted in disequilibrium conditions.

A major thrust of the International Biological Program (IBP) in the United States in the late 1960's and early 1970's was the study of ecosystem function. For these studies a great effort was made to find study sites which had been impacted little by human activities. The finding that virtually all ecosystems have been influenced by man to one degree or another and that these impacts are becoming increasingly greater has been a key factor in the design of the successor to the IBP, UNESCO's Man and the Biosphere Program (MAB). The MAB program has been characterized by the collaborative efforts of basic and applied scientists. Specifically the MAB program attempts not only to determine the structure and functioning of the biosphere but the changes induced by man and in turn their effects on human populations. MAB is an international interdisciplinary effort.

There have been other factors which have led to the convergence in the realms of basic and applied scientists. One is the finding that evolutionary adjustments can occur in relatively short time spans, as evidenced by the evolution of pesticide-resistant insects (Ehrlich, et al., 1977) and heavy metal tolerant grasses on mine tailings (Bradshaw, et al., 1965). Another was the realization that certain factors which were disruptive to equilibrium conditions, such as fire, often played a large role in molding the structure and functioning of these ecosystems. Thus, factors, which in the past received little attention by basic ecologists, all of a sudden were receiving considerable attention. Also, there was the increasing awareness that catastrophies of one sort or another, other than fire, such as hurricanes, droughts, etc., played a large role in structuring ecosystems (Sprugel and Bormann, 1981) and that an equilibrium ecosystem was more of an abstraction than a reality. There was also the realization that many human disturbances were often not too different from those resulting from natural disruptions (Mooney and Godron, 1982). The differences were often more a matter of scale and intensity.

Even though I have presented a picture of a general convergence of the spheres of activity of basic and applied ecologists I would like to note also that even in earlier times the divergence was not great. This can be appreciated by the background and publications of some of the pio-

[1]Presented at the Symposium in Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Professor of Biology, Stanford University, Stanford, California 94305 USA

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

neer ecologists who worked in the Californian mediterranean vegetation.

The F.E. Clements-J.E. Weaver Nebraska School of Ecology produced a large number of first generation California ecologists most of whom were associated with range and forestry programs. H.L. Shantz was a Clements PhD and A.W. Sampson was influenced by Clements as an undergraduate at Nebraska. H.H. Biswell, A.M. Schultz, and H. Heady were all students of Weaver. The publications of these scientists often were both basic and applied. W.S. Cooper of the University of Minnesota, who was a product of the Chicago School of Ecology (H.C. Cowles), and who did the classic study of the California chaparral, directed the PhD thesis of Joseph Kittredge a Californian forester who did both basic and applied work in the chaparral. W.C. Lowdermilk, who was important in the San Dimas lysimeter design, was a student of Sampson.

Thus it can be seen that all of these ecologists, although often having positions in applied schools, received their training in basic ecological programs.

RESEARCH VERSUS MANAGEMENT OBJECTIVES

Deriving information from research results, either basic or applied, for management purposes generally offers difficulties for a number of reasons. One, the technological approaches utilized in research are often not appropriate for management. Two, the research results are generally not gathered to answer specific management problems. Three, research information on specific sites is often difficult to transfer to another site without new research.

As Johnson and Bossort (1980) recently noted managers find the research approaches of basic scientists to be "faddish, speculative, and lacking in substance; in other words not practical". Basic scientists who work at the forefront of their trade feel that applied scientists do not avail themselves of the latest approaches and concepts. Managers, as Johnson and Bossort note cannot "use methods which are new and consequently potentially controversial. This is a result of the social and political implications of their projects". Thus independent of the ecological questions involved there is a fundamental difference in the way a research investigator and a manager may approach the problem. The manager needs methods which are "tried and true" whereas the researcher is looking for new approaches.

Then there is the matter of how research programs are formulated. Most often they are not designed to answer specific management questions, but rather questions of a more general nature. For example, research on the impact of fire on nutrient flow in an ecosystem will generally not be comprehensive enough to tell how intense, how often, and when controlled burns should be utilized and further how these variables will impact such ecosystem components as large herbivores. Closer interaction between managers and researchers is essential to insure that research leads to knowledge which can be applied directly in management.

Unfortunately, management needs often arise in response to a crisis which in turn has arisen from a research breakthrough. Management plans evolve in response to our understanding of how ecosystems operate. New knowledge may bring the question of how management is taking into account the problem which the research has just uncovered, eg., nutrient loss from ecosystems through fire. Obviously management plans cannot involve issues for which knowledge is lacking.

Even if we have a general understanding of the knowledge required to evolve comprehensive management plans it may be difficult to evolve specific management plans. Ecology is a developing discipline encompassing complex issues. The data base is slim even for the most fundamental issues. Textbooks in this area are often filled with "general principles" many of which have been derived from a few isolated studies. This is hardly the information base needed to design specific management plans. Then too, there are research areas which are just developing in ecology from which specific knowledge is needed for management. For example, as Keeley (1977), Noble and Slatyer (1977), and Zedler (1977) have shown so clearly for mediterranean-type ecosystems, knowledge of the life-history attributes of the resident species of an ecosystem is essential to predict the long term consequences of a particular fire management scheme. Yet practical knowledge of the population biology of even the commonest dominant species of an ecosystem is often lacking. The study of plant population biology is in itself a relatively new endeavor (Harper, 1977). We have very little information of how different species respond in distinctive ways to dissimilar thermal, moisture, and nutrient regimes, and yet this information is necessary to make predictions as to the outcomes of any management scheme. We do not know in detail how water and minerals move through various ecosystem types and yet again this information is vital to asessing the impact of diverse management practices.

Finally, there is the problem mentioned above of extrapolation of the results from one region to another. One need only recall the lively discussions which evolved around the proposals to convert chaparral to grassland in different regions of California. The success of programs on gentle topography were questioned for areas of high erodible steep terrain.

How can one approach these problems? For one, we can pool our efforts and concentrate our resources. We are already doing both to a certain extent.

INTERNATIONAL APPROACH TO THE STUDY OF MEDITERRANEAN-CLIMATE ECOSYSTEMS

It would certainly appear as if we are pooling our collective effort in the study of mediterranean-climate ecosystems. For no other ecosystem type is there such a high intensity of international cooperation in both applied and basic research. Further, it appears that the level of collaboration between managers and basic research workers in mediterranean-climate regions is unusual. This symposium certainly lends support to these assertions.

Ecologists from the various mediterranean-climate regions met together for the first time in March, 1971 in Valdivia, Chile. The objective of that conference was to summarize our knowledge about the environment and biota of these regions in order to lay the foundation for a new comparative in-depth study of the structural characteristics of Californian and Chilean mediterranean-climate ecosystems (di Castri and Mooney, 1973). It had been known for a long time that mediterranean-climate regions all had ecosystems which were quite similar in appearance. Studies by individuals in the late 1960's gave substance to the concept that these areas had evolutionarily converged to these similarities (Naveh, 1967, Specht, 1969a, b, Mooney and Dunn, 1970).

Determining the degree of convergence between these regions was an important task since from it would be derived the possibility of comparative ecosystem studies. As di Castri and Mooney (1973) noted, "One of the greatest barriers to understanding most ecosystems is the lack of repeatability. Hypotheses based on detailed studies of a particular ecosystem cannot be put in a context of generality because there are no standards of comparison, that is no precisely similar ecosystems built up from different starting points in which to test the principles involved. This question has major practical implications for the management of natural resources".

The Chile-California comparison, which was part of the International Biological Program, indicated that these ecosystem types were convergent in many structural (Mooney, 1977) and functional attributes (Miller, 1981). Differences were noted between these regions however some of which had management implications (Mooney, 1977).

The second international meeting of mediterranean-climate ecologists took place at Stanford, California in 1977. This was truly an international gathering which brought together basic and applied scientists to consider the dynamics of ecosystems where fire played a major role (Mooney and Conrad, 1977). The proceedings of that meeting made it clear that in all mediterranean-climate regions fire was a major consideration in management yet the approaches that were being utilized were often quite different. For example, at that time controlled burns were being used extensively in management in South Africa but only to a limited extent in California. The reasons for many of the differences in management policy were historical rather than because of anything fundamentally different about fire in these regions.

The complexities of managing fire-prone ecosystems were highlighted at that conference. It became clear that some of the simplistic views that were prevalent relevant to the use or exclusion of fire in management needed considerable revision as new information became available. Intercontinental comparisons greatly accelerated the rate at which we were acquiring new knowledge.

This past year there has been an intensification of efforts to compare properties of mediterranean-type ecosystems. In Greece, in August 1980, a conference focused on the, "components of productivity of mediterranean-type ecosystems". The issues discussed ranged from the basic environmental features limiting productivity in mediterranean-climate ecosystems to the effects of pollutants on productivity. The possibilities of harvesting biomass for energy, which at the same time would reduce fire hazards, were also discussed. At the Greek conference the similarities among mediterranean-climate ecosystems were reinforced further, however significant differences again became apparent such as the evidently greater importance of temperature in controlling plant distributions in the Mediterranean Basin than in other mediterranean-climate regions.

In September of 1981 at Stellenbosch, South Africa an intensive conference focused on the role of nutrients in determining the structure and function of mediterranean-climate ecosystems. As intercontinental comparisons were made at all ecosystem levels it was becoming evident that South Africa and Australia differed from their northern hemisphere counterparts in a number of fundamental ways (Cody and Mooney, 1978). It appeared that the basis for this divergence was not climate but rather soil types. The southern hemisphere mediterranean-climate ecosystems are extremely nutrient deficient, particularly in phosphorus. This leads to great differences in such ecosystem properties as the diversity of the dominants. These findings give us the basis then of assessing the importance of substrate in molding ecosystem structure and function since in a sense climate is controlled in an experimental sense.

The present conference is broad in its thematic coverage, again viewing all ecosystem levels. Further it continues the effort to forge links between scientists and managers. It does so by again calling upon the now large community of scientists and managers working in the world's mediterranean-climate ecosystems. This format has obviously been a highly successful one since there are already new international mediterranean-climate conferences in the planning stage. The next comprehensive conference will be held in Perth, Australia in 1984. This conference will be devoted to a view of the maintenance of species and structural diversity in mediterranean-climate ecosystems and their resilience to environmental stress. International mediterranean region conferences with more limited themes will be held in Sydney, Australia in August and in Marseille in November of this year. The Sydney meeting organized by Professor R. Specht and held in conjunction with the International Botanical Congress, deals with drought tolerance mechanisms of mediterranean-climate plants. The Marseille conference, sponsored by NATO and organized by Professor P. Quezel, deals with the characterization of mediterranean-climate regions.

AN ECOSYSTEM APPROACH

These international efforts certainly represent a pooling of our collective efforts. What about the concentration of resources in the study of mediterranean-climate ecosystems? It is a truism of ecology that everything is connected to everything else. Understanding the totality of these connections is in essence the challenge of ecosystems science. Many management programs involve manipulation of a single property of an ecosystem such as numbers of game birds or large mammals, reduction of fire hazard, enhancing water yield, etc. Because of the interactions between ecosystem elements accomplishment of one particular research objective may actually have adverse effects on other ecosystem properties. For example, reduction in fire hazard by controlled burning may result in a decrease in species diversity and a loss of nutrient stores.

Thus in order to predict the consequences of any particular management program for a given area it is essential to have some understanding of how the total ecosystem operates. Unfortunately we have a limited understanding of ecosystem function in general and most certainly for any specific ecosystem. The argument can be made that such an understanding should be based, initially at least, on detailed studies of a single site. Since the biota of a region have co-evolved, and further since each habitat has to a certain extent unique environmental properties, any comprehensive understanding of ecosystem organization should come from site-specific studies. Extrapolation to comparable ecosystems, where species composition or habitat features vary to a certain extent, can then be made in a total system context--rather than in a case by case manner. Also, any new knowledge learned about a single site is greatly enhanced by the knowledge already gathered there. This is particularly important since ecosystem-level studies require the approaches of numerous disciplines and thus such studies are likely to be of a long-term duration.

The value of site-specific ecosystem studies can certainly be seen from the important ecosystem-level findings at such sites as the Hubbard Brook watershed in New England. There, for example, the ecosystem impact of, and recovery from, timber harvesting was precisely documented (Likens, et al., 1970).

In mediterranean-climate regions there have been a number of site-specific ecosystem studies. Dark Island heath studies of Ray Specht and co-workers(see literature summary in Specht, 1973) was the forerunner of more comprehensive ecosystem studies elsewhere. In France, the production and nutrient studies at Le Rouquet and Le Puech du Juge (Lossaint, 1973) had an ecosystem character. The latter site included extensive manipulations including fire and grazing (Trabaud, 1973). In South Africa a comprehensive ecosystem study is now underway at a coastal site at Pella and an interior site at Jonkershoek. The International Biological Program study of California and Chile was centered at Boulder Creek and Fundo Santa Laura respectively (Thrower and Bradbury, 1977). Earlier intensive site studies in the California chaparral were focused at San Dimas (Mooney and Parsons, 1973).

Some, but not all, of these studies have involved landscape managers. Hopefully, in the future all such research efforts will involve not only basic and applied scientists but also managers who can provide an input into an experimental design which has meaning in terms of current management practices. At the research level, an obvious need is for the development of methods of extrapolation from the site-specific studies to regions.

CONCLUDING REMARKS

It would appear that our international network of mediterranean-climate ecosystem study sites offers a unique framework in which to make rapid advances in our understanding of how these systems function. Further effort is needed to extend these findings to determine the impact of various management treatments on ecosystem properties. In order to accomplish this there must be a closer collaboration between basic and applied scientists and resource managers.

LITERATURE CITED

Bradshaw, A.B.; McNeilly, T.S.; Gregory, R.P.G. Industrialization, evolution and the development of heavy metal tolerance in plants. In: Goodman, G.T.; Edwards, R.W.; Lambert, J.M., eds, Ecology and the Industrial Society. 1965: 327-343.

Cody, M.L.; Mooney, H.A. Convergence versus non-convergence in mediterranean-climate ecosystems. Annual Review of Ecology and Systematics 9: 265-321. 1978.

di Castri, F.; Mooney, H.A. Mediterranean-type Ecosystems: Origin and Function. New York, Heidelberg, and Berlin: Springer-Verlag. 1973. 390 p.

Ehrlich, P.R.; Ehrlich, A.H.; Holdren, J.P. Ecoscience: Population, Resources, Environment. W.H. Freeman. San Francisco. 1977. 1051 p.

Harper, J.L. Plant Population Biology. Academic Press: London, N.Y., San Francisco. 892 p.

Johnson, E.A.; Bossart, A.K. Problem solving and applied ecology. Ecology. 61: 1262-1263.

Keeley, J. Fire-dependent reproductive strategies in Arctostaphylos and Ceanothus. In: Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. H.A. Mooney and C.E. Conrad (Tech. Eds.). USDA Forest Service General Tech. Report WO-3. 1977: 391-396.

Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; Pierce, R.S. The effect of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook water-shed-ecosystem. Ecol. Monog. 40: 23-47; 1970.

Lossaint, P. Soil-vegetation relationships in mediterranean ecosystems of southern France. In: di Castri F.; Mooney, H.A., eds. Mediterranean-type Ecosystems. Origin and Structure. New York, Heidelberg, Berlin: Springer-Verlag; 1973; 199-210.

Mooney, H.A. (ed.). Convergent Evolution in Chile and California. Stroudsburg, Pa: Dowden, Hutchinson and Ross.

Mooney, H.A.; Dunn, E.L. Convergent evolution of mediterranean-climate evergreen shrubs. Evolution 24: 292-303; 1970.

Mooney, H.A.; Parsons, D.J. Struction and function of the California chaparral--an example from San Dimas. In: di Castri, F.; Mooney, H.A., eds. Mediterranean-type Ecosystems. New York, Heidelberg, Berlin: Springer-Verlag; 1973; 83-112.

Mooney, H.A.; Conrad, C.E. (Tech. Coordinators). Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service WO-3. 1977. 498 p.

Mooney, H.A.; Godron, M. (eds). Disturbance and Ecosystems--components of Response. Springer-Verlag; In press; 1982.

Miller, P.C. (ed.). Resource Use by Chaparral and Matorral. New York, Heidelberg, Berlin: Springer-Verlag; In press; 1981.

Naveh, Z. Mediterranean ecosystems and vegetation types in California and Israel. Ecology. 48: 445-496; 1967.

Noble, I.R.; Slatyer, R.O. Post-fire succession of plants in mediterranean ecosystems. In: Mooney, H.A.; Conrad, C.E. Tech. coordinators. Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Tech. Report WO-3. 1977: 27-36.

Specht, R.L. A comparison of the sclerophyllous vegetation characteristics of mediterranean type climates in France, California, and southern Australia. I. Structure, morphology and succession. Austral. J. Bot. 17: 277-292; 1969a.

Specht, R.L. Ibid. II. Dry matter, energy, and nutrient accumulation. Austral. J. Bot. 17: 293-308; 1969b.

Sprugel, D.; Bormann, F.H. Natural disturbance and the steady state in high altitude balsam fir forests. Science 211: 290; 1980.

Thrower, N.J.W.; Bradbury, D.E. (eds.). Chile-California Mediterranean Scrub Atlas: A Comparative Analysis. Stroudsburg, Pa: Dowden, Hutchinson and Ross, Inc. 1977.

Trabaud, L. Experimental study on the effects of prescribed burning in a *Quercus coccifera* L. garrigue: early results. Proc. Tall Timbers Fire Ecology Conference. 13: 97-129; 1974.

Zedler, P.H. Life history attributes of plants and the fire cycle: a case in chaparral dominated by *Cupressus forbesii*. In: Mooney, H.A.; Conrad, C.E. (Tech. Coordinators). Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Tech. Report WO-3. 1977: 451-458.

General Characteristics of Mediterranean-Type Ecosystems[1]

R. L. Specht[2]

Abstract: To maintain an evergreen foliage canopy, the evaporative capacity of mediterranean ecosystems must be so balanced that water, conserved during the wet season, is available for use throughout the dry summer season. Semi-deciduous or semi-succulent foliage may result if summer drought lasts for more than 100 days. Large increases in growth potential may result from increased soil water storage; structure will change from shrubland, to woodland, to open forest. Nutrient deficiencies or imbalances (in nutrient-poor soils, high pH-calcium-rich soils, serpentine soils) will also reduce growth potential and structure.

THE MEDITERRANEAN CLIMATE

The mediterranean climate is characterised by a seasonal cycle of a hot, dry summer alternating with a cool to cold, wet period throughout the rest of the year. Köppen (1923) climatic type Cs— a warm C climate with a mild humid winter (with at least one month below 18°C) and a dry summer season (s) — is typical of much of the mediterranean regions. Within this Cs climate, there is a gradation in intensity of the dry summer season from a mild summer (Csb climate, hottest month below 22°C) to a hot summer (Csa climate, hottest month above 22°C).

The pronounced summer drought, which alternates with a wet winter, extends from humid/subhumid areas (Köppen Cs climates) into more arid areas. Successful agriculture is still possible in the semi-arid (BS) climate with a mean annual temperature below 18°C (Köppen BSk climatic type).

EVERGREEN FOLIAGE CANOPY

Although mediterranean ecosystems experience a long period of drought during the hot summer season, the foliage of the overstory stratum remains evergreen. It is only when the drought period exceeds 100 days that the foliage canopy may become semi-deciduous (Miller in press).

Observations on the seasonality of evergreen overstories in mediterranean regions point to two phenological strategies (Specht and others in press).

1. On nutrient-rich soils, new shoot growth is initiated during spring, thus doubling or trebling the Leaf Area Index of the community during that season. Defoliation is initiated when the drought period begins in late spring and extends through summer, returning the Leaf Area Index to the base value (Mooney 1981, Mooney and Kummerow 1981, Specht and others in press). A small amount of shoot growth may occur during autumn (fall) if sufficient rain falls early in the season. This seasonal foliage rhythm is illustrated in figure 1.

2. On nutrient-poor soils, new shoot growth of the overstory canopy is not initiated until the onset of the drought season (late-spring into summer). Foliation then occurs at the same time as defoliation so that the Leaf Area Index remains relatively constant throughout the year (Specht and Rayson 1957a, Bond 1980, Kruger 1981, Specht and others 1981, Specht and others in press). The phenological rhythm of the evergreen overstory on nutrient-poor soil is illustrated in figure 2.

Foliage Projective Cover of Overstory

The dry mediterranean summer imposes considerable water-stress on evergreen vegetation. It would appear that a small, but continuous, supply of water is necessary to maintain the evergreen canopy throughout the dry period (Specht 1972a,b). In the mediterranean climate, water

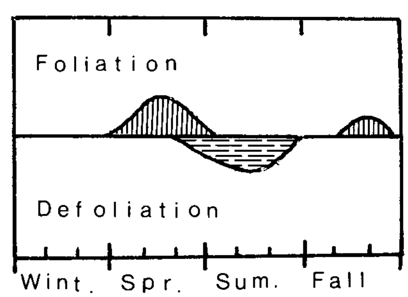


Figure 1--Seasonal changes in foliation and defoliation of evergreen overstory on nutrient-rich soils.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Botany, University of Queensland, St. Lucia, Queensland 4067, Australia.

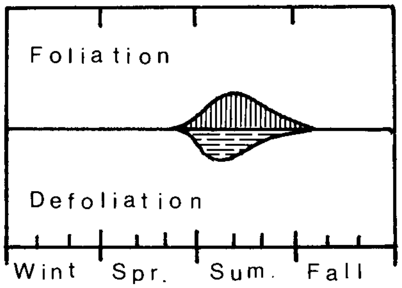


Figure 2--Seasonal changes in foliation and defoliation of evergreen overstory on nutrient-poor soils.

must be conserved as soil water during the wet period of the year for use, albeit at a low level, throughout the dry summer season. Too long a summer drought period (more than 100 days) will exhaust the supply of stored soil water and lead to excessive defoliation (Miller in press).

To ensure a balance between water conservation and water utilization, the evaporative capacity of the evergreen plant community must be delicately balanced with the annual climatic sequence. For a sclerophyllous plant community in the mediterranean region of South Australia, the monthly values of the Moisture Index are linearly related to available water by the following equation (Specht 1972a,b):-

$$\text{Moisture Index} = Ea/Eo = \underline{k}\ (P-R-D+S_{ext}) \qquad \text{Eq. 1}$$

where Ea = actual evapotranspiration,
Eo = class A pan evaporation,
P = precipitation,
R = runoff
D = drainage,
S_{ext} = extractable soil water in the rooting zone at the beginning of the month,
$\underline{k}$ = constant (evaporative capacity).
All values are measured in cm.

Equation 1 holds where available water is limiting. In humid areas of the mediterranean climate where available water may not be limiting during the wet months of winter-spring, the Moisture Index tends to unity:-

$$\text{Moisture Index} = Ea/Eo \rightarrow 1.0 \qquad \text{Eq. 2}$$

For an evergreen plant community at Keith, South Australia, the Moisture Index will oscillate seasonally about a mean value of 0.39 on the water balance equation shown in figure 3.

Two major parameters of the plant community act together to achieve this water balance: Foliage Projective Cover (FPC), the percentage of the landscape covered by foliage capable of transpiration (Specht 1970); and the degree of sclerophylly, as it affects leaf resistances to the evaporation of water from the plant. For sclerophyllous vegetation in southern Australia where leaf resistances are essentially similar, the evaporative capacity ($\underline{k}$, the slope of the line in figure 3) of the evergreen foliage canopy appears to be in equilibrium with FPC.

$$\text{FPC (pct.)} = 896.5\ \underline{k} - 6.4 \qquad \text{Eq. 3}$$

Studies in the mediterranean zones of South Australia, South Africa and southern California indicate that values of FPC of the overstories of mature communities observed in the field agree closely with values computed by Equations 1 to 3 (table 1).

It should be stressed that, in any particular climatic region, FPC of the mature overstory is independent of microclimatic and edaphic variations. It is only when the microhabit of the ecosystem is humid enough to maintain the Moisture Index at the maximum value of 1.0 for every month of the year that a sudden change in FPC from an open to a closed community results (Specht 1981a).

Table 1--Observed and computed values of Foliage Projective Cover of mature overstories in mediterranean areas of South Australia (Specht 1972a,b), South Africa (Specht and Moll in press) and California (Specht 1981b, Specht and Westman field data Nov. 1979).

Locality and Age after Fire	Foliage Projective Cover (pct.)	
	Observed	Computed
South Australia		
Keith (25 years)	32	31
Murray Bridge	37-38	35
Belair	36-42	38-40
Mount Lofty	61	56
South Africa		
Pella (25-30 years)	20	33
Oudtshoorn	24	23
Bain's Kloof (40+ years)	30	c.30
California		
San Dimas (4 years)	63	64
San Dimas (19 years)	61	64

It would appear that the value of FPC is little influenced by seasonal growth rhythms in evergreen mediterranean ecosystems. However, as shown above, the density of foliage (Leaf Area Index) of plant communities on nutrient-rich soils will increase during spring and possibly autumn (fall).

Sclerophylly

In order to ensure conservation of soil water during the wet winter-spring period for use during the dry summer season, the evaporative capacity of the plant community must be delicately balanced (figure 3). This is partly achieved in

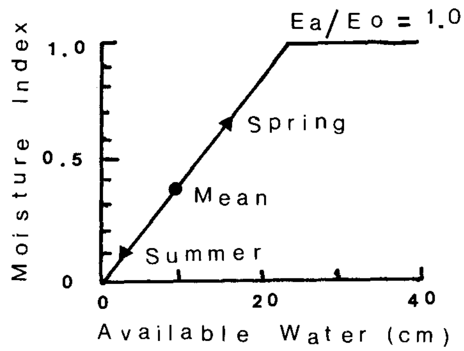


Figure 3--Relationship of monthly values of Moisture Index (Ea/Eo) to available water (P-R-D+Sext) in cm, at Keith, South Australia. Seasonal oscillations observed in heathland vegetation are shown.

nature by a sensitive adjustment of FPC to an equilibrium value for the area, but is complemented by an increase in leaf resistances to the movement of water vapour from the leaf. Various sclerophyllous attributes—in particular thick cuticles and sunken stomata—are essential. A highly reflective broad leaf capable of dissipating a reasonable percentage of the incoming solar radiation may also be necessary (Yates 1981).

Associated with sclerophyllous attributes concerned with reducing water-loss, the cells of the leaf must be able to withstand considerable water stress during the dry summer season. All evergreen mediterranean species possess desiccation-tolerant leaves, the shallow-rooted species often showing amazing powers of revival after drought (Gaff and Churchill 1976, Gaff and others 1976). Nevertheless, there is a limit to the length of the period of water-stress from which the sclerophyllous cells are capable of revival; after about 100 days, death and defoliation may result (Miller in press).

The young leaves initiated during the foliation cycles of evergreen mediterranean ecosystems take some time to develop sclerophyllous attributes, essential for survival. No water stress should be expected if shoot growth occurs in spring and autumn (characteristic of mediterranean ecosystems on nutrient-rich soil). However, summer shoot growth, typical of nutrient-poor ecosystems, can be disastrous (a) during a severe drought year or (b) if the mesophyllous growth phase is prolonged (say, by nutrient contamination) into the dry summer season (Specht 1963).

WOODY UNDERGROUND ORGANS

The structure of roots and root systems in the California chaparral vegetation has been examined in detail by Kummerow (1981) and for heathland in southern Australia by Specht and Rayson (1957b). Many of the long-lived, overstory species possess special woody underground organs termed lignotuber (Aust.), rootstock burl (Cal.), souche (Fr.), etc. Following fire which razes most of the above-ground biomass, these species regenerate rapidly, sprouting from the woody underground organs. It would appear that these underground structures act as storage organs for carbohydrates and mineral nutrients (Mullette and Bamber 1978), possibly a reserve of water. The organic and inorganic nutrients allow rapid regeneration following fire; metabolic water may buffer the overstory species against desiccation during summer drought.

The possible role of woody underground organs in drought survival needs investigation. Rootstock regenerators are a major component of all mediterranean shrublands. However, rootstock regenerators in heathland vegetation on nutrient-poor soils in the mediterranean region of Australia become less important as the period of summer drought increases (figure 4, from Specht 1981c, Moll and others in press).

UNDERSTORY

Compared with the overstory species, understory species are mostly shallow-rooted. The understory species thus experience more severe water stress during the dry summer season.

Two distinct understories may be distinguished in mediterranean ecosystems (Specht 1969, 1973, Specht and Moll in press):

1. On nutrient-rich soils—an herbaceous, grassy ground-stratum, typically of hemicryptophytes, geophytes and therophytes, showing seasonal oscillations of FPC attuned to the humid-arid cycle of the mediterranean climate.

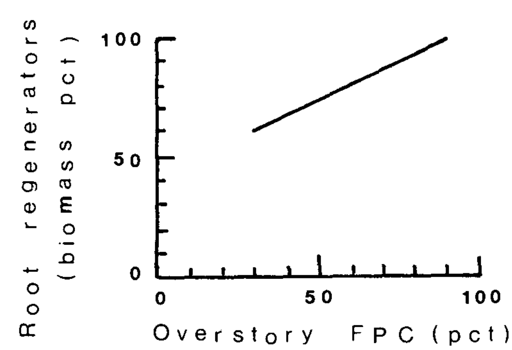


Figure 4--Rootstock regenerators (expressed as percentage of total above-ground biomass) are linearly related to Foliage Projective Cover (FPC) of the overstory of heathland vegetation in the mediterranean region of Australia (Specht 1981c).

2. On nutrient-poor soils—an evergreen understory of sclerophyllous (heathland) species (nanophanerophytes, chamaephytes and evergreen hemicryptophytes; few, if any, seasonal hemicryptophytes and therophytes). Compared to the deeper-rooted overstory species, the sclerophyllous understory species are typically narrow-leaved (Specht and others in press), less reflective (Yates 1981) and more desiccation-tolerant (Gaff and Churchill 1976).

Foliage Projective Cover of Understory

It would appear that there is an inverse interrelationship between the foliage projective covers of overstory and understory strata (Specht and Morgan 1981). A disturbance, such as fire, which is a common phenomenon in sclerophyllous mediterranean ecosystems, is followed by rapid regeneration. In a few years, FPC of the overstory attains a value in equilibrium with the ambient climate (see above), but to the detriment of the understory cover (figure 5) which flourishes in the early phases of the pyric succession. An inverse relationship between the FPCs of overstory and understory with a 45° slope may be expected.

Any landscape which shows a gradation of micro-climates favouring increasing FPCs of the mature overstory will show the same linear decrease of understory FPC as shown in figure 5.

NET PHOTOSYNTHESIS OF THE FOLIAGE CANOPY

In order to assess the photosynthetic potential of a plant community, Fitzpatrick and Nix (1970) suggested rating the photosynthetic capacity of the foliage canopy against an environmental variable when all other environmental factors were optimal. The relative growth response of the plant community to the environmental factor is termed the growth index. Five growth indices, which may affect the photosynthetic capacity of the foliage canopy, have been recognised (Specht 1972a, 1981b):-

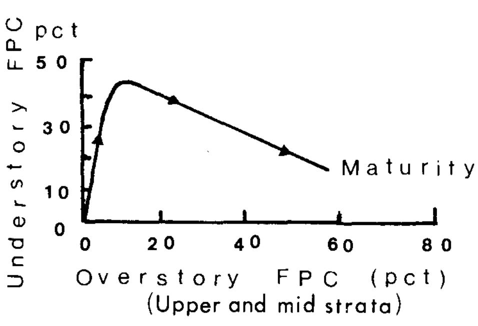


Figure 5--Relationship between understory and overstory Foliage Projective Covers as a mediterranean heathland regenerates after fire (Specht and Morgan 1981).

Foliage Projective Cover (FPC)
Light Index (LI)
Thermal Index (TI)
Moisture Index (MI)
Soil Fertility Index (SFI)

If these monthly or weekly indices are expressed on a scale of zero to unity, their relative values may be multiplied together to obtain an index of the Net Photosynthetic Index (NPI) of the foliage canopy:-

$$NPI = FPC \times LI \times TI \times MI \times SFI \qquad \text{Eq. 4}$$

The twelve monthly values of NPI of evergreen mediterranean canopies can be accumulated to give annual values which will provide an estimate of the maximum annual growth increment of the community (figure 6, from Specht 1981d). These biomass values, combined with the estimates of FPC of both overstory and understory strata, enable the structure of the resultant climax plant community to be predicted. Structural characteristics of plant communities typical of the mediterranean region of southern Australia (based on the two-way classificatory table developed by Specht 1970, 1981e) are shown in table 2.

Soil Fertility

As in all other parts of the world, soil fertility plays an important role in determining the net photosynthetic capacity of the foliage canopy (see Equation 4) of mediterranean ecosystems. In southern Australia, South Africa, and Provence-Corsica of mediterranean France, soils exceedingly low in plant nutrients are common. In California, serpentine soils with a high Mg-low Ca ratio occur within the mediterranean region. Around the Mediterranean Basin, in southern Australia and in South Africa, there are many soils developed over limestone; shallow calcareous soils (either natural or eroded by man's activities) are usually of high pH, making unavailable such elements as P, Fe, Cu, Co. Some idea of the range of nutrient

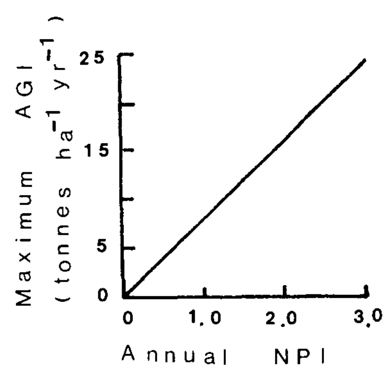


Fig. 6--Relationship between maximum Annual Growth Increment (tonnes ha^{-1} yr^{-1}) and Annual Net Photosynthetic Index for habitats of above average "site quality" (after Specht 1981d).

Table 2--Structural formulae for plant communities typical of the mediterranean region of southern Australia, based on Foliage Projective Cover (pct.) and annual Net Photosynthetic Index (NPI) of the foliage canopy of the overstory.

Annual NPI	Max. Annual Growth Increment (tonnes ha^{-1} yr^{-1})	Soil Fertility Index[1]	Foliage Projective Cover of Overstory		
			70-50 pct.	50-30 pct.	30-10 pct.
3 - 2.4	25 - 20	0.8	e T 3+[2]	-	-
		0.4	m L 3+	-	-
2.4 - 1.8	20 - 15	0.8	e M^+ 3+	e M 3-	-
		0.4	e S^+ 3+	-	-
1.8 - 1.2	15 - 10	0.8	e M 3+	e M 3-	-
		0.4	e S^+ 3+	-	-
1.2 - 0.6	10 - 5	0.8	-	e L/M 3-	e L 2
		0.4	e s 3+	e S 3-	e S 2
0.6 - 0.3	5 - 2.5	0.8	-	e L 3-	-
		0.4	-	e S 3-	e S 2
<0.3	<2.5	0.8			
		0.4	-	-	a S/Z 2

[1]Soil Fertility Index is shown at two levels - 0.8 (normal) and o.4 (reduced due to mineral deficiencies or imbalance).

[2]Structural formulae:- Dominant genus: e = Eucalyptus; m = Melaleuca; a = Acacia.

Life form: T = trees > 30 m; M^+ = trees 20 to 30 m; M = trees 10 to 20 m
L = trees < 10 m; S^+ = shrubs > 8 m; S = shrubs 2 to 8 m
Z = shrubs < 2 in.
FPC: 3+ = 70 to 50 pct.; 3- = 50 to 30 pct.; 2 = 30 to 10 pct.

availability which may be expected is shown by means of a polygon diagram expressing the foliar nutrient levels in mediterranean vegetation in South Australia and California (figure 7).

These nutrient deficiencies or imbalances considerably reduce the net photosynthetic capacity of the foliage canopy (figure 8). The reduction in Soil Fertility Index ultimately affects the structure of the climax plant communities which develop on these soils. As shown in table 2 an open-forest community which may be expected under a particular climate may be reduced to an open-scrub (calcareous mallee, garrigue, calcareous fynbos) or heathland (fynbos, maquis, manzanita-Vaccinium chaparral) community on nutrient-deficient soils. Extreme nutrient-deficiency may lead to dwarfism of species which normally possess a tree/tall shrub life form.

Soil Water Storage Capacity

Stunted plant communities may also be found in climatic areas where open-forest/woodland may be expected even though the soil is reasonably fertile (see figure 7, southern California). Here the water storage capacity of the soil appears to affect the Net Photosynthetic Index through the Moisture Index (figure 9). Shallow soils, characteristic of much of the chaparral of southern California, produce a lower value of the Moisture Index (Specht 1969, 1981b).

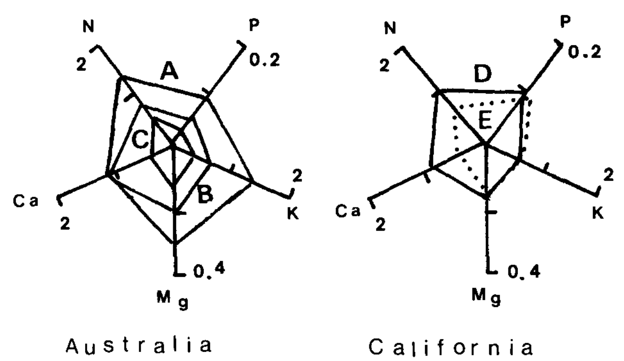


Figure 7--Foliar analyses (pct. dry weight) of representative overstory species in plant communities of diverse nutrient status in the mediterranean region of South Australia and southern California (after Specht and Moll in press).

A Savannah woodland
B Mallee open-scrub
C Heathland
D Chaparral, San Dimas
E Chaparral, Flicker Ridge

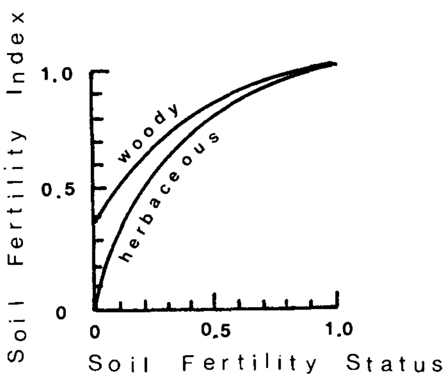


Figure 8--Relationship of Soil Fertility Index of herbaceous and woody perennial vegetation to soil fertility status (after Specht 1981d).

Within limits, a deep soil leads to a higher Moisture Index (figure 9). The water supply may be supplemented by seepage or the presence of a watertable within reach of the roots of overstory species. Under these conditions, the Moisture Index and, hence, the Net Photosynthetic Index are increased considerably. A similar increment in the Moisture Index may be produced on shady slopes (Specht 1972a,b).

GIANT MEDITERRANEAN OPEN-FORESTS

In the most humid zone of mediterranean regions where summer drought is still present but minimal, tall open forests containing the tallest trees in the world (Australia and California) have developed. The Moisture Index is almost optimal (1.0) for most, but not all, months of the year; Foliage Projective Cover is still less than 70 percent (an open community). The photosynthetic capacity of the foliage canopy, although high, is still not sufficient to explain such tall communities.

The high biomass of these communities may result from reduced respiratory loss from stems and roots (Specht 1981a,d). It appears that the living cells of stems and roots increase exponentially with time during the regeneration

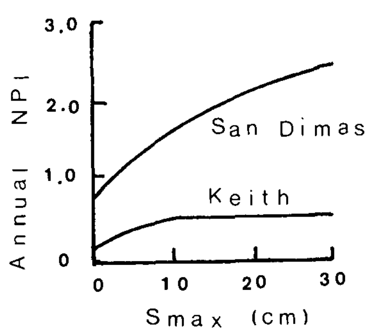


Figure 9--Changes in Annual Net Photosynthetic Index with soil water storage capacity (S_{max}) at San Dimas, California and Keith, South Australia.

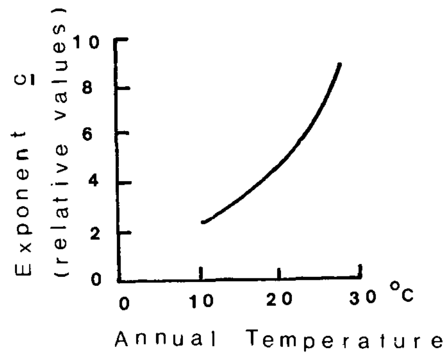


Figure 10--Relationship between exponent c of Equation 5 Mean Annual Temperature (°C) for plant communities along the eastern coastline of Australia (Specht 1981a).

phase of the plant community. Hence the resultant annual increment of biomass could be expressed:-

$$CAGI = CAGI_o \, e^{-ct} \qquad \text{Eq. 5}$$

where CAGI = Current Annual Growth Increment,
$CAGI_o$ = CAGI when respiration of stems and roots are almost zero,
t = age in years,
e = base of natural logarithms,
c = constant exponent.

The exponent c appears to be dependent on the mean annual temperature of the region, as it affects respiration (respiratory quotient Q_{10} = 2.0 for each temperature increment of 10°C). Relative values of exponent c for plant communities along the eastern coastline of Australia are shown in figure 10. It will be seen that exponent c is low in latitudes where mediterranean climates are found (latitude 35°, with a mean annual temperature about 15°C). With low values of exponent c, the accumulated values of CAGI (Equation 5) are much higher at latitude 35° than at lower latitudes. In areas where the net photosynthetic capacity of the foliage canopy is high, the accumulated values of CAGI reach extremely high levels.

LITERATURE CITED

Bond, W.J. Periodicity in fynbos of the non-seasonal rainfall belt. J. S.Afr. Sot. 46:343-354; 1980.
Fitzpatrick, E.A.; Nix, H.A. The climatic factor in Australian grassland ecology. In: Moore, R.M., ed. Australian grasslands. Canberra, Aust.: Aust. Natl. Univ. Press; 1970:3-26.
Gaff, D.F.; Churchill, D.M. Borya nitida Labill., an Australian species in the Liliaceae with desiccation-tolerant leaves. Aust. J. Bot. 24:209-224; 1976.

Gaff, D.F.; Zee, S.Y.; O'Brien, T.P. The fine structure of dehydrated and reviving leaves of Borya nitida Labill. - a desiccation-tolerant plant. Aust. J. Bot. 24:225-236; 1976.

Köppen, W. Die Klimate der Erde. Berlin: Bornträger,; 1923. 369 p.

Kruger, F.J. South African heathlands. In: Specht, R.L., ed. Ecosystems of the world. Vol. 9B. Heathlands and related shrublands. Analytical studies. Amsterdam: Elsevier; 1981: 1-4.

Kummerow, J. Structure of roots and root systems. In: Di Castri, F.; Goodall, D.W.; Specht, R.L., eds. Ecosystems of the world. Vol. 11. Mediterranean-type shrublands. Amsterdam: Elsevier; 1981:269-288.

Miller, P.C. Canopy structure of mediterranean type shrubs in relation to heat and moisture. In: Kruger, F.J., ed. Nutrients as determinants of the structure and functioning of mediterranean type ecosystems. Third Int. Conf. on Mediterranean-type Ecosystems, Sept. 1980. Berlin:Springer-Verlag; in press.

Moll, E.J.; Specht, R.L.; Manders, P.T. The role of woody underground parts in survival and growth. In: Kruger, F.J., ed. Nutrients as determinants of the structure and functioning of mediterranean type ecosystems. Third Int. Conf. on Mediterranean-type Ecosystems, Sept. 1980. Berlin:Springer-Verlag; in press.

Mooney, H.A. Primary production in mediterranean-climate regions. In: Di Castri, F.: Goodall, D.W.; Specht, R.L., eds. Ecosystems of the world. Vol. 11. Mediterranean-type shrublands. Amsterdam: Elsevier; 1981: 249-255.

Mooney, H.A.; Kummerow, J. Phenological development of plants in mediterranean-climate regions. In: Di Castri, F.; Goodall, D.W.; Specht, R.L., eds. Ecosystems of the world. Vol. 11. Mediterranean-type shrublands. Amsterdam: Elsevier; 1981: 303-307.

Mullette, K.J.; Bamber, R.K. Studies of the lignotubers of Eucalyptus gummifera (Gaertn. & Hochr.). III. Inheritance and chemical composition. Aust. J. Bot. 26: 23-28; 1978.

Specht, R.L. Dark Island heath (Ninety-Mile Plain, South Australia). VII. The effect of fertilizers on composition and growth, 1950-1960. Aust. J. Bot. 11: 67-94; 1963.

Specht, R.L. A comparison of the sclerophyllous vegetation characteristic of mediterranean type climates in France, California and southern Australia. I. Structure, morphology and succession. II. Dry matter, energy and nutrient accumulation. Aust. J. Bot. 17: 277-292, 293-308; 1969.

Specht, R.L. Vegetation. In: Leeper, G.W., ed. The Australian environment. 4th ed. Melbourne, Aust.: CSIRO-Melbourne University Press; 1970: 44-67.

Specht, R.L. Water use by perennial evergreen plant communities in Australia and Papua New Guinea. Aust. J. Bot. 20: 273-299; 1972a.

Specht, R.L. The vegetation of South Australia. 2nd ed. Adelaide, S.Aust.: Govt. Printer, 1972b. 328 p.

Specht, R.L. Structure and functional response of ecosystems in the mediterranean climate of Australia. In: Di Castri, F.; Mooney, H.A., eds. Mediterranean type ecosystems. Origin and structure. Berlin: Springer-Verlag; 1973: 113-120.

Specht, R.L. Ecophysiological principles determining the biogeography of major vegetation formations in Australia. In: Keast, A., ed. Ecological biogeography of Australia. The Hague: Junk; 1981a: 299-332.

Specht, R.L. Primary production in mediterranean-climate ecosystems regenerating after fire. In: Di Castri, F.; Goodall, D.W.; Specht, R.L., eds. Ecosystems of the world. Vol. 11. Mediterranean-type shrublands. Amsterdam: Elsevier; 1981b: 257-267.

Specht, R.L. Responses to fires in heathlands and related shrublands. In: Gill, A.M.; Groves, R.H.; Noble, I.R., eds. Fire and the Australian biota. Canberra: Australian Academy of Science; 1981c: 395-415.

Specht, R.L. Growth indices: their role in understanding the growth, structure and distribution of Australian vegetation. Oecologia 50: in press; 1981d.

Specht, R.L. Structural attributes - foliage projective cover and standing biomass. In: Gillison, A.N. and Anderson, D.J., eds. Vegetation classification in the Australian region. Canberra: CSIRO - Aust. Natl. Univ. Press; 1981e; p. 10-21.

Specht, R.L.; Moll, E.J. Heathlands and sclerophyllous shrublands - an overview. In: Kruger, F.J., ed. Nutrients as determinants of the structure and functioning of mediterranean-type ecosystems. Third Int. Conf. on Mediterranean-type Ecosystems, Sept. 1980; in press.

Specht, R.L.; Morgan, D.G. The balance between the foliage projective covers of overstorey and understorey strata in Australian vegetation. Aust. J. Ecol. 6:193-202; 1981.

Specht, R.L.; Rayson, P. Dark Island heath (Ninety-Mile Plain, South Australia). I. Definition of the ecosystem. Aust. J. Sot. 5: 52-85; 1957a.

Specht, R.L.; Rayson, P. Dark Island heath (Ninety-Mile Plain, South Australia). III. The root systems. Aust. J. Bot. 5: 103-114; 1957b.

Specht, R.L.; Rogers, R.W.; Hopkins, A.J.M. Seasonal growth and flowering rhythms. In: Specht R.L., ed. Ecosystems of the world. Vol. 9B. Heathlands and related shrublands. Analytical studies. Amsterdam: Elsevier; 1981: 5-13.

Specht, R.L.; Moll, E.J.; Pressinger, F.; Sommerville, J. Moisture regime and nutrient control of seasonal growth in mediterranean ecosystems. In: Kruger, F.J., ed. Nutrients as determinants of the structure and functioning of mediterranean-type ecosystems. Third Int. Conf. on Mediterranean-type Ecosystems, Sept. 1980. Berlin: Springer-Verlag; in press.

Yates, D.J. Optical properties of heathlands. In: Specht, R.L., ed. Ecosystems of the world. Vol. 9B. Heathlands and related shrublands. Analytical studies. Amsterdam: Elsevier; 1981: 91-97.

Dynamic Conservation Management of Nontillable East Mediterranean Upland Ecosystems[1]

Z. Naveh[2]

Abstract: East Mediterranean upland ecosystems are severely threatened by exponential landscape degradation and by the loss of biological diversity through monospecies afforestation and brush encroachment. Integrated landscape ecological research, planning, management and education are therefore urgently required to reconcile the need for bio-ecological conservation and restoration and for socio-economic advancement. Highest attainable diversity can be ensured by the maintenance of the dynamic flow equilibrium through controlled grazing, cutting and burning. Flexible multipurpose management for optimization of environmental protection, nature conservation, landscape and recreation amenities plus plant and animal production, should be based on ecosystem management and the creation of multi-layered fodder, fuel and/or recreation forests.

Mountainous uplands, too steep, shallow and/or rocky for profitable cultivation, make up large parts of the total area in all Mediterranean countries, especially in the Eastern Mediterranean Basin (Table 1). Whereas adjacent, arable lowlands are undergoing a rapid transformation into more intensive, irrigated agriculture, these nontillable, marginal uplands are either left to their fate of pastoral over-exploitation and uncontrolled urban-industrial -recreational encroachment or they are converted into closed, monotonous shrublands or dense, chiefly monospecies, pine afforestations. Both are highly inflammable and of low value for local populations.

There is, therefore, urgent need for new approaches in which the conservation and rehabilitation of these ecosystems can be reconciled with socio-economic advancement of the population. This is also true for all other nonarable uplands of similar nature in the Mediterranean Basin.

ECOLOGICAL CHARACTERISTICS

The greater part of these uplands is confined to coastal foothills and lower mountain regions with a typical Koeppen Cs "olive climate" -- dry, hot summers with wet, mild winters. This largely subhumid zone can be further divided into a drier xerothermo-mediterranean subzone merging into subdesert, and into a slightly wetter, cooler, accentuated thermomediterranean subzone merging into the humid, attenuated thermomediterranean zone (UNESCO, 1963). Both are within the 400-800 millimeter isohyetes, with true "Mediterranean fire bioclimes" in which acute fire hazards prevail for 150-200 biological dry days (Naveh, 1973). Their closest ecological counterparts outside the Mediterranean are the broad sclerophyll chaparral and woodland in central and southern California, and similar bioclimatic regions in central Chile.

Table 1--Major land uses in East Mediterranean countries in 1976. (After Le Houerou, 1980).

Country	Tot.area	Mediter. area		Cultiv. area	
	10^3 ha	10^3 ha	percent	10^3 ha	percent
Cyprus	924	855	100	432	50.3
Greece	13,080	8,102	62.0	2,331	28.8
Israel	2,033	1,367	67.2	433	31.7
Jordan	9,178	1,400	14.4	1,175	84.0
Lebanon	1,023	1,023	100	348	34.0
Syria	14,418	6,567	35.6	5,260	80.1
Turkey	77,076	77,110	22.2	8,309	48.6
Total	117,732	36,424	57.3	18,288	51.1

Country	Forest, maqui, shrub		pasture	
	10^3 ha	percent	10^3 ha	percent
Cyprus	330	38.5	9.3	10.9
Greece	2,618	32.3	3,153	38.9
Israel	116	8.5	818	59.8
Jordan	125	8.9	100	7.1
Lebanon	570	55.7	105	10.3
Syria	457	7.0	850	12.9
Turkey	6,051	35.4	2,750	16.6
Total	10,267	26.6	7,785.3	22.3

According to the extensive geobotanical description by Zohary (1973), both subzones belong to the Eu-Mediterranean vegetation belt of Quercetalia calliprini maquis and forests.

Great heterogeneity in macro- and micro-site conditions and a long history of active human modification have induced large floristic, faunistic, structural diversity which has contributed much to the attractiveness of these semi-natural landscapes and their complex, intricate vegetation

[1]Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Professor of Ecology, Technion-Israel Institute of Technology, Haifa, Israel 32 000.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

mosaics. These consist of dynamic regeneration-degradation patterns in sclerophyll, dwarfshrub and herbaceous plant communities. They range, according to site conditions and past and present land use pressures, from rich, productive open grasslands and woodlands to severely depleted dwarfshrub and man-made rock deserts, and from rich multi-layered semi-open shrublands and forests to one-to-two-layered, closed tall shrub maquis.

Most soils are shallow and/or rocky; many are heavily eroded, especially those which were terraced and cultivated and later on neglected. The fertile, well-structured, abundant terra rosa and brown forest soils (derived from hard limestone and dolomites of Upper Cretaceous and Tertiary rocks) and the dark rendzinas (derived from soft limestone with hard calcareous "nari" crusts), as well as the heavier basaltic soils (of volcanic origin), are conducive to vigorous growth of herbaceous plants. These include many valuable annual and perennial grasses, annual legumes and beautifully flowering geophytes, forming productive, stable shrub-free grasslands and woodlands in the xerothermic belts and their arid ecotones. However, in the more humid regions these pasture plants occur either as derived grasslands on abandoned fields, terraces and poorly drained shallow grumosols or as patchy understories of shrublands.

The highly calcareous, pale xerorendzinas (derived from soft limestone, chalk and Eocenic rock marls) as well as the brown soils derived from granitic rock, sandstone and metamorphic rock, are much poorer and highly erodable. Here, herbaceous plants are much less competitive and they are presently mostly covered by low-productive and species-poor "batha" (in Hebrew) and "phrygana" (in Greek) dwarfshrub communities dominated by Sacropoterium spinosa, Cistus and aromatic Labiatea species. Being favored by frequent burning and heavy grazing, these occupy large areas in all east Mediterranean countries. Their conversion into more valuable ecosystems should be considered therefore, as a major management challenge.

The natural potential vegetation of the cooler, wetter subzone consists of maquis dominated by Quercus calliprinos (in Greece by its western vicariant Q. coccifera) and other sclerophyll, mostly evergreen, phanerophytes. Distinguished by dual root systems, spreading both horizontally and penetrating deep into rock cracks, and by resprouting after burning, grazing and cutting, they also respond favorably to pruning and coppicing of one stem. If resprouting from suckers is prevented by recutting. or browsing, they soon attain the stature of trees. Thereby, closed one-layered, very fire prone maqui thickets which have been protected from grazing and human disturbances can be converted into rich, multi-layered park-like groves and forests. This, apparently, was the way sacred oak groves were created near cemeteries, which have mistakenly been regarded as remnants of "climax oak communities". The differences between such protected maquis thickets, lacking a herbaceous and sub-shrub understorey, and semi-open, disturbed multi-layered shrublands, in structural, floristic and faunistic diversity, are very striking (Naveh & Whittaker, 1979). There seems, therefore, to be very little justification for complete prolonged protection as a conservation management policy aiming at reconstructing the so-called "maqui forest climax", as suggested by Tomaselli (1977).

On the contrary -- one of the oldest existing Q. ilex "climax" forests in Sardinia, with huge scattered oak trees up to 1000 years old, is maintaining its open park-like structure and reproducing itself under traditional swine and cattle grazing. Removing pastoralists would only greatly increase fire hazards and endanger the forest (Susmel and others, 1976).

In the xerothermic subzone, the natural potential vegetation consists of thermophylous park-like maquis and shrublands made up of the valuable Carob tree (Ceratonia siliqua) and Pistacia lentiscus. This evergreen shrub, combining low palatability and great drought resistance with vigorous regeneration powers after fire and cutting, is one of the last shrubs to survive over large areas of overgrazed, depleted, mosaic-like shrub-grassland with low- or non-palatable early maturing annuals. However, if these pressures are released, a striking vegetative recovery of woody plants occurs, together with a very species-rich, productive grass cover. In such a xerothermic, recovered Pistacia shrubland, on 1/10 hectare, 52 woody, 127 herbaceous, 14 reptile, 7 rodent and 31 bird species were recorded (Naveh & Warburg, 1976).

Another important formation in drier parts, consists of deciduous oak woodlands -- Quercus ithaburense in Israel and Q. macrolepis in Turkey -- very much resembling Q. douglasii woodlands in California. Here, a very species-rich, productive grass and legume understorey is maintained under moderate grazing pressures. However, by over- or under-grazing species diversity is reduced, either to unpalatable weedy forbs or to tall aggressive grasses and perennial thistles (Naveh & Whittaker, 1979).

THE DISTORTION OF DYNAMIC FLOW EQUILIBRIUM BY MODERN LAND USES

Mediterranean land use and its impact on the landscape can be described as being cycles of multivariate anthropogenic biofunctions, corresponding to the main phases of changing land uses (Naveh & Dan, 1973). These started hundreds of thousands of years ago with the use of fire by paleolithic hunter-gatherer economies, which were replaced by agro-pastoral biofunctions lasting until recent times. In this long historical period a dynamic flow equilibrium or "homeorhesis" was maintained between the different woody and herbaceous strata by regular grazing, browsing, cutting, coppicing and/or burning cycles. As explained elsewhere in detail (Naveh, 1981) the thermo-dynamic behavior of these highly resilient, persistent, meta-stable ecosystems is comparable to dissipative structures (Prigogine, 1976). They are stabilized by a permanent exchange of energy with their environment through climatic- and man-induced fluctuations, thereby generating conditions of renewal of higher entropy production within new regimes of order, i. e., "creating order through fluctuation".

However, in recent years this dynamic flow equilibrium has been more and more distorted by exponentially growing rural and urban populations, with their increasing demands for animal and plant products, fuel, edible plants, etc., the patch-cultivation of steep non-terraced slopes after rootgrubbing of the protective shrub canopy and, above all, by the rapid process of urbanization, road development, tourism and mass recreation, which reach even the most remote villages. At the same time, the abandonment and prolonged protection of shrublands and the expansion of highly inflammable pine forests have further depleted diversity and aggravated fire hazards. The replacement of frequent traditional pastoral fire cycles by costly and ineffective policies of complete fire protection is now causing larger, more devastating wildfires than ever.

If these threatening trends proceed unhampered, only very few spots of open unspoiled landscape will be retained in small protected parks and reserves. Surrounded by ugly man-made deserts of dereliction and despoilation, these will very soon be turned into overcrowded "outdoor recreation slums", like the shores of the Mediterranean Sea.

PASTURE UPLAND MANAGEMENT--CONSTRAINTS AND PROSPECTS

Presently, the major economic benefit derived for local populations is still through pastoral utilization of primary plant production for cattle, sheep and goats. However, due to poor animal husbandry and grazing management, livestock and pasture production are very low and their impacts are disasterous. As goats are best adapted to the rugged terrain and can make best use of lignified woody plants, they have become the major source of income from east Mediterranean shrublands (FAO, 1965). Practical ways of goat husbandry and shrub-pasture improvement--including utilization of fenced bushranges by improved Turkish Angora goats from Texas--have been discussed elsewhere in detail (Naveh, 1974). However, there is little hope for improvement and to prevent further degradation without strictly controlled grazing.

For such rational management, public and communal ownership. allowing unrestricted grazing for everybody, are major constraints. In the past, diseases, starvation in drought years and fodder shortage in early winter, prevented overgrazing during the spring flush season and seed setting. But now, the "tragedy of freedom in the commons" (Hardin, 1968) is acting as run-away feedback for accelerated pasture depletion. Adverse effects on livestock, shared by all herdsmen and now partly eliminated by supplemental feeding, detracts only a small fraction from benefits gained by each individual keeping additional animals on common pastures. Grazing control can be achieved only as part of a new cultural, negative feedback by comprehensive over-all improvement and development of the Total Mediterranean Human Ecosystem (Naveh, 1978). The rise in livestock and pasture productivity must be combined with a rise in the socio-economic status of the pastoralist and with the elimination of ignorance and indifference at the communal, regional and national levels. This includes a change in the predatory attitudes of short-sighted exploitation and can be achieved, not merely by scientific and technological measures, but by a coordinated effort for <u>public environmental education</u> on all levels. In this, the short- and long-term advantages, both to the individual and the community, gained from improved livestock and conservation pasture management, should be clearly demonstrated by <u>dramatic</u> effects justifying these improvements and a complete change and breakthrough in perceptions and habits. Such great inputs in professional skill, human resources, education, technical and financial efforts, and investments, should serve not only the local livestock industry but should constitute an integral part of <u>multiple-benefit landscape development and rehabilitation</u>, as described below.

In the intensive farming systems of Israel, in Jewish collective settlements, these uplands are an integral part of highly productive beef cattle and sheep industries, based on rotational grazing, mostly in fenced, well-managed pastures. Since 1967 these methods have also been introduced into Arab villages in the Samarian and Judean Hills, with increasing success (Kamal, 1981). Many-fold rise in fodder production and quality has been achieved, even in the most shallow, dry hill sites, by reseeding with the annual legume <u>Medicago polymorpha (hispida)</u>, in combination with controlled deferred grazing (Briegeeth, 1981).

However, even by trebling the herbaceous pasture production from less than 100 to more than 300 grams/square meter/year and obtaining 200 kilograms of meat per hectare through intensive improvements, including fertilization, not only has the great dependence on seasonal and annual climatic fluctuations not best overcome but it has even increased (Naveh, 1981). On the other hand, the deep-rooted summer green sclerophyll shrubs, capable of tapping moisture surplus from deep rock layers, can provide green fodder in the dry season and in drought years, although their nutrient value and palatability are too low to sustain high economic livestock production. Therefore, improvements have been directed towards brush conversion by controlled burning and reseeding with perennial grasses. Because of their vigorous resprouting and the need for either frequent reburning or very expensive, not always efficient, highly undesirable, chemical treatments, their ecological and economic feasibility is very doubtful. This is true even where successful early establishment of such reseeded grasses has been achieved, both in Israel (Naveh, 1960) and in Greece

(Papanastasis & Liacos, 1980).

The prospects of grass conversion of low-fertility batha and phrygana are even poorer. As shown by Papanastasis (1980), only a low productive herbaceous cover can be maintained by 3-4 year burning cycles. On the other hand, the silvo-pastoral recreational conversion of dense maqui thickets has been carried out successfully on a large scale in Israel by selective thinning, coppicing, pruning and prevention of resprouting by controlled goat grazing. Thus, in the admirable Goren Forest in the western Galilee, most of the labor expenses have been covered by wood and charcoal production and in addition, the carrying capacity has risen from less than 1 goat/hectare to more than 3 goats. Species richness of the inpenetrable fire-prone maqui "climax", with less than 30 (woody) species/one-tenth hectare, has been increased to more than 70, including many highly valuable perennial pasture grasses and ornamental geophytes, together with the good landscape and recreation amenities attained[3].

DEADLOCK IN ECONOMIC UPLAND FOREST PRODUCTION

Up to now, the only way of preventing further denudation of depleted uplands was by converting them into dense, chiefly monospecies pine plantations. In addition to providing labor and revenues from wood and fiber, these forests have also served, in recent years, for outdoor recreation. However, from recent data on wood production (Le Houerou, 1980) it is apparent that the annual wood increment per hectare in Cyprus is only 0.52 cubmeter and in Israel, 1.00. These also include much more productive forests on fertile lowlands and higher elevations, i.e. productivity of shallow rocky slopes is even lower. Economic benefits are further reduced by loss of many trees to wildfires and steadily increasing fire prevention and fighting expenses. The early rapid development of such hardy pioneer trees as Pinus halepensis has created the mistaken impression that we can fool nature and establish dense, stable, productive conifer forests like those in much more favorable conditions in Europe. However, even their present low productivity is now severely threatened by combined impacts of photochemical air pollutants and pest infestations. Recent field and laboratory studies (Naveh and others, 1981) showed that widespread chlorotic mottle and decline is being caused in Israel, as in California, by atmospheric ozone concentrations above 0.05 ppm, followed in P. halepensis by severe infestations of Matsucoccus josephi scales. Most recently, ozone stressed P. canariensis trees are also being attacked and killed by bark beetles in the coastal region, where ozone levels already exceed 0.1 ppm. Similar damages can be expected in all other rapidly developing Mediterranean countries, where the sea breeze carries photochemical oxidants from urbanized, motorized coastal regions into forested slopes, and this will increase, without doubt (as in Israel) from year to year.

In younger pine stands there is still much grazable forage but with increasing shade and accumulation of undecomposed needle litter, palatable pasture plants are diminishing, together with edible plants, flowering geophytes and wildlife. Because grazing is mostly uncontrolled, it is regarded by foresters as a menace and not an asset. On the other hand, local populations, who have been deprived of their grazing and hunting grounds without gaining any direct benefits from new forests, are mostly hostile and non-cooperative. According to Morandini (1977) much more profitable, economic, wood and fiber production could be achieved from the deeper more fertile soils in wet lowlands and abandoned fields, which are suitable for mechanized cultivation. By more rational silvo-pastoral management, described in detail by Liacos (1980), many upland pine forests could yield both more wood and more pasture and fire hazards could be greatly reduced.

ALTERNATIVE MULTIPLE LAND USE MANAGEMENT STRATEGIES

From our discussion, it is obvious that neither one-sided pastoral nor silvo-cultural crop production oriented management can provide satisfactory socio-economic solutions. Non-arable uplands also fulfill many vital bio-socio-ecological functions for which no alternative land is available; therefore their loss would be irrevocable. They are not only of great biological, scientific, aesthetic and cultural value, as the last refuge for a wide variety of plant and animal species and ecotypes, they also serve as genetic stock for future evolution and potential economic uses for food, industrial, pharmaceutical and many other purposes. These functions and further speciation cannot be ensured in botanical gardens and in the few small nature reserves, but only in natural ecosystems. These should embrace the whole range of geological, pedological, topographical and climatical variety in which the above-mentioned dynamic flow equilibrium of the traditional agro-pastoral biofunction and its defoliation pressures can be continued. Further economic benefits can thereby be derived, while at the same time these ecosystems can fulfill their protective functions as buffering zones, providing drainage basins for flood, erosion and environmental pollution control for densely populated, intensively cultivated lowlands. In view of the rapidly vanishing open wildlands, these uplands also must fulfill vital phychohygenic functions for outdoor recreation by conserving and improving their scenic value and landscape amenities. An entirely new interdisciplinary landscape-ecological approach is therefore required in which all these socio-economic, bio-socio-ecological landscape functions can be optimized by dynamic conservation management. In this, all regulatory functions operating through the vegetation canopy as negative moderating feed-

[3]Personal communication from E. Josephi, Jewish National Fund, Forest Division--and data on file Faculty of Agr. Eng., Technion, Haifa.

backs of reduction of kinetic energy and abatement of adverse human impacts, ensuring self-regulation and dynamic stabilization, are combined with biotic production functions of both economic and non-economic richness, acting as positive amplifying feedbacks. For this purpose all non-arable uplands should be managed as closely interwoven networks of multiple land use patterns. In nature reserves highest priority should be given to sites with unique biological, geological and cultural value, aiming at maximum attainable ecological, biological diversity by careful, flexible, conservation management with different levels of controlled intervention, ranging from complete protection to controlled grazing, cutting and burning but with strict prevention of recreation pressures and other neotechnological interventions. For such studies, the MAB Biosphere Reserves are also most suitable. In nature parks and recreation areas optimization of landscape, wildlife and recreation amenities should enable maximum enjoyment with minimal damage to natural resources.

In the remaining open uplands, used primarily for economic benefits, landscape management and development should aim at optimization of all bio-socio-ecological, economic benefits, according to site potential, plus socio-economic and other requirements after weighing all relevant land use, environmental variables and their mutual influences. For this purpose, cybernetic, multidimensional sensitivity models, developed by Vester (1976), are most suitable. In a first approximation of such models (Naveh, 1979) environmental watershed protection, fire hazard resistance, biotic diversity, wildlife, recreation amenity, livestock production, forestry, plant production and water yields from aquifers were used as major variables. In these, highest over-all benefits were derived from flexible, multipurpose, silvo-pastoral-recreational systems, based on environmental afforestation.

On the basis of our promising introduction trials, we are now jointly realizing this with the Jewish National Fund's Forestry Division, by planting a multi-layered, semi-natural park-forest, resembling the richest semi-open maquis in structure and stability but being of much greater ornamental, recreational and economic value. Here, the local dwarf shrubs are being replaced by fast-growing, soil-protecting cover plants like Rosmarin officinalis, a highly ornamental, excellent honey plant, and the low-flammable Myoporum multiforum. The local, low-value sclerophylls are being replaced by highly ornamental, much more palatable, productive, nutritious evergreen shrubs such as Cotoneaster franchetti and Atriplex nummularia. In the most favorable niches, slower growing but persistent and shade-spending ornamental and fodder trees Certonia siliqua and Pistacia atlantica and promising Acacia introductions are being planted, while the few oak and other maqui tree remnants are being pruned.

EDUCATIONAL AND RESEARCH CHALLENGES

Such far-reaching programs can be implemented only within comprehensive regional and national masterplans, based on landscape ecological determinism in decision making on land use priorities and management strategies. As already mentioned, these require changes in the attitudes of land owners, users, planners and managers, from the top political level down to the grassroots of the village. Above all, we need to educate a new generation of interdisciplinary land managers and developers to replace one-track minded foresters, graziers, conservationists, recreationists and economists. This formidable educational challenge is closely interwoven with the research challenge, as rightly visualized in the MAB program. However, it needs much greater financial and moral support from local political and scientific authorities in order to have any immediate impact.

There is, without doubt, a great dearth of basic information on the structure and function of Mediterranean upland ecosystems. But at this crucial stage of exponential deterioration, not much can be gained from initiating pretentious, expensive and, alas, mostly very theoretical, far-fetched ecosystem studies aimed at creating the very fashionable not very realistic, mostly deterministic, "ecosystem models". In my opinion, it is much more important to continue to enlarge the "classical" down-to-earth botanical, zoological, pedological and other field studies--if these can be better coordinated and synthesized--so that their results can be applicable to practical ecosystem management. I envisage three major areas for which modern ecosystem and landscape ecological research is vital: 1) finding efficient "ecotechniques" for dynamic ecosystem management of the existing plant cover and its soil-plant-animal complex; 2) finding suitable plants and economic methods for establishing and managing multipurpose environmental afforestations; and 3) attempting to transform intangible, non-marketable landscape values into workable parameters and integrating these with economic land uses in cost-benefit analyses, computerized dynamic planning, optimization and simulation models, which are applicable to the solution of these problems.

As a first step, these challenges could best be realized by pilot research and demonstration schemes in representative sites in each country, with active cooperation of progressive communities and individuals.

LITERATURE CITED

Briegeeth, A.M. Pasture and range areas in Judea and Samaria. Proc. of Int. Symp. on pastoral sheep farming systems in intensive economic environments; 1981 March 8-14; Jerusalem, Israel: Tel Aviv Min. of Agr.; 1981.

FAO. Report on goat-raising policies in the Mediterranean and Near East regions. Exp. prog. of tech. assistance; FAO No. 1929; 1965; Rome.
Hardin, Garrett. The tragedy of the commons. Sci. 162:1243-1248; 1968 December.
Kamal, Hatem. Recent veterinary changes to promote the economy and development of sheep and goat production in a traditional Mediterranean agriculture system. Proc. Int. Symp. on pastoral sheep farming system in intensive economic environ. 1981 March 8-14; Jerusalem, Israel; Tel Aviv Min. of Agr.; 1981.
Le Houerou, H.N. L'impact de 1'homme et de ses animaux sur la foret mediterraneenne. Foret Mediterraneenne 2:155-174; 1980.
Liacos, Leonidas. Livestock grazing in Mediterranean forests. Int. Mtg. of Sci. on soil vegetation and fauna--safeguard and restoration of environmental equilibrium and regional planning in the Mediterranean regions; 1980 October; Palermo, Italy; :6-11 (mimeographed).
Morandini, R. Problems of conservation, management and regeneration of Mediterranean forests: research priorities. In: MAB Technical Notes 2; 1977; Paris, France; UNESCO:73-79.
Naveh, Z. Agro-ecological aspects of brush range improvement in the maqui belt of Israel. 1960; Jerusalem, Israel; Ph.D. Thesis, Hebrew University; 235 pp.
Naveh, Z. The ecology of fire in Israel. Proc. 13th Tall Timber Fire Ecol. Conf.; 1973; Tallahassee, Florida:139-170.
Naveh, Z. The ecological management of non-arable Mediterranean uplands. Environ. Mgt. 2:351-371; 1974.
Naveh, Z. The role of landscape ecology in development. Environ. Conserv. 5:57-63; 1978.
Naveh, Z. A model of multiple-use management strategies of marginal and untillable Mediterranean upland ecosystems. In: Cairns, John Jr.; Ganapati, P. Patil; Waters, William E., eds. Environmental biomonitoring, assessment, prediction and management--certain case studies and related quantitative issues. Statistical Ecology Series 11. Burtonsville, Maryland: Co-op. Pub. House; 1979: 269-286.
Naveh, Z. The evolution of the Mediterranean landscape as anthropogenic biofunctions. Theoretical and practical implications. Vegetatio; 1981a (in press).
Naveh, Z. The dependence of the productivity of a semi-arid Mediterranean hill pasture ecosystem on climatical fluctuations. Agr. & Environ; 1981b (in press).
Naveh, Z.; Dan, J. Human degradation of Mediterranean landscapes in Israel. In: deCastri, F; Mooney, H.A., eds. Mediterranean type ecosystems. Ecol. Studies. New York: Springer Verlag; 1973: 373-390.
Naveh, Z.: Warburg, M. Plant and animal species diversity along environmental gradients in a Mediterranean landscape of Israel. Haifa. Israel: Technion-Israel Inst. of Tech., B.S.F. No. 450; 1977; 185 pp (mimeographed).
Naveh, Z.: Whittaker, R.O. Structural and floristic diversity of shrublands in northern Israel and other Mediterranean areas. Vegetatio 41(3): 171-190; 1979.
Naveh, Z.: Steinberger, E.H.; Chaim, S; Rotmann, A. Photochemical air pollutants--a threat to Mediterranean coniferous forests and upland ecosystems. Environ. Cons. 74):301-309; 1980.
Papanastasis, Vasilios P. Effects of season and frequency of burning on a phryganic rangeland in Greece. J. Range Mgt. 33(4):252-255; 1980.
Papanastasis, Vasilios P.; Liacos, Leonidas G. Productivity of hermes oak brushlands for goats. Intern. symp. on browse in Africa; 1980 April 8-12; Addis Ababa, Ethiopia; Intern. Livestock Centre for Africa (mimeographed); 1980.
Prigogine, I. Order through fluctuation: self-organization and social systems. In: Jantsch, E.; Waddington, C.H., eds. Evolution and consciousness. Reading, Mass.: Addison-Wesley Pub. Co.; 1976:93-126.
Susmel, L.F.: Viola, F.: Bassato, G. Ecologia della lecceta supramonte di orgosolo. Padova: Annali del Centro di Economia Montana delle Venezie X.; 1976: 1959-1970.
Tomaselli, R. Degradation of the Mediterranean maquis. In: MAB Technical Notes 2; 1977; Paris, France; UNESCO: 33-72.
UNESCO. Bioclimatic map of the mediterranean zone. Explanatory notes. Arid Zone Research 21; Paris, France; UNESCO; 1963.
Vester, F. Urban systems in crisis. Understanding and planning of human living space: The biocybernetic approach. Stuttgart: Pentsche Verlagsanstalt; 1976.
Zohary, M. Geobotanical foundations of the Middle East. Stuttgart: G. Fischer Verlag; 1973; 5-5 pp.

Regional Management of Mediterranean Ecosystems in Spain[1]

Jose A. Carrera, Estanislao de Simon, and Manuel Fisac[2]

Abstract: Management of the fragile and greatly modified ecosystems in the Spanish Mediterranean climate is complex. Rainfall occurs in a few intensive storms on rough topography. Climax vegetation is sparse forest dominated by evergreen xerophilic species. The emphases of the National Institute for Nature Conservation (ICONA) are forest hydrology restoration, restoration of forest potential, attainment of forest structure, and protection of natural spaces with singular ecological characteristics. This paper discusses the goals of management, evolution of forest management, management problems, scientific information in forest management and restoration, and national level studies on reforestation, hydrology, and desert control.

Most of Spain has a typical Mediterranean climate. Because of its geographic situation and topography, many different climate varieties are represented, from the arid in southeastern Spain to the Mediterranean high mountain in the Sierra Nevada. This variety of climates gives rise to a series of ecosystems, normally much altered by human activity, and very difficult to restore because of their fragility and climatic characteristics.

The European Mediterranean climate is characterized by a very dry summer. Rainfall normally takes place in a few days but is very intensive. Together with a rough topography, this causes torrential watercourses. This is an aspect which conditions the management and control of large areas of our country.

The vegetation climax is the sparse forest or woodlot with evergreen xerophilic species, of which the holly-oak (Quercus ilex) is the most representative, occupying the greatest area. The most characteristic coniferous species in this region are Pinus halepensis, the Mediterranean subtype of Pinus nigra, Pinus pinaster, and Pinus sylvestris.

In the temperate and dry zones, the holly-oak overstory leaves room for the wild olive tree (Olea europea), represented in the transition zones by the "coscoja" (Quercus coccifera). In the driest zones, and where erosion has degraded the soil, the Mediterranean "garriga" appears on calcareous soils, representing the tropophyla vegetation and forming a clear and discontinuous bush. On siliceous soils the "maquis" appears, a closed underbush of rockrose (Cistus) with "lentiscos" (Pistacia) and strawberry trees (Arbutus) among which the holly-oaks (Quercus ilex), kermes oaks (Quercus faginea), and isolated pine trees stand out.

The scarcity of tree species compatible with our climate, and the differentiation between the existing ones, have caused numerous "endemismos." Professor Luis Ceballos considers that this is due to the isolation of Spain between the Pyrenean Cordillera and the Mediterranean Sea. Among these species are the Spanish fir tree (Abies pinsapo) in the Penibetica Mountains. In North America, north of the 36th parallel, more than 450 species of autochthonous forest trees can be cited, while in the south of Europe there are hardly more than 70. From fossils, it is known that many species now living far from the Mediterranean zone were present during the Tertiary in the European Meridian. This data should be useful for the restoration of degraded ecosystems, in which selection is difficult due to the scarcity of autochthonous species. Thus we could try to restore some trees lost by accident in the Mediterranean zones. On the other hand, the diversity of our Mediterranean climates allows us to try some species which were earlier represented in the habitat but later were replaced by other species of minor rank. Professor Ceballos considers that there are three conifers in a progressive stage to be borne in mind for the restoration of Mediterranean ecosystems: cypress (Cupressus sempervirens), cedar (Cedrus atlantica), and spruce fir (Abies pinsapo).

GOALS OF MANAGEMENT

Forest management is a dynamic concept as a consequence of social, economic, and political conditions. The human being has always tried to make full use of the resources available to him. While the resources were abundant and the population's necessities were met, there was no clear commitment to management. The forest was considered only as a timber producer and a supplier of fuel, which meant intense deforestation in Spain. When the resources became scarce and the needs for forest products increased, there was concern about the precarious situation of our forest, and a

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Dr. Engineers, ICONA (Instituto National para la Conservacion de la Naturaleza), Madrid, Spain.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

period of forest conservation began in the middle of the last century, coinciding with the creation of the Forest Corps.

Every ecological system has an optimum level of stable and permanent vegetation representing the biological maximum permitted by environmental conditions. In the Spanish forests the vegetation climax is represented by more or less closed forests of coniferous trees in the high mountain zones and of hardwoods in the middle and low mountains, and only in the dry zones of the littoral and on the tops does the bush represent the climax. The resulting ecosystems are briefly described according to land use; the limitations of this work do not allow us to particularize each one of the existing ecosystems and their precise relations.

The Spanish School of Management was born as an offshoot of the German School of Tharand, and its focus was basically economic, addressing maximum timber production. However, it was early adapted to the characteristics and problems of the Mediterranean forests, first taking into consideration other products, such as cork and resins, and from the beginning giving preponderance to soil protection. Already in 1930 it was taking into consideration such indirect benefits as esthetic, scientific, health, and recreational values.

Thus, we reached the present consideration of the forest as providing for multiple use, and the concept that forest management should direct and guide it to the optimum indicated of its natural, social, and economic functions, through convenient planning in time and space for its exploitation, utilization, substructure, and improvement within the limits imposed by the biological requirements.

This direction towards the optimum implies the following master lines of activity:

– Forest hydrologic restoration of watersheds.

– Forestation of areas with forest potential.

– Attainment of a suitable structure of forest stands.

– Protection of natural spaces with singular ecological characteristics.

As a result of past actions, there are at present nearly 2 million ha under management, the first dating from 1895, most of them softwood species (1,450,000 ha) mainly Pinus sylvestris and P. pinaster (each 466,000 ha) P. larico and P. halepensis (each 200,000 ha) P. uncinata (100,000 ha) and smaller surfaces with P. pinea, P. radiata, P. canariensis, and Abies pectinata. For hardwoods, there is a total area of 380,000 ha, most of these being Fagus sylvatica and Quercus robur (200,000 ha). Eucalyptus (125,000 ha), Q. suber (50,000 ha), and small areas of other Quercus spp. are included.

Almost half of the management work was concluded during the decade 1951-61.

Among the intact or little degraded ecosystems is the holly-oak forest of Quercus ilex, the most representative for the Mediterranean zone. It is the most typical tree in Spain and there are approximately 550,000 ha high forest, 850,000 ha woodlot forest, and 856,000 ha of coppice forest. During historic periods, this forest covered the majority of our land area. Its perfect adaptation makes it take advantage of all the Mediterranean climate characteristics, first of all keeping the soil moisture, thanks to the density of its crowns and the thickness of the organic horizon formed under it. These permit it to vegetate perfectly during the long dry periods, having strong resistance to drought, hot weather, and the dry air of the Mediterranean summer. It extends from sea level to 2000 m elevation, where it can be found in the Sierra Nevada, although its optimum is between 200 and 1200 m.

In a more humid environment, the climatic vegetation consists of gall oaks (Quercus faginea) and cork-trees (Quercus suber). The first can be found in almost all the provinces in Spain. It is perfectly adapted to the humid Mediterranean soil and is a half-light tolerant species. It can reclaim the habitat from where it was displaced and usually does at the expense of holly-oak, which acts as a subclimax species in the humid Mediterranean soil. The second oak species can be found on siliceous soils in the southeast and northeast of the country. In the mountains, Pinus sylvestris is extensively represented, and occupies this habitat from the Pyrenean Mountains to the Sierra Nevada, where in Cerro del Trevenque it reaches its most meridional spontaneous form.

The climax ecosystems of mountain peaks generally form a dwarf bush of savins, integrated by Juniperus sabina humilis and Juniperus communis nana, accompanied by cushioned bush of brooms mixed with fescue grass, which is graminaceous grass with stiff leaves.

On sandy ground and littoral marshes, the vegetation climax is integrated by Juniperus phoenicea, Retama monosperma, Lotus creticus, Corema album, etc., adapted to resist the action of dominant winds, which are very common in these zones.

Of great ecological value is the interesting ecosystem in the National Protected Space of "El Sabinar," on the coast of Almeria in the southeast of Spain. Its basic association of Juniperus and Pistacea is sporadically joined by Tamarix, and composes, with its fauna, a sabulous biocenosis, the only one on the Andalusian coast. It is a relic ecosystem, which once, in historic times, occupied all this coast.

As an example of transformed ecosystems, which have obtained an ecological balance due to the treatment received, there is a degenerated form of the holly-oak forest, known as "dehesa" (open woodlot with pasture). Its main object is the production of fruit (acorn). The brushwood vegetation has been taken away in order to obtain a pastureland and in this way a mixed grazing is obtained for pigs, cows, and sheep. The "dehesa" is formed by gradually reducing the tree density and modifying the crown of the holly oaks by successive prunings.

Finally, there is a stable ecosystem, which has not changed in 2000 years, known from the writings of the Greek Strabon, who crossed the Roman Empire during the time of Augustus and was consequently contemporary with Jesus Christ. In his "Geographica" book III, "Iberia" he describes his journey from Tarragona to Jativa, and from there, he writes: "he gradually left the coast, arriving later at the so-called "Spartarius", a big field without water where the "esparto" (matweed) grows abundantly."

This "esparto" is used for the weaving of cord and is exported all over the world, but mainly to Italy. The "spartarius campus" is a big plain extending from Cartagena to Almeria; it has remained almost unchanged since Strabon saw it.

As the oaks are the most representative family of the Mediterranean forest trees, the cistaceous are the most characteristic bushes; their formations of dense brush (maquis) reach the height of a man or even more, and occupy great areas of the country. Examples are "Sierra Morena" (the dark mountain), the name of which alludes to the dark green rockroses (jara) when they are seen in the distance; and the Montes de Toledo, Extremadura and Baja Andalucia, forming a stable ecosystem in regression, where the "Quercus coccifera" is present, not reaching tree size, and over which old individuals of holly-oak and cork-tree stand out. In the extensive representation of the cistaceae, Cistus ladaniferus predominates with C. laurefolius and C. populifolius, accompanied by the lentisco (Pistacia lentiscus), the strawberry tree (Arbustus unedo) and a big group of small heath (Erica), thyme (Thymus), rosemary (Rosmarinus), etc.

Degraded Ecosystems

In vast zones of Spain, a big alteration of the natural environment has taken place over the years. The climax ecosystems have been replaced by others very distant from the potential climax. The result has been a continuous deterioration of the soil as a consequence of the erosion produced by the lack of a suitable vegetal cover. In this way vast zones of the country are covered by deeply degraded bush, frequently with thorny plants, especially labiates.

A greater number of Spanish foresters are dealing with the management of these degraded ecosystems as their main mission and with a restoration criterion. Due to the degradation of these ecosystems and their fragility, the restoration has to be carried out starting virtually from the last stage of the phylum.

As we know, the management of an area consists in organizing it according to silvicultural and economic criteria in order to obtain the maximum protection, social, and production benefits. It is generally not possible to obtain these three maxima at the same time and therefore it is necessary to establish an order of priority among the possible objects.

HISTORICAL EVOLUTION OF FOREST MANAGEMENT

The deforestation stage has been as long as the history of Spain. Spain's geographic situation at the crossroads of Europe and Africa, its mild climate, and the abundance of its resources, were the reasons why different peoples settled in Spain. There was no serious deterioration of the environment while the population was still sparse, but repeated impact on an ecologically fragile environment determined the deterioration of the natural ecosystems and made restoration difficult, as the lack of vegetal cover accelerates the erosive process. The principal causes for deforestation have been these:

– The plowing of forest soil in order to install agricultural plantations, later abandoned.

– The secular protection of cattle. As Spain is a rather mountainous country and not propitious for the creation of meadows, grazing has been carried on with sheep and goats for 3000 years. During the Middle Ages and later in the 16th century, the wealth of Spain was based on its millions of sheep, with their privileges of pasture and browsing, which caused irreparable damage to the forests.

In "History of the Spanish Institutions" Professor Valdeavellano says that the origin of the "Mesta" was the associations of shepherds and local cattle breeders, who joined together during the Middle Ages in every municipality two or three times a year to take care of the pasture of their cattle. Those meetings were normally held after the reconquest of each town. By 1273 the cattle breeders and shepherds in the Kingdoms of Castilla and Leon were constituted in only one municipality of the "Mesta". Alfonso X granted it privileges and ordered its decisions to be obeyed. As all cattle of the "Mesta's" municipality were considered a service to the King, he ordered that the cattle should be safe and secure all over the kingdom, grazing freely on any pasture they came across as long as they didn't damage the cultivated fields, scythed pastures, and pasture woodlots. The honorable municipality of the "Mesta" took charge of the nomadic cattle and also the routes or paths used for the changing of livestock from summer pasture on the mountains in the north of the kingdom to winter pasture on the mountains and places in the south. These paths or "canadas" had a set width when passing across the cultivated fields, but on the mountains and uncultivated grounds the cattle could cross anywhere. The preponderance of the "Mesta" can be observed in the well-organized net of royal paths, lanes, and footpaths still existing and complete with resting-places, watering-places, and bed-grounds, today managed by ICONA, and consisting of 425,000 ha.

Another deforestation factor is numerous wars, when fire often was used as a punishment; the land or forest that the enemy was going to occupy was burned. The successive invasions of Celtics, Phoenicians, Cartaginians, Romans, Germans, Arabs, and French people among others, destroyed a great part of the forests. The Reconquest, which succeeded the Arab invasion and lasted eight centuries, caused a great deal of the destruction of the forests. As Dr. Erich Bauer says in "The Spanish Forests in History", the Spanish expression "emboscada" (ambushed) alludes clearly to attacks from dense forests, where the enemy could hide. To avoid ambushes, many forests were felled and burnt.

The situation of Spain with 3000 km of littoral has made it necessary during almost 3000 years to dispose of a great quantity of wood for the construction of ships. For this purpose the best oaks and pines were used to fill the demand for wood by the merchant navy and the Navy, which since the 15th century attended the presence of Spain in a great part of the world, especially on the American continent.

To this whole process, a policy of freedom from mortmain was in effect during the past century, with very unfavorable consequences for the forestry sector; 5.5 million ha of public forest and 2 million ha of forest belonging to the Church were auctioned and most of them were felled by the buyers.

Conservation starts with the creation of "Direccion General de Montes" in 1833 and the Corps of Forest Engineers, who established the most efficient measure to preserve the rest of the forest richness in Spain, the creation of the Public Forest Catalogue. The forests included in this catalogue are untransferable, unseizable and imprescriptible, the last condition limited to 30 years.

The catalogue included more than 10,000 forests with an area greater than 6.5 million ha, which were classified and catalogued, forming the first starting-point for the defense and restoration of the forests in Spain. The first Forest Law is dated 1863 and was in force until 1957, when another was published. Almost a century in force guarantees the success of its conception. From that period a series of dispositions served as a legal base to conserve the forest patrimony. It is worth mentioning the creation of the "Patrimonio Forestal del Estado" in 1935, very efficient in the conservation and restoration of the forest. Its mission was to restore, conserve, and increase the "National Forest Patrimony" and to create the National Institute for Nature Conservation (ICONA) in 1971, which continues the labor of the "Patrimonio Forestal del Estado," amplifying its functions regarding the conservation and restoration of natural ecosystems.

MANAGEMENT PROBLEMS

Problems in forest management can be divided into three groups: legal, social, and practical.

– Legal: Very complete legislation regulates action in the State forest and in general in the Public Utility forests, as well as in hydrological forestry restorations, but there is a lack of legal operative instruments for acting in the private forests in general.

Once approved, a forest management plan is enforced in the forest by legislation, requiring a management revision plan every 10 years.

In forests without a management plan, ICONA has to approve the harvesters of wood by marking and spotting standing trees to be cut and finally checking the felling. Excluded from this duty is wood on private property within the harvest area, intended for domestic use.

– Practical: Lack of resources, forest fires, amateur ecologists, weekend excursionists, lack of professionals, privileges without duties, and some very altered ecosystems are the practical problems that a Technical Director of Management or Restoration has to resolve.

– Social: These vary with regard to the economic situation. In periods with economic depression the forest resources are always overexploited. To make the pasturage more productive an extra range count per ha is needed. This damages the forest, and its herbaceous and even ligneous vegetation will diminish in a very short time, with irreversible degradation of the soil. The occupation of forest areas for urbanization and industrial plants often takes place at the expense of forest area.

SCIENTIFIC INFORMATION IN FOREST MANAGEMENT AND RESTORATION

A multiplicity of data and observations of interest are available. As forest management in Spain began in 1895, the amount of scientific data is very important.

The main parameters used are soil characteristics (geological formation, depth, composition, physical conditions, rush of water, etc.); orography and configuration of the ground; hydrographic position; climate (rainfall, seasonal distribution, temperature, relative humidity, etc.) expressed in bioclimatical diagrams; flora (species, vegetal associations, etc.); fauna (convenient and injurious species, etc.); diseases and plant pests; statistical risks of forest fires; livestock pressure (class and quantity); density of human population (characteristics and grouping); communication and access ways; mill industries; touristic and recreation demand, etc.

As well as scientific information about forestry, all complementary information is used: complete records of meteorologic stations in the forest, edaphologic studies, measurements of the soil moisture available for the roots of the plants, and the influence, dose, and results of the fertilization of forest soils.

In forest stands, species are analyzed for basal area, site quality, diametric distribution, height-diameter and diameter-age relations, stand volumes (tree-volume tables and management, tarifs), stand growth, etc. Industrial investigations are also used, as performed by the Forest Research Centre on the use of different species, characteristics of different products and agents acting on them, production and consumption studies, etc.

A consequence of the meticulous study performed and of the planning of the aims to be reached is the selection and settlement of the necessary measures, which end in a series of activities in time and space, with different intensity and method.

The management action can be integral or limited, the first referring to forest yielding products for a single market and the second referring to isolated forest stands of less importance.

When a plan has been made, a model is chosen for the forest, setting forth its management division, stand structure, method of management, rotation, reproduction period, allowable cut, felling method, accessory systems, means to use, financiation, etc., as well as a quantified objective.

Management projects are revised periodically (every 10 years) by accumulating and studying the obtained data or modifying or maintaining the directives indicated in the management project. In any management project or revision, there are three approaches: long term (general plan), medium term (special plan), and short term (annual plan).

Restoration Projects

Due to the fragility of the Mediterranean ecosystems, once the ecological balance is broken by man, generally through cutting or burning the tree vegetation, a progressive and irreversible deterioration is produced which requires management action.

The restoration of these very fragile and degraded ecosystems requires detailed scientific information to provide foresters with the necessary means of planning the management. This information should always be completed with the experience obtained from earlier restorations.

The first requirement is a complete study of the "habitat" on which the restoration will be performed. Information on the physical medium should include:

a. Morphologic characteristics, with analysis of the topographic aspects of the area to be studied; compactness index and relief studies.

b. Information about the soil in two ways: one analytical and another calculating indexes which can define the type of soil reaction.

c. Study of the climate through an analysis of meteorological data of the established seasons.

A parameter, recently introduced for this type of study is the bioclimatic diagram by Montero de Burgos and Gonzalez Rebollar. It is an invaluable help in the restoration of the Mediterranean ecosystems, as, due to the scarcity and irregular distribution of rainfall, a technique of climatical analysis with biological basis is needed, giving great importance to water balance.

The bioclimatical diagrams provide exact information, but are restricted to the proximity of the station. Bioclimatical maps serve the biological aims of the restoration by providing detailed and accurate information for the area.

d. Vegetation studies, carrying out analyses of associations and of indicator plants, of vegetation dynamics for land use, of climatic regression scales, and of the situation of the vegetation on the scale; also phytosociological studies as indicators of the species to be used.

Hydrological forestry projects, especially corrective work, are revised every 5 years to check if everything has been carried out according to plan and if any rectifications are to be done. Modifications of the project due to the influence of the work already accomplished can be made on reasonable justification.

It is of great ecological value to succeed in restoring the climax vegetation of the Mediterranean area as far as the tree forest, but there are a series of edaphological and economic factors that condition such restoration. The first one limits the nature of the plants to be installed, as the climax species are very exigent with respect to the environment and need a rather mature soil for good development. It has been proved that the climax species have very limited development and difficult rootage in eroded soils with little depth, little organic matter, and little-developed horizons, and this is the condition of most of the soils to be restored.

Another limiting factor is economic. As the areas to be treated are always large, the cost of conditioning the soil to give it the nutrition and texture it needs in order to receive the climax species are always too great for the Forestry Administration.

Therefore, regeneration of the vegetation climax must be restricted to forests with favorable ecological conditions; those with a more fully evolved soil, where the natural vegetation is conserved, even if only in shrubby form. We will describe the regeneration system used in the reconstruction performed by ICONA on holly-oak forest, the most typical Mediterranean forest. This is taking place in various forests, especially in Sierra Nevada, in the province of Almeria in the south-east of Spain, in an area with subhumid climate according to the Emberger classification.

The "habitat" on which we are acting contains a bushy vegetation of holly-oaks formed by discontinuous stunted bush-spots with some young shoots. The soil is very eroded, particularly in areas without bush cover. It has been cut for fuelwood and charcoal several times; the last felling was some 30 years ago, and it has supported continuous grazing by goats, which have eaten the annual buds. All this has produced a regression of the normal formation of the holly-oak, so that it reaches its most bushy form.

The reforestation system used consists of a combination of protective treatments completed with line planting of plants in bags and seeding of acorns. The initial treatment consists of a selection of young buds, which are pruned; a cleaning of surrounding brush; and a brushing of strips, even with the ground, in order to stimulate the sprouts and coppice shoots. This brushing is done manually or mechanically according to the slope and the degree of protection of the vegetation needed. The manual system is used in stands with mature soil. This careful treatment is very advantageous because it doesn't produce any appreciable alteration of the soil; the shoot distribution is much better and the ground is consequently better covered. Motor brush cutter or manual tools are used for the brushing, as in working at ground level, stones interfere with the action of the gear. The mechanical system is used in stands of lesser slope and with a more closed bush. The brushing at ground level is done with a bulldozer of 75 to 180 CV, cleaning alternate strips following contour curves.

The restoration system that gives best results is a combination of the three described treatments. The young existing shoots are first pruned and cleaned. Afterwards alternate strips are brushed with tractors at the level of the ground, and the tree bush and creeping vegetation is brushed by hand, for better distribution of the shoots. In the open strips, which are brushed with the bulldozer, the forestation is completed with a seeding of acorns and a planting of seedlings in bags on areas without bush.

With this system, a diversity of ages of the climatical ecosystem is obtained that guarantees its persistence. Finally when the selected stems have reached enough development, it is necessary to make a selection of the shoots, normally by cutting the surplus ones with long-handled pruning scissors. Once a tree crop is obtained, an important alternative is presented in the areas with less slope, consisting of a clear woodlot "dehesa" which permits grazing.

An important help in monitoring of regeneration treatment and comparison between the development of treated and untreated examples of the same stool is amplified microphotography on which the evolution of the shoots and the vegetative stage of the stems can be observed.

The management or restoration plan of a forest or a catchment basin is studied and written up by the Technical Director of the forest, who has the title of "Ingeniero Superior de Montes" assisted by "Ingenieros Técnicos Forestales" and an "Ingeniero Técnico Topografo". Specialists in other subjects, normally edaphologists and biologists, collaborate in the study. The Technical Director of the forest is in charge of the fulfillment of the plan and of necessary revisions. Periodically, there are specialization courses in the "Escuela Técnica Superior de Ingenieros de Montes," and others organized by ICONA, which those interested can attend as appointed by the Director or at their own request.

The new techniques, results of management, etc., are published in specialized magazines, among which we mention Central Station of Ecology ("Estación Central de Ecologia") Forests ("Montes"), Wild Life ("Vida Silvestre"), etc. The results of special projects and reports on the development and conclusion of the courses and seminars, etc., are published in the "Monografias" of ICONA. The results of the forest research are published by INIA, which includes the Forest Research Institute.

NATIONAL LEVEL STUDIES

Only studies closely related to management, restoration, and utilization of the natural environment are indicated.

National Plan of Reforestation

The object of the plan is to recover the barren areas with forest; where it is necessary, to do a reforestation with protective, productive, or socially beneficial effect. It comprises some 5.5 million ha and is to be performed in 50 years. A photogrammetric study of Spain has been required, each photogram covering a surface of 500 to 800 ha.

National Hydrological Plan

Its purpose is to regulate water yield, for which agrohydrological management of the catchment basins is necessary.

At the present time, the study is in a predefinition phase. A data bank has been formed, in which all studies and projects have been inventoried. With respect to the Natural Space, which is the sector where ICONA takes action, information on water supply and demand has been gathered.

Forest areas and new plantations have been mapped, as well as future reforestations, Natural Spaces with special protection, erosion centers, and restoration work on degraded ecosystems classified as necessary, performed and to be performed.

Register-cards of water demand as per use, and maps of water demand have been made.

Special plans of greatest interest are those referring to Protected Natural Spaces, e.g., the National Parks.

Desert Control Program

The deep valley of the Mediterranean Sea, the origin of civilization, has suffered through its history a progressive deterioration of the natural resources, caused by human activity with abusive practices of soil and a continuous use of some limited natural resources in a very fragile natural environment. This is mainly due to the characteristics of the Mediterranean climate, with a brief rainy season and a very irregular distribution of rainfall, where long periods of hot, dry summer and violent rainfall are frequent. The rough topography and the lack of a convenient vegetal cover in large areas gives a torrential character to most of the catchment basins. This gives tree vegetation very limited development in large areas; recovery of the ecosystem that man has altered is difficult.

The frequently torrential rainfall, the rough topography, and the lack of necessary vegetal cover results in very much altered ecosystems in important areas, where the erosion has impoverished the soil, with progressive exhaustion of the renewable natural resources. This pattern has decisively affected the, social and economic history of the area.

Increasing deterioration of the environment, aggravated by some very dry years in the southeast Spanish part of the Mediterranean watershed, has given desert control problems preference over other work in Spain.

At an international level, the World Conference on desert control held in Nairobi in 1977 made obvious the necessity for greater knowledge of the phenomena that produce the desert, and for improved technology to control it. At the same time, it was recommended to promote the necessary action to fight against the deserts at a national level as well as at an international level.

Spain has therefore followed a policy of conservation of the natural environment and reforestation programs, since the last century when the Forest Corps was created. Three million ha have now been reforested. With the obtained experience of restoration, it is considered that desert problems have such specific characteristics that the best way to fight efficiently against it is to establish a program to study and monitor erosion in Spain. For this purpose a working group has been formed within ICONA, in collaboration with the University and the Research Centers. It is working with the LUCDEME project (Struggle against the Desert of the Mediterranean).

As the problem covers a big part of the Mediterranean watershed, the Spanish Government is interested in promoting the cooperation of the Mediterranean Nations so that the studies performed and the recommendations reached will serve the Mediterranean countries with these problems.

The objects of this project are:

- To deepen knowledge of the existing national resources and their condition before their degradation due to human activity.

- To know in detail the reasons for the deterioration of the resources and their degradation levels.

- To define the existing correlation between the deterioration of the natural resources and the social and economic decline of the affected rural areas.

- To analyze the techniques applied up to now and to design new techniques for desert control.

- To study the costs of restoration of the natural resources, in order to develop the rural areas and achieve higher levels of life quality, analyzing the cost-benefit relation.

- To study historical research of this area, which traditionally has been the meeting point of developed and underdeveloped worlds. This Spanish area with great desert problems was a developing center during the first period of our occidental civilization with the culture of "Los Millares", "Villaricos" and "El Argar", probably due to the climatic conditions, that were good for the people and hostile for the environment.

- To continue research of the natural resources, ecology, land use, degradation level of the resources, sociology, meteorology, forest hydrology, etc.

- To study traditional systems of land use and evaluate technology applied on the works already performed and the techniques used. Study application of new techniques adapted to the Mediterranean ecosystems, etc.

- To improve utilization of the activities and results of research and technology for training of experts and investigators through symposia, courses, workshops, etc.

LITERATURE CITED

Abreu, Jose M. El medio natural en la planificacion del desarrollo. Madrid, ICONA, 1975.

Bauer, Erich. Los montes de Espana en la historia. Madrid, Ministerio de Agricultura, 1980.

Ceballos, Luis. Los matorrales españoles y su significación. Madrid, Escuela Técnica Superior de Ingenieros de Montes, 1945.

Gorou, P.; Papy, L. Compendio de geografía universal. Ediciones Rialp. 1972.

López Cadenas, Filiberto. Hidrologia forestal. Madrid, Escuela Tecnica Superior de Ingenieros de Montes. 1976.

Martin Bolanos, Manuel. Consideraciones sobre las encinas en España. Madrid, Instituto Forestal de Investigaciones y Experiencias. 1943.

Montero de Burgos, J. Luis; Gonzalez Reboller, J. Luis. Diagramas bioclimáticos. Madrid, ICONA, 1974.

Ramos, J. Luis. Selvicultura. Madrid, Escuela Técnica Superior de Ingenieros de Montes, 1979.

Ruiz de la Torre, Juan; Ceballos, Luis. Arboles y arbustos. Madrid, Escuela Tecnica Superior de Ingenieros de Montes, 1971.

Ruperez, Adolfo. La encina y sus tratamientos. Madrid, Ediciones selvícolas.

Biomass Production and Utilization of Natural Pastures in the Chilean Mediterranean Ecosystems[1]

Raul Callas, Claudio Aguilar, Osvaldo Paladines, and Gaby Munoz[2]

Abstract: In Chilean mediterranean ecosystems, rainfall and biomass production is correlated. Biomass productivity in the north is between 300 and 1200 kg/ha in the fall-winter period; in the south, maximum productivity is about 5000 kg/ha in the spring through fall months. Major restrictions for animal use are water, slope, soil nutrients, toxic plants, and weeds. Management has drastically changed with land tenure circumstances. Natural pastures provide more than 80 percent of grazing, but most research is in cultivated pastures. The few research projects in natural pastures have produced a very important impact.

Using Emberger's (1955a, 1955b, 1958, 1959) concept of mediterranean bioclimatical conditions, di Castri and Hajek (1976) located the Chilean mediterranean ecosystem between latitudes 28 and 41 degrees south. The non-antarctic territory of Chile is 77 million ha (similar to the State of Texas) and the mediterranean part is 25 percent of this area.

Physiographically, Chile extends from latitude 16 to 58 degrees south and the average width is 110 km. In the northern hemisphere, Chile would extend from Baja California to Alaska (fig. 1).

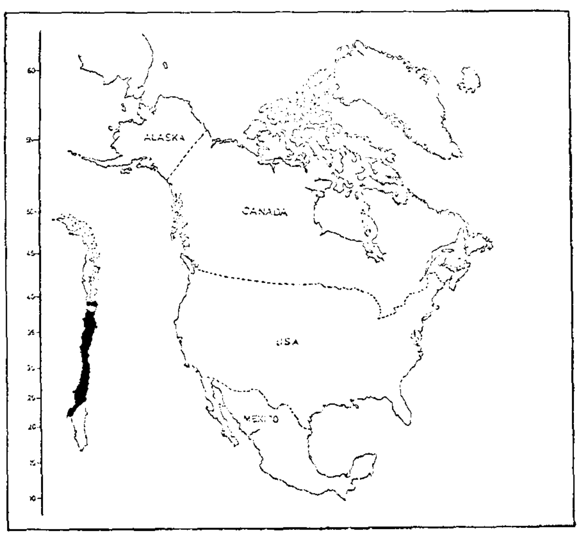


Figure 1--Comparative geographical location of Chile.

In general, rainfall increases and temperature decreases from north to south and from the ocean to the mountains. In accordance with these parameters, di Castri and Hajek (1976) divided the Chilean mediterranean in six zones: perarid, arid, semiarid, subhumid, humid, and perhumid. These subdivisions are highly correspondent with the production and utilization of each ecosystem. The limits of the zones are shown in figure 2.

PRIMARY PRODUCTION

Table 1 shows the productivity of the natural cultivated pastures. The data represent averages of different experiments in each area.

The average production of the natural pasture is between 0.55 and 3.5 ton of Dry Matter (DM)/ha. The variation is due to edaphic and climatic conditions. With irrigation, the productivity of the natural pasture can increase to 5.0 tons DM/ha, and in artificial pasture to 18 tons DM/ha. In natural conditions, the species of the mediterranean pasture are annuals, rainfall being the first limitant for plant growth.

Table 1 also shows that DM productivity of pastures increases with latitude corresponding with increased rainfall. This increase is present both in natural and cultivated pastures.

The introduction of cultivated pasture can change the ecosystem productivity drastically, especially in those areas where the rainfall is less limiting. Normal production of a *Trifolium repens* plus *Lolium* plus *Dactylis* in the perhumid Chilean mediterranean ecosystem can reach 15 tons DM/ha. Nevertheless, the cultivated pastures are less than 10 percent of the total mediterranean pasture. Similar results can be obtained using high levels of phosphorus fertilizer in the natural pasture.

The natural pasture of the Chilean mediterranean is, in general, characterized by two strata, the annual herbs and the matorral, similar to the California chaparral.

The most important herbs and their distribution is as follows:

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June *22-26,* 1981, San Diego, California.

[2]Departamento de Zootecnia, Facultad de Agronomia, Pontificia Universidad Catolica de Chile, Santiago, Chile.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

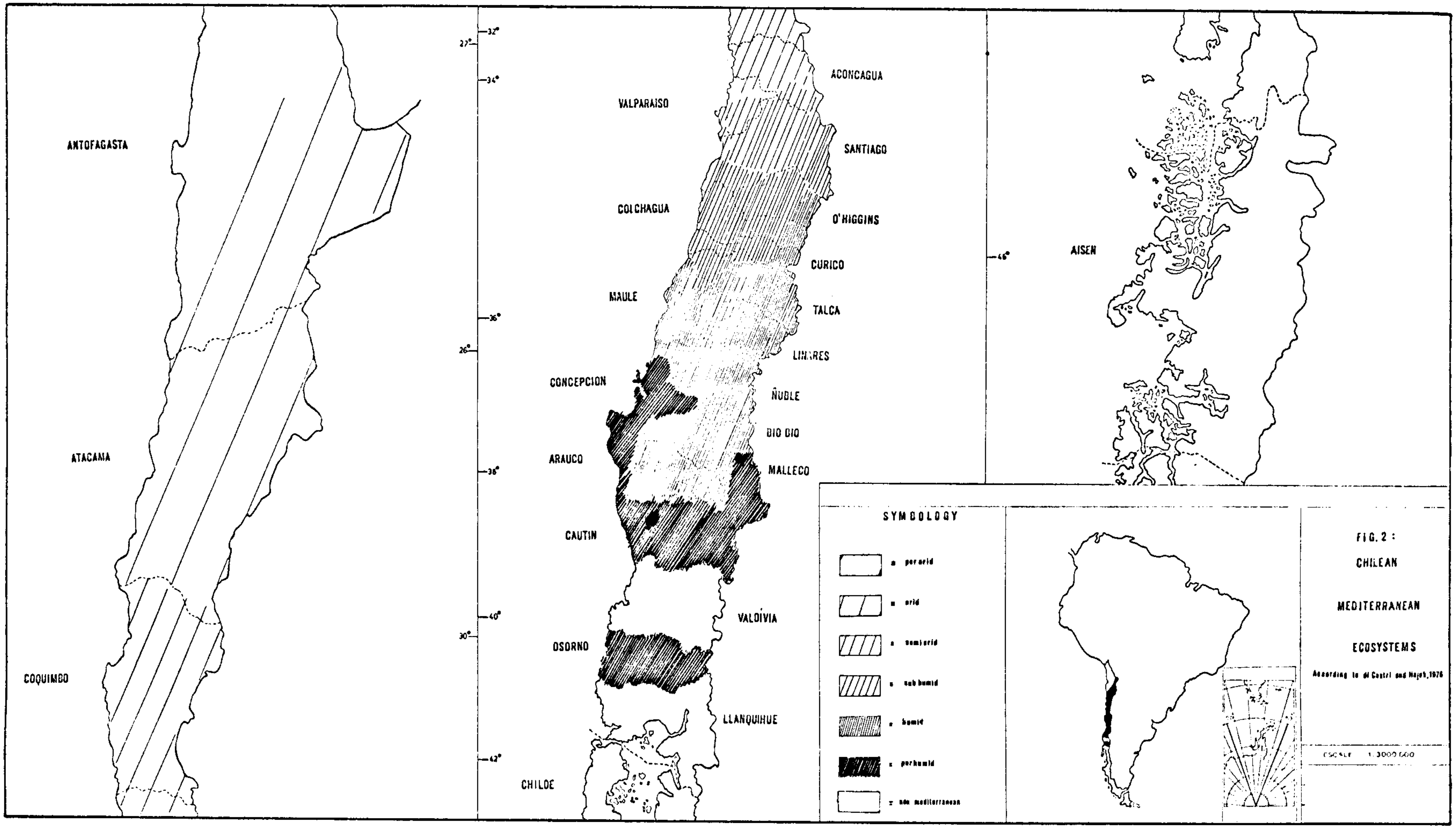


Figure 2--Chilean mediterranean ecosystems.
(According to di Castri and Hajek 1976)

Table 1--Primary productivity of pastures in the Chilean mediterranean at different latitudes

Zone	Provinces	Latitude	Rainfall mm/yr	Productivity: Natural pasture	Cultivated nonirrigated	Cultivated irrigated
				ton MS/ha/yr		
Arid	Coquimbo	32°	134.0	1.62	-	-
Semiarid	Aconcagua	30°30'	380.0	2.03	-	-
Semiarid	Valparaiso	33°	438.4	2.10	-	-
Semiarid	Santiago	33°30'	441.3	2.13	0.995	13.63
Humid	Talca	35°25'	712.8	2.48	-	-
Humid	Linares	35°45'	816.6	2.56	3.58	9.19
Perhumid	Bio-Bio	36°30'	1,034.2	2.72	6.43	7.07
Perhumid	Concepcion	36°50'	1,220.2	[1]1.75	5.67	-
Perhumid	Arauco	37°	1,599.1	2.06	3.15	-
Perhumid	Osorno	40°35'	1,216.9	3.38	8.91	-
				[2]6.85		

[1]Poorly drained soils.

[2]Naturalized introduced species.

Natural herbs

Chaetanthera ciliata	Arid
Solenomelus peduncularis	Arid
Pectocarya penicillata	Arid
Pasithea coerula	Arid
Helenium aromaticum	Arid
Vulpia dertonensis	Semiarid
Plantago mayor	Semiarid, Subhumid
Briza minor	Semiarid, Subhumid
Hordeum chilense	Subhumid

Naturalized

Erodium cicutarium	Arid
Bromus mollis	Arid, Semiarid
Avena barbata	Subhumid
Dactylis glomerata	Subhumid
Medicago arabica	Subhumid
Gnaphalium sp.	Subhumid
Hypochoeris radicata	Subhumid
Dichondra repens	Subhumid
Trifolium angustifolium	Subhumid
Trifolium repens	Subhumid
Lolium sp.	Subhumid

The matorral strata can be divided using criteria from Avila and others (1978) based on topographic gradient, into

1. Sclerophyllous evergreen forest located in the central part of the valley. The most important matorral species are

    Cryptocarya alba
    Maytenus boaria
    Quillaja saponaria

2. Matorral located on mountain slopes, south exposure. The most important species are

    Lithraea caustica
    Schinus polygamus
    Quillaja saponaria
    Colliguaya odorifera
    Kagenckia oblonga
    Satureja gilliessi

3. Low matorral located on gentle mountain slopes with north exposure. The most important species are

    Colliguaya odorifera
    Colletia spinosa
    Retanilla ephedra
    Trevoa trinervis
    Talaguenea quinquineruvia

In the southern part of the Chilean mediterranean ecosystem, there is also sclerophyllous forest with hydrophilic species. The most important species are

Nothopagus dombey
Drymis winteri
Nothopagus obliqua
Araucaria araucana

ANIMAL PRODUCTIVITY

Table 2 presents the population of animals in the Chilean mediterranean. Animal species are distributed according to the prevalent rainfall of the area. Goats are concentrated mainly in the arid and semiarid zones, sheep in the semiarid, and cattle in the perhumid zone (fig. 3).

Countrywide, the mediterranean contains 64 percent of the cattle, 32 percent of the sheep, and practically 100 percent of the goats.

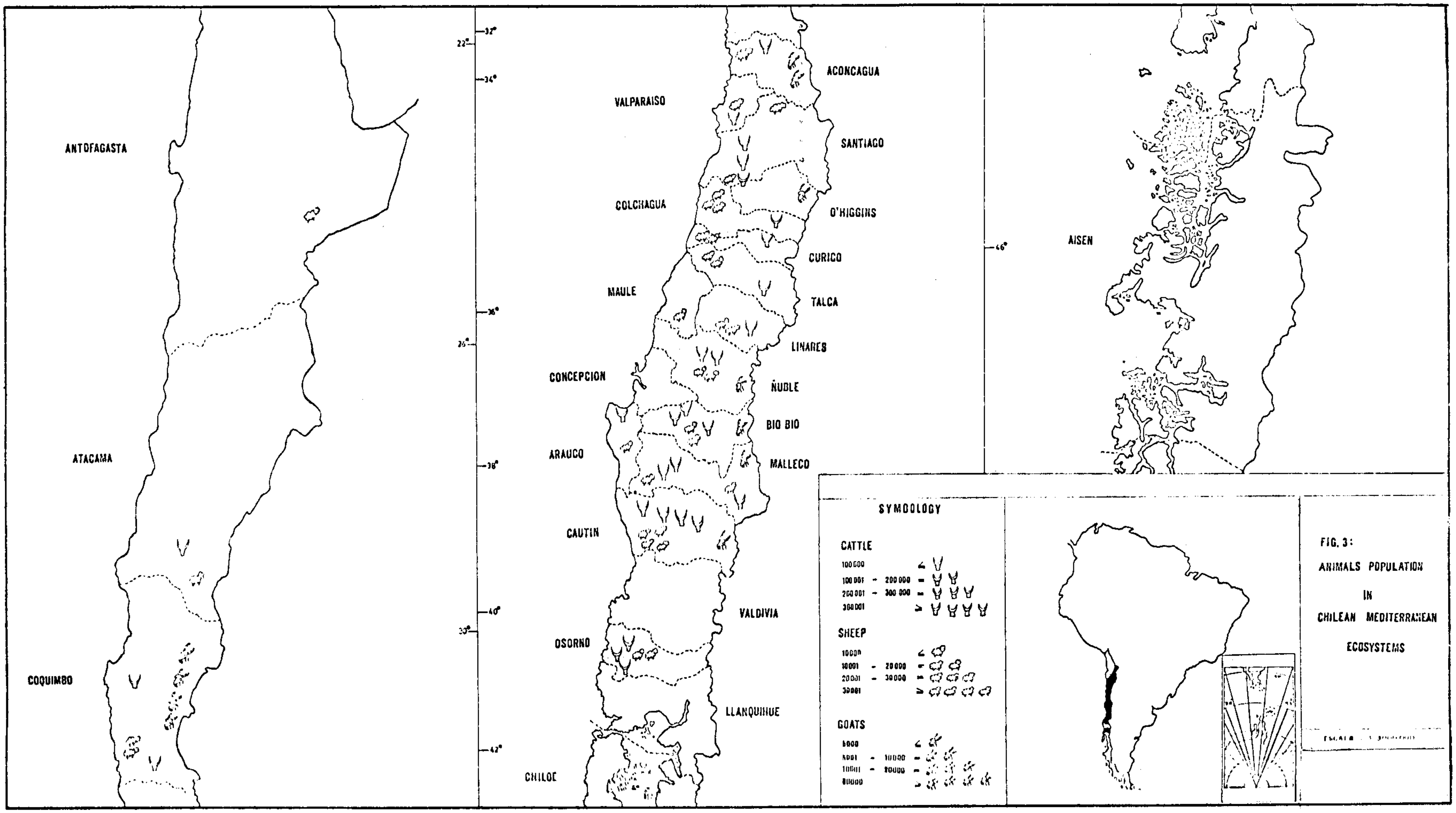


Figure 3--Animal population in Chilean mediterranean ecosystems.

Table 2--Animal population in the Chilean mediterranean[1]

Zone	Provinces	Cattle		Sheep		Goats		Total
		AU[2]	Percent	AU	Percent	AU	(Percent	AU
Perarid	Antofagasta	583.3	0.03	2,877.3	1.31	623.2	0.42	4,083.8
Arid	Atacama-Coquimbo	52,894.0	3.09	19,583.2	8.95	60,621.6	41.64	133,098.8
Semiarid	Aconcagua-Valparaiso	107,078.2	6.27	25,175.7	11.51	8,827.8	6.06	141,081.7
Semiarid	Santiago	109,443.6	6.41	5,208.9	2.38	3,044.3	2.09	117,696.8
Subhumid	O'Higgins-Colchagua	144,697.1	8.43	39,134.3	17.89	5,956.0	4.09	189,787.4
Humid	Curico-Talca	108,065.9	6.33	24,448.2	11.18	4,794.7	3.29	137,308.9
Humid	Linares-Maule	76,270.3	4.46	13,824.5	6.32	5,138.8	3.53	95,233.6
Humid	Nuble	116,417.8	6.82	19,459.2	8.89	8,936.4	6.13	144,813.4
Perhumid	Concepcion-Arauco	83,019.7	4.86	4,672.5	2.13	18,873.9	12.96	106,566.1
Perhumid	Bio-Bio-Malleco	285,455.6	16.72	20,104.3	9.19	11,537.4	7.92	317,097.3
Perhumid	Cautin	350,782.3	20.55	33,507.5	15.32	11,880.0	8.16	396,169.8
Perhumid	Osorno	271,897.5	15.93	10,656.4	4.87	5,323.2	3.65	287,877.1
TOTAL		1,706,605.3	100.00	218,652.0	100.00	145,557.3	100.00	2,070,814.6

[1]Extracted from the Nation Agricultural Census, 1975-1976.

[2]Animal Unit equivalent to a 500-kg steer.

Table 3--Animal productivity of the Chilean mediterranean

Zone	Provinces	Pasture area[1]			Animal population	Stocking rate	Animal weight gain
		Natural	Improved	Cultivated	AU[2]	AU/ha	kg/ha
Perarid	Antofagasta	111,899	0,000	1,843	4,083.8	0.29	-
Arid	Atacama-Coquimbo	1,748,091	7,138.4	10,736	133,098.8	0.07	-
Semiarid	Aconcagua-Valparaiso	539,343	14,233.6	14,024	141,081.7	0.24	105
Semiarid	Santiago	263,271	19,175.2	27,066	117,696.8	0.38	85
Subhumid	O'Higgins-Colchagua	553,141	25,801.8	43,588	189,787.4	0.30	62
humid	Curico-Talco	509,891	33,448.2	34,851	137,308.8	0.23	70
Humid	Linares-Maule	257,540	13,236.0	17,921	95,233.6	0.32	50
Humid	Nuble	344,599	24,181.4	30,121	144,813.4	0.36	90
Perhumid	Concepcion-Arauco	155,334	25,725.8	6,578	106,566.1	0.56	122
Perhumid	Bio-Bio-Malleco	729,475	148,000.9	91,286	317,097.3	0.32	130
Perhumid	Cautin	460,580	101,074.6	98,559	396,169.8	0.60	160
Perhumid	Osorno	178,952	144,089.4	43,850	287,877.1	0.78	180

[1]Natural = Native and naturalized pastures
Improved = Natural pastures subjected to improvement practices without plowing
Cultivated = Sown pastures

[2]Animal Units equivalent to a 500-kg steer.

Table 3 shows the productivity of pastures expressed in animal weight gain. Stocking rate trebles from the arid to the perhumid zones and coincidental with the increase in stocking rate is an increase in animal production.

The Chilean management of the mediterranean ecosystem is characterized by the extensive use of the natural pastures as a source of animal feed. These are normally annual pastures, with a very fast growth period, highly dependent on temperature and rainfall for total dry matter production. On the other hand, animal feed intake is dependent on pasture characteristics.

In general, the natural mediterranean ecosystems are fragile. They are easily damaged by abuse and are subject to drought. The original vegetation on a large part of these ecosystems has been depleted by a combination of these factors, with a rapid increase of unwanted matorral species and herbs (Fuentes and Hajek 1978, Gasto and Contreras 1979).

The major damage to the natural ecosystems is near the water sources and the animal keeper's house, due to higher animal density and the selective consumption by animals of plants and plant parts, producing changes in the botanical composition of the pasture. This selective harvesting pattern promotes the growth of unwanted matorral species and herbs over useful pasture species.

Rodriguez (1979) studied the digestibility of the available and animal-selected natural pasture. Pasture availability was estimated by cutting and the diet selected by animals via esophageal fistula.

Table 4 presents the contrasting digestibility in 5 months of the year as pasture becomes depleted by grazing.

Grazing animals select plants or plant parts with a higher content of protein, phosphorus, metabolizable energy, and lower content of fiber.

As shown in table 5, animals select different plants depending on maturity (as represented by season of the year) and digestibility. Sheep grazing a winter therophytic pasture select first _Erodium_ sp.; as soon as _Erodium_ sp. availability decreases, the animals select _Trisetobromus hirtus_ and later _Vulpia dertonensis_. There are some species, such as _Hordeum murinum_ and _Koelenia phleoides_, that are not eaten by the animals. With a very high stocking rate, the pasture will rapidly increase in these unwanted herbs.

LAND SURFACE REQUIRED PER FAMILY

The minimum annual wage of farm labor is $2000 (U.S.). Assuming that in a family of five persons there is only one land worker, the total family income will be $2000/year. A study of different farms along the mediterranean ecosystem was conducted in order to estimate the theoretical minimum farm size required for a worker to obtain the family income of $2000. Land price was not included in the calculation of the profit of different agricultural businesses, because it increases independent of the farm business.

Table 4--_In vitro_ digestibility of available and animal-selected pasture in the perarid zone of the Chilean mediterranean[1]

Season	Stage of grazing cycle[2]		
	Early	Medium	Late
Spring	56.91	55.42	46.73
Summer	53.56	49.39	37.91
Fall	53.38	43.65	37.92
Early winter	49.01	42.04	37.62
Late winter	51.90	47.60	42.72

[1]Taken from Rodriguez 1979.

[2]Each grazing cycle lasted for 20 days.

Table 6 shows average results. Land price is highly dependent, in the north and central zone, on the water available for irrigation. Thus, a goat farmer in the north part of the Chilean mediterranean ecosystem who has the opportunity to irrigate a portion of the farm prefers to eliminate the animals and grow fruit.

HISTORY OF PASTURE MANAGEMENT

The use of the mediterranean ecosystem has drastically changed with land tenure patterns. Before the Agrarian Reform (1965-73) large land holdings complemented their pasture utilization system by the movement of stock between ecosystems at different times of the year. Two such systems prevailed. In one, animals were raised in the humid and perhumid zones and moved to the semiarid ecosystem to be finished. This was possible, as depicted in figure 4, because the humid mediterranean ecosystem produces its maximal amount of digestible energy during spring and summer. Winter is cold and humid. The arid and semiarid ecosystems produce their maximum of digestible energy during fall and winter. Winter is not very cold but is humid. On the other hand, beef prices are minimum during fall and maximum during spring. Having these in mind, farmers raised their animals in the arid, semiarid, or irrigated pastures of the central zone, during fall, to be fed in good pasture during 150 days and sold with 530 kg of weight in the season of maximum price.

The second system corresponds to the "transumancia," by which the animals were sent to the high mountains during summer and returned to the lowlands for fall and winter. As shown in figure 5, peak DM production at the two altitudes complement each other very well. This system was employed principally in the Central Provinces of the country and especially applied to sheep production.

These two types of animal management systems produced long periods when pastures had very low or no stocking, giving a rest period to the pasture and in general more stability.

With Agrarian Reform, and the resulting subdivision of land holdings, farms were limited to a circumscribed small area and movement of animals was inhibited. Several situations were produced. In the humid and perhumid zones, farms decreased in size but maintained essentially the same production systems. In the semiarid and arid zones, drastic changes were produced, since by virtue of the smaller size, farms could not count on a highland-lowland combination. Farms in lowlands with irrigation turned to fruit production or other high-profit crop. Those on nonirrigated lands tended to maintain the original stocking rate, overgrazing their pastures because they did not have the complement of irrigated area for winter feeding.

Table 5--Botanical composition of a perarid-zone pasture of the Chilean mediterranean grazed with sheep[1]

Season	Species	Stage of grazing cycle[2]		
		Early	Medium	Late
		----Percent----		
Spring	Vulpia dertonensis	39.83	60.29	46.61
	Trisetobromus hirtus	23.58	15.40	17.65
	Erodium sp.	17.25	13.60	-
	Hordeum murinum	1.75	2.53	12.67
	Koelenia phleoides	1.96	2.41	3.17
	Compositae and legumes	10.72	4.33	-
	Others	4.91	1.44	19.91
Summer	Vulpia dertonensis	39.00	71.19	53.01
	Trisetobromus hirtus	28.41	10.90	14.46
	Erodium sp.	19.21	8.96	4.82
	Koelenia phleoides	1.66	1.45	3.61
	Compositae and legumes	1.24	-	-
	Proustia cuneifolia	7.31	-	-
	Others	3.17	7.5	4.10
Fall	Vulpia dertonensis	60.42	62.93	66.09
	Trisetobromus hirtus	13.36	17.33	9.78
	Erodium sp.	14.17	7.47	3.43
	Hordeum murinum	1.30	-	-
	Koelenia phleoides	1.95	-	-
	Compositae and legumes	3.91	4.00	-
	Others	4.89	8.27	20.70
Early winter	Vulpia dertonensis	65.10	73.18	18.09
	Trisetobromus hirtus	19.46	19.55	14.89
	Erodium sp.	9.40	5.18	-
	Compositae and legumes	2.01	-	-
	Others	4.03	2.09	67.02
Late winter	Vulpia dertonensis	63.27	46.27	48.78
	Trisetobromus hirtus	19.47	10.45	-
	Erodium sp.	13.72	26.87	17.07
	Others	3.54	16.42	34.15

[1]Taken from Rodriguez 1979.

[2]Each grazing cycle lasted for 20 days.

Table 6--Economic parameters of different agricultural business and theoretical land area necessary to obtain an income equivalent to the minimum farm wage

Zone and type	Land price	Principal use of the ecosystem	Average return to capital	Surface required per family
	U.S.$/ha		Percent	ha
North, natural pastures	300	Goats	6	102.7
North, with irrigation	2000	Fruit	25	3.7
Central, natural pasture	450	Sheep, beef	10	41.0
Central, with irrigation	3500	Fruit	20	2.64
South	2300	Milk, beef	10	8.04

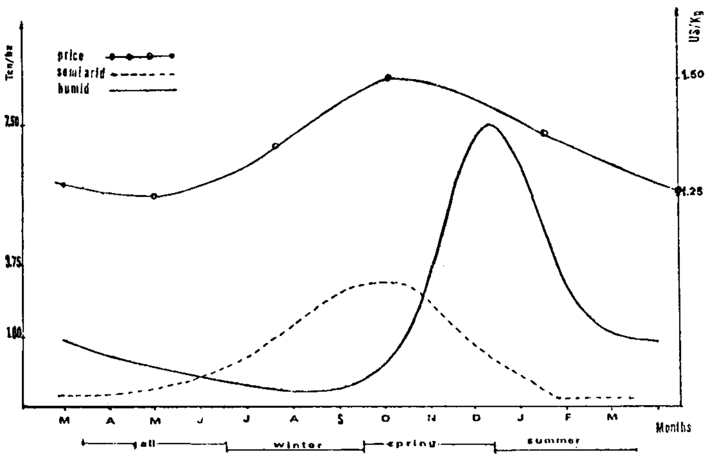


Figure 4--Pasture production of humid and semiarid mediterranean ecosystems, and its effect on beef price.

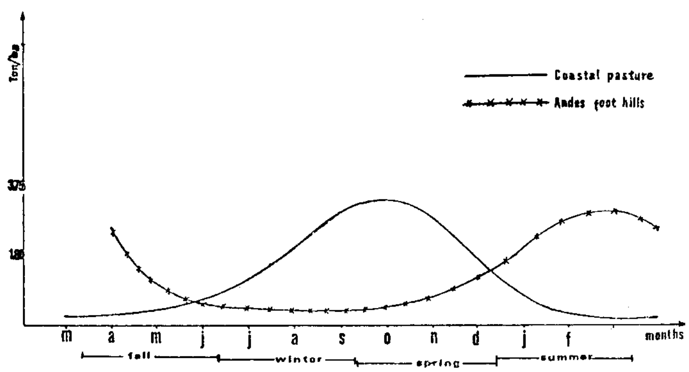


Figure 5--Pasture production in two complementary arid mediterranean ecosystems.

PASTURE RESEARCH IN THE MEDITERRANEAN ECOSYSTEMS

According to Paladines (1980) 85 percent of the Chilean pastures are natural, yet a very low percentage of the total pasture research has been designed to study some productive or management characteristic of the natural pastures.

Two schools of thought have developed in Chile in relation to the emphasis of pasture research. One school thinks that as natural pastures are such a large area, even if the unit value is not high, any small improvement can produce large changes at the country level. The other school thinks that the potential of natural pastures is so little that research priority must be placed on the introduction of exotic species, or even better, on the use of irrigation water.

There is an intermediate point which combines the utilization of natural and cultivated pastures to take advantage of the difference in seasonal growth pattern of the two types of pasture.

One of the most important conclusions of pasture research is that with a rainfall of less than 500, fertilizer effect is very low and nonprofitable. Also, with less than 500 mm, seeding of cultivated pasture is risky. With more than 900 mm of rainfall, the seeding of cultivated pasture and the incorporation of fertilizer is highly recommended, producing an increase in animal production and profit.

LITERATURE CITED

Avila, G.; and others. 1978. Estudio morfologico en raices de algunos arbustos del matorral chileno. Medio Ambiente 3(2):31-39.

Castri, F. di; Hajek, E. R. 1976. Bioclimatology of Chile. Vicerrectoria Academica. Universidad Catolica de Chile.

Emberger, L. 1955a. Project d'une classification biographique des climats. Ann. Biol. 31(5-6): 249-255.

Emberger, L. 1955b. Une classification biogeographique des climats. Recueil des travaux des laboratoires de Botanique. Geologie et Zoologie (Faculte des Sciences, Montpellier), Serie Botanique, Fasc. 7:3-43.

Emberger, L. 1958. Afrique du nord et Australie mediterraneene. En: Climatology and microclimatology. Proceedings of the Canberra Symposium. UNESCO, Paris: 141-147.

Emberger, L. 1959. La place de 1'Australie mediterraneenne dans 1'ensemble des pays mediterraneens du Vieux Monde. (Remarques sur le climat mediterraneen de l'Australie) Biogeography and Ecology in Australia (Monographiae Biologicae) 8:259-273.

Fuentes, E. R.; Hajek, E. R. 1978. Introduccion hombre-clima en la desertificacion del Norte Chico Chileno. Ciencia e Investigacion Agraria. 5:137-142.

Gasto, J.; Contreras, D. 1979. Un caso de desertificacion en el norte de Chile, El ecosistema y su fitocenosis. Boletin Tecnico M:42. Universidad de Chile, Facultad de Agronomia. 99 p.

Paladines, M. O. 1980. Investigacion sobre praderas en Chile. Convenio ODEPA-Pontif, Universidad Catolica de Chile.

Rodriguez, S. D. 1979. Influencia del momento de utilizacion de la pradera natural de la zona mediterranea central de Chile en el consumo ovino. Tesis de grado de magister Programa Permanente para Graduados en Ciencias Agropecuarias y Forestales de la Rep. de Chile. Universidad de Chile.

Use and Management of Mediterranean Ecosystems in South Africa—Current Problems[1]

F. J. Kruger[2]

Abstract--This paper summarises patterns of land-use and management in mediterranean-type ecosystems of South Africa and, in greater detail, aspects of current management of fynbos mountain catchments. The managed fire regime and how it is likely to affect ecosystems is outlined. Controversial questions about the effect of fire frequency on species diversity and on catchment nutrient and water balance, and about the ecological effects of unseasonal burning, indicate priorities for research. The biology of invasive plants needs more thorough study. Techniques of applying fire need development to allow more flexible management.

Ecosystems of the mediterranean type in South Africa include Mountain Fynbos, Coastal Fynbos, Coastal Renosterveld and a mesic form of Strandveld. These types extend outside the mediterranean climate into the zone of all-year rainfall but I will include these extensions here. Within this zone are Knysna forest, occurring where moisture regimes are unusually favourable (Specht and Moll, in press), and various Karoo formations, in areas with rainfall less than about 200 mm/yr; the dynamic relationships between these and the mediterranean-type formations can be strongly influenced by management. These ecosystems have been described in general terms by Adamson (1938), Taylor (1978), Kruger (1979) and Day and others (1979).

The ecology and management of Mountain Fynbos ecosystems were discussed at a previous conference (Bands 1977, Kruger 1977a). A broader view will be presented here, before returning to current problems in Mountain Fynbos.

PATTERNS AND TRENDS IN LAND-USE AND MANAGEMENT

History

Changes by man to Cape mediterranean-type ecosystems during the pre-settlement era appear to have been less than in Chile, California and the Mediterranean Basin (Aschmann 1973, Aschmann and Bahre 1977), especially in view of the absence of cultivation, late arrival of domestic stock, and absence of mining, and despite the longest history of occupation (more than 250 000 yr--Klein 1977). For example, available evidence suggests that major changes in extent of forest in the Holocene correlate with climatic change rather than human influence (Deacon in press). Also, the advent of pastoralism, about 2 000 B.P., seems to have had relatively little ecological effect overall because seasonal migration "... on a regular beat ..." relieved pressure on the vegetation, and stock was confined largely to the coastal forelands (Wilson 1969).

The changes that followed European settlement, real or inferred, influence present attitudes and policy toward land management. For example, much is made of destruction of the native evergreen forest and for the past century there have been continual pleas for reconstitution (e.g. Brown 1887, Phillips 1931, McKenzie and others 1976). However, one may infer from accounts in Katzen (1969) and elsewhere rather that forests were confined originally to locally favourable habitats; Acocks' (1953) implied much wider extent of forest is deceptive. Exploitation and destruction of forests caused degrade and local decline but no major landscape changes (see accounts in Brown 1887). For Coastal Renosterveld, major, widespread modification by new grazing practices, from a grassy shrubland, to the present rather low, open shrub formation,, is the usual inference (Acocks 1953, Taylor 1978, Boucher and Moll 1981) and this is often supported by historical evidence (Wilson 1969) though the extent of such change is not documented. Replacement of fynbos on clay soil by Elytropappus is often reported (Taylor 1978; see also below). An evident effect of settlement on the biota in general was the local extermination of nine or more species of larger mammal, and perhaps as much as 60 species of plant (Bigalke 1969) - a surprisingly small proportion of a flora of possibly 8 500 species.

There appears to be little evidence of change in the structure and composition of fynbos on low-nutrient soils, except for the great transformations locally that followed the introduction and spread of exotic trees and shrubs (see below).

Present patterns

Cook[1] has determined the broad patterns in modern land-use in each of the mediterranean-type

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Deputy Director for Conservation Research, S. African Forestry Research Institute, Dept. of Water Affairs, Forestry and Environmental Conservation, Pretoria, Rep. of South Africa.

[1]Cook, G. Department of Geography, University of Cape Town. Unpublished report of the Fynbos Biome Project. 1980

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--Approximate extent of different forms of land-uses or cover types in the major Veld Types of the mediterranean-climate zone of South Africa. (Veld types according to Acocks 1953.)

Land-use or cover type	Mountain Fynbos				Coastal Fynbos		Coastal Renosterveld		Total	
	Veld type		Veld type 70		(Veld type 49)		(Veld type 46)			
	Area,		Area,		Area,		Area,		Area,	
	sq. km	Pct	sq. km	Pct	sq. km	Pct	sq. km	Pct	sq. km	Pct
Agriculture (cultivated fields, orchards, etc.)	3,150	15.8	1,600	600	620	2,620	10,140	76.4	17,500	27.7
Urban development	120	0.6	72	72	260	260	80	0.6	530	0.8
Timber plantations	290	0.5	140	140	16	16	23	0.2	470	0.8
Water bodies and wetlands	105	0.5	21	21	220	220	58	0.4	400	0.6
Natural and semi-natural vegetation	16,200	81.6	18,400	400	640	6,640	2,980	22.5	44,300	70.1
TOTAL:	19,900	100	20,300	300	750	9,750	13,200	100	63,200	100

veld types, as shown on standard topographic maps. Her data are summarized in table 1. Agricultural development accounts for most landscape transformation. Overall, nearly 30 per cent of the land has been transformed from the natural state (Hall, 1978, estimated 60 per cent). But the relatively fertile Coastal Renosterveld is disproportionately affected; Coastal Fynbos, though readily accessible, has just about one-third under agriculture and Mountain Fynbos has lost 10 to 15 per cent to development. Topography, climate and soil severely limit the use of Mountain Fynbos. For example, no more than a further 150 sq. km is seen as afforestable. Reservoir construction and similar intensive developments create acute but strictly local problems. Thus we see that problems of management of mediterranean-type ecosystems in South Africa turn largely on questions concerning the use and management of wildlands or veld in the natural condition.

Use of wildlands

Public lands

Public lands that include wildlands in are small. Of Strandveld, around one per cent is publicly owned; of Coastal Renosterveld, about the same; Coastal Fynbos, 2-3 per cent, and Mountain fynbos, about 18 per cent (Edwards 1974). These are mainly reserves, either Provincial Nature Reserves or State Forests.

Some public land was used for pasturage on a lease system until the middle of this century but these lands are now held for nature conservation or catchment protection, usually both. Bands (1977) has described the background to this system and the evolution of the methods of managing State Forests.

Lands in private ownership

There is little published information on how wildlands in private ownership are used. What follows is based on personal observation and communication with various colleagues.

Pasturage--The relatively small remaining area of renosterveld is used as rough pasturage, on the basis of seasonal grazing and patch-burning (see Bands 1977 for a discussion of patch-burning). Injudicious combinations of grazing and burning leads rapidly to domination of the sward by *Elytropappus;* Taylor (1978) and Boucher and Moll (1981) discuss this problem. Coastal Fynbos is apparently still extensively grazed, also on a patch-burning system. There is a trend to integrate this use with flower harvesting (see below). There are no reports of marked degrade in this type.

Grazing of Mountain Fynbos, previously rather widespread, has declined generally in response to improved ley pastures in the renosterveld wheatlands (Wasserman 1979) and changing cultural and economic factors (Bands 1977). Nevertheless, the old practices do survive in many areas and present a problem in the control of land-use in water catchments, especially in remoter rural areas with relatively poor economies.

Harvesting of wildflowers--Of increasing importance is a wildflower industry which has grown over a decade to a business that brings in foreign exchange of around R6 million/yr. Much of this produce comes from the veld but the extent of the area used in this way is still unknown. Various products are harvested, from fresh blooms of Proteaceae and other shrub taxa available mainly from mature vegetation, through various kinds of dried material including Proteaceae capitula but also shoots of Restionaceae and Cyperaceae, optimally available from vegetation regenerating post-fire, as well as post-fire "everlastings", inflorescences of Helichrysum spp.

Much of this use tends to be exploitative. The markets and the industry are new, many of the harvesters lease the right to do so and many in the business no doubt see it as ephemeral. No consensus on sustained-yield management has yet emerged. Many practitioners do not presently allow fire, but fail to consider regeneration requirements. The established, organized industry tries to promote secure markets for quality products from orchards, but this seems to have had little impact on use of wildlands. Flower harvesting complicates management of Mountain and Coastal Fynbos; requirements for sustained yield management compatible with conservation of other resources must be determined and included in general policy.

Recreational development--In many cases, land is held simply for its tourist and recreation potential. A growing trend in the mountains toward resort development and for schemes for second homes is now discernible, but the extent and consequences of this have yet to be appreciated.

Invasive plants

Hall (1979) has estimated that about a quarter of the wildlands is occupied by exotic woody plants, to a greater or lesser degree. This problem has been thoroughly described elsewhere (Taylor 1978, Hall 1979). The most important invaders are Hakea sericea, Pinus pinaster and Acacia spp. Several costs arise from these invasions (Kruger 1977b). First, water yields from mountain catchments decline significantly. Second, the aesthetic, scientific, educational, recreational and other indirect values of the land are diminished. Third, problems and costs of management, especially of fire control, are greatly aggravated. There are few or no benefits, aside from firewood harvested from accessible infestations in the lowlands.

Though biological control is seen as a means to long-term control, removal or eradication of present infestations requires other means. An effective programme of control is now applied to hakea and pines in mountain catchment areas. First, measures are written into long-term management plans (see below). Second, control in any management unit is effected by (a) felling adult trees and shrubs (b) burning the slash with the natural vegetation within 12 months to kill seed and seedlings and (c) biennial surveys to detect and remove any escapees. This system reduces populations by several orders of magnitude over large areas (Fenn 1980), and has the prospect with biological agents of ensuring long-term control (not eradication) of these species. This programme critically determines many aspects of ecosystem management, and disqualifies laissez faire management because, for example, unplanned fires cause invaders to proliferate.

RESILIENCE OF SOUTH AFRICAN MEDITERRANEAN-TYPE ECOSYSTEMS

These ecosystems appear to vary significantly in their capacity to recover after disturbance. Such resilience seems to correlate with climate, soil and the nature of disturbance. Under a "normal" fire regime, any biotic community appears to recover more or less fully in structure and composition (e.g. references in Kruger 1979, Van Wilgen and Kruger 1981). Fynbos on low-nutrient soils appears to persist despite in the face of many forms of disturbance. For example, Coastal Fynbos appears highly stable under a grazing regime with patch-burning. Where fynbos on infertile soils has been deforested or cleared of weeds, most of the original species return. By contrast, fynbos on more fertile sandy loams or loams, especially where rainfall is less than about 1 000 mm/yr, is easily changed by disturbance. There, Elytropappus invades readily with overgrazing (Adamson 1938). Recovery after clearing of exotics is incomplete at best, and the regeneration is dominated by exotic, especially Mediterranean herbs. The same applies to Coastal Renosterveld. In the east, where summer rainfall is significant and grasses prominent, fynbos shrubs are a labile component of the vegetation and are reduced or exterminated by very frequent burning (Kruger and Bigalke in press). In the west, only a small proportion of the shrub flora is eliminated by the most frequent burning practical (Van Wilgen 1981b). These differences in the capacity to recover and their implications for management appear to need close attention in research for the development of management systems.

PROBLEMS WITH POLICY AND PRACTICE IN MOUNTAIN CATCHMENT AREAS

Approximately 4 000 sq. km of private land in fynbos ecosystems has been proclaimed Mountain Catchment Area; ultimately, nearly 20 000 sq. km of private and State land will managed integrally for water conservation. Three goals dominate policy for Mountain Fynbos ecosystems: (a) management to sustain yields of silt-free water in streams - this on all lands, whether public or private; on public lands (b) nature conservation and (c) a secondary goal, recreation opportunity of a kind compatible with the primary goals. Fire control is a general goal.

Experience over the past 10 yr in applying this policy has revealed certain pressing questions.

Present policy

Policy for mountain catchment areas includes the following (Bands 1977). Prescribed burning is an acknowledged management tool and is to be applied in any management compartment (500 - 2 000 ha in extent) at intervals of about 12 yr and preferably in the late summer though, in the initial phases of management when extensive areas of old vegetation are encountered, burning at safer times is permissible. Control of invasive plants is a prerequisite. Management of any given zone is based on a five-year plan which prescribes the measures to be applied to each compartment, in a manner that should optimally fulfill the goals for the area. It embodies principles established in a policy memorandum, in turn based on the findings of an inventory of resources.

The prescribed fire regime in practice

Policy memoranda have been approved, or are in advanced stages of review, for 18 management plans. Burning rotations agreed to range from 9 yr through 12 yr for most areas, to 15-20 yr for dry north slopes. In certain areas, "natural" burning regimes are to be allowed on an experimental basis: fires that occur in any given compartment will be allowed to burn while confined to the compartment. These areas are usually in dry zones (rainfall less than about 600 mm/yr on average) with low fuel accumulations and infrequent fires in the past.

The rotations laid down in policy memoranda are guidelines; vegetation is not necessarily burnt at that age, especially where fire has been excluded in the past. In the Kogelberg, on the eastern shores of False Bay, vegetation had been protected since an extensive wild fire in 1945, and burning was begun in 1967 to rehabilitate a rare species of Proteaceae, Orothamnus zeyheri (Boucher and McCann 1975). Three compartments, amounting to about 12 per cent of the area, are still protected, to allow forest succession, or as long-term reference areas. A classification by age at time of burning during the first planning cycle shows that more than 80 per cent of vegetation was burnt at an age of 20 yr or more in the first cycle, and 50 per cent at over 25 yr. Information for most other areas covered by plans indicates the same pattern: most vegetation is or will be older than prescribed at the time of burning in the first cycle. By the second cycle, however, the age-class distribution would have normalized around the prescribed age, barring wildfires and other accident. According to prescriptions, nearly 80 per cent of the area will be burnt at ages between 10 and 15 yr in the second cycle in the Kogelberg. A major shift in regime is therefore under way.

In the Kogelberg, nearly 50 per cent of the area has been burnt in spring, and over 30 per cent in winter; Van Wilgen (in press) shows that this pattern is general. Initially, spring burning was encouraged as being less hazardous with regard to erosion; now, burning between the end of April and the end of August is strongly discouraged. Burning between the end of February and the end of April is recommended and the intention is to limit spring burns only to cases where safety And the work load make them unavoidable.

The tendency to burn in spring reflects the managers' experience. Although prescribed burning was not extensive before 1967, firebreaks have been prepared by controlled burns since the institution of fire control in the Cedarberg around 1900 and more extensive protection of native rain forests and coniferous plantations in the Tsitsikamma area from about 1880 (Brown 1887). Official instructions have naturally prohibited burning without special authority during the hazardous season. Managers are therefore not accustomed to nor prepared for burning with any safety during the ecologically desirable season.

No data are available on actual fire intensities, the third component of fire regime.

Issues in management of Mountain Fynbos

Rotation (frequency) of burning

Moll and others (1980) have argued that frequent fires have eliminated trees from the fynbos and further that the presence in the flora of certain Proteaceae and other small trees and shrubs which have long youth periods indicates that prescribed burning regimes should have long intervals - 40 years and more - between fires. However, available data indicates that most fynbos shrubs are precocious, and the few species with youth periods of 8-10 yr and more tend to occur in special habitats infrequently burnt - cliffs, perennially cool-humid sites, arid sites with sparse vegetation - or, like Leucadendron argenteum, tend to survive as adults protected by insulating bark (Kruger and Bigalke in press). Further Bond (1980) and Van Wilgen (1981a, b) have shown how certain Proteaceae tend to enter senescence at ages of 30-45 yr. Bond (1980) found regeneration from seed after fire among Proteaceae that store seed in the canopy and among dicotyledons generally to be much reduced in senescent stands, relative to mature stands. Both suggest that fires at intervals greater than 20 yr could lead to changes in fynbos, including decreased plant species diversity, lower densities of Proteaceae, and possibly less effective catchment cover.

The effects of fire frequency, and fire per se, on catchment water and nutrient balances are still controversial. Van der Zel and Kruger (1975) reported substantial decreases in flow with advancing age of vegetation in a catchment at Jonkershoek, however, analysis of new data tend to confirm earlier reports showing that streamflow response to fire are relatively small and short-lived (Kruger and Bigalke in press). Regarding nutrient dynamics, Van Wyk (in these proceedings) adduces data to show that, at least in the cases he has studied, erosion losses are small after fire, changes in streamflow chemistry are short-lived and, even at rotations of 6-12 yr, there is no evident net loss of nutrients from the flush after fire. Patterns of hydrological response in relation to biomass and rainfall regime need to be examined to establish the general rule.

Season of burn

The present seasonal pattern of the managed fire regime, if maintained, is likely to degrade fynbos. For example, Jordaan (1949, 1965) predicted and demonstrated how a winter burn eliminated or severely reduced certain Proteaceae.

Bond (1980, and personal communication) has reported similar results from the Swartberg, east of Jordaan's study area.

Effects of season or burn on catchment condition are hypothetically important. Burns before the winter rains expose the soil to erosion and ashed nutrients to leaching. Van Wyk's work does not clearly show such effects, because rains after the experimental fires were small. Nevertheless, field observers report apparently increased wash, and deflation by berg winds, following late autumn and winter fires (Bands, Bond, pers. comm.).

Fire intensity

No experimental information is available on the effect of different fire intensities on subsequent regeneration and development of fynbos communities, nor of the spectrum of intensities encountered in the normal range of prescribed and wild fires. In view of results reported elsewhere (e.g. Warcup 1981), a shift in mean fire intensity is likely to alter vegetation composition; managed fires may have important effects of this kind.

Size of burn

Current evidence indicates that most fynbos plant species do not disperse seed any great distance, and dispersal is apparently effective mainly in securing safe-sites locally (e.g. Bond 1980). Seed and plant predators take a heavy toll, especially where old vegetation offers shelter (Bond 1980). Predation is much reduced, or eliminated, in burns depending on the proximity of shelter, mainly in the form of unburnt vegetation. This interaction between predation and fire may have crucial effects on plant species populations, as in Widdringtonia cedarbergensis (Luckhoff 1971), and the effect will in a large measure be mediated by size of burn. Size of burn is also important where local animal migrations occur. Size of prescribed burn corresponds with compartment size, which is determined by practical considerations (time to complete the job) and economy, as well as inferred ecological arguments.

CONCLUSION - RESEARCH REQUIREMENTS IN CATCHMENT MANAGEMENT AND NATURE CONSERVATION

General requirements - understanding the basics

No consensus on appropriate land-use zoning and land management practices will develop without studies that allow a proper depth of understanding of past and present ecosystem structure and functioning. The general requirements may be classified as follows:

(a) Palaeobiological and historical studies; clarify essential features of past ecosystem dynamics, especially regarding the influence of man.

(b) Biogeography: comprehensive biogeographic studies of the complex patterns of fynbos are required as a basis for planning conservation systems, predicting the consequences of land-use patterns, and accommodating ecological heterogeneity in management systems.

(c) The physiological ecology of plants and animals in the special conditions of climate and nutrition of these ecosystems need study to the point that the inherent tolerances to management may be understood.

(d) Patterns and trends in land-use are poorly perceived, have a marked effect on management, and must be clarified to allow rational policy.

The ecological effects of fire

There are inherent conflicts in goals of management, for example between fire control and nature conservation, each of which tends to influence the choice of prescribed regime in one direction or another. What is required is the knowledge to predict and evaluate, in ecological and other terms, the outcome of a shift in regime one way or another, as well as that of a choice between a variable regime as opposed to a relatively rigid one, and of the pattern and scale of burning. This will need additional information in the following fields.

Hydrological and mineral cycles--Modelling, and additional experiments for validation; specifically a much better understanding of the dynamics of nutrients in the plant-litter-soil system is needed.

Plant demography--Predicting the interactions between the fire regime and vegetation dynamics needs much better understanding of plant life-cycles. Patterns in the distribution of species with unusual life-cycles, especially long youth-periods, need investigation.

Plant-animal interactions--Vertebrates and invertebrates appear to play a key role in the functioning of especially fynbos plant communities, through predation on seed and seedlings, pollination and dispersal. The fundamental aspects of plant-animal interactions must be determined before fire regimes can be managed with any confidence.

Fire technology--Means of predicting fire behaviour, in the form of fire danger-rating models, need to be developed urgently to allow more flexible management, and especially the techniques to burn in the ecologically desirable season.

Ecology of invasions

Increased efficiency of present control measures depends on a better understanding of the biology of the target species. Long-term management of the complex of pest-plants will require understanding of the invasion process as such. Among the many questions requiring attention, for example, is Shaughnessey's (1980) hypothesis, that most "invasion" is owing to past propagation by man: whether or not this is valid for a given species will fundamentally determine approaches to management of the problem. What, therefore, are the actual processes of invasion and what characters of demography and ecophysiology especially fit an invasive species for success in this environment, especially where nutrients are apparently limiting? Is disturbance a prequisite for invasion, and if so, what nature of disturbance?

ACKNOWLEDGEMENTS

I thank the sponsors of this symposium and the South African Directorate of Forestry and Environmental Conservation for the support that enabled my contribution.

LITERATURE CITED

Acocks, J.P.H. Veld types of South Africa. Memoirs Bot. Survey S. Afr.; 1953; 28. 192 p.

Adamson, R.S. The Vegetation of South Africa. London: British Empire Vegetation Committee; 1938. 235 p.

Aschmann, C. Man's impact on the several regions with mediterranean climates. In: Di Castri, F.; Mooney, H.A. eds. Mediterranean type ecosystems: Origin and structure. Heidelberg, Springer; 1973 : 363-371.

Aschmann, H.; Bahre, C. Man's impact on the wild landscape. In: Mooney, H.A. ed. Convergent evolution in Chile and California: mediterranean climate ecosystems. Stroudsberg, Pennsylvania: Dowden, Hutchinson and Ross; 1977: 73-84.

Bands, D.P. Prescribed burning in Cape fynbos catchments. In: Mooney, H.A.; Conrad, C.E. (Technical Co-ordinators) Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-3, Washington; D.C. 1977: 245-256.

Bigalke, R.C. Conservation. In: Day, J. and others. eds. Fynbos ecology: a preliminary synthesis. Pretoria, South Africa. Rep. of the National Programme for Environmental Sciences; 1979; 40: 148-157.

Boucher, C.; McCann, G.D. The Orothamnus saga. Veld and Flora 61: 2-5; 1975.

Boucher, C.; Moll, E.J. South African mediterranean shrublands. In: Di Castri, F.; Goodall, D.W.; Specht, R.L. eds. Ecosystems of the world II. Mediterranean-type shrublands. Amsterdam, Elsevier; 1981: 1-52.

Brown, J.C. Management of the Crown Forests at the Cape of Good Hope. Edinburgh: Oliver & Boyd; 1887. 352 p.

Day, J.M.; Siegfried, W.R.; Louw, G.N.; Jarman, M.L. Fynbos ecology: a preliminary synthesis. Pretoria, South Africa. Rep. of the South African National Scientific Programmes; 1979; 40. 166 p.

Deacon, H.J. The comparative evolution of mediterranean-type ecosystems: a southern perspective. In: Kruger, F.J.; Mitchell, D.T.; Jarvis, J.U.M. eds. Mediterranean-type ecosystems: the role of nutrients. Heidelberg: Springer; in press.

Edwards, D. Survey to determine the adequacy of existing conserved areas in relation to vegetation types. A preliminary report. Koedoe 17:2-37; 1974.

Fenn, J.A. Control of hakea in the Western Cape. In: Neser, S.; Cairns, A.L.P. eds. Proceedings of the third National Weeds Conference of South Africa. Cape Town; Balkema; 1980: 167-173.

Hall, A.V. Endangered species in a rising tide of human population growth. Trans. Royal Soc. S. Afr. 43:37-49; 1978.

Hall, A.V. 1979. Invasive weeds. In: Day, J. and others. Fynbos ecology: a preliminary synthesis Pretoria, South Africa. Rep. of the South African National Scientific Programmes; 1979; 40; 133-147.

Jordaan, P.G. Aantekeninge oor die voortplanting en brandperiodes van Protea mellifera Thunb. J. S. Afr. Bot. 15: 121-125; 1949.

Jordaan, P.G. Die invloed van 'n winterbrand op die voortplanting van vier soorte van die Proteaceae. Tydskrif vir Natuurwetenskappe 5: 27-31; 1965.

Katzen, M.F. White settlers and the origin of a new society, 1652-1778. In: Wilson, M.; Thompson, L. eds. The Oxford History of South Africa. Oxford, Clarendon; 1969: 187-232.

Klein, R.G. The ecology of early man in Southern Africa. Science 197: 115-126.; 1977.

Kruger, F.J. Ecology of Cape fynbos in relation to fire. In: Mooney, H.A.; Conrad, C.E. (Technical Co-ordinators). Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA Forest Serv. Gen. Tech. Rep. WO-3, Washington, D.C. 1977a: 230-244.

Kruger, F.J. Invasive woody plants in the Cape fynbos, with special reference to the biology and control of Pinus pinaster Ait. In: Proceedings of the second National Weeds Conference of South Africa. Cape Town, Balkema; 1977b: 27-39.

Kruger, F.J. South African heathlands. In: Specht, R.L. ed. Ecosystems of the world. Vol. 9 Heathlands and related shrublands. Amsterdam, Elserivier: 1979: 19-80.

Kruger, F.J.; Bigalke, R.C. Fire in the fynbos. In: Booysen, P. de V. ed. The ecological effects of fire in South Africa; in press.

Levyns, M.R. Notes on the biology and distribution of the rhenoster bush. S. Afr. J. Sci. 52: 1956; 141-143.

Luckhoff, H.A. The Clanwilliam cedar (Widdringtonia cedarbergensis Marsh) J. Bot. Soc. S. Afr. 57: 17-23; 1971.

McKenzie, B.; Moll, E.J.; Campbell, B.M. A suggested management plan for the indigenous vegetation of Orange Kloof, Table Mountain, based on a phytosociological survey. S. Afr. For. J. 99: 1-6; 1976.

Moll, E.J.; McKenzie, B.; McLachlan, D. A possible explanation for the lack of trees in the fynbos, Cape Province, South Africa. Biological Conservation 17: 221-228; 1980.

Neser, S.; Annecke, D.P. Biological control of weeds in South Africa. Department of Agricultural Technical Services, Entomology Memoir 28: 1-27; 1973.

Phillips, J.F.V. Forest-succession and ecology in the Knysna region. Memoirs Bot. Surv. S. Afr. 14; 1931; 1-327.

Shaughnessey, G.L. Historical ecology of alien woody plants in the vicinity of Cape Town, South Africa. School of Environmental Studies, University of Cape Town, Research Report No. 23; 1980. 421 p.

Specht, K.L.; Moll, E.J. Heathlands and sclerophyllous shrublands - an overview. In: Kruger, F.J.; Mitchell, D.T.; Jarvis, J.U.M. eds. Mediterranean-type ecosystems: the role of nutrients. Heidelberg, Springer (in press).

Taylor, H.C. Capensis. In: Werger, M.J.A. ed. Biogeography and ecology of Southern Africa. The Hague, Junk; 1978: 171-229.

Van der Zel, D.W.; Kruger, F.J. Results of the multiple catchment experiments at the Jonkershoek Research Station, South Africa. 2. Influences of protection of fynbos on stream discharge in Langrivier. For. in S. Afr. 16: 13-18; 1975.

Van Wilgen, B.W. Some effects of fire frequency on the aerial plant biomass of fynbos communities at Jonkershoek, Stellenbosch. J. Ecol. (in press); 1981a.

Van Wilgen, B.W. Some effects of fire frequency on fynbos plant community structure at Jonkershoek, Stellenbosch. S. Afr. For. J. (in press); 1981b.

Van Wilgen, B.W. An analysis of fires and associated weather factors in Mountain Fynbos areas of the South-western Cape. S. Afr. For. J.; in press.

Van Wilgen, B.W.; Kruger, F.J. Observations on the effects of fire in Mountain Fynbos at Zachariashoek, Paarl. J. S. Afr. Bot. 47: 195-212: 1981.

Warcup, J.H. Effect of heat treatment of forest soil on germination of buried seed. Australian J. Bot. 28: 567-571: 1980.

Wassermann, V.D. Some views on the potential for legume-based pastures in South Africa. Proc. Grassland Soc. of Southern Afr. 14: 19-22; 1979.

Wilson, M. The hunters and herders. In: Wilson, M.; Thompson, L. eds. The Oxford history of South Africa. Oxford, Clarendon, 1969; 40-74 p.

Multiple Use Management in a Mediterranean Ecosystem—the Jarrah Forest, a Case Study[1]

S. R. Shea[2]

Abstract: The jarrah (Eucalyptus marginata Sm.) forest of southwestern Australia extends over 2½ million hectares. In addition to the climatic constraints on the formation of high, dense forest, the soils are impoverished and the vegetation is subject to frequent fire. As a consequence, the forest has developed unique adaptations. For 150 years, hardwood timber production was the principle objective. Now, there are true multiple use demands plus special disease problems and political constraints. This paper describes approaches to multiple use forest management in the presence of severe biological and political constraints.

The jarrah (Eucalyptus marginata Sm.) forests of Western Australia are located in the southwestern corner of the State and extend over 1.5 million hectares. The dominant species, jarrah, is a high quality, durable hardwood and the forest has been exploited for timber over the 151 years since European settlement of the State (fig. 1). Logging of the forest in the first 100 years following European settlement was uncontrolled, but in 1918 forest management was placed under the control of a professionally directed forest service. In the following 40 years, traditional hardwood forest management practices, for example, inventory, fire protections, thinning and regeneration, etc., were progressively introduced. Management and research intensified in the 20 years following the second world war but was almost entirely concerned with regulation of timber exploitation, improving timber production, and protection from fire.

The 1960's saw the beginning of a series of major events which have resulted in radical changes in jarrah forest management and research. In 1965, the causal organism of a serious forest disease, "Jarrah Dieback," was identified as an introduced soil-borne fungus Phytopthora cinnamomi Rands (Podger 1972) (fig. 2). By the late 1960's, increased recreational use of the forest, together with greater public awareness environmental issues, caused intensive public questioning of standard management practices such as prescribed burning. During this period, the whole forest was placed under a lease for bauxite mining, and strip mining for bauxite commenced. A series of severe droughts, an increased demand for water, and serious salination of irrigation and domestic water supplies resulting from clearing of forest and woodland areas for agriculture focused attention on the catchment protection values of the forest (fig. 3).

Many of the unique characteristics of the forest fire regime, hydrology, and pathology can be attributed to the Mediterranean environment. These characteristics are summarized and discussed in relation to multiple use management.

THE JARRAH FOREST ENVIRONMENT

Climate

Rainfall occurs predominantly in the 5 months from May through to September and averages 128 cm annually. Little or no "effective" rainfall falls from December to March, and daily potential evapotranspiration rates exceeding 1 cm are common during this period. Spatial variation in potential evapotranspiration is small within the forest, but rainfall is at a maximum at the western margin of the forest (178 cm) and declines to less than 76 cm on the eastern boundary.

Landform and Soils

The forest is located on the western boundary of the ancient and extensively laterized Great Plateau of Western Australia. The river systems in the western edge of the plateau have been rejuvenated following uplift and formation of the Darling Scarp which forms the western boundary of the forest. Thus, within the forest zone, there is a succession of valley types characterized by varying degrees of incision.

Soils consist of fully developed laterites or are formed on truncated laterites or colluvium. The laterites, which are the predominant soil type, consist typically of 10 to 20 cm of sandy loam in a gravel matrix underlain by concreted laterite and/or unconsolidated laterite to a depth varying between 2 to 16 meters which is in turn underlain by a deep horizon of pallid zone clay (Shea and others 1975).

Vegetation

Overstory composition can be used to broadly categorize the vegetation, although there are

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Officer, Forest Department, Research Station, Dwellingup W.A. 6213 Western Australia.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Figure 1--Virgin jarrah forest.

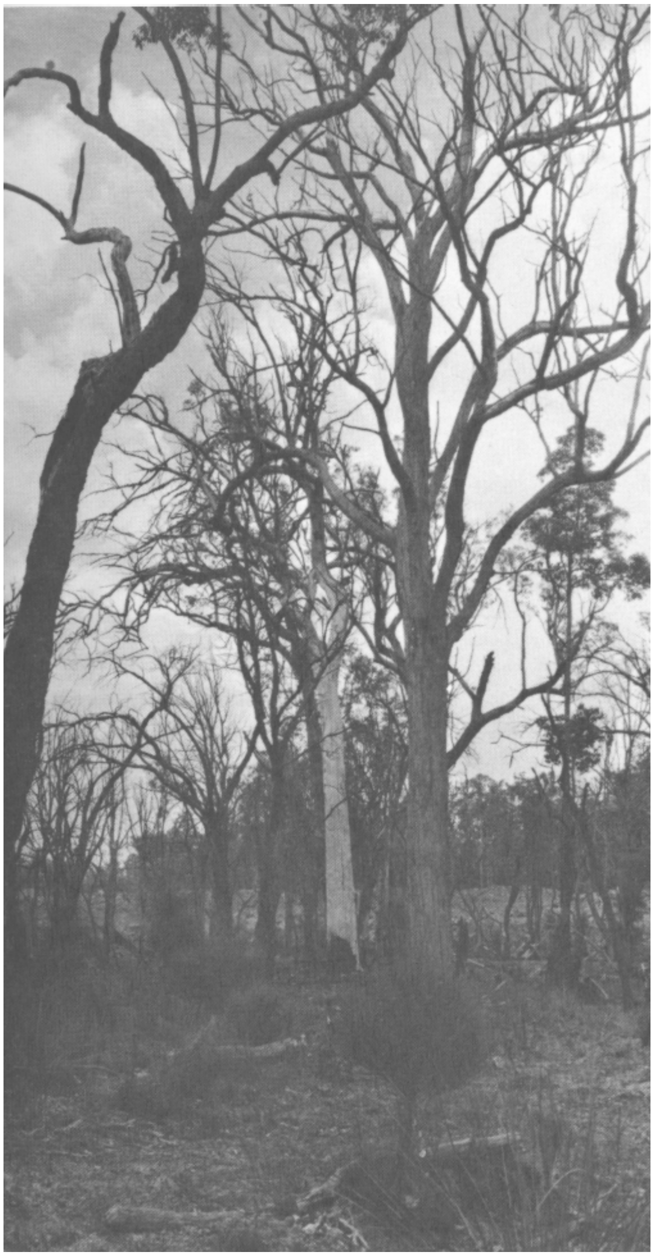


Figure 2--Jarrah Dieback, a disease caused by the soil-borne fungus Phytopthora cinnamomi.

numerous vegetation types that are associated with particular climatic and edaphic conditions (Havel 1975). The predominant type is dominated by jarrah and occurs on the lateritic uplands. Marri (Eucalyptus calophylla R. Br.) forms a minor component of the overstory; Banksia species are the major components of the understory, and numerous species form the shrub layer. In the western valleys, Eucalyptus patens Benth., Eucalyptus megacarpa S. Muell, and marri replace jarrah in the overstory. In the eastern valleys, Eucalyptus wandoo Blakely and Eucalyptus rudis Endl. are the dominant overstory species.

FOREST HYDROLOGY

The two outstanding features of jarrah forest hydrology are the low water yields and the presence of large salt accumulations in the soil profile in some forest areas. The average percent water yield from fully forested catchments varies from 10 to 20 percent in the western high rainfall zone of the forest to less than 1 percent in the eastern low rainfall zone. Total salt content of the soil profile may exceed 500,000 kilograms per hectare. Salt concentration is generally low in the western zone of the forest, increasing with distance from the Darling Escarpment, but there are significant departures from this gradient.

The low yield and salt accumulations in jarrah forest catchments are a consequence of the Mediterranean climate, the presence of deep soil profiles with a high moisture storage capacity, and the method by which the forest vegetation has adapted to the environment (Shea and others 1975). Between 31 and 133 kilograms of salt per hectare are deposited annually in rainfall in the forest (Peck and Hurle 1972). In high rainfall areas or where soils are shallow, most of this salt is flushed through the soil profile. However, in approximately two-thirds of the forest, there is a net accumulation of salt. This is a consequence of the ability of the vegetation to maintain transpiration rates approximating the potential rate throughout the year.

The exploitation of the water stored in the soil profile during the summer months is only possible because of the development of extensive vertical root systems (Kimber 1974).

Stream salinity levels in forested catchments are usually less than 250 ppm T.D.S., even though there are large salt storages in the soil profile because the system is in equilibrium. Removal of the forests by disease or changes in land use practices disturbs the equilibrium and excess salt discharge occurs. For example, weighted average stream salinities in excess of 18,000 ppm T.D.S. have been recorded in streams discharging from catchments which have been cleared for agriculture (Peck and Hurle 1972).

JARRAH DIEBACK

Small areas of dying forest were first recorded shortly after the turn of the century. The effected area increased slowly up until the end of the second world war. In the decade following the end of the war, the tramline system of log removal was replaced with one based on log trucks which required the development of an extensive roading system. The rate of disease development increased dramatically during the period and by 1972, 10 percent of the forest was severely diseased. As the severity of the disorder increased, research was intensified but it was not until 1966 that the causal organism, Phytopthora cinnamomi Rands, an introduced soil-borne fungal pathogen, was

Figure 3--Aerial view of bauxite mines and water reservoir within the jarrah forest.

identified (Podger 1972). The pathogen causes death of susceptible species by destruction of the root system and/or invasion of the lower stem.

The rate of disease development varies with site and climatic conditions (Shea 1975). However, in many forest sites, the end consequence of introduction of the pathogen is death of jarrah trees of all ages and sizes and the majority of the species comprising shrub and understory layer of the forest. Consequently, most forest values are severely reduced in diseased areas. The disease is concentrated in the western low salinity zone of the forest where destruction of the forest does not cause a deterioration of water quality. However, the disease has caused salination in some microcatchments where it has extended into the saline zone (Shea and others 1975).

Fungal spores can be transmitted in minute quantities of soil provided it is moist. Hence, any activity which results in transmission of the soil can result in the establishment of a new infection. The fungus can move passively in water running overland. Upslope extensions through the roots of highly susceptible species can occur at an average rate of approximately 50 to 100 cm per year (Shea 1975).

Following the discovery of the causal organism, research was primarily directed towards documenting the relationship between the pathogen and the forest environment (Shea 1975). P. cinnamomi is a water mold and requires high soil moisture levels and soil temperatures greater than 15° C to complete the asexual phase of the life cycle. The fungus cannot withstand prolonged soil drying. In moisture-gaining sites within the forest, environmental conditions are suitable for survival and reproduction for long periods during the year.

However, on free-drained sites in the forest, which constitute between 60 to 80 percent of the forest area, the relationship between the fungus and the soil environment is finely balanced (Shea and others 1980). During the summer months, soil moisture levels are too low for asexual reproduction and survival of spores outside large roots is limited. During winter, fungal spores can survive but soil temperature levels are too low for asexual reproduction. Hence, the periods during which the pathogen can reproduce are restricted to relatively brief periods in spring and autumn when there is a coincident of favorable soil moisture and temperature conditions. The capacity of the pathogen to cause extensive disease on free-drained sites within the forest, even though the environment on these sites is only marginally favorable for fungal pathogenicity, is attributed to:

1. Extensive distribution of fungal spores and mycelium in soil carried on vehicles.

2. The presence of a highly susceptible dense understory of *Banksia grandis.* (*P. cinnamomi* can invade the large horizontal roots and lower stem of this species, thus fungal extension can occur regardless of soil physical conditions.)

3. Soil and canopy disturbance which prolongs the periods during which the soil physical environment is suitable for asexual reproduction and spore transmission.

4. The occurrence of severe annual summer drought stress which increases the probability that species with root systems damaged by the pathogen will succumb to drought.

FIRE

Early forest managers were strongly influenced by European forest practices and for the first 35 years following the introduction of management, a policy of complete protection from fire was adopted. By the early 1950's, it became apparent that a fire exclusion policy was not practicable and that the vegetation was adapted to fire. Although exploitation of the forest for timber increased the intensity of wildfires and the frequency of these conflagrations was probably increased by accidental and deliberate ignition by European man, there is evidence that Aboriginal man used fire as a management tool for thousands of years prior to European settlement. Even in the absence of man, it is unlikely that the forest would remain unburnt for long periods in a Mediterranean environment when ignition from lightning strikes is common (Shea and others 1981).

Following the failure of the fire exclusion strategy, a program of periodic low-intensity prescribed burning was introduced with the single objective of hazard reduction. Over a period of 25 years, a sophisticated low-cost prescribed burning program involving rotational burning of the whole forest on a 5- to 7-year cycle has been developed (Shea and others 1981).

The hazard reduction burning program has resulted in a marked reduction in the area burnt by uncontrolled wildfire (Shea and others 1981). Broad scale, low-intensity hazard reduction burning currently remains the only practical method of fire management in the forest. However, it is highly improbable that periodic low-intensity burning in spring duplicates the "natural" fire regime, and research is being directed to determine if there are long-term adverse effects of this burning regime on the forest ecosystem, and if fire can be used as a management tool for purposes in addition to hazard reduction. For example, low-intensity burning disfavors the regeneration of a leguminous understory because heat penetration from normal hazard reduction burns is not sufficient to stimulate germination of leguminous seed stored in the soil (Shea and others 1979). It is possible that the absence of a leguminous understory could have an adverse effect on forest fertility (Shea and Kitt 1976) and fauna habitat (Christenson 1980).

FOREST MANAGEMENT AND RESEARCH

Objectives

The importance of the catchment protection function of the forest to the southwest of Western Australia has placed maintenance of water quality as the first priority of forest management. Where other land use practices do not conflict with water quality maintenance, the objectives of forest management is to maximize timber, conservation, and recreational values in perpetuity.

Site Classification

A system of site classification is being developed as the basis for the resolution of land use conflicts and the development of specific management strategies. The most important site characteristic is the presence or absence of significant salt accumulations in the soil profile. When salt is present, any activity which reduces canopy density for prolonged periods has the potential to cause salination. The forest has been classified into three broad zones based principally on rainfall isohyets--saline (eastern forest), nonsaline (western forest), and an intermediate zone where salinity is variable. Within each zone priority, land uses are designated primarily according to disease presence, landform, and vegetative type. A system of ecological site typing based on indicator species has been developed (Havel 1975) and is used to assist designation of priority land uses. For example, within the western low salt zone sections at the steeply incised river valleys which constitute a rare ecological type have been designated conservation priority areas, upland disease-free sites would have a timber production priority, whereas similar sites which are heavily diseased would have a water production priority.

Catchment Management

In high salinity areas, the management aims to maintain the native vegetation or where it has been removed by disease or prior land use practices, establishment of species which would restore the hydrological equilibrium. The rehabilitation of disturbed forest areas in salt-prone forest areas is a major problem. It is impossible to reestablish jarrah in these areas because of the susceptibility to *P. cinnamomi*. Hence, introduced species which are resistant to this pathogen must be used. However, in addition to disease resistance, the selected species must have the capacity to grow in a Mediterranean climate, on soils with unfavorable physical and nutrient conditions, in an environment which is subject to periodic fire of varying intensities while maintaining high evapotranspiration rates. Currently, no species have been identified which meet these criteria (Bartle and Shea 1978).

In the nonsaline forest zone, it is possible that significant increases in the yield of high quality water could be achieved by thinning (Shea and others 1975). It is possible that thinning for water production can also be made compatible with timber production. Current research is directed towards determining the range of canopy and stand densities which provide maximum water production while maintaining maximum wood increment on the minimum number of trees.

Disease Management

Currently, the only method of reducing the impact of *P. cinnamomi* on the forest is by restricting its spread by man. Following the identification of *P. cinnamomi* as the causal organism, intensive sanitation procedures were introduced. When it became apparent that these procedures were not adequate, the eastern two-thirds of the forest corresponding to the high salt zone were placed under quarantine (Shea 1978). Detailed aerial color photography is being used to permit precise identification of diseased areas within this zone so that management procedures based on avoidance of sources of inoculum can be developed.

The most promising approach to control is based on manipulation of the forest environment by changing the prescribed burning regime. Prior to exploitation of the forest, *Banksia grandis* only occurred as a scattered component of the forest. Disturbance and fire exclusion or low-intensity fire has favored this species, and it currently forms a dense understory on most upland sites. The presence of this highly susceptible understory is a major contributor to the spread and intensification of the disease. It has been shown that a moderate-to-high-intensity fire regime will significantly reduce *B. grandis* density and, in many forest sites, result in its replacement by an understory of leguminous species. It is possible that this could cause a significant reduction in disease intensity by (1) reducing the susceptible food base available to the pathogen, and (2) creating a soil physical and microbiological environment unfavorable for pathogen survival and reproduction (Shea 1975, 1978; Shea and others 1980).

Timber Production

Various modifications of the selection cut system of silviculture have been applied over the period since management was imposed. The principal species, jarrah, has a lignotuberous form and regeneration has not been considered a significant problem. The major factor affecting timber production is Jarrah Dieback, and the presence or absence of the disease is the major factor affecting logging and silvicultural procedures. In high quality regrowth stands, there is considerable potential to shorten rotation ages and increase log value by thinning, as the species does not thin naturally (Kimber 1976). However, thinning programs have been stopped because it is uncertain whether the investment in thinning would be returned because of the threat from Jarrah Dieback and competing land uses (e.g., bauxite mining).

Conservation

Conservation is recognized as an important management objective throughout the forest but in areas with special floral or faunal components, conservation is the first management priority. For example, an area of 40,000 hectares in the southwestern corner of the forest where 27 different mammal species have been recorded has been designated a fauna priority area (Christenson 1978). One of the major factors affecting fauna is fire regime and a specific fire management plan which provides for varying combinations of fire intensity and frequency, which will ensure preservation of major habitat types while minimizing fire hazard, has been proposed (Christenson, cited in Shea and others 1981).

Bauxite Mining

Economic grades of bauxite ore occur in pods on the ridge or upper slopes. Up to 20 to 30 percent of the forest may have mineable ore in high grade areas within the western zone of the forest, but the percentage decreases in the central and eastern zones of the forest. Mining involves removal of the surface soil horizons, blasting and extraction of the bauxite ore to a depth of 2 to 6 m, and replacement of the surface soil. Following ripping of the sites to a depth of 2 meters, the sites are planted with a variety of tree species and direct seeded with native shrub species.

Mining results in loss of forest in the mined-over areas and the forest areas adjacent to and downslope from the mine pits and predisposed to Jarrah Dieback because of the spread of the pathogen in infected soil during the mining process and the disruption of drainage which favors survival, reproduction, and transmission by the pathogen. Initial growth rates of the tree species which have been established on the mine pits has been rapid, but their capacity to survive in the long term in an environment which is not conducive to tree growth is not known (Bartle and Shea 1979).

CONCLUSIONS

The interactions between fire regime, hydrology and disease, and different land use practices are the major factors contributing to the complexity of multiple use management in the jarrah forest. For example, any land use practice that results in the movement of soil can cause spread of Jarrah Diehack and destruction of the forest. Loss of forest cover in salt—prone areas can cause salination. The species used to rehabilitate disturbed forest areas must be resistant to P. cinnamomi. It is possible that fire could be used to reduce disease susceptibility, but the presence of fire as a factor in the environment also means that species used to rehabilitate disturbed areas must be fire tolerant.

Given the complexity of the jarrah forest ecosystem and the severe conflicts between some land use practices, it is not surprising that management strategies which will satisfy the multiple use objectives are still being developed.

LITERATURE CITED

Bartle, J. R.; Shea, S. K. Selection of tree species for rehabilitation of degraded areas in the northern jarrah forest. In: Rehabilitation of mined lands in western Australia. Perth, Western Australia: Symposium West. Aust. Inst. of Tech.; 1978.

Bartle, J. R.; Shea, S. K. Development of the ecosystem after mining. In: Australian mining council environmental workshop, Vol. 1. Bunbury, Western Australia; 1979.

Christensen, P. E. The concept of fauna priority areas. 3d fire ecology symposium; 1978; For. Comm. Vic. and Monash Univ.

Christensen, P. E. S. The biology of Bettonsia pencillata Gray 1837, and Macropus engenii (Demarest, 1917) in relation to fire.: 1980; For. Dep. of West. Aust. Bull. 91.

Havel, J. J. Site vegetation mapping in the northern jarrah forest (Darling Range). I. Definition of site—vegetation types. For. Dep. of West. Aust. Bull. 86. II. Location and mapping of site—vegetation types. For. Dep. of West. Aust. Bull. 87. III. Relationship of site—vegetation types to land utilization. For. Dep. of West. Aust. Bull. [in press]; 1975.

Kimber, P. C. The root system of jarrah (Eucalyptus marginata Sm.) forests.; 1974; Dep. of West. Aust. Res. Paper 10.

Kimber, P. C. Thinning jarrah with hormone herbicides. Aust. For. 31:128—136; 1976.

Peck, A. J.; Hurle, D. H. Chloride balance in some farmed and forested catchments in south—western Australia. Water Resour. Res. 9:648—657; 1972.

Podger, F. D. Phytopthora cinnamomi a cause of lethal disease in indigenous plant communities in Western Australia. Phytopathology 62:972—981; 1972.

Shea, S. R. Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of Phytopthora cinnamomi Rands.: 1975; West. Aust. For. Dep. Bull. 85.

Shea, S. R. Forest management and Phytopthora cinnamomi Rands in Australia. In: Old, K. M., ed. Phytopthora and forest management in Australia. Canberra: C.S.I.R.O.; 1978: 73—100.

Shea, S. R.; Gillen, K. J.; Leppard, W. I. Seasonal variation in population levels of Phytopthora cinnamomi Rands in soil in diseased, freely—drained Eucalyptus marginata Sm. sites in the northern jarrah forest of south—western Australia. Prot. Ecol. 2:135—156; 1980.

Shea, S. R.; Hatch, A. B.; Havel, J. J.; Ritson, P. The effect of changes in forest structure and composition on water quality and yield from the northern jarrah forest. In: Kikkana, J.; Nix, H. A., eds. Managing terrestrial ecosystems, Vol. 9.; 1975; Proceedings of the Ecological Society of Australia.

Shea, S. R.; Kitt, R. J. The capacity of jarrah forest native legumes to fix nitrogen.: 1976; For. Dep. West. Aust. Res. Rep. 21.

Shea, S. K.; McCormick, J.; Portlock, C. C. The effect of fire on regeneration of leguminous species in the northern jarrah (Eucalyptus marginata Sm.) forest of Western Australia. Aust. J. Ecol. 4:195—205; 1979.

Shea, S. R.; Peet, G. B.; Cheney, N. P. The role of fire in forest management. In: Gill, A. M.; Groves, R. Eh.; Noble, I. R., eds. Fire and the Australian biota. Canberra: Aust. Acad. Sci.; 1981.

Chaparral in Southern California[1]

Robert R. Tyrrel[2]

Abstract: Chaparral is the most extensive vegetation type in California, covering over one-twentieth of the State or some 13.2 million acres (5.34 million ha). For thousands of years the vegetation in Southern California had very little impact from human use and activity, but in the past three decades this situation has changed with the increasing population. There are over 13 million people now living in Southern California. Eighty years of maintenance management of chaparral lands have generally resulted in extensive areas of decadent or very mature vegetation that is highly flammable and virtually impenetrable to wildlife, livestock, and man.

Description of Southern California Chaparral

The term chaparral comes from the Spanish word "chaparro" because the early Spanish explorers were reminded of the dense scrub oak found in the Mediterranean Region. Today, the term is applied to dense evergreen brushfields in general. Chaparral lands in this discussion will include predominantly brush-covered lands and brush-hardwood-conifer transition zones, transected by riparian vegetation.

Chaparral vegetation is a product of a "Mediterranean" climate system. In Southern California, Mediterranean-type climate is characterized by moderate, moist winters with long, hot, dry summer periods. Rainfall is generally sparse (12 to 24 inches/300-600 m) and often occurs in a few high intensity winter storms. Summer temperatures often exceed 100 degrees Fahrenheit (38 degrees Centigrade) and relative humidities are low, sometimes dropping to less than 5 percent. Most critical for management are the dry and often warm Santa Ana winds, blowing from the desert to the sea and sometimes reaching up to 100 miles per hour (160 kph).

Most of the chaparral in Southern California Mountain Ranges is found at elevations between 1,000 and 10,000 feet (300 and 3000 meters). Typically, these ranges are geologically young and still growing. A high percentage of chaparral is found on steep slopes. Soils vary considerably depending on topography, geology and climate prevailing in a particular area. Soils throughout the range are generally very porous, consisting mostly of decomposed granite. Chaparral soils tend to be very low in essential plant nutrients, with nitrogen often the most limiting nutrient. Following fires, erosion rates can be extremely high. Also, high intensity fires often produce a water-repellant layer in the soil which greatly increases runoff.

The chaparral landscape is a continuous cover of low-growing shrubs creating a mosaic in shades of green, but individual plants have certain diagnostic features in common. The plants are most easily identified by their leaves. Leaves are characteristically evergreen, small, thick, and stiff in order to cope with drought periods. The common genera of Southern California chaparral are Adenostoma, Arctostophylos, Ceanothus, Quercus, Heteromeles, and Rhus. Factors that affect the distribution of different chaparral species in Southern California are the local climate changes due to coastal or desert exposures; changes in elevation, slope and aspect.

Fire is a key element in the life cycle of the chaparral type. Seasonally, the moisture content of chaparral species can fluctuate rapidly. It is not uncommon for fuel moistures to drop to 8-13 percent during summer drought periods or during Santa Ana wind conditions. In addition, close spacing and continuity of vegetation cover plus high surface-to-volume ratios in the chaparral community leads to a high percentage of available fuel. Over time, the ratio of dead to live material increases dramatically. For example, by age 30, often as much as 50 percent of the standing mass of the crowns in a chamise stand can be dead and more material accumulates as litter on the ground. All these factors result in rapid ignition and spread of fires. Where fuel conditions are uniform over broad areas, fires tend to be quite large.

Because chaparral has evolved with fire, the vegetation has developed distinct survival mechanisms. Many shrub species found in Southern California resprout from root crowns following fire. Most species require heat treatment before the seeds will germinate. Seeds can survive for extremely long periods of time in soil.

Chaparral is the most extensive vegetation type in California, covering over one-twentieth of the State or some 13.2 million acres (5.34 million ha). Chaparral in Southern California covers in excess of 3.4 million acres (1.38 million ha). The Angeles, Cleveland, Los

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Forest Supervisor, San Bernardino National Forest, Forest Service, U.S. Department of Agriculture, San Bernardino, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Padres and San Bernardino National Forests encompass approximately 3.4 million acres (1.38 million ha). In excess of 60 percent of this National Forest land is covered with chaparral. Consequently, management of chaparral lands is an increasingly important part of National Forest resource management activities.

History

For thousands of years the vegetation in Southern California had very little impact from human use. It is adequately documented that California Indians set fires to chaparral at the time of first contact with white settlers. However, the frequency of, reason for, and seasonal patterns of burning by the Indians are not at all clear. Viewpoints range from assuming deliberately set fires to modify vegetation and thus yield more plant products, to support game or accomplish game drives, to nothing more than escaped campfires. We do know that the Indians had no way of suppressing fires. Fires would have to burn until reaching a natural barrier.

The first Spanish explorers arrived in Southern California in 1769 and established the San Diego Mission. In the early settlement of Southern California, the chaparral foothills formed logical boundaries for Spanish land grants which formed the basis of early California rancho economy based on livestock grazing and mission agriculture. The chaparral zones merely separated the mountain forests from the flat or tillable lands.

In the period from 1769 to the early 1800's man's impact on the vegetation was roughly concentrated in a ten-mile radius around missions and pueblos. To these early settlers, chaparral was mainly a source for game animals. Into the 1860's chaparral lands were used somewhat for grazing, although sheepherders found these lands unusable unless charred by fire. To miners these lands were a source of charcoal for processing ore, but equally a tough barrier to easy prospecting and cross-country travel.

In the late 1800's, water coming from the chaparral areas and above was considered the lifeblood of the intensive irrigation agriculture of fruit and citrus on the valley floor. Extensive dams were built during this period for irrigation, and small hydro-electric power plants sprung up in the canyon bottoms.

In 1892 and 1893 the first forest reserves, later to become the Angeles, Cleveland and San Bernardino National Forests, were established by the U.S. Congress to protect the mountain watersheds from destructive fires. These forest reserves were created in direct response to the vigorous appeals by local citizens. Creation of the Southern California reserves was in contrast to creation of other forest reserves in the west where eastern conservationists fought for their establishment in defiance of local wishes.

The early 1900's saw the formation of local citizen groups in Southern California to further the cause of watershed protection and conservation. These citizens were convinced that the fate of Southern California either as an agricultural domain or metropolis resided in the reliability and quality of its water supply. Pressure from these citizen groups led to the first Federally appropriated funds to construct fire lanes on the southern slopes of the San Bernardino Mountains. During this period, fire control in chaparral areas became more systematic and organized.

From 1910 to 1920 the advent of the automobile led to a sharp increase in the use of the forest watersheds for recreation purposes. This led to a large increase in fires caused by campers. The Forest Service recognized recreation as a major forest resource, and improved public campgrounds were established to meet the needs of campers as well as fire prevention. Large fires continued to occur and the decade of the 20's closed as one of the most severe fire loss periods in Southern California history. On the four National Forests in Southern California some 913,700 acres (369,900 ha) were burned. (This figure includes National Forest land only, and not the extensive burned areas outside the Forests' boundaries)

The 1930's saw the great depression and the establishment of the Civilian Conservation Corps (CCC) "to relieve distress, build men and build up the Nation's Forest resources". This led to the building of firebreaks, fire trails, look-outs, reforestation of burned areas, construction of recreation facilities, Ranger Stations, and road, range and wildlife improvements, etc. All of these men were trained as effective fire crews, and burned acres in Southern California, particularly in the chaparral areas, dropped to some 395,700 acres (160,200 ha). This figure remained fairly constant in the 1940's.

The 1950's saw a sharp upturn in burned acre-age. The biggest impact undoubtedly came from a doubling of Southern California's population to more than five million people in 1950. Public use of the Forests also doubled, leading to increased fire occurrence. Public concerns increased over massive soil erosion and water losses following fires in chaparral areas. This led to formation of more citizen groups and the establishment of more agency regulations to improve watershed protection. In the late 1950's the fuelbreak and type conversion concepts of removing chaparral and replacing it with grasses were developed and began to be implemented.

From 1960 to 1970 the population doubled again to over 12 million people. Most of this growth occurred in the valley and foothill areas below the chaparral watershed areas. Unique to the San Bernardino National Forest, growth also accelerated within its boundaries. Fire losses began to seriously affect personal property and residences during this period. Citizens and

Congress, through the National Forest Management Act and other legislation, emphasized the importance of proper land use planning and vegetative treatment in chaparral areas.

Basically since World War II, fire suppression equipment and techniques have made great progress. Most fires today are suppressed at a few acres. Total acres burned per decade have decreased, which has resulted in many older stands of chaparral. All of these factors have contributed to the accumulation of more dead material in chaparral. Today, when fires occur under extreme weather conditions (usually Santa Ana winds) they are extremely devastating, capable of jumping fuelbreaks and super highways and destroying lives and property.

In the past, citizens affected by devastating fires demanded more effective fire protection. However, in the past decade, new concepts have begun to emerge relative to managing the chaparral resource. With over 13 million people currently living in Southern California, ways of living in harmony with the chaparral system are becoming more and more important. Our management priorities are beginning to reflect that need.

Present Uses

During the fall of 1980, the San Bernardino National Forest experienced the most devastating fires, from a damage standpoint, in the history of the Forest. One of these, the Panorama Fire, started on November 24, 1980 during severe Santa Ana winds that often reached gusts of 100 miles per hour (160 kph). Before the fire was contained five days later, four deaths were attributed directly to the fire, 284 homes were totally destroyed, 49 other homes were damaged, 64 other structures were lost or damaged, and numerous vehicles were destroyed. Structural losses alone amounted to over $28 million, watershed losses were $11.8 million and suppression costs were in excess of $5 million. Numerous examples of devastating fires can be found in Southern California dating back to the early 1960's.

Water continues to be one of the most valuable commodities on chaparral areas in Southern California. Chaparral watersheds produce water used for recreational, agricultural, domestic and industrial purposes. Water produced locally in Southern California is extremely valuable and becomes more so each day as energy costs to import water are rising rapidly. The chaparral watersheds also play an extremely important role in preventing downstream flooding.

Numerous examples of serious life and property loss from water and mud flows occur after chaparral vegetation is removed by fire. Maintaining stability and productivity of these watersheds is extremely important. Past practices to protect and manage this resource have included construction of fuelbreaks and type conversions. In the future, prescribed fire as a 1 means of managing the age classes in chaparral will receive greater emphasis and the fuelbreaks and type conversions will help accomplish the overall objectives of age-class management.

Though the range resource is limited in Southern California, livestock often graze on type-converted areas and established fuelbreaks in chaparral. Grazing serves a dual purpose; maintaining fuelbreaks and type-converted areas, as well as producing red meat for the market.

Wildlife species, particularly large animals such as deer and bighorn sheep, have certain habitat needs which are benefited by prescribed fire. Manipulation of the chaparral vegetation is necessary to maintain habitat and ensure animal and plant diversity.

The chaparral areas in Southern California provide a visual backdrop for millions of Southern California residents and are used fairly extensively for recreation activities. These activities include hiking, off-road vehicle use, hunting, fishing, camping and picnicking both in developed and unimproved sites, shooting and plinking, etc. Most of these activities occur during the fall, winter and spring months when temperatures are cooler. Large areas of chaparral on the Southern California National Forests are closed to public access during the summer and fall months for fire prevention purposes. These closures have been in existence since the 1920's and limit some recreation opportunities. The need for fire closure is now being questioned.

The 13 million people living in Southern California look to National Forest lands, including chaparral, to meet residential and consumer needs. Chaparral lands are being used for home sites; waste disposal sites, including solid and liquid waste; industrial sites; utility corridors; mining operations; communications centers; etc. The physical location of chaparral adjacent to the population centers in Southern California and the fact that the growth rates are steadily increasing, adds new impacts each day. Most of the major impacts are occurring where cities, towns, and agricultural lands encroach directly into the chaparral-covered foothills. Management of these areas forming the urban/rural/wildland interface is complicated because numerous small landowners are involved. In addition to different owners, many different Federal, State, County and local governmental agencies have overlapping jurisdictions in these areas. Management of these chaparral interface lands provides one of the greatest challenges for interagency cooperation ever known in the nation, and one which needs the utmost support from all agencies.

Research

Currently, the Forest Service Pacific Southwest Forest and Range Experiment Station is in a five-year effort to develop, test, and demonstrate a wide range of options for maintaining or increasing the productivity of chaparral and related ecosystems. The study area is a 127,000 acre site on the Cleveland National Forest called the Laguna-Morena Demonstration Area. Goals for the demonstration area are to develop new ideas for chaparral management and test techniques that can be used elsewhere; to monitor the environmental impacts of these techniques; to demonstrate the effectiveness of these techniques to a concerned public; and finally, to reduce the potential for catastrophic wildfires. Numerous Federal, State and local agencies are cooperating in the study.

Current Management Direction for N.F. Chaparral Lands in Southern California

Eighty years of maintenance management of chaparral lands have generally resulted in extensive areas of decadent or very mature vegetation that is highly flammable and virtually impenetrable to wildlife, livestock and man. Management of chaparral lands and related vegetation has been identified as a major issue in the Forest Land and Resource Management Plans that are currently being developed on the Southern California National Forests. These plans will guide all future management activities on these Forests.

The crux of the chaparral issue is the management of chaparral lands in order to achieve an integrated resource program. What suitable uses can be identified for chaparral—covered slopes that will be compatible with other uses? What can we expect in the way of outputs, costs, and effects by implementing a range of vegetation management alternatives in the chaparral?

The chaparral management issue will be driven by the many diverse interests of the public and concerns of resource managers. Fire control agencies who seek ways to reduce fire losses will have significant impact. The livestock industry, which wants to increase the amount and value of forage, has concerns. The wildlife managers who must manage for wildlife habitat diversity have objectives to be met. Watershed managers want to manage cover to protect water quality and also exercise opportunities to increase water yield. Botanists have concerns for managing threatened and endangered plant species and maintaining species diversity. Consumers who want to harvest the chaparral commodities for energy purposes (heat) will have input. Hunters and recreationists want easy access through chaparral lands where impenetrable thickets now prevail. Many other people will be expressing their personal opinions and concerns for managing chaparral lands.

Conclusion

The Forest Service and other land management agencies have a real challenge ahead in responding to public needs and providing sound management of the vegetation resource over time. The time is right --we eagerly accept the challenge.

References

Aschmann, Homer. Man's Impact on the Southern California Flora, Symposium Proceedings, Plant Communities of Southern California; California Native Plant Society; 1976; 40-48.

Bauer, Don R. Forest Fire Control in Southern California - A Short Story. San Bernardino, California; U.S.D.A. Forest Service; 1973.

Hanes, Ted L. The Vegetation Called Chaparral. Symposium on Living With the Chaparral; Los Angeles; Sierra Club; 1973; 1-5.

Unknown. California Chaparral; Terrestrial Vegetation of California. New York: John Wiley and Sons, Inc.; 1977; 417-469.

Watershed and Chaparral Management Situation Statement for Regional Planning; San Francisco, California; U.S.D.A. Forest Service; Pacific Southwest Region; 1981.

Chaparral in Arizona[1]

Donald H. Bolander[2]

Abstract: Arizona has about 1.2 million hectares of a low-growing brushland known as chaparral. Most of the brush plants are prolific crown or root sprouters and resist fire or heavy use by grazing. Over 100 years of man's activities have not greatly modified the type with the exception of the impact of grazing on the herbaceous component. Initial research was aimed at grazing and erosion problems and current research is stressing the feasibility of increasing water yields. Mechanical equipment, fire, herbicides, and seeding are employed to modify the type in order to increase water yield, forage and recreation opportunities.

The State of Arizona, like California, has a large area of Mediterranean-type ecosystems, or chaparral as it is commonly called. There are, however, some important differences between the two States. The primary differences are in climate, size or average height of the brush plants, and the composition of the understory grasses and forbs. One other very important difference is in the relationship of population centers to the type.

The previous paper by Mr. Tyrrel has presented a brief discussion on the California chaparral. My paper will attempt to present comparable information for Arizona.

DESCRIPTION OF ARIZONA CHAPARRAL

The chaparral type in Arizona is found in a discontinuous band across the central part of the State which extends from northwest to southeast. Depending on the criteria used to classify the type, there are from 1.2 million to 2.4 million hectares in the type; 1.2 million hectares is considered close when the transitions into the Pinyon and Juniper woodland and the desert shrub are excluded.

The chaparral type is found under the following ownership:

	Percent
Federal Government	
Forest Service, USDA	52
Bureau of Land Management, USDI	15
Other Federal	2
State of Arizona	15
Private	12
Indian	4
TOTAL =	100

The shrub plants in the Arizona chaparral have much in common with those found in California. They are moderately-deep to deep-rooted evergreen shrubs. Most species are prolific crown or root sprouters. A few non-sprouters produce abundant seed which germinates following heat scarification. Except on the best sites, Arizona's chaparral tends to be of somewhat lower growth form and the stand more open than its California counterpart. Primary shrub species in Arizona include

Shrub live oak (*Quercus turbinella*)
Manzanita (*Arctostophylos* spp.)
Desert ceanothus (*Ceanothus greggi*)
Mountain mahogany (*Cercocarpus spp.*)
Silktassel (*Garrya* spp.)

Where shrub canopy is open, grasses and forbs are often moderately dense. On areas which have not been subjected to heavy, destructive grazing, perennial grasses such as sideoats grama (*Bouteloua curtipendula*) are common. On areas which have been heavily grazed, annual grasses such as red brome (*Bromus rubens*) are common. The presence of perennial grasses and the more open canopy is an important difference from the California type.

The topography where the Arizona chaparral occurs is highly variable. Most of the type is found on mountainous areas, much of it on extremely rough, steep terrain, and a relatively small amount on flat sites. It occurs between 900 and 1,800 meters elevation on all aspects.

Typical soils are moderately deep, coarse textured, and poorly developed. Most of the soil depth is in the C horizon. Soil texture varies from cobbly and gravelly loamy sand to gravelly loam. Parent materials include deeply weathered and fractured granite, schist, diabase and sandstone. Granites are found on more than half the total chaparral area, while diabase and sandstone comprise less than 10 percent.

The Arizona chaparral zone receives between 400 and 600 mm. of precipitation a year. About 55 percent comes as rain and snow between November and April, and 35 percent during the July to

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Forest Supervisor, Prescott National Forest, Forest Service, U.S. Department of Agriculture, Prescott, Arizona.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

September season, primarily as thunderstorms. The summer rainy season, which California does not have, is the primary reason for the perennial grasses that occur in the Arizona chaparral.

Mean monthly temperatures vary from less than 5°C in January to more than 27°C in July. Relative humidity is low with evaporation occurring at rates up to 2,100 mm. per year.

Wind generally is out of the southwest. The most windy period is May and June when average daily wind speeds are between 16 and 19 kilometers per hour. This coincides with the driest and warmest time of year. June is considered the most critical month for disastrous wildfires.

HISTORY

Arizona was inhabited for thousands of years by the native Indians before the Europeans arrived. The Indians made little impact on the chaparral type through their hunting, gathering of native plant fruits, nuts, and other material or through the simple agricultural practices they employed. Early-day explorers and trappers also made little impact.

A few years after the 1849 California gold rush had peaked, prospectors began to move eastward from California and elsewhere to the Arizona territory. In the early 1860's there were a few mining camps established within or near the Arizona chaparral. Army troops, prospectors, traders, trappers and others related stories of the fine grasses and ideal climate. Early in the 1870's a few cattlemen began to bring small herds of stock into the area. By 1890 there were a number of cattle and a few bands of sheep grazing on and near the chaparral country. Livestock numbers then increased rapidly and are believed to have reached a peak by 1900.

The first towns in or near the chaparral, such as Globe and Prescott, were settled by miners. A crude road and trail transportation system evolved to support these towns and mines. The wildlife was used by these early settlers to supplement their food supply. Fire in the chaparral occurred from time to time as it always had. Although man-caused fires increased, lightning-caused fires still accounted for most of the fires.

Early-day reports indicate that the chaparral was more open than it is today. The heavy, year-long grazing depleted the perennial grasses. Introduced annual grasses and forbs, typical of the Mediterranean area, largely replaced the native perennials that once grew in openings and the understory plants. The brush also has gotten thicker, influenced by fire suppression.

PRESENT USES

Today mining and cattle ranching continue to be important activities in the chaparral. The use of wildlife has shifted from subsistence hunting to recreational hunting. Deer and quail are the most sought game species. Road and trail access, with few exceptions, is still rather primitive. The towns have grown, but are still small by Southern California standards. Growth is attributed to a number of factors such as retirement, tourism, light industry and local government. Most recently, population is increasing rapidly.

There is one very important difference between the California and Arizona chaparral area as it relates to the pattern of settlement or the urban-wildland interface. Where California has extensive home building within the chaparral, there are few homes built within the type in Arizona. Where California has large metropolitan areas developed on the flats immediately below the steep brush covered hillsides, Arizona does not. Most of the land below Arizona's chaparral is undeveloped desert or semi-desert. The wildfires that denude the brushy hillsides set the stage for flooding. California has a higher and more concentrated rainfall than Arizona. This fact combined with the location of the developed areas in California, accounts for the major differences in damage from fire and subsequent flooding in California compared to Arizona.

RESEARCH

Early research by the USDA Forest Service was aimed primarily at grazing and erosion problems. Starting in the 1950's the research was expanded to study the feasibility of increasing water yields through modification of the chaparral. Research sites were established on the Tonto and Prescott National Forests. The sites represented conditions with different soils, climate and plant density and composition.

Most of the more recent research has been related to improving water yield. This research shows that the mean annual water yield from Arizona chaparral varies from less than 3 mm. per year on drier sites to 60 mm. on the wetter areas. Dry years produce little water, while wet years, particularly wet winters, may yield 20 percent of precipitation or more. A typical chaparral site with an average of 550 mm. of precipitation will yield 30 mm.

Water yields can be substantially increased by removing the deep-rooted shrubs and replacing them with shallow-rooted grasses and forbs that use less water. For example, that typical chaparral site with 550 mm. of annual precipitation will yield an on-site increase of 95 mm. following brush removal.

The effectiveness, costs, and effects on the environment which result from the different brush treatment methods have been a part of the research. Mechanical, chemical, fire and biological (grazing with goats) methods of removing brush have all been studied. The sprouting nature of the chaparral brush plants, and the steep, rocky nature of most of the type has made the use of herbicides a key element of past and current type conversion projects. Research to find an effective, safe herbicide continues to be an important part of the scientists task in developing a prescription for chaparral management.

RECENT PAST AND CURRENT MANAGEMENT

Land managers and owners started putting research findings to practical use on a small scale as the information became available. Serious efforts to convert chaparral sites to grass started in the 1960's. Relatively rock-free sites on gentle terrain were selected for root-plowing on the Prescott National Forest. The root-plow is a blade which is pulled by a tractor and cuts the brush roots off about 300 mm. underground. Grass seed is broadcast onto the newly disturbed area during the plowing operation. On the Prescott this operation increased grazing capacity for cattle by one-fourth of an animal unit month per acre.

The Tonto National Forest attempted to improve forage supplies and water yields through the use of prescribed fire and the use of herbicides. This method was successful when the use of herbicides was continued until the brush was removed. The phenoxy group (2,4-D; 2,4,5,-T; and silvex) were initially used but use was reduced after these herbicides became controversial. Soil active herbicides such as Fenuron and Picloram were also used to a limited extent.

Prescribed fire has been used to rejuvenate the brushland sites and temporarily improve the forage supply for both wildlife and livestock. This treatment results in improved range productivity for up to 10 years. The Prescott National Forest has used a roller-chopping implement to accomplish the same purpose. Grass and forb seed are also broadcast into the disturbed site. This treatment does not result in a type conversion but does introduce a more desirable forage which is available for a few years until the brush once again dominates the site.

Based on past research and land management practices, it is clear that the Arizona chaparral can produce more water, forage, and recreation than is currently produced. This increased production can be obtained by altering the chaparral site by various means. In 1978 a site was selected on the Prescott National Forest for a pilot application project. The current state-of-the-art would be applied to demonstrate how the chaparral type could be economically treated to improve production.

Structures and instruments have been installed at the Battle Flat demonstration area during the past two years to measure water and sediment yields and get water quality and climatic information. Special studies to obtain information on the geology, soils, vegetation, and wildlife have also been conducted. A proposed treatment plan is now being developed. In about 3 or 4 years, after the baseline pretreatment information is obtained, about 560 hectares of the 920-hectare watershed will be treated to convert the site from brush to grass and forbs. A brush-grass mosaic will be created. At this time it appears that a combination of fire, soil active herbicides, and broadcast seeding will be used to accomplish the type conversion in the most economical way. An adjacent 640-hectare watershed has also been instrumented to be used as a control for the treated watershed.

When the Battle Flat project has been completed, we will have a much better basis to predict what additional benefits can be obtained from the Arizona chaparral. It should be kept in mind that only a small portion of the 1.2 million hectares of chaparral can be treated. Some of the type is in wilderness and legally cannot be converted. Archeological sites are found on other areas and must be avoided. Some of the lower elevation, low rainfall sites have such a low potential for increased production that it is not economical to treat them. Other sites are so steep that mass soil movement would result if the brush cover were removed. The remaining, suitable area should be only partly converted to grass in order to maintain wildlife habitat and minimize the visual impacts. It has been estimated that only between 15 and 20 percent of the chaparral type on National Forest System lands in Arizona would actually ever be converted to grassland. The Bureau of Land Management, State and private lands are generally at lower elevation, less mountainous and drier then the National Forest segment. A somewhat higher percent may be suitable for conversion; however, herbage and water yields per acre would be less from most of these lands.

CONCLUSION

There are about 1.2 million hectares of chaparral in Arizona. The type has not been greatly modified by man's activities to date, with the exception of the impact of grazing on the herbaceous component. Planned site modifications have been very limited, and have been mostly confined to the better sites and to research-related activities.

Management direction on the National Forests has been to gain more information on the techniques and effects of treatment, and to apply this known information on a small scale. The fact that the chaparral type has the potential to produce more water, forage and recreation, primarily as hunting, is well known. The biggest restraints against site modification have been economics and the need for an effective, safe herbicide. I believe that we now have or will soon have an effective herbicide. High costs are still a problem.

Future management direction could abruptly change should new, more economical ways be found to harvest and process this woody material into such things as fuel or processed livestock forage for off–site use. Until such time as these new uses are found, I see a continuation of the past trend, i.e., slowly find new and better ways to convert or modify the site and implement these techniques as they become economical.

Perspectives of Managing Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Serena C. Hunter[2]

One of the principal objectives of this symposium was to provide a forum for exchange of information on a multinational scale. The purpose of this session, held on the opening day of the symposium, was to provide the participants with an overview of how Mediterranean-type ecosystems are being managed around the world. Each of the speakers in this session represented a different region; together, they covered the Mediterranean-type ecosystems on five continents. The speakers were asked to relate the following information for the regions they represented: (1) Object of Management, (2) history of Vegetation and Perception, (3) Constraints on Management, and (4) Role of Research.

Although some of the speakers did not address these four issues directly, all spoke on management issues they felt were important in their regions. It was possible, then to extract from these presentations some, if not all, of the important management objectives, constraints, and research interests in each region.

Management Objectives

Maintenance or improvement of grazing land was one of the management objectives mentioned most often by our speakers (Bolander, Canas and others, Carrera and others, Kruger, Naveh, Tyrrel, these proceedings). Most mentioned problems with overgrazing and some mentioned efforts at type conversion to increase pastureland acreage or cultivation to increase productivity. The other most often mentioned objective of management was recreation (Bolander, Carrera and others, Naveh, Shea, Tyrrel, these proceedings). Surprisingly, recreation was mentioned more often even than watershed protection (Bolander, Carrera and others, Kruger, Shea, Tyrrel, these proceedings) although most speakers implied that watershed maintenance was of utmost importance. Aesthetics (Kurger, Naveh, Shea, Tyrrel these proceedings), nature conservation (Kruger, Naveh, Shea, Tyrrel, these proceedings), and site rehabilitation (Canas and others, Carrera and others, Naveh, and Shea, these proceedings) were considered important enough to be mentioned by four of the seven speakers. within the area of nature conservation, Kruger, Naveh, and Tyrrel expressed the need to maintain or increase species diversity. Also in the interest of nature conservation, Kruger discussed the need to control invasive exotics and to limit commercial wildflower harvesting in South Africa. Timber (Shea, these proceedings), fruit (Canas and others, these proceedings), and energy (Naveh, Tyrrel, these proceedings) production and mining (Bolander, Shea, these proceedings) were objectives to be managed in some regions.

Land Use history

The histories of the Mediterranean-type ecosystems discussed during this session make an interesting comparison. The conditions of the ecosystems seem to be related to the length of time since settlement of the land and the extent of population pressure on the land. The ecosystems in the Mediterranean countries are in perhaps the most altered condition. The mountains and hills of Spain for example, have been grazed by sheep and goats for 3,000 years. Many forests there, long ago harvested and repeatedly burned, have been eliminated or degraded (Carrera and others, these proceedings). Mediterranean-type ecosystems in the United States, South Africa, and Australia, on the other hand, have been occupied by European settlers for much shorter periods of time and show less severe ecological effects. However, the nineteenth and twentieth centuries have been a time of rapid change and booming population growth around the world. During this period, fire regimes have been altered, plant material has been exchanged between continents, and large-scale lumber harvesting and mining have taken place. There is the potential for bringing about severe ecological change in much less than the 3,000 years it took in Europe.

All of our speakers seemed to be well aware of the effects of past land use practices on the ecosystems in their regions and in others. Theoretically, at least, some important lessons have been learned. The speakers also noted the importance of determining possible ecological effects of new or current management techniques such as frequent low intensity prescribed burning (Kruger, these proceedings), type conversion (Bolander, these proceedings), and thinning (Shea, these proceedings).

Constraints on Management

The speakers in this session discussed social, political, biological, and informational constraints to managing the Mediterranean-type ecosystems in their regions. Land ownership patterns (Canas and others, Naveh, Tyrrel, these proceedings); urban, industrial, and recreational encroachment (Carrera and others, Naveh, Shea, Tyrrel, these proceedings); and public ignorance and attitudes resulting in overgrazing and wildfires (Carrera and others, Naveh, these proceedings) are some of the social constraints experienced by resource managers. Political

[1]Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-2b, 1951, San Diego, California.

[2]Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

constraints included overlapping jurisdictions by public agencies (Tyrrel, these proceedings), legal constraints (Carrera and others, these proceedings), and lack of financial support (Bolander, Carrera and others, Naveh, these proceedings). Factors affecting plant establishment and growth were fire (Carrera and others, Naveh, Shea, Tyrrel, these proceedings), air pollution (Naveh, these proceedings), pests (Naveh, Shea, these proceedings), and the already degraded condition of some areas (Carrera, Nave, these proceedings). All speakers acknowledged that lack of scientific information limits management success.

Role of Research

Regional differences were more evident among our speakers on the subject of what questions should be addressed by researchers. The subject of ecosystem structure (past and present) including plant and animal interactions was emphasized by Canas and others, Kruger, and Naveh (these proceedings). Naveh, of Israel, was quick to point out that he considered "classical", down-to-earth field studies of greater value than "pretentious, expensive and, alas, mostly very theoretical, far-fetched ecosystem studies aimed at creating the very fashionable, not very realistic, mostly deterministic, 'ecosystem models'." Some areas in which he saw a need for practical research were in (1) developing "ecotechniques" for managing existing plant cover; (2) finding suitable plants and methods for afforestation projects; and (3) quantifying landscape values.

Several speakers in this and other sessions indicated the need for more research involving the socioeconomic factors affecting management of Mediterranean-type ecosystems (Carrera and others, Fuentes, Naveh, Tyrrel, these proceedings). New approaches are needed in which the conservation, rehabilitation, and use of these ecosystems can be reconciled with socioeconomic advancement of the population (Naveh, these proceedings). This is especially important in developing countries such as Chile where the welfare of the people is tied so directly to the land. It is also important in highly populated areas such as southern California and southern Europe where demands for wildland products often conflict.

Other research areas mentioned were patterns and trends in land use (Carrera and others, Kruger, these proceedings), hydrological or nutrient cycling or both (Bolander, Carrera and others, Shea, these proceedings), fire behavior (Kruger, these proceedings), ecology of invading species (Kruger, these proceedings), meteorology (Carrera and others, these proceedings), site classification (Shea, these proceedings), desert control (Carrera and others, these proceedings), and development of safe, effective herbicides (Bolander, these proceedings). In Chile, research efforts are being focused on improving both natural and cultivated pasturelands (Canas and others, these proceedings).

RECURRING THEMES

Although the Mediterranean climate regions of the world differ in some significant botanical, sociopolitical, geologic, and climatological features, they obviously have a lot in common. It is these common features that justify an international symposium such as this one. Several recurring themes appear in some or all of the papers of this session. The remainder of this summary paper will be a discussion of some of these shared concerns and interests. I have taken the liberty of including and interpreting parts of each speaker's contribution.

Human Population Pressures

The problems brought on by too many people and not enough resources are evident in southern California, Chile, and the European countries bordering the Mediterranean Sea. Although competition among land uses also occurs in Australia and South Africa, population pressures on the land are not nearly so acute in these regions. The problem in Arizona has been relatively minor in the past, but is increasing rapidly as more people move out into the wildlands.

In southern California, 13 million people live in, adjacent to, or in the valleys below chaparral-covered hills and mountains. These people require protection from fire and resulting floods. They also need fresh water, varied recreational opportunities, and protection for native wildlife. The aesthetic value of southern California's wildlands to its urban population is difficult to assess, but based on recorded visitor use of public lands, it is high (Leisz, these proceedings). The "people" dimension of chaparral management is becoming more and more important in southern California.

The ecosystems of the southern European countries have been subjected to centuries of excessive tilling, grazing, timber harvesting, man-caused fire, and numerous wars. The result is that the soils are heavily eroded on many sites, and the plant communities are drastically changed. Increases in rural and urban populations, road building, tourism, and mass recreation continue to take their toll. Efforts are being made to improve the situation through reforestation, public education, and regulation, but improvement is difficult where serious site degradation has already occurred (Carrera and others, Naveh, these proceedings).

In Chile, the principal use of the drier upland ecosystems is grazing. As a result of Agrarian Reform (1965-1973), the land has been divided into many small ownerships, making traditional movement of stock between ecosystems at different times of the year impossible. This has caused overgrazing of the annual grasslands and grazing during the time of year when seed should be produced. Overgrazing favors development of the matorral (brush) rather than the more palatable annual herbs.

Chilean researchers recognize the human need to protect anti improve the pastureland of their region (Canas and others, these proceedings).

Need to Understand Fire behavior and Effects

Fire is an important factor in most Mediterranean-type ecosystems. Low rainfall, strong winds, steep terrain, and highly flammable vegetation generate some of the world's most dramatic wildland conflagrations. Many Mediterranean-type ecosystems are characterized by a fire cycle and depend on fire to retain long-tern vigor. However, fire seems not to have been part of the natural situation in Chile (Fuentes, these proceedings).

Because fire is such an intimate part of most Mediterranean-type ecosystems, researchers and managers recognize the need to better understand its role. They want to know how fire behaves under various fuel, weather, and topographic situations. They also want to know what effects fires of various intensities and frequencies, taking place during various seasons of the year, have on the ecosystem. There is research of this type going on all over the world (Albini and Anderson, Barber, Delabraze and Valette, Green, Kruger, Trabaud, Vélez, these proceedings).

Interest in Prescribed Fire

The Australians were the first to recognize that a policy of strict fire exclusion and suppression would not work in a Mediterranean-type ecosystem adapted to fire. In the early 1950's, they began a program of periodic low—intensity pre—scribed burning to reduce fuels in the jarrah forest (Shea, these proceedings). Shea suggests that a change in the prescribed burning regime in the jarrah forest may now be wise. Moderate—to-high intensity fire would reduce the density of the understory species banksia grandis, replacing it on some sites with leguminous species. Banksia grandis is highly susceptable to and is a major contributor to the spread of the soil—borne fungus Phytopthora cinnamomi bonds which causes "Jarrah Dieback."

Prescribed burning in South Africa's fynbos began in the late 1960's. burning rotations range from 10 to 20 years depending on site and vegetation characteristics (Kruger, these proceedings).

Chaparral managers in southern California have recognised for some time that a policy of fire exclusion and suppression has contributed to the buildup of wildland fuels, but with southern California weather, fuel, and population conditions, prescribed tire was considered by the Forest Service to be too risky a method of reducing fuels. Although ranchers have been burning with permits for some 30 years, not until the last 5 years or so with the development of more sophisticated equipment such as the helitorch and more refined prescribed burning directions (Green 1981) has the practice of prescribed burning become acceptable on National Forest lands. There is now a widespread interest in continuing development of safe, low-cost burning techniques for use in the chaparral (Bungarz, Green, Rogers, these proceedings).

In the Mediterranean countries of Europe, uncontrolled burning in the past is credited with the degradation of many ecosystems. This is one reason why prescribed fire has not been used routinely in some of these countries. But, as fuel buildups increase, these countries too are showing an increased interest in controlled burning. At least limited burning, for research purposes or to maintain fuelbreaks, has been done in France (Delabraze and Valette, these proceedings), Italy (Susmel 1977), Greece (Liacos 1977), and Israel (Naveh, these proceedings), and Spain (Velez, these proceedings).

No matter what the extent of prescribed fire use in the various Mediterranean-type regions of the world, there is a continuing interest in improving its use. Answers to problems such as how often to burn, with fires of what intensity, and during what seasons require refinement even in Australia and South Africa.

Attempts at Type Conversion

The highly flammable sclerophyllous shrubs characteristic of many Mediterranean-type ecosystems have not endeared themselves to land managers. In some areas such as Chile and Spain, the shrubs have invaded abused grassland or forests making them less useful for grazing or wood production. In other areas such as the chaparral ecosystems of southern California, shrubby vegetation is the fire climax type. In every region, attempts have been made or are being made to convert less desirable vegetation types to more desirable ones. The desirability as well as the success of these attempts are subjects of debate.

In Israel, controlled burning of shrubs followed by reseeding with perennial grasses has been carried out to increase grazing potential. However, maintenance of these areas by frequent fire or chemical treatments tends to be either too expensive or not ecologically sound.

To stabilize badly depleted upland sites. Israeli foresters began several nears ago to establish Pinus halepensis plantations. Although these plantings have provided wood fiber and recreation, the economics of such plantings are questionable. Fire prevention and suppression expenses have increased, and many trees have been lost to fire (Naveh, these proceedings).

The current trend in Israel is toward establishment of "multilayered, seminatural park—forests, resembling the richest semiopen maquis in structure and stability out being of much greater ornamental, recreational, and economic value"

(Naveh, these proceedings). Time will tell whether this seemingly more natural approach to vegetation manipulation is successful.

In the province of Almeria in southeastern Spain, ICONA foresters are attempting to reestablish holly-oak (Quercus ilex) forests on highly eroded sites where cutting and grazing have reduced the oak to a bushy form (Carrera and others, these proceedings). They are regenerating the stands by a combination of sprouting and, in the areas without bush, planting and seeding. Carrera and his coauthors gave no indication of how long this project has been underway, but apparently it has been successful thus far. Many pine and Quercus suber plantations have also been established in the southern provinces of Spain.

In his discussion of the jarrah forests of Australia, Shea (these proceedings) did not discuss type conversion attempts. He did mention, however, the thus far unsuccessful attempt to locate a salt-tolerant tree species suitable for planting in forest areas where the native jarrah has succumbed to dieback. The introduced species would need to be resistant to the disease-causing fungus Phytopthora cinnamomi Rands.

Canas and others (these proceedings) discussed the advantages of converting natural annual pastures to cultivated pastures. Five or more times as much dry matter can be produced on seeded and irrigated land than on natural pastureland. At present, 85 percent of Chilean pastures are natural. Canas and his coauthors did not indicate to what extent irrigation might be feasible in Chilean pasturelands or where the water for irrigation would come from. They did note, however, that farms in the lowlands with better access to irrigation had converted from stock production to the more profitable production of fruits or other crops.

The concept of removing southern California's chaparral and replacing it with grasses was developed and began to be implemented in the late 1950's. These type conversions were designed to reduce the amount of wildland fuel, to increase watershed productivity, and to increase grazing land. The high costs of converting to grass and increasing concerns about the use of herbicides for brush control have contributed to a decrease in type conversion activities in southern California. Bolander (these proceedings) indicates that conversion of chaparral to grass and forbs may be feasible in Arizona. There, rainfall occurs in the summer as well as the winter providing a more hospitable environment for grasses and forbs than in southern California.

Attempts have also been made to convert southern California's chaparral to forest. Many of these plantings have failed. Even those trees able to tolerate the drought conditions and poor soils have often been killed by the frequent wildfires of the region (Radtke 1978).

Some small-scale site conversions in southern California and Arizona have been carried out to grow jojoba (for oil production), guayule (for rubber production), and other useful plants.

The increased pressures brought on by populations increasing in number and mobility, the need to better understand fire and vegetation relationships, the increased interest in prescribed fire, and the desire to make changes in the vegetation type are just a few of the common concerns or interests expressed by the international speakers in this session. Others were: (1) an interest in the history of the land; a desire to know what the "natural" fire frequency and vegetation type should be; (2) a recognition of the environmental movement that became vocal during the 1960's and has continued to influence land management activities; and (3) an emphasis on the need for integrated and planned resource management involving input from many disciplines; an interest in modeling.

CONCLUSIONS

The world we live in becomes smaller every day. Long distance communication and travel become faster and simpler.

A shrinking world offers advantages and disadvantages to our international efforts to understand and manage Mediterranean-type ecosystems. Managers in Australia's jarrah forests have learned already the disadvantages of international exchange--they must deal with the imported pathogen Phytopthora cinnamomi. In Arizona and California, native perennial grasses and forbs are commonly not able to compete with imported annuals. A similar battle with exotics is going on in South Africa. Damaging photochemical air pollutants produced in Europe, California, and other regions of the world cannot be expected to respect political boundaries.

But, there are advantages to our increased mobility and communicative abilities too. New technology, such as that relating to prescribed fire, developed in one part of the world can be made available to other countries without lengthy delays. There should be less duplication of research activities and fewer repeated mistakes. Beneficial exchanges of plant material will continue. For example, in their search for a salt-tolerant, disease-resistant tree to plant in areas where "Jarrah Dieback" is occurring, the Australians are not limited to a native Australian species. They may find an exotic species best suited to their needs.

It is important that we work towards a goal of improving management of Mediterranean-type ecosystems and recognize that the world is small. We must be ready to take advantage of the opportunities that improved communications and mobility can bring, and be ready to cope with new problems as they arise.

LITERATURE CITED

Green, Lisle R. Burning by prescription in chaparral. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981; Gen. Tech. Rep. PSW-51. 36 p.

Liacos, Leonidas G. Fire and fuel management in pine forest and evergreen brushland ecosystems of Greece. In Mooney, Harold A.; Conrad, C. Eugene, eds. Proceedings of the symposium on environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. WO-3; 1977; 289-298.

Radtke, Klaus. Wildland plantings native and exotic 1911-1977. Los Angeles: County of Los Angeles Department of Forester and Fire Warden; 1978; 135 p.

Susmel, Lucio. Ecology of systems and fire management in the Italian Mediterranean region. In: Mooney, Harold A.; Conrad, C. Eugene, eds. Proceedings of the symposium on environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. WO-3; 1977; 307-317.

Vegetation

Vegetation

Classifying Mediterranean Ecosystems in the Mediterranean Rim Countries and in Southwestern U.S.A.[1]

Marcel Barbero and Pierre Quezel[2]

Abstract: Methods of classifying ecosystems have developed differently in Europe and America. Individualization of bioclimatic zones and of altitudinal levels proved most valuable, particularly the role of edaphic factors. This methodology can be associated with the vegetation series concept, that is, a succession of community types which, within a given altitudinal level and bioclimatic zone, and for specific edaphic conditions, leads to establishment of the climax community. Man's impact in these theoretical schemas can be directly considered. The methodology is open to numerous applications.

Methods of classifying ecosystems, in particular forest ecosystems, which represent the most evident vegetation structures, have developed in a very different manner in European and Anglo-saxon countries. It is of interest to compare the methods used in the countries bordering the Mediterranean Sea and in Mediterranean California. We shall not discuss again the physiognomic and climatic analogies existing between both regions (cf. Di Castri and H. Mooney 1973), and shall only try to retrace the development of the methods of classifying ecosystems in both regions.

In the circum-mediterranean area, the study of vegetation started very early, but since the beginning of the present century it has taken two clearly different directions :

– Physiognomic studies of plant communities - the global study of vegetation landscapes and of their relationships in space, following especially the works of Flahault (1897) and Gaussen (1926).

– Phytosociology - the analysis of plant associations based essentially on floristic relevés, and seeking also to define the ecological and dynamic relationships existing between the various associations, a methodology initiated by Braun-Blanquet (1932). Throughout the 20th century, both methods, originally considered as difficult to reconcile, have in fact been the basis of all attempts at classifying ecosystems, though other techniques were elaborated all over the world: ecological groupings, quantitative studies, transect methods, theoretical models.

In California, as in the whole United States, methods of classifying ecosystems have nearly always been founded on physiognomy. There has been very little change between Cooper's studies (1922) and the recent synthesis by Barbour and Major (1977); the interpretations and the vegetal communities described remain physiognomic and are mostly defied in relation to dominant species. It should be emphasized that the methods of field study, even using relevés (quadrat or linear), are extremely diverse in the United States, practically each author using his own particular method. American, especially Californian, phytogeographers have often engaged in sometimes quite sophisticated ecophysiological or autoecological studies, which, in spite of their obvious interest, can not be used as classification methods for ecosystems.

For some ten years, phytogeographers of the Mediterranean countries in the Old World have tried a more synthetic approach to the problems raised when defining or classifying ecosystems, together with a more practical analysis of the problems, which could easily help in ecological planning or management. Purely physiognomical methods allow us to apprehend but a small part of the ecological facts, and still, in a very artificial manner. In Morocco, for example, the ecosystem "sclerophyllous forest with *Quercus rotundifolia*" that corresponds to an homogeneous physiognomic unit can be found between 500 and 3000 m altitude, under annual precipitation varying between 500 and 2000 mm and with mean temperatures ranging between 5 and 17° C. In this case, a classical phytosociological approach provides valuable complementary information by distinguishing in this whole, several syntaxonomic units characterized by floristic criteria as well as specific and edaphic requirements.

However, it is quite obvious that in the Mediterranean countries of the Old World, strictly physiognomical and phytosociological methods are now exhausting their scope of application. Nevertheless, in spite of its constraining character (numerous relevés are necessary together with an excellent knowledge of the flora), the phytosociological method has made it possible to go very deeply into the analysis and classification of great ecosystems, to determine their respective relationships and to establish ecological or dynamic analogies between geographically disjoined structures. Most of these results could not be obtained by a purely physiognomical method, and it is to be regretted that this type of approach is only just beginning in North America (Looman 1980; Campbell 1980).

It has been shown recently (Barbero and Quezel 1981) that the phytosociological method remains one of the best means of approaching planning or zoning problems on a small scale (cf. infra) provided that a more detailed conception of vegetation structures is adopted taking into account the heterogeneousness of stations from a geomorphological, geopedological and climatic point of view. This technique

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

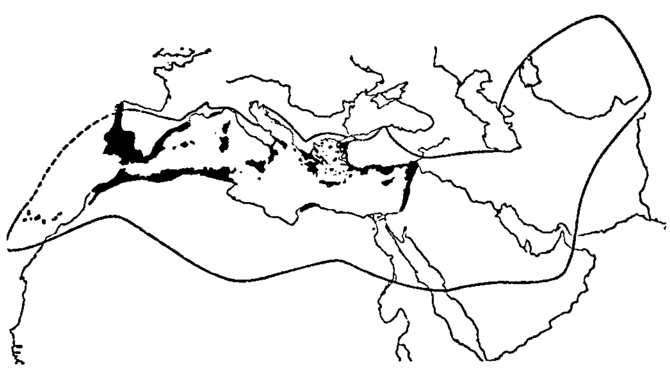
[2]Université d'Aix-Marseille III, Centre de Saint-Jérôme, Laboratoire de Botanique et d'Ecologie Méditerranéenne, 13397 MARSEILLE/CEDEX 4.

gives a preponderant place to relevés that are often limited but correspond to homogeneous ecological criteria. Therefore, one of the simplest and most significant solutions, to classifying ecosystems is to establish correlations between ecological and dynamic approaches, the analysis of vegetation structures being made through numerous phytosociological relevés (Braun-Blanquet 1952 ; Godron et al., 1968).

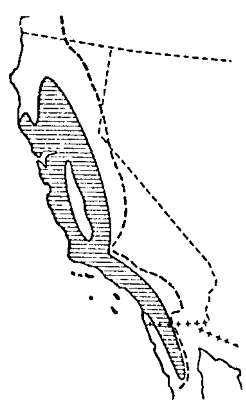
The major interest of the method is to provide a large sum of information with many possible applications, but also to render the results obtained by different authors compatible from the point of view of typology and ecological and dynamic characterization as well as from the point of view of analytical interpretations.

THE ECOLOGICAL APPROACH

The ecological approach relating to classification methods for ecosystems at a small scale in the Mediterranean countries cannot be but a global one. No doubt that at this stage the major ecological factors are connected with the climate, since all the Mediterranean areas in the world are essentially, and even exclusively, defined by this type of character. But climatologists and bioclimatologists of the Old World, as well as those of California, are far from having the same idea of the mediterranean climate. Though in the Old World most ecologists or biogeographers are agreed in making the limits of the mediterranean climatic region coincide, at least approximately, with those of the



Limits of Mediterranean Isoclimatic Area (DAGET, 1977); Black : Limits of the Mediterranean Region (ASCHMANN, 1973).



Hachured : True Mediterranean Climate (ASCHMANN, 1973); Packed line : Limits of the California floristic Province (RAVEN & AXELROD, 1977).

floristic Mediterranean region, the same does not hold true concerning California, as appears from interpretation of limits usually acknowledged for both units by climatologists (Aschmann 1973) and biogeographers (Raven & Axelrod 1978).

The climatic criteria

The criteria established in order to define the Mediterranean climate are alas ! not evident, though certain characters such as summer drought are unanimously admitted. It seems that De Martone (1927) was the first to define the mediterranean climate as a temperate climate with an undistinguishable winter, pertaining to the sub-tropical zone and characterized by a cold temperate (average temperatures for the coldest month > 5° C) and humid season, and by a hot and dry season (average temperatures for the hottest month > 20° C). Let us mention the definitions given by Koppens and Geiger (1936), Gaussen (1954), Trewartha (1954). The results obtained concerning the delimitation of the Mediterranean climatic region, though different, are more or less similar. The criteria acknowledged by North American climatologists, in particular Aschmann (1973), in defining the Mediterranean climate in California are distinctly more restrictive (annual rainfall between 275 and 900 mm out of which at least 65 % occurs in winter, and average monthly temperature 7 1° C), thus contracting the limits of the Mediterranean region in the Old World, position contradictory to the observations concerning vegetation structures. Only one climatic criteria has been admitted by all authors when defining the Mediterranean climate: the presence of a dry period within the hot season, that is to say, the existence of a period when the vegetation needs more water for its survival and development than the supply it receives. Thus, a climate is considered to be of the Mediterranean type when it fulfills the following conditions summer is the dryest season; there is a period of effective drought.

The bioclimatic criteria

Water balance is unfortunately a quite complex problem requiring delicate apparatus and experiments. Theoretically, the results obtained after Thornthwaite coefficients (1948) constitute the best method. They are generally used, especially in English-speaking countries, and a global approach to the problem in California is made by Major (1977). This method is also practised in the Mediterranean countries in the Old World, but it has been the subject of various critics, and finally it does not seem to be more accurate than other empirical methods. In the Mediterranean rim countries the coefficients defined by Emberger (1930) and Bagnouls and Gaussen (1953) are generally used by biologists and bioclimatologists. The most comprehensive attempt is represented by the bioclimatic map of the Mediterranean zone, and its analogues in the world, published by U.N.E.S.C.O. (1963). From the thermal criteria standpoint, Bagnouls and Gaussen are excluding from the Mediterranean climate the zones with a monthly average temperature under 0° C; American authors have a more restricted position. This restriction certainly explains the numerous confusions and doubtful classifications of the Mediterranean climate, leading to its limitation to juxta-littoral parallel strips, with mild winters. This does not correspond to any biogeographic reality and leaves out vast zones where flora and vegetation are still unquestionably Mediterranean. If we admit that there are no limits to thermal minima when individualizing the Mediterranean bioclimates, we can then distinguish a whole scale of ecologically evident thermal variants (Emberger 1939).

The bioclimatic zones

In the same way, all the bioclimatologists working on the Mediterranean bioclimate have also defined, in relation with increasing humidity, diverse zones for which the terms mostly used are: arid, semiarid, subhumid and humid (Emberger 1930; Thornthwaite 1948). These facts have recently permitted Daget (1977) to define an isoclimatic Mediterranean area corresponding to the whole north tropical territories of the Old World characterized by a Mediterranean type bioclimate. For example, Emberger's bioclimatic coefficient ($Q2 = 2000 P / M^2 - m^2$) in which P is the annual rainfall in mm, M the average maxima of the hottest month, m the average minima of the coldest month, is a quite classic concept. The values of P are of course decisive, and some authors (Le Houerou 1971) tried to use P and not Q2 for delimiting bioclimatic zones. Presented hereafter is the hierarchization and its schematic equivalents generally admitted in the Mediterranean region.

Bioclimatic types :	Q2	P (in mm and for the cool variant)
perarid	< 10	< 100
arid	10 to 45	100 to 400
semiarid	45 to 70	400 to 600
subhumid	70 to 110	600 to 800
humid	110 to 150	800 to 1200
per-humid	> 150	> 1200

In each of these bioclimatic types it is possible to distinguish thermal variants, defined in relation with the values of m (senso Emberger). The generally admitted limits (Daget 1977) are the following :

Variant	Values of m
very hot	> 10° C
hot	7 to 10° C
temperate	3 to 7° C
cool	0 to 3° C
cold	-3 to 0° C
very cold	-7 to -3° C
extremely cold	-10 to -7° C
icy	< -10° C

The combination of the bioclimatic zones and their climatic variants make it possible to establish a diagram—the climagram—(Emberger 1933) now classic in Mediterranean phytogeography.

Altitudinal levels

Following the works of Flahault (1901), Gaussen, (1926), Quezel (1974), Ozenda (1975), it is now conventional to distinguish in the Mediterranean region a schematic altitudinal arrangement of species and vegetation types corresponding essentially to thermal criteria. The following levels are generally distinguished:

– an Infra-Mediterranean level corresponding in western Morocco only to the Macaronesian zone with *Argania spinosa* and *Acacia gummifera*;

– a Thermo-Mediterranean level, extending all over the circum-Mediterranean area, made up of sclerophyllous formations with *Olea-Ceratonia*, *Pistacia lentiscus*, *Pinus halepensis*, *Pinus brutia* and *Tetraclinis articulata*;

– a Meso-Mediterranean level mostly constituted by sclerophyllous forests of *Quercus ilex* and *Q. rotundifolia* in western and central Mediterranean, and of *Q. calliprinos* in eastern Mediterranean. In this level *Pinus halepensis* and *Pinus brutia* forests are paraclimax ;

– a Supra-Mediterranean level which is the elective domain of deciduous forests within the humid bioclimate, replaced in subhumid and even semiarid bioclimates and in southern Mediterranean by an upper-Mediterranean level dominated by sclerophyllous oaks ;

– a Mountain-Mediterranean level, grouping essentially highlands coniferous formations (*Cedrus*, *Pinus nigra* and the Mediterranean firs) ;

– an Oro-Mediterranean level, often made up of grazed greens of thorny xerophytic garrigues with sparse arborescent *Juniperus* ;

– an Alti-Mediterranean level hardly distinguishable but on the Atlas or the Taurus, where only scattered dwarfed Chamaephytae can develop.

Sythetic climagrams

In the countries bordering the Mediterranean, the distinguishing of bioclimatic zones and altitudinal levels proved to be most valuable in defining and classifying ecosystems. Botanists and forest people can thereby individualize plant groupings, the ecological requirements of which can easily be represented on a climagram. The studies carried on for some ten years have shown that this state of facts is generally found and that each climacic forest association nearly always corresponds to one or several divisions of the climagram. This was confirmed in particular in Greece (Barbero and Quezel 1976) in Mediterranean Anatolia (Akmann, Barbero and Quezel 1978, 1979), in Lebanon (Abi-Saleh 1978) and in Morocco

(Achhal et al. 1980). We should not overlook the role of edaphic factors, which are of particular importance to evidence secondary divisions within the great bioclimatic systems. The results obtained with this method in Crete (Barbero and Quezel 1980) are particularly suggestive.

In Mediterranean California, phytogeographers and ecologists have never considered this approach; they did not proceed further than a global physiognomic approach of great systems. Let us note, however, that Whittaker (1951) and Whittaker and Niering (1965) have proposed an altitudinal zonation of vegetation based upon relevés, which at least permits a comparison with the above-mentioned conceptions of European authors or with the more recent diagrams established by Rundel et al. (1977) in the Sierra Nevada forests.

THE DYNAMIC ASPECTS

The first synthetic interpretation of the dynamics of this vegetation is probably that given by Braun-Blanquet in his work on the *Quercus ilex* forests of Languedoc. There he adopted the concept of "vegetation series" as previously defined, particularly by Flahault (1897), and placed it within the phytosociological context. This notion of "dynamic series" is of ever-increasing importance in phytosociology at the present, since it constitutes a major connecting element in any attempt to interpret the development of vegetation. A vegetation series may be seen as a succession of community types which, within a given region, in a given altitudinal level and bioclimatic zone and for given edaphic conditions, leads to the establishment of the climax community. The succession can be either progressive or regressive, reversible or irreversible according to the case in point. The more classic schema of succession in the Mediterranean-type ecosystems with humid or sub-humid climate and at the mesomediterranean level is the following : annual grassland → perennial grassland →scrubs → pre-forest formations → climacic forest. Some of these terms should be explained:

– under the name of "scrubs" are grouped dense structures made up of erect, 30 to 200 cm high chamaephyts for which the term "matorral" is also currently used instead of "maquis" or "garrigue" which have a more restrictive connotation (Tomaselli 1976) ;

– under the name of pre-forest are defined structures mainly composed of Phanerophyts with still abundant Chamaephyts on azonal soils and susceptible to develop naturally into typical forest formations ;

– under the name of forest we mean here dense, usually climacic formations with Phanerophyts on mature (zonal) soils and with a generally herbaceous lower stratum.

It should be noted that this schema is only valid for humid and subhumid bioclimates, yet without their dynamic variables "very and extremely cold". Under the semiarid climate (from cool to very hot), the succession, except for meso- or microclimatic compensations, comes to a standstill with pre-forest formations, mostly with *Pinus halepensis*, *Pinus brutia* or *Tetraclinis articulata*, but sometimes also with sclerophyllous or deciduous oaks. Moreover, under arid bioclimate as a whole, and also under the cold, very cold or extremely cold variables of other bioclimates, succession hardly proceeds further than the stage of scrubs (matorral or steppe) or that of pre-steppic forests when human action is still weak. Let us state that the pre-steppic forest consists of widely scattered and generally not well grown trees among which Juniperus species often play an important part ; practically no significant accompanying forest species can be found in the lower stratum.

Under the conditions described above — the same geographical region, the same altitudinal and bioclimatic zones, the same edaphic conditions and substrata — only one vegetation series can occur. Conversely, for a given region, even if relatively small, if these same criteria vary, different vegetation series can be distinguished. From this viewpoint, the example of Lebanon is particularly significant (Abi-Saleh 1978).

Vegetation dynamics and man's action

In the above-described theoretical schemas and classifying systems, man's impact has not been directly considered; no need to recall its drastic impact on the totality of the circum-mediterranean ecosystems (Pons and Quezel 1980). Cattle breeding and cultivation began in the Near-East more than 10,000 years ago; they extended in Crete or Greece towards 8000 B.P. and in western Mediterranean around 7000 B.P. In spite of its importance human action on Mediterranean vegetation did not bring any catastrophic modifications, until the 19th century. The situation was entirely modified towards the first half of last century, essentially owing to the breaking off from traditional exploitation techniques (mechanization), to the considerable increase of population and to new habits of modern society. It is quite obvious that any attempt to interpret and classify Mediterranean ecosystems should attach the utmost importance to these events.

A particularly important problem in the vegetational dynamics and evolution is that of fire, and it seems difficult not to evoke it here considering the particular part assigned to it by numerous authors in the countries with a Mediterranean climate (Hanes 1971 ; Le Houerou 1973 ; Naveh 1974).

In the Mediterranean French region, several works allow us to propose a seemingly quite realistic schema concerning the role of fire in the "garrigue languedocienne" (Trabaud 1980). This dynamic schema is consistent with the recent conceptions of numerous authors regarding the dynamic significance of "matorrals". But in California, phytogeographers and ecologists think that "chaparrals" generally constitute climax groupings for which an evolution into forest structures cannot be considered. We have previously (1979) presented our point of view about the question. However, let us recall that some authors (Patric and Hanes 1964) consider the possibility, at least locally, of an evolution of chaparral into forest. No doubt, a study carried out on the basis of the above-described model would make it possible to determine their dynamic potentialities.

METHODS OF CLASSIFYING ECOSYSTEMS AND THEIR APPLICATIONS

This methodology is not purely analytic or descriptive ; it opens directly on numerous applications. The major ones will be presented here.

Cartography

Instead of a simple physiognomic representation of vegetation, dominant species or vegetal associations, cartography allows us to establish "series of vegetation" and it leads thus to a cartography of potential structures showing not only the vegetational dynamics but also its ecological signifiance in relation with climatic, altitudinal or even edaphic criteria. This technique makes it possible to estimate in a fairly precise manner the forest or agronomic potentialities and to propose, on the basis of a simple field experimentation, management solutions forest techniques, choice of species for re-afforestation, delimitation of re-afforestation areas, and best utilization of soils. In California, where an analysis of the different methods utilized has just been made (Calwel 1977), it has proceeded no further than a representation of the prevailing forest trees or of the major physiognomic vegetation structures, generally delimited thanks to air or satellite photographs.

Analytical methods and biological indicators

The various methods of numerical analysis have been used very early by phytoecologiste in the Mediterranean countries of the Old World as well as in America mostly from phytosociological relevés and for miscellaneous purposes. These methods allow us to confirm (in most cases) or to invalidate the conclusions derived from the interpretation of vegetational structures. But they also make it possible to evidence a whole series of species or groups of species indicating ecological or dynamic criteria. According to the floristic and ecologic characters in a given region (Barbero and Quezel 1981) and for each dynamic series of vegetation, stability, change or compensation indicators (Ammer 1976) can easily be defined, which are also related to such and such climatic or pedologic factors : they are bioclimatic indicators.

Ecological zoning

The ecological zoning is widely practised in Europe (Long 1974) and in North America (Mc Harg 1971) ; it is considered as absolutely necessary to any serious realization of management planning. The above described method of classifying ecosystems, combined with cartography techniques and with the help of biological indicators can lead to concrete propositions of zoning on a small or medium scale. The ecological zoning must essentially take into account the following points:

- the ecological diversity of the environment, which can easily be apprehended thanks to the phytoecological methods just described ;
- the edaphic potentialities, which must be properly defined according to the objects aimed at (new cultivation of land, establishment of a productive forestry, extension of pasture land) ;
- the search for biological indicators which may bring valuable information : bioclimatic indicators such as the phenology (blossoming) of certain species with the prospect of a mesoclimatic zonation; potentiality indicators in order to define the environmental capacity and how to improve it (re-afforestation, pastoralism, biomass, etc ...;
- estimation of the biological and economic value of vegetation structures, with a view to protecting soil, development of marginal areas and the way for man to exploit them without neglecting preservation problems with regard to ecosystems as well as the genetic capital.

This approach, which constitutes the logical and practical issue of any attempt at classifying ecosystems, seems to be the only means to reveal the real potentialities and utilization limits of vulnerable ecosystems.

LITERATURE CITED

Abi-Saleh, B. Etude phytosociologique, phytodynamique et écologique des peuplements sylvatiques du Liban. Thèse Univ. Droit. Econ. Sciences Aix-Marseille III, 1978, 1-184 (l annexe tab. et fig.).

Achhal et al. A propos de la valeur bioclimatique et dynamique de quelques essences forestières au Maroc. Ecologia Mediterranea, Marseille, 1980, Marseille, 5, 211-249.

Akman, Y; Barbero, M.; Quezel, P. Contribution à l'étude de la végétation forestière d'Anatolie méditerranéenne. Phytocoenologia, 1979, 5 (1) 1-79, (2) 189-276, (3)277-346.

Ammer et al. Communauté économique européenne. Rapport intermédiaire n° 2. Cartographie écologique. Int. Landshaft. München, 1976, 1-269.

Aschmann, H. Distribution and peculiarity of Mediterranean ecosystems. In: F. Di Castri and H.A. Mooney (Editors), Mediterranean Type Ecosystems. Ecological Studies, 1973, 7. Springer-Verlag, Berlin, pp. 11-19.

Barbero, M.; Quezel, P. Les groupements forestiers de Grèce centro-méridionale. Ecologia Mediterranea, 1976, Marseille, 2, 1-86.

Barbero, M.; Quezel, P. La végétation forestière de Crète. Ecologia Mediterranea, 1980, Marseille 5 : 175-210.
Barbero, M.; Quezel, P. Les forêts de Méditerranée Orientale dans une perspective d'Ecologie appliquée à la Sylviculture méditerranéenne. Oecologia generalis, 1981 (sous presse).
Barbour, M.G.; Major, J. Terrestrial vegetation of California. A. Wiley Inter. Sc. Public. 1977, J. Wiley and Son New York.
Bagnouls, F.; Gaussen, M. Saison sèche et indice xérothermique. Bull. Soc. Hist. Nat. Toulouse, 1953, 88, 193-239.
Braun-Blanquet, J. Plant Sociology, 1932, McGraw-Hill, New-York, N.Y., 439 pp.
Campbell, B. Some mixed hardwood communities of the coastal ranges of southern California. Phytocoenologia, 1980, 8, 3-4: 297-320.
Colwell, W. The status of vegetation maping in California today. In: Barbour & Major, Terrestrial vegetation of California, 1977. J. Wiley and Son New York ed.
Cooper, W.S. The broad-sclerophyll vegetation of California. Carnegie Inst. of Washington Publ. 1922, 319, 1-124.
Daget, P. Le bioclimat méditerranéen: analyse des formes climatiques par le système d'Emberger. Vegetatio, 1977, 34, 2: 87-104.
Di Castri, F.; Mooney, H.A. (Editors) Mediterranean Type Ecosystems Ecological Studies 7, 1973. Springer-Verlag, Berlin, 405 pp.
Emberger, L. La végétation de la region méditerranéenne. Essai d'une classification des groupements végétaux. 1930. Rev. Gen. Bot. 42, 641-662, 705-721.
Emberger, L. Nouvelle contribution à l'étude de la classification des groupements végétaux. Rev. Gen. Bot. 1933, 45, 473-486.
Emberger, L. Aperçu général sur la végétation du Maroc. Veröf Geobot. Inst. Rübel Zürich, 1939, 14 : 40-137.
Flahault, C. La distribution géographique des végétaux dans la région méditerranéenne française. Paris Lechevalier, 1897-1937, 1-180 (publié en 1937).
Gaussen, H. Végétation de la moitié orientale des Pyrénées. Lechevalier, 1926, Ed. Paris, 526 pp.
Gaussen, H. Théorie et classification des climats et microclimats. VII Congr. Int. Bot. Paris, 1954, 7, 125-130.
Godron, M.; Daget, P.; Emberger, L.; Long, G.; Le Floch, E.; Poissonnet, J.; Sauvage, C.; Wacquant, J.P. Code pour le relevé méthodique de la végétation et du milieu. Centre National de la Recherche Scientifique, (C.N.R.S.), 1968, Paris, 296 pp.
Koppen, W.; Geiger, R. Handbuch der Klimatologie. Bornträger, Berlin, 1936, Band 1, Tell C, pp. C 42-43.
Le Houerou, H.N. L'écologie végétale dans la région méditerranéenne. Inst. Agron. Medit. Bari, 1971, 55 pp.
Long, G. Diagnostic phyto-écologique et aménagement du territoire. I. Masson, Paris, 1974, 252 pp.
Looman, J. The vegetation of the Canadian Prairie Province. Phytocoenologia, 1980, 8 (2): 153-190.
Major, J. California climate in relation to vegetation. In: Barbour & Major Terrestrial Vegetation of California, 1977, J. Wiley & Son Edit. New-York: 11-74.
Mc Harg, F.L. Design with nature. Amer. Mus. Nat. Hist. Doubleday. Nat. Hist. Press. 1971, New-York, 198 pp.
Martonne, E. de. Traité de géographie physique. Tome I, A. Colin, ed., 1927, Paris, 496 pp.
Naveh, Z. Effects of fire in the mediterranean region. Fire and ecosystems. 1974, Academic Press New-York : 401-434.
Ozenda, P. Sur les étages de végétation dans les montagnes du bassin méditerranéen. Doc. Cart. Ecol., 1975, 16, 1-32.
Patric, J.M.; Manes, T.L. Chaparral succession in a San Gabriel Montain area of California. Ecology, 1964, 45, 2, 253-360.
Pons, A.; Quezel, P. Mediterranean region, general presentation. In: Gomez-Campo, Plant conservation in Mediterranean area. Acad. Press. 1981, London.
Quezel, P. Les forêts du pourtour méditerranéen. U.N.E.S.C.O., Programme Homme et Biosphère. Com. Nat. Fr. Nab. 1974, 1-53.
Quezel, P. "Matorrals" méditerranéens et "Chaparrals" californiens. Quelques aspects comparatifs de leur dynamique, de leurs structures et de leur signification écologique. Ann. Sc. Forest, 1979, 36, 1, 1-12.
Raven, P.; Axelrod, D. Origin and relationships of the California flora. Univ. Cal. Public., Botany, 1978, 72 : 134 pp. Berkeley and Los Angeles.
Rundel, P.; Parsons, D.; Gordon, D. Montane and subalpine vegetation of the sierra nevada and cascade ranges. In: Barbour & Major, Terrestrial vegetation of California, 1977, J. Wiley and Son Edit. New-York: 559-599.
Thornthwaite, C.W. An approach toward a rational classification of climate geograph Rev. 1948, 38,: 55-94.
Tomaselli, R. La dégradation du maquis méditerranéen. In: Forêts et maquis méditerranéens. Notes Techniques, MAB 2, 1976, U.N.E.S.C.O. 35-76.
Trabaud, L. Impact biologique et écologique des feux de végétation sur l'organisation, la structure et l'évolution de la végétation des zones de garrigues du bas-Languedoc. Thèse Doct. Sc. Fac. Sc. Montpellier, 1980, 287 pp.
Trewartha, C. An introduction to climate. Mc. Graw Hill. Ed. 1954. New-York, 102 pp.
Whittaker, R.H. A criticism of the plant association and climatic climax complex Northwest ci. 1951, 25 : 17-31.
Whittaker, R.H.; Niering, W.A. The vegetation of the Santa Catalina mountains Arizona (II). Agradient analysis of the south slope. Ecology 1965, 46 : 429-452.

Vegetation Classification—California[1]

Timothy E. Paysen[2]

Abstract: Vegetation classification in California is evolving rapidly. Broad-brush classes generated by resource management functions and ecologists are not suitable for many current needs. A new California system for vegetation classification fills many current needs for communication between disciplines and for linking existing classification systems.

Vegetation classification is in a state of disorder; it is therefore a subject of concern to many people. Many different systems are in use throughout California. They do not focus on specific zones within the State, but instead on particular kinds of vegetation (frequently a result of resource management emphasis) or on a particular community or type definition (table 1). Consequently, several systems may be used in a given portion of the State--often on a single limited acreage.

The variety of vegetation classification systems now in use causes serious interdisciplinary communication problems. The divergence of principles behind the systems creates confusion, both to those who compare classification results, and to those who use the systems and try to communicate information.

The need for a common system for classifying vegetation has increased over the years, growing more severe and urgent as classification in the State has become more complex. We are attempting to meet that need with a system that approaches the required universality.

The form of the new California vegetation classification system reflects a careful evaluation of the role of such a system and the requirements of one that would serve as a common classification language. Vegetation classification in California lends itself well to such evaluation because it is the result of an evolutionary process. By reviewing this evolution, we can see how the goal of a classification system affects its form, and how confusion results from attempts to make the system accomplish goals beyond its proper role. On this basis, the rationale for the new system can be better appreciated, and its application understood.

THE IMPACT OF CHANGE

As needs have evolved, vegetation classification systems used in California have changed in emphasis and in the intensity of classification they provide. This evolution has been influenced by different schools of vegetation ecology (mainly Clements, Braun-Blanquet, and Daubenmire), by various resource management disciplines, and by the distribution analyses of taxonomists and other botanists. The evolution reflects a refined awareness of the nature of vegetation in the State, and a refinement of resource management and research goals.

The systems used in California reflect highly specific goals. Increasing specialization in both resource management functions and academic disciplines has led to creation of many single-purpose classification systems that categorize vegetation from a particular perspective. Often these systems go beyond mere categorization and classify such characteristics of vegetation as its suitability for a particular use, the nature of its dynamics, or its environmental affinities.

The changes that have occurred, with their resulting problems of communication between users of different systems and of complexity in the systems themselves, are not unique to California, as a review of the literature will show (Whittaker 1962, Shimwell 1972). What is unique is the relatively short period of time over which the changes have occurred, and the impact they have had on the overlapping activities of a mobile and diverse group of people. This impact has stimulated practitioners and researchers to evaluate current methodologies and the trend of thought they represent, and to ask if there is a better course of action.

A HISTORICAL PERSPECTIVE

California's early explorers left records describing vegetation in broad terms.[3] They recognized and described broad physiognomic patterns on the landscape, and did not classify with more precision until the need arose. Consequently, they left descriptions of grasslands in our valley bottoms, zones of chaparral and conifers, and riparian vegetation along streams.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1961. San Diego, California.

[2]Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

[3]Extracts from the files of Albert E. Wieslander, Pacific Southwest Forest and Range Experiment station, Berkeley, Calif.

Table 1--A cross section of predominant vegetation classification systems used in California during the 20th century. The emphasis of timber and range resource management systems can be compared with the more general systems of Munz (Munz and Keck 1963) and Wieslander (1935).

Timber cover types (Show and Kotok 1929)	Forest type group and (*) timber management types (Bolsinger 1980)	Vegetation types (Wieslander 1935)	Plant communities (Munz and Keck 1963)	Range grazing types - 1937 (Stoddart and Smith 1943)
Western yellow pine	Ponderosa and Jeffrey pines	Pine	North coastal coniferous forest	Conifer
Mixed conifer	Redwood	Redwood	Closed cone pine forest	
Douglas-fir	Douglas-fir	Douglas-fir	Redwood forest	
Sugar pine/fir	True firs	Fir	Douglas-fir forest	
Fir	*Mixed conifer/Douglas-fir/ sugar pine	Pine/fir	Yellow pine forest	
			Red fir forest	
	*Mixed conifer	Lodgepole and white pine	Bristlecone pine forest	
	Lodgepole pine	Whitebark and foxtail pine	Lodgepole forest	
	Incense-cedar	Spruce	Subalpine forest	
	*Other conifers	Miscellaneous conifers	Northern juniper woodland	Pinyon-juniper
		Pinyon-juniper	Pinyon-juniper woodland	
Woodland	Hardwoods	Woodland	Mixed evergreen forest	Broadleaf trees
		Woodland-grass	Northern oak woodland	
		Woodland sagebrush	Southern oak woodland	
			Foothill woodland	
Chaparral		Chaparral	Chaparral	
		Chamise chaparral		
		Timberland chaparral		
		Semidesert chaparral		
		Woodland chaparral		
Brush		Sagebrush	Northern coastal scrub	Browse shrub
			Coastal sage scrub	Sagebrush
			Sagebrush scrub	Creosote
			Shadscale scrub	Mesquite
			Creosote bush scrub	Saltbush
			Alkali sink	Greasewood
				Winterfat
				Desert shrub
				Half shrub
Grass		Meadow	Coastal prairie	Grassland
		Grassland	Valley grassland	Short
			Alpine fell-field	Tall
				Meadow
				Perennial forb
				Annuals
		Marshland	Coastal salt marsh	
			Freshwater marsh	
			Joshua tree woodland	
				Barren
				Waste
			Coastal strand	

During the late 19th and early 20th century, botanists, taxonomists, and dendrologists--such as Kellogg (Kellogg and Greene 1889), Abrams (1912), Parsons (1966), and Sudworth (1967)--were exploring the State in order to catalog its plant species. Their approach was still to identify broad physiognomic patterns of vegetation and life zones.

The need to address and describe vegetation as an entity, rather than a collection of individual species, began to emerge with interest in California's vegetation as a resource. The two predominant resources in California, timber and range, gave rise to divergent management views of vegetation.

Forested areas in California were addressed in broad classification systems that reflected an interest in timber production. Such vegetation types as Pine, Fir, Redwood, Mixed Conifer, and Brush were described (Show and Kotok 1929, Wieslander and Jensen 1946). Emphasis was placed on conifers, northern California, the Sierra, and the few forested areas of southern California. This emphasis has been frustrating to people with an interest in Mediterranean vegetation, because it virtually ignored the Mediterranean climate regions of California.

Range managers also classified vegetation in broad terms (Stoddart and Smith 1943), but they generally attempted to describe local stands in detail (Beeson and others 1940; U.S. Dep. Agric., Forest Serv. 1969). Range managers were naturally concerned with short-term succession because of the way vegetation on annual plant rangelands varies from year to year in response to vagaries of weather and use. They evaluated the successional status and degree of development of each stand, much along the lines of the Clementsian school of ecology (Weaver and Clements 1938). Being so concerned with the complexities of herbaceous vegetation dynamics, range managers made little attempt to recognize precise communities or precise vegetation types, and confined their system to broad classes, qualified stand by stand.

An interest in vegetation ecology resulted in Cooper's study and classification of the sclerophyllous vegetation of California (Cooper 1922). He addressed vegetation in much the same manner as Clements, but saw little need to give climax communities and seral communities different nomenclature. Cooper's work bears the mark of its time; his classification was broad, but he recognized the variability that exists within California's sclerophyllous communities.

As general resource management abilities became refined, and the need was felt to understand the dynamics and ecology of our vegetation more fully, interest arose in recognizing and describing the variability in California's vegetation more precisely than in the past. In the 1930's, fire management planning in southern California gave impetus to an ambitious classification and mapping of California's vegetation (Wieslander 1935). In this effort, Albert Wieslander also addressed broad physiognomic patterns of vegetation, but recognized subclasses of these types in greater detail than anyone before him. He also described dominant plant species within each subtype. The results of his work are found in many vegetation maps produced by the California Forest and Range Experiment Station (Critchfield 1971). This effort resulted in California's chaparral being broken down into more than one class (table 1). Wieslander's work has been abstracted and modified in various ways to meet the vegetation classification needs of wildlife managers (Jensen 1947) and timber managers (Wieslander and Jensen 1946). His influence is seen in the *way* others have since mapped and described California's vegetation.

In later years, Philip Munz developed a vegetation classification system to facilitate the use of his California Flora (Munz and Keck 1963). Because it accompanied his Flora, it has become one of the most popular systems in the State. It is not a true vegetation classification system, but rather identifies a broadly conceived set of biological communities characterized by specific kinds of vegetation. It also shows the influence of timber and range interests (table 1). His plant communities lean heavily towards forest and rangeland vegetation, and chaparral is relegated to a single class.

THE PRESENT

Today, the general classes typical of past systems are unsatisfactory for many current needs. For example, the broad timber types do little to promote understanding of forest vegetation in terms other than timber production. Even Wieslander's work is still too general for many specific needs. Munz' system is too ambiguous for site-specific application.

Interest in vegetation ecology and plant ecology has generated divergent systems for characterizing vegetation types, plant ecosystems, and biological communities wherein plants reside. Habitat types, after the manner of Daubenmire (1968), have been described for some northern conifer forests by Sawyer and Thornburgh (1977), and a system of biological communities has been developed by Thorne (1976). Cheatham and Haller listed habitat types, with subdivisions, identified within the University of California Natural Land and Water Reserves System. Their habitat types are equivalent to Munz' plant communities, and the subdivisions show sensitivity to habitat variability.[4] Southern California's vegetation is addressed in a biome system developed by Brown and

[4]Cheatham, Norden H., and J. Robert Haller. An annotated list of California habitat types. 1975. (Unpublished manuscript).

Lowe for the southwestern United States (Brown and others 1979). Vegetation characteristics of many specific localities have been described by various authors (Hanes 1976, 1977; Vogl 1976; Minnich 1976; Horton 1960), whose descriptions range from broad physiognomically defined zones to detailed vegetation types developed through the interpretation of aerial photographs.

Current understanding of California's vegetation and its ecology has been summarized recently in a volume edited by Barbour and Major (1977). Although this work does not address the classification of vegetation as such, it contains a map of California's potential natural vegetation--with a legend--by Kuchler.

The vegetation descriptions in all the work I have mentioned were developed in support of specific technical activities, ranging from timber management to pure vegetation ecology, and their level of abstraction reflects specific viewpoints. As a result, we have not had a single system for classifying vegetation that has been generally satisfactory.

The direct impetus to develop a widely acceptable treatment of California's vegetation comes from resource management. Those responsible for the various resource management functions find that they must understand the nature and dynamics of vegetation in more precise terms. They also recognize that people in different functions can work together easily if there is a common language to describe the vegetation resource, but not when each function relies strictly on its own technical classification system.

Although researchers and resource management specialists in California agreed on the need for a system that would be usable by most professionals, they were uncertain as to its feasibility. The patterns of vegetation people recognize are strictly a reflection of their particular needs, their training and background. To determine feasibility, extensive testing was carried out with individuals from a variety of disciplines, resource management agencies, and academic pursuits (Paysen and others 1980). A unit of vegetation was identified as one that all people who deal professionally with vegetation recognize; it was called the Association, and was adopted as the basic unit of the new classification system for California.

A NEW VEGETATION CLASSIFICATION SYSTEM

The new system is a component vegetation classification system; it addresses just the vegetation component of ecosystems. It does not address the ecology of vegetation, nor does it explain phytosociological relationships. It follows that the system is "neutral" with regard to plant community succession; it can he applied to seral vegetation, potential vegetation, or climax vegetation.

The system is designed around an aggregative hierarchy, its focus being a site-specific plant community. The same plant community is traced upward through the hierarchy at decreasing levels of descriptive precision (table 2). The system's focus and hierarchical design make it a flexible tool for crosswalking between other vegetation classification systems. They also make it adaptable to many phytosociology and other ecology-based schemes for analyzing plant communities and explaining their dynamics.

The elements that distinguish communities and provide the basis for community nomenclature are readily discernible, and are common to people's perception of vegetation character. The system is therefore usable by a wide range of people. The system distinguishes the physiognomic character of communities as well as predominant floristic differences.

The system's basic unit, the Association, is named in terms of the dominant overstory species and the dominant species in subordinate layers (dominance is based upon relative crown cover within a layer). Under strict rules of nomenclature, codominant-associated species can be included in the Association name. Associations are aggregated into Series according to dominant overstory species. The Series are, in turn, aggregated into Subformations according to leaf and stem morphology. Subformations are finally aggregated to Formations on the basis of the growth form of the overstory species.

An additional category, called Phase, is provided to facilitate the link to existing vegetation classification systems. It is flexible and can be used to describe such things as stand age, condition, or stage of development. It can be

Table 2--The hierarchy of the new California vegetation classification system, with classification criteria for levels and examples of classes within each level.

Level	Criteria	Example
Formation	Physiognomy	Woodland
Subformation	Stem and leaf morphology	Broadleaf woodland
Series	Dominant species in overstory	Canyon live oak
Association	Dominant species in all layers	Canyon live oak/ shrub live oak mountain lilac
....		
Phase	Flexible: user criteria	Age 40 yr; crown cover 40 pct.

applied to any level in the classification hierarchy. Phase does not enter into the formal classification of plant communities, but is used as a qualifier once the community has been classified.

The Phase provides a logical point of entry to the classification system from technical systems that are based on a particular functional perspective. By describing Phases in timber management terms, and aggregating some classes, we reach standard timber types; if the classes are left unaggregated, they provide a good framework for silvicultural prescriptions. By defining Phases that describe local site indicators, we relate the Associations to the scheme for addressing vegetation employed by the Zurich-Montpellier school of phytosociology (Becking 1957). At upper levels of the system's hierarchy, vegetation units can be combined with climate, geography, and soils data, resulting in community descriptions that fit the UNESCO (1973) system for classifying and mapping vegetation on a worldwide basis.

This is a system for classifying vegetation rather than a classification of vegetation. It does not limit a user to a preconceived set of classes; instead, it allows a user to identify communities as they actually exist. The rules for class recognition and definition, as well as those for nomenclature, are such that a significant amount of information can be conveyed about a community with a class name--and perhaps with a Phase designation.

The new California system underwent extensive field testing over a period of several years, and has proven to be a good crosswalking mechanism. It is a good vehicle for communicating information about vegetation between a variety of disciplines, and an excellent framework to use in developing an understanding of vegetation dynamics. The system fits well with existing systems for classifying vegetation or abstractions from vegetation (such as timber types and range types), and for classifying the processes of vegetation dynamics.

The system is compatible with those being used in adjacent States. Correlations can be defined between the Association and the plant communities being classified in Oregon and Washington (Hall 1973, 1976), and the Associations being described in the Southwest (Brown and others 1979). It is also directly compatible with the vegetation classification system current under development for use at the national level.[5]

[5]Merkel, Daniel L., Richard S. Driscoll, Darrel L. Gallup, James S. Hagihara, Donald O. Meeker, and Dale E. Snyder. National site (land) classification system - status and plans. 1980. Resources Evaluation Techniques Program, Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo. Unpublished.

The California system is continuing to be evaluated by individuals from a variety of disciplines, agencies, and universities throughout the State of California. The system can become the framework for coordinating vegetation classification, inventory, and vegetation ecology activities throughout the State.

I emphasize again that the new system is strictly a vegetation classification system. The system will not detail ecological processes, nor will it describe productivity. It is simply a framework to use for describing vegetation--past, present, and future. Managers and scientists should describe each vegetation class in a manner reflecting the ecological relationships of the species in and among the classes. Descriptions can reflect the productivity of plant communities defined by the classes in terms of timber, range, or any other kind of production that may be of interest. Classification of vegetation should be distinct from ecology, resource management, or other technical activities. Because the California system has been designed under this philosophy, it will have maximum application and usefulness.

LITERATURE CITED

Abrams, Leroy. A phytogeographic and taxonomic study of the southern California trees and shrubs. New York, N.Y.: Columbia Univ. Dep. Botany: 1912; Contrib. 247. 485 p.

Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley and Sons; 1977. 1002 p.

Becking, Rudy W. The Zurich-Montpellier school of phytosociology. The Bot. Rev. 23(7):411-488; 1957 July.

Beeson, R. W.; Cronemiller, F. P.; Deering, R. L. [and others]. Handbook for range managers, Region 5. Oakland, Calif.: Region 5, Forest Serv., U.S. Dep. Agric.; 1940. 212 p.

Bolsinger, Charles L. California forests: trends, problems, and opportunities. Portland, Oreg.: Pacific Northwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Resour. Bull. PNW-89. 138 p.

Brown, David E.; Lowe, Charles H.; Pase, Charles P. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the southwest. J. Ariz.-Nev. Acad. Sci. 14, suppl. 1:16; 1979 May.

Cooper, William S. The broad-sclerophyll vegetation of California. Washington, D.C.: The Carnegie Inst. of Washington. 1922; No. 319. 145 p.

Critchfield, William B. Profiles of California vegetation. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1971; Res. Paper PSW-76. 54 p.

Daubenmire, Rexford. Plant communities. New York: Harper and Row ; 1968. 300 p.

Hall, Fredrick C. Plant communities of the blue Mountains in eastern Oregon and southeastern Washington. Portland, Oreg.: Pacific Northwest Region, Forest Serv., U.S. Dep. Agric.: 1973; R-6 Area Guide 3-1. 62 p.

Hall, Fredrick C. Classification, designation, identification = confusion. Portland, Oreg.: Pacific Northwest Region, Forest Serv., U.S. Dep. Agric.: 1976; K-6 Regional Guide 4. 11 p.

Hanes, Ted L. Vegetation types of the San Gabriel Mountains. In: Latting, June, ed. Plant communities of southern California. Berkeley, California: Calif. Native Plant Soc.; 1976: 65-76. (Spec. Publ. 2).

Hanes, Ted L. Chaparral. In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley and Sons; 1977: 417-469.

Norton, Jerome S. Vegetation types of the San Bernardino Mountains, California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., G.S. Lep. Agric.: 1960; Tech. Paper 44. 29 p.

Jensen, Herbert A. A system for classifying vegetation in California. California Fish and Game 33(4); 266 p. 1947 October.

Kellogg, Albert; Greene, Edward L. Illustrations of West American oaks. San Francisco, Calif.: [Published from funds provided by James M. McDonald, Esq.]; 1889. 84 p.

Minnick, Richard A. Vegetation of the San Bernardino Fountains. In: Latting, June, ed. Plant communities of southern California. Berkeley, California: Calif. Native Plant Soc.; 1976: 99-124. (Spec. Publ. 2).

Munz, Philip A.; Keck. David D. A California flora. Berkeley, Calif.: Univ. Calif. Press; 1963. 1681 p.

Parsons, Mary E. The wild flowers of California. New York: Lover; 1966. 425 p.

Paysen, Timothy E.; Derby, Jeanine A.; Black. Hugh, Jr. [and others]. A vegetation classification system applied to southern California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., L.S. Dep. Agric.: 1980; Gen. Tech. Rep. PSC-45. 33 p.

Sawyer, John O.; Thornburgh, Dale A. Montane and subalpine vegetation of the Klamath Mountains. In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley and Sons; 1977: 699-732.

Shimwell, David W. The description and classification of vegetation. Seattle, Wash.: Univ. of Washington Press; 1972. 322 p.

Show, S. B.; Kotok, E. I. Cover type and fire control in the national forests of northern California. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1929; Agric. Dep. bull. 1495. 46 p.

Stoddart, Laurence A.; Smith, Arthur D. Range management. New York: McGraw-Hill; 1943. 547 p.

Sudworth, George b. Forest trees of the Pacific slope. New York: Dover; 1967. 455 p.

Thorne, Robert F. The vascular plant communities of California. In: Latting, June, ed. Plant communities of southern California. Berkeley, California: Calif. Native Plant Soc.; 1976: 1-31. (Spec. Publ. 2).

UNESCO. International classification and mapping of vegetation. Paris: UNESCO; 1973. 91 p.

U.S. Department of Agriculture, Forest Service. Range environmental analysis handbook, FSH 2209.21. 1969. U.S. Dep. Agric., Forest Serv., California Region. 214 p.

Vogl, Richard J. An introduction to the plant communities of the Santa Ana and San Jacinto Mountains. In: Latting, June, ed. Plant communities of southern California. Berkeley, California: Calif. Native Plant Soc.; 1976: 77-98. (Spec. Publ. 2).

Weaver, John E.; Clements. Fredric E. Plant ecology. New York: McGraw-hill; 1938. 601 p.

Whittaker, Robert H. Classification of natural communities. The Bot. Rev. 28(1):1-239; 1962 January-March.

Wieslander, Albert E. First steps of the forest survey in California. J. For. 33:877-884; 1935 October.

Wieslander, Albert E.; Jensen, Herbert A. Forest areas, timber volumes and vegetation types in California. Berkeley, Calif.: California Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1946; Forest Survey Release 4. 66 p.

Chaparral Succession[1]

Richard J. Vogl[2]

Abstract: Vegetation changes following fire usually result in a rapid return to the predisturbance species composition and structure. Regrowth takes place by root-crown sprouting and seed reproduction. Succession is cyclic except in ecotones and favorable sites where it is linear. Fire serves as a growth stimulus to the persisting plants, contributes to seed germination, and is a plant waste remover and ecosystem renewer. Other factors that affect succession are mountain building, landslides, erosion, soil development, climatic variability, and environmental stress.

A complete discussion of chaparral succession and a thorough review of the literature on the subject is presented by Hanes (1977). As a result, a review of the literature on chaparral succession will not be attempted in this manuscript. Rather, certain highlights of plant succession will be again presented and re-emphasized. In addition, a conceptual model of chaparral succession is advanced that is intended to help explain the controlling factors and dynamics of succession.

Chaparral vs. Classical Succession

Classical plant succession (Vogl 1970, Horn 1974, 1976) is largely nonexistent in California chaparral, except possibly in transitional areas where chaparral intergrades with other vegetation types. Missing in chaparral is the usual replacement series of various plants or seral stages, with each species modifying the site until it becomes unfavorable for that species and thereby available for invasion by another (Horton and Kraebel 1955, Sweeney 1956, Patric and Hanes 1964, Hanes and Jones 1967, Hanes 1971, Vogl and Schorr 1972, Biswell 1974, Keeley 1977, Keeley andLedler 1978). In most instances there is no species replacement that progresses until a stable or climax vegetation is established (Hedrick 1951). Even on virgin sites, the colonizing plants are also components of the mature vegetation. Virgin sites that are sometimes invaded by such species as annual grasses, Selaginella mosses, coffee fern (Pellaea andromedaefolia), and perennial herbs do not appear to be particularly modified or enhanced to encourage successional replacement with subshrubs followed by woody plants. Growth that resembles the early stages of classical primary succession does not necessarily lead to chaparral development, and primary succession is most often accomplished by the direct invasion of a site by climax chaparral elements. New sites in chaparral ecosystems are continuously produced by landslides which are triggered by rain or when slopes are undercut by runoff, or produced by instability as a result of tectonic activities.

With few exceptions, fire is the initiator of secondary succession in chaparral. Secondary succession following fire is also without seral stages (Hanes 1977). The temporary cover of annual fire-followers (Armstrong 1977) and short-lived perennial herbs (Keeley and Johnson 1977) and subshrubs does not modify the site to encourage a species invasion or replacement. In about 2 to 5 years after a fire almost all of these species cease growth (Vogl and Schorr 1972), and the spaces they occupied are usually taken by the expanding canopies of the resprouting or regrowing chaparral shrubs (Ammirati 1967); the same species that dominated the preburn vegetation. The seeds of these herbaceous plants apparently persist in place until their growth is again initiated by fire (Sweeney 1956). The rapidity and magnitude of the responses of these fire-followers, along with the usual large sizes of the burned areas, preclude that the seeds of most of these species invade the burned sites from adjacent unburned areas (Westman 1979).

Successional replacement is apparently hampered by the strong vegetative habits of many chaparral shrubs. Once a shrub occupies a site, it physically dominates that site. Perennial plants with the ability to recover after top damage or removal of stems have the potential to extend this dominance for long periods, perhaps for hundreds of years. Anything short of the destruction of the basal crown of the root system results in the persistence of these chaparral shrubs. Removal of the aerial portions of these perennials by fire is not just an adversity that these plants must overcome, but it also prevents-plant senescence by physiological rejuvenation and growth stimulation (Vogl 1980). Factors that help to initially determine the chaparral species that will become established on a given site are exposure of site, steepness of slope, soil moisture, elevation (Hanes 1977), and possibly the ash bed present after fire (Vogl and Schorr 1972).

Most chaparral shrubs also produce chemicals that inhibit competing invaders which contribute to site dominance (McPherson and Muller 1969, Hanes 1977). The allelopathic chemicals produced by nonsprouting shrubs may extend chemical suppression of other species after the nonsprouting shrubs have died, thus helping to ensure the re-establishment of the same species on that site. It has been noted that after the short-lived bush poppy (Dendromecon rigida) or certain species of Ceanothus die some 20 to 40 years or more after a fire (Quick 1959, Hanes 1971,

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Biology, California State University, Los Angeles, Calif. 90032.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Keeley 1975), the spaces they occupied remain open and unvegetated, or are only filled by the aerial portions of adjacent shrubs.

It has been generally assumed that among shrub species that possess the ability to regrow vegetatively after fire, plants established from seeds seldom contribute substantial numbers of individuals that become components of the mature vegetation (Hanes 1977). Usually little seedling growth occurs on sites dominated by shrubs capable of vegetative reproduction (Keeley 1977). It has been hypothesized that when seedlings do become established, they provide a temporary plant cover that is preferentially browsed by herbivores until the resprouting shrubs again regain dominance (Vogl and Schorr 1972). It appears that seed reproduction is only important as a replacement for shrubs that fail to recover vegetatively, or in places where the shrubs have been eliminated by such things as a landslide or a very hot fire.

An alternate explanation is that seed reproduction is commonplace among resprouting perennials and contributes substantially to the mature vegetational cover (Howe and Carothers 1980). If this assumption which contradicts most other studies is correct, then it appears that chaparral shrubs are shorter lived and have higher replacement rates than suspected, since the typical high densities of chaparral shrubs tend to otherwise physically saturate any given site with little or no space for successful seedling establishment (Hanes 1977). Further research is needed on this subject, particularly since shrub seedlings might often be misidentified as resprouts and vice versa (Howe and Carothers 1980).

Chaparral succession is also simplified by the absence of an understory vegetation (Hanes 1971, 1977). The mature chaparral usually consists of a single, although sometimes irregular, layer or stratum of dense shrub growth with canopies that are continuous and contiguous with each other. The general absence of an understory is considered to be a product of this dense growth, closed canopies, insufficient surface soil moisture, and allelopathic effects. Christensen and Muller (1975) and Ron Quinn (personal communication, Jan. 1980) have found that the establishment of an understory is also prevented by the activities of herbage and seed-eating small mammals. At any rate, the vegetational development does not usually progress beyond a single-layered formation.

Coastal Sage Scrub or Degraded Chaparral

Chaparral that has been severely disturbed or degraded is often dominated by different plant species than those found in undisturbed chaparral. Some of the more common of these are *Eriogonum fasciculatum*, *Eriodictyon* spp., *Lotus scoparius*, *Salvia* spp., *Eriophyllum confertiflorum*, *Heleanthemum scoparium*, and *Artemisia californica*. These subshrubs or half-shrubs usually produce open stands as they mix with introduced grass species and ubiquitous weeds. Such chaparral disclimaxes are often produced by long-term overgrazing and radical changes in fire frequencies (Vogl 1977). Much of what is presently classified as coastal sage scrub may have been either chaparral (Hanes 1977) or perennial grassland prior to its degradation. Grazing impacts usually extend well beyond the areas being directly used by livestock as rodent and other wild herbivore populations are displaced and reconcentrated. Ranching operations also often reduce the predators of an area thereby allowing prey populations to reach abnormal numbers that negatively impact the surrounding vegetation.

Coastal sage scrub appears to be relatively stable, in that in many areas it is not undergoing rapid vegetational changes and quickly reverting to chaparral (Mooney 1977). It may be that these areas are in a state of shock stagnation, whereby the degraded vegetation persists or is self perpetuating for an indefinite period with no evidence of species replacement. Degraded California grasslands and many desert plant communities also do not show signs of recovery indicating that the relative stability of these disclimax stages is commonplace among degraded ecosystems. Unless coastal sage scrub is not a product of degradation or the disturbances have not caused irreversible changes, such areas would be expected to be eventually replaced by chaparral.

The same floristic elements that characterize coastal sage scrub also occur on small, localized sites within undisturbed chaparral. They usually respond to minor soil disturbances caused by ground squirrels, pocket gophers, rock slides, erosion, and the like. Under such disturbance conditions, these species act like pioneer or weedy species responding to the open and unstable conditions. These species are replaced by the more stable chaparral species when the disturbances are eliminated. This type of successional replacement is similar to that found in perennial grasslands where short-lived opportunistic pioneers coexist with long-lived perennials. A natural grassland is constantly being turned over, a little at a time by various localized disturbances, with the result that "pioneer" species occur adjacent to and mixed with "climax" species (Vogl 1974). Apparently similar events happen in localized areas, but as in perennial grasslands, the pioneer species do not necessarily modify the site so that it can be invaded by the more stable species. Rather, small-scale disturbances favor opportunistic invader species and their absence favors the establishment of components of the stable vegetation.

Chaparral Ecotones

Chaparral succession involving a step-wise replacement of species occurs more commonly along ecotones where chaparral intergrades with other vegetation types. These transitional areas occur within and at the peripheral edges of chaparral distribution. Chaparral and the other vegetation types that it is juxtaposed upon usually form a mosaic of mutually-exclusive plant communities (Wells 1962).

This patchwork pattern is most pronounced at the lower elevational occurrences of chaparral where it impinges on grassland, oak savanna, oak woodland, and riparian forest. Chaparral and these other vegetation types appear to be distributed primarily by soil differences, including differences in pH, texture, ;water-retaining capacity, and nutrients, and the presence of ground water or soil moisture.

At the upper elevational and northern limits of chaparral distributions, angle and exposure of slope appear to be more effective than soil in determining vegetation patterns. Along these edges chaparral intergrades less distinctly with oak or with pine forest, principally Pinus coulteri, P. sabiniana, P. jeffreyi, and P. ponderosa.

Occasionally, sites dominated by grassland are invaded by chaparral shrubs, particularly on marginal grassland sites. Such replacement is probably most often facilitated by fire, with the time of the year of the fire perhaps being most critical (Biswell 1952, 1956). Replacement of chaparral by oaks or pines is a more common event along forest-chaparral ecotones (Wilson and Vogl 1965). This appears to occur often as a result of changes in fire frequencies and intensities. It appears that these transitional areas are in a continuous state of change, shifting from one vegetation type to another as subtle, but critical changes in environmental factors occur. In these transitional areas, forest cannot be considered the more mature or climax vegetation type, because over the long run forest is probably replaced by chaparral as often as chaparral is replaced by forest (Wilken 1967). Because of long-standing efforts of fire suppression in southern California, there is evidence that chaparral has replaced forest in numerous locations (Minnich 1977).

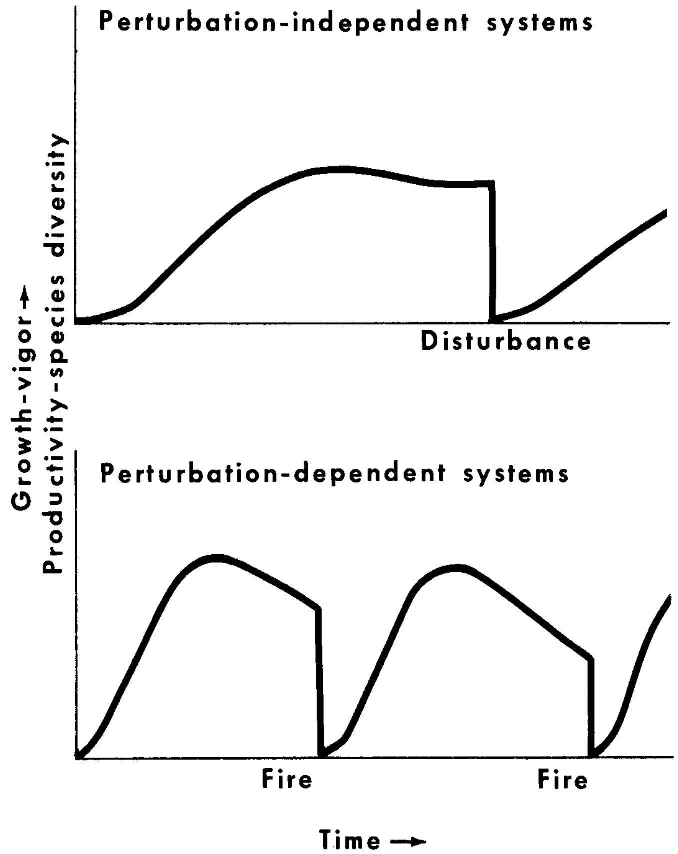


Figure 1--Disturbances in perturbation-independent ecosystems create vegetational setbacks and recovery is slow, whereas disturbances in perturbation-dependent systems such as chaparral stimulate pulses of growth which quickly decline unless disturbed again.

A Conceptual Model of Chaparral Succession

Vegetational changes in chaparral are best expressed as a series of simple, repetitive cycles Vogl 1970, Hanes 1977). If these changes are visualized linearly through time, perturbations are seen to cause pulsations or ocillations in growth and productivity (fig. 1). Disturbances in many other vegetation types act retrogressively to set back vegetational development to some earlier or more pioneer successional stage, and the vegetation slowly returns in a series of steps to the predisturbance composition. Fire in chaparral causes stimulating spurts of growth, vigor, productivity, and species diversity (Vogl 1980, Force 1981). These stimulating effects decline almost as rapidly as they increase, until I renewed by another perturbation. Maximum species I diversity, productivity, and energy capture are reached shortly after fire in chaparral, in contrast to classical plant succession where a considerable length of time is required as the vegetation progresses through various plant stages before maximum productivity is attained.

In many vegetation types the burned vegetation is often considered abnormal and a stressed environment, whereas the preburn vegetation is assumed to be normal and healthy. Many fire studies are concerned with the length of time that it takes for a burned site to recover or return to its preburn composition. When chaparral succession is considered a cycle and fire islconsidered a pulse stimulator, burned and unburned vegetational compositions and conditions become equally important. When postburn declines in productivity, species diversity, and community senescence occur, then the length of time until the next fire becomes more important, perhaps, than the recovery rates after a fire. The concern in chaparral is not so much if chaparral will recover after fire and how long it will take, but rather how rapidly the system will decline without fire. In other words, what fire frequencies or fire periodicity will maintain maximum chaparral productivity?

Pulse stimulation is common among perturbation-dependent systems (Vogl 1980), but the magnitude of response of chaparral following fire is exceptional. The short response time after disturbance and the rapid growth are particularly remarkable since chaparral exists under semi-arid conditions, being subject to drought stress during each growing season. Chaparral growth rates following fire stimulation may be unique among woody plants in dry environments.

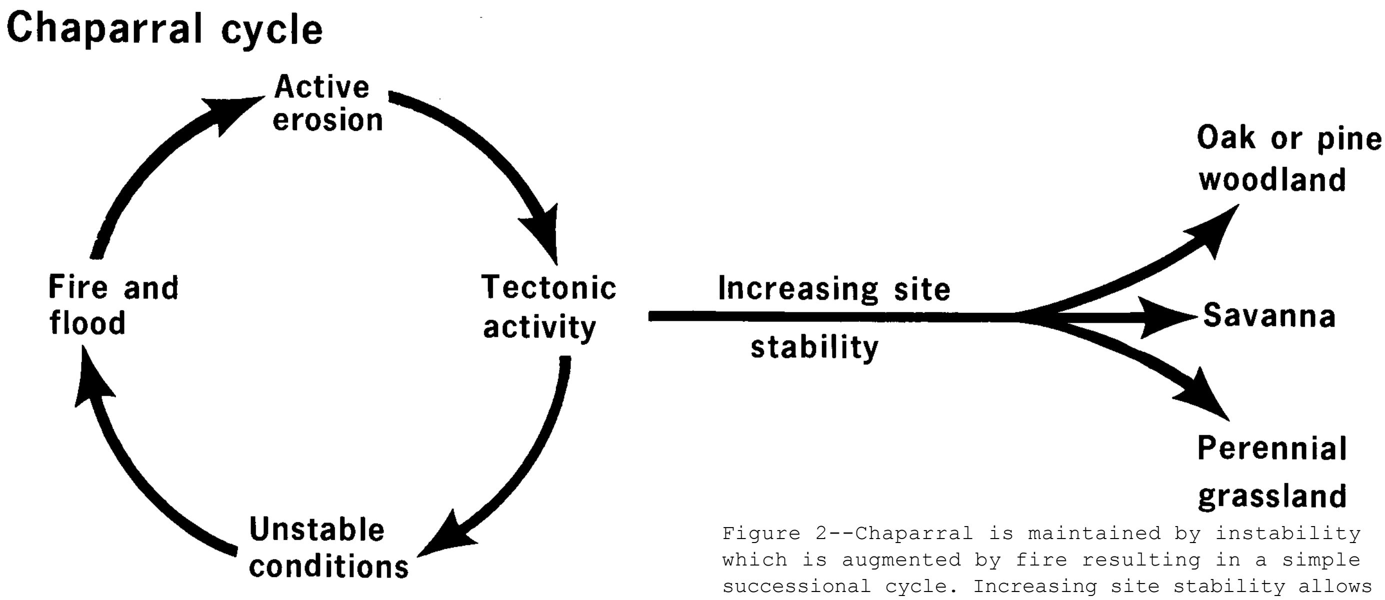


Figure 2--Chaparral is maintained by instability which is augmented by fire resulting in a simple successional cycle. Increasing site stability allows chaparral to be replaced by oak or pine woodland, savanna, or perennial grassland depending upon the degree of stability, fire frequencies, and location.

Nutrient flow through chaparral systems is largely open-ended, with most photosynthesis products moving down into adjacent communities such as valley grassland, riparian forest, and marshland where they remain or are temporarily trapped or detained before finally moving out to sea or on to desert playas. Chaparral fires also remove large quantities of materials off site in smoke plumes carrying particulates and volatilized products. Fire appears to act more as a waste remover than a nutrient recycler in chaparral (DeBano and Conrad 1978).

Continuance of this open-ended system is assured by the normal chemical and physical decomposition of bedrock by roots as well as by mountain building, uplifting, geological fracturing, fires, and floods which promote general instability and active erosion. This results in a continuous supply of new or raw nutrients which are readily extracted and utilized by the unique and extensive chaparral rhizosphere (Kummerow et al. 1977, Miller and Ng 1977).

A diagramatic model suggesting how instability contributes to a continuing chaparral cycle is presented in figure 2. Decreased erosion as a result of slopes wearing down without geological uplift and renewal leads to increased site stability. This new equilibrium allows chaparral to be replaced successionally by grassland or oak savanna or woodland at lower elevations and by pine or oak forest at higher elevations. The replacement of chaparral by these other types probably takes place slowly, an invasion which is undoubtedly augmented by changes in the fire frequencies that originally favored chaparral maintenance. In this model (fig. 2) fire not only serves as a pulse stimulator of growth and renewal, but also acts as a catalytic contributor to instability by encouraging erosion. This is accomplished by fire removing most of the above-ground growth and growth accumulations thereby allowing erosional materials to respond to the pull of gravity in an unimpeded manner. Fires followed by heavy rains create the notorious fire-flood sequences that perpetuate steep slopes and expose new substrates ((Munn 1920, Coleman 1953). Chaparral is able to replace chaparral as long as site instability prevails. The super-hot fires are just one of the key factors that contribute to the maintenance and continuance of chaparral (Hanes 1977). Other important factors include tectonic activities, the usual unstable and friable bedrock and soils (Krammes 1960), the typical heavy rains, and the fact that the steep slopes and substrates are not very receptive to water, particularly after fire (DeBano et al. 1979). The unreceptive soils result in rapid and heavy run off. These and other factors working together and in sequence help to ensure the continuance of steep and rugged topography; prime sites for optimum chaparral development. Successional replacement of chaparral with forest or grassland is prevented on most sites by controlling physical factors—various climatic and geologic features that help to perpetuate instability.

Acknowledgments

I thank Ted L. Hanes and Roland Case Ross for reviewing this manuscript.

Literature Cited

Ammirati, J. F., Jr. 1967. The occurrence of annual and perennial plants on chaparral burns. M. A. Thesis. Biology Department, San Francisco State College. 140p.

Armstrong, W. P. 1977. Fire-followers in San Diego County. Fremontia 4(4):3-9.

Biswell_, H. H. 1952. Factors affecting brush succession in the coast region and the Sierra Nevada foothills. p. 42-45. In: Proc. 4th Annual Calif. Weed Conf., San Luis Obispo, Calif.

____. 1956. Ecology of California grasslands. J. Range Manag. 9:19-24.

____. 1974. Effects of fire on chaparral, p.321-364. In Kozlowski, T. T., and C. E. Ahlgren [eds.]. Fire and Ecosystems. Academic Press, N. Y.

Christensen, N. L., and C. H. Muller. 1975. Relative importance of factors controlling germination and seedling survival. in Adenostoma chaparral. Amer. Midland Natur. 93:71-78.

Colman, C. A. 1953. Fire and water in southern California's mountains. California Forest and Range Exp. Stn. Misc. Paper No. 3:1-8.

DeBano, L. F., and C. E. Conrad. 1978. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59:489-497.

DeBano, L. F., Rice, R. M., and C. E. Conrad. 1979. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion, and runoff. U.S.D.A. Forest Service PSW-145 has. Paper. 21p.

Force, D. C.]981. Postfire insect succession in southern California chaparral. The Amer. Natur. 117:573-582.

Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. Ecool. Monogr. 41:27-52.

____. 1977. California chaparral. p.417-469. In Barbour, M. G., and J. Major [eds.] Terrestrial. Vegetation of California. John Wiley & Sons, N. Y.

Hanes, T. L., and H. W. Jones. 1967. Postfire chaparral succession in southern California. Ecology 48:259-264.

Hedrick, D. W. 1951. Studies on the succession and manipulation of chamise brushlands in California. Ph. D. Thesis. Dept. Range Management, Texas A. & College. 113p

Horn, H. S. 1974. The ecology of secondary succession. Annual Rev. Ecol. Syst. 5:25-37.

____. 1976. Succession. 189-204. In May, R. M. [ed.] Theoretical :Ecology : Principles and Applications. Saunders, Philadelphia.

Horton, J. S., and. C. J. Kraebel. 1955. Development of vegetation after fire in the chamise chaparral of southern. California. Ecology 36:244-262.

Howe, G. F., and L. E. Carothers. 1980. Postfire seeding reorc_uctio.. of Adenostoma fasciculatum. Southern California Acac. Sci. 79:5-13.

Keeley, J.E. 1975. Longevity of nonsprouting ceanothus. Amer. Midland Natur. 93:504-507.

____. 1977. Seed production, seed populations in soil, and seedling production after fire for two congeneric pairs sprouting and nonsprouting chaparral shrubs.Ecology 58:820-829.

Seeley, J. E., and P. H. Zedler. 1978. Reproduction of chapparal shrubs after fire: a comparison of sprouting and seedling strategies. Amer. Midland Natur. 99:142-161.

Keeley, S. C. and A. W. Johnson. 1977. A comparison of the pattern of herb and shrub growth in comparable sites in Chile and California. Amer. Midland Natur. 97:120-132.

Krammes, J. S. 1960. Erosion from mountain side slopes after fire in southern California. U.S.D.A. Pacific Southwest Forest and Range Exp. Stn. Res. Note No. 171. 8p.

Kummerow, J., Krause, D., and W. Jow. 1977. Root systems of chaparral shrubs. 0ecologia 29:163-177.

McPherson, J. K., and C. H. Muller. 1969. Allelopathic effects of Adenostoma fasciculatum "chamise", in the California chaparral. Ecol. Monogr. 39:177-198.

Miller, P. C., and E. Ng. 1977. Root: shoot biomass ratios in shrubs in southern California and central Chile. Madrono 24:215-223.

Minnich, R. A. 1977. The geography of fire and big cone douglas-fir, coulter pine and western conifer forests in the East Transverse Ranges, southern California. p.443-450. In Proc. of Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. U.S.D.A. Forest Service Gen. Tech. Rep. W0-3. Palo Alto, Calif.

Mooney, H. A. 1977. Southern coastal scrub. p.471-489. In Barbour, M. G., and J. Major [eds] . Terrestrial Vegetation of California. John Wiley a Sons, N. Y.

Munns, E. N. 1920. Chaparral cover, run-off, and erosion. J. For. 18:806-814.

Patric, J. H., and T. L. Hanes. 1964. Chaparral succession in a San Gabriel Mountain area of California. Ecology 45:353-360.

Quick, C. R. 1959. Ceanothus seeds and seedlings on burns. Madrono 15:7)-81.

Sweeney, J. R. 1956. Responses of vegetation to fire. Univ. Calif. Publ. Botany 28:143-250.

Vogl, R. J. 1970. Fire and plant succession. p.65-75. In Symposium on the Role of Fire in the Intermountain West. Intermountain Fire Res. Council. Missoula, Montana.

____. 1974. Effects of fire on grasslands, 2.139-194. In Kozlowski, T. T., and C. E. Ahlgren [eds.]. Fire and Ecosystems. Academic Press, N.Y.

____. 1977. Fire frequency and site degradation. p.193-201. In Proc. of Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. U.S.D.A. Forest Service Gen. Tech. Sep. WO-3. Palo Alto, Calif.

____. 1980. The ecological factors that produce perturbation-dependent ecosystems. p.63-94. In J. Cairns, Jr. [ed.]. The Recovery Process in Damaged Ecosystems. Ann Arbor Science Publ., Michigan.

Vogl, R. J. and P. K. Schorr. 1972. Sire and manzanita chaparral in the San Jacinto Mountains, California. Ecology 53:1179-1188.

Wells, P. V. 1962. Vegetation in relation to geological substratum and fire in the San Luis Obispo Quadrangle, California. Ecol. Monogr. 32:79-103.

Westman, W. E. 1979. A potential role of coastal sage scrub understories in the recovery of chaparral after fire. Madrono 26:64-68.

Wilken, G. C. 1967. History and fire record of a timberland brush field in the Sierra Nevada of California. Ecology 48: 302-304.

Wilson, R. C., and R. J. Vogl. 1965. Manzanita chaparral in the Santa Ana Mountains, California. Madrono 18:47-62.

Successional Dynamics of Chamise Chaparral: The Interface of Basic Research and Management[1]

Philip W. Rundel[2]

Abstract: Basic research on successional dynamics of chamise chaparral in the foothill zone of Sequoia National Park, California, can provide valuable data for assessing management alternatives for this zone. Fire seasonality and intensity strongly influence patterns of post-fire community development. An ecological understanding of both short-term and long-term successional dynamics is critically important to reach these management goals. Knowledge of flammability, fire behavior, plant demography and plant physiological ecology are all essential.

The subject of successional dynamics in chaparral has been a productive one for 60 years. Much of this past work, summarized in detail by Hanes (1977), has been descriptive, focusing on successional changes which may occur. There has been little attempt, however, oriented toward communicating the significance of these successional patterns for the development of informed resource management. In this paper, I will attempt to bridge this gap and provide a basis for the interface of basic research and management in studies of the successional dynamics of climax chaparral.

Intensive studies of chamise chaparral at Sequoia National Park have provided the large data base necessary to study the relationships between fire history and plant-soil interactions. These data, covering 43 0.1 ha plots with enumerations of species coverages, soil nutrients and structure, topographic patterns and fire history, has provided the basis for a quantitative model of the dynamics of successional change over a 90-year sequence following fire (Rundel and Lambert 1982).

SHORT-TERM SUCCESSIONAL PATTERNS

In this model (fig. 1) open stands following fire are rapidly recolonized by the same pre-fire dominants of older stands. Adenostoma reestablishes by both resprouting from underground root crowns and by post-fire seed germination. The two other important, long-lived shrubs; Ceanothus cuneatus and Arctostaphylos viscida, are obligate reseeders. In addition to these three shrubs, four other short-lived shrub species which are generally absent from mature chamise chaparral rapidly become established following fire and form the major shrub cover for the first ten years of succession. These are Eriodictyon californicum, Malacothamnus fremontii, Dendromecon rigida and Lotus scoparius.

Woody perennials are not the only important plant group in the early stages of succession. Mixed herb cover also becomes rapidly established and maintains dominance in direct response to the level of total shrub cover (Rundel and Lambert 1982). Fire is not a prerequisite for the establishment of dense herb cover, however. Manual cutting and removal of shrubs has a very similar effect in stimulating herb establishment, although the species composition of herbs may be quite different.

Fires play a very important ecosystem role in cycling limited nutrients back into the soil from litter and woody plant tissues. This role is particularly important in chamise chaparral where there is evidence that limited nutrient availability, particularly for nitrogen, may be a factor in bringing on senescence in mature

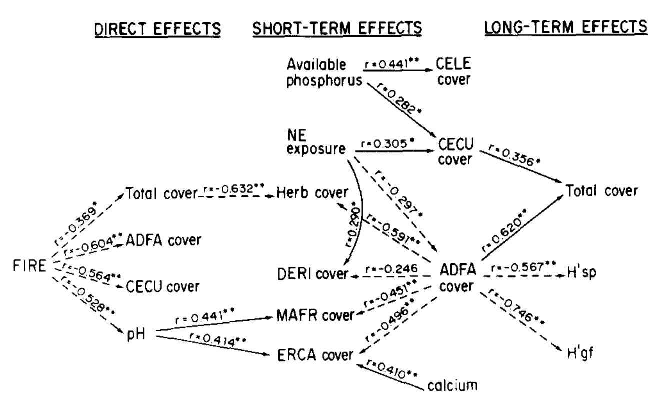


Figure 1. Dynamic model of significant interactions in succession of chamise chaparral at Sequoia National Park. Positive correlations are shown by solid lines and negative correlations by dashed lines. Statistical significance: $^{**}p < 0.01$, $^{*}p < 0.05$.

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-June 23, 1981, San Diego, California.

[2] Professor of Biological Sciences, Department of Ecology and Evolutionary Biology, University of California, Irvine, California 92717.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

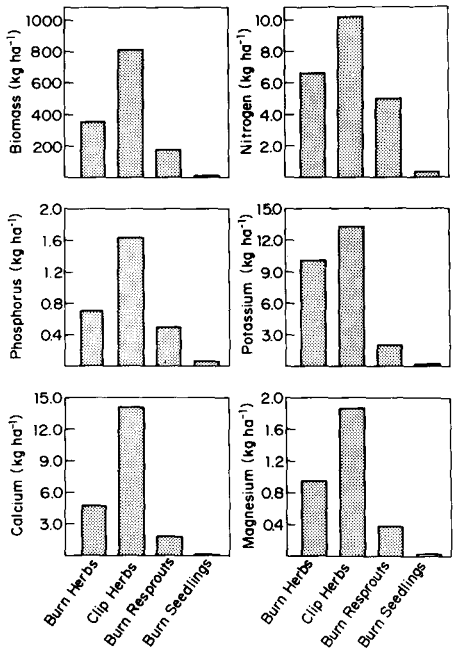


Figure 2. Above-ground biomass and nutrient pool in plant compartments after one year of growth following a fire in fall 1980. Resprout and seedling biomass of Adenostoma fasciculatum in clipped plots are comparable to those in burn plots.

stands (Rundel and Parsons 1980). Although total levels of soil nitrogen may be reduced by the heating effects of fire, inorganic forms of nitrogen available for plant uptake increase significantly (Rundel 1981).

Since litter and plant nutrients are initially recycled in the form of loosely consolidated ash, there has been considerable concern raised by resource managers in protecting this ash from erosion. While resprouts and seedlings of dominant shrub species take up relatively large concentrations of nutrients into their tissues, their total biomass is too small in the first year after fire to successfully tie up a significant percentage of the available nutrients deposited from ash. The dense post-fire herbaceous growth, however, does play a very important ecological role in immobilizing such nutrients and protecting them from loss from the ecosystem (fig. 2). At the end of the spring growing season following a fall 1979 experimental burn at Sequoia National Park, the total herb biomass was more than two times that of Adenostoma resprouts. Adenostoma seedlings were an insignificant part of the total biomass. A similar pattern of herb importance was found for all of the major nutrients as well, demonstrating the importance of herbaceous vegetation in sequestering nutrients. Herb biomass on clip plots was more than twice as great as on burn plots and sequestered considerably more nutrients.

LONG-TERM SUCCESSIONAL PATTERNS

As resprouts of Adenostoma continue to grow rapidly in the first decade of post-fire succession at Sequoia National Park, the importance of short-lived shrubs and herbs declines rapidly (fig. 1). Some species such as Malacothamnus fremontii appear to drop out largely due to a short life cycle and lack of reestablishments of seedlings. Other short-lived shrubs and herbaceous growth, however, appear to be shaded out since their decline in importance is inversely correlated with total shrub cover (Rundel and Lambert 1982). Adenostoma forms the major part of this shrub cover. Canopy closure by long-lived shrubs generally occurs by 20 years after a fire. By this stage short-lived shrubs and significant herb cover are absent from undisturbed stands of chamise chaparral.

Although most researchers suggest that 20-40 years may be a natural cycle for fire in chamise chaparral, many stands at Sequoia have reached considerably greater ages without burning under past policies of fire prevention (Parsons 1981). In such old growth chaparral, the increasing dominance of Adenostoma has very profound effects on the structure and diversity of the community. Ceanothus cureatus, the second most dominant shrub to Adenostoma and an importance browse plant for deer and other animals, drops out before stands reach 60 years of age. Arctostophylos viscida may reach 90 years of age before it dies out, but it is not a major browse plant. Adenostoma itself may live for considerably longer but old-growth chamise chaparral has an increasing level of dead branch tissues with age (Parsons 1976) and becomes less and less productive. Thus old growth chamise is not a productive source of wildlife browse. In addition, the accumulation of large amounts of dead fuels makes these stands highly flammable and subject to unnaturally high intensity fires.

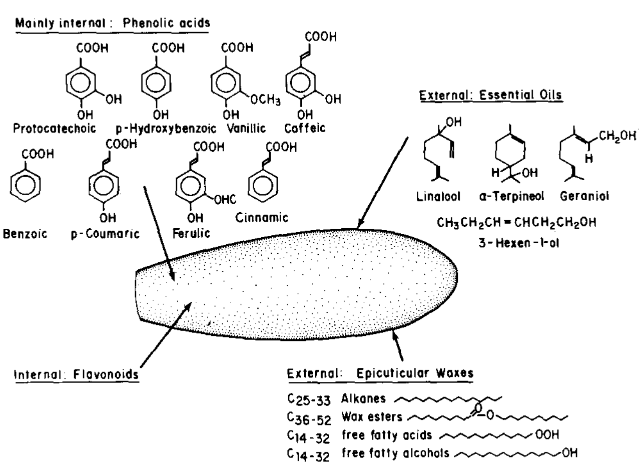


Figure 3. Secondary plant products present in leaves of Adenostoma fasciculatum.

From a management standpoint, therefore, a more natural cycle of chaparral fires would be beneficial.

SECONDARY CHEMISTRY OF ADENOSTOMA FASCICULATUM

The leaves of Adenostoma contain a diverse assemblage of secondary plant compounds and these chemical substances may play very important ecological roles (fig. 3). Phenolic acids in the internal leaf tissues have been associated with alleopathic effects of chamise on competing species. While the ecological significance of allelopathic consitituents in Adenostoma have perhaps been overstated in the past (Muller and others 1968, McPherson and Muller 1969), the potential role of such compounds does deserve careful quantitative consideration. Such studies are now being carried out in conjunction with work on chamise chaparral at Sequoia National Park.

A second group of chemical compounds of ecological significance are the essential oils on the leaf surface of Adenostoma (Fig. 3). These volatile, high-energy compounds are a very important indicator of relative flammability of chamise. They are the most critical aspects of the ether extractive components of leaf tissues which have frequently been linked to flammability (see review by Rundel 1980). As succession proceeds through time there is a significant increase in the ether extractive contents of 1-2 year old leaf and stem tissues in Adenostoma (Fig. 4). This increase has been associated with the increased flammability of older stands.

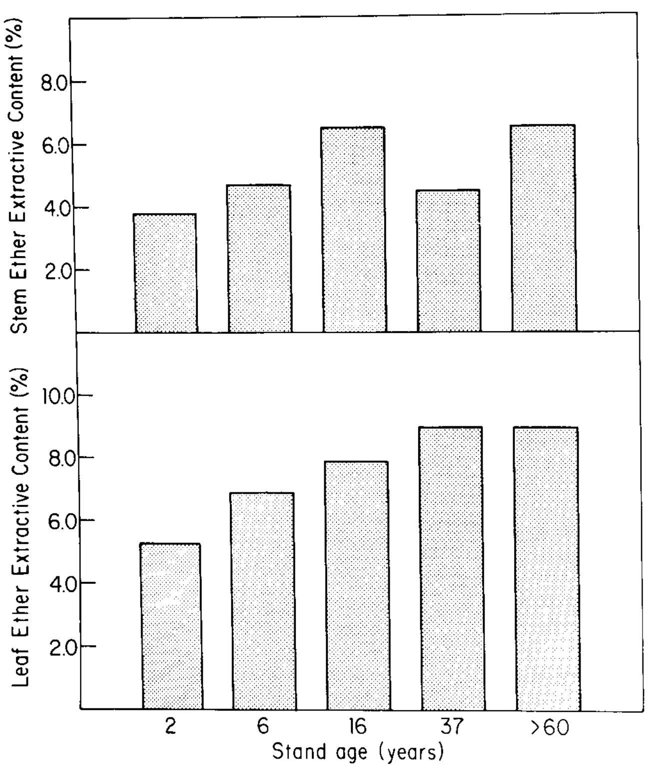


Figure 4. Concentration of ether extractives (percent of dry weight) in 1-2 year leaf and stem tissues of Adenostoma fasciculatum along a gradient of stand age.

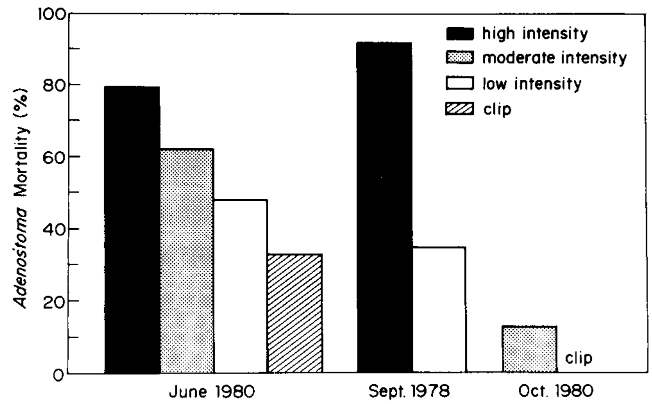


Figure 5. Mortality of root crowns of Adenostoma fasciculatum following fire or clipping treatments.

EFFECTS OF FIRE SEASONALITY AND INTENSITY ON SUCCESSION

Although Adenostoma fasciculatum recolonizes following fires primarily through resprouts, the seasonality and intensity of fire have a great effect on the level of shrub mortality which may occur. Data demonstrating this impact at Sequoia National Park are summarized in figure 5. High intensity experimental fires in June 1980 resulted in nearly 80 percent dead root crowns, while a modest and low intensity fire resulted in 64 and 46 percent mortality, respectively. Only 36 percent mortality resulted following clipping in an adjacent unburned plot. Although a small percentage of dead individuals were present in the stands before the fire, the treatments are the cause of the majority of the mortality. Studies of post-fire recovery from a man-caused chaparral fire in September 1978 at Sequoia found a similar pattern. A very high intensity portion of the fire resulted in 92 percent mortality of root crowns, while only 35 percent mortality was present in a low intensity portion of the burn. The pattern of mortality associated with burns later in the fall is totally different. A moderately intense experimental burn in October 1980 had only 14% mortality. There was no mortality associated with a clipping treatment at this same time.

The seasonal effect of fire on root crown mortality can be readily explained by physiological data on root sprouting collected at the Hopland Field Station of the University of California more than 20 years ago (Jones and Laude 1960, Laude and others 1961). During a "typical" rainfall year such as 1956-57, high levels of starch present in root tissues in the early spring are metabolized and translocated

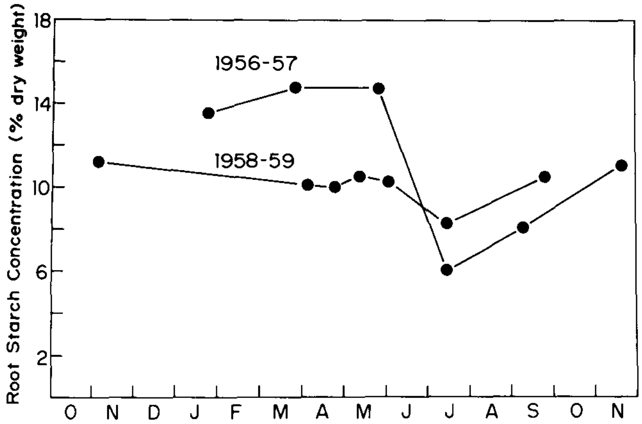


Figure 6. Seasonal pattern of concentration of starches in root tissue of Adenostoma fasciculatum during 1956-57 ("typical" year) and 1958-59 (a dry year). Data from Laude and others (1961).

out as shoot growth occurs (Fig. 6). These root stores of carbohydrate begin to slowly return in late summer and are reconstituted by late fall.

Chamise fires in late spring or early summer burn above-ground tissues at a time when there are few carbohydrate reserves in root systems to allow successful resprouting to occur. At these times of the year fire-or clipping-induced mortality of root crowns is high, particularly in smaller shrubs with less buffering capacity in their root crowns. By mid-fall when root carbohydrate stores have been reconstituted there is little mortality caused by removing above-ground tissues through burning or clipping. In dry years such as 1958-59, large starch reserves are not formed and major mobilization does not take place (Fig. 6). Under these conditions spring or summer fires might produce lower level mortality than in wetter years.

Fire intensity is clearly an important aspect of fire-induced mortality of Adenostoma root crowns. Intense fires, which burn away the major part of above-ground tissues, provide sufficient heat to cause the highest levels of mortality. As intensity declines down to zero (clip treatment), there is a resulting drop in mortality (fig. 5). Such an effect is caused by the depth of the heating front, a function of fire intensity, as it affects root crowns. Small shrubs have the shallowest root crowns with the lowest biomass and are thus most impacted.

MANAGFNENT IMPLICATIONS OF SUCCESSIONAL STUDIES

Basic research on patterns of successional dynamics provides an important framework for understanding the implications of management practices in chamise chaparral. In the first few years following fire, for example, herbaceous vegetation plays a very important role in sequestering nutrients that might otherwise be lost in erosion or runoff. Chaparral managers should be cognizant of this importance and protect this herb growth from livestock grazing or other destructive impacts.

As chamise chaparral matures, the diversity of associated species declines steadily, and the wildlife use also drops correspondingly. Old growth chamise chaparral provides very low productivity with little wildlife value, while producing highly flammable stand structures with the potential for high intensity fires. A return to more natural chaparral fire frequencies, through either controlled burning or allowing natural fires to burn under appropriate conditions, would provide the maintainance of greater stand species diversity and greater availability of wildlife browse. Lower intensity fires would reduce the potential for significant ecosystem damage or property destruction. Similar management recommendations to optimize wildlife values have been described in detail by Biswell and others (1952).

If controlled burning is utilized in chaparral, resource managers should give careful consideration to the implications of fire seasonality and intensity. Intense fires cause significantly more root crown mortality than do light fires. Late spring and summer fires cause far greater mortality than do fall fires. If the management goal is to restore natural fire conditions, as with the National Park Service, then late summer and fall fires should be utilized (see Parsons 1981). Type conversions of chamise chaparral to other vegetation covers, at the other management extreme, would be facilitated by intense early summer fires.

Acknowledgments: I thank Gail Baker, Tom Stohlgren, Steve DeBenedetti, Sherman Lambert, Pete Proksch and David Parsons for their help in this project. The study was supported by the National Park Service and by the Ecosystem Studies Panel of the National Science Foundation.

LITERATURE CITED

Biswell, H. H.; Taber, R.D.; Hedrick, D.W.; Schultz, A.M.. Management of chamise hrushlands for game in the north coast region of California. Calif. Fish and Game 38:453-484; 1952.

Hanes, T.L. Chaparral. In: Barbour, M.G.; Major, J., eds. Terrestrial Vegetation of California. New York: John Wiley. 1977: 417-470.

Hanes, T.L.; Jones, H.W. Postfire chaparral succession in southern California. Ecology 48:259-264; 1967.

Jones, M.B.; Laude, H.M. Relationships between sprouting in chamise and the physiolgical condition of the plant. J. Range Manag. 13:40-214; 1960.

Laude, H.N.; Jones, M.B.; Moon, W.E. Annual variability in indicators of sprouting potential in chamise. J. Range Manag. 14:23-326; 1961.

McPherson, J.K.; Muller, C.H. Alleopathic effects of Adenostoma fasciculatum, "chamise", in the California chaparral. Ecol. Monogr. 39:177-198; 1969.

Muller, C.H.; Hanawalt, R.B., McPherson, J.K. Alleopathic control of herb growth in the fire cycle of California chaparral. Bull. Torrey Bot. Club 95:225-231; 1968.

Parsons, D.J. The role of fire in natural communities: an example from the southern Sierra Nevada, California. Envir. Conserv. 3:41-99; 1976.

Parsons, D.J. The historical role of fire in the foothill communities of Sequoia National Park. Madrono (in press) 1981.

Rundel, P.W. Structural and chemical components of flammability. In: Mooney, H.A. et al, eds. The role of past and present frequency and intensity of fire on ecosystem development and management. Proceedings, conference on fire regions and ecosystem properties; 1978 December 11-15; Honolulu, HI. Gen. Tech. Rep. WO-26. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981.

Rundel, P.W. Fire as an environmental factor In: Lange, O.L. et al (ed.) Physiological Plant Ecology. Vol A. Interaction with the Physical Environment. Berlin; Springer-Verlag. 1981 (in press).

Rundel, P.W.; Lambert, S. Successional dynamics of chamise chaparral in Sequoia National Park, California. Madrono (in press).

Rundel, P.W.; Parsons, D.J. Nutrient changes in two chaparral shrubs aing a fire-induced age-gradient. Amer. J. Bot. 67:51-58; 1980.

Coastal Sage Scrub Succession[1]

Walter E. Westman[2]

Abstract: Unlike chaparral, shrubs of coastal sage are capable of continual seedling reproduction. As a result, mixed-aged stands form which show little senescence. Litter turnover is twice as rapid. The more open sage scrub canopy permits persistence of a diverse herb layer into mature communities. Crown sprouting potential is greater, but heat tolerance of root crowns may be more variable. Higher volatile oil contents compensate for lower fuel loads so that fire frequencies in sage scrub and coastal chaparral are comparable (once per 20 y). Seasonal dimorphism, poikilohydric behavior and leaf deciduousness permit sage species to survive in drier habitats and occupy dry chaparral sites in the early years following fire.

Coastal sage scrub is a soft-leaved (mesophyllous) shrubland community which occurs on sites drier than those of chaparral in the Mediterranean-climate portions of California. While basic patterns of succession in Californian chaparral have been known for some time (Sampson 1944; Horton & Kraebel 1956; Hanes 1971, 1977; Schlesinger & Gill 1978, 1980), those of coastal sage scrub have only recently begun to be examined (Westman 1980a, Westman et al. 1981). In the absence of more information, managers of southern California shrublands have had little alternative but to assume that processes of succession in coastal sage scrub were analogous to those in chaparral and that the two community types could be treated identically for management purposes. Recent information on ecosystem structure and dynamics in coastal sage scrub (Mooney et al. 1977b; Westman 1979a, 1981 a, b, c, d) leads to the conclusion that coastal sage scrub exhibits patterns of succession quite distinct from those of chaparral by virtue of differences in its structure, physiognomy and habitat. These differences suggest the need for distinctive management practices for the type. This paper contrasts structural and dynamic features of coastal sage scrub with those of chaparral in order to highlight how these differences lead to distinctive successional patterns.

DISTRIBUTION OF THE COMMUNITY TYPES

Coastal sage scrub occurs discontinuously from the latitude of San Francisco south to El Rosario in Baja California (Fig. 1). It is found most extensively in the lower elevations of coastal southern California, but occurs up to 1300m in elevation in the Coast Ranges (e.g. Cuyamaca Mountains, San Diego County), and intergrades to Mojave desert vegetation to the east and to Sonoran vegetation in Baja California. Kirkpatrick and Hutchinson (1977) and later Axelrod (1978) and Westman (1981b) recognized three major floristic associations in southern coastal sage scrub: a coastal group (Venturan), a cismontane inland group (Riversidian), and a Baja-influenced group (Diegan). The Diegan association shows the increased influence of succulents, and is probably best treated as a distinct community type (coastal succulent scrub: Mooney & Harrison 1972, Mooney 1977; Mooney et al. 1977b; maritime cactus scrub: Philbrick & Haller 1977). North of Point Conception, the coastal shrubland shows an increased abundance of evergreen shrubs (*Baccaris pilularis*, *Arctostaphylos* spp.), and is termed northern coastal scrub (Heady et al. 1977). The southern

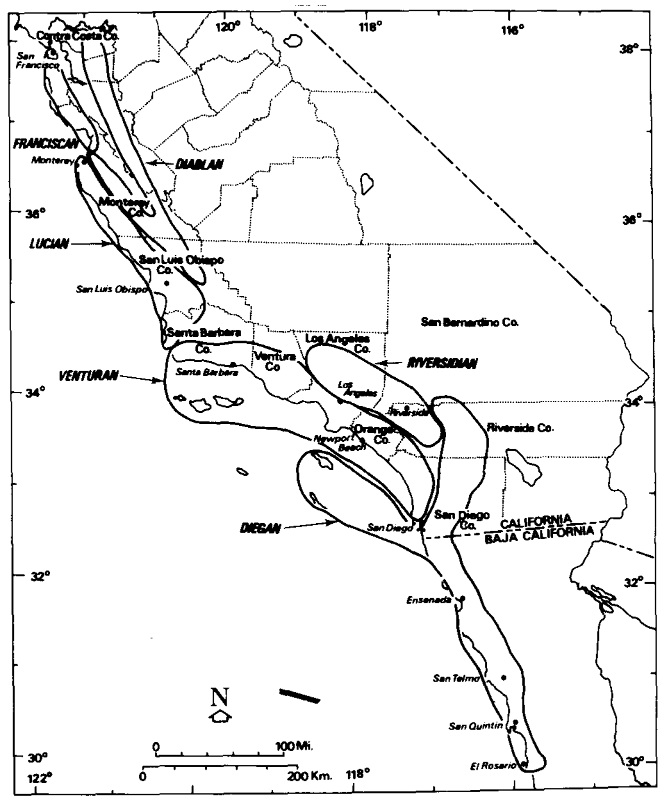


Figure 1. Approximate distributions of the major floristic associations within southern coastal sage scrub, after Axelrod (1978), Westman (1981b) and Westman, field observations.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Geography, University of California, Los Angeles, California 90024 USA

coastal sage scrub, dominated by species of Salvia, Encelia, Eriogonum and Artemisia, occurs in discontinuous patches on drier slopes to its northernmost occurrence in the Mt. Diablo area. In the present paper, the term "coastal sage scrub" refers primarily to the Venturan and Riversidian floristic associations. Where evergreen chaparral is adjacent to coastal sage scrub, it is found on more mesic sites, generally at higher elevations in the Coast Ranges. It also extends to the slopes of the Sierra Nevada, and to areas north of San Francisco (Hanes 1977).

PHYSIOGNOMIC ATTRIBUTES AND THEIR CONSEQUENCES FOR SUCCESSION

Leaf Structure

Chaparral shrubs have sclerophyllous leaves, typically thickly cuticularized and more resistant to water loss than the thin, mesophyllous leaves of coastal sage scrub. A few important chaparral dominants (e.g. Adenostoma fasciculatum) have narrow leaves, whereas virtually all mesophyllous sage dominants have broader leaves. The lower transpiration rates of chaparral leaves generally result in lower photosynthetic rates per unit leaf mass (Harrison et al. 1971). While net primary productivity on an areal basis is 1.4 - 3.3-fold greater for chaparral than sage scrub (chamise chaparral: Mooney & Rundel 1979; Ceanothus chaparral: Schlesinger & Gill 1980; Venturan sage: Gray & Schlesinger. 1981), the growth is spread more evenly over the year, whereas it is limited to the 5 - 6 months following onset of rains in sage scrub (Gray & Schlesinger 1981). While the latter is due in part to the drought-intolerant mesophyllous leaf structure, shallower roots and lower surface soil moisture stores also contribute to the shorter growing season of sage scrub. An implication of the mesophyllous leaf structure for succession is that sage scrub recovery is more likely to be sensitive to the time of year of applied stress than is chaparral. Thus sage scrub would probably suffer less damage to energy stores and recovery potential from defoliation stresses (grazing, fire, air pollution) occurring from June to November, and more from December to May, than chaparral.

Winner and Mooney (1980) have documented the increased susceptibility of the mesophyllous leaves of sage to SO_2 damage relative to sclerophyllous chaparral leaves. Suggestive evidence for damage to sage scrub in the field has been reported for SO_2 by Westman & Preston (1980) and for ozone by Westman (1979b). Preston and Westman are currently untertaking controlled fumigation experiments on sage species with SO_2 and ozone. A management implication is that sites of coastal sage make less desirable locations for siting of new pollution sources of SO_2 and ozone precursors than do chaparral sites.

Leaf Duration

The average life span of a leaf on a chaparral shrub is not precisely known. Leaf half-lives for other evergreen angiosperm species have been measured at 10 - 14 months (Eucalyptus spp.: Rogers & Westman 1981), and data of Mooney and Kummerow (Mooney et al. 1977, Fig. 5-18, 5-19) suggest similar durations for Heteromeles arbutifolia and Ceanothus leucodermis. By contrast, mesophyllous sage scrub leaves invariably have shorter leaf durations (e.g. 30-50 days for Artemisia californica: Gray & Schlesinger 1981).

Coastal sage scrub has frequently been referred to as a "drought deciduous" community type (e.g. Mooney 1977; Kirkpatrick & Hutchinson 1977; Westman 1979a). Very few shrub species in this community type, however, lose all of their leaves during the dry season. A number of small tree species in the Diegan formation (Aesculus parryi and A. californica (Mooney & Bartholomew 1974); Fraxinus trifoliata; Ptelea aptera; Prunus fremontii) do show total seasonal deciduousness. Some of these (F. trifoliata, Aesculus spp.) are of Miocene age in the region (Axelrod 1978). It is quite possible that these species retained the deciduous habit as a photoperiodically triggered one from seasonally dry tropical (Axelrod 1978) or even temperate deciduous forest ancestors. These species are absent from the Riversidian and Venturan associations, where most species were probably derived from xeric margins of live-oak woodland and dry tropic scrub in the early Quaternary (Axelrod 1978). Of the shrubs in the latter associations, one of the species showing most complete summer deciduousness is Lotus scoparius. Nilsen & Muller (1980) showed that this species, while dropping some leaves due to water stress, will drop them more completely during long days than short days, suggesting a photoperiodic component to deciduousness in this species.

The most common adaptation to summer water stress in coastal sage scrub is not total deciduousness, but the production of smaller leaves on side shoots developing from the axils of larger, main-shoot leaves. In the most common pattern, main-shoot leaves are formed in the first flush of winter growth when moisture is most abundant. Almost immediately after these leaves are formed, side shoots begin to grow. Main-shoot leaves fall off acropetally as the summer drought develops, but the smaller side shoot leaves persist, to varying extents, until the following winter rainy period, whereupon the leaves fall and the shoots may now become main stems producing larger leaves, or may die. Westman (1981c) observed this pattern in most mesophyllous coastal sage shrubs examined, and Gray & Schlesinger (1981) recently described it for Salvia leucophylla and S. mellifera. This seasonal dimorphism is best developed in analogous mesophyllous shrublands in the Mediterranean (Orshan 1963), where it has been shown to be photoperiodically triggered (Margaris 1975). The phenomenon has also been reported from Chile (Montenegro et al. 1979a) and South Africa (R.M. Cowling, pers. comm. in Westman 1981c).

A third leaf-duration strategy occasionally found in sage scrub is poikilohydric behavior: the ability of leaves to wilt for long periods, and rehydrate within hours of a rainfall. This behavior is exhibited by Artemisia californica (which is also seasonally dimorphic: Westman 1981c), a shrub with one of the widest moisture tolerances and distributional ranges of any sage scrub dominant (Westman 1981b). It has also been reported from analogous vegetation in Chile (Montenegro et al. 1979b), South Africa (Gaff 1971) and Australia (Gaff & Churchill 1976).

Much remains to be investigated regarding the small, summer leaves in sage scrub species. Are these leaves physiologically more drought-tolerant than the early growing season leaves? Cunningham & Strain (1969) and Smith & Nobel (1977) have shown this to be the case for the sage/desert-margin species, Encelia farinosa, but it is not known how widespread this phenomenon is. Is production of the smaller leaves triggered photoperiodically, as in the Mediterranean? Field observations suggest not, since the sage scrub leaves can begin growth almost at the same time as main-shoot leaves expand, and because the degree of their persistence in the dry season is so variable. Indeed, in the latter feature lies their adaptiveness, since seasonal dimorphism, combined with facultative drought-deciduousness, provides an extremely flexible strategy for fine-tuning total leaf mass to moisture availability in the highly variable precipitation regime of the Mediterranean climate, while providing individual leaves that can perhaps better withstand drier conditions.

The implications of these differences in leaf duration for succession are only beginning to be explored. Westman (1981c) reported that two years following fire, there was a two-fold increase in foliar cover of seasonally-dimorphic shrubs in a coastal Venturan-formation site, relative to a 22-year-old pre-burn condition. It is possible that seasonal dimorphism provides a more effective post-fire recovery strategy on the barren, dry burned sites. This may help explain why coastal sage species frequently occupy drier post-burn chaparral sites in early years of post-fire succession (Hanes 1977). Seasonal dimorphism is restricted to mesophyllous shrubs, and does not occur in sclerophyllous shrubs, either those of the chaparral, or those which occur as associates in coastal sage communities (e.g. Rhus laurina, R. integrifolia).

Leaf oil content

More of the dominant shrub species of coastal sage scrub are highly aromatic than those of chaparral. Unfortunately, quantitative data on the relative flammability and caloric contents of leaves in coastal sage and chaparral are lacking. Chamise (Adenostoma fasciculatum) is known to have unusually high flammability due in part to its oil content. Its leaf caloric content averages 5220 cal g^{-1} vs. a mean of 4890 cal g^{-1} for seven other chaparral shrubs (Mooney et al. 1977a). There are several preliminary bases for postulating a higher flammability for sage than chaparral species, all of which need further study: the high content (Tyson et al. 1974) and more widespread occurrence of volatile oils; the less dense wood; field observations suggesting that complete consumption of aboveground fuel is more common during fires in sage scrub than chaparral.

If the higher flammability of aboveground parts of sage scrub is confirmed, the evolutionary explanation for it may be sought as a corollary to the Mutch (1970) fire-dependence hypothesis. Because of a Mediterranean-type climate with a long dry season, but sufficient precipitation to support an aboveground biomass capable of sustaining fire, fires are common in both shrublands types, and adaptations for fire-dependence have evolved in both cases. The lower fuel mass and greater spacing of shrubs in coastal sage would normally act to decrease fire frequency in coastal sage relative to chaparral. This tendency could be counteracted by the evolution of a greater abundance of volatile, flammable oils in sage scrub than chaparral.

Indirect supporting evidence for this hypothesis comes from an analysis of fire frequency during the period 1930-1978 in chamise chaparral and coastal sage scrub in the western Santa Monica Mountains. In each vegetation type, 50 random points were located, and fire frequency determined. The vegetation map used was prepared by G. Nuno (1980, unpublished) based on data of the Vegetation Type Map Survey of Wieslander. This vegetation map was overlaid upon a map of fire occurrences in the Western Santa Monica Mountains (K. Radtke, unpublished). Results indicate that fire frequencies are just as great in coastal sage as in chaparral ($\overline{X}$ occurrences for the 48-year period ± s.e.: 2.46 ± 0.11 for coastal sage scrub; 2.32 ± 0.15 for chamise-chaparral) despite lower fuel loads in the former. Mean fire interval in both types was 20 years.

Twig and Stem Structure

Biomass

Wood of coastal sage shrubs is less dense and more brittle than that of chaparral (Mooney et al. 1977b; Gray & Schlesinger 1981). A consequence of this is that large woody stems do not remain standing, either dead or alive, as long as they do in chaparral. Gray & Schlesinger (1981) report a standing dead wood component of 18 percent in Venturan sage scrub, approximately half the amount for chaparral.

This feature in turn has two important implications for succession. Firstly, the more rapid return of dead wood to the litter layer provides improved nutrient turnover, and diminishes the chance for deficiencies in available nutrient stocks to develop, leading to the growth senescence reported for chaparral (Hanes 1971). A second implication is that dry fuel will be a

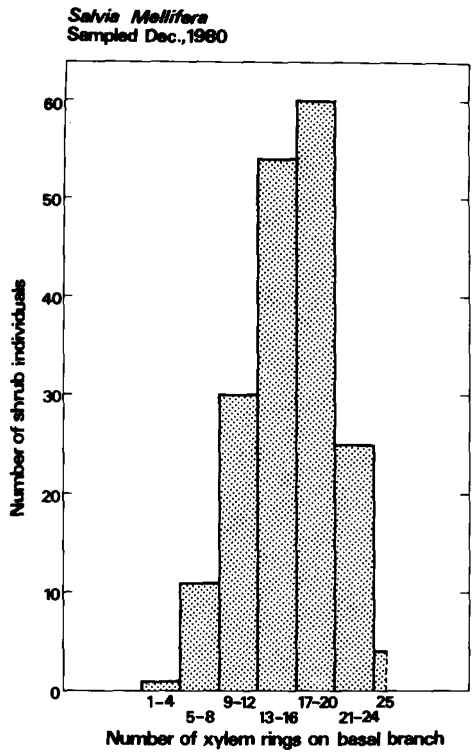


Figure 2. Numbers of individuals of Salvia mellifera showing a given number of xylem rings on the lowest branch, on a 23-year-old coastal Venturan site. Some individuals showed one or two extra rings as a result of the production of double rings in some years.

lower proportion of total biomass in coastal sage than chaparral, contributing to a reduction in fire intensity. This, combined with the lower living biomass per unit area, results in lower total fuel loads than chaparral. Whether these lower fuel loads result in lower fire intensities than chaparral has yet to be documented in the field and, as noted earlier, may be counteracted by higher volatile oil contents in foliage. Westman et al. (1981) calculated fire intensities on coastal sage sites, using the FIREMODS model of Albini (1976a) which is based primarily on fuel load, fuel moisture conditions and weather at the time of fire. For Venturan types reaction intensities were 170 - 200 kcal $sec^{-1}m^{-2}$; for Riversidian types, 120 - 170 kcal $sec^{-1}m^{-2}$. These values are low for the range of values modeled in fires in older chaparral (up to 600 kcal $sec^{-1}m^{-2}$; Albini 1976b), but the latter are not field measurements. Fire intensities clearly affect root crown survival, and subsequent patterns of successional regrowth (Westman et al. 1981).

Decomposition Rates

Whether the more rapid rate of return of wood to the litter layer in fact results in more rapid external nutrient cycling in coastal sage depends on litter decay rates. To calculate litter half-lives by the exponential decay-rate model requires assuming that the litter mass is in steady state (Whittaker 1970). Kittredge (1955) found that litter mass in a variety of chaparral and mixed sage-chaparral types reached equilibrium in 8 - 20 years. In the 22-year-old Venturan sage site, if litter mass is assumed to be at equilibrium, litter half life is 2.2 years (data of Gray & Schlesinger 1981). The litter half-lives of two mixed sage-chaparral sites in the San Dimas Experimental Forest (Los Angeles County) were 1.8 and 3.6 years (data of Kittredge 1955), during a period when sites were 14 - 31 years old. By contrast, nine chaparral sites of the same age range exhibited a mean litter half-life of 4.4 years (range: 1.8 - 12.4 years; data of Kittredge 1955). Though site-to-site variation is great, on the average litter decay rates are twice as great in coastal sage than chaparral. The sclerophyllous nature of chaparral leaves, and their lower nutrient contents (Mooney 1977) would inhibit leaf litter decay rates relative to sage scrub, as would the higher wood density of chaparral (Gray & Schlesinger 1981).

Canopy Closure

Stems of coastal sage species rarely exceed 2 m in height, and average canopy heights more commonly range from 0.5 - 1.8 m. By contrast, chaparral canopies are commonly 2 - 3 m. The density of foliage on stems is lower in sage, resulting in lower leaf area indices per shrub ($\overline{X}$ = 1.31 sage vs. 2.65 chaparral; Mooney et al. 1978). On drier sage sites, shrub densities fall below the point at which canopy closure is obtained. As a result of all of these factors, light penetration to ground level is greater in coastal sage than chaparral. For example, while stands of Ceanothus chaparral of 22 year age have irradiances immediately below the canopy of 200 - 900 microEinsteins m^2 sec^{-1} (Schlesinger & Gill 1980), two stands of Venturan sage of 22 year age at Leo Carillo State Park had mean irradiances of 900 - 1000 microEinsteins $m^{-2}sec^{-1}$ at 10 cm above ground, and one-fifth of the 50 readings per stand were in canopy gaps (Westman, unpublished).

Understory Growth

The result of this more open canopy structure is an increased persistence of understory growth as the sage scrub matures. Thus while herbs are reduced to a very minimal occurrence in chaparral by five years after fire, they remain an important part of total cover (greater than 20 percent) for 20 years or more following fire in coastal sage (Westman 1981c).

Muller (McPherson & Muller 1969 et subseq.) has argued that shading is not a factor in herb suppression in chaparral, since herbs are absent from bare areas under canopy openings in mature chaparral. He argues instead for the role of allelopathic substances in herb suppression in both chaparral and coastal sage scrub (Muller & Muller 1964; Muller et al. 1968). However, once herb cover in chaparral has been reduced for whatever reason, there will be fewer seeds locally to disperse into bare areas, so that the relative absence of herbs from these areas cannot be taken as unequivocal evidence for inhibition.

The presence of potentially allelopathic substances in both chaparral and sage species has been established (Christensen & Muller 1975; Halligan 1973). The dramatic differences in herb cover between the two community types despite the abundance of allelopathic substances in both in itself suggests that factors other than allelopathy are playing major roles in inducing herb cover differences. The role of shading, rodents and other factors in inducing these differences has recently been reviewed (Mooney 1977; Westman 1979, 1981d). The critical importance of allelopathy in herb suppression has not yet been established.

Long-term viability of chaparral and sage scrub herb seeds has never been established (Went 1969; Westman 1979a). Since 58 percent of the immediate post-fire herbs in chaparral can be found in sage sites that have not burned in seven years or more, Westman (1979a) has suggested that post-fire herbs in chaparral seed in from adjacent coastal sage (and recently burned chaparral sites) every year, rather than remaining dormant in the soil for the many decades that can elapse between fires on a chaparral site. The seedlings only survive in the immediate post-fire chaparral environment, because of the abundance of light and nutrients or other factors. This suggests that coastal sage scrub is playing a role as respository for herbs that colonize chaparral after fire. A management implication is that, in order to assure native herb colonization of post-fire chaparral sites, one should not only ensure a mosaic of chaparral sites of various ages, but also preserve stands of coastal sage scrub that may be in the vicinity.

Shrub Reproduction

Westman et al. (1981) report that shrub seedling reproduction following fire in coastal sage scrub does not become common until the second year after fire. In the cases of *Encelia californica*, *Artemisia californica*, *Eriogonum cinereum* and *Yucca whipplei*, they observed crown-sprouting in the first year, and seedling reproduction only after these sprouts had flowered and set seed. In the case of *E. californica*, abundant seedling reproduction was visible a few cm. downslope of a resprout of the species which had set seed. This strongly suggests that shrub seeds on the site arise largely from "self-sowing" by crown sprouts following fire, rather than by survival of seeds through fire or by long-term seed dormancy. This conclusion is further strengthened by the slow return of shrub seedlings to Riversidian sites in which little or no crown sprouting is occurring (Westman et al. 1981).

Malanson and O'Leary (1981, in preparation) have further documented the relative reproduction by resprouts and by seeds at the end of the second year after fire on 7 sites including 4 reported earlier (Westman et al. 1981). Of 17 coastal sage shrub species encountered, all but *Eriogonum fasciculatum* and *Malacothamnus fasciculatus* showed substantially greater reestablishment of foliar cover by resprouting than seeding. Total foliar cover of resprouts exceeded that of seedlings by factors of 13 to 71 on the sites.

These studies leave little doubt that when fires do not kill root crowns, the main strategy for post-fire recovery in coastal sage scrub is by resprouting. In fact, the number of sage scrub species with the ability to resprout appears to exceed that of chaparral. Hanes (1971) reported that only 50 percent of the 59 shrubs in coastal chaparral are capable of resprouting. By contrast, of the 25 most widespread and dominant shrubs and small trees in coastal sage scrub, 100 percent of them show crown-sprouting ability, as do 28 percent of the herb species (Westman 1981d).

Earlier authors (e.g. Zedler 1977; Bradbury 1978; Kirkpatrick & Hutchinson 1980) have asserted that crown sprouting was not as common in coastal sage scrub as in chaparral. These observations may have arisen from the fact that there are sites of coastal sage scrub in which no crown-sprouting occurs following a particular fire, despite the presence of shrubs with the genetic potential to resprout (Westman et al. 1981). Westman et al. (1981) studied the relative roles that fire inten-

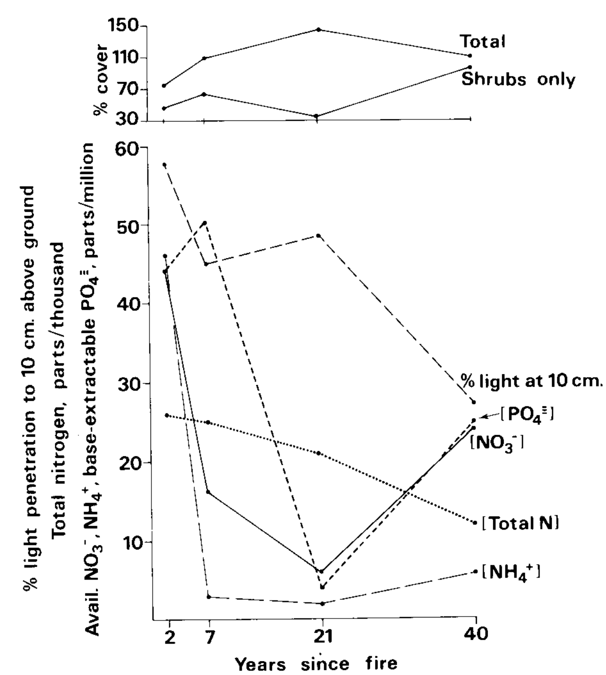


Figure 3. Trends in foliar cover, light penetration to herb level, and soil nutrient levels in four coastal sites of SW aspect, slope 7°-28°, in the Santa Monica Mountains (Los Angeles County). All substrates were shale, except the 7-year site, which was volcanic. The 21-year old site burned shortly after sampling and was resampled to provide the 2-year old site. Data from Westman 1981a, Westman et al. 1981 and Westman, unpublished.

sity, aspect, substrate and other factors might play in inducing this variability. They concluded that the potential vigor of resprouting is a genetic characteristic which varies widely from species to species, and possibly even among subspecies or ecotypes (e.g. Eriogonum fasciculatum). Thus a fire of lower intensity might be followed by less reprouting than a site of higher intensity burn, if the species colonizing the former have lower heat tolerances and are inherently less vigorous reprouters. Westman et al. (1981) provide a table of imputed tolerances of a range of coastal sage scrub species to fire intensity. It is possible that chaparral species capable of resprouting have a higher tolerance to fire intensity, but quantitative data on this point are lacking.

Age Structure

While chaparral seedlings cease to provide new recruits to the population after 5-10 years following fire, sage species are capable of continual seedling reproduction under their own canopy. Schlesinger & Gill (1978) document thinning in a chaparral stand of Ceanothus megacarpus in which there was apparently no seedling reproduction after the first year, and Hanes (1971) notes that seedling reproduction in chamise and mixed chaparral stands is only observable in the first decade after fire. By contrast, figure 2 shows the continual recruitment of individuals of Salvia mellifera to a Venturan coastal sage site in the 23 years after fire. Hanes (1971) similarly noted continual reproduction of sage species in openings in chaparral.

A significant implication of this difference in recruitment periods is that coastal sage scrub stands do not grow "senescent" as do chaparral stands of increasing age, because of the continual rejuvenation of the age structure in the former. Indeed, healthy stands of sage scrub occur which have not burned in 60 years or more, and in which the oldest dominant does not exceed 35 years in age (Westman 1981a). While allelopathy was suggested (Hanes 1971) as a cause of senescence in chaparral, this seems inadequate in view of the abundance of allelopathics in coastal sage scrub and the lack of senescence in its age structure. The failure of seedling survival, the tie-up of nitrogen in the aboveground parts, and the rising respiratory load of shrubs could provide an alternative explanation for chaparral senescence.

Differences in age structure between the community types also help us to understand why coastal sage and chaparral will occasionally maintain sharp, stable borders between them on a given hillside for many decades (e.g. Bradbury 1978). The sage shrubs, though shorter-lived, retain a healthy community through continual seedling reproduction. Sage seeds, while capable of germinating in the open canopy environment of sage scrub, are inhibited from growth under chaparral by shading (McPherson & Muller 1967). The chaparral, by contrast, produces seeds which typically germinate only in the first few years after fire, for a variety of reasons: scarification requirements, nutrient deficiencies, herbivore grazing, possibly allelopathic inhibition (viz. Bradbury 1978; Christensen and Muller 1975; Hanes 1977 inter alia). The chaparral shrubs are longer-lived, however, and maintain an even-aged stand composed of the original post-fire shrubs, for many decades. In situations where climatic conditions or herbivore pressure prevent seedling establishment in the first year or two after fire, and reestablishment of vegetative canopies occur rapidly through crown sprouting, conditions would have obtained which would prevent either community type from invading the other in subsequent years.

Figure 3 shows trends in nitrogen, phosphorus and light penetration on coastal sage sites of different ages, on similar aspects, slopes and substrates. While total nitrogen does decline with age, available pools of N and P remain high at 15 cm depth even to age 40. This suggests that high rates of external nutrient cycling, and lower nutrient stocks in standing biomass, are responsible for maintenance of available nutrient pools in sage scrub. Still, with the decline in light penetration, seedling reproduction can be expected to decline with age, inducing some senescence in age structure, though not as severe as that in chaparral.

Experimental application of N and P to stands of Salvia mellifera of similar age range resulted in maximum shoot growth response to N alone or N with P, at age 25 (Davis 1980). The nitrogen response is not surprising in view of the lack of symbiotic N-fixers in coastal sage after age 20 (Westman 1981a). A similar shoot growth response to N has been found in chaparral (Hellmers et al. 1955a).

Fibrous Roots

Roots of coastal sage scrub species are, in general, shorter in both lateral and vertical spread than those of chaparral, and more fibrous (Hellmers et al. 1955b). Hellmers et al. (1955b) discussed the implications of this difference for surface soil erosion, mass slumping and water infiltration. The more fibrous roots of coastal sage apparently make them somewhat more efficient at capturing the early and light rains, and using this moisture for shoot growth (Harvey & Mooney 1964).

The microbial associates of the root systems are still poorly known. Symbiotic N-fixation occurs in some Ceanothus spp. (Kummerow et al. 1978), which persist in chaparral stands for at least 40 years. By contrast, the only substantial N-fixing symbiotic shrub species identified in coastal sage scrub is Lotus scoparius, which dies out within 20 years (Westman 1981a). Minor species of Lotus and Lupinus occur generally only in the first few years after fire, and do not produce significant biomass. Dunn & Poth (1979) report no asymbiotic N-fixation in chaparral soils during the January-June period. The only known sources of initial N in coastal sage scrub at present, then, are a small amount of symbiotic N-fixation in the early post-fire years, and bulk precipitation. While nutrient recycling may be more rapid in sage, and uptake demand lower, the small sources of external N seem inadequate to balance the N budget; further research is needed on this point. A management implication, earlier drawn for chaparral, that fire temperatures be kept down to avoid N volatilization losses, and moist soils avoided during fire to avoid steam-killing of legume seeds (Dunn & Poth 1979), is even more critical to coastal sage scrub management.

Most coastal sage shrubs are believed to possess vascular-arbuscular mycorrhizae. The role these play in the plant nutrition of their hosts is unknown. Mycorrhizal associations are susceptible to air pollution damage (McCool & Menge 1978). Weeks and Westman are currently undertaking fumigation experiments to examine the effects of SO_2 and ozone on the endomycorrhizal associations of sage species.

CONCLUDING REMARKS

Analysis of the structural differences between coastal sage and chaparral permit an increased understanding of the differences in their successional processes. Malanson (1981, this volume) is currently working under Westman's supervision to produce a model of post-fire succession in coastal sage scrub based on the relative sprouting and seeding propensities of component species, scenarios of age-dependent natality and mortality rates, and models of interspecific competition. The underlying rationale for such a model is that succession in sage scrub is a process of scramble competition for resources following fire, in which crown sprouting vigor plays a key role. The model is in the tradition of the population-level analyses arising from the individualistic hypothesis (e.g. Whittaker & Levin 1977, Noble & Slatyer 1980).

Much remains to be learned about successional processes in coastal sage scrub. We already know that succession in coastal sage differs from that in chaparral in a number of respects. Herb growth after fire in sage scrub persists into the mature stands, where ground-level light continues to be abundant. Shrub dominants continue to reproduce by seed many decades after fire, maintaining healthy, mixed aged stands which may slow in growth rate and seedling reproduction only slightly after four decades or more. Crown-sprouting is even more important as a post-fire reproductive strategy among sage scrub dominants, but the vigor and heat-resistance of the sage species root crowns may be more variable than for chaparral.

For preservation of both root crowns and soil nitrogen levels, low-intensity fires are to be favored if rapid post-fire recovery is the goal. On the other hand, continued favoring of crown-sprouting will suppress the post-fire herb flora somewhat, and could lead to a gradual decline in seeds for both chaparral and sage scrub post-fire herb communities in the long term.

The susceptibility of coastal sage scrub to air pollution damage (SO_2, possibly ozone) is greater than that for chaparral. Sage scrub species therefore make better biological monitors of the air pollution damage being suffered by southern California shrublands than do chaparral species.

Finally, it should be noted that much less acreage of coastal sage scrub than of chaparral is in preserve status. Coastal sage scrub is one of the most endangered habitats in California. Estimates of the extent of the former vegetation which has been cleared range from 36 to 85 percent for coastal sage (Klopatek et al. 1979; Westman 1981a) compared to 12 percent for chaparral (Klopatek et al. 1979). The samples that do exist are virtually all of the Venturan type. Increased efforts should be made to set aside areas of Riversidian and Diegan, as well as Venturan associations of coastal sage scrub, for the benefit of present and future generations.

ACKNOWLEDGEMENTS

Unpublished data of W. Westman, G. Malanson and J. O'Leary were obtained with support of grant DEB 76-81712 from the Division of Environmental Biology, U.S. National Science Foundation.

LITERATURE CITED

Albini, F.A. Computer-based models of wildland fire behavior: a user's manual. Ogden, Utah: Intermountain For. Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1976a; 68 p.

Albini, F.A. Estimating wildfire behavior and effects. Forest Serv., U.S. Dep. Agric.: 1976b, Gen. Tech. Rep. INT-30.

Axelrod, D.A. The origin of coastal sage vegetation, Alta and Baja California. Amer. J. Bot. 65: 1117-1131, 1978.

Bradbury, D.E. The evolution and persistence of a local sage/chamise community pattern in southern California. Yearbook Assoc. Pacif. Coast Geographers 40: 39-56, 1978.

Christensen, N.L.; Muller, C.H. Relative importance of factors controlling germination and seedling survival in Adenostoma chaparral. Amer. Midl. Nat. 93: 71-78, 1975.

Cunningham, G.L.; Strain, B.R. An ecological significance of seasonal leaf variability in a desert shrub. Ecology 50: 400-408, 1969.

Davis, Z.W. The effects of applied nutrients on Salvia mellifera (black sage) stands of different ages. M.A. thesis, Univ. Calif., Los Angeles, 1980.

Dunn, P.H.; Poth, M. Nitrogen replacement after fire in chaparral. In: Gordon, J.C.; Wheeler, C.T.; Perry, D.A., eds., Symbiotic Nitrogen Fixation in the Management of Temperate Forests. Corvallis, Ore.: Forest Res. Lab., Oregon State Univ., 1979: 287-293.

Gaff, D.F. Desiccation-tolerant flowering plants in southern Africa. Science 174: 1033-1034. 1971

Gaff, D.F.; Churchill, D.M. Borya nitida Labill.: An Australian species in the Liliaceae with desiccation-tolerant leaves. Aust. J. Bot. 24: 209-224; 1976.

Gray, J.T.; Schlesinger, W.H. Biomass, production, and litterfall in the coastal sage scrub of southern California. Amer. J. Bot. 68: 24-33; 1981.

Halligan, J.P. Bare areas associated with shrub stands in grassland: the case of Artemisia californica. BioScience 23: 429-432; 1973.

Hanes, T.L. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41: 27-52; 1971.

Hanes, T.L. Chaparral. In: Barbour, M.; Major, J., eds. Terrestrial Vegetation of California. New York: J. Wiley; 1977: 417-470.

Harrison, A.; Small, E.; Mooney, H.A. Drought relationships and distribution of two mediterranean climate California plant communities. Ecology 52; 869-875; 1971.

Harvey, R.; Mooney, H.A. Extended dormancy of chaparral shrubs during severe drought. Madroño 17: 161-165; 1964.

Heady, H.F.; Foin, T.C.; Hektner, M.M., Taylor, D.W.; Barbour, M.G.; Barry, W.J. Coastal prairie and northern coastal scrub. In: Barbour, M.G.; Major, J. eds. Terrestrial Vegetation of California. New York: J. Wiley; 1977; 733-762.

Hellmers, H.; Bonner, J.; Kelleher, J.M. Soil fertility: a watershed management problem in the San Gabriel mountains of southern California. Soil Science 80: 189-197; 1955a.

Hellmers, H.; Horton, J.S.; Juhren, G.; O'Keefe, Root systems of some chaparral plants in southern California. Ecology 36: 667-668; 1955b.

Horton, J.S.; Kraebel, J.C. Development of vegetation after fire in the chamise chaparral of southern California. Ecology 36: 244-262; 1955.

Kirkpatrick, J.B.; Hutchinson, C.F. The community composition of Californian coastal sage scrub. Vegetatio 35: 21-33; 1977.

Kittredge, J. Litter and forest floor of the chaparral in parts of the San Dimas experimental forest, California. Hilgardia 23: 563-596; 1955.

Klopatek, J.M.; Olson, R.J.; Emerson, C.J.; Joness, J.L. Land-use conflicts with natural vegetation in the United States. Envir. Conserv. 6: 191-199; 1979.

Kummerow, J.; Alexander, J.V.; Neel, J.W.; Fishbeck, Symbiotic nitrogen fixation in Ceanothus roots. Amer. J. Bot. 65: 63-69; 1978.

Margaris, N.S. Effect of photoperiod on seasonal dimorphism of some mediterranean plants. Ber. Schweiz. Bot. Ges. 85: 96-102; 1975.

McCool, P.M.; Menge, J.A. Interaction of air pollutants and mycorrhizae. California Air Envir. 7: 1,2,4; 1978.

McPherson, J.K.; Muller, C.H. Light competition between Ceanothus and Salvia shrubs. Bull. Torrey Bot. Club 94: 41-55; 1967.

McPherson, J.K.; Muller, C.H. Allelopathic effect of Adenostoma fasciculatum, "chamise", in the California chaparral. Ecol. Monogr. 39: 177-198; 1969.

Montenegro, G.; Aljaro, M.E.; Kummerow, J. Growth dynamics of-Chilean mattoral shrubs. Bot. Gaz. 140: 114-119; 1979a.

Montenegro, G.; Hoffman, A.J.; Aljaro, M.E.; Hoffman, A.E. Satureja gilliesii, a poikilohydric shrub from the Chilean mediterranean vegetation. Can. J. Bot. 57: 1206-1213; 1969b.

Mooney, H.A. Southern coastal scrub. In: Barbour, M.; Major, J., eds. Terrestrial Vegetation of California. New York: J. Wiley; 1977; 471-490.

Mooney, H.A.; Bartholomew, B. Carbon balance of two Californian Aesculus species. Bot. Gaz. 135: 306-313; 1974.

Mooney, H.A.; Kummerow, J.; Chu, C.; Hays, R.I. Biomass, energy and mineral characteristics. In: Thrower, N.J.W.; Bradbury, D.E., eds. Chile-California Mediterranean Scrub Atlas. A Comparative Analysis. Stroudsberg, Pa.: Dowden, Hutchinson & Ross; 1977a; 162-164.

Mooney, H.A.; Kummerow, J.; Johnson, A.W.; Parsons, D.J.; Keeley, S.; Hoffman, A.; Hays, R.I.; Giliberto, J.; Chu, C. The producers -- their resources and adaptive responses. In: Mooney, H.A., ed. Convergent Evolution in Chile and California Mediterranean Climate Ecosystems. Stroudsberg, Pa.: Dowden, Hutchinson & Ross; 1977b; 85-143.

Mooney, H.A.; Harrison, A. The vegetation gradient on the lower slopes of the Sierra San Pedro Martir in northwest Baja California. Madroño 21: 439-445; 1972.

Mooney, H.A.; Rundel, P.W. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum, in the California chaparral. Bot. Gaz. 140: 109-113; 1979.

Muller, C.H.; Hanawalt, R.B.; McPherson, J.K. Allelopathic control of herb growth in the fire cycle of California chaparral. Bull. Torrey Bot. Club 95: 225-231; 1968.

Muller, W.H.; Muller, C.H. Volatile growth inhibitors produced by Salvia species. Bull. Torrey Bot. Club 91: 327-330; 1964.

Mutch, R.W. Wildland fires and ecosystems -- a hypothesis. Ecology 51: 1046-1051; 1970.

Nilsen, E.T.; Muller, W.H. An evaluation of summer deciduousness in Lotus scoparius Nutt. (T.&G.). Amer. Midl. Nat. 103: 88-95; 1980.

Noble, I.R.; Slatyer, R.O. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43: 5-21; 1980.

Orshan, G. Seasonal dimorphism of desert and Mediterranean chamaephytes and its significance as a factor in their water economy. In: Rutter, A.J.; Whitehead, R.H., eds. The Water Relations of Plants. Oxford: Blackwell Sci. Publ.; 1963; 206-222.

Philbrick, R.N.; Haller, J.R. The southern California islands. In: Barbour, M.; Major, J., eds. Terrestrial Vegetation of California. New York: J. Wiley; 1977; 893-908.

Rogers, R.W.; Westman, W.E. Growth rhythms and productivity of a coastal subtropical eucalypt forest. Aust. J. Ecol. 6(1): in press; 1981.

Sampson, A.W. Plant succession on burned chaparral lands in northern California. Calif. Agr. Exp. Sta.: 1944; Bull. 685. 144 p.

Schlesinger, W.H.; Gill, D.S. Demographic studies of the chaparral shrub, Ceanothus megacarpus,

in the Santa Ynez Mountains, California. Ecology 59: 1256-1265; 1978.
Schlesinger, W.H.; Gill, D.S. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61: 781-789; 1980.
Smith, W.K.; Nobel, P.S. Influences of seasonal changes in leaf morphology on water-use efficiency for three desert broadleaf shrubs. Ecology 58: 1033-1043; 1977.
Tyson, B.J.; Dement, W.A.; Mooney, H.A. Volatilisation of terpenes from Salvia mellifera. Nature 252: 119-120; 1974.
Went, F.W. A long term test of seed longevity. II. Aliso 7: 1-12; 1969.
Westman, W.E. A potential role of coastal sage scrub understories in the recovery of chaparral after fire. Madroño 26: 64-68; 1979a.
Westman, W.E. Oxidant effects on Californian coastal sage scrub. Science 205: 1001-1003; 1979b.
Westman, W.E. Diversity relations and succession in Californian coastal sage scrub. Ecology 62: 170-184; 1981a.
Westman, W.E. Factors influencing the distribution of species of Californian coastal sage scrub. Ecology 62: in press; 1981b.
Westman, W.E. Seasonal dimorphism of foliage in Californian coastal sage scrub. Oecologia: submitted; 1981c.
Westman, W.E. Plant community structure -- spatial partitioning of resources. In: Kruger, F.J.; Mitchell, D.T.; Jarvis, J.U.M., eds. Mediterranean-type Ecosystems. The Role of Nutrients. Berlin-Heidelberg-New York: Springer-Verlag; In press; 1981d.
Westman, W.E.; O'Leary, J.F.; Malanson, G.P. The effects of fire intensity, aspect and substrate on post-fire growth of Californian coastal sage scrub. In: Margaris, N.S.; Mooney, H.A., eds. Components of Productivity of Mediterranean regions -- Basic and applied aspects. The Hague: W. Junk. In press; 1981.
Westman, W.E.; Preston, K.P. Sulfur dioxide and oxidant effects of Californian coastal sage scrub. In: Proc. Symp. Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems. Berkeley, Calif.: U.S. Dep. Agric.: 1981; Forest Serv. Gen. Tech. Rep. PSW-43.: 256.
Whittaker, R.H. Communities and Ecosystems. New York: Macmillan; 1970.
Whittaker, R.H.; Levin, S.A. The role of mosaic phenomena in natural communities. Theor. Pop. Biol. 12: 117-139; 1977.
Winner, W.A.; Mooney, H.A. Ecology of SO_2 resistance: II. Photosynethic changes of shrubs in relation to S02 absorption and stomatal behavior. Oecologia 44: 296-302; 1980.
Zedler, P.H. Life history attributes of plants and the fire cycle: a case study in chaparral dominated by Cupressus forbesii. In: Proc. Symp. Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Washington, D.C.: U.S. Dep. Agric.: 1977; Forest Serv., Gen. Tech. Rep. WO-3: 451-458.

A Comparison of Two Types of Mediterranean Scrub in Israel and California[1]

Avi Shmida and Michael Barbour[2]

Abstract: Matorral/chaparral and phrygana/coastal sage vegetation types of Israel and California exhibit major differences in life form spectra, physiognomy, species richness, fire adaptations, spinescence, and leaf traits. In some cases it is possible to correlate such differences in climate, geologic history, soil, fire frequency, and human history. There seems to be only a superficial degree of convergence between comparable mediterranean types of vegetation in the two areas.

A mediterranean climate--hot, dry summer and cool, wet winter (Trewartha 1954, Flohn 1969)--occurs in at least five widely scattered regions of the world: the Mediterranean region itself, between Europe and Africa; the Pacific Coast of North America, from Oregon to northern Baja California; the Cape Region of South Africa; certain coastal portions of South and West Australia; and the central Chilean coast. As summarized well by Raven (1971), "Plant associations of the five regions. . . are extremely similar both in their physiognomy and in the morphology and physiology of the constituent plants. . . dominated by low, evergreen, sclerophyllous trees and with short thick trunks and twisted rigid often spreading branches." Since the seminal work by Schimper (1903), most studies of mediterranean vegetation have emphasized the degree of convergence (Specht 1969, Naveh 1967, Cody and Mooney 1978, Ashman 1973). Robert Whittaker had been intensively studying southern hemisphere examples until his recent, untimely death (Whittaker *et al.* 1979, Naveh and Whittaker 1980).

In this study, I shall compare mediterranean vegetation as found in California and Israel only, defining the mediterranean regions of each according to Raven (1971) and Zohary (1973). (Mediterranean is written in this paper with a capital M when the geographical region of the Mediterranean Basin is referred to, but with small case m when vegetation or climate is referred to.) I shall begin this review with a comparison of climates and floras, then follow with a sequential comparison of climates and floras, then follow with a sequential comparison of major vegetation types found in the two areas, including matorral, phrygana, woodland, and montane belts. Differences, as well as similarities, will be emphasized. Although the data were taken mainly from Israel, I think that the results are applicable to the whole Mediterranean Basin.

METHODS

The conclusions in this paper are based on field studies conducted in Southern California and Israel from 1977 - 1980 by the author and Dr. Robert Whittaker. Samples were taken along climatological gradients from various vegetation types in each of the mediterranean ecosystems.

On each site plots of 1/10th hectare (20x50 m= 1 dunam) were marked and all sampling was carried out in these plots. The tenth-hectare size was chosen as being large enough to represent the vegetation adequately but not too large for efficient sampling of all vascular plant species. The samples were taken at the peak of the spring blooming. Direct visual estimation of plant coverage was used to give relative importance value for species. Detailed plant presence and covers were also recorded in ten duplicate quadrats along a transect of ten 1 x 1 m squares. The percentage of rocks, stones and total plant cover and percentage of ground cover of all perennial species were estimated.

On each plant species sampled, the following parameters were recorded: number of species; coverage estimation, growth form and phenology. Detailed analyses of different species of this study have been published or are now in the process of being summarized (Shmida and Whittaker, 1981a, 1981b).

Although our studies in the Old World have been carried out in Israel, they reflect a pattern observed in other countries in the Mediterranean Basin, especially the eastern part of Greece, Turkey and Lebanon (personal observations in Turkey, France and Spain).

ENVIRONMENTAL COMPARISON

On a gross scale, both areas have a similar topography: shoreline running north-south, a colline (foothill) belt leading to main ridges running north-south with a steep eastern scarp facing a desert, and a rift valley. Climatic macro-gradients are also similar: a relatively long, gentle north-south gradient of precipitation (falling to the south) and temperature (rising to the south); and east-west orographic gradients of precipitation, temperature, and continentality. In Israel, the gradients are shifted toward the warmer, drier portion of the scale, but they occur over smaller distances and, thus, can be steeper than gradients in California (Atlas

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Professor of Botany, The Hebrew University, Jerusalem, Israel; and Professor, Department of Botany, University of California, Davis, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

of Israel 1970).

Differences between the two areas are also significant: A central valley, with its semi-arid climate, is absent from Israel; the Sierra Nevada ridge is much higher than the Galilee-Judean ridge; most of the colline belt of Israel is a low elevation Pleistocene plain with extensive sandy regions in the south that are open to invasion by desert elements, whereas the colline belt of California is of older metamorphic hills and mountains (Avnimelech 1962, Horowitz 1974). Geologically, Israel is mainly underlain by limestone, the weathering of which typically results in stony terra-rosa soil (Zinke 1973). But limestone is rare in California and the soils tend to be less stony and deeper. Climatically, summer precipitation is completely absent in Israel, whereas many Californian vegetation types receive at least 10 percent of annual precipitation during summer (Baily 1966, Baker 1944, Major 1977). Furthermore, ,the California coast experiences frequent summer fog and the central valley experiences frequent winter fog, in both cases effectively reducing evapo-transpiration and the annual amplitude of temperature (Martoz and Lahey 1975, Major 1977). Finally, human disturbance has gone on for a longer time in Israel, perhaps for 120,000 years (Naveh and Dan 1973, Ashman 1973).

FLORISTIC COMPARISON

Although the physiognomies of various herb-, shrub-, or tree-dominated vegetation types are similar in the two mediterranean regions, the underlying floras are quite distinct, even at the family level. In the shrub-dominated matorral, for example, only one species is shared: ***Styrax officinalis***. More than 400 taxa which have been introduced to California from other, predominantly mediterranean, areas are now naturalized and widely distributed in California. But apart from these, the phylogenetic differences in regional floras are profound, as even most of the common genera have had an independent origin" (Raven (1971). Most of the shared evergreen oaks, for example, are not systematically closely related (Miller, Tucker, Zohary, and Avishai, personal communications). Nevertheless, some pairs of taxa which do show relatively close systematic and/or ecological relationships in shrub-dominated vegetation are in the genera ***Cupressus***, ***Juniperus***, ***Pinus***, ***Arbutus***, ***Quercus***, ***Cercis***, ***Platanus***, ***Rhamnus***, ***Styrax***, ***Artemisia***, ***Salvia***, ***Lotus***, and ***Scrophularia***. Generic pairs include ***Umbellularia/Laurus***, ***Pickeringia/Calicotome***, ***Prunus/Amygdalus***, ***Rhus/Pistacia***, ***Helianthemum/Fumana***, and ***Brickellia/Varthemia***.

Life form spectra (after Raunkiaer) of the two mediterranean floras also show large differences (Table 1). California has significantly smaller fractions of annuals and geophytes, but larger fractions of chamaephytes, shrubs and trees. The large diversity of annuals in the Mediterranean is, I believe, an evolutionary response to two stresses: a dramatic two-phase (wet winters, absolutely dry summers) climate and human disturbance for at least the past 100,000 years. In California, the mediterranean climate is not so completely bi-phasic and human populations have been modest until the last several hundred years (anthropological remains do not extend beyond 10,000 yr BP). It is not surprising that Old World annuals are aggressive when introduced to western North America, for they are placed in a relatively empty adaptive zone (Robbins 1940, Stebbins 1965, Raven and Axelrod 1978).

MATORRAL

Definition of Terms

In tropical, sub-tropical, and temperate areas, as annual precipitation falls to 300-600 mm, forests give way to either woodland or matorral. If the forest opens up to trees with broad root systems and crowns but still with single trunks, then a woodland results; if canopy cover becomes less than 30 percent, a steppe forest results. On the other hand, if the forest becomes shorter (2-8 m), but canopy cover remains at 100 percent, and the trees are multi-stemmed, a matorral results. If the shrub canopy opens and the ground stratum is invaded by steppic herbs, the resulting vegetation is a marginal matorral.

The literature of both Israel and California is rich in synonymy for the terms defined above. In California, chaparral is the common term for matorral, desert chaparral for marginal matorral, and foothill for oak or oak-pine woodland for woodland. Steppe forest would be equivalent to pinyon-juniper woodland in California. Matorral has many synonyms in the Mediterranean region: garrige or gurique (Quezel 1976, Turril 1930, Taktajan 1941), matorral (Polunin and Smythies 1973), horesh (Zohary 1973), phrygana (Polunin 1980), batha (Fig 1946), and maquis (Zohary 1973). I shall use the term maquis to refer to Israeli matorral, reserving phrygana (batha or border batha) for a different, soft-leaved lower vegetation type. In Israel, the woodland is a ***Ceratonia-Pistacia*** or ***Quercus*** woodland, and the steppe forest is dominated by ***Pistacia*** or ***Juniperus***. I shall define deserts as regions receiving less than 150 mm precipitation yearly; semi-deserts, including marginal matorral, are defined as regions receiving 150-300(400)mm annual precipitation.

Physiognomy and Arboreal Richness

Both California chaparral and Israeli maquis are dominated by shrubs and multistem pygmy trees 1.5 - 4 m tall with evergreen sclerophyllous leaves; however, the details of canopy architecture are quite different. Chaparral is generally 1.5 - 2 m tall with a closed (> 80 percent cover) canopy; it is essentially a unistratal vegetation with an absence of herbaceous elements beneath the evergreen canopy. The maquis canopy generally

Table 1

Life form spectra of mediterranean floras (γ diversity scale) in Israel and California. Life form categories are modified from those of Raunkiaer. Based on the author's floristic lists compiled from vegetation samples.

Life form	Codes	Israel		California		World Normal
		No. Taxa	Pct.	No. Taxa	Pct.	
Annual, all	A	823	53.1	178	43.8	13
introduced	A-intr.			107	29.3	
facultative annuals	AB, AP	52	3.3	12	2.9	
Biennial & facultative perennial	B	75	4.8	4	1.0	
Geophyte	G	114	7.3	10	2.5	3
Hemicryptophyte, all	H	307	19.7	89	21.9	26
Chamaephyte, all	Ch	104	6.7	38	9.4	9
Subshrub	Csh	9	0.6	17	4.7	
Suffrutescent	Csf	64	4.1	10	2.4	
Nanochamaephyte	Chn	31	2.0	11	2.3	
Shrub (0.5	Sh	41	2.6	41	9.8	15
Tree (> 2.0	T	45	2.9	33	8.2	28
2-4 m tall	T2	15	1.0	21	5.3	
4-8 m tall	T4	24	2.5	1	0.2	
> 8 m tall	T8	6	0.4	11	2.7	
Climbing vines	V	23	1.5	7	1.7	
Parasites	P	22	1.4	2	0.5	

averages 4-5 m in height and is open many times throughout, averaging less than 40 percent cover. In some areas the openings are due to grazing and cutting, but in other areas they are not related to animal or human activity. Open maquis has been dominant for thousands of years in large parts of Israel, and succession to a closed matorral is very slow. I postulate that these openings have an important role in the annual richness.

The maquis in Israel is very poor in woody taxa, compared to chaparral. It is typically dominated by one species of evergreen oak, ***Quercus calliprinos*** (its vicariads--***Q. coccifera, Q. aucheri, Q. rotundifolia***--sequentially replace each other along the northern Mediterranean toward Spain). Other arboreal elements typically contribute less than 5 percent cover and may be restricted to particular substrates, as ***Arbutus*** on marls and chalk and ***Laurus*** on karstic dolomite. The chaparral in California typically shows a mixed dominance by species in at least five genera: ***Quercus, Ceanothus, Rhamnus, Adenostoma,*** and ***Arctostaphylos*** (Hanes 1977, Cooper 1922). Pure stands of ***Adenostoma fasciculatum*** can, however, be found on hot, xeric, steep, stony, or frequently burned sites. From my own sampling data, it appears that the average number of arboreal taxa per dunam in southern California chaparral is 12, versus five in Israel. In all the mediterranean area of Israel, there are only 40 different arboreal species in the matorral, whereas in a comparable area in southern California we sampled 143 different chaparral elements. This indicates that not only is a diversity (community richness) higher in California than in Israel, but also that γ and β diversity (regional richness and differential diversity) are higher in California (Shmida and Whittaker 1981b).

<u>Deciduous Elements</u>

Evergreens dominate the vegetation, but floristically in Israel they account for only 65 percent of the species in maquis. In chaparral, evergreens account for over 95 percent of arboreal species (this excludes riparian elements). As will be elaborated in a later section, California has a general paucity of deciduous species, particularly in montane belts.

Most of the deciduous elements are winter deciduous, perhaps (in Israel) reflecting an invasion of Irano-Turanian (steppic) taxa and a lingering result of recent glaciation (Zohary 1973, Shmida 1978). Obligate summer deciduous elements are absent in California and rare in Israel (only three species - ***Duphorbia dendroides, E. hierosolyminthana,*** and ***Anagyris foetida***). Some shrubs, however, are facultatively summer deciduous and have green stems--the retamoid syndrome (Zohary 1973, Shmida and Whittaker 1981) which is common in certain Leguminosae (***Calcycotome, Genista, Retama, Spartium, Ulex).*** Spinescence is often associated with this syndrome. In California, only ***Pickeringia montana*** exhibits this syndrome. It is a monotypic paleorelict (Raven, personal communication) which shows striking convergence with ***Calycotome villosum*** from the Mediterrean Basin. The ***Ceanothus leucodermis*** group in California appear to be evolving toward this syndrome. The retamoid syndrome is best developed in desert elements and, thus, is more common in the desert chaparral of California (***Baccharis sarothroides, Eriogonum trichopex, Gutierrezeia*** *sarothrae*).

Herbaceous Understory

The herbaceous stratum beneath chaparral is very sparse and low in species richness (Hanes 1977, Shmida and Whittaker 1981). Allelopathy, especially with respect to *Adenostoma* (McPherson and Muller 1969), is often invoked as a causative factor. There is no evidence from the Israeli literature, or from my own observations, that allelopathy may be a factor in the maquis. In general, species richness is greatest at the canopy edge of shrubs, but even beneath the canopies a number of geophytes and hemicryptophytic grasses can be found in vigorous condition (Naveh and Whittaker 1980, Barbour *et al.* 1982).

Adaptations To Fire

The ability to stump-sprout following crown removal is common in both maquis and chaparral, but lignotubers are absent from Israeli taxa. Lignotubers are thought to be ancient and phylogenetically primitive (Nobs 1963), and may have evolved in response to some factor other than fire (Axelrod, personal communication), but the fact remains that today they are a powerful adaptation to fire.

Serotiny is another adaptation to fire in California, but not in Israel. A number of closed-cone pines and cypress (*Cupressus*) in California are associated with chaparral vegetation (Vogl *et al.* 1977). The fossil record of some closed-cone pines extends back to the Miocene (Axelrod 1967). Serotinous diaspores which require heat scarification (e.g., seeds of *Ceanothus integerrimus*) are also common in chaparral, as they are in the Australian matorral (mallee; Moore and Perry 1970). Closed-cone conifers or other taxa with serotinous diaspores are absent from Israel. Although some Mediterranean pines do have cones which remain attached to the tree for some time, all open fully on hot summer days and are not serotinous despite some references in the literature to the contrary (Axelrod 1975, Naveh and Dan 1973).

There seems, then, to be a profound difference in the degree of fire adaptedness of the two matorrals. Possibly the maquis, in the absence of a fire-type climate, with frequent dry lightning strikes so characteristic of the chaparral, has not become adapted to burning.

Spinescence

Compared to chaparral, the maquis exhibits fewer spinescent arboreal elements but many more spinescent hemicryptophytes and annuals (Table 2).

Table 2

Numbers and percentages of spinescent taxa by growth forms in the mediterranean floras of California and Israel. Based on the author's floristic list compiled from vegetation samples.

	Spiny Leaves		Spiny + Rigid Stem		Total Spiny			Total No. of species studied
	No.	pct.[1]	No.	pct.[1]	No.	pct.[1]	pct.[2]	
ISRAEL								
Annuals	20	4.4	-	-	20	4.4	23.3	451
Per. herbaceous	32	18.9	2	1.2	34	20.1	39.5	169
Suffrutescents	1	1.4	3	4.	4	5.4	4.7	74
Low shrubs)	-	-	3	23.	3	23.	3.5	13
)arboreal								
Shrubs)	1	4.	19	76.	20	80.	23.3	25
)elements								
Trees)	-	-	5	15.2	5	15.2	16.6	33
Total	54	7.1	32	4.2	86	11.2	100	765
CALIFORNIA								
Annuals	-	-	-	-	-	-	-	166
Per. herbaceous	3	2.7	-		3	2.7	12.5	110
Suffrutescents	3	7.9	-	-	3	7.9	12.5	38
Low shrubs)	2	10.5	3	15.8	5	26.3	20.8	19
Shrubs)arboreal)	4	12.1	5	15.1	9	27.2	37.5	33
Trees)elements)	2	7.6	2	7.6	4	15.2	16.6	26
Total	14	3.6	10	2.6	24	6.1	100	392

[1]Percentage of spiny plants relative to the total number of species in this growth form category (x 100).
[2]Percentage of spiny plants relative to the total number of all spiny species in the assemblage.

About 10.3 percent of the chaparral overstory taxa have spinescent leaves (e.g., some *Prunus, Quercus, Rhamnus, Ceanothus* spp.), and 12.8 percent have spinescent stems (and all of these are deciduous). In Israel 32 percent of the arboreal element of the marquis flora have spiny stems while only 2 percent have spiny leaves.

Spinescence may be an adaptation to aridity or to grazing (Shmida and Whittaker 1981). It may be no accident that some of the more pernicious weeds/adventives introduced to California from the Mediterranean are spinescent: *Ulex europaeus, Centaurea solstitialis, Silybum marianum, Cirsium vulgare, Carduus pycnocephalus.* It is likely that annual and hemicryptophyte species of other spinescent Israeli genera, such as *Echinops, Onopordon,* and *Notobasis,* will reach California and also become widespread.

Leptophylly

Leptophylls (small, needle-like sclerophylls) are common in heath vegetation which grows on poor soils in several parts of the world. The trait is often linked with the family Ericaceae. Leptophyllic species are absent from the Israeli maquis. They are floristically uncommon in California chaparral, but vegetationally they may dominate many areas. Two such species are *Adenostoma fasciculatum* and *A. sparsifolium* of the Rosaceae. The adaptive value of leptophylls is unclear, as the broad sclerophyll appears to be optimally adapted to matorral climate (Mooney *at al.* 1974, Miller and Mooney 1974). *Adenostoma* leaves are resinous and contain many terpenes which are flammable (Countryman and Philpot 1970), and the selective force may have been fire frequency.

PHRYGANA

Definition Of Terms

Phrygana vegetation is dominated by suffrutescent chamaephytes: subshrubs 20-70 cm tall with shoots which at least partly die back each year (that is, the buds are not at branch apices; Orshan 1964, 1972). Canopy cover may be as extensive as in matorral, but total biomass is much lower (Mooney 1977). Leaves tend to be soft and pungent, emitting volatile terpenes, and winter foliage is regularly replaced in summer by smaller, more sclerophyllous foliage; some species are facultatively drought deciduous. Phrygana occupies drier sites than matorral.

Synonyms for this vegetation in California include coastal sagebrush (Jensen 1947), soft chaparral (Whittaker 1954), and coastal sage scrub (Mooney 1977); in the Old World they include batha (Eig 1946, Zohary 1973), low matorral (Polunin and Smythies 1973), and phrygana (Margaris 1976, Polunin 1980). I shall refer to the California example as coastal sage and to the Israeli one as Israeli Phrygana (capitalized).

Comparative Features

California coastal sage is mainly distributed south of the Santa Monica Mountains (Raven 1977, Jensen 1947, Mooney 1977). Major dominants include *Artemisia californica, Salvia mellifera,* and *S. leucophylla.* Moving to the more arid south and east, more and more desert elements are added (e.g., *Simmondsia chinensis, Viguiera deltoides, Mammilaria dioica, Trixis californica, Sphaeralcea ambigua, Franseria dumosa, Mirabilis bigelovii).* It occupies only about 2 percent of the state's area, that is, only about ¼ of the area occupied by chaparral.

In Israel, the Phrygana is relatively much more extensive, covering more than 40 percent of all hilly, upland terrain, and 75 percent in some areas such as the Judean-Samarian province. Dominant genera include *Sarcopoterium, Cistus, Satureja, Helianthemum, Fumana, Corydothymus, Salvia,* and *Ononis.* Near the desert, the Phrygana opens up and becomes predominantly herbaceous, with many desert geophyte additions; this phase of the Phrygana can be called border batha (Zohary 1973). It is likely that the Israeli Phrygana now occupies more territory than it once did because of the activities of man. Zohary (1973) and Naveh (1973) assume that it is a successional stage which follows degradation of maquis. Throughout the Mediterranean phrygana does become established following cutting and heavy grazing in matorral (Zohary 1973, Litav 1961, 1967); in southern California it may follow frequent burning in chaparral (Cooper 1922, Wells 1969). Danin (1970) postulated that the origin of the phrygana was on the border of the Mediterranean and, as civilization devastated the maquis, the phrygana expanded. In California, this process may just be beginning.

A summary of life forms in coastal sage scrub, Phrygana, chaparral, and maquis is presented in Table 3. There is a close parallelism in the percent of phrygana floras in each life form category, with a few exceptions: 1) Annuals are more common in the Israeli Phrygana than in California. This difference is even more pronounced if we exclude from the list the introduced species (15.8 percent) which came from the Mediterranean Basin. 2) The Israeli Phrygana has more geophytes but less hemicryptophytes compared with the California phrygana. 3) Cacti and succulents are absent in Israel, while in California they are consistently found in the phrygana. 4) On the whole, woody species are more abundant in California than in Israel and the opposite pattern is true for the herbaceous species.

ACKNOWLEDGEMENTS

This research has been supported by a grant from the National Science Foundation to R. H. Whittaker who was my supervisor during my postdoctoral period at Cornell. I would like to thank the naturalists, taxonomists, and ecologists R. Beauchamp, Mary Dedecker, R. Haller, J. Major,

Table 3

Comparison of Growth-form Spectra on α diversity scale of the Matorral and Phrygana Formation between Israel and California. Based on the author's floristic lists compiled from vegetation samples.

			Matorral				Phrygana			
			201 species		112 species		356 species		190 species	
			6 samples		6 samples		12 samples		12 samples	
Growth-forms	Codes		Israel		California		Israel		California	
Annual, All	A		48.1		33.6		60.5		48.9	
Introduced	A	A-Intr.	-			6.2	-			15.8
Biennial + facultative perennials			1.5		0.9		4.8		1.6	
Geophyte	B		7.4		3.7		8.0		3.2	
Hemicryptophyte	G		24.5		19.3		10.1		17.3	
Chamaephyte	H		11.5		9.1		15.3		16.3	
Subshrub	C	Ch		1.5		6.0		0.5		5.3
Suffrutescent		Csf		8.0		1.0		12.1		6.8
Nanochamaephyte		Chn		2.0		2.1		2.6		4.2
Shrub (.5-2 m)	Sh				20.3				6.8	
Tree	T		4.5		11.0		0.3		3.7	
2-4 m tall		T2		2.5		9.2		0.3		2.6
4-8 m tall		T4		2.0		.9		-		-
above 8 m tall		T8		-		.9		-		1.1
Climber	V		2.0		2.7		0.3		1.6	
Parasite	P		0.5		-		0.7		0.5	
Total (pct.)			100		100		100		100	
Succulents (cactoids)	Su		-		4.2		0.5		6.2	
Woody			18.5		56.6		16.6		28.4	
Herbaceous			81.5		43.1		83.4		72.6	

D. Taylor, B. Prigge, A. Thompson, H. Lewis, H. Mooney, A. Gibson, R. Moran, J. Tucker, C. Muller, R. Thorne, P. H. Raven, the Santa Ana Botanical Garden, Reid Moran, Mary Dedecker.

LITERATURE CITED

Aschman, H. Distribution and peculiarity of Mediterranean ecosystems. In: Di Castri, F.; Mooney, H. A., eds. Mediterranean type ecosystems. Springer-Verlag: 1973: 11-19.

Atlas of Israel. Surveys of Is. Min. of Labour. Amsterdam: Elsevier Pub. Co.: 1970.

Avnimelich, M. The main trends in the Pleistocene-Holocene history of the Israelien coastal plain. Quaternaria 4: 1962: 479-495.

Axelrod, D. I. Evolution of the California closed-cone pine forest. In: Philbrick, R. N., ed. Biology of the California Islands. Santa Barbara Bot. Garden: 1967: 93-150.

Axelrod, D. I. Evolution and biogeography of the Madrean-Tethyan sclerophyll vegetation. Ann. Missouri Bot. Garden: 1975: 284-334.

Baily, H. P. The climate of southern California. Calif. Nat. History Guide 17. Berkeley: Univ. Calif. Press: 1966: 87 p.

Baker, F. S. Mountain climates of the western United States. Ecol. Monogr. 14: 1944: 223-154.

Barbour, M.; Shmida, A.; Johnson, A. Comparison of coastal dune scrub in Israel and California: physiognomy, species diversity, associations. Amer. J. Bot. (Submitted): 1982.

Cody, M. L.; Mooney, H. A. Convergence and dissimilarities on Mediterranean ecosystems. Ann. Rev. Eco. Sys. 9: 1978: 265-321.

Cooper, W. S. The broad-sclerophyll vegetation of California. Washington: Carnegie Inst.: 1922.

Countryman, C. M.; Philpot, C. W. Physical characteristics of chanise as a wildland fuel. Berkeley, California: Southwest Forest and Range Exp. Sta.: 1970.

Eig, A. Synopsis of the phytosociological units of Palestine. Pal. J. Bot. Jerusalem series 3: 1946: 183-246.

Flohn, H. Climate and weather. World Univ. Lib.: Weidenfield and Nicolson: 1969.

Hanes, H. Chaparral. In: Barbour, M.; Major, J., eds. Terrestrial vegetation of California. John Wiley: 1977.

Horowitz, A. The late Cenozoic stratigraphy and paleogeography of Israel. Tel-Aviv.: Study Pub. of Tel-Aviv Univ.: 1974.

Jensen, H. A. A system for classifying vegetation in California. Fish and Game, No. 33, No. 4: 1947: 199-266.

Litav, M. Studies on the phytosociology and ecology of the batha community in the Judean hills. Ph.D. thesis. Hebrew Univ. Jerusalem (in Hebrew, English summary): 1961.

Litav, M. Micro-environmental factors and species interrelationships in three batha associations in the foothill region of the Judean hills. Israel J. Bot. 16: 1967: 79-99.

Major, J. California climate in relation to vegetation. In: Barbour, M.; Major, J., eds. Terrestrial vegetation of California: New York: John Wiley & Sons: 11-72.

Marotz, G. A.; Lahey, J. E. Some stratus-fog statistics in contrasting coastal plant communities of California. J. Biogeog. 2: 1975: 289-295.

Miller, P.; Mooney, H. The origin and structure of American arid ecosystems. The producers: interactions between environment, form, and function. Proc. First Int. Congr. of Ecology. The Hague, Netherlands: 1974: 201-209.

Mooney, H.; Pearson, D.; Kummerow, J. Plant development in Mediterranean climate. In: Lieth, ed. Phenology and seasonality modeling. New York: Springer-Verlag: 1974: 255-267.

Mooney, H. Southern coastal scrub. In: Barbour, M.; Major, J., eds. Terrestrial vegetation of California. New York: John Wiley & Sons: 1977: 471-489.

Moore, R. M.; Perry, R. A. Vegetation. In: Moore, R. M., ed. Australian grassland. Canberra: Aust. Nat. Univ. Press: 1970: 59-74.

Naveh, Z. Mediterranean ecosystems and vegetation types in California and Israel. Ecology 48: 1967: 445-459.

Naveh, Z.; Dan, J. The human degradation of Mediterranean landscape in Israel. In: Di Castri, F.; Mooney, H., eds. Mediterranean type ecosystems. Springer-Verlag: 1973: 378-390.

Naveh, Z.; Whittaker, R. H. Structure and floristic diversity of shrublands and woodlands in northern Israel and other mediterranean areas. Vegetatio 41: 1980: 171-190.

Nobs, N. A. Experimental studies in species relationships in *Ceanothus.* Carnegie Inst. Wash. Pub. 623: 1963: 1-94.

Orshan, G. Seasonal dimorphism of desert and Mediterranean chamaephytes and its significance as a factor in their water economy. In: Blackwell's Scien. Publ. The water relation of plants. 1964: 206-222.

Orshan, G. Morphological and physiological plasticity in relation to drought. In: McKell, C. M. *et al.*, eds. Wildland shrubs their biology and utilization. USDA Forest Service Gen. Tech. Rep. INT-l: 1972: 245-254.

Polunin, P. Flowers of Greece and the Balkans. Oxford Univ. Press: 1980: 474 p.

Polunin, O.; Smythies, B. E. Flowers of southwest Europe. Oxford Press: 1973: 385 p.

Quezel, P. Les forêts du pourtour Mediterranéen. Note technique du MAB. W: UNESCO: 1976: 35-76.

Raven, P. H. The relationships between Mediterranean floras. In: Davis, P. H.; Harper, P. C.; Hedge, T. C., eds. Plant life of Southwest Asia. Bot. Society of Edinburgh: 1971: 119-134.

Raven, P. H.; Axelrod, D. I. Origin and relationships of the California flora. Univ. of California Publ. in Bot. Vol. 72. Univ. of Calif. Press: 1978.

Robbins, W. W. Alien plants growing without cultivation in California. Calif. Agric. Exp. Sta. Bull. 677: 1940: 128 p.

Schimper, A. F. W. Plant geography upon a physiological basis. Oxford Univ. Press: 1903: 1143 p.

Shmida, A. Remarks on the Paleo-climate of Sinai: based on the distribution patterns of relict plants. In: Bar-Yosef, O; Phillips, L., eds. Prehistoric investigation in Gebel Maghara, Northern Sinai. Kedem. No. 6. Jerusalem: 1978: 36-54.

Shmida, A.; Whittaker, R. H. Spiny plants: an adaptation to arid climate? Ocecologia (in press): 1981.

Shmida, A.; Whittaker, R. H. Pattern and biological microsite effects in two shrub communities, southern California. Ecology 62: 1981a: 234-251.

Shmida, A.; Whittaker, R. H. Growth forms and diversity trends between the Mediterranean and the desert in Israel and California. (Manuscript): 1981b.

Specht, R. L. A comparison of the sclerophyllous vegetation characteristics of mediterranean type climates in France, California, and southern Australia, I. Structure, morphology and succession. Aust. J. Bot. 17: 1969: 277-292.

Stebbins, G. L. Colonizing species of native Californian flora. In: Baker, H. G.; Stebbins, G. L., eds. The genetics of colonizing species Academic Press: 1965.

Takhtajan, A. L. Phytogeographical survey of Armenia SSR. 1941: 4 p.

Trewartha, G. T. An introduction to climate. New York: McGraw-Hill: 1954: 391 p.

Turril, W. B. The plant life of the Balkan peninsula. A phytogeographical study. Oxford Univ. Press: 1930: 490 p.

Vogl, J. O.; Thornburgh, D. A.; Griffin, J. R. The closed-cone pines and cypresses. In: Barbour, M.; Major, J., eds. Terrestrial vegetation of California. New York: John Wiley & Sons: 1977: 295-358.

Wells, P. V. The relation between mode of reproduction and extent of speciation in woody genera of California chaparral. Evolution 23: 1969: 264-267.

Whittaker, R. H. The ecology of serpentine soils IV. The vegetation response to serpentine soils. Ecology 35: 1954: 275-288.

Whittaker, R. H.; Niering, W. A.; Crisp, M. D. Structure, pattern and diversity of a mallee community in New South Wales. Vegetatio, 39: 1979: 65-76.

Zinke, P. L. Analogies between soil and vegetation types. In: Di Castri, F.; Mooney, H., eds. Mediterranean type ecosystems. New York: Springer-Verlag: 1973: 61-80.

Zohary, M. Geobotanical foundation of the Middle East. Gustav Fischer Verlag: 1973: 737.

Vegetation Classification and Plant Community Stability: A Summary and Synthesis[1]

Ted L. Hanes[2]

I have attempted not only to summarize each paper but also to refer to other information and papers so that the reader can evaluate its contribution. I take full responsibility for the interpretation of these papers in this summary. The first two papers deal with vegetation classification, the third paper contrasts California - Israel shrublands, two papers deal with chaparral succession, and the final paper presents a timely discussion on coastal sage scrub succession. Each author has made a significant contribution to the manner in which we classify and perceive the dynamics of Mediterranean-type vegetation.

A Mediterranean System

The classification of Mediterranean-type vegetations has been a challenge to biologists and geographers through the 20th Century. Barbero and Quezel herein build a strong case for phytosociological and bioclimatic analysis of Mediterranean-type plant associations. They claim that the traditional physiognomical and the more sophisticated ecophysiological and autecological studies used in the United States are not suitable methods for classifying Mediterranean-type ecosystems. They suggest that purely physiognomical methods portray only a small part of the total ecology of vegetation. Even strictly phytosociological methods have limited application in classifying ecosystems.

Barbero and Quezel (these proceedings) propose a correlation of ecological and dynamic approaches to be used in classifying ecosystems. They point out that problems arise when climatic criteria are the sole basis of classification. In America plant ecologists are aware of the severe limitations of the old Merriam life zones based upon thermal minima. Furthermore, Barbero and Quezel give evidence that climatic zones do not match vegetation zones based on physiognomy. They propose that the problem can be rectified by using bioclimatic criteria such as water balance by means of instruments or theoretically, using coefficients. Summer drought is universally accepted as a bioclimatic component of Mediterranean-type vegetation.

Barbero and Quezel show that by not setting a limit on thermal minima, an entire scale of vegetation types emerges. Also, annual rainfall and humidity create bioclimatic zones that are useful in vegetation classification. Finally, altitudinal levels can be correlated with thermal criteria, species composition, and vegetation types.

It is stated that dynamic approaches to classifying ecosystems consider successional trends of vegetation and the development of stands of vegetation. Readers may find the use of the term "vegetation evolution" confusing since the authors are actually describing succession (vegetation change through time). The authors' traditional view of vegetation succession does not consider the different adaptive strategies of various species to perturbations nor the current debate on different types of succession (Drury and Nisbet 1973, Grime 1979). It is unclear how the authors determine successional stages and how such determinations are used in their classification scheme.

The authors identify the classical successional sequence of: annual grassland - perennial grassland - scrubs - pre-forest formation - climacic forest. If this classical sequence applies broadly to the entire Mediterranean rim it differs markedly from California chaparral succession. In California, chaparral replaces itself and does not give way to forest except in its upper elevational reaches. Disturbance initiates physiognomic changes (to herb and scrub phases) concomitant with shrub seedlings and crown sprouts. Over most of the chaparral lands of California, the climax vegetation is chaparral. The existence of herb and scrub phases, a few years after disturbance, are not obligate preparatory sere to chaparral development.

Barbero and Quezel end their paper by suggesting various methods of classifying ecosystems for applied purposes. These are mapping, numerical analysis, and ecological zonation. Practitioners may find the reduction of vegetation parameters to numerical values of limited utility.

A California System

Paysen gives an extensive review of vegetation classification in California and describes a new system suited to various user needs. Justification for a new classification system is provided by showing that serious interdisciplinary communication Problems exist due to divergent Principles and uses of classification output. Earlier systems of vegetation classifi-

[1] Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2] Professor of Biology, California State University, Fullerton, Fullerton, California, U.S.A. 92634.

cation are no longer suitable to resource managers and researchers due to changing perceptions of vegetation.

Historically, California's vegetation has been described in natural terms. Broad physiognomic types, such as grassland and timber, emerged when California's vegetation was viewed as a resource. Classification systems developed in relation to timber production and range values, neither of which included the shrublands with their watershed values. In the 1930's, fire management planning in southern California led to a major vegetation classification and mapping effort undertaken by Wieslander. The widely used Munz system of classifying vegetation into plant communities, first introduced in the late 1930's, leaves much to be desired since it is entirely subjective in nature. Several studies in the 1970's recognized habitat types and detailed vegetation composition, but fail to provide a universal system of classification.

The new vegetation classification system developed in California acknowledges the need resource managers have for an understanding of the nature of dynamics of vegetation in precise terms rather than phytosociological abstractions. It assumes that anyone in the field, practitioner and researcher alike, can classify a site-specific plant community by tabulating a few vegetation characteristics. This tabulation follows an aggregative hierarchy in logical sequence.

Classification starts with a basic unit, the Association, and builds upward through the hierarchy in progressively broader descriptive terms. It is important to realize that the Association is considered independent of the ecology, phytosociology, or stage of development of the vegetation. The Association is named in terms of the relative crown cover of dominant overstory species and the dominant species in subordinate layers. Codominant species can be included in the Association name.

Associations are aggregated into Series based on dominant overstory species; into Subformations based upon leaf and stem morphology; into Formations based upon growth form. The Phase is a flexible qualifier category used to describe Associations of varying age, condition, or stage of development. Most of these vegetation parameters are readily determined by experienced field workers.

The greatest strength of this new classification system is that it is a system rather than a classification of vegetation. It is a universal framework into which any and all vegetation can be fit. If all future studies classify vegetation with this system, a large groundswell of information will be developed that will communicate vegetation information to all practitioners and researchers familiar with the system. The vast array of Environmental Impact Reports (E.I.R.'s) prepared in the past decade would have contributed immeasurably to our knowledge of California vegetation had this system been in use. The same can be said of all mandated U.S. Forest Service resource inventories, as well as watershed management studies, fuel modification and type conversion studies, control and prescribed burn studies, and plant ecological and wildlife habitat studies.

Unfortunately Paysen's paper does not present results of trials and case studies. This void is particularly evident when one considers chaparral. Does the system chop chaparral into large, medium or small chunks? Several other questions may occur to the student of classifying methodology. Since both Subformations and Formations are based upon life form characteristics, what is the difference? Does growth form in Formations refer to plant height, crown diameter, or the physiognomy of the vegetation? Further, no indication is given of difficulties experienced with the system. One wonders what the training, experience, and commitment of the classifiers was or needs to be. Undoubtedly, uniform classification results will depend upon the background of those who use the system. Finally, the system needs and deserves a name. After all, if it is intended to communicate between disciplines, we all need to know what it is called.

The common language and the universal application of what I think should be called the California System of Vegetation Classification makes it the system that all people involved in vegetation work should adopt now and use consistently. Its widespread use throughout California could be the most significant, unifying vehicle in vegetation studies and vegetation management in the 1980's. One can only speculate as to its contribution to our understanding of the various vegetations we call chaparral.

California-Israel Shrublands

By contrasting and comparing the mediterranean-type vegetations of California and Israel, Shmida has given us insights into their unique features. Although they represent the same physiognomic types, the vegetative compositions of the two regions are distinctly different. This of course, is why the concept of convergent evolution has been so productive. It says, given groups of plants of different phylogenies and independent origin but exposed to similar environmental conditions through time, the plants will develop similar morphologies, physiologies, and physiognomies. Readers may question the validity of Schmida's extrapolations from Israel to the other Mediterranean rim countries.

Israeli maquis compared with California chaparral is taller, less dense, and less woody. Israeli maquis is also richer in species and genera, both in local stands and between regions. Chaparral is composed almost entirely of evergreen species where Israeli maquis contains many deciduous species. Few chaparral shrubs are spinescent stemmed but many have spinescent leaves. There is usually no herbaceous understory in the chaparral. Lignotubers and root-crown sprouting in chaparral are strong adaptations to fire, but there is no counterpart in Israel. California chaparral is more clearly fire adapted both in vegetative and sexual reproduction.

Montane chaparral invades the coniferous forest as an understory. In Israel there is no such invasion in the tree zone above; it is mainly deciduous.

Coastal sage scrub vegetation differs from Israeli phrygana in several respects. It is more restricted in distribution and may reflect a shorter exposure to overgrazing than in Israel. Students of coastal sage scrub ecosystems will note that dominant species (Encelia farinosa and Eriogonum fasciculatum) were not included but that Shmida included many desert species not commonly a part of sage scrublands. Rather than coastal sage scrub expanding into disturbed chaparral on a grand scale, we are seeing the demise of coastal sage scrub owing to urbanization. Sage scrub has more woody shrubs and fewer annuals than phrygana, yet in the springtime the intershrub spaces may support a diverse herb carpet. Several cacti and other succulents are components of coastal sage scrub.

Dynamics of Chaparral Change

Succession has been a fruitful concept in understanding the dynamics of California chaparral since the turn of the century (Plummer 1911, Clements 1916, Cooper 1922). Yet more recent studies have shown that classical "replacement" succession does not apply to California chaparral (Hanes 1971, 1977). Dr. Vogl contrasts chaparral with classical succession, showing that the absence of seral stages with their site modification properties makes chaparral distinctive. There are several additional features that need to be emphasized, however.

Dr. Vogl is correct in his description of primary chaparral succession as direct, that is, invasion of a site by climax species. It is important to note that primary chaparral succession does not involve the complete spectrum of chaparral plant species. Rather, only a few half-woody and woody species colonize virgin sites. These include California buckwheat (Eriogonum fasciculatum), chaparral yucca (Yucca whipplei) pricklypear cactus (Opuntia spp., yerba santa (Eriodictyon spp.), and chamise (Adenostoma fasciculatum). Increased species diversity on colonized sites seems to be a protracted process, and if the substrate is unstable, species diversity remains low indefinitely.

Primary chaparral succession occurs on broken rock surfaces in mountains and on alluvial fans and washes in valleys. Alluvial scrub, the vegetation that develops on floodplains (Cooper 1922, Smith 1980), reveals many vegetation dynamics that result from periodic flooding; (1) New substrates are formed by stream deposits during intense winter storms. (2) Colonization is accomplished by seeds of ruderals, subshrubs of coastal sage scrub, and woody chaparral species. (3) Mature stands are composed of a rich flora of springtime herbs and extensive stands of subshrubs punctuated with large evergreen chaparral shrubs. In this vegetation type there does not seem to be a decline in productivity or species diversity, or an increase in senility with age. For these and other reasons it is a suitable vegetation type upon which to test conceptual models of succession.

Chaparral contrasts with many ecosystems in that there is little if any increase in species diversity as the stand matures (Horton and Kraebel 1953, Patric and Hanes 1964). In fact, if one considers the ruderals (annuals) as part of the chaparral, there is a dramatic reduction in species diversity within the first five years after fire. Even by excluding the ruderals of the herb phase, the number of individuals and the demise of some woody species results in stands of low species diversity. This is particularly true on the more xeric sites that support chamise chaparral (Hanes 1971). This "unstocking" of chaparral stands as they mature is a unique feature that correlates with a decline in live tissues of those plants that remain (Hanes 1971).

In Dr. Vogl's conceptual model of chaparral succession, the process is considered cyclic rather than linear retrogressive. The cycle or pulse is initiated by a perturbation, mainly fire. Like an off-centric at the top of a wheel, fire results in high initial productivity and species diversity that gradually decrease through time until the next perturbation accelerates them again. Dr. Vogl raises an interesting point when he states, "The concern in chaparral is not so much if chaparral will recover after fire and how long it will take, but rather how rapidly the system will decline without fire". We know that chamise chaparral stands 60-90 years old have very low productivity and species diversity, and are often decadent (Hanes 1971). In more mesic chaparral, such as scrub oak chaparral, the rate of vegetation decline is much more protracted, perhaps two to three times as long.

Dr. Vogl's claim that decreased erosion leads to chaparral replacement by grassland and savanna or forest should lead readers to some questions and debate. There are numerous steep sites occupied by oak and pine forests. Steep rocky slopes are not the exclusive domain of chaparral. Surely there are many other factors than steep slope gradients and high erosion rates that account for the presence of California chaparral on the millions of acres (hectares) upon which it grows.

Chamise Chaparral Succession

Rundel's study of chaparral succession is significant in several ways: (1) It deals with the chamise chaparral in Sequoia National Park in central California mountains, (2) the pattern of succession is the same as that found in Southern California and Coastal Northern California studies, (3) it reveals important soil-plant interactions, and (4) it provides useful information to land managers in relation to fire intensity and season.

Rundel proposes that first pulse or herb phase of post-fire chaparral succession serves as a reservoir for nitrogen on burned sites. Without this tie-up by herbs, soil nitrogen would be vulnerable to erosion from the site. The woody species, present in the early stages of plant succession, also tie up nutrients but to a lesser extent than the herbs. Heavy livestock grazing during the herb phase reduces the protective cover and exposes nutrients to leaching and run–off.

In our understanding of chaparral dynamics the picture continues to emerge that the shrubs composing the mid-successional stand are of two types; short-lived and long-lived. Within the short-lived group some Rundel found were half shrubs such as Malacothamnus, Lotus, Eriodictyon, and Dendromecon, whereas the others are woody shrubs having developed from seed, but die out of the stand when it is middle-aged. Many species of Ceanothus are of this type. These drop-outs can be explained on the basis of competition, and yet differences in life span and tolerance to stress must be considered (Grime 1979).

Senility of old chamise chaparral has been recognized for some time (Hanes 1971). However, its cause has only been speculative until recently (Rundel and Parsons 1980). Limited nutrient availability, especially nitrogen, may contribute to the decline of chamise chaparral. More work is needed to show whether the fire-induced pulse results in a high input of nitrogen by the young vegetation. If the initial input must serve the chaparral throughout its development and maturation, then a deficiency could help explain the low productivity of old stands.

Not all resprouting shrubs survive fire (Hanes and Jones 1967). Even though Rundel's data show unusually high percentages of rootcrown kill, his findings serve as a caution at this time of increasing interest in control burning. Old stands of chaparral with high fuel loads can generate heat sufficient to kill many rootcrowns. Rootcrown mortality from fire is also correlated with the season of the year as it relates to starch reserves in the roots. Low starch reserves in late spring and early summer reduce resprouting potentials. But low moisture content in the soil reduces the impact of fire on seed reserves (Dunn & Poth 1979). Resource managers must fit control burn schedules to their post-fire vegetation needs.

Coastal Sage Scrub Succession

Westman's paper on coastal sage scrub succession is timely. For too long botanists and land managers alike have treated coastal sage scrub and chaparral as one vegetation type. Several characteristics argue against this practice. Among them are leaf type (mesophyllous, drought deciduous), half-woody (subligneous) stems, and greater drought tolerance. When compared to the hard (sclerophyllous), evergreen leaves of chaparral shrubs, and their woody stems and greater stature, it is unfortunate that these distinctly different Mediterranean-type vegetations have been considered as one. The use of soft chaparral when speaking of coastal sage scrub is an unfortunate misnomer that should be abandoned.

Westman provides ample evidence for treating coastal sage scrub as distinct from chaparral in structure, composition, physiognomy, phenology, physiology, habitat, and distribution. Two major formations are recognized: northern coastal scrub and southern coastal sage scrub. The southern formation is further subdivided into Venturan, Riversidian, and Diegan.

As with chaparral, the leaf is the single most diagnostic feature of coastal sage scrub vegetation. It is small to medium size, mesophyllous, drought-intolerant, has higher transpiration rates than chaparral sclerophylls, and is susceptible to SO_2 damage.

Three leaf duration features are described: (1) short (1-2 months), (2) small leaves on lateral stems during summer drought, (3) recovery after prolonged wilt. Westman proposes that photoperiod may be the trigger mechanism for seasonal leaf dimorphism rather than drought. Yet his findings indicate a higher incidence of leaf dimorphism on recent burns where environmental conditions are more stressful.

Coastal sage scrub is known for its aromatic properties and subligneous stems. The leaf oil content of dominant species is high, resulting in high flammability. Both coastal scrub and chaparral vegetations are fire types. Yet due to the lower fuel loading from both live and dead stems, scrub communities support low fire intensities. Such low fire heat allows for abundant seed survival and the sprouting of burned rootcrowns, even though they lack root-crown burls (lignotubers).

The subligneous stems and the mesophytic leaves of coastal scrub species have other implications as described by Dr. Westman. Decomposition rates are high, resulting in rapid nutrient turnover. The life expectancy of most sage scrub species is generally short (10-30 years), and so the death and decomposition of entire plants accelerates nutrient turnover.

A unique feature of coastal scrub species is their ability to colonize disturbed sites as well as replace dead companions in intact stands. This feature allows scrub species to invade burned chaparral sites at low elevations, form enclaves within chaparral stands, and to maintain a climax community of coastal sage scrub with a mosaic of shrub ages.

Dr. Westman has laid a strong foundation in our understanding of the coastal sage scrub vegetation of California. It should be clear that this vegetation is a unique Mediterranean-type, distinct from chaparral, and that its compositional features as well as its vegetation dynamics demand attention from scientists and practitioners.

Literature Cited

Clements, F. E. 1916. Plant succession - an analysis of the development of vegetation. Carnegie Inst. Wash Pub. 242. 512 p.

Cooper, W. S. 1922. The broad-sclerophyll vegetation of California - an ecological study of the chaparral and its related communities. Carnegie Inst. Wash. Pub. 319. 122 p.

Drury, W. H. & I. C. T. Nisbet. 1973. Succession. J. Arnold Arboretum Vol 54(3): 331-368.

Dunn, P. H. & M. Poth. 1979. Nitrogen replacement after fire in chaparral. In: Gordon, J. C., C. T. Wheeler, & D. A. Perry (Eds.) Symbiotic Nitrogen Fixation in the Management of Temperate Forests. For Res. Lab., Oregon St. U., Corvallis, Or. pp. 287-293.

Egler, F. E. 1954. Vegetation science concepts: Initial floristic composition, a factor in old-field vegetation development, Vegetatio 4:412-417.

Grime, J. P. 1979. Plant strategies and vegetation process. Wiley & Sons, N. Y. 222 p.

Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41:27-52.

_____. 1977. Chaparral. In: Barbour, M. G. & J. Major, eds. Terrestrial Vegetation of California. Wiley & Sons, N. Y. 417-470.

Hanes, T. L. & H. Jones. 1967. Postfire chaparral succession in southern California. Ecology 48:259-264.

Noble, I. R. & R. O. Slatyer. 1977. Post-fire succession of plants in Mediterranean ecosystems. In: Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. U. S. For. Serv. Gen. Tech. Rep WO-3. pp. 37-45.

Patric, J. H. & T. L. Hanes. 1964. Chaparral succession in a San Gabriel Mountain area of California. Ecology 45:353-360.

Plummer, F. G. 1911. Chaparral - studies in the dwarf forests, or elfin-wood, of southern California. U.S.D.A. For. Ser. Bull. 85. Wash. D.C. 54 p.

Rundel, P. W. & D. W. Parsons. 1980. Nutrient changes in two chaparral shrubs along a fire-induced age-gradient. Amer. J. Bot. 67:57-58.

Smith, R. L. 1980. Alluvial scrub vegetation on the San Gabriel River floodplain, California Madrono Vol. 27(3):126-138.

Vegetation Changes in Mediterranean Australia Since European Settlement[1]

Marilyn D. Fox[2]

Abstract: This paper reviews the vegetation of the mediterranean regions of Australia : as it was before European settlement less than 200 years ago, its degradation under agricultural practices with introduced plants and animals, and current and future land use. The main agencies of change have been clearing, grazing, fertilizing, altered fire regime and introduced species, both exotic plant species and introduced grazers. There have been extinctions (both total and local) while other native species have had their demographies and distributions altered.

The Australian continent has only recently been exposed to the effects of the agricultural and industrial revolutions. Its existence was known to navigators of the late sixteenth century, and in particular its northern and western coasts were charted through the early seventeenth century but with few recorded excursions ashore.

The first European settlement was at Sydney in 1788, with the mediterranean regions being settled later: on the Swan River (Perth) in Western Australia in 1828 and in the Gulf of St. Vincent (Adelaide) in South Australia during 1836. At the time of exploration and settlement the continent was home to an aboriginal people who had been there for at least 40,000 years. The dingo (*Canis familiaris dingo*) was the only animal associated with these hunter-gatherers and their only tools were spears, woomeras (throwing sticks), boomerangs and stone axes, plus their use of fire. Fire, then and now, was used to drive large game into ambush, but more significantly it attracted game to the resulting soft regenerating growth which was also gathered by the women. The Australian aborigine did not practise agriculture; fire was the only agent used to modify the environment.

With the coming of European man, a continent that had known only the sparsely dispersed aborigines was invaded by an industrialized people and their retinue of plants, animals and microorganisms. The Australian biota which had evolved in isolation suddenly encountered the domesticated animals and crop plants of Europe. More tragically, the aboriginal people suddenly encountered the disease organisms of Europe, these together with alcohol and the more direct measures of poisoning and shooting, decimated their populations in just a few decades.

Mediterranean Climate in Australia

The occurrence of mediterranean climate in Australia has been interpreted differently by different authors. Those who have used the stricter interpretation of Köppen's *Cs* type (Köppen 1936), of a distinct summer half-year drought with appreciable rainfall during the winter months, include Aschmann (1973) and Milewski (1979). Specht and Moll (in press) extended this by including the cool semiarid (*BSk*) type. Figure 1 shows the distributions of these types, as well as that of the hot semiarid (*BSh*) type where this corresponds more closely with vegetation boundaries. The figure is redrawn from Dick (1975, after Köppen 1936). The mediterranean-type climate (*Csa*, *Csb* and *BSk*) occurs over 8 percent of the continental area.

The mediterranean regions are roughly the south-west of Western Australia and the eastern edge of the Great Australian Bight. Perth and Adelaide are the only centres of population in these regions. To the north the mediterranean regions are bounded by the arid (*BW*) zone while to the east the climate is humid with more evenly distributed rainfall (*Cf*).

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean -Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Ecologist, National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, 2000, Australia.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

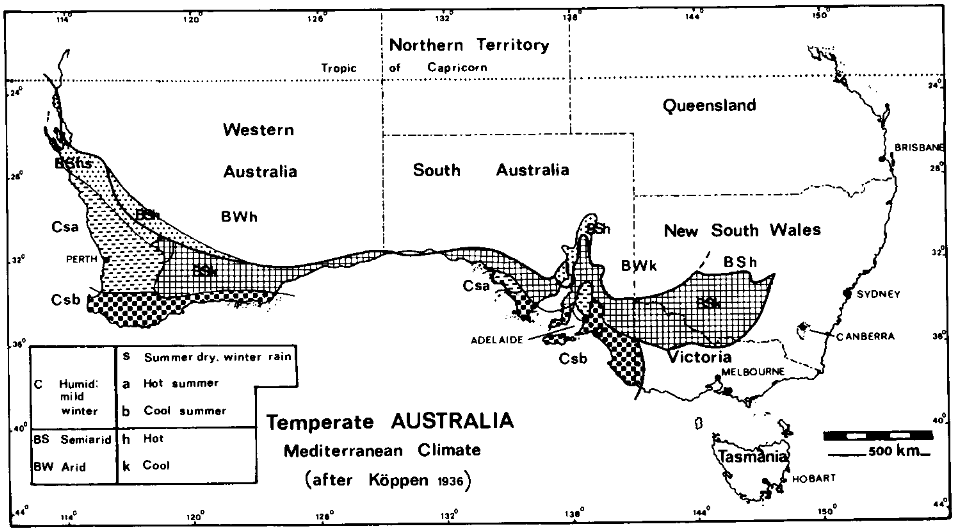


Figure 1--
The climates of temperate Australia after Koppen (1936) from a map by Dick (1975). The mediterranean climates (*Cs*) and cool semiarid (*BSk*) types are shown as well as the warm semiarid (*BSh*) type where this corresponds to vegetation boundaries

THE ORIGINAL VEGETATION

The vegetation of the mediterranean regions of Australia is illustrated in Fig.2 (based on a map by Moore 1969). This ranges from the impressive forests of south western Australia through the woodlands of characteristically "mallee" eucalypts, to the heathlands and chenopod shrublands. Given the uniformity of climate, the principal determinant of vegetation structure is the nature and nutrient status of the substrate and absolute amount of precipitation. The three major soil suites of southern Australia are the base-rich, nutrient-poor and calcium-rich soils, and their relationship to vegetation is reviewed by Specht and Moll (in press).

Temperate sclerophyll forests grow in mediterranean regions of the south-west of Western Australia. These forests are dominated by eucalypts, the wetter tall open forests on soils derived from granite and gneiss by karri (*E. diversicolor*), the drier open forests on soils from the ancient laterites by jarrah (*E. marginata*). Woodlands are also usually dominated by eucalypts such as the black box (*E. largiflorens*) of south-western NSW, but may also be composed of acacias such as mulga (*A. aneura*).

The eucalypt shrublands or mallee is the form of vegetation most closely associated with the mediterranean regions. These multistemmed, low (usually less than 10m) eucalypts grow where the soil is sandy but often overlies an alkaline clay subsoil (Rossiter and Ozanne 1975). The understorey can vary from a chenopod synusium to one dominated by porcupine grass (*Triodia irritans*).

Much comparative work has been done on the sclerophyllous low shrublands or heaths of Australia and other mediterranean

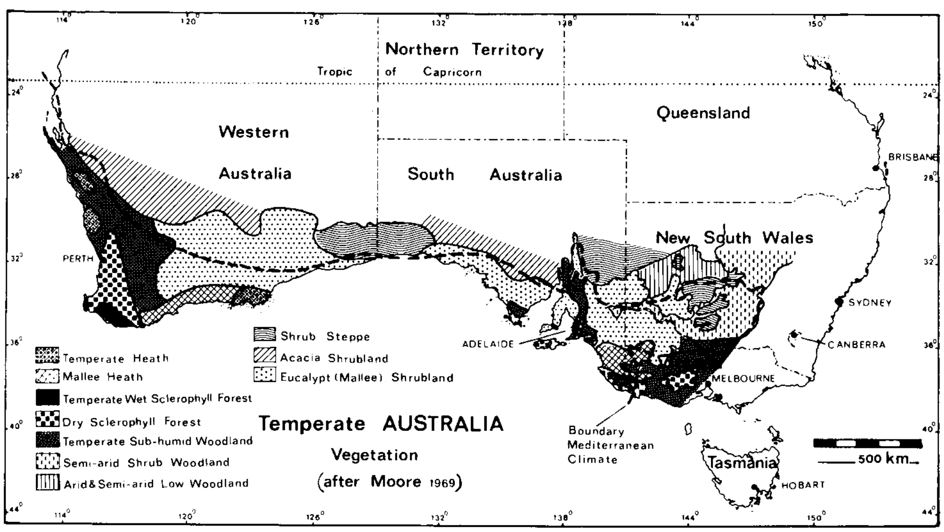


Figure 2--
The vegetation of the mediterranean regions of Australia from a map by Moore (1969). The limit of the mediterranean-type climate (*Csa*, *Csb* and *BSk*) is shown as a heavy dashed line.

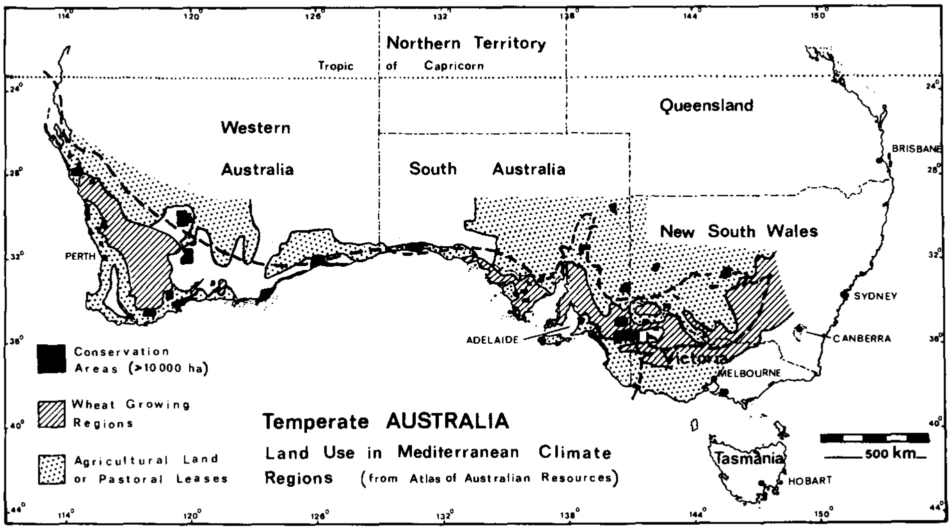


Figure 3--
Sources of alienation of the mediterranean regions of Australia. The distribution of the wheat belts and sheep grazing areas are shown and the limit of the mediterranean -type climate. The location of major conservation areas is also shown.

regions (e.g. Specht and Moll in press). Extending into the semiarid regions, this is replaced by chenopod shrublands or shrub steppe of Moore (1969).

The arid zone extends to the coast at the head of the Great Australian Bight and effectively divides the mediterranean regions into western and eastern provinces. These are recognised as separate floristic zones (Burbidge 1960), the south-western temperate zone being the richest floristic zone on the continent.

The vegetation of Western Australia has recently been mapped by Beard (see Beard 1979 for a review). Satellite imagery was used to map the environments (including vegetation) of South Australia (Laut et al 1977) and previously the vegetation was described by Specht (1971). The mediterranean region of Victoria has received the sporadic attention of ecologists and botanists. It is mapped on Carnahan's (1976) map of the natural vegetation of Australia. The vegetation of western New South Wales was mapped by Beadle (1948) and Fox (1980) is currently mapping it at a larger scale.

LAND USE IN MEDITERRANEAN REGIONS OF AUSTRALIA

Degree of Alienation

In less than 200 years of European settlement the entire continent has been alienated to some extent. The degree of alienation ranges from clearing and subsequent cultivation, altered nutrient levels, altered fire regime, to interaction with introduced animals and plants.

Figure 3 summarizes the major land uses or sources of alienation within the mediterranean regions. Major conservation areas are also shown; these are usually national parks, however some are aboriginal reserves.

The mediterranean regions correspond with the wheat belts and sheep grazing areas so that generally the level of disturbance is high (Adamson and Fox, in press). In such areas the alienation is compounded by the use of fertilizers, suppression of fire and an abundance of introduced animals and plants.

With the loss of habitat many native animals have become locally extinct. A small marsupial, the tammar wallaby (Macropus eugenii), which was once "the most plentiful and widely-distributed wallaby in the south-west" (Thomas, 1888), but "rapidly disappearing in the cultivated districts" (Shortridge 1909) is "now restricted to a few small scattered main-land colonies, and a number of islands" (Poole 1978).

The effects of fertilizers on compos-ition and growth of heathlands in mediterranean South Australia have been demonstrated by Heddle and Specht (1975). Contamination of conservation areas, often islands in a sea of alienated land, is a major management problem. There is the dual response of death or suppression of native species and invasion by exotic species adapted to the higher nutrient levels.

At present about ten percent of vascu-lar plants in Australia are exotics (Wace 1973). The highest incidences of these

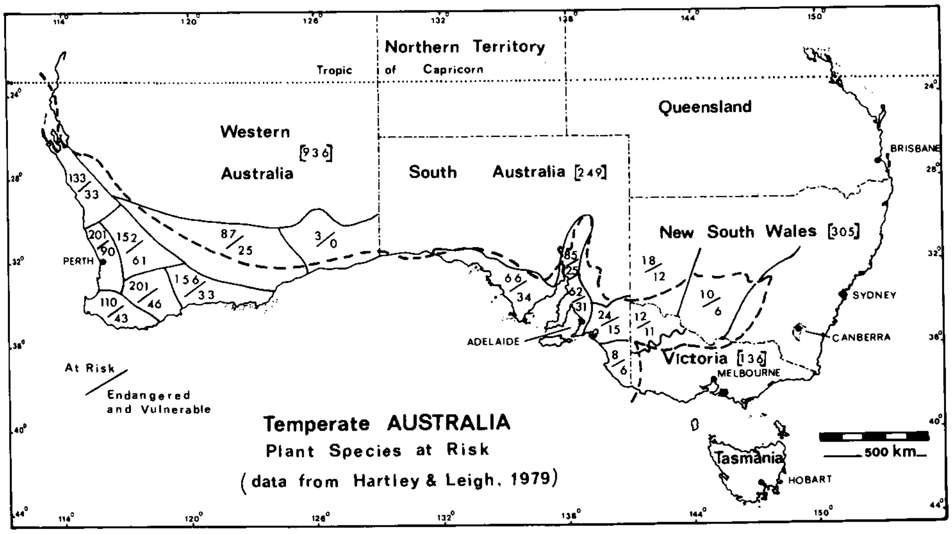


Figure 4--
Plant species at risk in the mediterranean regions of Australia (based on figures in Hartley and Leigh 1979). The total number of species considered at risk in each state is shown, as is the total for each subdivision, and the number considered to be endangered and vulnerable.

are in the humid regions of the south-east of Australia, with relatively few in the mediterranean regions.

The successful weeds of the mediterr-anean regions generally have Mediterranean origins and are often close-ly associated with crops. One such plant is skeleton weed (Chondrilla juncea). It was introduced to south-eastern Australia prior to 1910; it has spread steadily and now covers most of the eastern mediterr-anean region and across to the coast near Canberra. In Western Australia it was ;first recorded in 1963 and is spreading rapidly, especially along the railway net-I work (Cullen and Groves 1977).

With the conversion of natural vege-tation to improved pasture in the last sixty years or so, a very large area (almost 5 million hectares) of south western Western Australia now supports sub-clover (Trifolium subterraneum) an introduced legume. This is maintained by substantial addition of fertilizers such as superphosphate. Other exotic species, such as the South African capeweed (Arctotheca calendula) can become established in these annual pastures.

Possibly the most disastrous animal introduction to Australia was that of the rabbit (Oryctolagus cuniculus L.). Rabbits arrived with the first settlers but the main release which established them as feral populations was in 1859. They spread rapidly and now can be found through-out mainland Australia south of the tropic of Capricorn. The populations in some mediterranean habitats have the highest capacity for increase, with almost 30 young per female per year, compared to a mean of about five for other habitats (Myers 1970). Biological control through the myxoma virus dramatically reduced populations in the fifties. Today the main control measures include poisoning, fumigation, warren-ripping, shooting and fencing. However in over a century of occupation they have markedly altered the vegetation of vast areas by both grazing and browsing pressure as well as selective feeding.

As with exotic plant species, the introduced animals have either completely replaced entire endemic communities, such as with sheep and cattle, or have entered an otherwise pristine community, such as the early colonizing rabbits or more recently, feral goats (Capra hircus). In the second instance the introduced animal is having an insidious effect on the vegetation without manipulation by people.

Changes in the Vegetation

With the widespread clearance of land for agriculture there have been losses of associations and of species. It is possible that there were species, of both plants and animals, that were never known to science. Some areas such as the coastal sand plain near Perth are virtually unrepresented in any conservation area.

Recently Hartley and Leigh (1979) have classified over two thousand plant species in various risk categories. Figure 4 shows those regional subdivisions they used which encompass the mediterr-anean regions. The total number of species considered at risk in the state is shown, as is the total for each sub-division, and the number considered to be endangered and vulnerable. The four sub-divisions corresponding to the Western Australia wheat belt have the highest incidence of species at risk (a distinct-ion shared only by the rainforest of Cape York).

There is a range of responses of plant species to the altered environments in which they now grow. The most extreme of these is extinction; this can be total and there are some species believed to be extinct (Hartley and Leigh 1979), or it can be local. An example of local extinction is of the highly palatable old man saltbush (*Atriplex nummularia*). This once widespread chenopod is now found in very restricted areas. Other palatable plants are now less dense and restricted compared to their former distributions. By contrast unpalatable species may become more dominant. These often woody shrubs such as turpentine bush (*Eremophila sturtii*) are an increasing problem in grazed semiarid regions such as western New South Wales.

There may also be delayed responses still working through ageing populations. Recent studies have demonstrated that many individuals of shrubs and small trees of the mediterranean and semi-arid zones may be older than European settlement here. Crisp (1978) has found that mulga (*Acacia aneura*) and other acacias can live to about 250 years and that bluebush (*Maireana sedifolia*) individuals reach similarly impressive ages. However, recruitment of seedlings is very rare or episodic, and given the current grazing pressure it is possible that individuals of these dominant shrubs will not be replaced. It is probable that this combination of very old and senescing individuals with reproduction suppressed by grazing pressure is a common feature of especially the semiarid zone. The progressive senescence and eventual death of living shrubs may cause slow extinction.

In discussing these changes to the vegetation I have emphasized the role of grazing. Altered fire regimes can have similar effects with some species being enhanced, others disadvantaged by changed intensity, frequency or season of burn.

Regeneration Studies

Although the history of settlement is short there are some outstanding studies of regeneration after degradation of habitat. One of the most famous is for Koonamore in the semiarid region of South Australia (Osborn, Wood and Paltridge 1935). The vegetation reserve was established in 1925 and permanent quadrats were studied from 1926. In particular permanent photopoints have supplied data on the regeneration (after sheep and rabbit grazing) of the perennial vegetation (Hall, Specht and Eardley 1964).

Much of the mallee country of north-western Victoria has been cleared and Onans and Parsons (1980) have recently reported on the regeneration of sites cleared and left undisturbed for periods up to 39 years. When an adequate seed source is lacking they found areas would regenerate to a shrubland of seral species of *Acacia* and *Dodonaea*.

THE FUTURE OF THE VEGETATION IN MEDITERRANEAN REGIONS OF AUSTRALIA

Vast areas of the mediterranean regions of Australia have been modified since the arrival of European settlement. Even where the overt forms of alienation such as clearing are absent, there are covert forms in the introduced animals with their destructive grazing. The grazing pressure from feral and domestic animals may have reduced some long-lived shrub and tree species to senescent populations which will not be replaced unless the grazing pressure is reduced.

There are some large conservation areas within the mediterranean regions and attempts are being made to minimize the impact of exotic grazers. However park authorities must accept the responsibility when land is acquired to attempt to have it revert to its pre-European condition. As well as removing exotic weeds and pests, this means removing sources of nutrients and maintaining "natural" fire regimes (or at best a mosaic of patches of different ages since last fire).

LITERATURE CITED

Adamson, D.A.; Fox, M.D. Change in Australasian vegetation since European settlement. *In*: Smith, J.M.B. ed. A History of Australasian vegetation, Sydney: McGraw Hill; (in press).

Aschmann, H. Distribution and peculiarity of mediterranean ecosystems. *In*: DiCastri, F.; Mooney, H.A., *eds*. Mediterranean-type ecosystems, origin and structure. Berlin: Springer; 1973: 11-19.

Beadle, N.C.W. The vegetation and pastures of Western New South Wales. Sydney: Department of Soil Conservation; 1948.

Beard, J.S. Vegetation mapping in Western Australia. J. Royal Society of Western Australia. 62: 75-82; 1979.

Burbidge, N.T. The phytogeography of the Australian region. Australian J. Botany 8: 75-211; 1960.

Carnahan, J.A. Natural Vegetation. In: Atlas of Australian resources, 2nd series. Canberra : Dept. of Natural Resources; 1976.

Crisp, M.D. Demography and survival under grazing of three Australian semi-desert shrubs. Oikos 30: 520-528; 1978.

Cullen, J.M.; Groves, R.H. The population biology of Chondrilla juncea L. in Australia. In: Anderson, D., ed. Exotic species in Australia - their establishment and success. Proceedings of the Ecological Society of Australia 10: 121-134; 1977.

Dick, R.S. A map of the climates of Australia : according to Köppen's principles of definition. Queensland Geographical Journal, 3rd Series, 3: 33-69; 1975.

Fox, M.D. Mapping the vegetation of the mallee landscapes. In: R.R.Storrier-M.E. Stannard Aeolian Landscapes in the semi-arid zone of south eastern Australia. Riverina branch: Australian Society of Soil Science, Inc.; 1980: 147-148.

Hall, E.A.A.; Specht, R.L.; Eardley, C.M. Regeneration of the vegetation on Koonamore Vegetation Reserve, 1926-1962. Australian J. Botany 12: 205-64; 1964.

Hartley, W.; Leigh, J. Plants at risk in Australia. Occasional paper No.3, Australian National Parks and Wildlife Service, Canberra: 1979.

Heddle, E.M. and Specht, R.L. Dark Island Heath (Ninety-Mile Plain, South Australia). VIII The effect of fertilizers on composition and growth, 1950-1972. Australian J. Botany 23: 151-164; 1975.

Köppen, W. Das geographische System der Klimate In: Köppen, W.; Geiger, R., eds. Handbuch der Klimatologie. Berlin: Borntraeger, Bd. I. Teil C; 1936: 1-44.

Laut, P.; Heyligers, P.C.; Keig, Gael; Löffler, E.; Margules, C.; Scott, R.M. Environments of South Australia. Canberra: Division of Land Use Research, CSIRO; 1977.

Milewski, A.V. A climatic basis for the study of convergence of vegetation structure in mediterranean Australia and southern Africa. J. of Biogeography 6:293-299; 1979.

Moore, R.M. Vegetation of Australia. In: Moore, R.M., ed. Australian Grasslands. Canberra: Australian National University Press; 1969.

Myers, K. The rabbit in Australia. In: Dynamics of populations. Proceedings of the Advanced Study Institute, Oosterbeck. Wageningen: Centre for Agricultural Publishing and Document-ation; 1970: 478-506.

Osborn, T.G.B.; Wood, J.G.; Paltridge, T.B. On the climate and vegetation of the Koonamore Vegetation Reserve to 1931 Proceedings of the Linnean Society of N.S.W. 60: 392-427; 1935.

Poole, W.E. The status of the Australian Macropodidae. In: Tyler, M.J., ed. The status of endangered Australasian wildlife. Adelaide: Royal Zoological Society of South Australia; 1978: 13-27.

Rossiter, R.C.; Ozanne, P.G. In: Moore, R.M. ed. South-western temperate forests, woodlands and heaths in Australian Grasslands. A.N.U. Press, Canberra; 1975.

Shortridge, G.C. An account of the geographical distribution of the Mar-supials and Monotremes of south-west Australia. Proceedings of the Zoological Society of London 60: 803-848; 1909.

Specht, R.L. The vegetation of South Australia, 2nd edition. Adelaide: Government Printer; 1972.

Specht, R.L.; Moll, E.J. Heathlands and sclerophyllous shrublands - an overview. In: Nutrients as determinants of the structure and functioning of mediterr-anean-type ecosystems. Proceedings of Third International Conference on Mediterranean-type Ecosystems (in press).

Thomas, O. Catalogue of the Marsupialia and Monotremata in the collection of the British Museum (Natural History). British Museum, London; 1888.

Wace, N. Naturalized plants and native vegetation in Australia. Proceedings Second Victorian Weeds Conference 7: 13-29.

Prescribing Fire Frequencies in Cape Fynbos in Relation to Plant Demography[1]

F. J. Kruger[2]

Abstract--Regulating fire frequency in Cape fynbos areas causes marked changes in vegetation. Very frequent fire eliminates seeding shrubs with long youth periods; infrequent fire reduces shrubs because of senescence. Variation between these extremes will cause more subtle compositional changes. Research on plant fecundity schedules and on the dynamics of seed pools is necessary to understand these.

Problems in the ecology and management of South African mediterranean-type ecosystems have been outlined in several recent papers (Bands 1977, Kruger 1977 and these proceedings, Day and others 1979): fire is generally acknowledged as a useful tool in these ecosystems. In this paper I attempt to set out a framework for research on the demography of Mountain Fynbos plants, so that a deductive and a predictive system can be developed for deciding on proper burning frequencies for any given management goal.

Management goals for Mountain Fynbos centre mainly on maintenance of certain dynamic equilibria in the ecosystem, for sustained yield of clean water, and so on. Designing the managed fire regime is largely dependent on our understanding of how a change in regime will determine a new equilibrium in the vegetation. We know, for example, that a change in fire frequency, from about once in 20 yr to about once in 6 yr, can change a dense tall shrubland to a low vegetation dominated by herbaceous plants, eliminating species with slow life cycles (Van Wilgen 1981a, b). On the other hand, if fire is kept out for 40 yr or more, shrub populations decline, seedling recruitment after fire is reduced, and there is an apparent trend toward a sparse shrubland (Bond 1980, Van Wilgen 1981a, b); under favourable conditions, long intervals between fire could result in replacement of fynbos by evergreen rain forest.

Of the elements of fire regime that are regulated by management, fire frequency has the greatest potential for making immediate and marked changes to fynbos. The manager must invariably reconcile conflicting goals. Fire control, for example, is best achieved through frequent burning, which reduces the average biomass in the area. Nature conservation, where species diversity is to be maintained, probably requires intermediate fire frequencies. It is not sufficient to select an arbitrary frequency that will safely achieve one or other of his goals. Therefore, our empirical knowledge of the effects of fire regime must be supplemented through the study of plant demography and hence the dynamic responses of vegetation to fire.

SPROUTING vs. SEEDING PLANTS

In fynbos as in other mediterranean-type vegetation, fire regime strongly influences the relative abundance of plants that regenerate by sprouting and those that rely on seed. Very frequent fire favours sprouting plants. Survival of fire seems to be high. First, mortality in *Watsonia pyramidata*, a geophyte, is zero or nearly so (Kruger and Bigalke in press). For *Protea nitida*, Haynes (1976) reported mortalities of 1 to 13 per cent in different fires. Second, fires stimulate vegetative reproduction among herbaceous species (Kruger and Bigalke in press) and, possibly, sexual reproduction among shrubs such as *Protea nitida* (Haynes 1976). Although long absence of fire causes a decline in herbaceous sprouters, most sprouters, woody or herbaceous, appear to be very long-lived so that infrequent fires may also favour sprouters over seeders (Bond 1980, Van Wilgen 1981a, b, Kruger and Bigalke in press). Plants of species such as *Watsonia pyramidata* and *Protea nitida* seem to be very long-lived and populations are therefore well able to persist despite long intervals of low recruitment. It is only at very high and very low fire frequencies that sprouters are markedly favoured over seeding shrubs in fynbos. Otherwise, sprouters rarely form dense stands, and most usually are subordinate to seeders. This is unusual in mediterranean-climate ecosystems (Kruger in press) and it would be intriguing to find the reasons. For management, however, the present need is for data that describe the dynamics of sprouter populations.

DEMOGRAPHY OF SEEDING SHRUBS

Regeneration

A review shows that seeding shrub populations in mediterranean-type ecosystems are mostly even-aged and that effective population recruitment from seed is generally confined to the period immediately post-fire, and further that this is from propagule stocks of three kinds (a) soil seed-banks (b) canopy-stored seed and (c) continually replenished stocks (Kruger in press). In the first case, populations can survive long intervals between fires in the dormant state after death of adult plants, though the relative decay rates of

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Deputy Director for Conservation Research, South African Forestry Research Institute, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, Republic of South Africa.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

the seed-banks must partly determine the composition of the regenerating flora, depending on the length of the fire-free interval. Circumstantial evidence (Kruger 1977) indicates considerable longevity among such seed in fynbos, and the habit would therefore be adaptive in a fire regime marked by variability in the fire recurrence interval. It is apparently present in many fynbos species, including Proteaceae, Aspalathus, and many other large taxa.

Effective reproduction by canopy-stored seed or continually replenished stocks, where dormancy is not marked and seed life after dispersal is short, depends on an extant parent population and hence is ineffective where intervals between fire exceed plant life-spans; Bond (1980) has produced data to support this. Fynbos is often dominated by shrub species that store seed in closed capitula on the plant, until the parent dies, usually after fire. Seed released in unburnt vegetation is subject to very heavy predation (Bond 1980); seed in these species is relatively large, and contains high concentrations of proteins (Van Staden 1978); thus storage in capitula is apparently adaptive in a low-nutrient environment, in that seed tend to be protected against predators and efficient reproduction ensured because seed tend to be released by a reliable cue into the post-fire environment where predation pressure is low and germination conditions favourable. The effectiveness of canopy-stored seed is in some dispute. Seed ripens over seven or more months after flowering, and both Jordaan (1949, 1965) and Van Staden (1978) have claimed or suggested that seed in capitula are short-lived and that there are insufficient viable seed to ensure regeneration if parents are killed during the time of seed ripening (winter and spring). This does not accord with results reported by Lombaard (1971), nor with observations in Williams (1972) and Rourke (1980). Assuming that canopy-stored seed is effective in ensuring regeneration, the habit is adaptive in a predictable fire regime, where recurrence intervals are longer than the youth period but do not exceed the reproductive life-span of parent plants.

Martin (1966) has implied that certain important fynbos taxa, including Ericaceae, are dependent on the annual seed rain for reproduction. He maintained further that, in his study area, no seed store was available on site for post-fire regeneration. This habit will not be adaptive in the fire environment of the fynbos, especially where many species are local, unless species have highly dispersible seed. In view of the generally low capacity for long-range dispersal reported thus far among plants in general (Cook 1980), except among bird-dispersed seed, of which there are few in fynbos (personal observation), it seems necessary first to establish the importance of this trait among fynbos species before management-related research is launched. For a start, careful study is necessary of the floras of the soil seed-bank to determine which species are in fact not represented in the seed-bank.

Primary youth periods and fecundity schedules

In the even-aged shrub populations of the fynbos the reproductive potential of a species in a stand of uniform fire history depends on its age. Hence, fire frequencies prescribed for conservation of fynbos are based in the first instance on some estimate of the minimum age at which reproductive potential suffices to replace the parent population; latterly, the question of the period of peak fecundity has become important (e.g. Bond 1980).

The first question of importance relates to the youth period, i.e. time between establishment and age at the beginning of the fecundity period. In fynbos there is interspecific variability in this respect, but relatively little (Kruger and Bigalke in press). Thus, from records for nursery plants of 42 fynbos Protea species quoted by Rourke (1980) we find the following:

Youth period, yr	No. of species
2-4	22
5-7	16
> 7	4

These nursery records are not grossly unrepresentative of field performance, as indicated by Kruger and Bigalke (in press).

Species with differing youth periods sometimes occur in disparate habitats. Thus, Protea rupicola, one of those exceptionally slow to mature, inhabits cliff faces near mountain crests, where fires are infrequent and short primary youth periods are not necessarily adaptive. In management it is important to know the distribution of such species and the behaviour of fire in such habitats; the compartment management system followed in fynbos does not allow fine-grained burns and relies presently on the assumption that if a compartment contains patches of such habitat then prescribed burns will not traverse these patches at excessive frequencies, despite their spreading elsewhere within the compartment.

The present working hypothesis in prescribing fire frequencies is that sympatric species tend to have similar youth periods, and that these are relatively short, i.e. 3-8 yr (Kruger 1979 and unpublished). Prescribed burns at intervals that approach these will begin to eliminate species locally (Van Wilgen 1981a). Where precocious species occur with others that are markedly slow to mature (for example, Protea repens with P. laurifolia) the latter tend to be species where some individuals survive fire, even though they do not sprout (Kruger 1977).

An estimate of the youth period is not sufficient to define the minimum interval between fires. First, the population is seldom uniform with regard to youth period and second, more than one year of flowering would be required to ensure population replacement. Field data for the reproductive performance for Protea stokoei are as follows (Kruger and Lamb, unpublished):

No. of times an individual has flowered	Per cent of sample 5 yr post-fire	8 yr post-fire
0	85.5	47.9
1	13.3	31.9
2	0.8	17.7
3	0	2.5

A rule of thumb sometimes applied is that in any compartment the species that is slowest to mature should have developed to the point where at least half the individuals have flowered three or more times, before the area is burnt once more. One may simplify and assume that individuals mature at an exponential rate after the age at which the first matures, and that once having flowered, each individual flowers every year after. For Protea stokoei the following function applies approximately:

$$\ln y = 4.6 - t/6,$$

where y is the percentage of the population in the juvenile stage, and t the number of years since the first individual has matured - which occurs at 4 yr, since one year is required after flowering for seed to mature. From this one may calculate that a species such as Protea stokoei requires about 11 years after fire to reach the arbitrary "safe" reproductive condition.

There is variation within the species in the age at which individuals mature and this appears to correlate with habitat factors (see Protea lacticolor in Kruger 1979). Thus populations may expand or contract their ranges, depending on the frequency of fire.

This kind of approximation is a necessary but temporary expedient and must be superseded by rules based on knowledge of the fecundity schedules of plants. Data to construct fecundity curves for fynbos species are urgently necessary. Of particular importance are data to show the ages at which peak fecundity is reached, especially in relation to senescence.

Plant longevity and senescence

Senescence is used here in Leopold's (1961) sense, for the tendency for mortality in a population to occur toward the end of the maximum life-span of the species. Elsewhere (Kruger in press) I have quoted information that indicates pronounced senescence among fynbos shrubs, and Bond (1980) and Van Wilgen (1981a, 1981b) provide supporting field data and observations. Our experience presently suggests the following features common to seeding fynbos shrubs in the majority of habitats: relatively low seedling to adult ratios in post-fire regeneration (Bond quotes ratios from 12:1 to 18:1 for a burn in a favourable season); low density-dependent mortality, irrespective of absolute densities, in young and middle-aged plants; density-independent mortality is usually also low after establishment, barring extreme drought or other catastrophe; most species therefore exhibit senescence, and the age of senescence appears to be species-specific, little affected by environment; among dominant Proteaceae it appears to vary between 30 and about 50 years, according to species. This relatively short life is associated with species whose life-cycles are strongly dependent on the fire cycle, including those that have canopy-stored seed. Among species such as Leucadendron argenteum, Leucospermum conocarpodendron and Protea laurifolia, where individuals tend to survive fire and populations are not even-aged, greater ages are attained and population dynamics are fundamentally different.

Declining density as well as declining reproductive output per individual with onset of senescence severely reduces effective reproductive potential of the local population (e.g. Bond 1980). Therefore, species that do not accumulate seed-banks in the soil are liable to local extinction when fire recurrence intervals approach 30-40 yr.

Conclusion

The rather tentative evidence now available indicates that an important proportion of the fynbos flora is adapted to fire frequencies ranging between about once in 10 to once in 40 yr. How does variation within this range affect the relative abundance of species?

The variety of plant forms with different life-history characteristics that may be encountered in any given stand suggests that marked compositional changes are likely, but much more experimental and demographic data are required before this question can be addressed.

MODELLING REQUIREMENTS

Both the research scientist and the manager need to synthesize information on relevant aspects of vegetation dynamics in order to explore the implications of varying fire frequency; for this, demographically based models will be necessary. The first requirement is for heuristic models that accommodate the life-cycles typical of fynbos plants. To overcome the problem of diversity in fynbos "archetypal" species will necessarily be used in the models. The practitioner would then need to know the composition in terms of these archetypes of the stand whose dynamics he wishes to model.

Noble and Slatyer (1977, 1980) outline an approach to modelling plant succession that is explicitly intended to accommodate the problems discussed here. They have reduced the particulars of succession to a finite and tractable list of phenomena that essentially define the process. Nevertheless, their approach is based on the assumption that species populations change from one discrete and uniform stage to the next; from juvenile to mature, for example. The models do not allow for dynamics of populations in each stage, for example, for fecundity schedules in the mature stage. As shown, fynbos-fire models must incorporate these dynamics, especially where one considers fire recurrence intervals that approach the thresholds between life-history stages. Their approach is therefore not sufficient for analysis of likely compositional changes in fynbos although it provides the essential framework. It is clear that modelling of stand dynamics after the manner of Botkin and others (1972) and Shugart and Noble (in press) will be necessary.

CONCLUSION

This paper has focused on the effects of fire frequency on fynbos vegetation structure and dynamics. We know that fire season, and probably fire intensity, will also have important effects and these must also be accommodated in a synthesis for management. There is also growing evidence for a key role of animals, especially seed and seedling predators. Research by various groups on the demography of selected shrub and herbaceous species and on evidently important plant-animal interactions is currently under way. Nevertheless, the first need is for simulating and predicting fire frequency effects. Successful simulation of vegetation dynamics will also allow progress in simulating fire frequency effects on hydrological and nutrient cycles.

ACKNOWLEDGEMENTS

I thank the sponsors of this symposium and the South African Directorate of Forestry and Environmental Conservation for the support that enabled my contribution.

LITERATURE CITED

Bands, D.P. Prescribed burning in Cape fynbos catchments. In: Mooney, H.A.; Conrad, C.E. (Technical Coordinators) Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA Forest Serv. Gen. Tech. Rep. WO-3, Washington, D.C. 1977: 245-256.

Bond, W.J. Fire and senescent fynbos in the Swartberg, Southern Cape. S. Afr. For. J. 114: 68-71; 1980.

Botkin, D.B.; Janak, J.F.; Wallis, J.R. Some ecological consequences of a computer model of forest growth. J. Ecol. 60: 849-872; 1972.

Cook, R. The biology of seeds in the soil. In: Solbrig, O.T. ed. Demography and evolution in plant populations. Oxford, Blackwell Scientific Publications; 1980: 107-129.

Day, J.M.; Siegfried, W.R.; Louw, G.N.; Jarman, M.L. Fynbos ecology: a preliminary synthesis. Rep. of the South African National Scientific Programmes; 1979; 40. 166 p.

Haynes, R.A. Aspects of the ecology and life-history of *Protea arborea* Houtt. Department of Zoology, University of Zimbabwe; 1976. 68 p.

Jordaan, P.G. Aantekeninge oor dir voortplanting en brandperiodes van *Protea mellifera* Thunb. J. S. Afr. Bot. 15: 121-125; 1949.

Jordaan, P.G. Die invloed van 'n winterbrand op die voortplanting van vier soorte van die Proteaceae. Tydskrif vir Natuurwetenskappe 5: 27-31; 1965.

Kruger, F.J. Ecology of Cape fynbos in relation to fire. In: Mooney, H.A.; Conrad, C.E. (Technical Coordinators). Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA Forest Serv. Gen. Tech. Rep. WO-3, Washington, D.C.; 1977: 230-244.

Kruger, F.J. South African heathlands. In: Specht, R.L. ed. Ecosystems of the world. 9B Heathlands and related shrublands: descriptive studies. Amsterdam, Elsevier; 1979: 19-80.

Kruger, F.J.; Bigalke, R.C. Fire in the fynbos. In: Booysen, P. de V. ed. Ecological effects of fire in South Africa; in press.

Kruger, F.J. Plant community diversity and dynamics in relation to fire. In: Kruger, F.J.; Mitchell, D.T.; Jarvis, J.U.M. Mediterranean-type ecosystems: the role of nutrients. Heidelberg, Springer; in press.

Leopold, A.C. Senescence in plant development. Science 134: 1727-1732; 1961.

Lombaard, H.B. 'n Ekologiese studie van aspekte van die generatiewe voortplanting van *Protea mellifera* en *Protea pulchella*. Thesis, University of Stellenbosch; 1971. 72 p.

Martin, A.R.H. The plant ecology of the Grahamstown Nature Reserve 2: Some effects of burning. J. S. Afr. Bot. 32: 1-39; 1966.

Noble, I.R.; Slatyer, R.O. Post fire succession of plants in mediterranean ecosystems. In: Mooney, H.A.; Conrad, C.E. (Technical Coordinators). Proceedings of the Symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA For. Serv. Gen. Tech. Rep. WO-3; Washington, D.C.; 1977: 27-36.

Noble, I.R.; Slatyer, R.O. The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43: 5-21; 1980.

Rourke, J.P. The Proteas of Southern Africa. Cape Town: Purnell; 1980. 236 p.

Shugart, H.H.; Noble, I.R. A computer model of succession and fire response of the high altitude Eucalyptus forests of the Brindabella Range, Australian Capital Territory. Austr. J. Ecol.; in press.

Van Staden, J. Seed viability in Protea neriifolia 1: the effects of time of harvesting on seed viability. Agroplantae 10: 65-67; 1978.

Van Wilgen, B.W. 1981a. Some effects of fire frequency on the aerial plant biomass of fynbos communities at Jonkershoek, Stellenbosch. J. Ecol.; in press.

Van Wilgen, B.W. 1981b. Some effects of fire frequency on fynbos plant, community structure at Jonkershoek, Stellenbosch. S. Afr. For. J.; in press.

Williams, I.J.M. A revision of the genus Leucadendron (Proteaceae). Contributions from the Bolus Herbarium 3: 1-425.

Plant Demography and Chaparral Management in Southern California[1]

Paul H. Zedler[2]

Abstract: Vegetation consists of interacting populations, with gap-formation and invasion having important short and long term consequences. Plant species differ in their requirements for establishment, and this must be considered in predicting their response to management.

From the population point of view ecosystem behavior is the result of change in populations that is describable in terms of establishment, growth, and death. One example of the rigorous application of these ideas is the review of S. Levin (1976) which is sufficiently general to serve as a model for this discussion.

A landscape may be viewed as a mosaic of patches. The state of the ecosystem can be defined by the abundance of species measured in some appropriate way. Within each patch the species populations change as the result of mortality and establishment. Through time, species populations are disappearing in some patches and dispersing to and becoming established in others where they are absent; the general case of "island biogeography".

This simplification focuses attention on the processes which cause local extinction (disappearance from a patch) and which control local invasion (dispersal from outside the patch.) Extinction can result from biotically induced changes (competition, interference, parasitism, and predation); and from environmental extremes, including human disturbance.

Invasion into unoccupied patches by definition depends on dispersal ability, and the number of propagules of a particular species that will arrive in a patch during a period of time cannot be predicted unless the spatial distribution of the species is known. Predicting long-term change at the landscape level requires consideration of species distributions.

The disappearance of a species from a patch occurs when the local population is overwhelmed by biotic pressures or by environmental extremes. By causing mortality, competition generally acts to destabilize ecosystems. Predation and parasitism can be stabilizing forces, but interaction with variable factors of the physical environment means that often they are not. The expected situation is that species populations observed at any particular time will be undergoing change. True equilibrium or steady state probably does not exist in real ecosystems, and quasi-equilibrium (i.e. climax) can only be expected at large spatial scales which average the effect of local changes. The traditional emphasis on a hypothetical climax endpoint is now thoroughly discredited (White 1979).

Species differ markedly with respect to their liability to local extinction and capacity for invasion. Within a very large area, say 10,000 hectares, dominant species will have effectively a zero probability of extinction over a short period of time. The capacity to persist may be achieved by a short life span but high dispersal, or by living longer but perhaps sacrificing seed production or dispersal. Because of these kinds of life history differences, the rate of change of different species given a change in ecological circumstances can be different by orders of magnitude.

GAP REGENERATION

Despite the fact that ecosystems, especially those of arid regions, are expected to be continually reeling from the latest environmental extreme, it does not follow that there is an abundant supply of unoccupied space. Environments change, but not in a completely random way. At least before the unprecedented increase of the human population, ecosystems were formed of accumulations of species able to cope with the more-or-less recurrent patterns of environmental change superimposed on generally slowing changing averages. Assemblages of species in natural communities are able to survive and rebound from recurrent extremes, and large reservoirs of exploitable resources do not lie untapped for long. It seems reasonable to assume that if such instances of resource excess occurred, evolution would lead to the formation of genotypes capable of exploiting them. As a result, ecosystems, even as they are changing, tend to be close to fully occupied, with competitive interactions important, and conditions very unfavorable for the survival of immature individuals.

A consequence of the full occupancy of habitats is that a major factor limiting most plant populations is a suitable place in which to establish new individuals. Propagules of many, perhaps most species of plant require some kind of "gap" in which to become successfully established. Very few plants are capable of dispersing to a fully occupied habitat and maturing without relief, at some stage, from the competition of

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems. June 22-26, San Diego, California.

[2]Biology Department, San Diego State University San Diego, California, 92182.

surrounding established individuals. Grime (1979) has elucidated some of the reasons for this pattern.

Because situations in which excess resources become available can be dramatically different, plant species have tended to specialize for establishment in particular circumstances. Grubb (1977) has discussed the importance of what he terms the "regeneration niche" of species, arguing that plant species diversity can only be understood by considering the critical importance of the establishment phase of plant life histories.

One measure of "regeneration niche" is the abundance of resource that must be available in order for a species to become established. A simple measure of the resource available at a particular point is whether or not another plant already occupies the space, and if it does not, how much unoccupied space lies around the point; that is, is a gap present, and what is its size. The concept of gap-dependent regeneration traces at least to A.S. Watt's classic 1947 paper, but it has recently been successfully applied to tropical rainforest, and it is clear that the concept can be generalized to provide useful insights into ecosystem change anywhere (Denslow 1980).

Plant species can be characterized by the properties of the gaps into which they are capable of invading. Some species appear to require large gaps in which the effect of competition is minimal, while others are capable of establishment in small gaps in which only limited growth is possible before competition with established individuals becomes significant. But capacity to invade depends not only on physiologically based stress-tolerance and competitive ability (Grime 1979), but also on dispersal characteristics which determine the ability of a species to find all of the available habitat.

GAP REGENERATION IN THE CHAPARRAL

The prevalence of fire in the chaparral obscures the fact that as in other vegetation types, chaparral species tend to be limited by the lack of suitable situations in which to become established. This has lead to this hypothesis of vegetation change in the chaparral: For most of the interval between fires establishment of new individuals is unimportant because of competition and the accumulation of metabolic poisons in the soil. Exploitable gaps occur only when fire kills existing plants or portions of plants and stimulates germination. Dispersal is of limited importance. This hypothesis appears to have ample confirmation from the numerous studies that show that mortality of established shrubs results mainly from fire and that seedlings are common only after fire.

This model undoubtedly is correct for some species, such as the obligate seeders, but there is considerable variation among species with regard to features that determine ability to exploit gaps--dispersal, dormancy of propagules, dormancy breaking requirements, and seedling physiology. An alternative hypothesis is: What constitutes an exploitable gap differs among species. The recurrent nature of fire has resulted in many species developing an apparent dependence on fire for the creation of suitable gaps, but others may exploit gaps which arise without fire from the death of individuals from stress, predation, competition, or some combination of these. Dispersal, observed over lengths of time equivalent to the particular species generation time, will be significant.

EVIDENCE FOR THE GENERALIZED GAP HYPOTHESIS

It is well known that many species of the California shrublands do not require fire to establish seedlings. Less widely commented on are those species that do not seem to utilize the ideal conditions after fires to establish new individuals, such as *Heteromeles arbutifolia*, and *Xylococcus bicolor* in San Diego County (Zedler 1977, 1981). These species do not require fire-created gaps for establishment, and therefore projections of future stand composition based on knowledge of fire frequency without information on size, frequency, and distribution of gaps arising from other causes could lead to highly inaccurate predictions.

Heteromeles arbutifolia produces berries containing relatively small seeds which are bird dispersed. In studies conducted in chaparral in San Diego County, seedlings have not been observed in the first year after fire, but have been noted in both burned and unburned chaparral in a very wet year (Zedler 1980). *H. arbutifolia* is a vigorous sprouter which appears to suffer little mortality from fire. If the observed pattern of seedling establishment is typical, population change in this species is little affected by fire. The occurrence of gaps suitable for the survival of the seedlings to a stage where they can resprout after fire could be critical. Such gaps may occur independently of fire. It is possible that historically *H. arbutifolia* populations depended upon the senescence of shorter lived species for the creation of gaps suitable for establishment.

Heteromeles arbutifolia illustrates a general complication which arises in ecosystems of arid regions. During runs of dry years death or decline of individuals can produce gaps, but these gaps may not be exploitable because of insufficient moisture for germination and early survival, even though the supply is sufficient for the growth of established individuals. When a wet year or period occurs, the accumulation of unoccupied space may be available for colonization by species which have dispersed seeds into the gaps. What constitutes a "gap" varies from year to year, even when the biotic occupancy does not.

FIRE FREQUENCY AND GAP FORMATION

In the chaparral fire, frequency clearly is a major determinant of the kinds of gaps that will occur. As the interval between fires increases, gaps formed by the death of individuals from other causes become more prevalent. In the limit, as in some ecosystems of moist regions, the establishment of species would become dependent on dispersal to relatively small gaps which appear from a variety of causes, and which therefore appear asynchronously.

The obvious accommodations of species to fire is clear evidence that chaparral in southern California burned frequently. However, the frequency of fire in the past is a matter of debate, and it is appearing increasingly likely that at least some portions of the southern California chaparral had fire frequencies much lower that has been previously thought (J. Keeley, this symposium).

If it is true that many areas in the chaparral remained unburned for 50 years or more, it may be that gaps created by the death of senescent individuals were a major feature of the landscape. This would explain the seemingly anomalous behavior of species such as H. arbutifolia. Also, with increasing interval between fires, the average size of dominant individuals would increase, so that the longer the interval between fires, the larger will be the average size of gaps created by the death of individuals. Increasing fire frequency would have the effect of decreasing the frequency of gaps formed by species senescence, and decreasing their average size. The diversity of gap types would therefore be reduced, and composition would gradually shift toward those species that are best adapted to exploit fire- created gaps.

The exploitation of fire-created gaps requires either an ability to build up a seed reserve between fires or dispersal from outside the area burned. Most species which are important fire-gap exploiters are of the first type, and dispersal plays only a limited role in post-fire recovery (Hanes 1971). But as fire frequency increases, species which depend on a local seed source run the risk of being burned before they have accumulated enough seed to regenerate. This has been documented for obligate-seeding species (e.g. Zedler 1977), but the same effect at a less drastic level might be expected for sprouting species. If a fire occurred after post-fire germination of seed reserves, but before the age of first reproduction of resprouts and seedlings, a drop in population abundance would result. Fire-gap exploiters with limited dispersal, even those that resprout, could suffer from very short intervals between fires. In such cases either the site would remain open until the next fire, or it would be gradually filled by species which produce seeds which germinate without fire. Dispersal from outside the area is certain to be more important in instances where local seed banks are depleted.

FIRE-CREATED GAPS: AN EXTREME CASE

An opportunity to observe the effect of a short fire-free interval in mixed chaparral and coastal sage scrub was provided by a combination of circumstances on Otay Mountain in southwest San Diego County, California. In August of 1979 a wildfire burned a large area of shrubland, the greater part of which had not been burned since 1943. A portion of this burn was aerially seeded with annual ryegrass (Lolium multiflorum) as an erosion control measure. Rainfall was above normal in the 1979-80 growing season, and the ryegrass cover was dense over most of the seeded area. In the summer of 1980, an arsonist set fire to the grass, reburning a several-hundred-acre area within the 1979 burn. Although the fire burned in a somewhat irregular pattern, within the burned patches nearly all above-ground biomass was either consumed or badly charred. A study was designed to determine the effect of the grass fire on the regenerating shrubs. Five study sites were selected in which paired plots, one burned only in 1979 the other also burned in 1980 were established. Data were obtained on the frequency, density, and condition of shrubs and herbs in both areas, preliminary summaries of which are presented here. For simplicity, data from the twice-burned plots (1979 and 1980) are used with seedling densities for 1979-80 estimated from paired plot burned only in 1979 to produce a single merged set of data to show the population effects of the fire.

The changes in shrub densities and frequencies are the data most relevant to the the present discussion. Density (number of individuals per square meter) was measured for all species for which genus could reasonably be determined. Frequency was measured for all species.

The mortality of mature shrubs caused by the 1979 fire, which could be estimated by examination of the burned remains, followed patterns commonly observed (Table 1.) Ceanothus oliganthus, an obligate seeder, suffered complete mortality, as did Artemisia californica, a species which is sometimes capable of resprouting. Adenostoma fasciculatum suffered a little less than 50% mortality. Xylococcus bicolor is the most important species for which individuals could not be satisfactorily determined, and the change in frequency in 1/4 square meter plots is used as measure of fire effect. The species was considered present if at least one stem arose within the quadrat. The data (Table 2) show that in stand F, Xylococcus reappeared in 1980 in all quadrats in which it was present in 1979, showing that there was little if any mortality in this vigorous resprouter.

Table 1. Changes in density of selected species of shrubs after fire.

	Individuals (no./square meter ± SE)		
	Before 1979 Fire	After 1979 Fire	After 1980 Fire
Adenostoma fasciculatum			
mature (or sprouts)	1.5 ± 0.3	0.8 ± 0.2	0.2 ± 0.1
seedlings	nil	22.2 ± 6.1	0.6 ± 0.8
Artemisia californica			
mature (or sprouts)	0.3 ± 0.1	nil	0
seedlings	?	2.6 ± 0.6	0.4 ± 0.2
Ceanothus oliganthus			
mature (or sprouts)	0.2 ± 0.1	0	0
seedlings		6.0 ± 3.0	0

Table 2. Change in frequency (% occurrence in 1/4 meter square plots) of two species.

	Before 1979 Fire	After 1979 Fire	After 1980 Fire
Adenostoma fasciculatum			
mature (or sprouts)	.27	.15	.07
seedlings	nil	.75	.04
Xylococcus bicolor			
mature (or sprouts)	.13	.13	.04
seedlings	nil?	0	0

The 1980 grass fire caused severe to moderate mortality in both seedlings and resprouts which emerged after the 1979 fire (Tables 1 and 2). *Ceanothus oliganthus* seedlings were eliminated, *Adenostoma fasciculatum*, seedlings were reduced by over 95%, and those of *Artemisia californica* by 85%. Surprisingly, the mortality from the grass fire was also substantial for the resprouts, with a 75% reduction in the number of individuals for *Adenostoma fasciculatum*, and almost a 70% reduction in frequency for *Xylococcus bicolor*.

Change in frequency of occurrence is a simple index of the creation of gaps by fire. The grass fire substantially decreased the occurrence of all four species, as is made clear by these data which give the percent change in frequency of occurrence of the species in 1/4 meter square plots resulting from the 1980 fire:

Artemisia californica	-15
Xylococcus bicolor	-66
Adenostoma fasciculatum	-84
Ceanothus oliganthus	-100

For *Ceanothus oliganthus*, this amounts to local extinction within the area of the 1980 burn. *Adenostoma fasciculatum* and *Xylococcus bicolor* also suffered substantially, while *Artemisia californica,* present at lower elevation sites, was much less affected, primarily because unlike most other species, a high proportion of burned seedlings resprouted after the 1980 fire.

It is clear that the 1980 fire has produced a disequilibrium, at least locally, in the vegetation on Otay Mountain. The gaps created may remain gaps, or as seems more likely, they will eventually be closed. If the interval between fire is long, the remaining individuals may become large enough to utilize all available space, with annual herbs and sub–shrubs occupying the space in the interim. However, there could also be establishment of shrub species that do not require fire for germination. It is possible that some of the chaparral species discussed above that do not establish seedlings after fire and that have animal-dispersed seeds could invade. More likely, however, is the expansion of coastal sage scrub species such as *Eriogonum fasciculatum* and *Artemisia californica* which produce large amounts of seeds and are common on disturbed sites. The changes to be expected will certainly vary locally and will be dependent on the local seed rain.

Elsewhere on Otay Mountain there are sharp boundaries between chaparral and coastal sage scrub that do not seem to correlate with soil type or topographic position. It seems possible that these boundaries are the margins of areas which might have been burned with one or more very short intervals, causing local extinction of chaparral species.

MANAGEMENT IMPLICATIONS

Whether planned or inadvertent, man's activities exert a strong influence on the many aspects of the environment which play a role in the formation and colonization of gaps. We have created novel ecological situations which have set in motion readjustments of species abundances in shrubland vegetation. The sharp changes observed in the grass fire of 1980 on Otay Mountain no doubt had natural analogs, but human influences have greatly increased the frequency of unique and rare episodes of gap formation.

Practical constraints make it unlikely that shrubland management in southern California can mimic the natural patterns of gap formation, assuming that these can ever be known. Although land managers speak of "restoring fire to its natural role"; this is probably impossible. Many natural fires must have been large and intense, and there is good reason to suppose that one large intense fire cannot be simulated by two smaller, cooler ones. Burning often enough to eliminate the possibility of wildfire may mean eliminating the distinctive micro-habitats needed for the germination and survival of some species. It seems certain that comprehensive management, no matter how carefully planned, will cause shifts in species abundances and distribution. These shifts may be readily observable, or they may take place slowly over many decades. Predicting what changes will occur will require much more knowledge of the population ecology of shrubland species, including native and introduced herbaceous plants.

It doesn't follow that all management must grind to a halt until research scientists certify that our knowledge is sufficient to make predictions within appropriate error bounds. However, skepticism about prevailing ideas and caution in implementing large-scale programs based on them are necessary. Research and evaluation by scientists from many disciplines and all sectors should be made an integral part of any management scheme.

Acknowledgements: I thank Clay Gautier and Greg McMaster for permission to use unpublished data from our Otay Mountain fire study. This work was supported in part by NSF Grant DEB-7913424.

LITERATURE CITED

Denslow, J.S. Patterns of plant species diversity during succession under different disturbance regimes. Oecol. 46:18-21. 1980.

Grime, J. P. Plant strategies and vegetation processes. Chichester, England: John Wiley and Sons; 1979. 222 p.

Grubb, P. J. The maintenance of species richness in plant communities: The importance of the regeneration niche. Biol. Rev. 52:107-145; 1980.

Hanes, T.L. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41:27-52. 1971

Levin, S.A. Population dynamic models in heterogeneous environments. Ann. Rev. Ecol. and Syst. 7:287-310. 1976.

White, P.S. Pattern, process, and natural disturbance in vegetation. Bot. Rev. 45:230-299. 1979

Zedler, P.H. Life history attributes of plants and the fire cycle: A case study in chaparral dominated by *Cupressus forbesii*. In: Mooney, H.A. and Conrad, C.E., eds. Environmental consequences of fire and fuel management in Mediterranean ecosystems: Proceedings of a symposium. U.S. Forest Service. Palo Alto, Calif.; 1977: 451-458.

Zedler, P. H. Vegetation change in chaparral and desert communities in San Diego County, California. In: West, D.C.; Shugart, H.H.; and Botkin, D. B.; eds. Forest Succession: Concepts and Applications. New York. Springer Verlag. (in press).

The Role of Allelopathy, Heat, and Charred Wood in the Germination of Chaparral Herbs[1]

Sterling C. Keeley and Jon E. Keeley[2]

Abstract: The herbaceous flora of the chaparral includes annual and perennial species which differ in their temporal relationship to fire. Germination cues for these herb groups could be expected to reflect these temporal differences. Thirty species of herbs were tested for germination in response to Adenostoma leachate and charred stems, direct heat, and their combinations. For herbs present pre-and post-fire, germination was best under control conditions, or with leachate. Fire following herbs germinated best with a combination of charred stems and low heat. The enhancement effect of burned Adenostoma stems was found to be generalizable to other woody plants and was not a fertilizer effect.

The southern California chaparral is dominated by woody sclerophyllous-leaved shrubs which are drought tolerant and fire-adapted. Shrubs resprout from root crowns or appear from seedlings once fire has removed the adult plants and provided proper conditions for seed germination. There is also an herbaceous component to the chaparral, the most well known herbs being "fire annuals" which appear in great numbers after the chaparral shrubs have burned. The germination responses of these herbaceous species has been tied to two major effects: the allelopathic properties of shrubs which inhibit herb germination in the mature chaparral, and/or the stimulating effects of the burning process; heat, scarification and chemical changes. Herbs are generally inconspicous under the mature shrub canopy.

Annual and perennial herbaceous species are associated with chaparral, both before and after fire. It has been suggested that these herbs can be divided into 4 groups on the basis of life form and time of appearance (Table 1; Keeley and Keeley 1981, Keeley et. al. 1981). The perennial herbs form two groups (Table 1), those present within the mature chaparral, but rarely flowering at this time & those which appear abundantly after fire. This second group is composed of suffructescent species such as Helianthemum scoparium and Eriophyllum confertiflorum which become prominent the second through fifth years after fire (Keeley et. al. 1981), or until they are shaded out by the reestablishing shrubs. Annual species can be similarly divided into those which appear in openings within the mature chaparral, and those annuals which are strict fire followers (Table 1). This diversity in life history suggests differences in seed germination cues.

The development of hypotheses on seed germination has resulted primarily from the pioneering work of Sweeney (1956). Sweeney (ibid.) investigated the possibility of inhibitory substances which might be produced by the shrubs and retard or prevent herb germination. He also investigated the possible stimulatory role of heat and ash on herb germination. Sweeney (1956) found no effect due to Adenostoma leachate on the germination of several chaparral herb species or on the cultivated radish, under normal aerated conditions. He obtained stimulated germination of refractory herb species, such as Emmenanthe penduliflora, when wood excelsior was burned over the top of seeds planted in soil. Separate tests on the effect of heating, at temperatures similar to those found in fire, and tests with wood ash alone failed to reproduce the result obtained with burned excelsior. Heating for extended periods did increase germination in one species (Oenothera micrantha) but had no effect on other herbs tested. Wood ash generally decreased germination for both scarified and non-scarified herb seeds.

Muller, Hanawalt & McPherson (1968) and McPherson and Muller (1969) pursued the possibility of an inhibitory substance present in mature shrubs which could prevent herb germination. In tests of germination using rainwash and concentrated Adenostoma leachate they recorded some decrease in germination at the highest concentrations, although this was not uniform. These findings were partially confirmed by later tests with 11 annual species (Christensen and Muller, 1975). Germination of herbs from samples of chaparral soil, which may have contained leached compounds, was higher when the soil was heated at temperatures of 80-100°C. Christensen and Muller (1975) found no significant increase in germination when herb seeds were heated directly.

Wicklow (1977) tested the effect of ashed and partially burned (charred) stems of Adenostoma on the germination of Emmenanthe penduliflora, a fire annual. Like Sweeney (1956) he obtained no results with completely ashed stems, but he found that charred stems significantly promoted germination. The effect of charred, but not ashed stems on Emmenanthe germination was confirmed by Jones and Schlesinger (1980).

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-27, 1981, San Diego, California, USA

[2]Assistant Professor of Biology
Whittier College, Whittier, California 90608,USA; and Assistant Professor of Biology, Occidental College, Los Angeles, California 90041

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

EXPERIMENTAL DESIGN AND METHODS

Experiments were conducted to test both the effect of possible inhibitors such as Adenostoma leachate, and possible stimulants to herb germination such as heating and charred stem material. Since several agents could be acting in concert interaction effects were also tested.

Our initial experiment was a multifactorial test of the effects of heat, Adenostoma leachate charred Adenostoma stems and combinations of these, using 30 species of chaparral herbs (Table 2-5 & Appendix). Follow up experiments were undertaken to further test those factors which significantly affected germination.

Seeds were collected from burned and unburned chaparral of all ages from throughout southern California during June and July 1980. Seeds were collected in paper bags, returned to the lab and sorted free of debris. Cleaned seed was placed in glass jars and stored at room temperature. Seeds of Emmenanthe penduliflora collected in 1st year burns proved inviable so seeds of this species were obtained from C. Jones (Jones and Schlesinger 1980). Only their Santa Monica Mt. population was used.

For heat treatments seeds were counted into lots, placed in glass petri dishes and put in the oven for varying periods as shown in Tables 2-5.

Leachate was prepared according to the technique of McPherson and Muller (1969). Concentrated leachate (4X) was made by evaporating standard leachate and reducing the volumne.

Charate was prepared by burning Adenostoma stems of <1 cm diameter with a propane torch until they were blackened throughout, and then grinding the stems in a Wiley mill to produce a uniform powder. 2.4 ± 0.2 gms of charate were applied to each seed lot to be tested.

Seeds of all treatments were planted in petri dishes on sterilized, screened potting soil, and watered with 25 mls ± 2 of deionized water. The plates were then placed on trays, covered with plastic to retard evaporation and given a cycle of 20 days cold (10°C) and 15 days at room temperature (23°C). All plates were run for three cycles. Scoring took place at 10 days into the first cold treatment and at 5 day intervals after that.

For follow up experiments sorting, handling and planting procedures were the same. A cold treatment of 30 days was applied in some experiments as indicated, with 12 hour light/dark periods at room temperature.

For tests on other shrub species charate was prepared identically. Partial charate was made by burning the stems to the point that some unblackened material remained in the center.

Table 1. Perennial and Annual herbs by groups, in mature and post-fire chaparral (from Keeley et. al. 1981)

Group	Mature Chaparral	Post-fire Chaparral
1-Perennial	Adults and Seedlings, Flowering Rare	Resprouts, Few Seedlings Flowering 1st yr.
2-Perennial	Rare, In Openings	Abundant from Seedlings (1st yr.)
3-Annual	Infrequent, In openings	Abundant for first several years
3-Annual	Rare	Abundant- First Year Only

Grinding was done as described above. Baked stem material was prepared by cutting small segments of branches, less than 1 cm diameter, placing them in foil packages (open) on a metal sheet. These were baked for selected intervals, cooled and ground in the Wiley mill. Quantities applied were 2.4 ± 0.5 gms of charate.

A water extract of fully charred, but not ground Adenostoma stems was prepared by pouring deionized water over the stem sections and watering as described above. Filter paper as well as soil was utilized in this experiment.

For a test of fertilization on germination half-strength and 2X strength Hoagland's solution was used (as determined by package directions). This solution was used instead of deionized water for the experiment. Normally watered plates were used as a control. Cold/warm cycles were as described for the multifactorial experiment.

RESULTS AND DISCUSSION

Results of the multifactorial experiment will be presented using a representative member of each of the four herb groups (Table 1). These species are: Paeonia californica, Group 1; Eriophyllum confertiflorum, Group 2; Oenothera micrantha, Group 3; and Phacelia cicutaria, Group 4. Since several factors were tested singly and in combination, the individual factor responses will be considered first, with selected follow up experiments and then their interactions.

Effect of Leachate

The responses of members of all four groups of herbs to single strength Adenostoma leachate was not significantly different from the control in most cases. Germination was stimulated in some species, no inhibitory effects were seen (Table 2-5).

Table 2. Percent germination of Paeonia californica in response to heat, leachate and charate (N = 8 dishes/ 20 seeds per dish)

	Control	80°C (2 hr)	120°C (5 min)	150°C (5 min)	P	LSD
Control	67.5	0.6	5.6	1.9	.01	10.4
Leachate	79.4	5.6	20.6	5.0	.01	21.6
Charate	55.0	0.0	12.5	1.3	.01	13.3
Leachate + Charate	41.9	0.0	12.5	0.6	.01	12.9
P	.01	ns	ns	ns		
LSD	16.5					

Germination of the perennials was slightly, but not significantly enhanced with leachate as shown for Paeonia (Table 2) and Eriophyllum (Table 3). Stipa coronata, a group 1 perennial, was significantly enhanced (P< .01); no perennial was negatively affected.

The annual species showed a more varied pattern of responses, but none were negative. Group 3 annuals, such as Oenothera micrantha (Table 4) and Cryptantha muricata, Apiastrum angustifolium, Descuriana pinnata, and the generalized exotic Brassica nigra were significantly enhanced by leachate; germination was double that of controls. Fire annuals (Group 4) showed a mixed response to leachate, however. Phacelia cicutaria (Table 5) and P. grandiflora showed significantly enhanced germination, but P. brachyloba, P. fremontii, and Emmenanthe penduliflora showed no effect with germination percentages remaining low (<15%) in all cases.

The lack of inhibition in herb germination with single strength Adenostoma leachate seen here is similar to the findings of Sweeney (1956),

Table 3. Percent germination of Eriophyllum confertiflorum in response to heat, leachate and charate (N = 8 dishes/ 50 seeds per dish)

	Control	80°C (2 hrs)	120°C (5 min)	150°C (5 min)	P	LSD
Control	3.8	5.5	3.8	1.0	.05	2.7
Leachate	7.8	5.5	5.5	0.5	ns	
Charate	51.5	58.2	65.7	1.8	.01	11.7
Charate + Leachate	58.3	63.2	65.2	2.8	.01	10.6
P	.01	.01	.01	.01	ns	
LSD	11.8	8.7	9.6			

Table 4. Percent germination of Oenothera micrantha in response to heat, leachate and charate (N = 8 dishes/50 seeds per dish)

	Control	80°C (2 hr)	120°C (5 min)	150°C (5 min)	P	LSD
Control	30.0	48.5	65.5	69.0	.01	10.2
Leachate	51.7	58.9	58.7	80.0	.01	19.3
Charate	26.0	33.0	22.0	20.0	ns	
Leachate + Charate	45.4	50.7	29.8	58.2	.05	17.8
P	.01	.05	.01	.01		
LSD	20.3	17.8	19.8	17.9		

Muller, McPherson and Hanawalt (1968) and McPherson and Muller (1969). Sweeney (ibid., p. 190)also observed a slight, but non-significant increase in germination in some species. However, McPherson and Muller (1969) did report decreased germination with concentrated leachate, at least for one perennial species, Helianthemum scoparium, and Christensen and Muller (1975) also detected some inhibition with leachate. A follow up experiment was undertaken using 4X concentrated Adenostoma leachate.

Concentrated leachate enhanced the germination of both perennial and annual herb species found within the mature chaparral (Groups 1 & 3, Table 1). The degree of this increased germination varied from a statistically non-significant increase in the case of Paeonia, (control 36.6 pct. germ; 4X leachate, 46.9 pct. germ) or Salvia columbariae (control 6.8 pct. germ; 4X leachate, 14.3 pct. germ, p. <. 01, LSD 15.7) to strongly and significantly enhanced germination in Convolvulus cyclostegius (Control, 5.8 pct. germ; 4 X leachate 12.0 pct. germ, p<.01, LSD 5.2) or Descuriana pinnata (Control 19.8 pct. germ; 4X L. 38.0, p<.O1, LSD 15.4).

The response of fire following perennials and annuals was more heterogenous and included one case of clear inhibition. Helianthemum scoparium was significantly inhibited by high leachate concentrations (Control 16.0 pct. germ., 4X leachate 10.3 pct. germ., p<.05, LSD 4.6). This is the same species shown to be inhibited by leachate by McPherson and Muller (1969). Eriophyllum confertiflorum was not significantly affected. None of the fire annuals tested showed a significant effect due to concentrated leachate.

On the basis of both sets of experiments reported here leachate cannot be regarded as a strong deterrent to growth by chaparral herbs. It may actually stimulate growth of those species tolerant of sub-canopy conditions. The effect of any toxic substances found within leachate, if they are present, may be exerted on the growth and development of herbs once they germinate. This was not tested here.

Effect of Heat

Heat treatments produced variable effects within and between herb groups. In only a few cases did it stimulate germination above control conditions.

For the perennials like Paeonia which appear both before and after fire (Table 2) heating the seeds resulted in decreased germination from the non-heated control. The highest temperature tested, 150°C reduced germination of all species, and was lethal in the case of Zigadenus fremontii and Stipa coronata.

Fire following perennials such as Eriophyllum (Table 3) germinated at low levels under control conditions and with heat. However, Helianthemum scoparium was stimulated at 120°C (Control 23 pct. germ.; 120°C, 43 pct. germ; P<.01, LSD 9.6). High temperatures reduced germination to less than 5 percent in both species.

Annuals of Group 3, present before and after fire, showed both strong positive and strong negative responses to heating. 0enothera (Table 4), Lotus salsuginosus, Apiastrum angustifolium and Brassica nigra were significantly enhanced by heating at either 80°C or 120°C, but not at 150°C. In contrast, Salvia columbariae, and Avena barbata were inhibited by heating at even low temperatures (Salvia, Control 29.5 pct. germ.; 80°C 8.8 pct. germ.); other species were not affected except at the highest temperature.

The fire annuals were not affected by heating at moderate temperatures with the exception of Phacelia cicutaria (Table 5). In this species moderate heat stimulated germination above the level of the control. For most other species there was no significant difference at lower temperatures; 150°C was lethal.

Sweeney (1956), Christensen and Muller (1975) and McPherson and Muller (1969) also found that direct heat resulted in little stimulation of germination except in a few species, including 0enothera micrantha and Helianthemum scoparium. For the majority of species they tested germination remained low under heat treatments.

It appears that moderate heat may have some stimulative effect on germination of chaparral herbs, but that this is probably not the major factor promoting germination either before or after fire. Soil heating by sun (Christensen and Muller 1975) and during fire may serve in concert with other factors to promote germination of herbs away from the shrub canopy.

Table 5. Percent germination of Phacelia cicutaria seeds in response to heat, leachate and charate (N = 8 dishes/ 50 seeds per dish)

	Control	80°c (2 hr)	120°C (5 min)	150°C (5 min)	P	LSD
Control	4.8	10.8	5.8	0.0	.01	6.0
Leachate	12.8	20.3	12.5	0.5	.01	8.7
Charate	32.0	45.2	56.7	0.0	.01	16.2
Leachate + Charate	38.0	51.2	33.2	0.0	.01	12.6
P	.01	.01	.01	.01	ns	
LSD	14.6	10.2	14.6			

Effect of Charate

Charred Adenostoma stems produced significantly enhanced germination in fire following perennials and annuals, but had mixed effects on those species present both before and after fire. Germination of fire preceeding perennials like Paeonia did not differ significantly between controls and charate treated seeds (Table 2). For all species tested in this group germination remained within 15 percent of control. Germination of annuals species found before as well as after fire varied. It was similar to control conditions for a number of species: 0enothera (Table 4), Lotus salsuginosus, Apiastrum angustifolium and Descuriana pinnata, and the adventive grass Avena barbata. Brassica nigra was strongly and negatively affected (Control, 24.3 pct. germ. vs 4.0 pct. germ. with Charate). Cryptantha muricata showed significantly enhanced germination with charate (Control, 24.3 pct. germ. vs 66.7 pct. germ. With Charate) as did Salvia columbariae (Control, 29.5 pct. germ., vs. 40.0 pct. germ With Charate).

Fire following perennials like Eriophyllum (Table 3) were strongly enhanced by the addition of charate as were most fire annuals. Germination was strongly stimulated in Phacelia species (Table 5) and P. grandiflora and P. fremontii, in Emmenanthe penduliflora (Table 7), Antirrhinum coulterianum and Chaenactis artemisaefolia. Germination was often less than 10 percent under control conditions for these species and was greatly increased by charate. The magnitude of this response was greater than that observed with leachate or heat for most species.

Given the magnitude of the germination enhancement shown in fire following annuals and perennials further experiments were undertaken to determine the nature of this effect. Charred wood of other chaparral, and non-chaparral species was tested on

Table 6. Effect of charate of chaparral and desert shrubs, and pine on the germination of Eriophyllum confertiflorum and Emmenanthe penduliflora (N = 5 dishes/ 50 seeds per dish; seeds given 30 day cold treatment, 12 hr lt/dk at room temperature)

	PERCENT GERMINATION	
	Emmenanthe	Eriophyllum
Control	0.0	19.2
CHARATE:		
Species		
Arctostaphylos glauca	6.4	70.0
Ceanothus crassifolius	5.6	71.2
Quercus dumosa	11.6	78.0
Rhus laurina	8.4	77.6
Larrea divaricata	54.8	74.0
Artemisia tridentata	10.0	71.6
Pinus coulteri	13.6	98.0
P	.01	.01
LSD	9.8	20.7

two herbs which had shown significant enhancement with Adenostoma charate (Table 6). The results of this experiment indicated that charred wood from other shrubs and Pine also stimulated the germination of these herbs at levels similar to that of Adenostoma. (Compare Tables 3 & 5).

A second experiment was conducted to determine if stem material would be effective in stimulating germination if it were only heated, or partially burned. Results of this experiment are shown in Table 7. These results indicated that complete burning was not necessary to produce significant improvement in germination. There was no significant difference between the enhancement of germination observed with partially charred or baked stems. Evidently, whatever the factor responsible for stimulating germination it is produced prior to combustion. The difference in effect of completely and partially charred stems seen here (Table 7) was not confirmed in other tests (unpublished data) using Emmenanthe and three other chaparral herb species.

Table 7. Effect of heated, partially and fully charred Adenostoma stem material on germination of Emmenanthe penduliflora seeds (N = 5 dishes/ 50 seeds per dish; 30 day cold treatment; 12 hr lt/dk at room temperature)

	PERCENT GERMINATION
Control	0.0
Charate	37.3
Partial Charate	68.0
Baked, 260° C (10 minutes)	68.0
Baked, 175° C (30 minutes)	66.0
P	.01
LSD	14.5

An aqueous extract of charred stems was also found to enhance germination of Eriophyllum. The effect of this water extract varied with the substrate on which germination trials were conducted. Germination was highest on filter paper (64 pct.) and lowest on soil (12 pct.) with intermediate values for the control (deionized water) on filter paper (40%). Good germination was obtained when charate was applied directly to soil and then watered as usual.

The stimulation of germination by charate, and charate extract, and perhaps by filter paper may reflect some common substance found in treated or processed wood, or it may reflect some property of soil that binds water soluble wood-derived compounds, at least in low concentrations. Further experiments are being conducted to determine if the same results can be obtained on glass filters and/or with other wood products.

Another possible effect of charate might be that of a general fertilizer since nutrients would be released from structural compounds during the burning process. To test this effect, which would be common to any woody species, we applied Hoagland's solution in two concentrations (Table 8). Levels of germination with fertilization were similar to that of controls and significantly lower than with charate and water. Apparently the effect of charred stems is not due to increased nutrients.

Germination was enhanced to a greater degree in most fire following species with the addition of charate than by any other single factor tested. From our data it is apparent that charred wood from both chaparral and non-chaparral species is equally efficacious. Its effect is probably due to some common, although unknown, property of wood.

Table 8. Effect of fertilization using Hoaglands solution in 2 concentrations and the effect of charate on the germination of Eriophyllum confertiflorum and Chaenactis artemisaefolia
(N = 8 dishes/ 50 seeds per dish)

	PERCENT GERMINATION	
	Eriophyllum	Chaenactis
Control	10.5	27.2
½ X Hoaglands	8.8	29.3
2X Hoaglands	2.8	25.8
Charate	60.8	86.5
P	.01	.01
LSD	12.7	9.9

Even though the exact basis for this stimulation of germination is unclear, charate evidently provides a very precise, and in some species, e.g. Emmenanthe an obligate cue to germination. This sort of cue to fire would seem to be highly adaptive to annual species, with high light requirements and low competitive ability. The only time such conditions are readily available in the chaparral is after fire when shrubs are temporarily removed. Such a close tracking of the environ ment suggests a long association between fire and the flora of the chaparral.

Interactions

Although interactions between heat, charate and leachate are likely to occur at some point in the fire cycle, such combined effects are apparently limited (Tables 2-5). For perennial species present before and after fire such as Paeonia (Table 2), Zigadenus fremontii and Marah macrocarpa germination was best under control conditions. The combination of leachate and low heat did stimulate germination in some cases, but was not significantly different from controls. Charate plus leachate, plus heat produced significantly lower germination than either alone, and again less than the control.

The annual species present before as well as after fire germinated best with the addition of leachate and in some with the combination of leachate and moderate heat (Table 4). Oenothera responded strongly to heating, including heat of 150°C (Table 4), however most other species were negatively affected by this heat. Like Oenothera, Cryptantha muricata, Lotus salsuginosus, Apiastrum angustifolium and Brassica nigra responded significantly to a combination of moderate heat and leachate. For species such as Cryptantha muricata which showed increased germination with charate, the effect of leachate and charate together was similar to the effect of charate alone. In some cases low heat together with leachate and charate raised the percentage of germination, but this was not significant. In the case of Brassica nigra, which was strongly inhibited by charate alone, the combination of leachate (and heat) and charate significantly increased germination.

The combination of leachate plus moderate heat produced high levels of germination in both annuals and perennials found before fire. These conditions could be expected to occur within the mature canopy and may provide a cue to suitable sites and/or environments. Seeds germinating in response to these factors would provide a low level seedling population in those patches of suitable habitat within the shrub vegetation. The proportion of seeds within each species seed pool which would react to these factors would be expected to be low since the availability of suitable sites would not be great in mature chaparral.

Although these species are present before fire they are also in evidence, and often more abundant after fire. They also germinate well in response to charate. This response would appear to provide a way to track changes in the environment from pre-to post-fire. Conditions for growth of all herbs would be improved when the shrub cover was destroyed and light and nutrients more available. A significant proportion of the seed pool can tolerate, and cue into these conditions. Individual species evidently vary in their responses to combinations such as heat and charate, but a certain number of all species remain, even under the most severe conditions. This may represent the best adaptive compromise to the unpredictable nature of fire within the chaparral.

The responses of fire following annuals and perennials were more strongly cued to charate and the combination of charate plus moderate heat (Tables 3 & 5). Leachate in combination with any of these factors resulted in lower levels of germination than seen with charate alone. For the most part the effect of either leachate and/or high temperatures was ameliorated and enhanced by charate. In Phacelia cicutaria for example (Table 5), germination was greatest with a combination of charate and heat. Such a synergistic effect was observed in other species as well. A positive response to this combination, more than to any single factor would appear to provide a precise way to track fire and the conditions most suitable to growth.

The germination responses of chaparral herbs appear to vary with differences in life history characteristics and in relation to time of fire. For those species which are present both pre- and post-fire germination and growth activities are at a low level until after fire. These species have the ability to germinate under all conditions, but respond positively to the post-fire environment. This response was strongest in the annuals, perhaps due to their greater light requirements and lower competitive ability than perennials. The fire following species on the other hand, have apparently adapted to germinate only in response to those factors which are present as a direct result of fire. Burned stem material and moderate heat are the result of burning the mature canopy and these effects would gradually dissipate with time. It may be that given the genetic background of these species, particularly the annuals, that fitness is maximized only under post-fire conditions. Although the exact nature of the germination responses observed is not fully understood, it is apparent that the herbaceous component of the chaparral flora is well adapted to the fire cycle. The variety of responses to different germination cues demonstrates the precision of this adaptation.

Acknowledgments: This work was partially supported by an NSF Undergrate Research Participation Grant to J.E.K.; Bryce Morton, Occidental College, Anthony Pedroza (U. C. Santa Barbara) and Patricia Trotter (Whittier College) participated. Carol Chen, Gretchen Van Steenwyk, Kazumi Sugimua (all of Occidental College) also assisted in data collection. A major contribution to charate experiments was made by R. Patrick Mathews (Whittier College). Partial support for this project was provided by a Faculty Research Grant to S. C. K.

LITERATURE CITED

Christensen, N.L.; Muller, C. H. Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45: 29-55; 1975.

Jones, C. S.; Schlesinger, W. H. Emmenanthe penduliflora (Hydrophyllaceae) further considerations of germination response. Madrono 27: 122-125; 1980.

Keeley, J. E.; Keeley, S.C. Post-fire regeneration of southern California chaparral. Amer. J. Bot. 68: 524-530; 1981.

Keeley, S. C.; Keeley, J. E.; Hutchinson, S. M.; Johnson, A. W. Post-fire succession of the herbaceous flora in southern California chaparral. Ecology (in press, 1981).

Muller, C. H.; Hanawalt, R.B.; McPherson, J.K. Allelopathic control of herbaceous growth in the fire cycle of California chaparral. Bull. Torrey Bot. Club 95: 225-231; 1968.

McPherson, J. K.; Muller, C.H. Allelopathic effects of Adenostoma fasciculatum, "chamise," in the California chaparral. Ecol. Monogr. 39: 177-198; 1969.

Munz, P. A. A California Flora. Berkeley, Calif.; University of California Press; 1959.

Sweeney, J. R. Response of vegetation to fire. U. C. Pub. in Bot. 28: 143-250; 1956.

Wicklow, D. T. Germination response in Emmenanthe penduliflora (Hydrophyllaceae). Ecology 58: 201-205; 1977.

APPENDIX

Herb species tested multifactorial germination experiments. Nomenclature according to Munz (1959)

Antirrhinum coulterianum Benth in DC.
Apiastrum angustifolium Nutt. in T. & G.
Avena barbata Brot.
Brassica nigra (L.) Koch.
Calyptridium monandrum Nutt. in T. & G.
Calystegia macrostegia (Greene) Brummit ssp. arida (Greene) Brummit
Chaenactis artemisiaefolia (Harv. & Gray) Gray
Claytonia perfoliata (Donn) Howell
Cryptantha muricata (H. & A.) Nels. & Macbr.
Descuriana pinnata (Walt.) Britton ssp. menziesii (DC.) Detl.
Dicentra ochroleuca Engelm.
Emmenanthe penduliflora Benth.
Eriophyllum confertiflorum (DC.) Gray
Festuca megalura Nutt.
Gilia splendens Dougl. ex Lindl.
Helianthemum scoparium Nutt.
Lotus salsuginosus Greene
Marah macrocarpa (Greene) Greene
Nicotiana attenuata Torr.
Oenothera micrantha Hornem ex Spreng.
Paeonia californica Nutt. ex T. & G.
Phacelia brachyloba (Benth.) Gray
Phacelia cicutaria Greene
Phacelia fremontii Torr.
Phacelia grandiflora (Benth.) Gray
Phacelia viscida (Benth.) Torr.
Salvia columbariae Benth.
Sisrynchium bellum Wats.
Stipa coronata Thurb. in Wats.
Zigadenus fremontii Torr.

Seasonality, Growth, and Net Productivity of Herbs and Shrubs of the Chilean Matorral[1]

Gloria Montenegro, María E. Aljaro, Alan Walkowiak, and Ricardo Saenger[2]

Abstract: The physiognomy and species composition of the matorral, as well as growth period and net productivity of shrubs, change with altitude. In shrubs, vegetative growth period is shorter at higher altitudes; leaf area indices are significantly higher at lower sites, while biomass indices increase with altitude. At the community level, productivity is lower in the montane matorral. Growth and productivity of the herbaceous understory markedly varies depending on precipitation. Most vegetative growth occurs between winter and early spring.

Chile, located between 18° and 56° latitude south, has a climate which markedly varies according to geographical position (Di Castri 1968, Hajek and Di Castri 1975). Drought predominates in the north of the country and rainfall is characteristic of the central and southern regions. The natural vegetation is closely related to the different climatic patterns. The northern part of the country is desertic, while evergreens predominate in the south (Pisano 1954, Di Castri 1968, Heusser 1974, Hueck 1978). The central region, with a mediterranean climate, has a typical matorral vegetation (Di Castri 1973, Mooney and others 1974, Quintanilla 1974, Miller and others 1977, Rundel 1981).

Three physiographic regions can be distinguished in Central Chile: the Coastal Range with a highest altitude of 2200 in, the Central Valley, and the Andean Cordillera where the highest peak reaches 7000 m a.s.l. (Rundel 1981). The matorral is the dominant vegetation of the Mediterranean zone: it extends from 33° to 38° S. latitude and along an altitudinal gradient from the coast up to 2300 m a.s.l.

The study sites were Cachagua, on the coast, at 50 m a.s.l. (2-year observations); Santa Laura in the Coastal Range, at 1000 m a.s.l. (5-year observations); Quebrada Seca at 1000 m a.s.l. and Paso Marchant, at 2200 m a.s.l., both in the Andes Cordillera (5-year observations).

Evergreen sclerophyllous shrubs and trees, succulents, and drought-evading herbs predominate in Central Chile, from the coast to about 1000 m elevation (Mooney and others 1970, Mooney and others 1977, Montenegro and others 1979a). Evergreen shrubs predominate on polar-facing slopes, while drought-deciduous shrubs and succulents are mostly found on equatorial-facing slopes (Rundel 1975, Parsons 1976, Mooney and others 1977, Armesto and Martinez 1978).

The midelevation matorral in the Coastal Range and the sclerophyllous scrub at the foothills of the Andes are replaced at about 1850 m by a montane evergreen scrub community (Mooney and others 1970, Rundel and Weisser 1975, Hoffmann and Hoffmann 1978, Montenegro and others 1979b). At 2300 m in the Andes the matorral gives way to a low subalpine scrub. Over 3000 m, alpine herbs and cushion plants predominate (Villagran and others 1979, Arroyo and others 1979).

Here we will analyze the phenology, dynamics of growth, net productivity, and mortality of shrubs and herbs of the Chilean matorral along an altitudinal gradient, from the coast up to 2200 m altitude in the Andean Cordillera. Our aim is to assess the fluctuations in growth and phytomass in ecosystems of semiarid area. The results of this study may help in design of optimal management practices in these ecosystems, which are being progressively affected by man's activities.

HERBACEOUS VEGETATION

Herbs are an important component of the shrub-dominated vegetation in Central Chile. Mooney and others (1977) and Keeley and Johnson (1977) found over 60 percent herb cover in the midelevation matorral zone. Native species usually grow under the canopy of shrubs, with no obvious indications of allelopathic interactions (Montenegro and others 1978), while the introduced species dominate the open areas. This is in contrast to what has been reported for the Californian chaparral, where the herb cover is poor (Mooney and others 1977), probably due to allelopathic effects (McPherson and Muller 1969, Chou and Muller 1972).

At 1000 m elevation, on the matorral zone, 75 percent of the 32 native herb species are perennials and constitute about half of the cover (Keeley and Johnson 1977). The annual cover decreases with increasing altitudes, from values of 40 percent at 1000 m elevation to 2 percent at 2000 in, in the Andes (Martínez, unpublished data). In general, on the Andes, the herb cover is found mostly under shrubs. The rocky spaces between shrubs show very low herb density.

The growth of the herbaceous understory in all mediterranean areas along the altitudinal transect

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Laboratorio de Botánica, Facultad de Ciencias Biológicas, Universidad Católica de Chile, Santiago, Chile.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--Dominant species along the transect on parallel 33° South latitude

Species	Family	Life - form
Aster haploppapus	Compositae	Summer deciduous half-shrub
Flourencia thurifera	Compositae	Summer deciduous shrub
Baccharis concava	Compositae	Evergreen sclerophyllous shrub
Peumus boldus	Monimiaceae	Evergreen sclerophyllous shrub
Satureja gilliesii	Labiatae	Summer deciduous half-shrub
Talguenea quinquenervia	Rhamnaceae	Thorny summer-deciduous shrub
Trevoa trinervis	Rhamnaceae	Thorny summer-deciduous shrub
Colliguaya odorifera	Euphorbiaceae	Semideciduous sclerophyllous shrub
Baccharis linearis	Compositae	Evergreen sclerophyllous shrub
Quillaja saponaria	Rosaceae	Evergreen sclerophyllous shrub
Kageneckia oblonga	Rosaceae	Evergreen sclerophyllous shrub
Cryptocarya alba	Lauraceae	Evergreen sclerophyllous shrub
Lithraea caustica	Anacardiaceae	Evergreen sclerophyllous shrub
Porlieria chilensis	Zygophyllaceae	Semideciduous sclerophyllous shrub
Gochnatia fascicularis	Compositae	Summer deciduous sclerophyllous shrub
Valenzuelia trinervis	Sapindaceae	Winter deciduous shrub
Colliguaya salicifolia	Euphorbiaceae	Evergreen sclerophyllous shrub
Escallonia myrtoidea	Escalloniaceae	Evergreen malacophyllous shrub
Kageneckia angustifolia	Rosaceae	Evergreen sclerophyllous shrub
Plantago hispidula	Plantaginaceae	Native annual herb
Erodium cicutarium	Geraniaceae	Introduced annual herb
Hypochoeris radicata	Compositae	Introduced annual herb
Fortunatia biflora	Liliaceae	Native bulb-perennial
Trisetobromus hirtus	Gramineae	Native annual herb
Pectocarya penicillata	Boraginaceae	Native annual herb
Trifolium polymorphum	Papilionaceae	Native rhizome-perennial
Clarkia tenella	Onagraceae	Native annual herb
Chaetanthera ciliata	Compositae	Native annual herb
Solenomelus pedunculatus	Iridaceae	Native rhizome perennial
Pasithea coerulea	Liliaceae	Native bulb-perennial
Helenium aromaticum	Compositae	Native annual herb
Stellaria cuspidata	Caryophyllaceae	Native annual herb
Loasa triloba	Loasaceae	Native annual herb
Madia sativa	Compositae	Native annual herb
Nasella chilensis	Gramineae	Native rhizome-perennial
Acaena pinnatifida	Rosaceae	Native rhizome-perennial

is highly variable from one year to another, and seems to depend on the amount and distribution of annual precipitation (Kummerow and others 1981). In general, most of the vegetative growth in the herbaceous layer along the transect occurs between winter and early spring (fig. 1). In midsummer the annual plants and the aerial organs of the herbaceous perennials are usually dried up. Leaf area growth rate of herbaceous species is not directly correlated with altitude. The highest rates (0.75 cm^2/day) are found in species located at 1000 m, in one of the midelevation areas of the Andes. This may be due to the microclimate offered by the canopies of shrubs. In the mid-elevation matorral of the Coastal Range, differences have been observed between vegetative fractions of exposed and protected herbs. Perennials growing among shrubs have smaller vegetative fractions than those under shrubs (Jaksić and Montenegro 1979). Exposed individuals allocate more energy to reproductive tissues than the protected ones (Hickman and Pitelka 1975). The lowest rates of leaf area growth are shown by species at the montane evergreen scrub (0.08 cm^2/day). Near the coast, the herb cover is mainly formed by annuals, and the herbaceous species reach greater leaf area rates than these located at higher altitudes (0.32 and 0.20 cm^2/day respectively). Annuals usually reach higher rates than perennials. Biomass production of herbaceous plants in the midelevation-Coastal Range matorral varied from 100 to 200 g $m^{-2}yr^{-1}$, when precipitation was from 350 to 850 mm (Montenegro and others 1978). Trisetobromus hirtus, with a large number of individuals per m^2, is the most productive species in the herbaceous layer, contributing 30 percent of the total biomass. Chaetanthera ciliata, less dense, contributes only 2 percent of the total biomass of this stratum.

In rainy years (851 mm), both annuals and perennials show significant increase in aerial vegetative, underground vegetative, and reproductive biomass (Montenegro and others 1978). How-

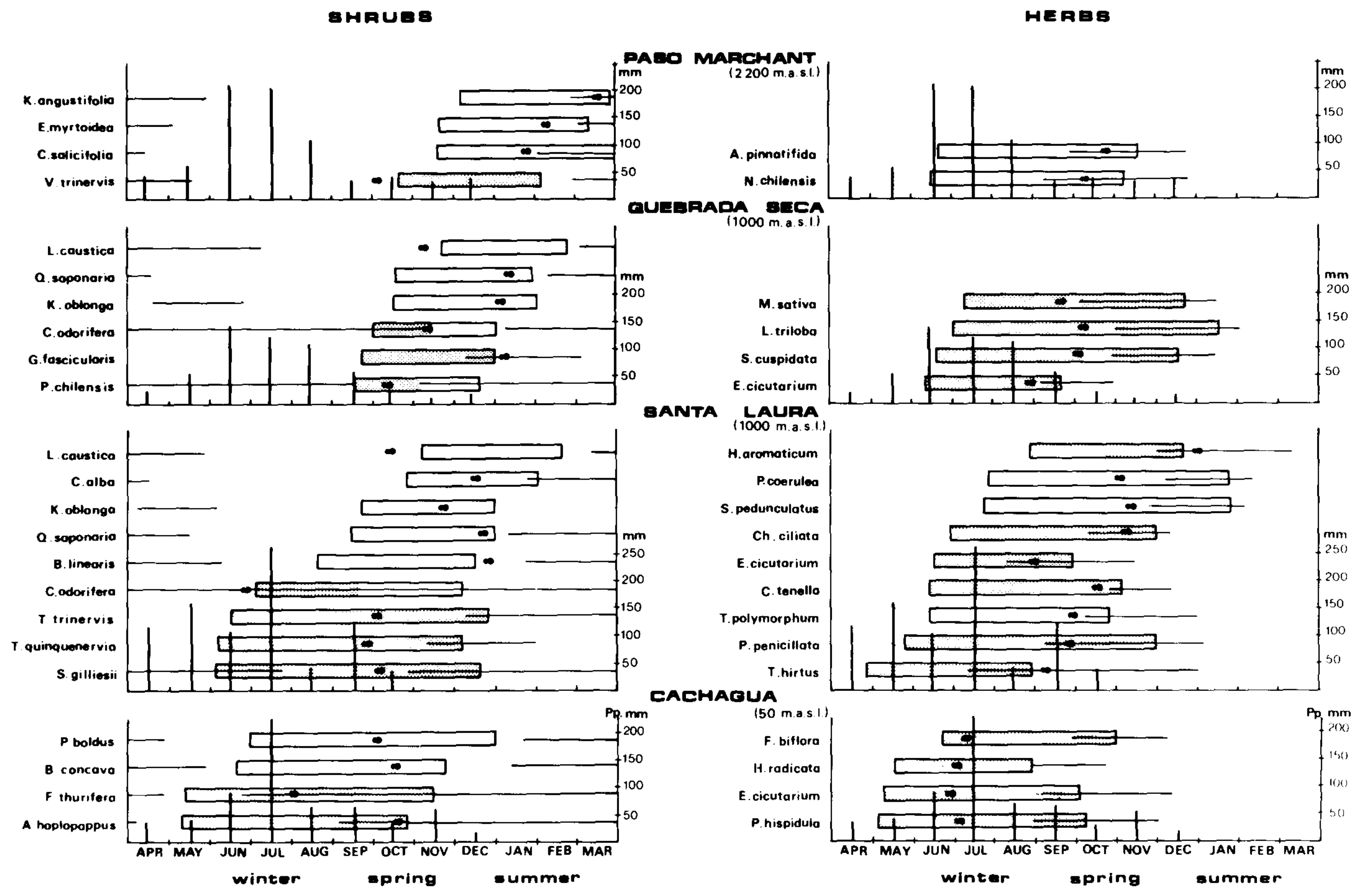


Figure 1--Phenology of shrub and herb species. Vegetative growth ( ); flowering ( ); leaf shedding ( ). Shaded bars: deciduous shrubs and annual herbs; white bars: evergreen shrubs and perennial herbs. Vertical lines: amount of precipitation.

ever, annuals show a significant increase in vegetative fractions in relation to reproductive fraction (Jaksić and Montenegro 1979) which is not observed in perennials. This might be ascribed to the particular biology of perennials. While annuals depend for their growth only on resources of the current year, perennials can eventually use stored carbohydrates synthesized with resources of the previous year. The effects are then likely to be observed in the next growing season.

Recent studies (Avila, unpublished data) have shown that, one year after a fire, the herb cover does not increase in number of species but in–creases twice in biomass. This finding would lend support to the idea that there are no allelopathic interactions between shrubs and herbs.

SHRUB VEGETATION

The vegetative growth period of shrubs is shorter at high altitudes (fig. 1). At the highest sites, growth starts about 6 months later than at the lowest. Water availability and temperature seem to influence growth initiation and the intensity of phenological events. However, the correlation between phenophases and environment is not synchronous for all species (Kummerow and others 1951). Seasonal activity starts with shoot elongation and development of leaf area in most species, and with the development of flower buds in a few others. In general, deciduous and semideciduous shrubs show a winter–growth or spring–growth period, whereas evergreens grow mainly in spring or summer. In some deciduous species, the differentiation of buds which give rise to brachyblasts and flowers occurs in the previous growing period, hence only buds which originate dolichoblasts use the photosynthates of the current season (Hoffmann and Walker 1980). Leaf and branch shedding of deciduous shrubs occurs in summer. The summer deciduous Trevoa trinervis one Talguenea quinquenervia shed their brachyblasts at the onset of the drought period (Hoffmann 1972, Hoffmann and Walker 1980). This seasonal leaf and stem tissue reduction is an important factor in controlling water loss (Orshan (1964). in other summer deciduous such as Fluorencia thurifera, Gochnatia fascicularis, and Satureja gilliesii, leaves gradually dry up with increasing drought stress, but they remain on the shrub throughout summer and fall. Satureja gilliesii has been described as a poikilohydric plant (Montenegro and others 1979c), since its leaves are able to withstand the drought period, under marked dehydration, but they regain turgidity and probably photosynthetic capacity as soon as soil moisture is available. Valenzuelia trinervis, growing on the montane matorral, is a winter deciduous.

The semideciduous Colliguaya odorifera and Porlieria chilensis retain their leaves for one season; these leaves are then gradually shed during the following growing season, as new leaves are formed. Maximum leaf ages were found in the evergreens Crytocarya alba and Lithraea caustica, which keep their leaves for periods of 3 and 4 years respectively.

Growth patterns of the shrubs along the altitudinal transect have been studied, using the following methodology: 10 individuals of each species were monitored in each altitude site; two branches of each individual shrub were tagged at the level of the last leaf formed during the previous growth period. The length of the newly formed shoot and that of each leaf on it was measured throughout the growth season. Silleptic shoots arising from axillary buds of the current year were also measured. The area of each leaf growing on the tagged branches was determined by a correlation factor between length and area (Montenegro and others 1979a).

The flushing pattern of most of the study species follows the classical sigmoid curve. However, the leaf area curves of Kageneckia oblonga and K. angustifolia exhibit two periods of more intensive growth (Montenegro and others 1979b, Montenegro and Aljaro 1979). The time of bud burst for species in the coastal scrub and for some species in the midelevation matorral in the Coastal Range depends mainly on water availability (fig. 1). Bud burst seemed to be markedly affected by temperature at higher altitudes, since most shrubs began shoot growth within a relatively short timespan. Bud break occurred in a period of 22 days in species located at 1000 m, and 27 days at 2000 m. however, leaf area growth rate is not significantly different in comparisons between localities (table 2). Species on the Coastal Range site show a larger leaf area per shoot and longer individual shoots (Montenegro and others 1979a, Kummerow and others 1981), but require a longer growth period than species located on the Andean Cordillera sites.

A comparison of current leaf area indices between individuals of the same species growing at different sites shows values significantly higher

Table 2--Net Productivity of leaf area for dominant species in mid elevation (A), foothill (B), and montane (C), matorral zones.

SITE	ALTITUDE		SPECIES	Total leaf area/shoot (cm^2)	Rate of leaf area growth (m^2 day)	Growth period (days)	Leaf-area[1] Index $m^2\ m^{-2}\ yr^{-1}$
COASTAL RANGE	SANTA LAURA 1000m	A	C. odorifera	35.3 ± 21.1	0.23	150	0.72
			L. caustica	100.9 ± 98.0	1.02	99	0.33
			K. oblonga	87.2 ± 42.0	0.74	117	2.04
			Q. saponaria	40.7 ± 24.0	0.46	88	1.30
			T. quinquenervia	16.9 ± 2.8	0.10	171	1.14
			T. trinervis	22.4 ± 4.6	0.14	156	2.34
			S. gilliesii	20.0 ± 2.3	0.12	168	1.07
			C. alba	110.4 ± 43.7	1.14	97	3.43
			E. pulverulenta	211.2 ± 54.7	1.90	120	2.14
ANDEAN CORDILLERA	QUEBRADA SECA 1000 m	B	G. fascicularis	17.16 ± 6.36	0.23	73	0.49
			K. oblonga	126.04 ± 28.66	1.05	119	0.66
			Q. saponaria	22.33 ± 3.41	0.40	55	0.41
			L. caustica	4.17 ± 0.73	0.06	71	0.02
			C. odorifera	15.18 ± 3.39	0.19	76	0.39
			P. chilensis	3.36 ± 0.63	0.06	61	0.05
			T. quinquenervia	10.4 ± 1.9	0.18	56	0.74
	PASO MARCHANT 2200 m	C	K. angustifolia	12.02 ± 5.66	0.12	98	0.60
			V. trinervis	7.21 ± 3.93	0.06	106	0.14
			C. salicifolia	27.76 ± 15.03	0.31	87	1.80

[1] Values correspond to the area occupied by the indicated species and not to the community as a whole.

for species of the Coastal Range. Besides having a larger amount of leaf area per shoot, they have more branches that initiate growth.

The current biomass index, calculated by the area occupied by the shrubs (table 3) shows significantly higher values for species located at higher altitudes. however, at the community level, the absolute cover decreases with altitude from almost 60 percent at the midelevation matorral (Mooney and others 1977, Armesto and Martínez 1978) to 20 percent at the montane matorral (Martínez, unpublished data).

Lithraea caustica has the lowest biomass index (table 3) and is one of the shrubs which suffers more damage from phytophagous insects (Montenegro and others 1980a, Fuentes and others 1981); but its net productivity increases at the community level due to its high percent (11.1) of relative cover. Instead, Kageneckia oblonga, with a high biomass index, only reaches 3.6 percent of relative cover (Mooney and others 1967). Lithraea caustica shows morphological and physiological adaptations which allow it to live throughout the aridity gradient from equator-facing slopes to pole-facing slopes (Mooney and Kummerow 1971, Kummerow and others 1977, Montenegro and others 1980b, Montenegro and others 1980c). Kageneckia oblonga is found only on mesic sites.

Although a large biomass is allocated to the reproductive fraction (fig. 2), recent studies (0. Balboa, pers. commun.) have proven that production of seeds can greatly vary from one year to another, and that seed viability is rather low.

These findings suggest that the regeneration of the system as a whole depends to a great extent on vegetative reproduction.

The data on growth rate and net productivity suggest that the montane matorral could be the most vulnerable community along the gradient. Recent studies (Aljaro and Montenegro, unpublished data) have shown that, due to frequent defoliation and browsing by goats, the productivity of some of the species of these communities has decreased significantly. In management practices, the timing and intensity of grazing might well be adjusted to vegetative or reproductive periods.

Acknowledgments: The authors are grateful to Professors H. A. Mooney, P. C. Miller, J. Kummerow, and J. Martinez for valuable discussions on this research. Supported by grants DEB 7713944 from National Science Foundation, DIUC 302/77; 43/80; 73/81 and 71/81 from the Catholic University of Chile and by grant UNEP/UNESCO 1105-77-01. The technical assistance of Mr. Luis Gonzalez is greatly appreciated.

Table 3--Net Biomass productivity for dominant species in the mid elevation (A), foothill (B), and montane (C) matorral zones.

SITE	ALTITUDE	SPECIES	Gram Dry weight of Average Shoots			Biomass index	Shrub cover[1]
			Leaves	Stems	Reproductive Structures	$g\ m^{-2}\ yr^{-1}$	Relative percent
COASTAL RANGE	SANTA LAURA 1000 m A	C. odorifera	0.41 ± 0.18	0.09 ± 0.03	0.57 ± 0.48	114	7.10
		L. caustica	1.25 ± 1.23	0.32 ± 0.39	0.42 ± 0.43	65.4	11.10
		K. oblonga	1.83 ± 0.38	0.48 ± 0.33	0.17 ± 0.08	580.9	3.66
		Q. saponaria	0.46 ± 0.33	0.06 ± 0.05	0.41 ± 0.18	298.7	0.54
		T. quinquenervia	0.22 ± 0.03	0.28 ± 0.06	0.21 ± 0.02	480.6	0.10
		T. trinervis	0.13 ± 0.16	0.17 ± 0.27	0.03 ± 0.02	345.6	8.47
		S. gilliesii	0.28 ± 0.12	0.35 ± 0.29	0.30 ± 0.06	268.1	13.27
		C. alba	1.07 ± 0.61	0.18 ± 0.12	0.11 ± 0.01	422.8	28.32
		E. pulverulenta	3.05 ± 0.78	0.80 ± 0.50	1.34 ± 0.94	82.6	
ANDEAN CORDILLERA	QUEBRADA SECA 1000 m B	G. fascicularis	0.37 ± 0.22	0.52 ± 0.14	0.43 ± 0.22	384.9	27.13
		K. oblonga	1.08 ± 0.53	0.21 ± 0.11	0.19 ± 0.04	78.7	13.87
		Q. saponaria	0.42 ± 0.31	0.08 ± 0.04	0.35 ± 0.16	161.5	3.33
		L. caustica	0.46 ± 0.10	0.06 ± 0.05	0.34 ± 0.12	43.5	10.87
		C. odorifera	0.32 ± 0.13	0.04 ± 0.03	0.38 ± 0.19	193.7	11.50
		P. chilensis	0.16 ± 0.07	0.13 ± 0.05	0.10 ± 0.02	67.9	5.47
		T. quinquenervia	0.11 ± 0.02	0.17 ± 0.04	0.18 ± 0.03	331.6	13.43
	PASO MARCHABT 22000 m C	K. angustifolia	0.58 ± 0.19	0.24 ± 0.09	0.04 ± 0.06	438.1	6.01
		V. trinervis	0.16 ± 0.08	0.06 ± 0.02	0.09 ± 0.04	67.9	17.27
		C. salicifolia	0.46 ± 0.29	0.04 ± 0.02	0.22 ± 0.03	481.4	22.90

[1] Shrub cover data for Santa Laura after Mooney and others 1977 and for the Andean Cordillera sites

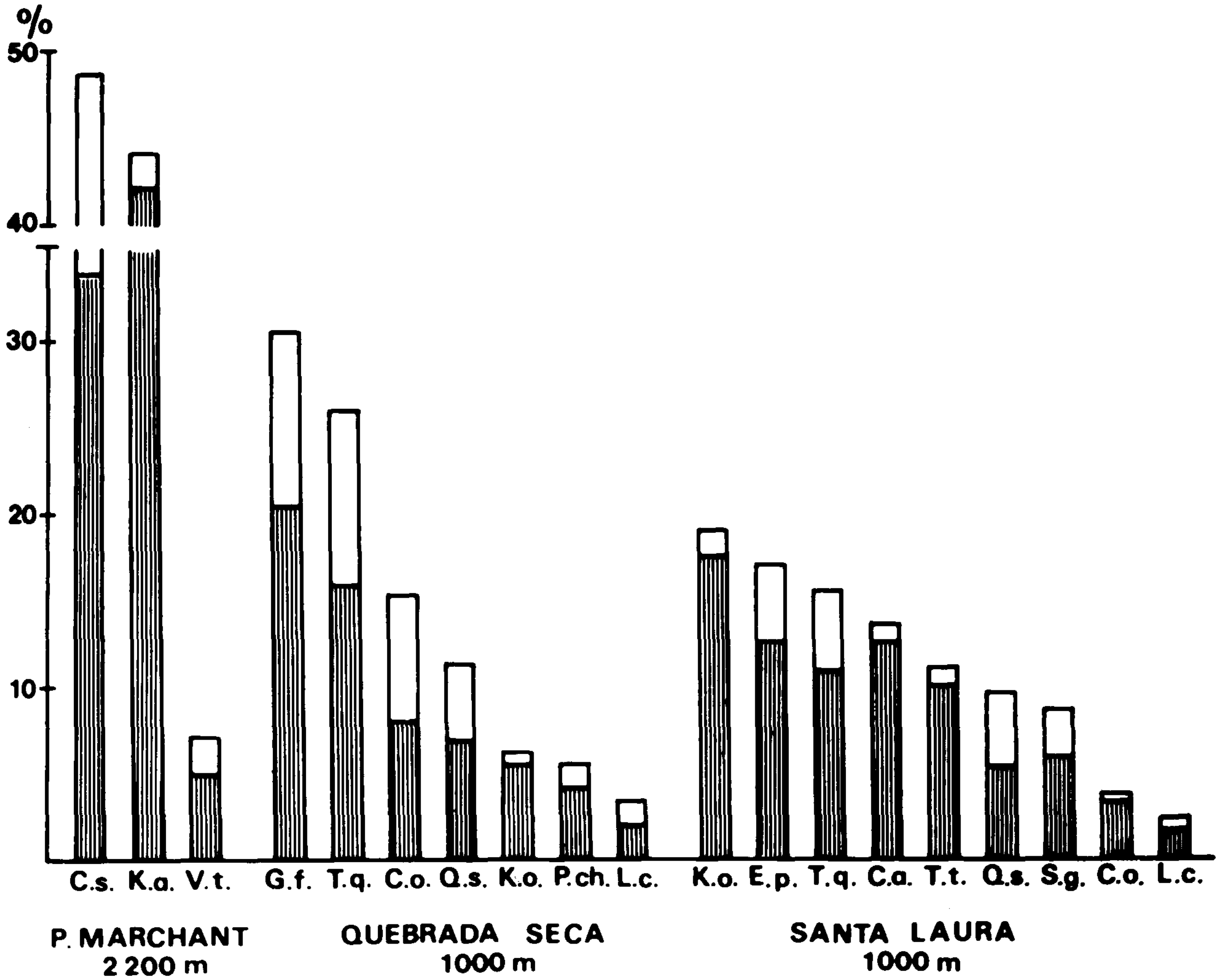


Figure 2--Relative percent of current biomass for shrubs in every study site. Shaded bars: vegetative fractions; white bars: reproductive fraction.

LITERATURE CITED

Armesto, J. J.; Martínez, J. A. Relations between vegetation structure and slope aspect in the mediterranean region of Chile. J. Ecol. 66:881-889; 1978.

Arroyo, M. T. Kalin; Armesto, J.; Villagrán, C. Plant phenological patterns in the high Andean Cordillera of Central Chile. J. Ecol. 69:205-233; 1980.

Chou, C. H.; Müller, C. H. Allelopathic mechanisms of Arctostaphylos glandulosa var. zacaensis. Am. Mid. Nat. 88:342-347; 1972.

Di Castri, F. Esquisse écologique du Chili. In: Delamare-Deboutteville, C.; Rapoport, E., eds. Biologie de 1'Amerique Australe. Paris: Centre National de la Recherche Scientifique; 1968; 4:7-52.

De Castri, F. Climatographical comparisons between Chile and the western coast of North America. In: Di Castri, F.; Mooney, H. A., eds. Mediterranean type ecosystems: Origin and structure. New York: Springer-Verlag; 1973:21-36.

Fuentes, E.; Etchegaray, J.; Aljaro, M. E.; Montenegro, G. Shrub defoliation by matorral insects. In: Di Castri, F., ed. Ecosystems of the world. Elsevier Scient. Publ. Amsterdam (in press).

Hajek, E. R.; Di Castri, F. Bioclimatografía de Chile. Universidad Católica de Chile, Santiago; 1975. 107 p.

Heusser, C. J. Vegetation and climate of the southern Chilean lake district during and since last inter-glacial. Quat. Res. 4:290-315; 1974.

Hickman, J. C.; Pitelka, L. F. Dry weight indicates energy allocation in ecological strategy analysis of plants. Oecologia 21:117-121; 1975.

Hoffmann, A. J. Morphology and histology of Trevoa trinervis (Rhamnaceae), a drought deciduous shrub from the Chilean matorral. Flora 161:527-538; 1972.

Hoffmann, A. J.; Hoffmann, A. E. Comportamiento fenológico de plantas de la Cordillera de los Andes. Arch. Biol. Exp. 11:188; 1978.

Hoffmann, A. J.; Walker, M. J. Growth habits and phenology of drought-deciduous species in an altitudinal gradient. Can. J. Bot. 58(16):1789-1796; 1980.

Hueck, K. Los bosques de Sudamérica: Ecología, composición e importancia económica. GTZ, Germany; 1978. 476 p.

Jaksić, F. M.; Montenegro, G. Resource allocation of Chilean herbs in response to climatic and microclimatic factors. Oecologia (Berl.) 40:81-89; 1979.

Keeley, S. C.; Johnson, A. W. A comparison of the pattern of herb and shrub growth in comparable sites in Chile and California. Am. Mid. Nat. 97(1):120-132; 1977.

Kummerow, J.; Montenegro, G.; Krause, D. Biomass, phenology and growth. In: Miller, P., ed. Resource use by chaparral and matorral. Elsevier Publ. Springer-Verlag (in press).

McPherson, J. K.; Müller, C. H. Allelopathic effect of Adenostoma fasciculatum, "chamise", in the Californian chaparral. Ecol. Monogr. 39:177-198; 1969.

Miller, P. C.; Bradbury, D. E.; Hajek, E.; Lamarche, V.; Thrower, N. J. W. Past and present environment. In: Mooney, H. A., ed. Convergent evolution in Chile and California. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Penn.; 1977:27-72.

Montenegro, G.; Rivera, 0.; Has, F. Herbaceous vegetation in the Chilean matorral. Dynamics of growth and evaluation of allelopathic effects of some dominant shrubs. Oecologia (Berl.) 36:237-244; 1978.

Montenegro, G.; Aljaro, M. E.; Kummerow, J. Growth dynamics of Chilean matorral shrubs. Bot. Gaz. 140(1):114-119; 1979a.

Montenegro, G.; Aljaro, M. E.; Arrieta, A. Dinámica de crecimiento y productividad de especies dominantes, en un transecto altitudinal de la Cordillera de los Andes. Proc. Seminario sobre el Programa de Investigación Integrada "Impacto del Hombre en los Ecosistemas de Montana. MAB 6 UNESCO; 1979b Enero 23-25; Arica, Chile.

Montenegro, G.; Hoffmann, A. J.; Aljaro, M. E.; Hoffmann, A. E. Satureja gilliesii, a poikilohydric shrub from the Chilean mediterranean vegetation. Can. J. Bot. 57(11):1206-1213; 1979c.

Montenegro, G.; Aljaro, M. E. Crecimiento de especies arbustivas dominantes en un transecto altitudinal de Chile Central. Proc. II Reunion Nacional de Botánica; 1979 Septiembre 27-29; Santiago, Chile. 30 p.

Montenegro, G.; Jordan, M.; Aljaro, M. E. Interactions between Chilean matorral shrubs and phytophagous insects. Oecologia (Berl.) 45:346-349; 1980a.

Montenegro, G.; Riveros, F.; Alcalde, C. Morphological structure and water balance of Chilean shrub species. Flora 170:554-564; 1980b.

Montenegro, G.; Martínez, J.; Aljaro, M. E. Estructura de comunidades y estacionalidad de especies dominantes en un gradiente altitudinal de Chile Central. Proc. VIII Reunión Argentina de Ecologia; 1980c Mayo 11-17; Santa Fe, Argentina. 27 p.

Mooney, H. A.; Dunn, E. L.; Shropshire, F.; Song, L. Vegetation comparisons between the mediterranean climatic areas of California and Chile. Flora 159:480-496; 1970.

Mooney, H. A.; Kummerow, J. The comparative water economy of representative evergreen sclerophyll and drought deciduous shrubs of Chile. Bot. Gaz. 132:245-252; 1971.

Mooney, H. A.; Parsons, D. J.; Kummerow, J. Plant development in mediterranean climates. In: Lieth, H., ed. Phenology and seasonality modeling. New York: Springer-Verlag; 1974:255-267.

Mooney, H. A.; Kummerow, J.; Johnson, A. W.; Parsons, D. J.; Keeley, S.; Hoffmann, A.; Hays, R. I.; Giliberto, J.; Chu, C. The producers, their resources and adaptative responses. In: Mooney, H. A., ed. Convergent evolution in Chile and California. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Penn.; 1977:85-143.

Orshan, G. Seasonal dimorphism of desert and mediterranean chamaephytes and its significance as a factor in their water economy. In: The water relation of plants. Blackwell's Scientific Publications, Adlard & Son Ltd. Bartholomew Press, Dorking; 1964:206-222.

Parsons, D. J. Vegetation structure in the mediterranean climate scrub communities of California and Chile. J. Ecol. 64:433-447; 1976.

Pisano, E. La vegetación de las zonas geográficas chilenas. Rev. Geog. Chile Terra Australis 11:95-107; 1954.

Quintanilla, V. G. La carta bioclimática de Chile Central. Rev. Geogr. Valparaíso 5:33-58; 1974.

Rundel, P. W. Trichocereus in the mediterranean zone of Central Chile. Cactus Succ. J. 46:86-88; 1975.

Rundel, P. W.; Weisser, P. J. La Campana, a new national park in Central Chile. Biol. Conserv. 8:35-46; 1975.

Rundel, P. W. The matorral zone of Central Chile. In: Di Castri, F.; Goodall, D. W.; Specht, R. L., eds. Mediterranean type shrubland. The Hague: Elsevier; 1981.

Villagrán, C.; Armesto, J.; Arroyo M.; Uslar, P. Comparación de la vegetación de tres transectos altoandinos de Chile. Proc. II Reunión Nacional de Botánica. 1979 Septiembre 27-29; Santiago, Chile. 22 p.

The Relation Between Root and Shoot Systems in Chaparral Shrubs[1]

Jochen Kummerow[2]

Abstract: Purpose of this study was to determine the balance between root and shoot growth in chaparral shrubs. Under controlled conditions with ample water and nutrient supplies, growth of roots and shoots continued exponentially for 5 months. In contrast, in the field shoots had flushing periods in the spring, lasting 31-69 days. Fine root growth however extended over 5-7 months. Fine root surface area and leaf area per shrub were estimated for different environmental conditions. It was found that increasing water stress produced higher fine root surface:leaf area ratios.

The purpose of this paper is to analyse the growth relations between root and shoot systems of chaparral shrubs. Data from the literature and results from our own experiments will be used to demonstrate the plasticity of the root:shoot balance of chaparral shrubs.

Traditionally, the relation between roots and shoots has been described by root/shoot biomass ratios, and values ranging from 0.3-4.9 for non-sprouting and stump sprouting shrubs respectively have been obtained (Miller and Ng 1977, Hoffmann and Kummerow 1977, Kummerow and Mangan 1981). The large ratios, common to stump sprouters, derive primarily from the mass of burls (=lignotubers or root crowns) which are massive woody organs developed from hypocotyl and root crown tissue. It is difficult to demonstrate annual increases in size or biomass of older burls and aging such structures has been possible only by using ^{14}C methodology with a relatively wide margin of error (Hanes 1965). Thus, in spite of their large biomass, studies of older burls have not contributed much information to our understanding of the seasonal growth dynamics of root systems. A similar argument is valid for larger roots and stems. That is, as important as their functions may be, these organs do not visibly reflect short term changes in the physical environment. A different approach is needed.

The fraction of the root system which is directly responsive to the seasonal changes of the environmental conditions is the "fine root system". This term refers to the population of ephemeral rootlets which do not live for more than one growing season and may be as shortlived as two weeks (Lyr and Hoffmann 1967, Lyford 1975). Data on the seasonal changes in rootlet growth are sketchy. Some information on rootlet phenology from the southern California chaparral has been published (Kummerow and others 1978) but more data are needed.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California

[2]Botany Department, San Diego State University, San Diego, California 92182

The data base on seasonal shoot growth dynamics is substantially broader. Growth of leaves and branchlets of shrubs has been studied in detail in all the mediterranean areas of the world (Specht 1957, Margaris 1976, Hoffmann and others 1977, Montenegro and others 1979, Kruger 1980). Typically, a growth flush lasting 3-8 weeks occurs between early spring and late summer with some variation depending on local conditions and the species in question.

In the following parts of this paper we will attempt to relate shoot (=leaves + branchlets) and fine root growth. This approach appears useful for several reasons. Leaves and rootlets are analogous with respect to their determinate growth and the distal position in their respective organ systems. Both have as their main function the uptake of basic resources, i.e. light energy and CO_2 by the leaves and water and minerals by the roots. Consequently, both have large surface areas.

ROOT AND SHOOT PHENOLOGY OF CHAPARRAL SHRUBS

Individual shrubs of Arctostaphylos glauca Lindl., Adenostoma fasciculatum H. & A., Ceanothus greggii var. perplexans (Trel.) Jeps., and Rhus ovata Wats. were selected for a detailed analysis of stem, leaf, and fine root growth. Field research area was confined to our Echo Valley site located at 1000 m elevation about 10 km north of Descanso in San Diego County, California, 55 km east of the Pacific Ocean. Climatic and biological information on this mixed chaparral site has been published previously (Mooney 1977). Individual buds of the above species were tagged and the developing shoots monitored until the end of the growth flush. Total leaf area per shoot was calculated from allometric formulas.

Growth curves of the shoots show the characteristic sigmoid form which has been demonstrated earlier for the California chaparral and Chilean matorral (Kummerow and others 1981). Duration of the flushing period, leaf area per shoot, shoot length, and the rates of leaf area and stem growth, showed significant differences between species (Table 1).

Adenostoma fasciculatum developed a relatively small leaf area (2.5 cm^2 per shoot when com-

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1. Leaf area per shoot, growth rates, shoot length, and the length of growth periods of four chaparral shrub species at Echo Valley. Growth rates with the same letters are not statistically different (ANOVA). The rates are calculated on the basis of the entire growth period (Kummerow and others, 1981).

	Leaf area per shoot cm^2	Rate of leaf area growth cm^2 d^{-1}	Mean shoot length in season cm	Rate of shoot elongation cm d^{-1}	Date of growth initiation	Duration of growth days
Adenostoma fasciculatum n = 7	2.5 ± 0.45	0.03 ± 0.01a	5.2 ± 1.70	0.09 ± 0.03ab	09 April	69 ± 26
Arctostaphylos glauca n = 17	33.0 ± 6.50	0.82 ± 0.136	6.9 ± 1.24	0.13 ± 0.026	30 April	48 ± 4
Ceanothus greggii n = 20	7.9 ± 1.52	0.12 ± 0.02c	4.2 ± 0.83	0.06 ± 0.01a	12 April	68 ± 4
Rhus ovata n = 6	43.5 ± 24.05	1.19 ± 0.43bc	2.9 ± 1.18	0.08 ± 0.06ab	06 June	31 ± 5

pared with the other 3 species. The shrub with the highest value was Rhus ovata with 43.5 cm^2 leaf area per shoot. This difference is due in large part to differences between species with respect to the number of shoots per m^3 of shrub volume (944 ± 533 in A. fasciculatum, 97 ± 92 in R. ovata). It should be pointed out that leaf area index measurements of the same site gave values of 1.9 for both species (Mooney and others 1977). The situation is further complicated in A. fasciculatum, because of the short shoot organization of this species. New foliage is not limited to current year's growth. Short shoots remain active and produce leaves on 2-8 year-old branches (Jow and others 1980). Of special interest for our comparison of the duration of shoot and root growth is that the growth flush for A. fasciculatum had a duration of 69 ± 26 days vs. 31 ± 5 of R. ovata (Table 1). This then causes the data in Table 1 to be somewhat misleading as the total growth increment of the season was divided by the number of days of the growth flush. Nevertheless, a comparison of the leaf area produced by one shoot during the week of most rapid extension growth does not change the order of the four shrub species. In R. ovata a maximum of 8.4 cm^2 of leaf area per shoot was produced in one week compared to 5.7, 0.9, and 0.3 cm^2 in A. glauca, C. greggii, and A. fasciculatum respectively.

Our knowledge regarding the phenology of root growth is more limited. The seasonality of secondary growth for larger roots has been documented in central Chile (Riveros de la Puente 1973), and it is assumed that data from other mediterranean type ecosystems would be similar. Year ring widths in stems and large roots were strongly correlated. Fine roots in the chaparral also show clear seasonal trends (fig. 1). These data were obtained from soil core analyses and thus are based on large rootlet populations rather than being derived from non-destructive observations as are possible with individual shoots. Nevertheless, the data demonstrate that in April and May fine root growth increased rapidly; in June and July the values remained on a high plateau and declined in August. The fact that an unusual rainstorm at the end of August, 1976, with 33 mm of precipitation produced a significant increase of rootlet growth, perhaps reflects a soil moisture limitation in the ecosystem. A comparison of the duration of shoot and root growth of our four shrub species demonstrates the main differance between the growth of shoot and root systems. Rootlet growth continued for 5-7 months while shoot growth lasted only 4-9 weeks (fig. 2).

In order to circumvent the destructive nature of root studies in the field and obtain more information on root dynamics, it seemed justified to grow chaparral shrubs hydroponically under near optimum conditions. Such a technique would allow monitoring growth rates of the root system simultaneously with leaf area increases. The results of such an experiment might be expected to demonstrate the equilibrium in the growth of roots and shoots. It is understood of course that the

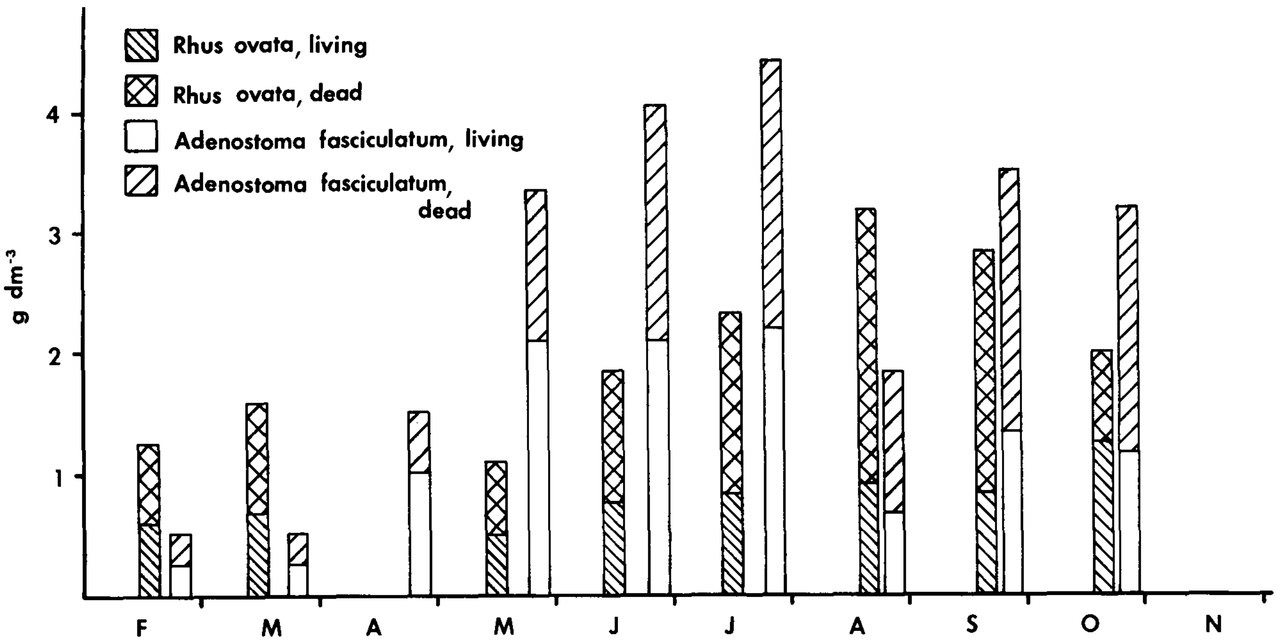


Figure 1--Seasonal changes in fine root biomass of 2 chaparral shrub species. Note the increasing amount of dead fine roots in summer and autumn. Each column represents a mean value of 12 soil cores of 125 cm^3 each (after Kummerow and others 1978).

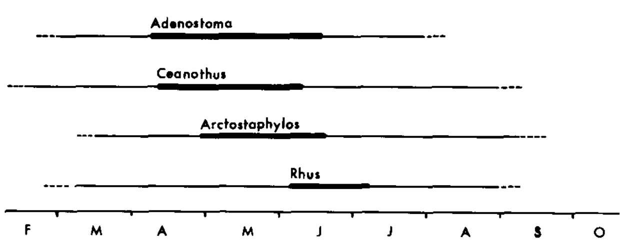


Figure 2--Timing and duration of shoot growth (thick line) and fine root growth (fine line) of 4 chaparral shrubs. Initiation and end of fine root growth not as well defined as shoot growth (dashed line).

results from such an experiment cannot be applied directly without further work under field conditions.

Fifteen 2-months old seedlings of A. fasciculatum were selected from healthy nursery stock. Twelve were cultivated individually in 14 1 plastic buckets with aerated standard Hoagland solution. The remaining 3 plants were potted and grown in a sand-peat moss mixture. The nutrient solutions were changed every 2 weeks and the potted plants were irrigated and fertilized at appropriate intervals to avoid water and nutrient stress. Over the 5 months experimental period all plants were maintained under controlled environmental conditions at 16 h light 25°C and 8 h dark, 20°C. Light intensity was 800 ± 60 µE m^{-2} sec^{-1}.

Root volumes and leaf areas were determined for each plant at two week intervals. The root volumes were obtained by water displacement using adequately sized glass cylinders. The leaf areas were determined by measuring shoot lengths and using an allometric formula for shoot length conversion into leaf area.

The two computer fitted regression lines (fig. 3) represent the leaf area and root volume increases. They document the continuous exponential growth of the two plant compartments. The fact that the regression line for root growth shows a greater slope than the one for leaf area increase is irrelevant in this context, because area is not quantitatively compared with a volume. In the framework of our theme it is significant that root and shoot system grew continuously in a balanced way over the five month experimental period. The root/shoot biomass ratios at the end of the experiment for the solution grown plants reached a value of 0.52 ± 0.3 (n=12) and 0.53 ± 0.5 (n=3) for the sand-peat moss grown plants. This means that the ratio of root/shoot biomass had not been altered by the growth substrates.

THE INFLUENCE OF SOIL MOISTURE ON FINE ROOT SURFACE AREAS

The role of root/shoot biomass ratios and their limitations regarding interpretation of growth dynamics in arid areas have been discussed (Barbour 1973). It has also been shown that under controlled conditions the physical character of

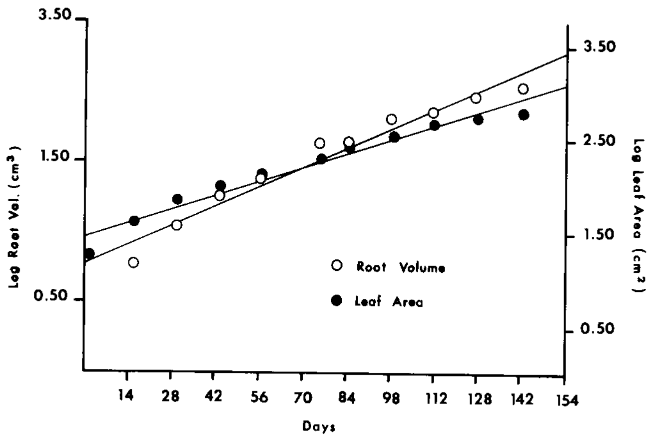


Figure 3--Root volume and leaf area growth in 2-month old Adenostoma fasciculatum, cultivated in aerated nutrient solution. Each data point represents the mean of roots and leaves from 12 plants.

the root environment did not influence root/shoot ratios as long as nutrients and water were not limiting. Since chaparral shrub growth has frequently been considered as water and nutrient limited (Hellmers and others 1955, Vlamis and others 1954, Vlamis and Gowans 1961), it appeared to be of interest to test the hypothesis that the root systems of chaparral shrubs, exposed to variable degrees of water stress, should be more extensive than those from an environment without water stress. However, it would be difficult to test such an hypothesis when one considers the level of accuracy which can be obtained from field observations. Further, root systems of young seedlings may have growth patterns different from those of older plants and larger roots with secondary growth and their large biomass may well camouflage changes in the biomass of fine roots. To overcome these difficulties at least in part it was decided to assess fine root densities and the fine root surface area of container grown chaparral shrubs and relate the estimated absorbing root surfaces with the leaf area of the respective shrub. This ratio would allow for a comparison of shrubs of heterogenous sizes and relate the CO_2-fixing leaf area with the nutrients and water absorbing root surface.

Redwood boxes, 75 cm high, 60 cm wide, and 20 cm deep, filled with a fertilized sand-peat moss mixture, were planted in March 1976, with 1.5 year old Adenostoma fasciculatum, Arctostaphylos glauca and Yucca whipplei. Six of these redwood boxes were placed in a relatively shaded area and watered frequently, thus simulating a moist ravine. Three boxes were fully sunexposed and watered only when wilting symptoms became visible. The last four boxes were transported to the Echo Valley research area and placed into a ditch excavated for this purpose. After sinking these boxes into the ditch the plants were level with the original soil surface; empty spaces between the boxes and the ditch were filled with the excavated soil. No rain fell between March and October but these boxes were watered three times. Presumably these plants experienced severe water stress as only two survived.

Between October 25 and November 10, 1976, all the plants were harvested. The leaf area (LA), as well as leaf and stem biomass were recorded for each shrub[3]. The total root mass was extracted from the redwood boxes and separated into fine roots (diam. <1.0mm) and larger roots. A representative sample of the fine roots was separated visually into suberized and non-suberized roots. For the estimate of "absorbing" fine root surface (FRSA) only whitish and light brown fine roots were considered. This distinction is somewhat arbitrary since suberized roots can absorb water (Kramer and Bullock, 1966). The mean diameter of the unsuberized fine roots was measured and the length of 1 g fresh weight of these rootlets was estimated by the line intersect method of Newman (1966) as modified by Tennant (1975). This estimate was used to calculate the unsuberized fine root surface area. Although the number of analyzed shrubs was too small for far reaching conclusions a trend was evident: With increasing aridity of the rooting medium the FRSA:LA ratio increased (fig. 4). These results could be interpreted to mean that under water stress relatively more carbohydrate is allocated to the fine root system.

THE EFFECT OF PERTURBATIONS ON SHOOT AND ROOT GROWTH OF CHAPARRAL SHRUBS

Abundant information regarding the effect of major perturbations such as burning, browsing, or fertilizer application has been accumulated (Mooney and Conrad 1977). However, this information refers to the above ground plant parts and the effect of these disturbances on the root systems remains unstudied.

In spite of this lack of information we can draw some tentative conclusions based on field observations and some smaller experiments under controlled environmental conditions. The interpretation of the effect of burning of obligate seeder shrubs is relatively straightforward. The destruction of the shoot system causes the consequent decay of the roots. Shrub reestablishment is possible only by seedlings. The aboveground structures of resprouting shrubs are likewise destroyed by fire. However, new shoots emerging

---

[3]Data on file, Botany Department, San Diego State University

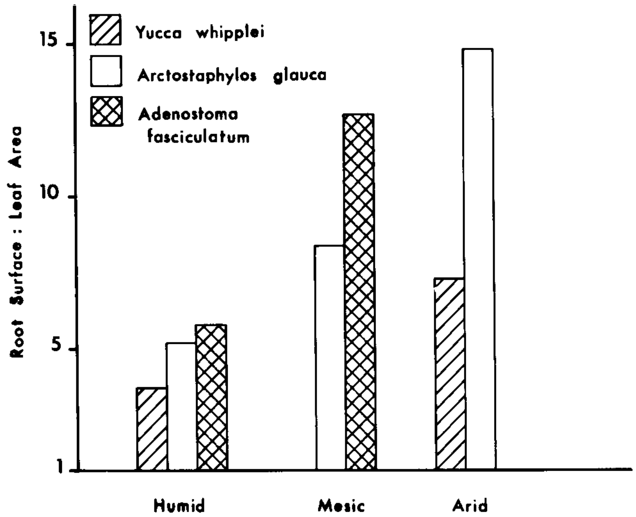


Figure 4--Root surface/leaf area ratio in 3 chaparral shrubs cultivated under 3 different watering regimes. The column of Arctostaphylos at the humic site represents the mean from 3 plants (range of the ratio 4.7-5.9) and 1 plant each from the mesic and the arid site. Yucca: 2 plants at the humid site (range 3.3-4.2) and 1 plant at the arid site. Adenostoma: 1 plant each at the humid and the mesic site.

from burls insure permanence of the shrub on its site. These burls can reach considerable size and substantial amounts of non-structural carbohydrates (TNC) have been found. Values ranging from 2 percent to 9 percent TNC for Adenostoma fasciculatum and Rhus ovata respectively were found[4]. Quercus dumosa burls with 15 kg dry weight, 3 to 4 times the biomass of the aboveground plant structures, are by no means exceptional (Kummerow and Mangan, 1981). Thus, adequate amounts of TNC for resprouting shoots after fire would seem to be available. However, the question remains, how much of the original root system survives fire. We can only assume that the surface-close fine roots will be killed by fire while deeper located roots, protected from excessive heat, can survive. Stored carbohydrate has been shown to be important in shrub survival after shoot destruction (Jones and Laude, 1960). Thus, fire at a time of minimum TNC stored will be more destructive than at a time with high amounts of TNC in burl and large root tissue.,

Partial destruction of shoot systems by browsing deer or cattle or by insect predation should be considered in the same line of thought. If the severed shrub has enough TNC accumulated, reduction of the leaf area can be buffered by TNC reserves. If these reserves are low and damage to the shrub is extensive, reduction of the absorbing root surface may result. Experiments with hydroponically grown Ceanothus tomentosus seedling plants showed that pruning of 1/2 and 3/4 of the shoot system resulted in a significant decrease of root system development[4]. These observations are supported indirectly by results from root pruning experiments which established in all cases the close interdependence of root and shoot systems (Buttrose and Mullins 1968, Raper and others 1978).

A special case of disturbance is chaparral fertilization. The growing influx of permanent residents and visitors into the seasonally dry mountain areas of southern California has created deficiencies in waste disposal systems and the potential of waste water use for chaparral fertilization for biomass harvesting has been tested (Youngner and others 1976). A fertilizer experiment with conservative doses of nitrogen and phosphorus, 80 kg and 40 kg ha^{-1} respectively, produced significant aboveground shrub biomass increase. Unfortunately, corresponding values of the belowground vegetation could not be analyzed. However, it follows from the data shown by Turner (1926) and Shank (1945) that increasing amounts of nitrogen and phosphorus reduced significantly the root/shoot ratios of various crop plants. The complex effect of fertilizer addition to chaparral becomes especially evident when observations include the herbaceous vegetation. Annuals absorbed a substantial fraction of the applied fertilizer, thus competing successfully with the woody vegetation[4]. Thus we can but speculate that fertilizer addition to chaparral may reduce the fine root:leaf area ratios in shrubs. Experimental work has to be done to test the hypothesis that fertilized shrubs would be exposed earlier to water stress with increasing summer drought than unfertilized plants.

CONCLUSIONS

Interpretation of chaparral growth dynamics requires consideration of both shoot and root growth. Growth occurs in seasonal flushes with shoot growth lasting only a fraction of the time of seasonal root growth. Growth in chaparral is limited by water and nutrients. With increasing water and nutrient stress the relative allocation of carbohydrates to the fine root system probably increases. Fertilizer application to the chaparral produces increased aboveground biomass but may decrease the relative carbohydrate allocation to the root system. Thus, biomass increase with fertilizer may result in shrubs with high water loss through transpiration and a relatively small fine root system. Such an imbalance of leaf area and fine root surface area may result in less drought resistant chaparral shrubs. Experimental work is needed to test this hypothesis.

---

[4]Data on file, Botany Department, San Diego State University

Acknowledgments: I thank Mr. David Krause and William Jow for their assistance in this study and Dr. David Rayle for helpful suggestions with the manuscript preparation. The research was supported by NSF-Grant DEB 77-13944.

LITERATURE CITED:

Barbour, M. G. Desert dogma reexamined: Root/ shoot productivity and plant spacing. Amer. Midl. Nat. 89:41-57; 1973.

Buttrose, M. S.; Mullins, M. G. Proportional reduction in shoot growth of grapevines with root systems maintained at constant relative volume by repeated pruning. Austr. J. Biol. Sci. 21: 1095-1101; 1968.

Hanes, T. L. Ecological studies on two closely related chaparral shrubs in southern California. Ecol. Monographs 35:213-235; 1965.

Hellmers, H.; Bonner, J. F.; Kelleher, J. M. Soil fertility: A watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80:189-197; 1955.

Hoffmann, A.; Kummerow, J. Root studies in the Chilean matorral. 0ecologia 32:57-69; 1978.

Hoffmann, A.; Mooney, H. A.; Kummerow, J. Qualitative phenology. In: Thrower, N. J. W.; Bradbury, D. E., eds. Chile-California mediterranean scrub atlas. Stroudsburg, Penn.: Dowden, Hutchinson & Ross; 1977:102-120.

Jones, M. B.; Laude, H. M. Relationship between sprouting in chamise and the physiological condition of the plant. J. Range Management 13: 210-214; 1960.

Jow, W. M.; Bullock, S. H.; Kummerow, J. Leaf turnover rates of Adenostoma fasciculatum (Roseacea). Amer. J. Bot. 67:256-261; 1980.

Jow, W. M.; McMaster, G. S.; Kummerow, J. Response of Adenostoma fasciculatum and Ceanothus greggii to nitrogen and phosphorus. Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

Kramer, P. J.; Bullock, H. C. Seasonal variations in the proportions of suberized and unsuberized roots of trees in relation to the absorption of water. Amer. J. Bot. 53:200-204; 1966.

Kruger, F. Seasonal growth and flowering rhythms: South African heathlands. In: Specht, R. L., ed. Heathlands and related shrublands of the world. Amsterdam: Elsevier Scientific Publishing Co., in press.

Kummerow, J.; Mangan R. Root systems in Quercus dumosa dominated chaparral in southern California. Acta Oecologica/Oecol. Plantarum 2 (16): 177-188.

Kummerow, J.; Montenegro, G.; Krause, D. Biomass, phenology and growth. In: Miller, P. C., ed. Resource use by chaparral and matorral. New York: Springer-Verlag in press. 1981.

Kummerow, J.; Krause, D.; Jow, W. M. Seasonal changes in fine root density in the southern Californian chaparral. 0ecologia 37:201-212; 1978.

Lyford, W. H. Rhizography of non-woody roots of trees in the forest floor. In: Torrey, J. G.; Clarkson, D. T., eds. The development and function of roots. New York: Academic Press; 1975:179-196.

Lyr, H.; Hoffmann, G. Growth rates and growth periodicity of tree roots. Intern. Rev. For. Res. 1:181-236; 1967.

Margaris, N. S. Structure and dynamics in a phryganic (East Mediterranean) ecosystem. J. of Biogeography 3:249-259; 1976.

Miller, P. C.; Ng, E. Root:shoot biomass ratios in shrubs in southern California and central Chile. Madrono 24:215-223; 1977.

Montenegro, G. M.; Aljaro, M. E.; Kummerow, J. Growth dynamics of Chilean matorral shrubs. Bot. Gaz. 140:114-119; 1979.

Mooney, H. A., ed. Convergent evolution in Chile and California: Mediterranean climate ecosystems. Stroudsburg, Penn.: Dowden Hutchinson & Ross; 1977:224 p.

Mooney, H. A.; Kummerow, J.; Johnson, A. W.; Parsons, D. J.; Keeley, S.; Hoffmann, A.; Hays, R. I.; Giliberto, J.; Chu, C. The producers - Their resources and adaptive responses. In: Mooney, H. A., ed. Convergent evolution in Chile and California. Stroudsburg, Penn.: Dowden, Hutchinson & Ross; 1977:85-143.

Mooney, H. A.; Conrad, C. E. Technical Coordinators. Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Palo Alto, California: Forest Serv., USDA, Washington, D. C. 498 p.

Newmann, E. I. A method for estimating the total length of root in a sample. J. appl. Ecol. 3: 139-145; 1966.

Raper, C. D. Jr.; Osmond, D. L.; Wann, M.; Weeks, W. W. Interdependence of root and shoot activities in determining nitrogen uptake of roots. Bot. Gaz. 139:289-294; 1978.

Riveros de la Puente, G. F. Ritmo anual del crecimiento en raices de Quillaja saponaria y Cryprocarya alba. Santiago de Chile: Thesis, Univ. Catolica de Chile, Inst. de Ciencias Biol. 1973:27 p.

Specht, R. L.; Rayson, P. Dark Island heath (Ninety-Mile Plain, South Australia). Austr. J. Bot. 5:52-85; 1957.

Shank, D. B. Effect of phosphorus, nitrogen, and soil moisture on top-root ratios of inbred hybrid maize. J. Agr. Res. 70:365-377; 1945.

Tennant, D. A. Test of a modified line intersect method of estimating root length. J. Ecol. 63: '955-1001; 1975.

Turner, J. M. The effect of varying the nitrogen supply on the ratios between the tops and roots in flax. Soil Sci. 21:303-306; 1926.

Vlamis, J.; Stone, E. C.; Young, C. L. Nutrient status of brushland soils in southern California. Soil Sci. 78:51-55; 1954.

Youngner, V. B.; Williams, T. E.; Green, L. R. Ecological and physiological implications of greenbelt irrigation. Davis: Univ. of California, Contribution No. 157; 1976; 104 p.

Plant Population Interactions and Management: A Summary[1]

Philip C. Miller[2]

Vegetation changes, which have taken place in Mediterranean regions because of man's influence, have occurred because of interactions between changed fire frequencies and introduced plant and animal species on one hand and plant demographic and species growth properties on the other. The clarification of these interactions will place the prediction of the long—term impacts of man's activities on the vegetation of Mediterranean regions on a more scientific basis. Species composition depends on seed germination, the increasing number of shoots on the individual plant, development of reproductive shoots, and patterns of growth and death of the individual shoots. These processes take place within the seasonal rhythm of the Mediterranean-type climate with its cool, wet winters and hot, dry summers and with low nitrogen and phosphorus availabilities.

The paper by Marilyn Fox reviewed the changes in the vegetation of the Mediterranean regions of Australia from before European settlement through the degradation of the natural vegetation under agricultural practices, with introduced species, and altered fire regimes. The paper presented a case study of vegetation change in a Mediterranean—type region.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean—type ecosystems, June 22—59, 1981, San Diego, California.

[2]Systems Ecology Research Group, San Diego State University, San Diego, California.

Fred Kruger's paper, which is based on experiments in the Cape Fynbos of South Africa, developed the patterns of the influences of fire frequency on vegetation composition. Frequent fires can eliminate certain seeding shrubs which have long growth periods before they reach the age of reproduction. Infrequent fires can also eliminate certain shrubs where senescence in some species results in less production or lower quality of seeds that need a fire before release or germination. Kruger pointed out the need for research on the demography of seed production and on the dynamics of soil and canopy seed pools.

The paper by Paul Zedler developed the importance of the demographic patterns of seed production. This paper also emphasized the role of seed dispersal and the size of individual disturbances in affecting the long-term species composition following several disturbances. Jon and Sterling Keeley's paper dealt with the controls of the germination of herbs, which characteristically are abundant in Californian chaparral for only a short period after a fire. The growth of the plant involves the plant as a physiological unit and the seasonal dynamics of growth, reproduction, and death. Gloria Montenegro and co—workers reviewed the phonology, growth dynamics, net productivity, and mortality of shrubs and herbs of the Chilean matorral. Finally, Jochen Kummerow described the functional balance between root and shoot growth in chaparral shrubs and how the balance changes with water stress.

The papers taken together demonstrate new and important areas of research needed to predict more precisely the long—term effects of management on the vegetation of Mediterranean regions. An important topic omitted in much of the literature on Mediterranean—type ecosystems is the demography of shoots on the individual shrub, a domain which links the growth measurements with whole plant demography. The modeling of demographic and physiological concepts should he completed as soon as possible and should add completeness to the understanding of the dynamics and management of Mediterranean—type ecosystems.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Harvesting Chaparral Biomass for Energy—An Environmental Assessment[1]

Philip J. Riggan and Paul H. Dunn[2]

Abstract: Age-class management techniques for the California chaparral are being developed to reduce the incidence and impacts of severe wildfires. With periodic harvesting to maintain mosaics in high productivity areas, chaparral fuels may also provide a locally important source of wood energy. This paper presents estimates for biomass in chaparral; discusses the potential impacts of harvesting on stand productivity, composition, and nutrient relations; and suggests directions for future research.

Management techniques for chaparral are being developed to reduce the incidence and severity of wildfire, minimize the associated flooding and debris production, and enhance watershed resource values. One important technique is the periodic use of harvesting or prescribed fire to maintain a coarse mosaic of different-aged stands of chaparral. These mosaics break up large areas of heavy fuel accumulation and maintain a substantial area of chaparral in a young, productive state. The probability of large, intense wildfires and the accompanying adverse fire effects are reduced because fire spread is considerably retarded in young stands with their low dead fuel volume (Rothermel and Philpot 1973, Philpot 1974, Countryman 1974). Furthermore, harvesting in high productivity areas allows the use of energy accumulated in native fuels and could provide a locally important alternative source of energy.

CHAPARRAL BIOMASS

Considerable amounts of potential energy are present in the biomass of some chaparral communities. Biomass in mature Adenostoma - Ceanothus stands is as high as 50 MT/ha with average accumulation rates of 0.8 to 1.2 MT/ha-yr (table 1). Higher biomass accumulations are found in Quercus dumosa stands on north-facing slopes (fig. 1), where biomass as high as 100 MT/ha has been observed (Lisle Green, pers. commun.). Biomass in mature (age greater than 25 years), north-facing Quercus-dominated chaparral is commonly in the range of. 45 to 60 MT/ha. If the biomass on the higher quality sites is harvested on a rotational basis, a substantial source of energy could result. With an energy content of 5 kcal/gm and biomass of. 50 MT/ha, a 1-ha stand contains the energy equivalent of 182 barrels of oil (assuming 1.38×10^6 kcal/barrel [Zavitkovski 1979]). On this basis, 400 ha (1000 acres) of chaparral has a gross energy equivalent value of $2 million (assuming $30/barrel).

Chaparral harvesting is being considered as a management technique. Systems for the production of chaparral wood fuel products have been proposed, and a transportable wood densification unit is being developed under contract from the California Department of Forestry. This unit will be used for demonstrations using both chaparral biomass and industrial wood wastes to produce a compact product that is suitable as a charcoal substitute or an industrial fuel.

An engineering feasibility study has shown that the cost of harvesting and processing chaparral fuels using existing technology is prohibitive (Riley and others 1980). The market for chaparral fuel products is also limited because other wood wastes are more readily available and few industrial plants can use wood fuels (J. A. Miles, pers. commun.). However, alternative technologies have been proposed, including a mechanical harvester to cut and windrow the chaparral, a cable warder for collection (Miles and Moini 1980), and a compactor for producing a transportable product (Miles, pers. commun.), and these could improve the economics of harvesting. The energy costs of producing a fuel product from chaparral biomass are also favorable, since only 17 percent of the gross energy content is consumed during harvesting and initial processing (Riley and others 1980). If the economics of harvesting are improved and systems for using other wood fuels are developed, opportunities for using chaparral biomass may be realized.

Management of larger hardwood fuels, such as stands of Quercus chrysolepis, could also provide a highly desired source of firewood. Currently, the National forests are able to supply only a small fraction of the firewood demand in southern California. For example, the Mt. Baldy Ranger District, Angeles National Forest, receives about 3000 annual requests for wood permits and issues about 400, while commercial operators market oak firewood at $150 to $300 per cord. A harvesting system designed around such labor-intensive and less technological uses of wood energy could be feasible in southern California.

As research and demonstration of engineering and operational techniques for utilizing chaparral

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-2b, 1981, San Diego, California.

[2]Soil Scientist and Microbiologist, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

Table 1--Biomass accumulations in mature chaparral stands

Location	Species[1]	Biomass	Biomass increment	Age (yrs)	References
		MT/ha[(2)]	MT/ha—yr[(2)]		
1. San Dimas Los Angeles Co.	a. Ccr	37 to 85	1.8 to 4.0	21	Weaver and Riggan, unpubl. data
	b. Af, Ccr	49	1.2	37	Specht 1969
2. Kitchen Creek, San Diego Co.	a. At, Cg	28	0.8	35	Riggan and Lopez 1981
	b. Qd	2.8	2.8	1	
	c. Qd	18.5	0.5	35	
3. Boulder Creek, San Diego Co.	Af, Cg	23	1.0	23	Mooney and others 1977
4. Santa Barbara Co.	Cm	63	2.7	21	Schlesinger and Gill 1980
5. Santa Barbara Co.	As, Af, Cc	30	1.2	25	Debano and Conrad 1978
6. Camp Pendleton, San Diego Co.	Qd	54			Chandler 1955
7. North Mtn. Exp. Area, Riverside Co.	Ar	72			Green 1970

[1]Af.--Adenostoma fasciculatum, Ar--Arctostaphylos spp., As--Adenostoma sparsifolium, Cc--Ceanothus cuneatus, Ccr--C. crassifolius, Cg--C. greggii, Cm--C. megacarpus, Qd--Quercus dumosa.

[2]Divide by 2.25 to obtain tons per acre.

Figure 1--Overview of biomass accumulation and cover in a 5—year—old mixed chaparral stand dominated by Quercus dumosa. The stand is located on a north—facing slope adjacent to the San Dimas Experimental Forest.

biomass continues, concurrent research must address the environmental implications of chaparral harvesting. Conceptually, two modes of harvesting may be envisioned with diverse environmental effects: harvesting with permanent fuel modification and a sustained yield, rotational harvest system in designated energy management areas.

HARVESTING FOR PERMANENT FUEL MODIFICATION

A number of serious resource problems can accompany permanent chaparral fuel modification or type conversion, and these should limit the use of harvesting for this purpose. Fuel type conversion of chaparral to grass can greatly increase rates of erosion and sediment yield, flooding, and watershed nutrient loss.

Erosion from converted areas on steep or unstable slopes can be high. At the San Dimas Experimental Forest, widespread soil slippage during the large storms of 1969 occurred in 16.7 percent of the area on converted hill slopes and 5.5 percent of comparable chaparral areas. Soil slippage was restricted to slopes greater than 60 percent (Rice and Foggin 1971). In the 354—ha

Monroe Canyon, where 17 ha of riparian zone vegetation were removed and 57 ha of hill slopes were converted to grass during 1958–60, flooding and debris production caused massive changes in stream channel geometry, removed eight times more material than from a comparable channel reach in a nearby chaparral watershed, and contributed a large portion of the 296,000 m^3 of debris deposited in the Big Dalton reservoir (Orme and Bailey 1970).

The deep–seated roots of the chaparral contribute considerable stability to steep slopes. Conversion replaces these with a more dense but shallow grass root system, and the shear plane of soil slips often coincides with the lower reaches of this rooting zone. Removing chaparral for fuelbreaks similarly decreases slope stability. The resulting soil slips are a frequent feature of fuelbreaks above steep slopes in the San Gabriel Mountains.

A fuels management program in the National forests of southern California must deal with extensive areas of steep terrain. On the San Dimas Experimental Forest, for example, 86 percent of the hill slopes have a gradient exceeding 55 percent (Bentley 1961). Serious problems with erosion, debris production, and flooding could be expected if widespread type conversion were attempted.

Conversion of chaparral to grassland can lead to long–term changes in watershed nutrient loss because of inherent differences in the nutrient cycling properties of these communities. Type conversions to grass established in 1960 at Bell Canyon in the San Dimas Experimental Forest export eleven times more nitrate–nitrogen in streamwater than do comparable chaparral watersheds (Riggan and Lopez, in press). This could lead to a decline in primary production on the watershed and contribute to the existing nitrate pollution in streams and groundwater of the San Gabriel Valley.

Type conversions to grass, fuelbreaks, and areas of reduced stocking density in the chaparral are also subject to invasion by "flash–fuel" species such as the subshrubs, *Eriogonum fasciculatum* and *Salvia mellifera* (fig. 2). These species produce finely divided, compact fuels; rapidly accumulate dead material; and can establish relatively continuous fuel beds. The *Salvia* also contains high concentrations of volatile organic compounds (Montgomery 1976). With these characteristics, they can burn readily even at young stand ages, severely aggravate fire hazard problems, and require periodic maintenance to prevent elimination of planted grasses.

Figure 2--Incursion of *Eriogonum fasciculatum* on a fuelbreak system north of the San Dimas Experimental Forest.

HARVESTING FOR AGE–CLASS MANAGEMENT

Rotational harvesting in designated energy management areas is consistent with the concept of age–class management and in some chaparral communities, may have few of the problems associated with permanent fuel modification. However, several critical elements must be considered in designing a rotational system.

1. *Productivity must be maintained from one rotation to the next or considerable site degradation could occur*. Natural regeneration must be sufficient to maintain stocking density and stand composition, and nutrients removed in harvested material must be replaced by natural means.

2. *Watershed resource values must be maintained*. No fuel hazards may be created by the harvesting operation or incursion of more highly flammable species, and soil erosion must not increase substantially over natural rates.

3. *Primary production must be sufficiently high to maintain periodic harvesting on the available land base*. The higher the productivity per unit land area, the higher the economic return relative to harvesting costs and the lower the impact on the regional environment.

At present, it is unclear whether these criteria can be satisfied in the different chaparral community types and site conditions. Yet, a number of chaparral species have attributes compatible with periodic harvesting. These include vegetative regeneration from underground lignotubers, rapid growth following disturbance, and associated free–living or symbiotic nitrogen fixation. Harvesting in stands composed of these species is most likely to satisfy the criteria for a successful sustained–yield system. At the same time, harvesting could lead to severe site degradation in some community types and environments.

Chaparral Life History

The life history characteristics of chaparral species reflect a strong adaptation to the periodic occurrence of fire, and these will affect the stand response to harvesting.

A number of important species reproduce from both vegetative structures and seed, including Quercus dumosa, Adenostoma fasciculatum, Ceanothus leucodermis, and Arctostaphylos glandulosa. In stands composed of these species, essentially the same individuals are present before and after a disturbance. They can be expected to regenerate with rapid early growth and maintenance of stocking density, although we have observed some mortality in Adenostoma fasciculatum stands that were found on poor quality sites (Riggan), old when burned, or infected by fungal pathogens while regenerating (Dunn).

Other chaparral species must reproduce from seed stored in the soil, including a number from the genera Ceanothus and Arctostaphylos (such as C. greggii, C. crassifolius, C. megacarpus, and A. glauca). Harvesting these plants can induce epicormic sprouting from remaining stem tissue, but this effect is not reliable.

Most seedling establishment of the dominant chaparral shrubs occurs the first year following fire (Horton and Kraebel 1955). There are important exceptions, such as Quercus dumosa and Cercocarpus betuloides whose establishment is infrequent and probably substantial only in years of high precipitation. The fire-induced germination is probably due to a break in seed dormancy caused by heating (Stone and Juhren 1951, 1953; Hadley 1961). Although heat treatment enhances the germination of seed from several species, not all seed from those species requires treatment. Germination rates of 10 to 20 percent may be expected without heat treatment (Sampson 1944).

Seedling establishment following harvesting is expected to be considerably less than after burning, and greatly reduced stocking density could result. The relatively high densities found after burning may be required to maintain stocking of species that reproduce from seed alone, since seedling mortality from herbivory and water stress can be high in young stands.

If regeneration success is poor, the stand stocking density will remain low and an incursion of grasses or species with easily dispersed seed (such as Salvia mellifera and Eriogonum fasciculatum) could occur. Stands degraded by incursion of these flammable species can propagate wildfires frequently, and if this occurs, a positive feedback may develop with more severe loss of nutrients and production, reductions in stand density, and increasing dominance of the "flash-fuel" species. A single fire in an immature stand of nonsprouting species could cause stand deterioration if sufficient seed for regeneration has not been produced. Arctostaphylos glauca has apparently been eliminated from large areas of the San Dimas Experimental Forest by fires with a frequency of 15 years (J. S. Horton, pers. commun.).

Stand regeneration has been observed on harvested areas at the Kitchen Creek Research Area on the Cleveland National Forest. In mixed chaparral stands at this site, harvesting has elicited a good regeneration response and stocking density has been maintained (table 2). The harvested areas were cleared in June 1979 and resprout regeneration of Quercus dumosa, Adenostoma fasciculatum, and Ceanothus leucodermis was rapid during the first growing season. Epicormic sprouting was also apparent on some individuals of the obligate seeder, Ceanothus greggii, although their vigor was poor. After two growing seasons, approximately one-third of the Ceanothus greggii showed a vigorous growth of epicormic resprouts. Seedlings of Adenostoma fasciculatum, Quercus dumosa, and Ceanothus greggii were also established during the second growing season (table 2), and it is apparent that a change in stand composition may result. The only mature shrubs exhibiting substantial mortality following harvesting were the Ceanothus greggii. However, seedlings of other species, most notably the Quercus and Adenostoma, have been successfully established, and it is likely that some of these will survive in open areas left by the Ceanothus mortality.

Primary Production

Patterns of primary production have important implications for the design of a chaparral harvesting system. They will affect the selection of appropriate species, sites, and rotation intervals for harvesting.

Production in the chaparral is most limited by plant water stress during the summer drought. Evapotranspiration and other losses deplete the soil moisture in mature stands by the end of the summer, regardless of rainfall during the previous season (Miller and Poole 1979). Sustained high rates of production are most likely in areas of higher elevation and annual precipitation, on more mesic north-facing slopes, and slopes with deeper soils, where water is most available.

Annual precipitation increases markedly with elevation. At the San Dimas Experimental Forest, annual precipitation increases from 660 mm/yr at an elevation of 460 m to 965 mm/yr at 1550 m. Over the same elevation gradient, the decline in air temperature is less; mean daily air temperatures decrease with elevation from 10.2° to 6.3° C during January, and actually increase from 22.3° to 23.1° C during Jul., (Reimann 1959). Furthermore, photosynthesis rates of a number of chaparral species are relatively insensitive to changes in temperature (Oechel and others, in press), so differences in production with elevation are expected to correspond roughly to the increase in water availability.

Table 2--Vegetation composition on the chaparral harvesting research area at Kitchen Creek, Cleveland National Forest. Estimates are averages from four, 1 by 75 m belt transects located within the north, 0.5-ha hand-cleared area

	Q. dumosa	A. fasciculatum	C. greggii	Total
	Stocking density (per ha)			
Preharvest composition (34-year-old stand)	1230	2100	7200	10,530
Postharvest (2-year-old stand)				
Resprouts	1230	2000	2270	5,500
Dead	0	100	4930	5,030
Seedlings	1730	400	2530	4,660
Total live	2960	2400	4800	10,160
	Relative composition (percent)			
Preharvest	12	20	68	
Postharvest	29	24	47	

Chaparral communities on north-facing aspects develop larger leaf areas (Krause and Kummerow 1977) and apparently sustain higher rates of production than those on south-facing slopes. These differences result from the lower levels of air temperature, direct solar radiation, evaporative demand, and plant water stress on the north-facing aspect. On south-facing slopes at San Limas, maximum daily air temperatures under the chaparral canopy can be 6° to 12° C higher and evaporation rates 15 percent greater than on north-facing aspects (Miller 1947). In areas of chaparral with relatively high precipitation rates (greater than 650 mm/yr), the north-facing slope can have roughly 30 percent more available water in the soil (Miller 1947). In drier areas, the larger leaf area can actually dry the soil more rapidly on the north-facing aspect (Ng and Miller 1980) while maintaining less severe levels of plant water stress (Krause and Kummerow 1977).

The more mesic sites in the chaparral are frequently dominated by mixed-species stands with a large component of Quercus dumosa (for example, see Krause and Kummerow 1977). This species has a rate of annual carbon uptake per unit leaf tissue that is among the highest measured in the evergreen chaparral species (Oechel and Nustafa 1979). It is also able to maintain relatively high leaf areas per area of crown coverage (Krause and Kummerow 1977). Together these properties give it a relatively high rate of net primary production. Rates of biomass accumulation as high as 2.8 MT/ha have been observed in resprouting stands the first year following burning (Riggan and Lopez 1981). Relatively high rates of biomass accumulation are also apparent in well-stocked stands of some obligate-seeder Ceanothus species. Biomass accumulates at rates as high as 4.0 MT/ha-yr in C. crassifolius stands at the San Dimas Experimental forest (J. K. Weaver and Riggan, unpubl. data) and 2.7 MT/ha-yr in C. megacarpus near Santa Barbara (Schlesinger and Gill 1980) (table 1). However, harvesting in these productive Ceanothus stands could result in serious regeneration problems.

Rates of biomass accumulation may decline in older stands of chaparral as stand nutrients are sequestered in organic material and the stand accumulates a high proportion of respiring woody biomass. If this is true, long-term yield could possibly be improved by harvesting a stand at the culmination of the early period of rapid growth. At present, there is little information to characterize the trends of biomass accumulation during stand development, but biomass is known to accumulate at high rates through age 20 in Ceanothus megacarpus.

Nutrient Cycling

The availability of nitrogen in chaparral soils can limit the growth and production of a number of species, including Adenostoma fasciculatum, Arctostaphylos glandulosa, and several Ceanothus species (Vlamis and others 1954, 1958; Hellmers and others 1955). Phosphorus supply may also be marginal for growth of native shrubs (Kummerow, pers. commun.; Hellmers and others 1955).

harvesting could have a major impact upon the nutrient balance in the chaparral ecosystem by removing large quantities of nutrients in harvested material and interfering with natural processes of nutrient input. Adverse effects upon nutrient availability would limit the production in subsequent rotations and the success of the harvesting system.

The impact of harvesting nutrient losses must be evaluated in relation to the naturally high rates of fire-associated loss. In an ideal harvesting system the community is maintained in a young state with low dead fuel accumulations, and this should lower its susceptibility to wildfire. The reduction of fire-associated losses could be greater than the losses due to harvesting.

Fire-associated nitrogen losses occur by volatilization and subsequent erosion, and these can be considerable. Volatilization losses during moderate-intensity prescribed fires can remove 10 to 25 percent of the stand's nitrogen content, primarily from fine fuels, ground litter, and the upper soil profile (table 3). Nitrogen loss during intense wildfires could be even greater. Harvesting these stands would remove the nitrogen in the standing vegetation but would not remove nutrients in the litter or soil, so a less severe impact on the nutrient balance of the system should result. Nutrient losses from harvesting could also be reduced by allowing the cut chaparral to dry and partially defoliate on site before it is processed. Foliage contains one-third of the nitrogen in the aboveground vegetation (Riggan and Lopez 1981), and this need not be removed.

Fire-associated erosion losses are potentially an even larger path of nitrogen loss. Hill slope sediment yield can increase 200-fold the first year following fire (Unpublished U.S. Forest Service report cited by Wells 1981) as the soil surface is exposed to eroding forces and the structure and infiltration properties of the soil are altered. During chaparral fires, a water repellent layer can form several centimeters below the soil surface when hydrophobic organic compounds distill downward and condense in the soil profile (DeBano 1981). The water repellent soil confines water in the upper wettable layer, with an increase in pore pressure and reduced internal friction. The instability formed can result in soil loss by mass wasting and miniature debris flows that form rills (Wells 1981). Loss of organic matter and alteration of soil clays during burning (Wells 1981) can also reduce soil stability and accelerate erosion.

Extremely high rates of erosion loss are possible. For example, losses of 210 m^3/ha (2.1 cm of soil) and 830 m^3/ha (8.3 cm of soil) have been estimated for the Sweetwater River watershed in San Diego County and the Little Dalton Canyon watershed at the San Dimas Experimental Forest, respectively (Rowe and others 1949). If this material originates from surface soils, 830 m^3/ha of sediment would carry with it approximately 2500 kg of nitrogen per ha (assuming 0.2 percent nitrogen), and cause a catastrophic change in site nitrogen.

Hill slope erosion losses following harvesting are expected to be considerably less than those associated with wildfire if harvesting equipment does not disturb the soil surface. Harvesting would temporarily remove the protective cover of the vegetation canopy, but the severe water repellency and changes in soil structure associated with intense heating would not occur. A relatively protective litter layer would also remain in stands of Quercus dumosa.

It appears that nutrient losses from harvesting are considerably less than those associated with burning at a comparable frequency. However, harvesting could take place on a rotation interval that is less than the frequency of fire, if short rotations are used to optimize long-term production and yield. By contrast, wildfires generally occur in older stands with larger accumulations of dead fuel. Increasing the frequency of harvesting also increases the export of nutrients, and a point is reached where benefits from maintaining the stand in a young, productive state are outweighed by a decline in productivity from nutrient loss.

Table 3--Comparison of nitrogen distributions and losses from fire-associated volatilization and biomass harvesting in contrasting chaparral types. Estimates are for 25-year-old Adenostoma-dominated chaparral in the Los Padres National Forest northeast of Santa Maria, California (DeBano and Conrad 1978) and 35-year-old Quercus dumosa-dominated chaparral in the Cleveland National Forest at Kitchen Creek (Riggan and Lopez 1981). Harvesting is assumed to remove the aboveground plant only. Erosion losses are not considered.

	Adenostoma chaparral			Quercus dumosa chaparral		
	Distribution	Losses from volatilization	Harvesting	Distribution	Losses from volatilization	Harvesting
Aboveground vegetation	134	161	134	88	61	8
		+8			+317	
Litter	147	109	-	382	378	-
Soil (0 to 10 cm)	1140	36	-	1586	138	-
Total	1426	145	134	2056	516	88

The mechanisms of nitrogen input and processes that affect nitrogen availability must also be considered in the design of a harvesting system. Harvesting may interfere with natural nitrogen replacement in some chaparral communities, and the behavior of these processes will affect the allowable frequency of harvesting and location of energy management areas.

Nitrogen enters the system in precipitation and dryfall, and by N_2 fixation associated with postfire legumes, free-living microbes, and symbiotic associations with members of the genera *Ceanothus* and *Cercocarpus.* Precipitation inputs are low, generally less than 8.0 kg/ha-yr (Liljestrand and Morgan 1978), and are generally unaffected by management.

Legumes of the genera *Lupinus* and *Lotus* are common components of the profuse annual and perennial flora found after chaparral fires. They are relatively short-lived and are host to symbiotic fixation with rates in the range of 3 to 40 kg/ha-yr (Dunn and Poth 1979; Poth, pers. commun.). Higher rates of N_2 fixation may be associated with members of the genera *Ceanothus* and *Cercocarpus*. Studies in the greenhouse and under mesic field conditions have shown that substantial rates of fixation can occur (Hellmers and Kelleher 1959, Vlamis and others 1958, Youngberg and Wollum 1976). However, estimates of N_2 fixation by *Ceanothus* in southern California chaparral are uncertain. Annual nitrogen accretion over 13 years in developing *Ceanothus crassifolius* was estimated to be 49 kg/ha-yr (Zinke 1969), but process study estimates in mature stands and 1-year-old seedlings have shown only low rates (Kummerow and others 1978; Dunn and Poth, pers. commun.). Substantial rates of N_2 fixation have been measured in 4-year-old *Ceanothus crassifolius* seedlings at San Dimas (Dunn and Poth, pers. commun.), and this suggests that N_2 fixation may be restricted to established young stands.

Dinitrogen fixation by free-living microbes may also be important in chaparral soils, although process studies have yet to show sustained fixation by this mechanism in the field. Lysimeter studies at San Dimas have shown that the annual nitrogen accretion over 13 years associated with *Quercus dumosa,* 38 kg/ha-yr, and *Eriogonum fasciculatum,* 32 kg/ha-yr, can be substantial. Over the same period, lysimeters kept free of vegetation lost nitrogen at an average of 26 kg/ha-yr (Zinke 1969).

If periodic harvesting reduces the occurrence of fire on a site, the establishment of postfire legumes would be precluded and the establishment of *Ceanothus* seedlings could be greatly reduced. A considerable impairment of N_2 fixation in the stand could result.

Dinitrogen fixation will affect the suitability of stands for harvesting and the stand response to different rotation intervals. Stands with more mesic environments and those comprised of resprouting *Ceanothus* or *Quercus* species are expected to have relatively high rates of nitrogen replacement. Dinitrogen fixation rates may be highest when these are relatively young, declining as they mature and senesce. If so, harvesting with a short rotation interval would maintain the stand in a state with high N_2 fixation rates, and increase long-term nitrogen accretion. Periodic harvesting could also result in more favorable soil-water conditions, warmer soil temperatures during the spring, and a favorable carbohydrate balance in resprouting individuals. Each of these effects would be conducive to N_2 fixation and could counter the loss of nitrogen in harvested biomass.

Land Area Requirements

If the development of chaparral harvesting as a source of renewable wood energy is to provide a significant amount of the energy needed by California, the area of land managed for this purpose must be large. Approximately 1000 mi^2 of relatively high-productivity chaparral would be required to supply the residential energy requirements for a city the size of Pasadena, California.[3] The size of this undertaking would greatly magnify the impacts of harvesting. Other considerations such as visual impacts and erosion from roads and equipment landings would have to be assessed for any specific operational program, and these might limit its scope and practicality.

RESEARCH NEEDS

A number of important research problems should be addressed concurrently with the development and demonstration of chaparral harvesting.

1. *Adverse impacts of harvesting may limit production in subsequent rotations or create other resource management problems.* Research is needed to determine the following for major chaparral community types: (a) the probability of site

---

[3]Estimated as follows:
Residential energy use in the City of Pasadena (1980 population of 119,000, 50,000 residences, 4700 kwh/yr average use) is 2.35×10^8 kwh/yr (City of Pasadena, Water and Power Department, 1980 Annual Report). With reference to a 3.3×10^8 kwh/yr, hybrid geothermal-wood energy powerplant using 75 percent wood energy and 2.3×10^5 MT/yr (U.S. Dep. Agric., Forest Serv. 1978), expected energy yield from biomass is 1.1×10^3 kwh/MT, and an annual harvest of 2.1×10^5 MT is required. Assuming chaparral with 50 MT/ha, and harvesting on one-third the land area with a 20-year rotation interval, the necessary sustained yield of wood energy would require a land area of 2.5×10^5 ha or 1000 mi^2. Eight percent of the managed chaparral would be less than 5 years of age at any time.

degradation from incursion of highly flammable species, such as sage or buckwheat; (b) the magnitude of nutrient loss in harvested material and interference with nitrogen fixation; (c) loss of stocking density due to poor seedling regeneration; and (d) the magnitude of erosion losses due to soil disturbance by equipment.

2. Existing biomass accumulations and rates of net primary production are not well known, nor are there good inventory methods or predictive models available. Research is needed to (a) estimate rates of biomass accumulation in major community types and identify the most productive sites, (b) estimate the rates of biomass accumulation during stand development, and (c) develop predictive models from which guidelines could be made for selection of energy management locations.

3. Research is needed to determine the effects of short rotation intervals on stand production, regeneration, and nitrogen balance. The patterns of nitrogen replacement, seed production, and stand susceptibility to fire during stand development should be identified.

SUMMARY

The characteristic life histories, patterns of primary production, and nutrient cycling in a chaparral community will determine its response to harvesting. A number of *Quercus* and *Ceanothus* species such as *Q. dumosa*, *Q. chrysolepis*, *Q. wislizenii*, and *C. leucodermis* may have attributes compatible with periodic harvesting. These include vegetative regeneration from lignotubers or burls, rapid growth following disturbance, and associated free-living or symbiotic nitrogen fixation. Several of the *Ceanothus* species which reproduce from seed alone (e.g., *C. crassifolius* and *C. megacarpus*) have relatively high rates of biomass accumulation and may support symbiotic N_2 fixation, but these are probably not compatible with harvesting because of poor regeneration success in the absence of fire. Stands of *Adenostoma fasciculatum* generally have lower rates of biomass production and nitrogen input, and could be degraded by periodic harvesting.

Serious site degradation could result from periodic harvesting if stand stocking density is not maintained. Open stands are subject to incursion of "flash-fuel" subshrubs and grasses that could propagate fires frequently. This would accelerate nutrient and soil losses and further reduce stocking density and productivity. Similarly, burning through any residual harvesting slash could seriously degrade the stand.

Chaparral age-class management employing harvesting on selected sites could reduce the incidence of severe wildfires and the associated erosion. The reduction of fire-associated nutrient losses may be greater than the loss of nutrients in harvested biomass.

LITERATURE CITED

Bentley, J. R. Fitting brush conversion to San Gabriel watersheds. Misc. Paper PSW-61. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1961. 8 p.

Chandler, C. C. The classification of forest fuels for wildland fire control purposes. Berkeley, CA: Univ. of California; 1955. 91 p. M.S. Thesis.

Countryman, C. M. Can southern California wildland conflagrations be stopped? Gen. Tech. Rep. PSW-7. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1974. 11 p.

DeBano, L. F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

DeBano, L. F. Water repellent soils: a state-of-the-art. Gen. Tech. Rep. PSW-46. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 21 p.

Dunn, P. H.; Poth, M. Nitrogen replacement after fire in chaparral. Proceedings of the symposium on symbiotic nitrogen fixation in the management of temperate forests; April 2-5, 1979; Corvallis, OR. Corvallis, OR: Oregon State Univ.; 1979; 287-293.

Green, L. R. An experimental prescribed burn to reduce fuel hazard in chaparral. Res. Note PSW-216. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1970. 6 p.

Hadley, E. B. Influence of temperature and other factors on *Ceanothus megacarpus* seed germination. Madrono 16:132-138; 1961.

Hellmers, H.; Bonner, J. F.; Kelleher, J. M. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80:189-197; 1955.

Hellmers, H.; Kelleher, J. M. *Ceanothus leucodermis* and soil nitrogen in southern California Mountains. For. Sci. 5(3):275-278; 1959.

Horton, J. S.; Kraebel, C. J. Development of vegetation after fire in the chamise chaparral of southern California. Ecology 36(2):244-261; 1955.

Krause, D.; Kummerow, J. Xeromorphic structure and soil moisture in the chaparral. Ecol. Plant. 12(2):133-148; 1977.

Kummerow, J.; Alexander, J. V.; Neel, J. W.; Fishbeck, K. Symbiotic nitrogen fixation in *Ceanothus* roots. Amer. J. Bot. 65(1):63-69; 1978.

Liljestrand, H. M.; Morgan, J. J. Chemical composition of acid precipitation in Pasadena, California. Environ. Sci. and Tech. 12:1271-1273; 1978.

Miles, J. A.; Moini, S. An approach to harvesting chaparral for energy. Paper presented at the Amer. Soc. of Agric. Eng., Pacific Region annual meeting; March 18-20, 1980; Hilo, Hawaii. 1980. 11 p.

Miller, E. H., Jr. Growth and environmental conditions in southern California chaparral. Amer. Midi. Nat. 37:379-420; 1947.

Miller, P. C.; Poole, D. K. Patterns of water use by shrubs in southern California. For. Sci. 25:84-98; 1979.

Montgomery, K. Ether extractives and flammability of Mediterranean-type shrubs. Pomona, CA: California State Polytechnic Univ.; 1976. 38 p. M.S. Thesis.

Mooney, H. A.; Kummerow, J.; Johnson, A. W.; and others. The producers--their resources and adaptive responses. In: Mooney, H. A., ed. Convergent evolution in Chile and California Mediterranean climate ecosystems. Stroudsburg, PA: Dowden, Hutchinson and Ross; 1977:85-143.

Ng, E.; Miller, P. C. Soil moisture relations in the southern California chaparral. Ecology 61(1):98-107; 1980.

0echel, W. C.; Lawrence, W. T.; Mustafa, J.; Martinez, J. Energy and carbon acquisition. In: Miller, P. C., ed. Resource use by chaparral and matorral: a comparison of vegetation function in two Mediterranean-type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag; [in press] 1981.

0echel, W. C.; Mustafa, J. Energy utilization and carbon metabolism in Mediterranean scrub vegetation of Chile and California. II. The relationship between photosynthesis and cover in chaparral evergreen shrubs. 0ecologia 41:305-315; 1979.

Orme, A. R.; Bailey, R. G. The effect of vegetation conversion and flood discharge on stream channel geometry: the case of southern California watersheds. Proc. Assoc. Amer. Geog. 2:101-106; 1970.

Philpot, C. W. The changing role of fire on chaparral lands. Proceedings of the symposium on living with the chaparral; March 30-31, 1973; Univ. of California, Riverside. Sierra Club Spec. Publ.; 1974; 131-150.

Reimann, L. F. Mountain temperatures. Data from the San Dimas Experimental Forest. Misc. Paper 36. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1959. 33 p.

Rice, R. M.; Foggin, G. T. III. Effects of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resour. Res. 7(6):1485-1496; 1971.

Riggan, P. J.; Lopez, E. Nitrogen cycling in the chaparral ecosystem. Proceedings of the symposium on the classification and distribution of chaparral ecosystems; December 28-29, 1979; Pomona, CA: Calif. State Polytechnic Univ. [in press].

Riggan, P. J.; Lopez, E. Nitrogen relations in a *Quercus dumosa* chaparral community. Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems; June 22-26, 1981; San Diego, CA.

Riley, J. G., Moini, S.; Miles, J. A. An engineering study of the harvesting and densification of chaparral for fuel. Report to the Resources Agency of California, Department of Forestry, Sacramento, CA. Davis, CA: Univ. of California; 1980. 91 p.

Rothermel, R. C.; Philpot, C. W. Predicting changes in chaparral flammability. J. For. 71:640-643; 1973.

Rowe, P. B.; Countryman, C. M.; Storey, H. C. Probable peak discharges and erosion rates from southern California watersheds as influenced by fire. 1949. Unpublished report, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Sampson, A. W. Plant succession on burned chaparral lands in northern California. Bull. 685. Berkeley, CA: Univ. of Calif. Agric. Exp. Stn.; 1944. 144 p.

Schlesinger, W. H.; Gill, D. S. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, *Ceanothus megacarpus* after fire. Ecology 61(4):781-789; 1980.

Specht, R. L. A comparison of the sclerophyllous vegetation characteristic of Mediterranean type climates. II. Dry matter, energy, and nutrient accumulation. Aust. J. Bot. 17(2):293-308; 1969.

Stone, E. C.; Juhren, G. The effect of fire on the germination of the seed of *Rhus ovata* Wats. Amer. J. Bot. 38:368-372; 1951.

Stone, E. C.; Juhren, G. Fire stimulated germination. Calif. Agric. 7:13-14; 1953.

U.S. Department of Agriculture, Forest Service. Hybrid geothermal - wood powerplant proposal. California Region. 1978. Unpublished report.

Vlamis, J.; Stone, E. C.; Young, C. L. Nutrient status of brushland soils in southern California. Soil Sci. 78:51-55; 1954.

Vlamis, J.; Schultz, A. M.; Biswell, H. H. Nitrogen fixation by deerbrush. Calif. Agric. 12(1): 11, 15; 1958.

Wells, W. G. II. Some effects of brushfires on erosion processes in coastal southern California. Proceedings of the symposium on erosion and sediment transport in Pacific Rim steeplands; January 26-30, 1981; Christchurch, N.Z.; Publ. 132. International Association of Hydrological Sciences; 1981; 305-342.

Youngberg, C. T.; Wollum, A. G. Nitrogen accretion in developing *Ceanothus velutinus* stands. Soil Sci. Soc. Am. J. 40:109-112; 1976.

Zavitkovski, J. Energy production in irrigated, intensively cultured plantations of Populus 'Tristis #1' and Jack Pine. For. Sci. 25(3):383-392; 1979.

Zinke, P. J. Nitrogen storage of several California forest soil-vegetation systems. *In*: Biology and ecology of nitrogen. Washington, DC: Nat. Acad. Sci.; 1969:40-53.

Carbon Balance Studies in Chaparral Shrubs: Implications for Biomass Production[1]

Walter C. Oechel[2]

Abstract: Photosynthesis and respiration rates were determined for chaparral shrubs as a function of temperature and/or light intensity. In mature stands at Echo Valley, Calif., net seasonal carbon assimilation by leaves ranges from a dry weight equivalent of 673 g m^{-2} $^{-1}$ in pure stands of *Rhus ovata* to 1439 g m^{-2} y^{-1} in *Arctostaphylos glauca*. Net accumulation of dry matter ranges from 261 g m^{-2} y^{-1} for R. *ovata* to 525 g m^{-2} y^{-1} for *A. glauca*. Stem respiration utilizes about 30 percent of the assimilated carbon; total respiration accounts for about 60 percent of the carbon assimilated. This data and growth models are used to calculate optimal harvest intervals and productivity of shrubs.

There is considerable energy available for harvesting in chaparral biomass. Each year, on the average, about 3 percent of California's 3.3 million hectares of chaparral burns. Using values from Riggan and Dunn (*In press*), at an average biomass of 50 m tons per hectare this 100,000 hectares burned represents the gross energy equivalent of 18.2 x 10^6 barrels of oil or 546 million dollars at current oil prices. This is roughly the energy equivalent of 2 Hoover Dams or 1/2 of the on shore oil production of the central California coast (2 X 10^{13} kcal of renewable energy, McCartor 1976).

The magnitude of the energy available means that it is possible that chaparral will be utilized as an energy source at some point in the near future.

If chaparral is to be used as an energy source, there are several major management problems to consider including the environmental effects of harvesting and how to mitigate them and the best way to maximize yield on a sustained basis. Mooney (*In press*) noted the major biological factors which must be considered in making management decisions. These included life history attributes, fluxes of minerals and environmental responses of species. This paper will consider the contribution that carbon balance research can make to the last two of these areas as input to management considerations.

The controls on net carbon uptake is of obvious importance in evaluating the potential for biomass harvesting in chaparral and in evaluating optimal harvesting patterns to maximize long term production while minimizing flammability. This paper will consider the intrinsic and extrinsic controls on photosynthesis and respiration in chaparral plants and the implication of carbon allocation patterns, nutrients, moisture, temperature and stand age on net production of chaparral stands in southern California.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean—type Ecosystems, June 22—26, 1981. San Diego, California.

[2]Research Professor, Systems Ecology Research Group, San Diego State University, San Diego, Calif., 92182.

This paper will not make major management recommendations, but will present information upon which management decisions can be based and which will suggest areas for further research.

Controls on Net Photosynthesis

Potential net photosynthesis

Maximum photosynthetic rates in evergreen chaparral shrubs vary by species. This means that stand productivity may vary with species composition according to the realized patterns of net photosynthesis. In one study, measured maximum photosynthetic rtes varied from 7.6 mg CO_2 g^{-1} dry wt h^{-1} for *Ceanothus leucodermis* to 1.1 mg CO_2 g $^{-1}$ dry wt h^{-1} for *Rhus ovata* (table 1). Photosynthesis decreased in the order: *C. leucodermis* > *Cercocarpus betuloides* > *Arctostaphylos glauca* > *Quercus dumosa* > *Adenostoma fasciculatum* > *Ceanothus verrucosus* > *Rhus integrefolia* > *R. ovata*. Because of differences in leaf density thickness, the pattern on a surface area basis may be quite different. These maximum observed rates are further modified by site and environmental factors to yield an observed annual value.

Photosynthesis varies seasonally, by elevation, and by slope. The seasonal total photosynthetic uptake correlates strongly with the cover produced by various evergreen shrub species in the chaparral. Species with higher seasonal photosynthetic uptake rates tend to have higher observed cover in the chaparral. Competitive advantage is therefore correlated to photosynthetic ability (0echel and Mustafa 1979).

Temperature

Temperature appears to exert little limitation on net photosynthesis over normally experienced ranges of temperature (Figs. 1 and 2). The average Californian shrub or the average Chilean shrub shows relatively high photosynthesis rates at 5°C and at 40°C. For Californian species the average photosynthetic rate at 40°C is greater

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--Maximum photosynthesis rates in May and June determined by $^{14}CO_2$ and infrared gas analysis (IRGA) techniques and leaf density-thickness for chaparral species in San Diego County (modified from Oechel *et al.* *In press*).

Growth form and species	Elevation (m)	Sampling date (Day/Mo/Yr)	Leaf density-thickness (g dry wt dm^{-2})	Maximum photosynthesis rates ($mg\ CO_2\ g^{-1}$ dry wt h^{-1})	($mg\ CO_2\ dm^{-2}\ h^{-1}$)	
				$^{14}CO_2$		IRGA
Evergreen sclerophyllous shrubs						
Adenostoma fasciculatum						
Equator-facing slope	1000	03/06/76	1.17	3.6	4.3	
Equator-facing slope	1000	17/05-01/06/76				6.6
Pole-facing slope	1000	05/06/76	1.17	3.0	3.5	
Arctostaphylos glauca						
Equator-facing slope	1000	03/06/76	2.08	4.1	9.0	
Equator-facing slope	1000	03-14/06/76				10.5
Pole-facing slope	1000	05/06/76	2.18	3.5	7.6	
Ceanothus greggii						
Equator-facing slope	1000	03/06/76	3.13	3.3	10.4	
Equator-facing slope	1000	16-20/06/76				7.6
Ceanothus leucodermis	1000	05/06/76	0.94	7.6	7.2	
Ceanothus verrucosus	120	12/06/76	3.13	2.6	8.3	
Cercocarpus betuloides	1150	10/06/76	1.56	4.3	6.8	
Quercus dumosa	1000	05/06/76	1.56	4.0	6.2	
Rhus integrifolia	85	12/06/76	3.13	1.4	4.3	
Rhus ovata						
Equator-facing slope	1000	03/06/76	3.13	1.1	3.5	
Equator-facing slope	1000	22-27/06/76				4.7
Mean				3.5	6.5	7.4

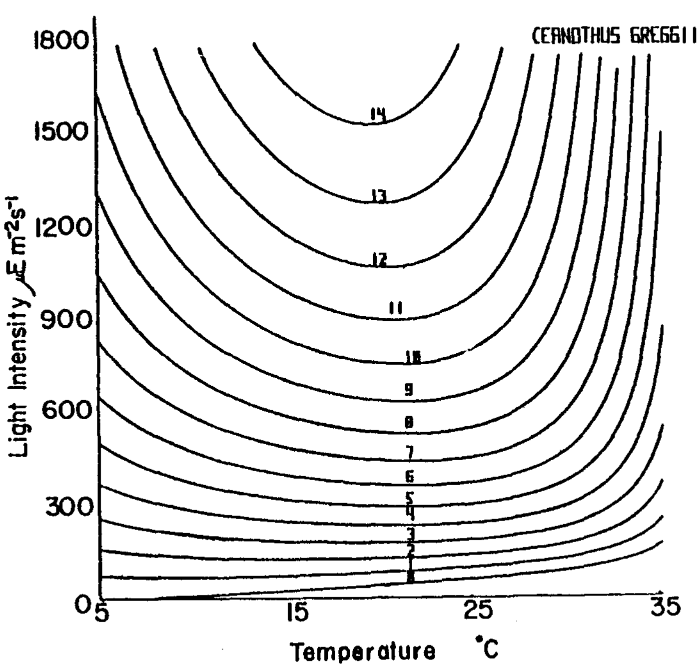


Figure 1--Isopleths of photosynthetic rates with respect to temperature and light intensity for *Ceanothus greggii* growing at Echo Valley, California in May 1976. Rates predicted with nonlinear regression analysis using a Michaelis-Menton form for the light response. From Oechel, Lowell, and Jarrell (*In press*).

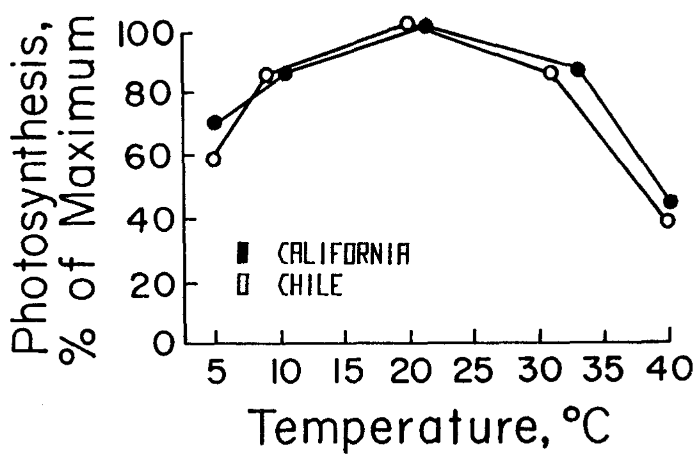


Figure 2--Average photosynthetic response of four chaparral species (●): *Ceanothus greggii*, *Arctostaphylos glauca*, *Adenostoma fasciculatum*, and *Rhus ovata*; and four matorral species (○): *Trevoa trinervis*, *Colliguaya odorifera*, *Satureja gilliesii*, and *Lithraea caustica* to temperature at saturating light (1,401-1,800 µE m-2 s-1). From Oechel *et al.* (*In press*).

than 45 percent of the maximum rate (fig. 2). Low winter temperatures would seldom suppress photosynthesis. At 5°C the photosynthetic rate is still about 70 percent of the maximum rate. This implies that substantial increases or decreases in annual mean temperature which could be caused by differences in elevation or latitude would have little effect on net photosynthesis. Simulations confirmed this showing that an increase or decrease in mean annual temperature would have less than a 10 percent effect on photosynthetic uptake over the course of the season (fig. 3). Temperature is therefore unlikely to limit production in chaparral over much of range of chaparral in southern California.

Light

Light levels may have a major influence on photosynthesis rates and productivity. At optimal temperature, light levels below full sunlight may limit photosynthesis of intact branches with naturally oriented leaves (e.g. see fig. 1). Therefore, even at full solar radiation levels, light may limit photosynthetic rate within the canopy, especially at higher leaf area indicies.

Periods of reduced radiation, whether due to time of day and/or cloud cover, will reduce productivity. The short photoperiods in winter, which often occur when ample moisture is available for photosynthesis and when temperature allows appreciable photosynthetic rates, may result in marked limitation in photosynthesis below that potentially possible.

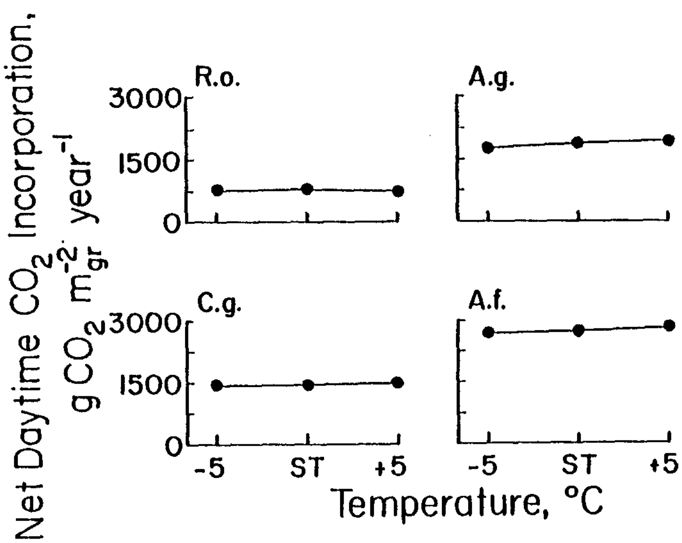


Figure 3--The effects on simulated seasonal (daytime) photosynthesis incorporated in grams CO_2 per square meter of ground per year of an increase or decrease in temperature of 5°C from observed standard temperatures (ST) in 1973-1974 in Rhus ovata (R.o.), Arctostaphylos glauca (A.g.), Ceanothus greggii (C.g.), and Adenostoma fasciculatum (A.f.) with a leaf area index of 1 and a stem area index of 0.9. From Oechel et al. (In press).

Moisture

As water potential decreases, plant moisture stress has a major effect on photosynthetic rate through its effect on stomatal conductance. Arctostaphylos glauca, decreases from a maximum daily uptake rate of 33 mg CO_2 $^{-1}$ dry wt d^{-1} at -0.5 MPa bars dawn water potential to 7 mg CO_2 g^{-1} dry wt d^{-1} at -3.5 MPa bars dawn water potential (fig. 4). Adenostoma fasciculatum shows a somewhat less rapid decline in daily photosynthetic rate with decreasing maximum water potential. In both cases, zero daily carbon uptake is projected to occur at about -4 to -4.5 MPa.

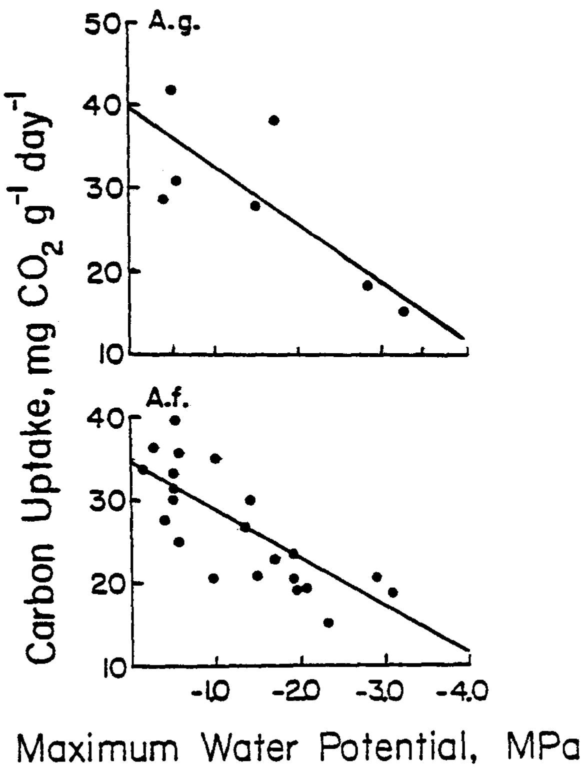


Figure 4--Relationship between maximum (dawn) water potential and seasonal daily carbon uptake of Arctostaphylos glauca (A.g.) and Adenostoma fasciculatum (A.f.) in San Diego County, California. From Oechel et al. (In press).

Species vary with respect to the limitation of carbon uptake by summer drought. For example, compared to spring (May) values, Adenostoma fasciculatum, Quercus dumosa, and Cercocarpus betuloides may show less than 40 percent depression in carbon uptake by late summer (August) (fig. 5). Other evergreen species including Rhus ovata, Rhus integrifolia, Ceanothus greggii, and Ceanothus verrucosus may show greater than 60 percent depression in photosynthesis during the summer. Species which show the greatest suppression in photosynthesis may not necessarily be those experiencing the greatest water stress. This is especially true in the case of Rhus ovata and Rhus integrifolia which reduce stomata] conductances at relatively high water potentials (Poole and Miller 1975),

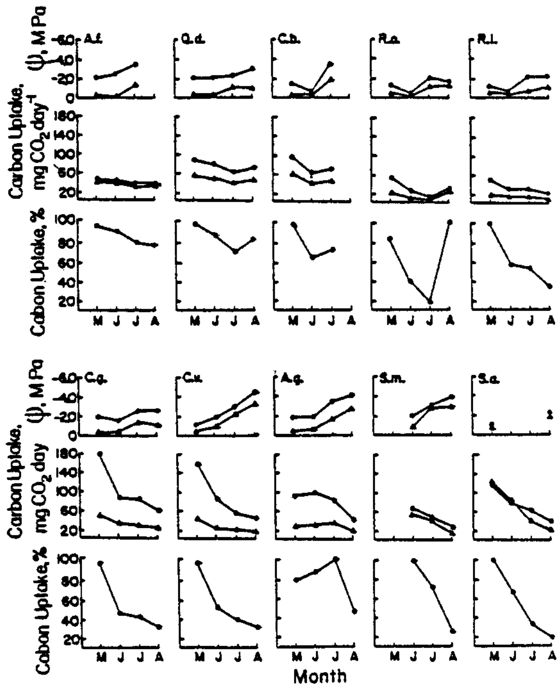


Figure 5--Seasonal patterns of dawn (▲) and midday (●) water potentials in MPa, carbon uptake in milli-grams of CO_2 per day per gram dry weight of leaf (▲) and per square decimeter of leaf (●), and the relative carbon uptake as a percent of the maximum monthly rate for Adenostoma fasciculatum (A.f.), Quercus dumosa (Q.d.), Cercocarpus betuloides (C.b.), Rhus ovata (R.o.), Rhus integrifolia (R.i.), Ceanothus greggii (C.g.), Ceanothus verrucosus (C.v.), Arctostaphylos glauca (A.g.), Salvia mellifera (S.m.), and Salvia apiana (S.a.).

and which experience marked depression in photosynthesis at midday water potentials of -2.0 MPa. Adenostoma fasciculatum and Quercus dumosa on the other hand, maintain substantial photosynthetic rates at midday water potentials of -3.5 to -4.0 MPa. As a result, both the site moisture status and the species specific photosynthesis vs. plant water potential relationships must be considered when predicting site carbon balance.

Nutrients

Nutrient responses of photosynthesis yield conflicting results. While production of chaparral species is stimulated by nitrogen fertilization (Kummerow pers. cow.), laboratory studies may indicate an inverse relationship between treatment nitrogen levels and photosynthetic rate (0echel, Lowell, and Jarrel In press). Despite this reduction in photosynthetic rate with increasing nitrogen, whole plant carbon balance and growth increase with increasing nitrogen treatment. This indicates a negative correlation between photosynthetic rate and growth rate in this situation.

However, marked increases in photosynthetic rates following fire indicate a nutrient limitation of photosynthesis in the field (0echel and Hastings In press). Following a fire, young plants tend to have higher photosynthetic rates than do mature species. These rates may be up to 500 percent higher in Adenostoma fasciculatum burn resprouts than in the mature vegetation (0echel and Hastings In press). Interestingly this elevation of photosynthetic rate does not appear to be primarily due to an increase in available moisture (fig. 6). Resprouts of A. fasciculatum following hand-clearing showed little increase in photosynthetic rate. The conclusion is that the nutrients released following fire produce the elevated photosynthetic rates.

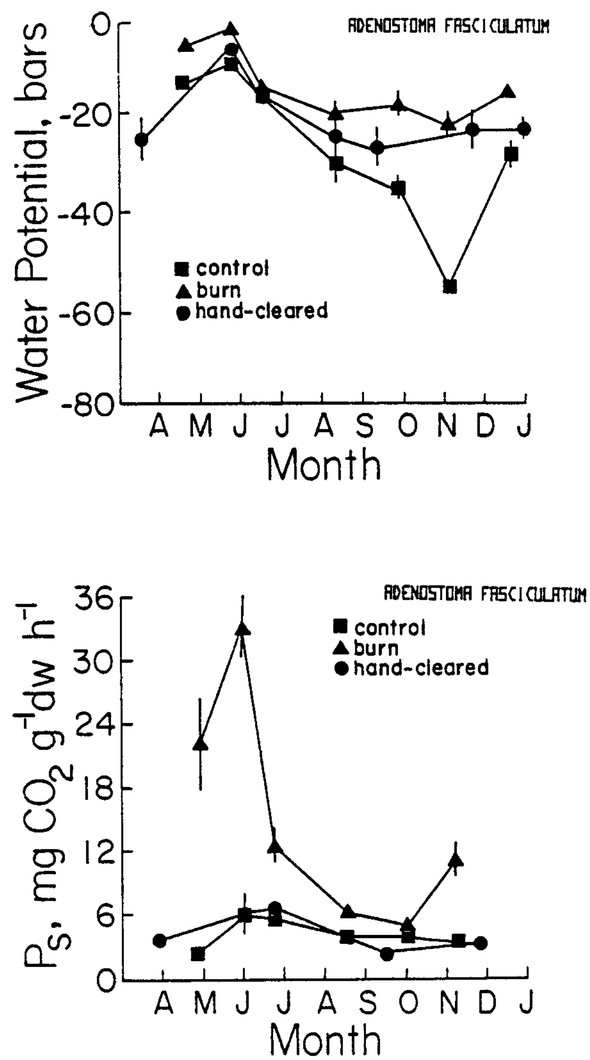


Figure 6--Photosynthesis rates and tissue water potential in 1980 in mature (34 year old) Adenostoma fasciculatum control plants and in resprouts following hand clearing in June 1979 and burning in November 1979.

Water relations and photosynthetic rates following biomass harvesting

Harvesting immediately reduces leaf area index which generally takes several years to restore its original area. As a result, water potentials in plants are elevated in resprouts for at least 20 months following harvesting. For example, plants were harvested from plots between 30 May and 13 June 1979. Near the end of the drought in October 1980, midday, water potentials for Adenostoma fasciculatum averaged -5.7 MPa in mature vegetation versus -2.9 MPa in resprouts (fig. 6). Arctostaphylos glandulosa resprouts and Quercus dumosa resprouts showed similarly elevated water potentials in the resprouts (Hastings and Oechel In press, Oechel and Hastings In press) (fig. 7). This elevated water potential allows increased leaf conductances and, for some species, increased photosynthetic rates. Leaf conductances are systematically elevated in the resprouts compared to the mature vegetation. In October, mature vegetation and resprouts showed conductances in A. fasciculatum of .12 and .26 cm s^{-1}, the rates were .22 and 0.38 cm s^{-1} for A. glandulosa and in Q. dumosa conductances were 0.51 and 1.37 for mature vegetation and resprouts respectively. At almost all measurement periods, resprouts of Quercus dumosa had equivalent or higher conductances than mature vegetation (fig. 7). For Quercus dumosa, this elevated water status apparently resulted in an increase in the photosynthetic rate of resprouts compared to mature vegetation. The elevation in photosynthetic rate on resprouts of Quercus dumosa is appreciable, with the photosynthetic rates in June in mature plants being 4.3 mg CO_2 g^{-1} dry wt. h^{-1} versus 6.6 for the resprouts. In October, the photosynthetic rate of mature vegetation is 2.8 while the resprout are 230 percent higher at 6.5 mg. CO_2 g^{-1} dry wt. h^{-1}. As discussed earlier, A. fasciculatum shows only a marginal increase in photosynthetic rates, in hand—cleared resprouts compared to burn resprouts. Arctostaphylos glandulosa resprouts following hand clearing initially show a higher photosynthetic rate but by August, 9 months after harvesting the rates are only marginally higher (Oechel and Hastings, unpublished data). Since resprouts following hand—clearing do not show the marked increases in photosynthetic rate generally shown by post—fire resprouts it appears that nutrient release associates with fire is more important than improved moisture status following fire in elevating resprout photosynthetic rates. This difference between photosynthesis rates in resprouts following burning and hand—clearing makes it difficult to predict regrowth rates following biomass harvesting from regrowth rates following fire. While data for growth rates following fire is limited, regrowth rates following harvesting is more limited and extrapolations from fire resprouts is tenuous.

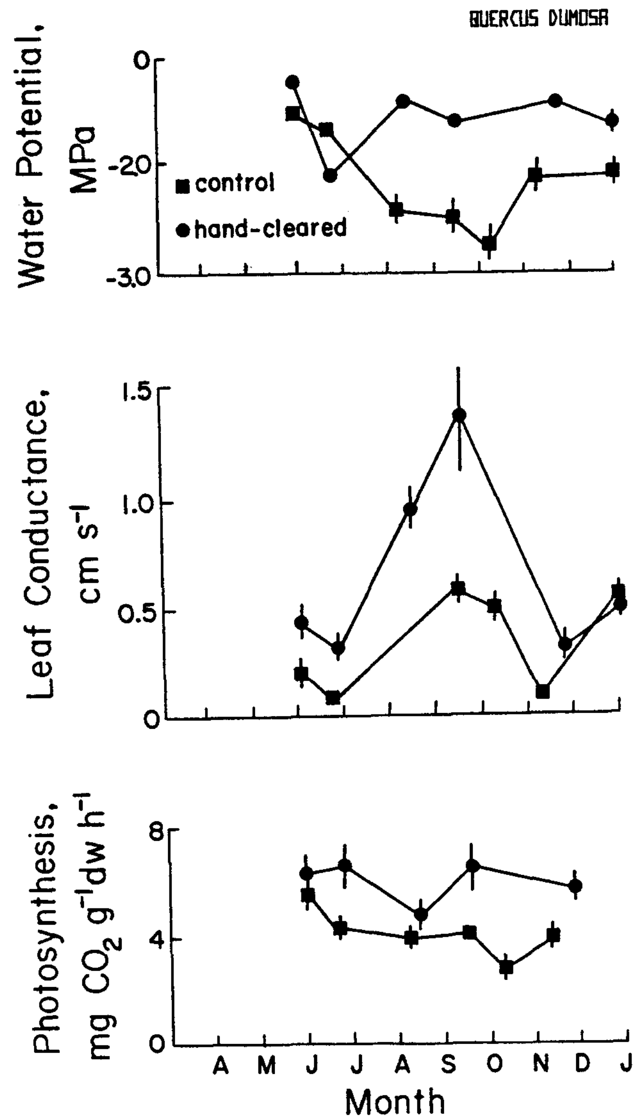


Figure 7--Photosynthesis rates, leaf conductance, and tissue water potential in 1980 in mature (34 year old) Quercus dumosa and in Q. dumosa resprouts following harvesting in June 1979.

Controls on Net Carbon balance and Biomass Accumulation

Net productivity depends on net photosynthesis, respiration and carbon allocation patterns. Respiration rates for stems is fairly low on a dry weight basis, the rates being less than 0.8 mg g^{-1} dry wt. h^{-1} in stems larger than 6 mm in diameter. However stem diameter effects respiration rate on a dry weight basis with decreasing diameter below 6 mm, respiration rapidly increases on a dry weight basis (fig. 8).

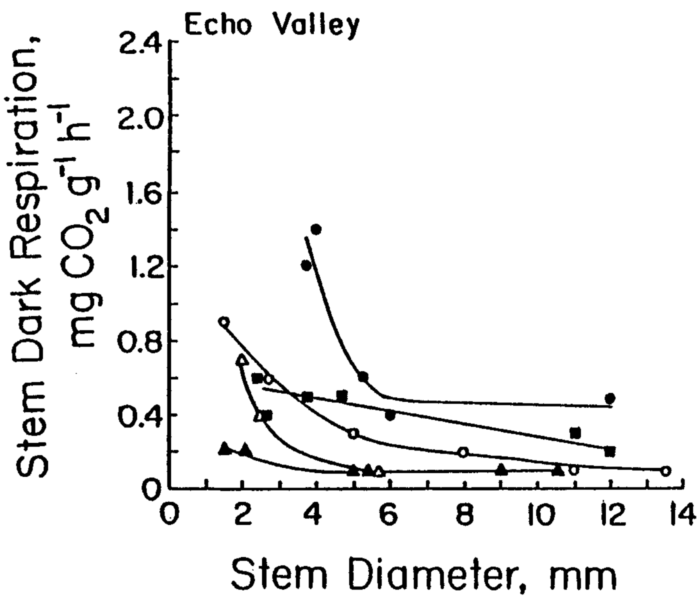


Figure 8--Relationship between stem diameter and stem dark respiration rate at 25°C for: Arctostaphylos glauca (●), Quercus dumosa (■) Rhus ovata (△), Ceanothus greggii (○), and Adenostoma fasciculatum (▲) measured in May-June at Echo Valley. From Oechel and Lawrence (In press).

In mature shrubs about 2/3 of the net photosynthesis goes to maintenance and growth respiration leaving about 1/3 of the net photosynthesis for growth (fig. 9). Carbon allocation is about equally distributed between leaves, stems and roots, each receiving about a third of the fixed carbon. The harvested material, however, well may be comprised of leaf material which will turn over at a high rate (72-235 g m^{-2} y^{-1}) (Oechel et al. In press) but which will not accumulate on an annual basis once the maximum leaf area index is reached following harvesting. This means that the only accumulation accessible for harvesting comes from

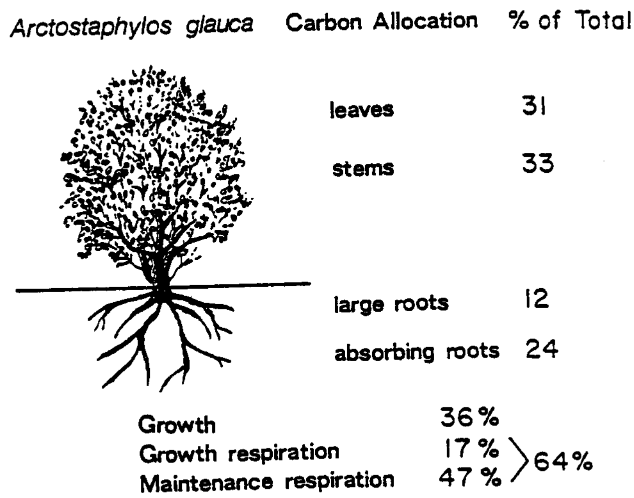


Figure 9--Estimated carbon allocation to growth and respiration of various structures in Arctostaphylos glauca. Values were calculated from field and laboratory experiments, field observations, and calculations and extrapolations using simulation models. From Oechel and Lawrence (In press).

stem growth, which is only 14 to 45 percent of the total plant biomass production and only 5 to 16 percent of the net photosynthesis (table 2) (Oechel and Lawrence In press).

Allocation patterns of shrubs in the chaparral are of prime importance in attempting to model biomass accumulation following harvesting. However, relatively little is known of the pattern of carbon accumulation following fire or harvesting.

In young seedlings of Ceanothus crassifolius fertilized with 1/4 strength Hoagland's solution and 1 mM NO_3, only about 50 percent of the carbon taken up in photosynthesis is respired by the plant. The remaining 50 percent goes to growth (table 3). Stem respiration, which is a major

Table 2--Simulated annual allocation (g dry wt m^{-2} y^{-1}) to leaves, stems, main roots and absorbing roots in four shrubs from pure stands of 22-year-old Californian chaparral (modified from Oechel and Lawrence In press).

Species	Leaves	Stems	Main roots	Absorbing roots	Total
	g dry wt m^{-2} y^{-1} (pct. of total)				
Arctostaphylos glauca	235 (48)	74 (14)	22 (4)	194 (37)	525
Adenostoma fasciculatum	72 (17)	190 (22)	94 (22)	67 (16)	423
Ceanothus greggii	181 (49)	58 (16)	25 (6)	108 (29)	372
Rhus ovata	109 (42)	64 (25)	31 (12)	57 (22)	261

Table 3--Calculated annual budget for Ceanothus crassifolius seedlings receiving one-quarter strength Hoaglands solution containing 1mM NO_3. Respiration calculated for 24 h/d at 15°C except for leaves (11 h/d). Photosynthesis is calculated at the maximum photosynthesis rate for 12 h/d (modified from Oechel, Lowell, and Jarrell In press).

Leaf photosynthesis	Leaf respiration	Stem respiration	Root respiration	Net plant CO_2 flux
	g CO_2 y^{-1} $plant^{-1}$			
512	179 (35)	57 (11)	31 (6)	243 (48)

source of carbon loss in mature stands, accounts for only an 11 percent loss of the carbon assimilated in photosynthesis by the seedling. Similarly, root respiration is much lower in seedlings than in mature plants being 6 percent of the net CO_2 uptake in Ceanothus crassifolius seedlings (table 2) compared to a calculated 26 percent in mature Ceanothus greggii individuals (table 4). Therefore, seedlings would be expected to accumulate carbon more rapidly than mature individuals of the same leaf area index, due to the lower loss of carbon to respiration in the seedlings.

Table 4-- Simulated carbon budget (g CO2 m^{-2} y^{-1}) for four shrubs from Californian chaparral (modified from Oechel and Lawrence In press).

Species	Net CO_2 uptake	Leaf respiration	Stem respiration	Root respiration	NA plant CO_2 uptake
Arctostaphylos slimes	2116	300 (14)	615 (29)	429 (20)	772 (36)
Adenostoma fasciculatum	1784	638 (30)	291 (14)	232 (11)	622 (29)
Ceanothus greggii	1556	222 (14)	390 (25)	397 (26)	547 (35)
Rhus ovate	978	130 (15)	176 (18)	267 (27)	384 (39)

Interestingly, 11 month old seedlings of Ceanothus crassifolius accumulate carbon at the annual rate of 248 g CO_2 per plant. At a density of 1 plant per meter square, this translates to a dry weight accumulation of 165 g dry wt m^{-2} y^{-l}. For plants of only 22 g m^{-2} the rate of biomass increased is 165 g m^{-2} y^{-1}. This is 44 percent of the value achieved by mature Ceanothus greggii with a standing crop of 5085 g dry wt m^{-2} (Oechel and Lawrence In press)

Lower accumulation rates of biomass with increased age are well known for chaparral (Sampson 1944, Mooney 1977). Two factors may account for this. Firstly, resprouters possess a well formed root system following fire which facilitates water and nutrient uptake. The extent of the root die back following fire is not known, but the major roots and many of the fine roots may persist to maintain favorable moisture and nutrient balances following fire or harvesting. Secondly, immediately after fire or harvesting, stored reserves in the burl may augment initial shoot growth, resulting in rapid initial rates of growth. Thirdly, younger plants have a lower "overhead" of respiring stem mass. Young plants from seed also lack a massive burl and root system to maintain.

Short rotation intervals have been suggested for shrub harvesting. However, on a short rotation basis, respiration rates of the burl and secondary roots may begin to consume large proportions of the available carbohydrate, and may result in lower production than predicted from data acquired from regrowth rates following longer rotation intervals where reserves have had an adequate period to accumulate.

The rate of shoot-growth may be very great the first year after fire. This rapid growth rate is presumably largely dependent on reserves stored since the last fire and may be enhanced by the increased moisture and nutrient availability following fire. This spurt of growth may be important when competing for light and other resources after harvesting or fire. Rapid exposure of leaf area may be very important in the long term net carbon uptake by an individual. Therefore, it would be dangerous to extrapolate from regrowth following fire to regrowth following harvesting, especially under altered periods between regrowth.

As the interval between harvesting decreases, the time to restore reserves used in the regrowth process also decreases. The net result may be decreasing reserves in the burl and hence regrowth rates less than those predicted from resprouts following fire.

Also, photosynthetic rates will be lower in resprouts following biomass harvesting due to the lack of stimulation of growth and photosynthesis from the increased nutrient availability which follows fire.

There is little evidence of stem or leaf carbohydrate levels being lower in resprouts following harvesting (Oechel and Hastings In press). However, the abundant carbohydrate levels found in resprout stem and leaf material may represent movement of carbohydrate from the burl and root system to growing points in the shoots.

CONCLUSIONS AND FUTURE RESEARCH NEEDS

Possible management techniques include managing for fewer, larger diameter stems rather than smaller diameter stems which have higher respiration rates. Stands with younger, higher density seedlings and sprouts should be much more productive than mature stands with the same leaf area index. To predict the long term potential of harvesting chaparral, and the optimal intervals for harvesting, studies of the entire carbon balance of resprouts are necessary. Such a study should include photosynthetic rates, respiration rates, nutrient levels and the carbohydrate content of leaves, stems, burls and root systems following harvesting. These results should be compared to those from fire resprouts.

Further research needs include:
1) Study of the fate of the fine root systems of resprouters following fire and harvesting; 2) Determination of the carbohydrate content of burls and secondary roots of resprouts following fire and harvesting; 3) Determination of the changes in stem size classes and distribution through time; 4) Determination of the causes of elevated photosynthetic rates of resprouts

harvesting with rotation intervals.

ACKNOWLEDGEMENTS

The help of Bill Lawrence and Steve Hastings at all stages of the research and manuscript preparation is gratefully acknowledged. Patsy Miller, Rhonda Watson, and Marie Kolb assisted with preparation of figures and text. Support was provided by grants from the National Science Foundation and the U.S. Forest Service.

LITERATURE CITED

Hastings, S. J.; 0echel, W. C. In Press. Proceedings of the Symposium on the Dynamics and Management of Mediterranean-type Ecosystems. June 22-26, 1981, San Diego, California.

McCartor, G. 1976. Chaparral as an energy source, pp. 99-117. In: Chaparral for energy information exchange. PSW Exp. Stn. Angeles National Forest, Pasadena, California.

Mooney, H. A. 1977. The carbon cycle in Mediterranean-climate evergreen scrub communities, pp. 107-115. In: H. A. Mooney and C. E. Conrad (eds.). Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. August 1-5, 1977, Palo Alto, California.

Mooney, H. A. In press Proceedings of the Symposium on the Dynamics and Management of Mediterranean-type Ecosystems. June 22-26, 1981, San Diego, California.

0echel, W. C.; Hastings, S. J. In press. The effects of fire on photosynthesis in chaparral resprouts. Third International Conference on Mediterranean-type Ecosystems, September 22-23, 1980, Stellenbosch, South Africa.

0echel, W. C.; Lawrence, W.; Mustafa, J.; Martínez, J. In press. Energy and carbon acquisition. In: Miller, P. C., ed. Resource use by chaparral and matorral: A comparison of vegetation function in two mediterranean-type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag: 151-184.

0echel, W. C.; Lawrence, W. In press. Carbon allocation and utilization. In: Miller, P. C., ed. Resource use by chaparral and matorral: A comparison of vegetation function in two mediterranean-type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag: 185-235.

0echel, W. C.; Lowell, W.; and Jarrell, W. In press. Environmental controls on carbon flux in mediterranean shrubs from California and Chile. In: H. Lieth (ed.). Tasks for vegetation science. Dr. W. Junk Publishers, The Hauge. (Proceedings of symposium September 1980, Kassandra, Greece).

0echel, W. C.; Mustafa, J. 1979. Energy utilization and carbon metabolism in mediterranean scrub vegetation of Chile and California. II. The relationship between photosynthesis and cover in chaparral evergreen shrubs. 0ecologia 41: 305-315.

Poole, D. K.; Miller, P. C. 1975. Water relations of selected species of chaparral and coastal sage communities. Ecology 56: 1118-1128.

Riggan, P.; Dunn, P. In press. Proceedings of the Symposium on the Dynamics and Management of Mediterranean-type Ecosystems. June 22-26, 1981, San Diego, California.

Sampson, A. W. 1944. Plant succession on burned chaparral lands in northern California. Calif. Agric. Exp. Stn. Bull. (Berkeley) 685. 144pp.

Maquis for Biomass[1]

N. S. Margaris[2]

Abstract: Mediterranean regions, like Greece, have to face many problems, such as fuel, wood and paper deficiency. In addition to that, great amounts of money are spent every year for fire fighting. The suggested harvest of mediterranean-type ecosystems every 10 years will contribute to a combined solution of all these problems.

In the Mediterranean basin region, about 200,000 hectares are burnt every year. In moderate estimations, the aboveground biomass lost is of the order of magnitude of $1.2X10^7$ tons, and according to Le Houerou (1973) the direct damage is at least 50 million dollars. From the other side, great amounts of money are spent for fire-fighting. The same situation prevails not only in the regions of the Earth with mediterranean-type climate (California, S. Africa, Chile, Australia) but almost in all ecosystems, except for those in the very cold and/or very humid climates. In Canada, for example, forest fires cause a loss of the order of magnitude of 50 million barrels of oil per year (Bene et al. 1978).

Nowadays, when liquid fuel deficiency distresses extended areas of the Earth, it is time to stop this great loss of energy and organics. Greece will be taken as an example in the discussion because, first, the author has an adequate experience of this region and, second, because this country has to confront many oppressive problems, such as fuel, wood, and paper deficiency and great expenditures on fire-fighting. If these problems are studied all together, it is quite probable that the one will offer the solution to the other.

CURRENT PROBLEMS RELATED TO THE LACK OF LIQUID FUELS IN GREECE

Greece has to import the whole quantity of liquid fuels needed. The anticipated oil production from 1981 of 25,000 barrels per day will cover only 10 percent of needs. Even before the liquid fuels price raising of June 1979, the Greek Government has been trying to diminish their consumption. Nevertheless, it is still increasing at a rate of 10 percent per year. The need of saving foreign exchange for oil purchase maximizes the problem, especially during the last period, when price raising has been extremely high. Petrol price, for example, came to be 0.85 US $ per liter (not gallon!.) and it is most possible one of the highest in all the world. Beside this increase, the Government proceeded to a whole series of relative ways and means. The most important among them is the prohibition of cars circulation every second weekend from 5 o' clock in the morning of Saturday to 5 o'clock in the morning of Monday. Others were the shortening of oil disposal for heating or cooling purposes, the turning off lights of shop boards and advertisements, in streets and national roads, the application of differential office and shop hours, the closing of every place of amusement at 2 o'clock in the morning, etc.

These means led to .a quite significant life disturbance of the Greek population after 1979 summer. At that time there appeared a tendency on behalf of those who could afford it, to purchase a second car - fact not so common in Greece - in order to avoid the problem of family transport during week-ends. However, the Government imposed such a heavy taxation that car purchase became problematic, especially, for those who had none. In this way cars price, in Greece, is almost three times higher than that in the other western countries. In the same time, the Government promised to give more money to the research on other energy sources, something not realized yet. Inflation (25 percent for 1980) and the tremendous increase of payment balance deficit - since imports far exceed exports - which was during 1980 about 2.0 billion dollars, are two major problems in Greek economy. Large amounts of foreign exchange are also expended for the import of wood and paper, since the Greek production covers only 25 percent of the needs for the first and just 10 percent for the second.

THE NATURAL ENVIRONMENT

The total surface of Greece (9 million people) covers 13 million hectares from which 20 percent are forests, 30 percent cultivated land, 10 percent urban and semi-urban areas, roads, water surfaces, etc., while the rest 40 percent correspond to mediterranean-type ecosystems. Two types of mediterranean climate ecosystems can be discerned; maquis and phrygana. Plants dominating in maquis are adapted to the summer drought by means of evergreen sclerophylly, while those in phrygana (coastal sage) by the mechanism of seasonal dimorphism.

The combination of high temperatures and water deficiency during the summer, leads to a high frequency of recurring fires in them. The relation of this climatic type with fire has been since long noticed (Griesebach 1872). Shantz (1945), in his review for the mediterranean type ecosystems of California, refers to them as "fire-type" and

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Ecology, University of Thessaloniki, Thessaloniki, Greece

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

says further: "... that this type was ever free from fires seems unlikely". According to Mutch (1970), ecosystems subject to frequent fires for thousands of years have developed, in the course of evolution, properties, which make them extremely flammable.

Biswell (1973) says: "Fire in chaparral is both natural and inevitable. It has always occurred and probably always will, because vegetation becomes extremely dry near the end of a long, hot, nearly rainless summer. At that time, also, humidity may be extremely low and winds high".

As we have already mentioned mediterranean type ecosystems are called "fire-induced" or "fire-adapted". Plants dominating in them, have developed such adaptations which not only help them to survive after fire attack but periodic fires every 15-20 years or so appear necessary to maintain their good health.

Plants recovery after a fire, follows, basically, two ways. Perennials, dominating in maquis, usually recover by resprouting. Naveh (1973) refers to them as obligatory resprouters, while to those dominating in phrygana as facultative resprouters, since they recover both by resprouting and through their seeds, the germination of which is activated after a fire. The plant species <u>Pinus</u>, found in maquis, and <u>Cistus</u>, in phrygana, recover only through their seeds.

The growth of the new plants is very quick and after 5-10 years, the burnt area cannot be distinguished from the unburnt. The quick recovery can be attributed to an increased photosynthetic rate of the resproutings, since after fire the new leaves are larger and have a greater chlorophyll content per unit of weight (table 1).

THE SOCIAL ENVIRONMENT

For reasons which are beyond the scope of this article, the Greek society considers fire as a terrible and unnatural event, which did not happen in earlier times. From that derives the governmental policy, based on fire exclusion. We must mention, however, that both in earlier times and today fire burned every year the same percentage of land (figure 1).

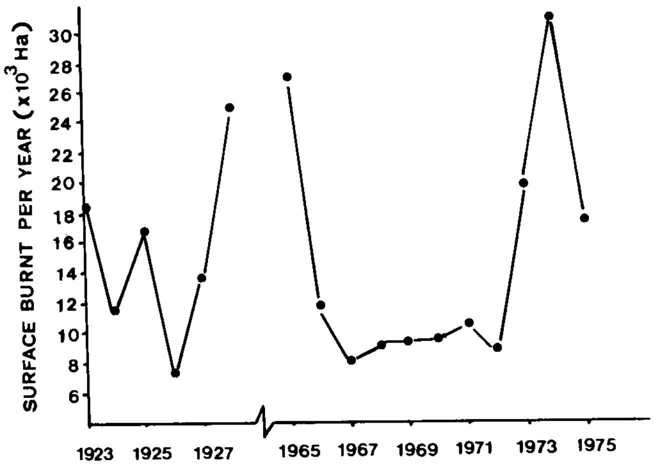


Figure 1--Area burnt per year in Greece.

The exact effect of fire is essentially confused with overgrazing. But the fact is, that the after fire resproutings are either eaten or trampled by the passing animals and only the combination of fire and overgrazing leads to the degradation of

Table 1--Chlorophyll content (mg.g^{-1} leaf dry weight) in leaves of normal and burnt plants. Fire occurred in July 1976 (Arianoutsou 1979).

	January 1977		April 1977	
	Normal	Burnt	Normal	Burnt
<u>Phlomis</u> <u>fruticosa</u>	2.0	3.5	2.4	4.6
<u>Sarcopoterium</u> <u>spinosum</u>	2.3	5.7	2.2	5.0
<u>Euphorbia</u> <u>acanthothamnos</u>	4.7	5.4	4.9	5.2

ecosystems and to the "Asphodel deserts".

In this way, quite often during the summer months the most important article of the Greek newspapers concerns fires which almost always are attributed to criminal activities. By being opposed to such an oversimplified explanation we do not deny its validity in a few cases, since it is known that shepherds, themselves, in NW Greece (Papanastasis 1977), Crete island and other places, light on fires which, they believe, improve the pasture production, since the first one or two years after the fire an interlude of herbaceous vegetation appears in the burnt area. The way with which the Greek State confronts fires. is excellently described by Biswell (1974) although he is occupied with the situation in California. Of course, the available material and the experience of the Greek firemen are still far back.

> "In spite of man's capability to fight wildfires with the most modern aerial and ground equipment and the best trained firemen in the world, it seems certain that wildfires in chaparral cannot be completely prevented. Good intensions and large expensive efforts in fire control do result in fires at less frequent intervals. But with longer time between fires, the fuels continue to build up and become more widespread, and when fires do get out of control, the toll in human life, natural resources, and cost is enormous".

Biswell (1974) proposes prescribed burning every 15-20 years for confronting these problems. In Australia, in areas of relative climate, this has already become a reality with the use of aerial ignition (Vines 1968). Before proceeding further we must mention that the chief objection to burning mediterranean type lands both in California and in the Mediterranean basin is its alleged detrimental effect on soil erosion and stability. Sampson (1946), in California, expressed his opposition to the rash and broad generalization and suggested, in contrary, a fire consideration taking into account the specific ecological conditions. The same suggested later on Naveh (1974) for Israel and Liakos (1973) for Greece.

The official policy of fire exclusion and the confusion of protection of environment with protection of forests as well as convenience in using liquid fuels led Greece in less than 20 years in complete dependence upon oil as a fuel. Therefore, 80 percent of the Greek population uses oil for heating purposes. During only the period 1970-1975 the production of oil stoves was 600,000 items. In the same time the prohibitions of wood cutting result inevitably in fuel accumulation as aboveground biomass, which will cause catastrophes, when fire, early or late outbreaks.

ARE THERE MEANS OF FACING THESE PROBLEMS?

The above mentioned may be summarized in that from the one side there is a social disturbance due to the oil deficiency and the excessive demand of foreign exchange for its purchase as well as for the import of wood, paper, animal food, and from the other side the problem of fires which in the way it is faced will lead to severe damages. What we propose is the utilization of fire-type ecosystems. Rotating harvesting of them will, if not exclude, moderate in a considerable extent all these problems. We believe that our suggestion surpasses that of Biswell (1974) for prescribed burning in that not only the fire problem is faced but also energy and organics which these ecosystems contain are not lost.

In figure 2 our suggestion is presented in a simplified way. According to the present data, concerning the frequency of fires, it seems that an ecosystem, aged 20 or 30 years is mature to be burnt (Trabaud 1973, Biswell 1974). However, the net productivity, especially as the ecosystem approaches the climax is always declining. Therefore, 10 years after fire the aboveground biomass is only slightly increasing. If instead of waiting a fire outbreak, we harvest the ecosystem every 10 years, the possibilities of a catastrophic fire are reduced and in parallel to that the net productivity is maintained at a high level, and consequently, there is a gain in energy and organics.

The next step is to find the appropriate areas where such a harvest can take place. Since, in Greece, mediterranean type ecosystems comprise 40 percent of the total surface, a 4 percent harvesting every year will yield about $94X10^{12}$ kcal, which is equivalent to over 80 percent of our imports in oil (Margaris 1979). It is certain that the mountainous relief of Greece does not permit for the time this kind of harvesting. However, such a project may be applied in maquis, which consist about half of the surface covered by mediterranean type ecosystems, but contain 80 percent of their total above ground biomass. A ten year rotating harvesting of those maquis located on level ground, which cover about 10 percent of the total Greek surface seems quite feasible. It is estimated that the aboveground biomass contained in them is about 6 $kg.m^{-2}$. Therefore, harvesting 1 percent of the Greek surface (or 10 percent of maquis ecosystems, which may be easily harvested) every year, will yield a biomass of the order of magnitude of $12X10^6$ tons. This amount is equivalent to over 40 percent of our oil imports. The fuel needed for this harvest will not be too costly, in these level ground areas, if self-propelled harvesting machines are used, like those suggested by Mitre Corporation (1971) for harvesting large-scale energy plantations with harvesting ability of 35 tons per hour.

The estimations of a prefeasibility analysis published in a previous work (Margaris 1981) have shown that the harvesting cost of a 23,000 hectares unit harvested by 1/10 every year will not surpass 3 US $ per ton dry matter, which seems quite satisfactory.

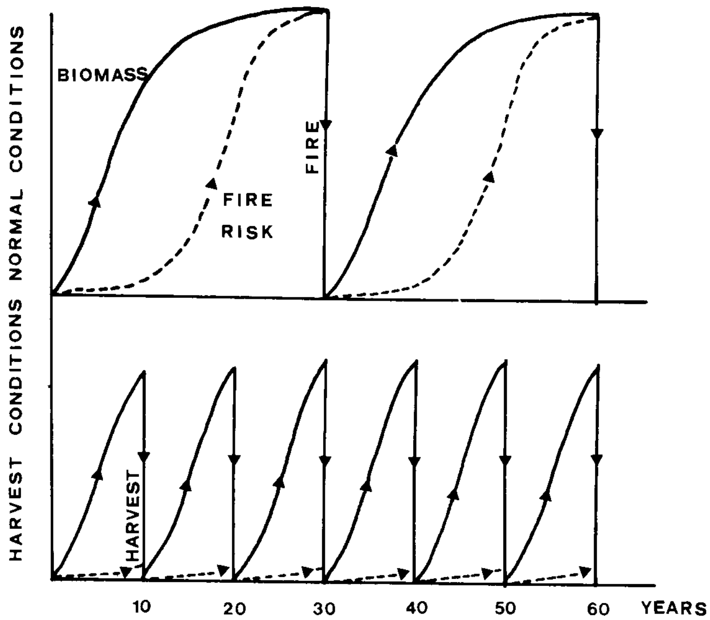


Figure 2--Biomass and fire risk in Mediterranean-type ecosystems under natural and harvest conditions.

CAN HARVESTING SUBSTITUTE FIRE?

One of the first remarks when harvesting is suggested is whether the harvested system recovers in the same way as the burned system.

As a first attempt to give an answer to this question we have started observations in regions cleared in the past by the National Electric Corporation in order to install high voltage lines.

In harvested areas it seems at first sight that the system has developed quite normally. Of course it is obvious that there is less biomass in the harvested area, but it must be taken into account that the unharvested area of the picture has reached the climax and has not suffered the fire impacts for the last 40 years.

Another observation is related with erosion which is believed to get intensified after harvesting. However, reality seems to counteract the pessimism of the theory.

In the profile of figure 3 we show schematically the biomass location in the harvested and unharvested areas. It can be seen that biomass is denser over the height of 1 meter in the unharvested whereas below 1 meter in the harvested area. Consequently, in the unharvested area there are but the trunks of the bushes at the height of 0-1 meter, while herbaceous vegetation is totally absent. As a result the soil is swept away forced by the downwards movement of water. On the contrary, in the harvested area the resproutings are in soil contact thus alleviating the erosion effect.

Of course we must say that with the harvesting we propose a quantity of nutrients will be taken away from the systems. We have shown, however, in a previous work (Nargaris 1979) that they will be very probably replaced by the nutrients, coming with the rain. Also, our first observations in the areas already harvested by the Electric Corporation show that Papilionaceae species increase their contribution to the biomass, something very interesting.

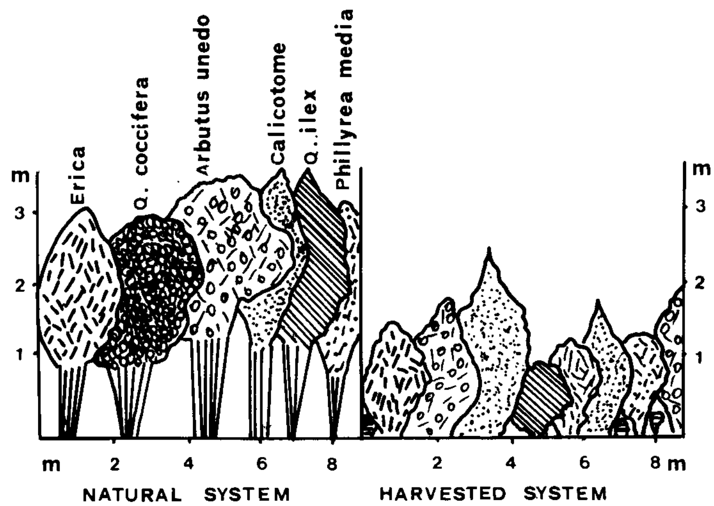


Figure 3--A schematic biomass profile under natural and harvested conditions in an area in North Greece harvested before 7 and 17 years.

ECOLOGICAL ADVANTAGE

It is mentioned above that the technique of prescribed burning is used both in Australia and in California in the management of mediterranean-type ecosystems. However, it must be taken into account that with this technique the natural ecosystems are successfully preserved but on the other hand immense quantities of energy and organics are lost; moreover, there is always the danger the fire become uncontrolled.

In comparison with energy plantations the advantages are much more. There are no problems such as sensitivity, diseases, inputs of energy and fertilizers, common to all monocultures.

However, what is more important in our opinion, is the possible increase of the system diversity.

Ten years after the initial harvesting there will coexist areas harvested before 1-10 years, so that different stages of the post-harvest succession will be present in the same ecosystem. Furthermore, there is a possibility of 1X2X3X...X10 combinations between different post-harvest stages which can be brought into contact. In this way, the roles, the organisms can play in the system, are multiplied with a subsequent possible increase of the total number of both plant and animal species in the post-harvest period.

LITERATURE CITED

Arianoutsou, M. Effect of fire in a phryganic ecosystem. Ph. d. Thesis. University of Thessaloniki, Greece; 1979.

Bene, J.G., Beall, H.W. and Marshall, H.B. Energy from biomass for developing countries. International Development Research Centre-MR3 Ottawa, Canada; 1978.

Biswell, H.H. Effect of fire on chaparral. In: Fire and Ecosystems. T.T. Kozlowski and C.E. Ahlgren (Eds) Academic Press, New York; 1974; pp. 321-364.

Griesebach, A. Die Vegetation der Erde nach ihrer klimatischen Anordnung. Engelman, Leipzig; 1872.

Liakos, L.G. Present studies and history of fire in Greece. Proc. 13th Annual Tall Timbers Fire Ecology Conference; 1973; pp. 65-96.

Le Houerou, H.N. Fire and vegetation in the Mediterranean basin. Proc. 13th Annual Tall Timbers Fire Ecology Conference; 1973; pp. 237-277.

Margaris, N.S. Can we harvest mediterranean type ecosystems to obtain energy and organics? In: Biological and Sociological Basis for a Rational Use of Forest Resources for Energy and Organics. S. Boyce (Ed). Asheville, North Carolina: USDA/ Forest Service Southeastern Forest Experimental Station; 1979; pp. 121-128.

Margaris, N.S. Maquis for biomass: Costs and benefits. In: Components of Productivity in Mediterranean Regions (N.S. Margaris and H.A. Mooney, Eds), Junk, The Netherlands; 1981; (in press).

Naveh, Z. Effect of fire in Mediterranean region. In: Fire and Ecosystems. T.T. Kozlowski and C.E. Ahlgren (Eds), Academic Press, New York; 1974; pp. 401-434.

Papanastasis, U.P. Fire ecology and management of phrygana communities in Greece. Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Palo Alto; 1977; pp. 476-482.

Sampson, A.W. Plant succession on burned chaparral lands in North California. California Agricultural Experimental Station Bull., 685; 1944; 1-144.

Shantz, H.L. The use of fire as a tool in the management of the brush ranges of California. Sacramento, California; California State Board of Forestry; 1947.

Trabaud, L. Experimental study on the effects of prescribed burning on Quercus coccifera garrique: Early results. Proc. 13th Annual Tall Timbers Fire Ecology Conference; 1973; pp. 97-129.

Vines, R.G. The forest fire problem in Australia a survey of past attitudes and modern practice. CSIRO, Aust. Sci. Teacher's J.; 1968; pp. 1-11.

Hardwood Biomass Inventories in California[1]

Norman H. Pillsbury and Michael L. Kirkley[2]

Abstract: A base of information about hardwood resources in California has been accumulating as a result of on going studies as well as several which have been completed in the last three or four years. Inventory studies can be classified at three general levels: by measuring individual trees, stands of trees, or extensive forested areas. Those studies relating to tree inventory are often used for volume table development, while the second level of inventory describes stands of trees with interpretation aimed at hardwood management practices. Lastly, large-scale inventories are being conducted to determine the acreage of hardwood forest and woodland resources in selected areas of California. These inventories represent the development of an important data base necessary for management and protection of hardwood forests in California.

The first hardwood inventory in California was not published until 1950. However, in the past three years about 15 studies have either been published or are in progress. This rapid increase in studies largely stems from the increased value and utilization of wood and the decreasing hardwood land base. Even though the price of a cord of wood has quadrupled in the past three years, wood cutting suppliers are providing greater volumes of wood to consumers each year (Pillsbury and Williamson 1980; Department of Forestry 1980). It appears that using wood to supplement home heating is still an important economical and recreational use of wood for many Californians. However, the current high value of wood also encourages many landowners either to harvest their hardwoods as a one-time cash crop or as part of a long-term management plan. Interest in the management of hardwood resources for aesthetics, wildlife, range, wood products, and urban uses was expressed by many people at a recent symposium on the ecology, management, and utilization of California oaks (Plumb 1980). Unfortunately, only a small amount of hardwood management information is available about a resource that has been largely ignored or cleared in favor of competing land uses. Of primary importance is the need for a sound inventory - the data base necessary for developing management guidelines.

A review of existing studies shows that several state and federal resource agencies are becoming more supportive of hardwood resource investigations, but that our total knowledge is rudimentary and inadequate. This report traces the history of hardwood inventory research in California. The following inventory studies can be classified into three general levels: those that measure individual trees, stands of trees, and extensive forested areas.

TREE INVENTORIES

Those studies relating to tree inventory are often designed to create volume tables. Approximately five reports containing volume tables for California hardwood are in progress or have been completed. All existing tables have been developed for specific uses in a local or regional area and generally are not compatible due to different methods of measurement and utilization standards.

Unmanaged stands

Board-foot and cubic-foot volume tables were developed in 1950 by Hornibrook and others for California black oak (*Quercus kelloggii* Newb.). Oregon white oak (*Q. garryana* Dougl.), Pacific madrone (*Arbutus menziesii* Pursh) and tanoak {*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.}. Sample trees were selected along right-of-way clearings in Mendocino, Trinity, Humboldt and Del Norte counties in California and Josephine County in Oregon. The sample did not cover the complete range of each species. The volume of each tree was determined by planimetering measurements that were plotted on Forest Service Tree Measurement forms. Board-foot tables used a log scaling length of 8' and a minimum top diameter inside bark of 10 in. and the log had to contain a straight and sound 2 in x 8 in x 8 ft plank. The cubic-foot tables include all volume inside bark between stump and a 4 in top (inside bark). The form class value, diameter at breast height (d.b.h.), and height need to be determined before using the tables.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Professor and Graduate Research Assistant, respectively, Forestry Program, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

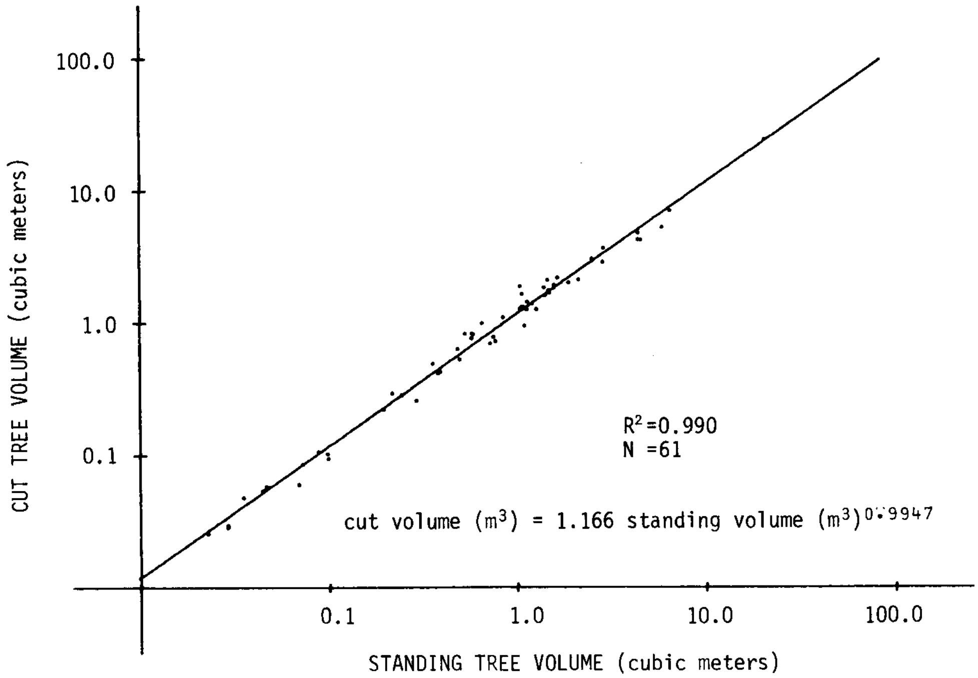


Figure 1. The relationship between tree volumes measured standing and again after being cut for San Luis Obispo, Monterey, San Benito, and Santa Cruz Counties, California.

The next study did not occur until 15 years later when papers by Wiant and Berry (1965), Berry and Wiant (1965) and Berry and Wiant (1967) discussed the development and accuracy of cubic-foot volume and tarif access tables for tanoak in Humboldt County. Cubic foot volumes were calculated from stump height (about 1 foot) to a 4-inch top (diameter inside bark) excluding bark and branches by the Huber formula for section lengths of 10 ft. or less. D.b.h. and total tree height values are necessary to use the tables. The authors found that the greatest accuracy occurred when tree-volume tarif tables were applied to stands of uniform heights.

The species measured in the studies discussed above tend to be less branchy and have fewer major forks than hardwood species growing in the southern half of California. A specialized field measurement technique was developed by Pillsbury and Stephens (1978) to construct volume and weight tables for coast live oak (*Q. agrifolia* Nee), blue oak (*Q. douglasii* Hook. & Arn.), and tanoak in Santa Cruz, San Benito, Monterey and San Luis Obispo counties. Harrington and others (1979) used the technique to develop a gross volume table for California white oak (also called valley oak, *Q. lobata* Nee) in San Luis Obispo and Monterey counties. Tree volume was determined (both outside and inside bark) by an optical dendrometer while the trees were standing, and again after felling, by calipers and tape for a sample of 61 trees. Every tree segment (from ground level to a 10 cm diameter) was measured using Smalians formula. In addition, the length of branch tips (defined as the length from the tip back to a 10 cm diameter) were estimated and volumes were computed using the formula for a cone to obtain total tree volume, excluding foliage. The volume obtained from standing trees correlated well to the volume of the trees that were cut (Figure 1). Thus, further sample tree measurements were only taken on standing trees. Trees that were felled were also cut into firewood-sized pieces and weighed (fresh green weight). Foliage and branches less than 5 an in diameter were not included in the sample (Pillsbury *et al* 1978). Standard volume and weight tables were developed for both English and metric units for each species.

In order to more rapidly inventory local woodlands, tree photo volume and weight tables were developed for Monterey, San Benito and San Luis Obispo counties in 1979 (Pillsbury and Brockhaus) for coast live oak, blue oak and valley oak. Stereo color transparencies at a scale of 1:5,000 were obtained by the U.S. Forest Service for plot sites. Visible crown diameter and total tree height were measured for each sample tree on the photo pair and correlated to sample tree gross volume and fresh green weight obtained from equations developed by Pillsbury and Stephens (1978). An aerial photo cruising example is also included in the report. The authors recommend that a subsample of field plots be obtained to adjust photo volumes to obtain more accurate volume estimates for stands of trees.

Two other volume table studies in California are currently in progress. McDonald (manuscript in preparation) is developing local volume tables for Pacific madrone, tanoak and California black oak on high site lands in and adjacent to the Challenge Experimental Forest in Yuba County. An optical dendrometer was used to measure sections of standing trees. A computer program written by Grosenbaugh (1967) is being used to reduce field data and express volumes for different species and utilization standards. Cubic- and board-foot volumes (inside bark) will be given for each species to tree top, and to a 4-inch diameter top.

The volume tables discussed so far were developed from sample trees located in local or regional areas. Only seven of the native hardwoods in California have been included in these studies. Existing tables have used different measurement techniques and utilization standards making large scale inventories impractical. The Renewable Resources Evaluation unit, Pacific Northwest Forest and Range Experiment Station is supporting a study at California Polytechnic State University, San Luis Obispo to develop standard volume tables for 13 of the primary hardwoods in California. Species selected for volume table development are: tanoak (*Lithocarpus densiflorus* Hook. & Arn.), coast live oak (*Q. agrifolia* Nee), interior live oak (*Q. wislizenii A.DC.),* blue oak (*Q. douglasii* Hook. & Am.), Engelmann oak (*Q. engelmannii* Greene), canyon live oak (*Q. chrysolepsis* Liekm.), California black oak (*Q. kelloggii* Newb.), California white oak (*Q. lobata* Nee), Oregon white oak *(Q. garryana* Dougl.), Pacific madrone (*Arbutus menziesii* Pursh), California laurel {*Umbellularia californica* (Hook. & Arn.) Nutt}, bigleaf maple (*Acer macrophyllum* pursh), giant chinquapin {*Castanopsis chrysophylla* (Dougl.) A. DC.}.

To develop tables that can have statewide application it is necessary to sample trees throughout much of their natural range and in areas of different site quality, densities, and topography. U.S. Geological Survey 15 minute quadrangle maps were randomly chosen from each region and sample trees were selected from stands located within the map area.

Trees 12.7 cm (5 in) dbh and larger were sampled. Tree segments were measured up to a 10 cm (4 in) top using an optical dendrometer. Smalian's formula was used to compute segment volumes. Branch tips (i.e. the end of a branch having a 10 cm diameter at the large end) were tallied and an average length assigned. Branch tip volumes were computed as a cone.

Three tables for each species are being developed in units of cubic feet and cubic meters: (1) Total tree volume (volume includes all stem and branch wood plus stump and bark; excludes foliage); (2) Wood volume (volume computed from stump height up to a 10 cm top, outside bark; excludes bark); (3) Sawlog volume computed for trees 28 can (11 in) d.b.h. and larger (volume computed from stump height to a 23 cm (9 in) top for straight sections 2.5 m (8 ft) long; excludes bark).

Approximately 60 trees of each species were sampled for a total of 780 trees measured in the State. Multiple regression volume equations will be developed using d.b.h. and total height as independent variables.

Managed Stands

Most California hardwoods are not managed, however the potential for establishing plantations for rapid production of woody biomass for energy is possible in parts of California because a vast amount of land is located in a favorable growing climate. The earliest known plantation volume tables in California were developed by Margolin (1910) for blue gum (*Eucalyptus globulus,* Labill.). Over 1000 of the largest trees from groves in the southern half of California were felled and diameter measurements were taken at intervals of 10 feet along the stem of the tree. Volumes were determined by a graphical solution method for: (a) gross volume in cubic feet including bark from stump height to a 2-inch top (inside bark), (b) board-foot volume for logs having a diameter (inside bark) of 5.5 inches or more, and (c) cubic-foot volume of the parts of a merchantable tree between 5.5 inches and 2.0 inches in diameter inside bark. This is the remaining tree tops not measured in part (b). Tree spacing ranged from 6 ft x 6 ft to 12 ft x 12 ft and included ages between 1 and 40 years.

In 1974, Barrette and Jackman published cubic-foot and board-foot volume tables for blue gum in the Jackson State Forest. The trees were initially planted for windbreak protection in rows with a six foot spacing in a long narrow area consisting of about one acre. In the 75 years since then they have spread over 94 acres. Volume tables were graphically developed by plotting tree data collected from wood scaling operations. Sample tree ages ranged from 24 to 73 years.

In another plantation study, sponsored by the California Department of Forestry, twelve eucalyptus species are being grown for short rotation biomass production at California Polytechnic State University, San Luis Obispo. Volume, weight, and energy (BTU) tables will be developed for *E. camaldulensis* (Dehuh.)*, E. cinera* (F. Muell.), *E. viminalis* (Labill.), *E. polyanthemos* (Schau.) *E. pulverulenta* , *E. globulus* var. *'compacta'*, *E. citriodora* (Hook.), *E. globulus* (Labill.), *E. melliodora* (A. Cunn. ex Schau.), *E. paniculata (&n.), E. sideroxylon* (A. Cunn. ex Woolls), and *E. stellulata* for spacings ranging from 2 ft x 2 ft to 10 ft x 10 ft. The study is one year old and data is to be collected annually for approximately seven years.

STAND DENSITY INVENTORIES

The second level of inventory describes stands of trees. These inventories include stand density, volume, and growth studies for several regions in California.

Stand density characteristics for hardwoods native to San Luis Obispo, Monterey, San Benito, and Santa Cruz are described by Pillsbury (1978). Average per acre values for these counties are presented for gross volume (with and without bark), number of cords, stem surface area, fresh green weight, number of trees, and basal area. Natural stands were divided into three classes by volume and weight density. These density classes are used to indicate where the distribution of the hardwood resources discussed below under "Large Scale Inventories" occur in the Central Coast counties.

In an unpublished thesis, Nguyen (on file at Humboldt State University 1979) presented a preliminary growth and yield model on tanoak for selected sites in northern Humboldt County. Equations were developed to estimate projected cubic-foot volume, basal area growth rate, cubic-foot volume growth, board-foot yield (to a 6-inch top), and projected board-foot volume (to a 6-inch top) on a per acre basis.

Porter and Wiant (1965) published equations predicting site index for tanoak, Pacific madrone, and red alder (*Alnus rubra* Bong.). About 30 dominant trees of each species were felled and sectioned for stem analysis on a wide variety of sites in Humboldt County. Sampling was restricted to stands which approached full stocking. The equations can be used to compute site index at 50 years for any combination of total age and height.

Site index curves were developed in 1972 by Powers for California black oak, sampled in stands located in Shasta, Tehama, Butte, Yuba, Nevada, and Placer counties, California. All sample trees were located in stands of sprout origin and stems were free of forking for the first 18 feet of the bole. Stems were not sectioned for analysis, rather, sample plots associated with ponderosa pine (*Pinus ponderosa* Laws) were stratified into five pine site index classes to obtain homogeneous data sets. Separate equations were developed regressing age versus height for each stratum and the mean site index was determined by solving each equation for height at an index age 50. A procedure for using the site index curves is provided.

Currently, the U.S. Forest Service is supporting a study to obtain information about site and yield for blue oak and coast live oak in San Luis Obispo and Monterey counties. The study, being conducted at California Polytechnic State University, will provide age data, stand increment and growth dynamics, stand composition and structure, site, and general yield data. This information is needed to evaluate cutting levels, to determine rotation age, and to estimate stand growth. It will also help professionals develop stand management prescriptions for native hardwood species on the Central Coast of California.

Managed stand inventory data are also being collected at California Polytechnic State University, on their Silvicultural Biomass Energy Plantation. Average per acre data for twelve eucalyptus species (listed under "Tree Inventories") are being accumulated for stand volume, weight and energy content (BTU's). The growth response for each species is being measured for different densities (ranging from about 400 to 11,000 trees per acre), fertilizer treatments (time release tablets), and weed control techniques. The results will be used to help plan large-scale, eucalyptus plantations that will be intensively cultured and harvested on short rotations on similar climate and soil types in California.

A hardwood thinning study for the Central Coast counties area is currently being planned by the California Department of Forestry.[3] The purpose of the study is to determine growth in moderate to high density blue oak and coast live oak stands on gentle slopes following different thinning treatments. Four treatments are planned for this study: (1) leaving 100 square feet basal area/acre, (2 leaving 50 square feet basal area/acre, (3) removing all trees, (4) no cutting. Ten sites will be evaluated and each site will have four plots, one of each treatment. Growth rates will be monitored for a 10 year period.

McDonald updated the results of a long-term thinning study on the Challenge Experimental Forest in Yuba County, California at a recent oak symposium proceedings (Plumb 1980). Sixty-year-old stands of tanoak, California black oak and Pacific madrone are being studied. Seven plots were thinned from an average stocking of 198 sq ft/acre to basal areas ranging from 85 to 141 sq ft/acre. Average diameter growth doubled after 8 years while average cubic volume growth ranged from 66 to about 89 cu ft/yr. The author considers the results preliminary and any conclusions drawn from them to be speculative.

LARGE SCALE INVENTORIES r

Large scale inventories are being conducted to determine the acreage of hardwood forest and woodland resources for selected counties in California.

The U.S Geological Survey, Land Use/Land cover and Associated Maps Program (formerly called the LUDA Program) has developed a national land use and land cover classification system (Anderson 1976). This system was used to develop broad vegetation cover maps at a scale of 1:250,000 for

[3]Personal communication, 1981, Raymond Jackman, California Department of Forestry, Monterey, Calif.

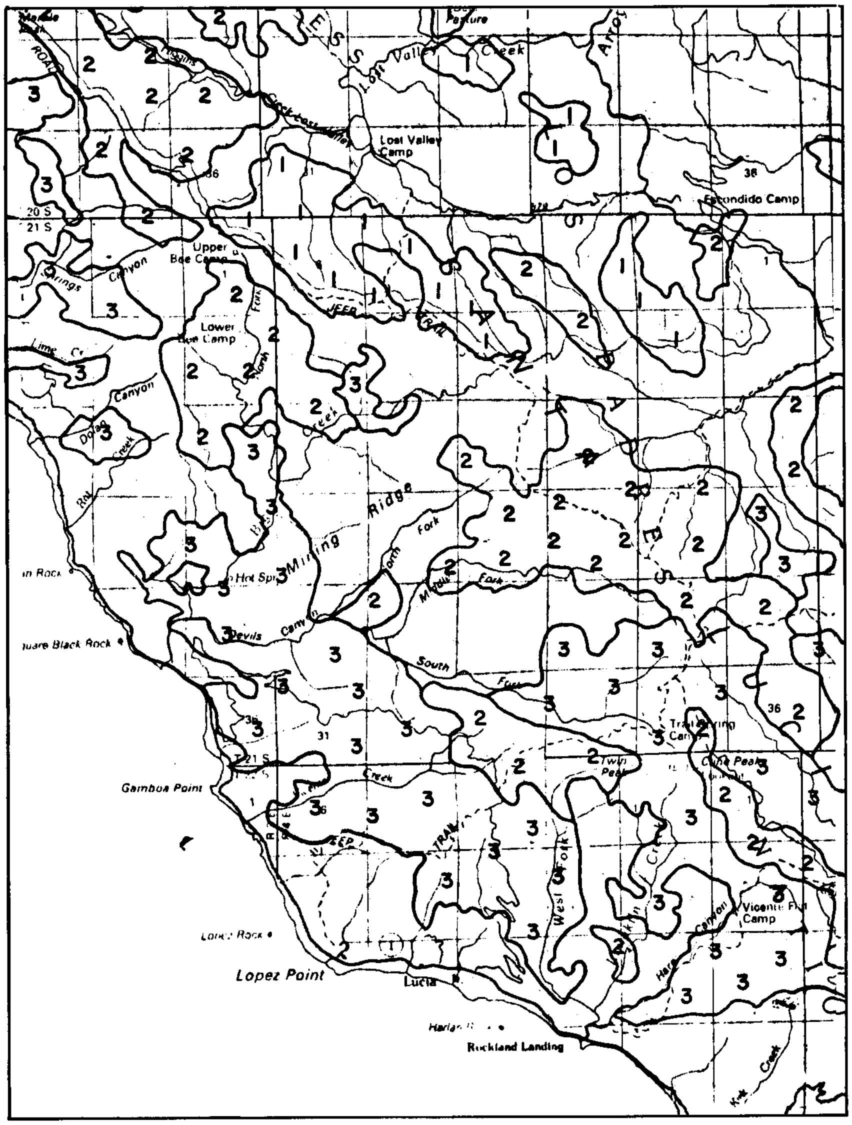


Figure 2. Hardwood fuel inventory map example for Monterey County, California. Symbols refer to stand volume classes (S = scattered trees, 1 = low, 2 = moderate, 3 = high).

California. Forest lands (i.e. lands having a 10% crown cover closure or more) are divided into deciduous, evergreen, and mixed forest lands. Deciduous forest land includes all forested areas having a predominance of trees that lose their leaves at the end of the frost-free season or at the beginning of a dry season. Evergreen forest lands are dominated by trees which remain green throughout the year, while mixed forest lands include both deciduous and evergreen trees neither of which predominates. When more than one-third intermixture of either evergreen or deciduous species occur, it is classified as mixed forest land. Cover type map resolution is 40 acres. U-2 infrared, and black and white quad centered (1:80,000) photography was used for interpretation and data transfer.

Hardwood inventory maps (Pillsbury and Brockhaus 1981) have been completed for San Luis Obispo, Monterey, San Benito and Santa Cruz counties. The USGS land use and cover maps discussed above were used as "base maps" for the inventory project. Deciduous forest lands identified by the USGS were subdivided into hardwood stand density classes discussed in part II, Stand Density Inventories. Density classes 1 (law volume), 2 (moderate volume), 3 (high volume) or S (for scattered woodlands) were mapped on 1:100,000 scale county maps at a resolution of about 10 acres (Figure 2). All USGS land cover boundaries were inspected for accuracy and refined to this resolution when necessary. These maps provide the first estimate of the hardwood volume and weight distribution for any region in California.

The Renewable Resources Evaluation Unit, Pacific Northwest Forest and Range Experiment Station, Portland, Ore. is planning a large scale hardwood inventory to obtain information necessary for policy decisions.[4] Exact diameter increment will be measured on thousands of trees in existing plots and used to calculate growth. In addition to these plots, several hundred new plots will be established in hardwood forests that were formally classified as "noncommercial". Information on tree species, crown class, crown ratio, defect, and damaging agents will be recorded. Estimates of cubic volume by species will be computed from the plot data using volume equations being developed at California Polytechnic State University, San Luis Obispo. Tree volumes will be expanded to regional and State levels. Periodic remeasurement will provide information on growth mortality, and other trends.

The California Department of Forestry, Forest Resource Assessment Program has sponsored three pilot projects to examine the potential and to develop the methodology of using LANDSAT (LAND SATellite) data for classifying extensive areas of forest resources. The vegetation resources in two counties, Santa Cruz and Humboldt, have been classified. The hardwood signatures developed for Santa Cruz County are discussed.

The classification effort generated 41 resource classes, 13 which represented sites dominated by hardwoods. Figure 3 shows the relative brightness of reflected light for each hardwood class plotted at the four wavelengths where the reflected light was measured. The two basic trends seen for these hardwood signatures reflect the differences between classes heavily vegetated by oaks (*Quercus* spp.) mixed with lesser amounts of brush, and hardwood classes dominated by tanoak and madrone (Pillsbury *et al* 1981). The two trends shown in Figure 3 aid in the separation and identification of these resources. A verification study indicated that the ability of LANDSAT data to correctly classify the resource type is about 85%.

LANDSAT classification systems such as the one discussed above have shown their potential for fast cover type classification for extensive areas at reasonable cost.

HARDWOOD INVENTORY NEEDS

The task of inventorying the hardwood regions defined by Griffin and Critchfield (1972) needs to be completed. They have mapped the range of 86 forest and woodland species at a scale of about 1:5,000,000. A comprehensive inventory

[4]Personal communication, 1981, Charles Bolsinger, Renewable Resources Evaluation Unit, Pacific Northwest Forest and Range Experimental Station, Portland, Ore.

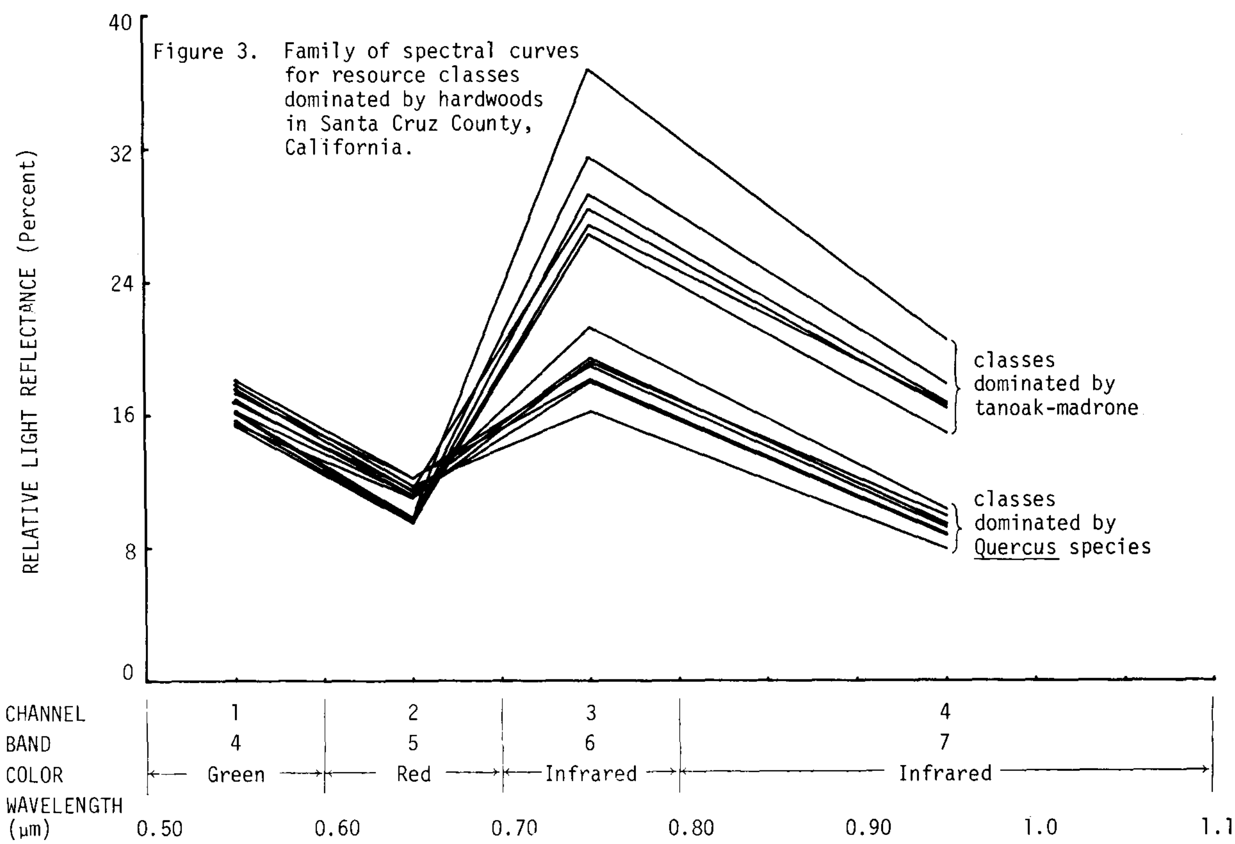


Figure 3. Family of spectral curves for resource classes dominated by hardwoods in Santa Cruz County, California.

that shows the actual location of hardwood forests is needed by land managers for resource planning and management.

Although a number of volume tables have been or are being developed, there are still a large number of important hardwood species that have not been studied in California. Efforts to generate these tables will provide information that is needed in many parts of the State.

The type of inventory that is needed most is one that will provide information useful for stand management. Only a few selected stands in California have been or are currently being measured to provide stand and stocking tables, site, and growth and yield data. Land managers need to have this information in order to make the basic land use decisions, such as, should they convert their hardwood forests and woodlands to another use or should they manage the land for forest values? Currently these decisions are being made without the benefit of adequate stand inventory information.

In addition to the inventory needs discussed here, little is known about California's hardwood forests in the general disciplines of autecology, silviculture, protection, wildlife, range, and recreation impacts. Nonetheless, the inventories discussed here represent the initial development of a data base necessary for developing a management and protection plan for the hardwood forests in California.

LITERATURE CITED

Anderson, J. R.; Hardy, E. E.; Roach, J. T.; Witmer, R.E. A land use and land cover classification system for use with remote sensor data. Washington, D.C.: U.S. Gov. Print. Off.; Geol. Surv. Prof. Paper 964. 28 p.

Barrette, Brian R.; Jackman, Raymond E. Jackson State Forest-Caspar Orchard Eucalyptus Grove, History and volume tables. Sacramento, Calif.: Dep. of For.: 1974; State Forest Note No. 57. 6 p.

Berry, W. S.; Wiant, Jr., H. V. Preliminary test of tree volume tarif tables for determining stand volume in tanoak. Div. of Nat. Res., Forestry, Humboldt State College, Arcata, Calif.: 1965 September; Res. Rep. No. 3. 5 p.

Berry, W. S.; Wiant, Jr., H. V. Sampling for tarif number and volume determination in tanoak stands. J. For. 65(9):650-651; 1967 September.

Grosenbaugh, L.R. STK-Fortran 4 program for estimates of tree populations from 3P sample-tree-measurements. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1967; Research Paper POW-13, revised.

Harrington, T. J.; Pillsbury, N. H.; Barrette, B. A gross volume table for California white oak in Monterey and San Luis Obispo counties. Sacramento, Calif.: Dep. of For.: 1979; State Forest Note No. 77. 4 p.

Hornibrook, E. M.; Larson, R. W.; VanAkkeren, J. J.; Hasel, A. A. Board-foot and cubic-foot volume tables for some California hardwoods. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1950; Res. Paper No. 67. 31 p.

Margolin, Louis. Yield from Eucalyptus plantations in California. Sacramento, Calif.: California Board of Forestry: 1910; Bulletin No. 1. 38 p.

McDonald, Philip M. A local volume table for Pacific madrone, tanoak, and California black oak on a good site in north-central California. Redding, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: (manuscript in preparation).

Pillsbury, Norman H. Hardwood stand density characteristics for Central Coast counties in California. Salinas, Calif.: Central Coast Resource Conservation and Development Area: 1978. 32 p.

Pillsbury, Norman H.; Stephens, J. A. Hardwood volume and weight tables for California's Central Coast. Sacramento, Calif.: Dep. of For.: 1978. 54 p.

Pillsbury, Norman H.; Stephens, J. A.; Jackman, R.; Barrette, B. Weight tables for hardwoods in Central Coast counties, California. Sacramento, Calif.: Dep. of For.: 1978; State Forest Note No. 70. 4 p.

Pillsbury, Norman H.; Brockhaus, J. A. Tree photo volume and weight tables for California's Central Coast. Salinas, Calif.: Central Coast Resource Conservation and Development Area: 1979 October.

Pillsbury, Norman H.; Williamson, D. P. The landowners guide for fuelwood marketing opportunities in the Central Coast. Forest Service, U.S.D.A., State and Private Forestry, San Francisco: 1980 June. 13 p.

Pillsbury, Norman H.; Brockhaus, J. A. Hardwood inventory maps for California's Central Coast. Sacramento, Calif.: Dep. For.: 1981. 4 maps and pamphlet.

Pillsbury, Norman H.; Brockhaus, J. A.; Brass, J. A LANDSAT classification of the forest resources of Santa Cruz County, California, A demonstration project. Moffett Field, Calif.: NASA, Applications Branch: (final report for NASA contract #NCA2-08678-001, publication forthcoming).

Plumb, T. Technical Coordinator. Proceedings of the Symposium on the ecology, management, and utilization of California oaks, June 26-28, Claremont, Calif. Berkeley, Calif.: Pacific Southwest For. and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Tech. Rep. PSW-44. 368 p.

Porter, D. R.; Wiant, Jr., H. V. Site index equations for tanoak, Pacific madrone, and red alder in the redwood region of Humboldt County, California. J. For. 63:286-287; 1965.

Powers, Robert F. Site index curves for unmanaged stands of California black oak. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1972; Res. Note PSW-262 5 p.

State of California, Dep. of For.. Markets for woodland products in California. Wood Energy Program, Sacramento; 1980 May. 83 p.

Wiant, Jr., H. V.; Berry, W. S. Cubic-foot volume and tar if access tables for tanoak in Humboldt County, California. Div. of Nat. Res., For., Humboldt State College, Arcata, Calif.: 1965; Res. Rept. No. 2. 10 p.

Screening *Prosopis* (Mesquite or Algarrobo) for Biofuel Production on Semiarid Lands[1]

Peter Felker, Peter R. Clark, G. H. Cannell, and Joseph F. Osborn[2]

Abstract: Eighty collections of Prosopis have been screened in field experiments for biomass production, frost tolerance, and heat/drought tolerance. Selections have been examined in the greenhouse for nitrogen fixation and salinity tolerance in which one species grew on a nitrogen free media in salinities equivalent to seawater. A 44 percent sugar pod producer was identified and successfully fermented to ethanol by Avgerinos and Wang at MIT. Individual trees have grown 5 to 7 cm in basal diameter and 2 to 3.2 meters in height per year with 600 mm total water application. Dry matter production of 14,000 kg/ha has been obtained at projected harvested costs of $23.00 per ton or $1.35 per million Btu and compare favorably with natural gas, heating oil, and coal at $3.0, and $6.0, and $1.50 per million Btu's respectively.

In many regions of the world, wood is an energy source that is locally available, decentralized, and requires little capital expenditure for either acquisition or conversion to useful forms of energy. In the last 5-8 years these characteristics have led wood to overtake nuclear energy as an energy source for the United States without the enormous federal expenditures of the nuclear R & D program (Smith, 1981).

In some lesser developed countries (LDC's) the lack of wood availability is a severe problem. Laborers in Ouagadougou, Upper Volta may spend 30 percent of their income on cooking fuel (Anon, 1980). In the same region woodcutters must travel 60 km from the city to obtain wood. Virtually all of these rapidly depleting wood resources come from natural stands of unselected genetic stock. In the semi-arid regions much of this wood is either Acacia or Prosopis which possess self-incompatible flowers which result in an outcrossing breeding mechanism (Self-el-Din, pers. comm; Simpson, 1977). Thus seed propagated progeny from Acacia or Prosopis are exceedingly variable in biomass production, thorniness, insect resistance, etc. so that artificial regeneration attempts using seed sources can yield disappointing and variable results. Thus seed collections, progeny production trials, and development of superior clonal propagules will ultimately be required to support wood energy based rural economies.

In the screening of new plants for biofuel production it is important not to rule out a particular natural ecosystem because of low productivity since the biomass productivity of natural stands provides little insight into productivity possible for managed food or fuel production systems. The productivity of wild oats growing along a highway or of wild progenitors of corn such as teosinte or tripsacum growing in Mexico bear little resemblance to oat productivity on commercial South Dakota farms or to hybrid corn production on Illinois farms.

In the screening of plants for biomass production or in the evaluation of the productivity of natural stands, screening for a single process such as photosynthesis or nitrogen fixation is to be avoided. To illustrate, plant physiologists have stated the reason P. tamarugo survives so well in the northern Chilean rainless salars is because of its capability to extract water from the atmosphere, or from its ability to develop a moist matted root zone, or because it possesses extremely high salt tolerance. While P. tamarugo is more salt tolerant than its near P. alba relatives (Felker et al., 1981c), it possesses 20 fold less biomass productivity than many other Prosopis species (Felker et al., 1981a). We feel the real key to P. tamarugo success in the Chilean salars is its complete resistance to psyllid insects. If algarrobo (P. alba (?)) trees possess moderate to good psyllid resistance they will tolerate the salinity, heat and low humidity of the salar de Pintados equally as well as P. tamarugo (Felker mss). Algarrobo trees in this region nearly devoid of leaves exhibit high psyllid predation while healthy green algarrobo's are devoid of psyllids (Felker, mss).

With the exception of the United States wood pulp industry, which uses "scrap" bark for electrical generation and process heat, and of several Brazilian industries, wood is not used as an energy source in commercial scale operations. In the United States the primary energy use of wood probably has been the widespread use in family dwellings (Smith, 1981).

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystem. June 22-26, 1981, San Diego, California.

[2]Assistant Research Scientist, Caesar Kleberg Wildlife Research Institute, Texas A&I Univ., Kingsville, Texas; Staff Research Associate, Professor of Soil Physics, and Staff Research Associate, University of California, Riverside, Riverside, California.

We believe that areas such as south Texas where extensive flatlands are available at reasonable land leases ($10 acre^{-1} year^{-1}), where low sulfur coal must be shipped more than 1,000 miles, where possibilities for co-generation of process heat and electricity exist, and where a need for tax shelters for biomass type investments are attractive - that woody biomass production from plantation grown trees can and will favorably compete with traditional energy sources in small commercial (20 megawatt) power generating plants. Managed even-aged, uniform small diameter stands of regularly and closely spaced trees are expected to be easier and less expensive to harvest than uneven aged stands of greatly differing size classes, that occur in random densities and spacings. The large quantities of wood or fuel required for commercial sized power plants or for chemical feedstocks and the sensitivity of transportation costs to distance, mandate rapid and renewable biofuel production close to the site of utilization. Since harvesting and transportation costs play a major role in the economics of wood biofuel production, dedicated biomass plantations of easily harvestable, even stands of highly productive selected strains offer significant advantages over some natural stands.

The work which follows is a result of U. S. Department of Energy sponsored research to develop woody biofuels for marginal semi-arid lands.

GERMPLASM ACQUISITION PROGRAM

In developing any new crop plant it is imperative to obtain as much genetic diversity as possible to be able to provide products of various qualities, and to be able to adapt to stress conditions such as heat, drought, insect predation, frost and salinity. Our Prosopis collection consists of: approximately 150 accessions obtained from Professor Solbrig which were used in the IBP project comparing North and South American deserts; of 150 collections of native Prosopis collected on a 3,000 mile field trip through the California desert; of 300 Peruvian collections obtained through contract with Dr. Alva of Lima, Peru; of approximately a dozen tamarugo (P. tamarugo), algarrobo (P. alba?), and chanar (Geoffrea decorticans) collections made by Felker in Chile; of several hundred second generation progeny of UCR and Imperial Valley grown trees; of miscellaneous collections from Argentina, Hawaii, the Caribbean, Senegal, Sudan and South Africa, and of a very limited number of cuttings of approximately a dozen clones.

NITROGEN FIXATION AND SALINITY TOLERANCE

Representatives of twelve Prosopis species were inoculated with a rhizobia strain isolated from the California desert and grown for 8 months on inert vermiculite that was watered with a nitrogen-free nutrient solution. The capability of mesquite to fix nitrogen was firmly established since all species were found to nodulate, fix nitrogen (reduce acetylene to ethylene) and accumulate dry matter on nitrogen free media (Felker and Clark, 1980). A ten fold range in mean nitrogen fixation per accession was observed which suggests the possibility for selecting lines with high nitrogen fixing characteristics.

Having established that mesquite could fix nitrogen in a greenhouse environment an experiment was conducted to determine why mesquite had never been reported to nodulate in natural ecosystems. A phraeatophytically grown mesquite was simulated in a 3.05 m tall soil column with water or nutrient solution only being added to a soil-containing bucket beneath the soil column (Felker and Clark, mss). Sixteen months after the seedings were planted, the top 0.5 m layer of soil was drier than 2200 kPa (22 Bars) but the bottom of the tube which received frequent irrigations never experienced water potentials more negative than -70 kPa. Acetylene reduction assays conducted through ports in the soil column observed no nitrogen fixation within 2.7 m of the surface although large quantities of nitrogen fixation (1.9 mg ethylene per hr) were fixed at the bottom. This nitrogen fixation occurred at leaf xylem water potentials of 3000 kPa (30 Bars) and air temperatures of 44°C. After the assays were conducted the tubes were disassembled and the roots examined for presence of nodules as a function of depth. No nodules were observed in the top 2.7 m although over 100 nodules were located at the bottom of the tube in the moist root zone (Felker and Clark, mss). Nodules probably have not yet been observed in nature because nodules have not been sought at deep enough depths in moist soil zones.

Species of Prosopis grow near the seacoasts in Hawaii, close to salt flats in southern California deserts, and in 0.5 m thick salt flats in northern Chile which suggests that considerable salt tolerance occurs in the genus. We measured the salinity tolerance of six species in greenhouse sand culture experiments (Felker, et al., 1981c). All species tested, P. glandulosa var torreyana from California P. velutina from Arizona, P. articulata from Baja Mexico, P. chilensis from Argentina, P. pallida from Hawaii, and P. tamarugo from Chile all tolerated a 6,000 mg/L NaCl treatment with no reduction in growth. P. velutina was the only species that poorly tolerated the 12,000 mg/L salinity level. P. articulata, P. pallida, and P. tamarugo tolerated the 18,000 mg/L salinity level with 30-40 percent decrease in height growth and grew slightly in a salinity (36,000 mg/L NaCl) greater than seawater. As these plants were on a nitrogen free media they probably fixed nitrogen. These salinity tolerances are much greater than those of annual legumes such as peas and beans. Prosopis is the first legume we are aware of that has been reported to be able to grow at salinities equivalent to seawater.

FIELD SCREENING EXPERIMENTS

Selections of Prosopis were screened for response to irrigation on the University of California, Riverside experiment station (Felker et al., 1981a); for tolerance to winter freezing temperatures at 1500 m (5,000 ft) elevation in the mountains near Riverside, and for heat/drought tolerance in the California Imperial Valley at minus 30 m (100 ft) where mean daily July maximum temperatures are 42°C.

Thirty-two collections representing North and South American and African germplasm were established on the UCR experiment station in three irrigation treatments in July 1978. Cultural management practices, origin of the germplasm and estimates of the first year's biomass productivity have appeared (Felker *et al*., 1981a). Twelve trees of each accession were grown in each of three basins that were irrigated when the soil water potential at the 30 cm depth reached either 60 kPa (0.6 Bars), 200 kPa (2 Bars) or 500 kPa (5 Bars). Riverside has a mediterranean type climate with no summer rainfall that makes imposition of these treatments possible. In the first season six-100 mm irrigations were applied to most of the wet (60 kPa) plots while no irrigations were made to the dry (500 kPa) plots. In the second season differences between treatments were not observed for *P. chilensis* which was the accession with the greatest biomass production. Consequently in the third growing season the dry (500 kPa) treatment received only winter rainfall and no irrigation to force differences between treatments.

At the end of the third season the trees were harvested, weighed, stem diameter measurements taken, and selected whole trees homogenised (chipped) to obtain subsamples for moisture content determination. Regressions of log dry biomass versus log stem diameter, which have been shown to be most satisfactory for mesquite biomass estimation (Felker *et al*., 1981b), were computed for dry biomass prediction. The estimated dry biomass at the end of the third growing season is presented in Table 1. Five accessions had zero biomass because they were killed during the first winter by an abnormally low -5°C freeze. Three of the accessions killed by the freeze *P. juliflora* (0044), *P. pallida* (0140) and *P. pallida* (0041) had substantial biomass the first year while the *P. africana* accessions did not. The ranked order for the biomass producers were approximately the same in the third season as for the first season as previously reported (Felker *et al*., 1981a) with *P. chilensis* (0009) having the greatest biomass productivity among all accessions. The 18 fold range in biomass productivity the first year was similar to the 20 fold range observed the third year. The accessions from the ranges of the southwest i.e. 0028 from West Texas, 0074 from New Mexico, and 0080 from Arizona were among the least productive accessions in both studies. Excluding those accessions which were killed by frost, *P. tamarugo* increased in order of biomass productivity from 26th to 19th.

The response of the accessions to irrigation treatments changed considerably from year one to year three, since in year one the 200 kPa treatment had the lowest overall productivity while in year three it had the highest productivity.

The biomass productivity in table 1 is expressed as dry kg/tree rather than dry kg ha^{-1} because there were only 12 trees of each moisture treatment on a 4x3 array so that a substantial edge effect could not be avoided. Nevertheless it is useful to have an order of magnitude estimate of the biomass productivities in these plots realizing that edge effects have not been accounted for, and that these productivities could over-estimate actual productivity by 50 percent. As the trees were on a 1.22 x 1.22 m (4 ft) spacing the density was 6718 trees/hectare. The 3 season total dry matter production ranged from approximately 2500 kg ha^{-1} for *P. kuntzei* to 50,000 kg ha-1 for *P. chilensis* or an annual productivity of approximately 800 to 16,000 kg ha^{-1} respectively. The rangeland accession 0074 from New Mexico had a 3 season average dry matter production of 9200 kg ha^{-1} or 3000 kg ha^{-1} $season^{-1}$. The least productive accessions did not have complete canopy closure and probably experienced less of an edge effect than the more productive accessions which achieved complete canopy closure in the second season.

A biomass screening trial under heat/drought conditions was conducted on 55 tree legumes in the California Imperial Valley where the July daily maximum temperature is 42°C (108°F) and the mean annual rainfall is 65 mm (2.5"). Total water received by the plot the first season was 400 mm (16") in three irrigations and the total the second season was 680 mm(27") in a single irrigation in January preceding the second growing season. At the end of the second season four blocks of 55 trees each were harvested and representative whole trees oven dried so that regression equations could be developed to estimate biomass on companion plots of the same age. The mean measured oven dry biomass per accession for these second season (1 3/4 year old) trees ranged from 0.23 to 36.8 kg. Individual trees ranged from 0.2 to 56.3 kg oven dry biomass. The largest trees exceed 6 m height and 16 cm basal diameter. Progeny of California ornamental *Prosopis alba* (?) had the greatest biomass. The California native *P. glandulosa* var *torreyana* exhibited a wide range in biomass. The least productive accessions were *P. tamarugo* from Chile and *Olneya tesota* from California deserts. *Parkinsonia aculeata* and *Leucaena leucocephala* (Hawaii Giant K-8) ranked 4th and 14th in mean biomass per accession respectively. Trees in three accessions had a 45 kg oven dry biomass that have been cloned. Since this biomass was obtained in two seasons on a 1.5 x 3.6 m (5 x 12 ft) spacing we project a 45 kg tree average should be possible over large areas from clonally propagated trees in 3 seasons. At a 3 x 3 m spacing this would yield 50 metric tons per hectare for a 3 season annual production of 16 metric tons (7 dry english tons $acre^{-1}$ $year^{-1}$). This production level is assumed in economic section that follows later.

Table 1

Predicted UCR Third Season Dry Biomass Per Tree

Species	Accession Number	Biomass per tree (Kg) Irrigation treatment 60kPa	200kPa	500 kPa	Average
P. chilensis	0009	6.96	8.15	7.34	7.49
P. alba	0039	7.44	5.55	5.85	6.29
P. alba	0098	4.08	6.73	6.44	5.58
P. articulata	0016	5.40	6.22	4.70	5.44
P. alba	0137	5.54	6.18	4.18	5.33
P. alba	0013	5.33	5.61	4.51	5.11
P. nigra	0133	3.71	5.55	4.02	4.45
P. alba	0132	4.24	7.00	2.07	4.44
P. alba	0138	5.28	4.24	3.43	4.32
P. spp	0108	5.48	5.60	1.79	4.26
P. alba	0037	4.04	4.76	3.98	4.25
P. glandulosa var torreyana	0001	3.24	4.21	5.11	4.19
P. velutina	0025	3.08	3.82	3.46	3.45
P. alba	0134	2.98	4.08	3.28	3.45
P. nigra	0038	3.32	3.70	2.89	3.30
P. velutina	0020	3.94	2.25	2.83	3.00
P. spp	0116	2.15	3.18	3.72	3.00
P. laevigata	0114	2.03	4.07	2.40	2.87
P. nigra	0036	2.99	2.89	1.95	2.64
P. velutina	0032	2.38	4.09	1.44	2.64
P. spp	0028	1.42	2.22	1.39	1.69
P. tamarugo	0042	1.66	1.43	1.88	1.66
P. spp	0074	1.06	1.82	1.24	1.37
P. spp	0080	1.31	1.69	1.03	1.34
P. nigra	0034	0.83	1.36	0.95	1.05
P. ruscifolia	0131	1.01	1.80	0.39	1.05
P. kuntzei	0130	0.23	0.50	0.39	0.37
P. juliflora	0044	0.00	0.00	0.00	0.00
P. pallida	0140	0.00	0.00	0.00	0.00
P. pallida	0041	0.00	0.00	0.00	0.00
P. africana	0045	0.00	0.00	0.00	0.00
P. africana	0040	0.00	0.00	0.00	0.00
Mean		3.40y	4.03x	3.05y	3.49

Values followed by the same letter are not significantly different at 5% level as judged by "Student Newman-Keuls Procedure". The regression equation used for prediction of the dry biomass, $\log_{10}$ dry matter (Kg) = 2.247 $\log_{10}$ basal stem diameter (cm) - 0.7538, had an r^2 of 0.84 for 1352 observations.

COLD/FROST SCREENING

A field planting at 1500 m (5,000 ft) elevation in the mountains 60 km from Riverside California was used to screen Prosopis accessions for winter hardiness (Felker et al mss.). Thirty accessions were evaluated as single tree replicates in 21 randomized blocks. A freeze on the UCR experiment station prior to this experiment indicated that the Hawaiian P. pallida, the West African P. juliflora, and the African P. africana could tolerate short duration -1.5°C freezes but not a short duration -5°C freeze. Accordingly these selections were not included in the mountain cold screening trial. At the 1500 m elevation site South American P. alba, P. chilensis, P. nigra and the Baja Mexico P. articulata species tolerated a -5° freeze but not a 12 hr freeze that included a -5° freeze. The longest duration freeze was tolerated by the North American species P. glandulosa var glandulosa, P. glandulosa var torreyana, and P. velutina with only moderate damage. In general biomass production, predicted from regression equations, was greater for cold sensitive South American accessions than slower growing cold-hardy N. American accessions. However, a few cold hardy N. American accessions were fast growers and a few fast growing S. American accessions were cold hardy. Individual trees from these latter categories were dug up for future germplasm breeding studies.

Table 2. Energy Costs for Coal, Natural Gas, Oil & Wood

Commodity	Unit Price	Price 10^{+6} Btus
Natural gas	$3.0 MCF	$3.00
Crude oil	$35 BBL	$6.00
Western Coal	$25 ton	$1.48
Mesquite chips*	$23 dry-ton	$1.35

* Plantation grown Mesquite averaged over 9 years (3 harvests).

ETHANOL PRODUCTION FROM MESQUITE PODS

The proximate analysis for mesquite pods shows a range of 11-17 percent crude protein, 20-30 percent fiber, and 13-44 percent sucrose (Felker et al., 1980; Avgerinos and Wang, 1980; Becker and Grosjean, 1980). Fermentation of high sugar content Prosopis pods to alcohol for use in the transportation sector is attractive because unlike high moisture content sorghum and sugar cane, the pod sugar is dry and non-perishable and at 44 percent sucrose is considerably higher than most plant sources. Perhaps even more important, unselected mesquite strains presently occur on 30 million hectares of semi-arid marginal land in southwestern United States. This large land resource base is crucial to development of energy or chemical feedstock crops because of the enormous quantities of fuel or chemical feedstocks (10-100 tons/hr) consumed by commercial scale chemical manufacturing or power plants.

A recent workshop sponsored by the Solar Energy Research Institute (SERI) on energy from tree crops contracted with MIT for the fermentation of 2 mesquite pod varieties and one honey locust (Gleditsia triacanthos) pod selection. A P. alba x P. velutina hybrid mesquite tree which produced 73 kg of 40 percent sugar pods identified by Felker et al. (1980) was included in these fermentation trials. According to the MIT analyses the second season hybrid mesquite pods were 43.5 percent sugar. The hybrid mesquite pods had the highest yield and rate of ethanol production of the 3 substrates examined with an ethanol yield of 0.23 g ethanol/ g substrate fed, at a rate of 0.44 g ethanol/L - hr (Avgerinos and Wang, 1980). The resulting enriched protein residue can be sold as livestock food with a considerable by-product credit. Another substantial by-product credit can be derived from galactomannan gums which constitute approximately 25 percent of the seed weight and 3 percent of the pod weight, and are similar in chemical composition to high value ($0.5 kg^{-1}) industrial carob and guar gums.

ECONOMICS OF PLANTATION GROWN PROSOPIS BIOMASS PRODUCTION

The recent rapid escalation in fossil fuel prices and associated transportation costs have made the economics of biomass production appear more favorable. Table 2 lists 1980 natural gas prices in south Texas, current world prices for new crude oil, and prices for western coal delivered by rail to a San Antonio Texas utility.

This $25 per ton price is the subject of current litigation between the railroad and the utility. If the utility loses the litigation, its price for delivered western coal will rise to $33 per ton. Another south Texas utility, Central Power and Light, pays $45 per ton for 8,200 Btu/lb western coal that is of the same energy density as mesquite wood (Wiley and Manwiler, 1976). Plantation grown mesquite wood at $23.00 per dry english ton is the cheapest energy source, the only renewable energy source, and the least likely of all to escalate in price.

Table 3 outlines plantation grown mesquite wood chip production cost estimates. A land lease of $10 per acre per year is approximately double the return for south Texas cattle ranching (Herbel, 1975). Site preparation costs of $178 assume the site has moderate brush which must be bulldozed, stacked, burned, and the resulting field disced into a normal seedbed. No credits are assumed

Table 3. Mesquite Wood Chip Production Cost Estimates.

Item	Costs per Harvest per Acre		
	Initial Planting	Stump Resprout	Stump Resprout
Land lease 3 yrs at $10/yr	$30	$30	$30
Site preparation Bulldozing, discing, etc.	178	--	--
Seedling costs 436 @ $0.10 each	44	--	--
Planting costs	14	--	--
Herbicides	20	--	--
Fertilizer (P, K, S)	67	67	67
Total Production Cost	$353	$97	$97
Product (7 tons $acre^{-1}$ yr^{-1} x 3 yr)	21 tons	21	21 tons
Production cost per dry ton	$16.80	$ 4.60	$ 4.60
Harvesting cost per ton	14.00	14.00	14.00
Total Cost per ton	$30.80	$18.60	$18.60
Average cost per ton averaged over 9 years $22.70/ton=$1.33/10+6 Btu			

for harvesting existing brush for boiler fuel, cordwood, or mesquite lumber which sells for luxury prices of $4-5 per board food (Mouat pers. comm.). Seedling costs assume the trees are planted on a 10 ft x 10 ft spacing for 436 trees/acre at a cost of $0.10 each which is slightly under our current production cost of $0.12 per seedling. Planting costs assume use of mechanical transplanter capable of planting 1,000 trees per hour with a three man crew. Herbicide costs assume a 1.5 quart application of trifluralin per acre prior to transplant and a 2 lb/acre simazine application 4 months after transplant. Fertilizer costs are calculated to replace nutrients removed in biomass and assume 220 lbs of triple superphosphate, 300 lbs of muriate of potash (60 percent K_2O), and 50 lbs of granulated sulfur in a single application at transplant. No nitrogen is required since Prosopis can fix its own nitrogen (Felker and Clark, 1980). The total production cost for the first 3 year rotation is $353 per acre. Prosopis coppices or resprouts from the stump so that subsequent rotations will avoid site preparation costs, seedling costs, planting costs, and herbicide costs. Total production costs for subsequent coppice rotations are projected to be $97 per acre.

As discussed earlier, we project a 7 dry ton acre^{-1} year^{-1} aboveground biomass production for Prosopis in south Texas. We have not measured the biomass production of the coppice regrowth but visual estimates of regrowth of Imperial Valley plantings appear larger than from first year seedling production. Due to large carbohydrate root reserves, coppice regrowth is often more productive than initial seedling production.

Harvesting costs assume use of the mesquite combine developed by Dr. Ulich at Texas Tech University. This combine is a modified 130 hp diesel Massey Ferguson tractor which can harvest 4 tons per hour in light stands at a cost of $14.00 per dry ton (Ulich, 1980). Total harvested costs are $30.80 for the first rotation and $18.60 for subsequent rotations or an average of $22.70 over 9 years (3 rotations). As the number of coppice rotations increases, the average cost per ton would approach $18.60 per ton ($1.09 per million Btu's). This crude economic analyses does not include a profit, or return on the investment but it does include a significant return to the landowner in the form of land lease.

Some inexpensive energy sources do not readily lend themselves to deliver the huge quantities of energy currently used in the United States. Figure 1 graphically expresses the size biomass farms required to power commercial sized power plants assuming a 33 percent Btu to Kwh conversion efficiency.

This graph assumes an unrealistic 100% use of land area encompassing the electrical generation facility and avoids areas required for access roads, municipalities, etc. Nevertheless, it provides a concept of the size of biomass farm required for electrical generation. At our projected yield of 7 dry tons acre^{-1} year^{-1} a circle of radius of 1.38, 4.35, 6.15, and 13.75 miles would be required for 5, 50, 100 and 500 MW power plants respectively. A 50 MW plant provides enough electricity for approximately 50,000 people.

The land/water resource base in south Texas has sufficiently high rainfall (20-27" annually) and land area (55 million acres in Texas are currently occupied by mesquite) to appear feasible to support biomass plantations large enough for commercial size electrical generating facilities.

Land/water resources in California are more limited but use of saline irrigation drainage water in San Joaquin and Imperial Valleys, and use of shallow (1-4 ft) saline groundwater in San Joaquin Valley might support commercial sized electrical generating facilities.

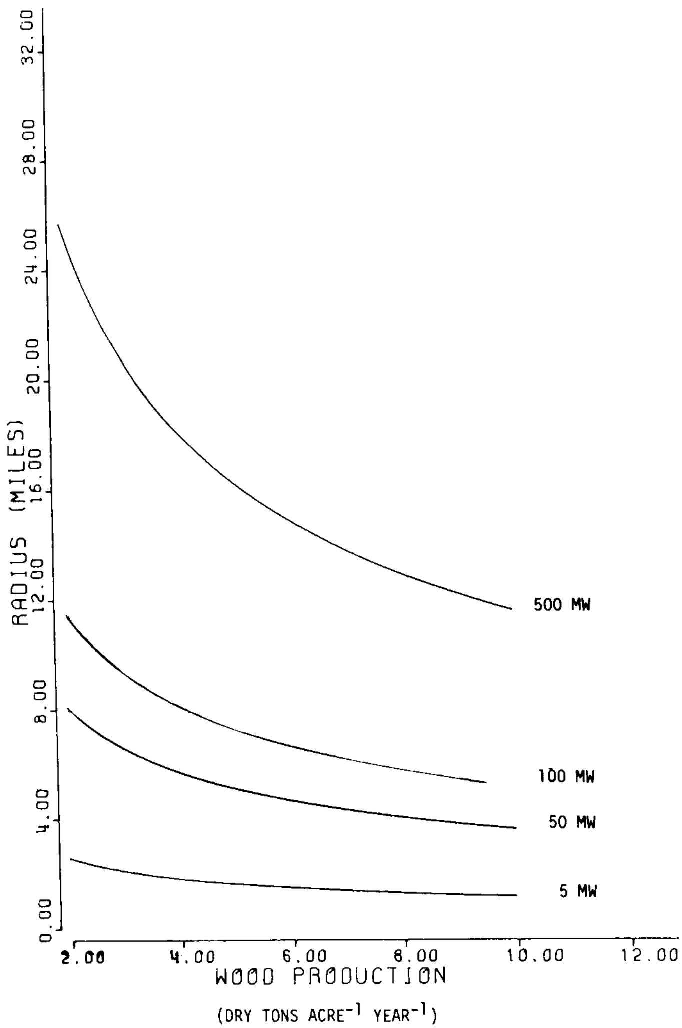


Figure 1- BIOMASS FARM RADIUS AND PRODUCTION LEVELS REQUIRED FOR ELECTRICAL GENERATION AT 33% $\frac{KWH}{BTU}$ CONVERSION EFFICIENCY

ACKNOWLEDGEMENTS

The financial support of the U. S. Department of Energy, Grant Number ET-78-G-01-3074 and of the Caesar Kleberg Wildlife Research Institute is gratefully acknowledged.

LITERATURE CITED

Anon. Firewood Crops - Shrub and tree species for energy production - National Academy of Sciences, Washington, D. C. 1980.

Avgerinos, G. C.; Wang, D.I.C. Utilization of mesquite and honey locust pods as feedstocks for energy production. Proc. Workshop on tree crops for energy co-production on farms. Solar Energy Research Institute, Golden, Colorado. 1980: 239-217.

Becker, B.; Grosjean, O.K. A compositional study of pods of two varieties of mesquite (Prosopis glandulosa, P. velutina) J. Agric. Food Chem. 28:22-25: 1980.

Felker, P.; Clark, P. R. Nitrogen fixation (acetylene reduction) and cross inoculation in 12 Prosopis (mesquite) species. Plant and Soil 57: 177-186; 1980.

Felker, P.; Clark, P.R.; Osborn, J.F.; Cannell, G.H. Utilization of mesquite (Prosopis spp) pods for ethanol production. Proc. Workshop on tree crops for energy co-production on farms. Solar Energy Research Institute, Golden, Colorado. 65-78; 1980.

Felker, P.; Cannell, G.H.; Clark, P.R. Variation in growth among 13 Prosopis (mesquite) species. Expl. Agric. 17:209-213; 1981a.

Felker, P.; Clark, P.R.; Osborn, J.F.; and Cannell, G.H. Biomass estimation in a young stand of mesquite (Prosopis spp), ironwood (Olneya tesota), leucaena (Leucaena leucocephala) and palo verde (Cercidium floridium and Parkinsonia aculeata). J. Range Manage. In press. 1981b.

Felker, P.; Clark, P.R.; Laag, A.E.; Pratt, P.F. Salinity tolerance of the tree legumes mesquite (Prosopis glandulosa var torreyana, P. velutina, and P. articulata, algarrobo (P. chilensis, kiawe (P. pallida) and tamarugo (P. tamarugo) grown in sand culture on nitrogen-free media. Plant and Soil. In press. 1981c.

Herbel, C.H. Utilization of grass and shrublands of southwestern United States. In management of semi-arid ecosystems. Elsevier Publ. Co. New York. 1979; 186.

Simpson, B.B. Breeding systems of dominant perennial plants of two disjunct warm desert ecosystems. Oecologia (Berl) 27:203-226; 1977.

Smith, N. Wood: An ancient fuel with a new future. Worldwatch paper 42. World watch Institute, Washington, D. C. 1-48; 1981.

Ulich, W.L. Harvesting and potential utilization of mesquite brush. Paper presented at Texas Section "American Society of Agricultural Engineers". San Angelo, Texas. Oct. 30, 1980.

Wiley, A.T.; Manwiler, F.G. Market potential of mesquite as a fuel. Forest Products J. 26:48-51; 1976.

The Potential of Utilizing Chaparral for Energy[1]

James R. S. Toland[2]

Abstract: The world energy crisis has caused the United States and other countries to start developing technology for alternative energy systems. Biomass is a versatile fuel with many end uses. Chaparral has the potential to be harvested for energy production from direct utilization, conversion to alternative energy crops such as Jojoba, and by providing energy production sites for techniques such as wind generator farms and solar arrays. This would approach the umbrella objective of reducing the fire-flood sequence thus saving damage costs and energy. Chaparral harvesting techniques need further development, but enough equipment exists to start pilot testing.

ENERGY ASPECTS OF CHAPARRAL

Little did Georgius Agricola of Saxony realize in 1553, when he authored a book on substances in the ground, that the term he invented called "petroleum" would become perhaps the most significant word in any language in the late 20th century (Hoover 1912). Petroleum, then in limited use for heating and lighting, went on to fuel modern civilization in almost every facet of life. Four hundred twenty years later (1973), the world awoke to the realization of the "energy crisis."

Throughout the history of human civilization, mankind has shown a remarkable ability to paint itself into a corner. The resulting crisis, whether it be famine, war, economic peril, or some other circumstance, traditionally brings the world to a crossroad. When it does this, two options usually emerge for the nations of the world. The first option is a strong tendency to become nationalistic or really isolationistic. The second option, more rarely invoked, is to cope with the crisis by motivating the entire population to join forces. Conceivably, the energy crisis could unite the four billion citizens of this planet into recognizing that what is best for the world may also be best for the individual nations.

This may be overly optimistic, given the current political state of the world today. In any case, those nations who must import energy--non members of the Organization for Petroleum Exporting Countries (OPEC)--certainly have a strong motivation to cooperate in research and development of alternative energy sources. It is sobering to realize that of the known petroleum reserves, OPEC controls 70 percent, Communist countries control 16 percent, which leaves 14 percent available in the free world (Van Syck 1980). Although each country must organize and attack the energy issue, there is still a strong need to concomitantly work with other countries. Here in the United States, the response to the energy crisis has finally reached the point where one can dare to be optimistic. We are a long way from energy self-sufficiency, but there are some encouraging indicators.

1. A concerted National energy policy is developing in practice--not just on paper.

2. Energy conservation is finally understood by every citizen and stringent efforts to reduce consumption are becoming a way of life. Candidly, only a modest amount of this conservation effort is attributable to altruistic motivation; most is due to one factor--Cost! However, we will cheerfully accept the composite result, which is a well-defined energy conservation effort showing dramatic reductions in energy consumption.

3. We have awakened to the realization that no single entity can solve the problem--not Government, not industry, not labor, not some other country. Rather, we observe a concerted effort evolving to confront the crisis and tackle the solution with less shouting, hair-pulling, and accusations of who caused the problem.

Realistically, any cooperative progress at this stage may be best described as embryonic, but encouraging, nonetheless. I propose to you that this approach is transportable--exportable to the rest of the world. It is true that many countries are seriously involved in the same struggle. The purpose here is merely to remind you of the need for continued and expanded mutual cooperation in energy development. There is a need to look calmly and cooperatively at the achievable rather than dwell upon the dimension

[1]Presented at the Symposium on Dynamics and Management of Mediterranean--Type Ecosystems, June 22-26, 1981, San Diego, Calif.

[2]Energy Coordinator, Forest Service, U.S. Department of Agriculture.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

of the catastrophe. The world does not lack alternative energy, only the facilities to utilize what already exists. As the world supply of petroleum and natural gas diminishes and the price escalates, we must turn to other energy sources.

The seriousness of the situation can be graphically illustrated by a quick look at the energy situation in the State of California. The State consumes more energy than any other State and depends upon fossil fuels for 90 percent of total energy needs. Of that total, 54 percent must now be imported from other States and countries (Teller, 1981). It is imperative that the State and the Nation develop alternative energy sources.

The Use of Wood for Energy

In the near term, wood combustion is one of the more promising alternative fuel technologies. The process technology is known, package systems are available, less pollution is generated than for most other alternatives, and the technology for economically harvesting the resource exists or is under development. Wood can be chipped, densified into pellets and briquets to improve its fuel qualities, distilled into alcohol, gasified, pyrolyzed to produce oil and charcoal, and converted to chemicals and plastics to replace petroleum-based products.

The Forest Service has outlined a national program for achieving a goal of 6.4 quads[3] of energy from woody biomass by 1990. There are relatively large quantities of unutilized wood that could be used for energy. This includes logging residues, thinnings, wood manufacturing residues, urban wood waste, and trees and brush that cannot now be economically manufactured into wood products. The Forest Service has estimated that over 25 million tons of this material could be made available on an annual basis in California. Economics currently limit the use of much of this material. However, with increasing petroleum prices and better application of research and development efforts, more is being used for energy each year.

World petroleum prices have leveled off during the last few months and this has given rise to a proliferation of optimistic forecasts. The most reliable look at the future is given in the Global 2000 Report. Very briefly, the projection for energy is spiraling costs and decreased supply.

Achievement of the 6.4 quad goal for woody biomass will have a profound effect on the economy, primarily in rural areas. It will mean at least 300,000 new jobs, $9 billion annually in wood industry receipts, and an equal amount of business for supporting industry. The Forest Service expects an additional $60 million in stumpage receipts plus a savings of $75 million annually in timber management costs. The equivalent of 760 million barrels of oil will be displaced annually by wood energy. The proportionate effect in California would also be significant (U.S. Dept. of Agric., Forest Service 1980).

Chaparral has the potential to play an important role in biomass utilization for alternate energy development. The magnitude of this resource is significant. There are approximately 11 million acres (4,500,000 ha) of this vegetative type of which 1.5 million acres (607,000 ha) are located in San Diego County (Bolsinger 1980). In our relentless pursuit of the hallowed Btu, chaparral deserves special attention.

Until recently, management of chaparral, particularly in Southern California, has been one of fire exclusion. This has involved a major commitment of workforce and funds by fire protection agencies directed toward prevention and, inevitably, to fire suppression. The approach seemed valid: prevent the chaparral from burning and thereby preserve the watershed and the downstream values. The result has been, rather consistently, the well-known fire--flood sequence. Denuded, the steep slopes lose most of their water and soil retaining ability. When the rainy season arrives, runoff is greatly increased, carrying with it topsoil and even rocks. This often results in heavy downstream damage particularly where the drainages meet the urban zone.

During the last few years, a new concept has been evolving--that of vegetation management. This is defined as actually managing the vegetation with objectives that encompass multiple use. The technology is evolving and as it does the premise of vegetation management looks better each year. "Multiple use" means different things to different people, but certainly one main purpose of a vegetative management program is reduction of the number and size of disastrous wildfires. Currently vegetation management is heavily skewed to prescribed burning. Although this is an acceptable interim measure, it does waste tremendous amounts of energy. From the energy perspective, it is equivalent to "flaring" natural gas in the oil fields and refineries, which was formerly the norm.

To illustrate the energy potential of chaparral, a value of 8,6000 Btu per pound is used.[4] Chaparral dry weight loading of 10 tons to 50 tons per acre (22,477 kg/ha to 112,038 kg/ha) are quite common. Energy values, therefore, range

[3]quad = 10^{15} Btu (British thermal unit). This is approximately equivalent to the energy content of one-half million barrels of oil per day for one year.

[4]Personal Communication from Jay Shelton, Wood Energy Research, 1981.

from 172 million Btu per acre to 602 million Btu per acre (426 million Btu/ha to 2,124 million Btu/ha).

A major thrust of vegetation management could be energy production by several approaches, including direct utilization of the existing chaparral biomass, type conversion to alternative vegetation which produces a greater energy return, and by designating special areas for energy production utilizing such devices as windmill farms (Wind Energy Conversion Systems) or photovoltaic arrays. Any of these approaches would have many payoffs, including reduction of conflagrations.

A Vegetative Classification and Inventory System

Before land managers can really begin scientific management of chaparral, there must exist a commonly accepted classification and inventory system. We do have an energy shortage, but we certainly do not have a shortage of classification systems. A search of the literature shows an impressive number of such systems, each based upon different criteria. There is tremendous variation in data, even in the basic factor of total area of chaparral. The most significant breakthrough needed in chaparral management today is an agreement by land protection and management agencies to adopt one classification system and one biomass inventory system. The California Department of Forestry and the U.S. Forest Service are nearing agreement to standardize using the "CALVEG" vegetative classification system. Accomplishing this would be a very worthwhile step. Nationally, a Federal inventory group based at the Forest Service Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., has developed a National vegetative classification system. The CALVEG system is designed to fit within this hierarchical scheme, and this is important.

The Honey Lake Project, discussed later in this paper, has resulted in the development of an excellent biomass inventory system. Computer-based, this system provides a standardized inventory system, currently being used on 15 million acres (6,072,875 ha) of forest land in Northern California. It would be an ideal system for State-wide application. To do this would require agreement of principal land management and protection agencies and the assistance of research in developing accurate coefficients to the degree required. This system is up and running, and would be a highly cost-effective method to implement State-wide.

Chaparral Assessment

Data supplied by the above systems would make possible a complete assessment of chaparral lands integrating all significant information. This, for the first time, would provide a data base needed by chaparral planners and decisionmakers. It can only be accomplished by agreement among land management agencies and the strong support of research.

Alternative Energy Crops

After chaparral on adaptable areas of suitable geomorphology is cleared either by wildfire or harvest, the site would be treated to control brush regrowth. Plantation location, size, and extent of appropriately prescribed energy plants could then be established.

A substantial amount of research and development has been done with some of these energy plants. The plants mentioned here are especially suited for arid or semiarid growing conditions. Collectively, these plants produce a remarkable variety of products including cosmetics, high grade lubrication oils, waxes, rubber, and other chemical feedstock.

Jojoba (*Simmondsia chinensis*) appears to be the most attractive of these plants. The Office of Arid Lands Studies, University of Arizona, provides leadership and coordination for research and development. Several other universities, particularly the University of California at Riverside, private companies and associations are also actively involved in research, development, and pilot testing of this plant. Jojoba seeds contain 50 percent by weight high grade lubrication oil quite similar to sperm whale oil. Results from a 5-year-old plantation show yields of up to 357 pounds per acre (400 kg/ha) (Yermanos 1979).

Guayule (*Parthenium argentatum*) produces a different form of energy--rubber. Emergence of this plant as a source of rubber is not new. During World War II, faced with uncertain supplies of this essential commodity, the U.S. Government established the Emergency Rubber Project and planted 30,875 acres (12,500 ha) in California and the Southwest. Interestingly, this organization was largely staffed with personnel from the U.S. Forest Service. When the war ended, so did the project.

In 1976, Mexico launched a research and development program and has an operating pilot processing plant. In 1978, the U.S. Congress passed the Native Latex Commercialization Act authorizing a renewed research, development, and demonstration project for guayule.

Other plants with apparent energy potential include:

1. Buffalo Gourd (*Cucurbita* spp.)
2. Gopher Plant (*Euphorbia lathyris*)
3. Meadowfoam (*Limnanthes* spp.)
4. South American Mesquite (*Prosopis chilensis*)

Energy farming could also include tree farm crops. Several species of eucalyptus (Eucalyptus spp.), have shown potential for high growth rates with short rotation periods.

Biomass is a very versatile fuel. The major categories include the following:

1. direct combustion
2. gasification
3. pyrolysis
4. chemical production feedstock
5. alcohol production feedstock
6. vegetative type conversion to energy crops.

Each of the above are broad categories and have a number of distinct process variations.

Fuel Processing

Trees and larger brush stems have been used for fuelwood in the past and could form a part of an integrated energy development program. The remainder of the plant with or without the larger component must be chipped, hogged, or densified to facilitate economic transportation. Many types of chippers or hogs already exist which can be ordered off the shelf. Examples include the Fling Demolisher and the Morbark chipper. Some additional development is required to produce an efficient hopper and infeed mechanism to accommodate shrubs instead of logs or slash. For many direct combustion devices, the fuel is now suitable for use. An additional step of reducing the fuel moisture content could improve efficiency and make the fuel suitable for many other types of burners. Densification is a further refinement of chipping or hogging with the added step of applying pressure to produce pellets or briquets.

The California Department of Forestry is the proponent of a contract to produce a prototype mobile densifier. The results of pilot tests with that device should be carefully analyzed. Pressure application devices can also produce products including "Presto Logs" or various sized wafers, flakes, or pellets. The Woodex pelletizer produces a fuel now in wide use. Agri-Fuel is a recent development of Combustion Equipment Associates. This product is a dry, free-flowing powder with a low-ash and low sulfur content, and has a heating value of approximately 8,000 Btu per pound (17,637 Btu/kg). It is suitable for use in many types of furnaces. Obvious advantages include ease of transportation, storage, and handling. The processed fuel or feedstock is also suitable for chemical extraction, alcohol or synfuel production.

Direct Combustion

Residential use of fuelwood for heating and cooking extends from the caveman to modern times. The current resurgence in popularity could not have been predicted just a few years ago. Some of the newly developed fuels, such as briquets or pellets, are suitable for use in existing burning devices without modification. For large-scale use, there is a wide range of commercially available boilers and furnaces with all appurtenances for a complete plant installation. Once a decision is reached on the type of fuel to be used, a complete system can be easily designed for the specific facility.

The proposed Honey Lake Project in Lassen County, California, is an example of an innovative approach to energy production. The project is a hybrid geothermal-wood residue electric power generating facility with a projected output of 50 megawatts.[5] The process involves using geothermal fluid in the temperature range of 240°F to 350°F (116°C to 177°C) to provide heat for three purposes: (1) to preheat the boiler feedwater; (2) to preheat the furnace combustion air; and (3) to reduce the moisture content of the biomass fuel. As planned, the facility would require 1,000 dry tons (907,200 kg) of biomass per day, which is considered entirely realistic. Involved in funding the feasibility studies are GeoProducts Corp.; Department of Water Resources, State of California; U.S. Department of Energy; and the Forest Service.

An example of innovative technology for producing energy is a steam motor called the Gordon-Torquer, currently being tested. This motor incorporates a new method of utilizing steam with a low engine weight to horsepower ratio and appears to have tremendous potential. It is suitable for direct use with geothermal steam or steam generated by any source.

Gasification

This is an old technology which has been updated with many improvements. Off-the-shelf equipment is available to produce low and medium Btu gas. Medium Btu gas can be compressed, and later reconstituted into a variety of petroleum products. Direct use to operate internal combustion engines or to fuel boilers is a common application.

A gasification unit has been recently installed for a hospital in Rome, Georgia, to provide a complete heating and cooling system, replacing the natural gas and oil fired system used previously. The new unit consumes three tons (2,777 kg) per hour of wood chips which have a moisture content

[5] 1 megawatt = 1,000,000 watts.

of approximately 50 percent. The resulting low Btu gas (150 Btu/ft^3) (530 Btu/ds) provides 19,000 pounds (8,618 kg) of steam per hour. Capital cost will be amortized in two years.

During the 1930's, Nazi Germany made heavy investments in the development of wood burning gasification systems for vehicles. This was, of course, motivated by a planned future major war which would limit available petroleum. The Germans brought the technology to a point of complete feasibility. During the World War II, this technology was used extensively throughout Germany and German-occupied countries mostly for civilian vehicles. As petroleum once again became available after the end of the war, gasifiers were quickly replaced and the technology was relegated to history--or so it was thought. Since 1973, renewed interest has brought this system out of retirement, updated it with modern technology and this system could be marketed on short notice (Skou and Papworth 1974). Who knows, in the future, a person may drive into a fuel station and order 10 kilos of wood pellets--perhaps chamise (*Adenostoma fasciculatum*) for short, fast freeway trips, and oak (*Quercus* spp.) for longer trips.

Pyrolysis

Pyrolysis is a process in which an organic material is heated to high temperatures and broken down in the absence of oxygen. The result is that 80 percent of the energy value of the biomass is converted to oil, gas, and char. The relative yields are determined by the temperature. The oil fraction equates approximately to number 6 fuel oil, although the heating value is about 30 percent less, or 12,800 Btu/lb (28,211 Btu/kg). The gas so produced can be utilized to operate the pyrolytic converter. One ton (907 kg) of dry feedstock can produce up to two barrels of oil, 200 to 400 pounds (91 kg to 181 kg) of char, plus a quantity of combustible gas. The oil-char mix can be used (with some adjustment) in conventional oil-fired boilers. The char can be separated and aggregated for use as charcoal. Pyrolysis to produce charcoal only is also a feasible alternative. The State of California Solid Waste Management Board has recently completed and has been testing a mobile pyrolytic converter. Data from pilot testing is not yet available. Other versions of converters are successfully operating in various parts of the country.

Chemical/Alcohol Feedstock

Biomass utilized as a feedstock for chemical and alcohol production show much promise. New, more efficient processes are being developed regularly.

Magnetohydrodynamics (MHD)

This is a process to generate electricity that has the potential for greater efficiency than any other method. The technology is in the advanced research and development stage, but results from subscale tests look promising. Basically, this process involves pumping a gas at high velocity through a tube surrounded by a powerful magnetic field. Electrodes protruding into the gas stream cause an electrical current to flow. Experimental design utilizes coal as a source of the necessary gas. Conceivably, biomass could be used and offers the advantage of much lower emissions of SO_X and NO_X. Highly efficient electrical power generation facilities fueled by biomass with low emission rates would be welcome additions to Southern California, in particular.

Biomass Combustion Emissions

Emissions from large scale wood fueled devices are primarily particulates, consisting mainly of ash and unburned char. Emissions of CO, SO_X and NO_X are sufficiently low that no special control is required.

For particulate control, there are six basic types of emission control systems recommended for use: baghouse, wet scrubber, venturi scrubber, multiple cyclone, electrostatic dry scrubber, and electrostatic precipitator. Each type can be used and, of course, each has advantages and disadvantages. For large-scale devices, the most cost-effective type is the electrostatic precipitator.

Environmental Consideration

Harvesting chaparral for energy will require a thorough Environmental Analysis. Careful consideration must be given to archaeology, rare and endangered flora and fauna, soil erosibility and productivity, nutrient depletion, riparian/pseudo-riparian zones, clear-cut block size, visual impacts, coordination with all landowners and public involvement. Data derived during the comprehensive assessment mentioned earlier would be invaluable.

The Laguna-Morena Demonstration Area located in San Diego County, represents a monumental step in coordinated research and development on chaparral management. It has pulled together the most knowledgeable people to develop vastly improved systems for integrated chaparral management. Harvesting for energy has been considered as an alternative and this project offers the most logical springboard for active demonstration of chaparral harvesting and energy farming.

Harvesting Methods

The motivation for harvesting chaparral to date has been mainly to clear fuel breaks and for type conversion to grass. Since this presented a limited market, the incentive has been lacking for the development of mechanized equipment specifically designed for chaparral. The proposed new objective of chaparral harvesting for energy is economic removal of a maximum volume of surface vegetation with appropriate environmental safeguards. Vegetation may be either cut and piled for later removal, chipped, or densified and removed from the site in one operation. Stumps and root systems must be left intact to encourage sprouting.

Conventional Methods

Clearing by hand has included the use of hand tools, gasoline-powered chain saws, and circular wand saws. The work can be done very selectively and on any type of terrain. However, since this is a labor-intensive method, production is slow and per-unit cost is high.

Mechanized equipment includes tractors of various sizes using either straight bulldozer blades or brush rakes. Although this process effectively removes and piles the brush and production rates are good, two serious disadvantages limit extensive use:

1. Excessive soil disturbance with resulting increased erosion potential.

2. Removal of many root crowns and root systems which restricts resprouting.

Other ground-operated methods such as chaining and mulching are considered inappropriate for energy harvesting because of their many disadvantages such as excessive soil disturbance and mixing soil with the biomass.

The Optimum Harvesting System

Terrain dictates two distinct systems for large-scale harvesting operation.

1. For slopes up to 30 percent, an all-terrain vehicle is needed which cuts, shreds, and self-loads an economic payload free of soil and rock. Equipment must be able to avoid rocks, small groves of vegetation, and even individual specimen plants.

2. A system for harvesting steeper slopes.

Unfortunately, such systems are not yet stocked by equipment dealers. Some vehicular harvesters do exist which at least approach the optimum. If a market for such equipment existed, it is probable that development would rapidly follow. The biomass harvester developed by Georgia Pacific Corporation does perform all the above operations, but current design limits its use to flat land or gentle slopes at the most.

The Shar Twenty manufactured by the Shar Corporation does an impressive job of cutting and shredding brush, but retrieving the debris is not yet perfected. This general type of equipment currently offers the greatest potential.

The ultimate system for steep terrain proposed by several and set forth in detail by Miles and Moini (1980) borrows from the high lead or skyline log yarding system used in many parts of the Western United States.

Such a system could be much lighter in weight and more portable. A ground-operated feller-buncher would cut and stack or windrow the brush. The skyline equipped with tongs would then pick up the material and transport it to a road where further processing would take place. A mobile clipper would reduce the bulk and load it directly onto a truck or storage bins. A densifier could be used on site to produce pellets. Another alternative is to bale the brush much like hay is baled. Transportation could be by truck or large-capacity helicopter. The possibility exists to utilize the biomass on site in a mobile pyrolytic converter. Another "ultimate" system is a harvester similar to the Shar Thirty Machine which would deposit shredded material either in containers or on cargo type nets. When dry, the containers or nets would be picked up by the aircraft called the Helistat and transported to a centrally located concentration yard. The Helistat is under development by the Forest Service in cooperation with the Air Force. Four helicopters are attached to a dirigible with a theoretical payload of 24 tons (21,800 kg).

SUMMARY AND CONCLUSION

1. There is a compelling need to reduce the fire/flood sequence which has historically prevailed on chaparral lands. Managing chaparral lands for energy would be an effective solution to this problem while providing an energy output urgently needed by this country.

2. Biomass is a proven feedstock for a wide variety of energy producing processes.

3. Harvesting chaparral for energy utilization should be an important consideration in chaparral vegetation management.

4. There is an urgent need for land management agencies to reach agreement on using one chaparral vegetative classification and inventory system with complimentary subsystems. There is a significant role in this for research.

5. A complete assessment of chaparral and chaparral lands is needed using data developed in the previous conclusion.

6. An aggressive equipment development program is needed and methods should be pursued to fund this effort. The annual cost of fire and flood damage is ample justification. A joint project involving Federal and State agencies and private companies is suggested.

7. A concerted Research and Development Program using state-of-the-art equipment and techniques should be implemented now.

8. There is a need for an accelerated research program because there are still more questions and guesses about chaparral than there are factual, scientific answers.

LITERATURE CITED

Anonymous. A national program for forestry; Washington, D.C.: Forest Service, U.S. Dep. Agri.: 1980. Misc. Publ. 1394.

Bolsinger, Charles L. California forests: trends problems and opportunities. Portland, Ore.: Pacific Northwest Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agri.: 1980. Res. Bull. PNW-89. 138 p.

Hajny, George J. Biological utilization of wood for production of chemicals and foodstuffs. Madison, Wisc.: For. Prod. Lab., Forest Service, U.S. Dep. Agri.: 1981 March; Res. Paper FPL-385. 65 p.

Hoover, Herbert. Translation of De Re Metallica. 1912.

Howard, James O. Wood for energy in the Pacific Northwest: an overview. Portland, Ore.: Pacific Northwest Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agri.: 1979; Genl. Tech. Rep. PNW-94. 28 p.

Jaasma, Dennis R.; Kurstedt, Harold A. The contribution of wood combustion to national pollutant emissions. Blacksburg, Virg.: Virg. Polytechnic Institute and State Univ. 16 p.

Johnson, Jack D.; Hinman, C. Wiley. Oils and rubber from arid land plants. Science 208:460-463. 1980 May.

Miles, J.A.; Moini, S. An approach to harvesting chaparral for energy. Proceedings of the American Society of Agricultural Engineers; 1980 March 18-20; St. Joseph, Mich.: Hilo, Hawaii; American Society of Agricultural Engineers. 11 p.

Shirley, A. Ray. Wood energy in Georgia. Atlanta, Ga.: Georgia Forestry Commission; 1980 October. 14 p.

Skou, Miels A.; Papworth, Mark L. The Pegasus Unit. Olympia, Wash.: Pegasus Publishers Inc.; 1974. 133 p.

Teller, Edward. Speech to the Commonwealth Club, San Francisco, Calif. 1981 January.

Yermanos, Demetrius M. Jojoba--a crop whose time has come. Berkeley, Calif.: Div. of Agricultural Sciences, Univ. of Calif.; Calif. Agri. 1979 August. 11 p.

Utilization of Biomass in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

C. Eugene Conrad[2]

This session on the potential of Mediterranean-type ecosystems to supply biomass as a supplemental source of energy is a natural result of the present worldwide shortage of low-cost fuel. Some of these ecosystems are highly productive, partly because the summer drought is modified by dense fog which reduces the normal maximum air temperature to less than 25° C. Also, wet-season precipitation approaches 1000 mm. Biomass from such ecosystems is often used for sawtimber, and only residue is available for energy. At the other extreme of Mediterranean climate, marine air influence is low and the dry season is hot and nearly devoid of any form of precipitation. Under these conditions, most of the presently available methods of biomass processing may use as much energy as the biomass can provide.

By the definition of Mediterranean climate attributed to Koppen, precipitation in at least one summer month must be less than 3 cm and one or more winter month must receive at least three times the amount received in the lowest summer month. Also, the temperature of the coolest month must be between -3° C and 18° C and that of the warmest month above 10° C (Hidore 1969). Aschmann (1973) adds the conditions that total precipitation must be at least 275 mm at coastal sites and 350 mm at inland sites. His upper boundary is 900 mm. his intent seems to be to fit the definition to the chaparral zone of California.

In this summary of the papers presented in the session, some source material from other publications is included to clarify certain points. The summary begins with discussion of a few fundamentals of biomass production from 0echel. Methodology for measuring biomass is the second topic; the Pillsbury and Kirkley paper is the key source of information, with additions from Margaris, Toland, and Riggan and Dunn. We then shift to a discussion of technology for biomass utilization, drawing on papers by Toland, Riggan and Dunn, and Felker and others. Finally, for comments on the impacts of biomass removal, the Margaris, Riggan and Dunn, Felker and others, and Toland papers are primary source documents.

Recently, there have been many papers and at least five symposia dealing with biomass. A French review of forest biomass published in Forestry Abstracts (Parde 1980) identifies the "oil crisis" as one of three reasons for the current high level of interest in biomass. The other reasons cited by Parde are a significant shift in the timber trade and industry during the 1960's toward transactions in weight rather than volume, and an increasing tendency by scientists to measure biological productivity of forests as dry weight of plant biomass. Parde sees these three impacts as leading to scientific and technical upheaval. He points to an "explosion" of literature on the subject.

BIOMASS PRODUCTION

Vegetation managers are concerned about how much biomass is available. Basic physiological processes control biomass accumulation. Primary production starts with the assimilation of carbon, and an understanding of this process suggests some of the factors that control production. Oechel considers nutrients, moisture, temperature, and stand age to establish the groundwork for net production in biomass. Potential production is not equal among different shrub species. Of the species measured, chaparral whitethorn (*Ceanothus leucodermis* Greene.) has the highest potential photosynthesis rate, followed by seven other common chaparral species in California. The species with the lowest maximum photosynthesis rate is sugarbush (*Rhus ovata* Wats.).

Water stress is usually the most limiting factor in Mediterranean-type ecosystems. A key point in Oechel's analysis is that temperature is relatively unimportant in chaparral areas of southern California. Winter temperature is not low enough to suppress photosynthesis, and summer temperature is not so high that photosynthesis will be stopped. This, of course, does not mean that temperature would not otherwise control growth. Plant moisture stress can limit photosynthesis in several ways in addition to its direct effect. A plant's vascular system must deliver water from the roots to the leaves; if translocation cannot keep up with evaporation, the leaf stomata close so that photosynthesis slows and may nearly cease.

Conflicting information is available on the nutrient budget of chaparral species, according to 0echel. Nitrogen fertilization appears to depress the photosynthetic rate in greenhouse studies; photosynthesis increases when nitrogen is less available. However, nitrogen also affects patterns of carbon allocation, so that even though photosynthesis is depressed, a higher proportion of carbon may be allocated to growth. Consequently, fertilizing a stand of field-grown plants may show that adding nitrogen increases growth rate.

Plant age and stage of ecosystem development play an important role in determining biomass accumulation in chaparral and some other Mediter-

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Botanist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

ranean–type ecosystem communities. Biomass accumulation in chamise (Adenostoma fasciculatum H. & A.) is pointed out as an example of age dependence. Photosynthesis rates in resprouting chamise can be up to five times higher than in shoots on mature plants. Furthermore, Oechel makes an interesting (and frustrating) observation that although postfire sprouts show a marked increase in photosynthesis, sprouts from cut plants behave like the old vegetation and do not show enhanced growth. The information leading to this observation is from only one study however, and may not be conclusive.

Oechel identifies some outstanding problems for which answers are needed, regardless of how chaparral plant resources are used. First, the effect of harvesting on water relations and photosynthesis is complex and in need of study. Chaparral species appear to respond differently to burning and cutting. Mature plants use two–thirds of the carbon assimilated in photosynthesis for respiration, whereas sprouts use substantially less. The amount of stored carbohydrate is significant in promoting initial and subsequent sprout growth, but the processes controlling storage and availability for sprout growth are not well defined or understood.

METHODOLOGY FOR MEASURING BIOMASS

Hundreds of equations have been devised for calculating biomass yield. Parde (1980) notes that 137 new equations were added in 1979 to a list first issued in 1967; nearly all of these appeared after 1977.

Pillsbury and Kirkley (these Proceedings) summarize sources of information about hardwood biomass inventories in California. An interesting note is that the first hardwood inventory for California was published as recently as 1950, by the Forest Service. The others recognized by Pillsbury and Kirkley are from either Humboldt State University or California Polytechnic State University San Luis Obispo. In the past, lack of interest by other organizations was due to low demand for the resource and to the difficulty of obtaining precise inventory data. However, the level of interest is increasing and new techniques for inventorying hardwood are being developed. Good estimates are needed to clarify site–specific interrelationships.

Pillsbury and Kirkley recognize that the present need is to provide relatively gross inventory maps based on LANLSAT and U–2 remote sensing imagery. A cited paper (Griffin and Critchfield 1972) gives the range of hardwoods in California and urges completion of the inventory in these regions. Pillsbury and Kirkley also highlight the need to develop volume tables for each of the important species. They stress that stand management in California hardwoods runs the gamut from removing the hardwood to developing alternative land uses to directly managing; for the hardwood resource value.

Inventories of biomass and suitability of sites for harvesting have not been made for most of the noncommercial forests and shrublands in the United States. Without these data, the validity of proposals to harvest biomass are difficult or impossible to assess. Methods presently available limit where and how much biomass can be harvested because of yield, land surface features, and continuity of harvestable area. Margaris (these Proceedings) estimates that there is an average of 60 t/ha of standing biomass in the readily harvestable area of Greek maquis. Toland (these Proceedings) estimates a range of 22 to 78 t/ha on selected chaparral areas in California. An immediate problem is definition of a set of site conditions that specify present and near–future limits to harvesting. Inventories of biomass and site conditions should be made to standards that would provide the required information.

Much of the Mediterranean–type area is not sufficiently enticing to energy marketers to cause an insistent demand for areas to harvest. Parde (1980) gives one set of data showing aboveground productivity ranging from 6.5 to 15.5 t/ha/yr and another set showing annual increments of 1.2 to 7.4 t/ha/yr. Biomass accumulation in California chaparral is reported from several sources by Riggan and Dunn (these Proceedings). They show values ranging from 0.5 to 4 t/ha/yr. Schlesinger and Gill (1980) found that Bigpod ceanothus (Ceanothus megacarpus Nutt.) stands at 5, 12, and 21 years produced 3.3 t/ha/yr average accumulation of standing living and dead biomass. Living biomass growth in 12– and 21–year–old stands was 2.7 and 2.3 t/ha/yr, respectively (Schlesinger and Gill 1980, table 1). Certainly, these data for biomass accumulation are not comparable with those reported for coast redwood (Sequoia sempervirens [D. Don] Endl.) at 8.8 t/ha/yr at age 260 years or a Douglas–fir (Pseudotsuga menziesii [Mirb.] Franco.) stand that produced 4.27 t/ha/yr at age 375 years (Fujimori, in Parde 1980).

Usable biomass appears to be visualized as different amounts by various workers. Riggan and Dunn do not suggest a rule, but caution against removing foliage and fine stem material which contains the highest concentrations of nutrients. The biomass reported in their tables is whole stand plant material, however. Rockwood and others (1980) take a different view--branch and foliage biomass is "potentially unusable biomass." If data are to be of greatest value, criteria should be developed that will provide some standard breakdown of foliage, twigs, branches, and stems.

UTILIZATION TECHNOLOGY

Adequate technology for using biomass is missing but the papers by Toland and by Riggan and Dunn show development is occurring. Technology development in these low-producing ecosystems is slow because biomass is diffuse. Arguments such as those by Riggan and Dunn, which show how extensive an area of harvesting would need to be in order to supply a small city of 70,000 people, certainly seem valid. Except for certain very high yield sites, economic consideration appears to be an overriding problem. This may, on the other hand, be a shortsighted viewpoint. For example, the work of Miles (cited by Riggan and Dunn) suggests technology is capable of being improved beyond the clumsy plant cutters, tub grinders, and high—pressure pelletizers that Toland mentions in his paper. It is reasonable to assume that if the existence of a significant renewable resource is demonstrated, technology will be developed to obtain and process that resource. Pimentel and others (1981) analyzed the potential for using residues following harvesting of crops and forests; they conclude that 4 percent of the electrical energy now used in the United States could be supplied from processing 22 per— cent of the harvest residues for energy.

The energy shortage is expected to get worse. Hafele (1980) suggests that per capita energy available by the year 2030 may be 1 kW per year compared with 2 kW per year in 1980. He cites studies indicating that such a scenario is likely even if energy resources increase above present levels. Population increases alone will cut energy supply in half.

Biomass, especially on the most productive sites, contains considerable energy. Where above—ground biomass is 50 t/ha, Riggan and Dunn calculate a gross energy equivalent of 182 barrels of oil. Chaparral harvesting is therefore being actively considered. Riggan and Dunn note that a University of California engineering feasibility study reported by Riley and others concludes that harvesting and processing costs are prohibitive. The current technology referenced by the University of California study is rapidly changing, however. When only 17 percent of the gross energy (Riley and others) [3] is consumed in harvesting and initial processing, there is good reason to believe that a way will be found to extract the remaining energy. Riggan and Dunn report that one southern California National Forest Ranger District receives about 3000 firewood requests each year, but only a small part of this number are granted. These authors conclude that the ongoing effort to find ways to harvest chaparral and associated woodlands makes it imperative that we know what the environmental implications will be.

Margaris confronted the problem of energy harvesting in Greece by suggesting a rotational type of harvest. Energy in Greece is an even more immediate and serious problem. Margaris reported that gasoline sells for $0.85 (U.S.) per liter. This compares to $0.40 or less per liter of unleaded gasoline in most of southern California. Margaris suggests that maquis can be harvested on a sustained—yield basis once each 10 years. The area suggested for harvesting is sufficiently level to allow for harvesting by current equipment and technology. On such a continuing basis, yield of maquis would be 80 percent of maximum. Mediterranean—type ecosystems cover about 40 percent of Greece and maquis dominates about one—half of these ecosystems. Maquis accounts for about 80 percent of the aboveground plant biomass in the Greek Mediterranean—type ecosystems. Maquis areas found on "level ground" make up about 10 percent of the land surface area of Greece. Margaris estimates that harvesting this amount of land would yield biomass containing energy equal to about 40 percent of the current Greek oil imports.

Toland discusses the problem of energy harvesting in a general way, stating first that the Forest Service has establishel5a national goal of providing 6.4 quads (1.6 x 10^{15} kcal or 6.4 x 10^{15} Btu) per year from woody biomass by 1990. The biomass contribution of the Pacific Southwest Region is from an estimated 23 million t/yr or about 0.4 quads of energy.

Toland recognizes that current economic efficiency is unfavorable for developing wood biomass energy, but sees that picture as changing. Significant improvements in technology is likely to make use of wood biomass an attractive alternative. At present, potentially commercial harvest from sources such as chaparral could be subsidized to reduce costs of fire and postfire erosion. Lack of adequate technology for biomass removal is probably the major deterrent to harvesting, but even with present technology, biomass removal for energy from highly productive areas is occurring.

Toland also discusses various means of harvesting and processing. Each seems to need major improvements if the shrub biomass is to be accommodated. Use of forest slash appears to be already an acceptable practice where very large quantities are available. The most obvious use of biomass, Toland reports, is for direct combustion; also noted are use for updated techniques of gasification, to produce low Btu gas (1353 kcal/m^3); use for pyrolysis, to convert woody biomass to oil, gas, and char; and use as feed—stock, to produce chemicals, including alcohol. More sophisticated forms of these processes are being developed, but it is unlikely that any will be used unless biomass produced is the highest available quantity and quality to assure efficient processing. Certainly, chaparral and other shrub types are unlikely candidates for energy contribution at present.

Toland suggests that consideration be given to converting chaparral brushfields to product—specialized species such as guayule (_Parthenium argentatum_ Gray) or jojoba (_Simmondsia chinensis_ [Link] C. K. Schneid.). The potential for these product—oriented species has had little research emphasis. Species screening for such specialty production is not new, especially for forage, human food, drugs, and other fiber. Pillsbury and Kirkley report continued interest in developing

[3] Riley, John G., Samad Moini, and John A. Miles. An engineering study of the harvesting and densification of chaparral for fuel. 1980. Unpublished draft.

better understanding of hardwood site quality relationships. They also suggest a plantation approach to fast–growing, fiber–producing trees as alternatives or in addition to native hardwoods.

In their paper, Felker and others (these Proceedings) effectively illustrate the problems of selecting and testing highly productive species. Mesquite (Prosopis spp.) is an excellent plant from which to make genetic selections for high fiber production and for other specialty products. Species of mesquite are found in hot climates, commonly associated with desert areas, but do require substantial amounts of water to be productive. Felker and others also report that mesquite species tested were hosts of nitrogen–fixing nodules. These nodules were most effective below 2.7 m in a phreatophyte greenhouse test. In this experiment, water entered the rooting zone from below the 3.05–m soil column as it would in a desert streambed. Another interesting and potentially very useful trait is the ability of several mesquite species to tolerate high salinity levels. These plants even grew slightly where salinity was comparable with seawater. One test showed growth at 36,000 mg NaCl per liter of water.

IMPACT OF BIOMASS REMOVAL

Although, in Greece, according to Margaris, and possibly in some of the other Mediterranean–type ecosystem areas, the impact of biomass removal is slight, in California it could have serious negative effects. Probably more concern is properly placed on ecosystem stability following harvesting in southern California. Stark's (1980) work shows the potential for serious nutrient loss associated with biomass removal. her studies were in Montana, where she worked with the nutrient budget in a Douglas–fir (Pseudotsuga menziesii)/blueberry (Vaccinium caespitosum Michx.) habitat type. From measurements of nutrient movement out of the root zone and also, apparently, on effects of removal of nutrients from the forest, she concludes that biomass removal should be restricted to large stems and branches, and that twigs and foliage should be left on site. Stark brings attention to the fact that balance among nutrients must be a major concern.

Riggan and Dunn (these Proceedings) note that harvesting may be aimed at either permanent fuel modification or sustained yield in energy management areas. They suggest that type conversion has serious environmental hazards, which could be prohibitive in large parts of southern California ecosystems. Both site stability and productivity could he seriously affected. Comments from both Felker and others and Toland seem to suggest that alternative species of woody plants may be desirable to a chaparral ecosystem and provide products that satisfy some highly specialized human needs. on the other hand, Toland, and Riggan and Dunn, caution that type conversion aggravates the problems of erosion and related massively destructive flooding from denuded steep watersheds in some areas of Mediterranean–type climates. Type conversion as a way of producing significant harvestable biomass for energy seems to offer minimal opportunity even if species of very rapid growth are used. Adequate production would be possible on few sites and even these would probably require supplemental water. Other uses of such land and water resources would probably be of higher priority.

The alternative approach to the Mediterranean–type climate ecosystems for energy biomass, sustained–yield management, presents some problems that must be seriously considered. Riggan and Dunn discuss the opportunities and damages related to reduced fire hazard, plant community composition changes, and nutrient loss. Nutrient removal may become severe if the entire aboveground biomass is removed. Fire hazard may be worsened by either the harvesting operation itself or the encouragement of species that produce more highly flammable debris. Riggan and Dunn chart the life history of southern California chaparral and identify species significant in stand development. Many of these species can support symbiotic nitrogen fixation, and their persistence may be essential to site and stand stability. Loss of robust and tall species of Ceanothus or Quercus is likely to encourage establishment of species that mature more rapidly, produce more flammable fine fuel, and have more shallow root systems. Riggan and Dunn identify black sage (Salvia mellifera Greene.) and buckwheat (Eriogonum fasciculatum Eenth.) as two such less desirable species.

CONCLUSIONS

Each author represented in the session has an individual emphasis on what constitutes Mediterranean–type ecosystems; most seem to feel the ecosystems are dominated by shrublands. I do not agree with that conclusion. Ecosystems found in Mediterranean climates include some conifer communities, as well as hardwood forests and shrub–lands. The climate is characterized by wet winters with an upper bound of at least 900 mm of rain and by rainless summers. The coldest month is between -3° C and 18° C.

The range defined by the above climate conditions includes marginally desert climate but stops short of the summer rainfall areas. When yield is below 60 to 75 t/ha, harvesting technology for biomass use must he more efficient than that now available. Apparently, there is more opportunity to use low–yield areas in Greece and other developing countries than in California. At least three criteria for evaluation seem appropriate. The first is energy efficiency, and asks how much energy is used to obtain the energy in biomass. If 17 percent of the residual energy in biomass is used to harvest and process it into fuel (Riley and others[3]), how efficient must the remaining processes be? If the answer is a value comparable to that for equally available resources, the next questions are environmental and economic.

From the papers in this session, it is clear that we do not know how efficient biomass processing must be, how the return on dollars invested can be made adequate, or how acceptable the environmental impact can be made. Biomass quantities and quality are unknown. Even for high–yield conifer timber areas, we do not know total biomass.

The Old World countries in the European Mediterranean have long demonstrated the results of unwise biomass utilization. The papers presented indicate that we do not understand any of the ecosystems well enough to make reasonable predictions about the effects of mechanically removing the entire vegetation biomass of the ecosystem. We have reasonably good understanding of the effects of removing vegetation by fire, and some knowledge of the impact of vegetation type conversion. If mechanical removal of vegetation is repeated often enough, then research and experience with type conversion may apply, but no research is known on mechanical removal in the 20– to 46–year rotation suitable for a harvesting program.

LITERATURE CITED

Aschmann, Homer. Distribution and peculiarity of Mediterranean ecosystems. In: di Castri, Francisco; Mooney, Harold A., eds. Mediterranean type ecosystems: origin and structure. New York: Springer–Verlag; 1973: 11–19.

Griffin, James R.; Critchfield, William B. The distribution of forest trees in California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1972; Res. Paper PSW–82. 114 p.

Hafele, Wolf. A global and long–range picture of energy developments. Science 209:174–182; 1980 July.

Hidore, John J. A geography of the atmosphere. Wm. C. brown Co. Publ.; 1969. 106 p.

Parde, J. Forest biomass. For. Abstr.; Commonw. For. bur. 41(8):343–362; 1980 August. [English translation by Sinclair.]

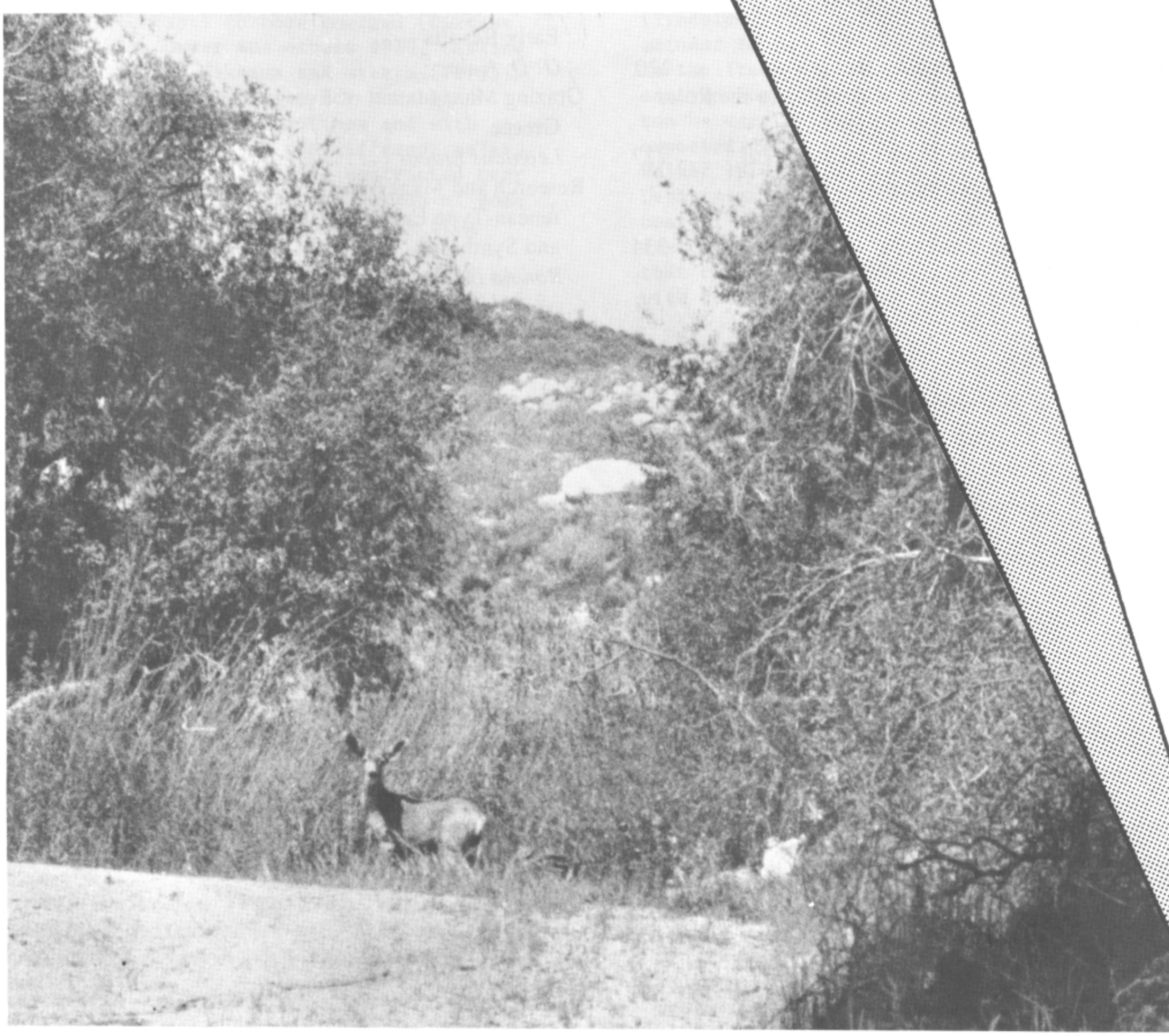
Pimentel, David; Moran, Mary Ann; Fast, Sara; [and others]. Biomass energy from crop and forest residues. Science 212:1110–1115; 1981 June.

Rockwood, U. L.; Conde, L. F.; Brendemuehl, R. H. Biomass production of closely spaced Choctawhatchee sand pines. Asheville, N.C.: Southeastern Forest Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Res. Note SE–293. 6 p.

Schlesinger, William H.; Gill, David S. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61(4): 781–789; 1980 August.

Stark, N. Changes in soil water quality resulting from three timber cutting methods and three levels of fiber utilization. J. Soil and Water Conserv. 35(4):183–187; 1980 July/August.

Fauna



Fauna

Small Mammals, Habitat Components, and Fire in Southeastern Australia[1]

P. C. Carling, A. E. Newsome, and G. Dudzinski[2]

Abstract: In Australia, eucalypt forests are the major vegetation form. They are highly fire-prone, but also the major repository of the vertebrate fauna. Recent studies have demonstrated that the fauna, like the flora, may be adapted to fire. Simple divisions of environments into habitats satisfactorily predicted the abundance and diversity of small mammals. The habitat preferences of four species of small mammal were examined in relation to various components of the habitat using principal component analysis. The environmental components scored were the abundance of litter, brush and boulders, of ground vegetation, and of shrubs, and of trees and their canopies. The patterns which emerged are examined for projected effects of fires of high or low intensity upon the habitat components and hence upon the small mammal fauna.

Although the study of the effects of fire on the Australian vertebrate fauna is still at an early stage, sufficient data exist for general evolutionary concepts to have emerged (Kikkawa and others 1979, Dwyer and others 1979, Catling and Newsome 1981). Kikkawa and others (1979) concluded that specialization for heathland living must have arisen many times and with differing chronologies for the different major vertebrate taxa. As heathlands contracted over evolutionary time, widespread extinction of some forms is envisaged with radiation away from heathlands for some groups. Significant adaptations of the vertebrate fauna to fire, as for the flora, have also been examined (Catling and Newsome 1981) with eight a priori propositions being erected:

1. Archaic forms would survive in the least fire-prone habitats;
2. Species diversity overall would be low;
3. There would be fire specialists;
4. The seral response would be truncated;
5. Species diversity would be highest in the least fire-prone habitats;
6. Reproductive patterns would be modified;
7. There would be a prevalence of ecological generalists;
8. There would be few forms in the lowest strata of vegetation.

Supportive evidence was found for all of them except Proposition 5. It was the wet sclerophyll forest (Eucalyptus dominated) which held the highest diversity of mammals and birds and not the rainforest (non-Eucalyptus) as at first thought. Eucalypt forests provide the habitats for the great majority of birds and mammals (Tyndale-Biscoe and Calaby 1975). One pre-eminent feature of the Australian Eucalypt forest is the frequency of intense wildfire. South-eastern Australia has a summer fire season which can be very severe and major fires can be expected every 3-10 years or so (Cheney 1979, Walker 1979) (fig. 1.). Managers in Forest Departments and National Parks utilize "cool control" fires to reduce the chance of those fierce uncontrollable wildfires. Yet it seems that the eucalypts themselves ensure such fires with their oils (hutch 1970).

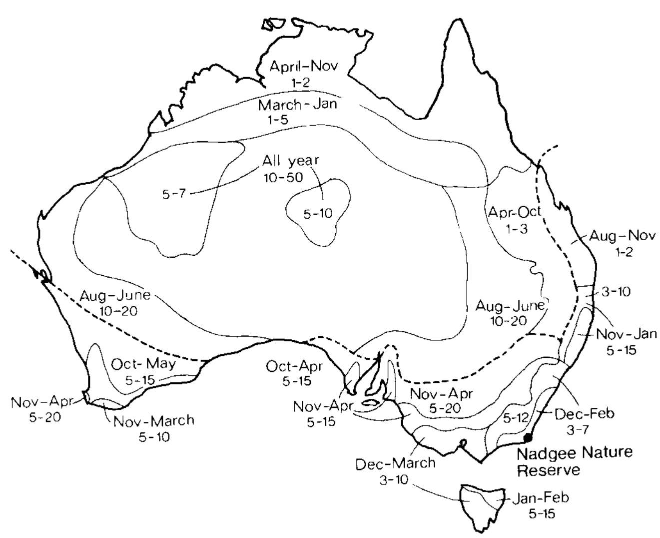


Figure 1--Fire frequency (range in years) for the fire season regions (range in months) in Australia. Area below dotted line is summer fire season only (after Walker 1979).

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems: An International Symposium, June 22-26, 1981, San Diego, California.

[2]Division of Wildlife Research, CSIRO, P.O. Box 84, Lyneham, A.C.T. 2602, Australia.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Models of successional vegetative responses exist in Australia (Specht and others 1958, Jackson 1968, Noble and Slatyer 1981), although little is known similarly for the fauna. However, some general points can be made from the study of the vegetative changes in a heathland in a mediterranean climate burnt at various times over 25 years and 50 years prior to the study (Specht and others 1958). Four groups of plants burgeoned sequentially: The grasses and forbs, the understorey, the undershrubs and the trees (Banksia ornata). If burnt every 5 years then only the grass and herb layer would remain, so that we could expect animals utilizing that habitat to be present. If burnt every 10-15 years we would expect fauna that frequent healthy shrubs to be present. Animals exploiting the tree layer would do best if fire was avoided for 20-30 years, unless they nest in holes, when only old senescent trees might suffice.

In Australian forests the small mammal fauna is never as diverse or abundant as in North America. Moreover, they never irrupt like their North American counterparts, nor their Australian desert counterparts (Carstairs 1974, Newsome and Corbett 1975). Some species of small mammal have specific habitat requirements and so are limited in their distribution (Keith and Calaby 1968, Posamentier 1976, Cockburn 1978, Braithwaite and Gullan 1978, Barnett and others 1978, Newsome and Catling 1979, Fox, in press). Other studies have been more general and the association between small mammals and the vegetation has often been described in relation to broad vegetation types (Golley 1962, Tyndale-Biscoe and Calaby 1975). For example, dry sclerophyll forest includes both forest with a thick heathy understorey and one with a grass and herb understorey with few shrubs. Newsome and Catling (1979) concluded that the simple grouping of environments into "habitats" was more satisfactory in predicting small mammal species abundance and diversity than broad structural formations. The reason was that other components of the environment such as litter and brush, creeks, swamps, boulders, shrubs etc. were considered part of the habitat.

The paper is based on data collected for seven years following the severe wildfire which swept through Nadgee Nature Reserve in south-eastern Australia in December 1972 (fig. 1). From this study, patterns of population responses have been documented (Newsome and others 1975, Catling and Newsome 1981), habitat preferences and particular components of those habitats identified (Newsome and Catling 1979) and models erected of possible responses to changes in supplies of food and shelter and in numbers of predators (Newsome and Catling, in press). This paper examines the effects of individual habitat components on four small mammal species in south-eastern Australia and the projected effect of fire on those components, and hence on the small mammals. The predictions are also examined relative to known responses.

MATERIALS AND METHODS

(a) Trapping Grids

In April 1972 five trapping grids were established in different habitats in Nadgee Nature Reserve as part of the study of the diet of dingoes (Newsome and Catling unpublished). The five habitats were lowland and upland open sclerophyll forest, closed scrub, closed and open graminoid heathland. Twenty traps were set on each grid in two parallel lines 10 metres apart. There were 10 traps per line set 7 metres apart. Each trap was set in the same location for three consecutive nights every three months. The traps were baited with peanut butter and rolled oats, cleared in the morning and reset. In 1979 when small mammal populations were at their highest (P. Catling and A. Newsome unpubl. fig. 2) vegetational data (see below) were collected around each trap site in the grids and related to the captures of each species of small mammal there for 1978 and 1979.

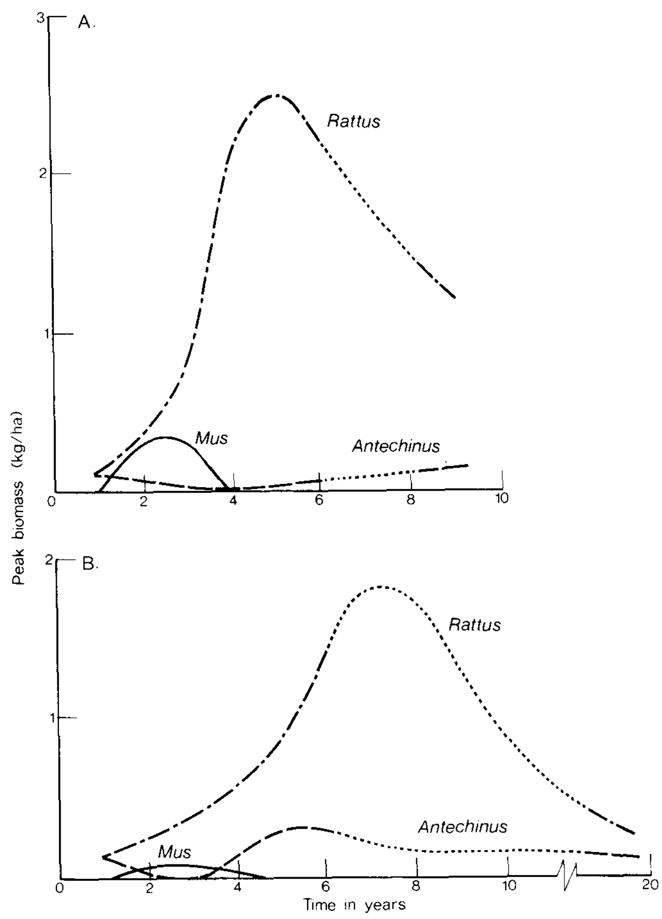


Figure 2--Peak biomass (kg/ha) per year after fire. The end points represent values immediately before the fire transposed to time since previous fires (from Catling and Newsome 1981).

A. Wet habitats - closed scrub and closed graminoid heath.

B. Open sclerophyll forest.

(b) The Animals

The small mammals studied were the two small dasyurid marsupials, Brown Antechinus (Antechinus stuartii Macleay) (20-40 g) and Dusky Antechinus (Antechinus swainsonii (Waterhouse)) (40-120 g), and two native rodents, Bush rat (Rattus fuscipes (Waterhouse)) (90-180 g) and Swamp rat (Rattus lutreolus (Gray)) (90-180 g). The introduced House mouse (Mus musculus Linnaeus) was also trapped, but numbers were too low in 1978/1979 for inclusion in the analysis. The animals were weighed, toe-clipped, and released. Other biological data were obtained but are not used here.

(c) Habitat Components

A 36 m^2 area around each trap site was visually estimated for ground vegetation cover (pct); cover of litter, brush, logs and rocks (pct); tree cover (pct) and shrub cover (pct). The tree height (m) directly above the trap site was measured with an inclinometer and the sedge and grass height (cm) and shrub height (cm) were measured at four points (the major points of the compass) 1.5 metres from the trap site and then averaged.

(d) Analysis

The grids were divided into treed and treeless groups. No animals were trapped on the open graminoid heathland, so it was not included in the analysis (see below for further comment).

The dependent variables Y_1 ....Y_4 were captures of Y_1 - Antechinus stuartii, Y_2 - Antechinus swainsonii, Y_3 - Rattus fuscipes, Y_4 - Rattus lutreolus. These were examined relative to the independent variables X_1....X_7, X_1 - ground vegetation height (cm), X_2 - shrub height (cm), X_3 - tree height (m), X_4 - cover of litter, brush, rocks and logs (pct), X_5- ground vegetation cover (pct), X_6 - shrub cover (pct), X_7 - tree cover (pct). Tough captures on quadrats within any grid may not be independent, we decided to investigate the data assuming no bias, seeking insights into the effects of different habitat components upon the catch. To aid the interpretation of the relationship between the catch (Y_1 .... Y_4) to the intercorrelated environmental measurements (X_1 .... X_7), the X_1 ... X_7 measurements were transformed by Principal Component Analysis into orthogonal (uncorrelated) variables (Z_1 .... Z_7). For detailed description of the use of Principal Component Analysis in multiple regression see Dudzinski (1975).

RESULTS

(a) Captures

The five habitats were trapped 8 ti2es generating a total of 2,400 trap nights. Total captures for each species were A. stuartii (112), A. swainsonii (44), R. fuscipes (184) and R. lutreolus (168).

(c) Correlation of Vegetation Components

The correlation between the vegetation components are presented in Table 1. In general, in the treeless sites the higher the shrubs and the cover of litter etc. the lower the cover and height of the ground vegetation. In the treed sites the higher the trees and shrubs the lower the ground vegetation height and cover and cover of shrubs.

Table 1--Correlation between the original habitat variables.

(i) Treed sites

	X1	X2	X3	X4	X5	X6
X2	.11					
X3	-.41	-.01				
X4	.31	.10	.31			
X5	.47	.17	-.71	-.06		
X6	.40	-.40	-.19	.18	.61	
X7	-.22	-.08	.37	.15	-.27	-.19

(ii) Treeless sites

	X1	X2	X4	X5	
X2	-.43				
X4	-.62	.71			
X5	.86	-.48	-.71		
X6	.25	.08	-.03	.19	

Values > 0.31 are significant at .05.

(b) Principal Component Analysis

The Principal Component loadings for each habitat variable and the percent of the overall variation accounted for by each component are presented in Table 2.

Table 2--Solution of Principal Component Analysis.
(i) Treed sites.

	Components						
	Z1 37.5*	Z2 20.5	Z3 18.3	Z4 10.0	Z5 6.7	Z6 5.1	Z7 1.7
X1	-.43+	-.31	.13	.54	.15	.62	.08
X2	-.13	-.25	-.74	-.10	.56	-.13	.17
X3	.47	-.39	-.07	-.29	-.29	.39	.54
X4	.01	-.75	.12	.25	-.22	-.55	-.11
X5	-.54	.11	.29	-.18	-.01	-.31	.70
X6	-.42	-.31	.10	-.71	-.05	.21	-.41
X7	.34	-.14	.57	-.12	.73	-.03	.02

(ii) Treeless sites.

	Components				
	Z1 58.7*	Z2 22.5	Z3 11.3	Z4 5.0	Z5 2.5
X1	.51+	.22	-.43	-.37	.61
X2	-.43	.41	-.60	.53	.11
X4	-.51	.20	-.21	-.76	-.26
X5	.53	.14	-.38	.04	-.74
X6	.10	.85	.51	.02	-.03

+ Values <.29 are assumed not to contribute significantly to the interpretation of the Z variable.
* Percent variability accounted for.

(d) Interpretation of Principal Components

The components in Table 2 are interpreted in terms of the interrelationships of the vegetation as follows:

(i) Treed sites - upland and lowland open forest.

Z1 Height and cover of ground vegetation plus shrub cover contrasts with height and cover of trees.
Z2 Abundance of litter etc., and shrubs and height of trees and ground vegetation.
Z3 Shrub height contrasts with tree cover.
Z4 Shrub cover and tree height contrasts with height of ground vegetation.
Z5 Tree cover and shrub height contrasts with tree height and litter.
Z6 Height of trees and ground vegetation contrasts with cover of litter etc. and height of ground vegetation.
Z7 Cover of ground vegetation and tree height contrasts with shrub cover.

(ii) Treeless sites - closed scrub, open and closed graminoid heath.

Z1 Cover and height of ground vegetation contrasts with shrub height and litter and brush cover.
Z2 Shrub cover and height.
Z3 Shrub cover contrasts with shrub and ground vegetation height and ground vegetation cover.
Z4 Ground vegetation height and cover of litter etc. contrasts with shrub height.
Z5 Ground vegetation cover contrasts with height of ground vegetation.

(e) Regression of Catch on Habitat Components

The following equations resulted from regressions of captures on significant components:-

(i) Treed sites

Antechinus stuartii
$Y_1 = 2.15 + 0.92\ Z_5 + 1.48\ Z_7 + 0.36\ Z_2$
(P < 0.001; percent variance accounted for : Z_5 14.8, Z_7 9.5, Z_2 6.8; Total = 31 1)

Antechinus swainsonii
$Y_2 = 1.07 - 0.59\ Z_1$
(P < 0.001; percent variance accounted for: Z_1 34.8; Total = 34.8)

Rattus fuscipes
$Y_3 = 1.95 - 0.71\ Z_2 - 0.61\ Z_3$
(P< 0.02; percent variance accounted for: Z_2 10.5, Z_3 6.7; Total = 17.2)

Rattus lutreolus
$Y_4 = 0.40 - 0.28\ Z_1 - 0.58\ Z_6$
(P < 0.001; percent variance accounted for: Z_1 13.1, Z_6 7.3; Total = 20.4)

(ii) Treeless sites

Antechinus stuartii
Y_1 - no relationship.
Antechinus swainsonii
Y_2 - no relationship.
Rattus fuscipes
$Y_3 = 2.65 + 1.32\ Z_2 + 0.71\ Z_3$ (P < 0.001; percent variance accounted for: Z_2 40.8, Z_3 4.9; Total 45.7).
Rattus lutreolus
$Y_4 = 3.8 + 1.92\ Z_2 + 2.41\ Z_5 + 1.00\ Z_3$ (P < 0.001; percent variance accounted for: Z_2 37.0, Z_5 5.3, Z_3 4.0; Total 46.3).

(f) Interpretation of Regression

The interpretations of the above equations in terms of habitat components for each species are as follows (see Table 2 for detail):

(i) Treed sites

Antechinus stuartii
The greater the tree cover and height, shrub height, and ground vegetation cover, the higher should be the catch. The cover of litter, brush, and logs is also contributing (Z_2...6.8%). Generally, the improvement of alt habitat components should improve the catch. A. stuartii should be favoured by a maturing forest.

Antechinus swainsonii
The better the ground vegetation cover and height and the shrub cover, (i.e. the lower vegetation strata), the better should be the catch. Those strata are suppressed in tall closed forest. A. swainsonii should not be as successful as A. stuartii in maturing forests, but should be favoured by low open forests with a thick understorey.

Rattus fuscipes
The supply of litter, logs, and brush is a major habitat component, but the height of all vegetation strata and shrub cover contribute importantly. All these items infer preference for maturing stands of relatively open forest

producing much litter. Like A. stuartii, Rattus fuscipes should be favoured by maturing forests.

Rattus lutreolus

The shrubs and ground vegetation are again important together with the litter, logs and brush, but the cover and height of trees reduces the favourability of habitat. Forests should not favour these rats.

(ii) Treeless sites

Rattus fuscipes

Shrubs are all important in treeless habitats, both their height and cover. The catch should be best on older heaths. Young heaths would not have adequate shrub cover or height.

Rattus lutreolus

Again shrub cover and height are important, but ground vegetation height is more important than for Rattus fuscipes. The catch should be best on maturing heaths; however, R. lutreolus could be expected on young heaths providing the ground vegetation height was adequate.

DISCUSSION

Before discussing the results in general, one particular aspect of them is addressed. The low capture rates in this study highlight the statement earlier that small mammal populations are characteristically sparse in Australian forests. We had followed population changes for 7 years post-fire, and populations were maximal at the time of this study (fig. 2).

The results of this study confirm the importance of cover to native small mammals as found in other Australian studies (Barnett and others 1978, Braithwaite and others 1978, Suckling and Heislers 1978, Braithwaite and Gullan 1978, Newsome and Catling 1979), and in North America (Gunderson 1959, Cook 1959, Birney and others 1976,. Kirkland 1978, Quinn 1979). By identifying particularly relevant habitat components, however, our study can be extended to predict the effect of fire on small mammals due to changes in the vegetation. Known effects from our earlier study (Newsome and others 1975, Newsome and Catling 1979, Catling and Newsome 1981) and other studies are then compared.

(a) Rattus lutreolus and Rattus fuscipes

R. fuscipes is primarily a forest species (Catling and Newsome 1981); however, it is known to inhabit older stands of heath where the shrubs are tall and litter cover is good (Braithwaite and others 1978, Braithwaite and Gullan 1978; Fox in press; this paper). R. lutreolus is the converse being primarily a wet heath species (Braithwaite and others 1978, Braithwaite and Gullan 1978, this paper) and will inhabit shorter heaths than R. fuscipes.

Our results indicate that Rattus lutreolus might be expected in all habitats as ground vegetation regenerates from fire in the early stages of vegetation succession. R. fuscipes might be expected in later stages as shrubs predominate and trees regain their leafy canopy. We would expect few Rattus fuscipes after a fire on heathlands, low-medium densities as ground vegetation increases and maximum densities as shrubs become dominant and litter and brush increase.

In our study, Rattus lutreolus quickly disappeared from all burnt areas (fig. 3) and only returned once the ground vegetation thickened (fig. 2). However, in the first few years post-fire, Rattus lutreolus was the first to invade the forest, and persisted - presumably because of the dense, tall ground vegetation which contained a high percentage of sedges. Braithwaite and Gullan (1978) found R. lutreolus preferred wetter areas with a good sedge cover both for cover and food. After the fire there were several very wet years which may have aided the invasion of R. lutreolus into the forest. Pre-fire, R. lutreolus was not caught at all in the forest, which had not been burnt for about 20 years (A. Fox, pers. comm.). Understorey shrubs were sparse and grasses dominant. Moreover, Braithwaite and others (1978) considered R. lutreolus to be a riparian species and that forest habitat is marginal. The results obtained here provide an explanation.

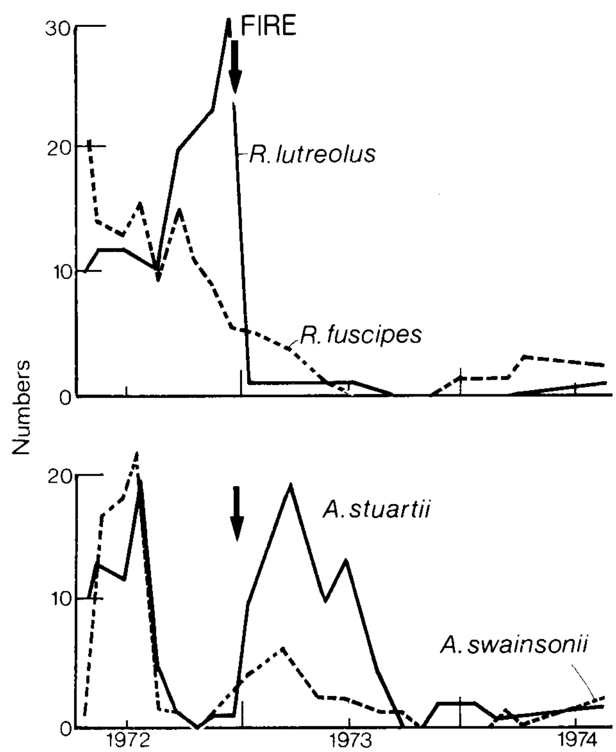


Figure 3--Detailed short-term fluctuations of small mammals after wildfire (from Newsome and others 1975).

Post-fire R. fuscipes survived for a few months before disappearing until the ground vegetation began to recover (fig. 3). Cowley and others (1969), Leonard (1972), Christensen and Kimber (1975), and Fox (in press) found similar results. Christensen and Kimber (1975) attributed the disappearance of R. fuscipes to the lack of ground cover and increased predation. In our study in the longer term (5-7 years post-fire) R. fuscipes reached levels well above that found pre-fire (fig. 2). This coincided with the shrub cover and height, and litter and brush cover reaching their maxima particularly in the forest. Bell and Koch (1980) report that the decline in plant diversity in jarrah forest in Western Australia after about 6 years was apparently due to senescing of "fireweed" species and reduction in number of smaller herb species. From our vegetation analysis shrubs were very important for R. fuscipes. It could be postulated that as the forests age and shrubs die out R. fuscipes abundance would decline as indicated in fig. 2.

(b) Antechinus stuartii and A. swainsonii

The vegetation analysis revealed Antechinus would not be expected on treeless habitats. In forests post-fire, Antechinus may be expected to survive where the tree canopy had not been severely damaged and in particular A. stuartii, as they are known to be scansorial (Wakefield and Warneke 1967). However, as the important shrubs and ground cover are removed by fire, Antechinus would not be expected to persist, and recovery not to begin, until the vegetation recovered.

Post-fire, Antechinus survived well, with A. stuartii doing the better (fig. 3). However, breeding appears to have failed in the second year with numbers falling dramatically to remain low or non-existent for several years (fig. 2). The reasons are unknown as there seems to have been an adequate supply of insects (Fox, A. 1978). Antechinus are insectivorous (Wakefield and Warneke 1963, 1967) and appear to be generalist and largely opportunistic (Hall 1980). Leonard (1972) found that the energy content of the leaf litter fauna fell 30% in the year post-fire, but he felt that it was unlikely that food for mammals was limiting. Similar results were obtained by Campbell and Tanton (1981). Predation is another possibility for the decline of Antechinus (Newsome and Catling in press). Leonard (1972) found that A. stuartii were not affected where some cover remained after fire. However, where dense cover was eliminated there was a significant decrease in the number of A. stuartii, (particularly females) although some individuals were able to persist. Leonard (1972) and Newsome and Catling (1979) found A. swainsonii mainly along gullies and creeks in dry sclerophyll forest, which are likely to survive fires of low intensity. Antechinus have been much slower to recover in the treeless habits (fig. 2). This is possibly because the heaths have not reached maximum height and cover, whereas the density of shrubs etc. has reached its maximum in forest by year 6 or 7 post-fire.

(c) Other Species

Braithwaite and others (1978) suggest that although some species do have special structural requirements, resource partitioning appears to be primarily food orientated. They define five basic food niches in south-eastern Australian heath and forest communities, but only rarely are all five occupied. In this study R. fuscipes would be the common omnivore, R. lutreolus the specialist herbivore, A. stuartii the scansorial insectivore, A. swainsonii the soil fossicking insectivore. There was no generalist herbivore, which is usually filled by Pseudomys spp. in other studies (Braithwaite and others 1978), but no Pseudomys is present in Nadgee Nature Reserve though found both north and south of it. Cockburn (1978) found the Heath mouse (Pseudomys shortridgei (Thomas)) on heaths that had a maximum or near maximum diversity of woody plant species, an association which developed about 6-9 years post-fire in his study. Prior to 1965 farmers burnt the heaths in Nadgee every 3 or 4 years (A. Fox, pers. comm.). Perhaps the heaths have been burnt too frequently to allow them to reach maximum plant species diversity and so Pseudomys have disappeared. An example of such a heath is the open graminoid heath which was not used in our analyses. The ground vegetation and shrub height is low (< 30 cm) and the soils are very hard ground-water podzols. No native small mammal has been trapped there.

In most studies on fire and mammals in Australia there has been an invasion of Mus musculus into the burnt area within about 6 months post-fire (Christensen and Kimber 1975, Newsome and others 1975, Recher and others 1975, Fox in press) (fig. 2). Mus as well as being the immediate post-fire colonizer is considered to fill the food niches of A. stuartii and A. swainsonii in their absence (Braithwaite and others 1978).

No grid had more than three species present pre-fire. However, in the years 2-5 post-fire most grids at some stage had four species and the closed scrub had five species present 2 years post-fire. The number of food niches may therefore be increased by fire.

(d) Effect of Fires of Low and High Intensity

Fire itself, especially of low intensity, is unlikely to he a major mortality factor for small mammals (Leonard 1972, Cowley and others 1969). In fact most authors have found that fire-induced mortality only occurs under extreme conditions. In an experimental fire applied to fenced enclosures - reduced cover and seed availability and increased predation were the major factors for population declines (Crowner and Barrett 1979). Komerek (1969) observed cotton rats removing young from nests ahead of a fire of low intensity and so surviving. However, a high intensity fire (wildfire) usually travels at considerable speed and consumes everything in its path including many birds and mammals. One exceptionally destructive situation arises when spot fires in Eucalypt forests coalesce. An enormous amount of energy is released in the form of flaming whirlwinds which can uproot and snap off trees with winds up to 100 km per hour (Cheney 1979).

In most cases fires and particularly those of low intensity leave a mosaic of unburnt patches as well as not burning all vegetation strata. This is most likely along creeks and drainage lines where the abundance and species diversity of small mammals could be expected to be greatest (Newsome and Catling 1979). The mosaic of unburnt vegetation is probably the most important factor in the survival and recolonization of small mammals.

Frequent, man-made "control" fires are, however, another matter. Vegetation analysis has revealed the importance of ground vegetation, shrubs, and litter for small mammals in south-eastern Australia. The vegetation correlations in Table 1(i) indicate that these components will increase if the canopy is opened up. There is no known fire which will selectively open up the tree canopy. There is evidence that repeated and frequent burning may convert open forest with a shrub understorey to open forest with a grassy understorey (Coaldrake 1961). With repeated fires Gilbert (1959) found the conversion of multi-layered understoreys to a single layer and Christensen and others (1981) found a 66 percent reduction in shrub density. Our vegetational analysis indicate that this will not favour small mammal abundance nor diversity. Therefore the small mammal fauna of south-eastern Australia seems advantaged and perhaps dependent in the longer term on the shrub regrowth which flourishes after severe fire, and disadvantaged by "cool control fires" lit to prevent severe wild fires.

This study was conducted at years 6-7 post-fire, when shrubs averaged 1.8 metres with an average cover of 38% in the treed sites and 1.1 metres and 37% on the treeless sites. This is near their maximum, and yet conclusions have been drawn about earlier successional stages. It is encouraging that records of Rattus from those times, particularly soon after the fire, support these conclusions. Rattus lutreolus was the first native species into all habitats then, even the forest. Antechinus is a little more difficult to understand, however, mainly because it survived so well in the first year post-fire. It must be added, of course, that the precise resources required by the species have not been deduced, merely what appear to be preferred habitat associations.

ACKNOWLEDGMENTS

We thank the N.S.W. National Parks and Wildlife Service for permission to work in Nadgee Nature Reserve. We are grateful to Mr. R.J. Burt and Mr. H.L. Wakefield for field assistance. Mr. Frank Knight drew the figures and Mrs. Wendy Guy kindly typed the manuscript. The early part of the study to 1976 was part of Grant CS8S and CS17 from the Australian Meat Research Committee for the study of dingoes.

LITERATURE CITED

Barnett, J.L., How, R.A.; Humphreys, W.F. The use of habitat components by small mammals in eastern Australia. Aust. J. Ecol. 3:277-285; 1978.

Bell, D.T., Koch, J.M. Post-fire succession in the northern jarrah forest of Western Australia. Aust. J. Ecol. 5:9-14; 1980.

Birney, E.C.; Grant, W.E.; Baird, D.D. Importance of vegetative cover to cycles of Microtus populations. Ecology 47:1043-1051; 1976.

Braithwaite, R.W.; Cockburn, A.; Lee, A.K. Resource partitioning by small mammals in lowland heath communities of south-eastern Australia. Aust. J. Ecol. 3:423-445; 1978.

Braithwaite, R.W.; Gullan, P. Habitat selection by small mammals in a Victorian heathland. Aust. J. Ecol. 3(1):109-127; 1978.

Campbell, A.J.; Tanton, M.T. Effects of fire on the invertebrate fauna of soil and litter of a eucalypt forest. In: Gill, A.M.; Groves, R.H.; Noble, I.R., eds. Fire and the Australian Biota. Canberra: Australian Academy of Science; 215-242; 1981.

Carstairs, J.L. The distribution of Rattus villosissimus (Waite) during plague and non-plague years. Aust. Wildl. Res. 1: 95-106; 1974.

Catling, P.C.; Newsome, A.E. Responses of the Australian vertebrate fauna to fire: an evolutionary approach. In: Gill, A.M., Groves, R.H.; Noble, I.R., eds. Fire and the Australian Biota. Canberra: Australian Academy of Science; 273-310; 1981.

Cheney, N.P. Our changing bushfire scene. Rural Research 105:8-13; 1979 December.

Christensen, P.E.; Kimber, P.C. Effect of prescribed burning on the flora and fauna of south-west Australian forests. Proc. Ecol. Soc. of Aust. 9:85-106; 1975.

Christensen, P.; Recher, H.; Hoare, J. Responses of open forests (dry sclerophyll forests) to fire regimes. In Gill, A.M.; Groves, R.H.; Noble, I.R., eds. Fire and the Australian biota. Canberra: Australian Academy of Science; 367-393; 1981.

Coaldrake, J.E. Ecosystems of the coastal lowlands, southern Queensland. CSIRO Aust. Bull. No. 283; 1961.

Cockburn, A. The distribution of Pseudomys shortridgei (Muridae: Rodentia) and its relevance to that of other heathland Pseudomys. Aust. Wild. Res. 5(2):213-219; 1978.

Cook, S.F. Jr. The effects of fire on a population of small rodents. Ecology 40:102-108; 1959.

Cowley, R.D.; Heislers, A.; Ealey, E.H.M. Effects of fire on wildlife: combination of papers. Vict. Resour. 11(3):18-22; 1969.

Crowner, A.W.; Barrett, G.W. Effects of fire on the small mammal component of an experimental grassland community. J. Mamm. 60(4):803-813; 1979.

Dudzinski, M.L. Principal Components Analysis and its use in Hypothesis Generation and Multiple Regression. In: Bofinger, V.J; Wheeler, J.L., eds. Developments in field experiment design and analysis. Commonwealth Agricultural Bureaux; Alden Press, Oxford, 196.1975

Dwyer, P.D.; Kikkawa, J.; Ingram, G.J. Habitat relations of vertebrates in subtropical heathlands of coastal southeastern Queensland. In: Specht, R.L., ed. Ecosystems of the World: Heathlands and Related Shrublands. Descriptive Studies; Vol 9A, 281-299; 1979.

Fox, A. The '72 fire of Nadgee Nature Reserve. Parks and Wildlife 2(2):5-24; 1978.

Fox, B.J. Small mammals and forest fire. Aust. J. Ecol. 5: in press.

Gilbert, J.M. Forest succession in the Florentine Valley, Tasmania. Pap. Proc. Roy. Soc. Tas. 93: 129-51; 1959.

Colley, F.B. Mammals of Georgia. University of Georgia Press, Athens. 1962.

Gunderson, J.B. Red-backed voles habitat studies in central Minnesota. J. Mammal. 40:405-412; 1959.

Hall, S. The diets of two co-existing species of Antechinus (Marsupialia:Dasyuridae). Aust. Wildl. Res. 7:365-78; 1980.

Jackson, W.D. Fire, air, water and earth - an elemental ecology. Proc. Ecol. Soc. Aust. 3: 9-16; 1968.

Keith, K.; Calaby, J.H. The New Holland mouse Pseudomys novaehollandiae (Waterhouse) in the Port Stephens district, New South Wales. CSIRO Wildl Res. 13:45-58; 1968.

Kikkawa, J.; Ingram, G.J.; Dwyer, P.D. The vertebrate fauna of australian heathlands - an evolutionary perspective. In: Specht, R.L., ed. Ecosystems of the World: Heathlands and Related Shrublands. Descriptive Studies. Vol 9A, 231-275; 1979.

Kirkland, G.L. Jr. Population and community responses of small mammals to 2,4,5-T. USDA. Forest Service Res. Note, PNW-314, 6 pp; 1978.

Komerek, E.V. Fire and animal behaviour. Proc. Tall Timbers Conf. No. 9. Tallahassee, Florida; 161-207; 1969.

Leonard, B.V. The effect of fire upon selected small mammals and leaf litter fauna in sclerophyll forest in southern Australia. M.Sc. Thesis, Monash University; 1972.

Mutch, R.W. Wildland fires and ecosystems - a hypothesis. Ecology 51: 1046-1051; 1970.

Newsome, A.E., Corbett, L.K. Outbreaks of rodents in central Australia: origins, declines, and evolutionary considerations. In: Prakash, I., Ghosh, P., eds. Rodents in desert environments. Monographiae Biologicae. Dr. W. Junk: Den Haag. 1975.

Newsome, A.E.; McIlroy, J.C.; Catling, P.C. The effects of an extensive wildfire on populations of twenty ground vertebrates in south-east Australia. Proc. Ecol. Soc. Aust. 9:107-123; 1975.

Newsome, A.E.; Catling, P.C. Habitat preferences of vertebrates inhabiting heathlands of coastal, montane and alpine regions of south-east Australia. In: Specht, R.L., ed Ecosystems of the World. Heathlands and Related Shrublands. 301-315; 1979.

Newsome, A.E.; Catling, P.C. Animal demography in relation to fire and shortage of food: some indicative models. In: Mediterranean Type Ecosystems. The Role of Nutrients. Kruger, F.J., Mitchell, D.T., Jarvis, J.U.M., eds. Springer-Verlag (Ecological Studies) In press.

Noble, I.R., Slatyer, R.O. Concepts and models of succession in vascular plant communities subject to recurrent fire. In: Gill, A.M., Groves, R.H., Noble, I.R., eds. Fire and the Australian biota. Canberra, Australian Academy of Science, 311-338. 1981.

Posamentier, H. Habitat requirements of small mammals in coastal heathlands of New South Wales. M.Sc. Thesis, Sydney University; 1976.

Quinn, R.D. Effects of fire on small mammals in the Chaparral. In: Koch, D.L., ed. Proceedings of Cal-Neva Wildlife Transactions (Long Beach, California. 125-133; 1979.

Recher, H.F.; Lunney, D.; Posamentier, H. Effects of wildfire on small mammals at Nadgee Nature Reserve N.S.W. Third Fire Ecology Symposium, Monash Univ. Forestry Commission of Victoria; 30-36; 1975.

Specht, R.L.; Rayson, P.; Jackman, M.F. Dark Island Heath (Ninety-mile Plain, South Australia). VI. Pyric succession: changes in composition, coverage, dry weight, and mineral nutrient status. Aust. J. Botany 6(1):59-88; 1958.

Suckling, G.C.; Heislers, A. Populations of four small mammals in radiata pine plantations and eucalypt forests of north-eastern Victoria. Aust. Wildl. Res. 5:305-16, 1978.

Tyndale-Biscoe, C.H.; Calaby, J.H. Eucalypt forests as refuge for wildlife. Aust. Forestry. 38: 117-133; 1975.

Wakefield, N.A.; Warneke, R.M. Some revision of Antechinus (Marsupialia) - 1. Vict. Nat 80: 194-219; 1963.

Wakefield, N.A.; Warneke, R.M. Some revision of Antechinus (Marsupialia) - 2. Vict. Nat. 84: 69-99; 1967.

Walker, J. Aspects of fuel dynamics in Australia. CSIRO Div. of Land Use Res., Canberra. Tech. Mem. 79/7; 1979.

The Effects of Fire Regime on Small Mammals in S.W. Cape Montane Fynbos (Cape Macchia[1]

K. Willan and R. C. Bigalke[2]

Abstract: Small mammal species richness, abundance and biomass were determined in representative S.W. Cape montane fynbos habitats of various post-fire ages, and in riverine and rocky outcrop habitats respectively too wet and too poorly vegetated to burn. In fynbos the parameters measured displayed bimodal distributions, with early (2,4 years) and late (38 years) peaks and intervening troughs (10-14 years). Correlations with plant succession are discussed. In comparison with other ecotypes, recolonisation of burns by small mammals occurs more slowly in fynbos. Species richness, abundance and biomass of small mammals was consistently higher in riverine habitats than on rocky outcrops. The former may serve as major sources of recolonisation after fire.

There is no published information on the effects of fire on small mammals in fynbos although ecosystem dynamics cannot be fully understood without knowledge of these effects. Three studies have been undertaken (Toes 1972; Lewis In prep; Bigalke and Repier, Unpubl.),and Bond and others (1980) commented on potential fire effects in the Southern Cape mountains. The present pilot study took place in S.W. Cape montane fynbos preparatory to intensive investigation of the effects of fire regime on non-fossorial small mammals. The project has been temporarily suspended, and preliminary conclusions are presented here.

METHODS

Trapping was undertaken from August to November 1979 at selected sites in three Department of Forestry mountain catchment reserves, Jonkershoek (33°59'S, 18°59'E; ± 400m), Wemmershoek (33°48'S, 19°02'E; ± 8OOm) and Lebanon (34°09'S, 19°09'E; ± 900m). 34 sites were trapped, 22 in representative fynbos and 6 each in riverine habitats and rocky outcrops. The riverine and rocky outcrop habitats appeared respectively too wet and too poorly vegetated to burn; they were sampled to ascertain their potential as refuge habitats after fire (Vesey-Fitzgerald 1966), when the surrounding vegetation had been destroyed. The fynbos study areas were selected on the basis of' the post-fire age of the vegetation (2, 4, 10, 14 and 38 years old). The effects of variables other than post-fire age were largely neutralised by sampling a number of sites in each area which were analogous to sites in other areas. In this way area effects resulting from differences in aspect, slope, rockiness and proximity to surface water were more or less eliminated. Unavoidable variation occurred in season, altitude and vegetation floristics and physiognomy. In the 2-14—year-old areas, trapping sites included vegetation dominated respectively by Proteacea, Ericacea and Restionacea, but this was impossible in the 38-year-old area where *Protea repens* and *Widdringtonia nodiflora* were dominant, although the proteas were dying out, leaving much dead wood on the ground and permitting recolonisation by ericas and restios. The most important feature of these habitats in relation to the study objectives was that while the young (2-and 4-year-old) and old (38-year-old) vegetation could be regarded as productive (i.e. actively growing, the latter due to recolonisation by ericas and restios), the 10-and 14-year-old vegetation was clearly moribund, and floristic and physiognomic diversity was consistently lower than in either the young or senescent habitats. In an attempt to obtain an overview of small mammal preferences for these habitats, data are combined where areas of the same general type (i.e. riverine or rocky outcrop habitats, or ones of the same post-fire age) were sampled in different catchments.

A summary of sampling effort in each type of habitat is given in Table 1. In the fynbos and mesic refuge habitats, trapping took place on transect lines of variable length (10-20 stations, depending on local conditions), with 15m between stations. Trapping on rocky outcrops was more or less *ad libitum*, with traps set at places where they seemed most likely to make a catch. 2 live-traps were used at every station, 1 Sherman 230 x 80 x 90 mm and 1 PVC tunnel trap 250 x 65 x 78 mm (after Willan 1979). Traps were set within 1m of station markers abutting small mammal runways if present, and checked morning and evening for a total of 4 days and nights. Bait was a mixture of rolled oats, raisins and sunflower oil; pre-baiting was not employed. Animals were released at the point of capture after species and mass

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Lecturer in Zoology, University of Fort Hare, Private Bag X 1314, Alice 5700, South Africa; Professor of Nature Conservation, University of Stellenbosch, Stellenbosch 7600, South Africa.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--Sampling effort (station-nights) in various S.W. Cape fynbos habitats. The number of sites sampled within each area is given in brackets.

Study areas	Month sampled	Montane fynbos - age in years					Mesic refuges	Rocky outcrops	Totals
		2	4	10	14	38			
Wemmershoek	August	130 (2)			180 (3)		180 (3)	200(4)	690 (12)
Lebanon	September			300 (6)			40 (1)	100(2)	440 (9)
Jonkershoek	November	80 (2)	430 (6)			180 (3)	100 (2)		790 (13)
Totals		210 (4)	430 (6)	300 (6)	180 (3)	180 (3)	320 (6)	300(6)	1920 (34)

had been recorded and to avoid interfering with proposed trap-mark-release studies, they were marked only by clipping the fur. Results are interpreted as indices of relative abundance, expressed as trap-success/station-night of effort, where "station-night" described trapping for a 24-hour period with two traps/station. Data of this type may be expressed in terms of "trap-success" (e.g. Meester and others 1979; Mentis and Rowe-Rowe 1979), but in the present report this would have been misleading since it was uncommon (less than 3 percent of captures) for more than one animal to be trapped at the same station at the same time. Relative biomass was calculated as total biomass divided by sampling effort, hence as g/station-night.

Otomys spp. are difficult to distinguish in the field, and while J. Meester (pers. comm.) identified as O. irroratus all specimens in a small voucher series from the 3 catchments, O. laminatus and O. saundersae also occur in fynbos (Davis 1974), with O. saundersae previously recorded from Jonkershoek (Stewart 1972). The possible irroratus/laminatus/saundersae complex present in the sample is referred to as Otomys throughout, although the great majority were probably O. irroratus. This approach appears reasonable in view of the similarity in habits of Otomys spp. (Roberts 1951; Kingdon 1974).

RESULTS

A total of 460 rodents and insectivores, representing 12 taxa, were captured during the study (table 2), 83 percent of which were Aethomys namaquensis, Otomys spp., Rhabdomys pumilio and Mysorex varius.

Species richness (fig. 1) was highest in the riverine habitats, where all but one species (Elephantulus edwardii) were present, and lowest on rocky outcrops and in 14-year-old fynbos. In the fynbos habitats it was variable, with early (4-year) and late (38-year) peaks, and an intervening (10-and 14-year) trough.

Relative abundance (fig. 2) was highest in the riverine habitats, and lowest on rocky outcrops. In the fynbos habitats, relative abundance displayed early and late peaks, with an intervening trough, but within the overall bimodality considerable species-specific variation existed. The most important characteristics of the distribution illustrated in figure 2 are as follows:

1--Abundance of Aethomys namaquensis, Mus minutoides and Dendromus melanotis declined with increasing age of the vegetation, and D. mesomelas replaced D. melanotis as the vegetation became more rank.

2--Otomys spp. were initially (2 years) poorly represented, but thereafter maintained an important presence.

3--Rhabdomys pumilio was most abundant in young (2-and 4-year-old) and old fynbos, but declined in middle age; ad libitum trapping in an area of younger fynbos (specific age unknown) adjoining the 10 year-old habitat showed this species to be present at Lebanon.

4--Acomys subspinosus was generally poorly represented, and was absent from 2 and 14 year-old habitats.

5--Insectivores were absent from 2 year-old fynbos; small numbers of Crocidura cyanea and C. flavescens were present only in the 4 year-old habitat, but Myosorex varius showed an almost linear increase with increasing age of the vegetation ($r = 0.985$; $P < .01$).

6--Praomys verreauxi and Elephantulus edwardii were respectively restricted to riverine and rocky outcrop habitats. P. verreauxi is, however, not generally restricted to riverine habitats, occurring on scrubby hill-slopes or forest margins in the Knysna area (Davis 1974), and on well-vegetated slopes in the Southern Cape mountains (Bond and others 1980).

7--The riverine small mammal communities were dominated by Otomys spp. and R. pumilio, and rocky outcrops by Aethomys nanaquensis.

Relative biomass (fig. 3) was bi-modally distributed in the fynbos habitats, with peaks at 4 and 38 years. The high incidence of Otomys spp.

Table 2--Numbers of small mammals trapped in various S.W. Cape fynbos habitats.

Species	Montane fynbos - age in years 2	4	10	14	38	Mesic refuges	Rocky outcrops	Totals
Rodents:								
Acomys subspinosus		12	5		2	7		26
Aethomys namaquesis	23	4	2			11	14	54
Dendromus melanotis	6					1		7
Dendromus mesomelas			8		3	3		14
Mus minutoides	9					4	1	14
Otomys spp.	1	62	22	15	15	32		147
Praomys verreauxi						6		6
Rhabdomys pumilio	18	36			15	38		110
Insectivores:								
Crocidura cyanea		1				3		4
Crocidura flavescens		1				3		4
Elephantulus edwardii							2	2
Myosorex varius		3	16	12	27	14		72
Totals	54	119	53	30	62	122	17	460

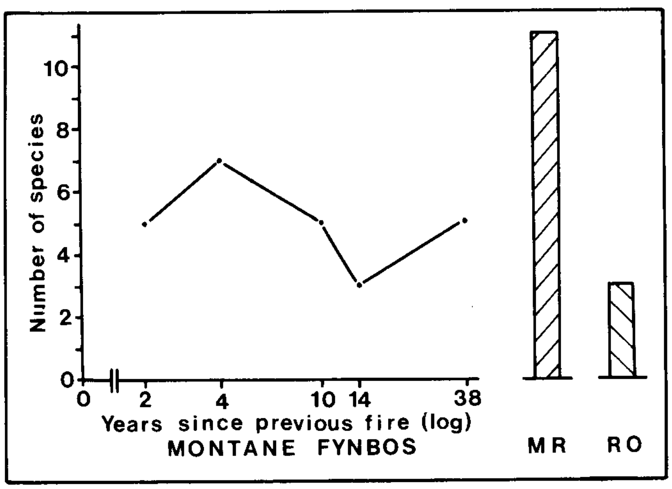


Figure 1--Species richness of small mammals in various S.W. Cape fynbos habitats. MR = mesic refuges; RO = rocky outcrops.

($\overline{X}$ = 99g) in 4-year-old fynbos (52 percent of total captures) and the reduced importance of this taxon at 28 years (24 percent), together with high 38-year numbers of M. varius (44 percent; $\overline{X}$ = 12g), largely explains the shift of the higher peak from 38 years (abundance; fig. 2) to 4 years (biomass; fig. 3). Relative biomass in the mesic habitats was identical to that in 4-year-old fynbos (19.0g/station-night), while rocky outcrops (2.5g/station-night) supported only 27 percent of the biomass of the next lowest habitat (10-year-old fynbos; 9.1g/station-night).

DISCUSSION

Successional Trends

The available data demonstrate the existence of bimodal distributions of small mammal species richness, abundance and biomass in respect of post-fire age of montane fynbos, with early and late peaks, and intervening troughs. The de facto existence of a decline in middle-aged fynbos is supported by the fact that Toes (1972) recorded only 3 small mammal species in a 14 year-old Protea repens stand at Jonkershoek, and Lewis (in prep.) found only 1 species to be present at the same site when the vegetation was 17 years old. It is significant that small carnivores, as evidenced by tracks and scats observed during the present field work, and by interference with traps, were only active in 4-and 38-year-old fynbos, and in riverine habitats, where small mammals were most abundant.

A similar bimodality has previously been described in humid montane grassland (Natal Drakensberg; Mentis and Rowe-Rowe 1979). These authors proposed that the reason for the bimodality they observed is that different species (including small mammals, antelope and francolin) are adapted either to frequently burned (fire accessible) or infrequently burned (fire inaccessible) habitats, but not to moribund habitats of intermediate post-fire age. It seems more economical to argue that some species are preadapted to recently burnt environments, exploit the resources available there and decline in the later seral stages. The second peak results from the presence of core species and those confined to old unburnt habitats.

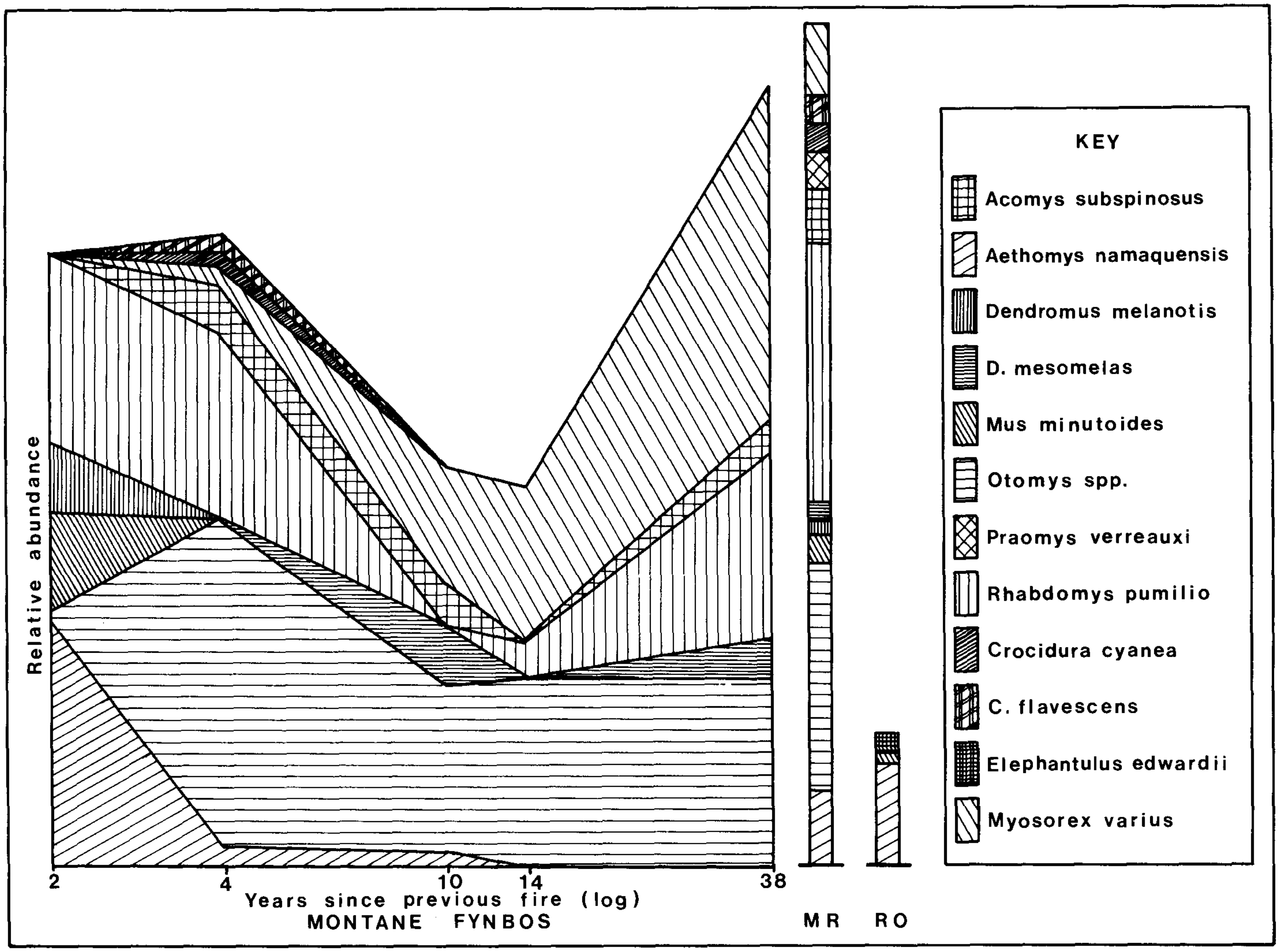


Figure 2--Relative abundance of small mammals in various S.W. Cape fynbos habitats. MR = mesic refuges; RO = rocky outcrops. Relative abundance calculated by dividing total captures for each species by sampling effort (station-nights).

On present knowledge the successional pattern in fynbos indicated by our results is not easy to explain fully. Limited cover and food may both restrict small mammal species richness and density on young burns. Cover requirements of Aethomys namaquensis are low and Rhabdomys pumilio prefers "grassy" ground cover, which includes Poaceae as well as the Cyperaceae and Restionaceae prominent in young fynbos (Bond and others 1980). The small size of Mus minutoides may enable it to use small residual patches of shelter (Bigalke and Willan in press). 4 of the 5 rodents trapped on the youngest burns (table 2) are omnivorous (Bigalke and Willan in press) and thus able to exploit whatever food resources are available. The fifth, Otomys sp., is a specialist herbivore and only becomes abundant later in response to increasing cover (see below).

Peak small mammal species richness, density and biomass measured at 4 years (table 2, fig. 2) is attained when the vegetation is reaching the end of its youth phase. During this time fynbos becomes dominated by restionaceous and graminoid plants and sprouting shrubs, the herbaceous plants reaching maximum biomass of up to 8000kg/ha. Canopy cover reaches about 80 percent of pre-burn levels and remaining sprouting species attain reproductive maturity (Kruger and Bigalke in press). Food resources are likely to be plentiful and of good quality. For some mammals abundant at this time cover density is known to be important. Bond and others (1980) found a positive correlation between the presence of Acomys and foliage density between 20 and 60cm although high elevation and rocky areas were also significant habitat factors in Baviaanskloof. Otomys spp. also exhibit a marked preference for dense shrubby vegetation (Bond and others 1980).

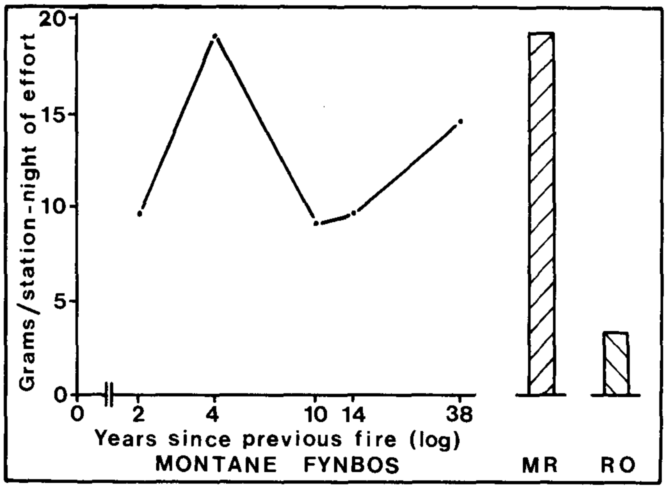


Figure 3--Relative biomass of small mammals in various S.W. Cape fynbos habitats. MR = mesic refuges; RO = rocky outcrops. Relative biomass calculated by dividing total biomass by sampling effort (station-nights).

The decline of small mammals in mature fynbos may reflect responses to dense canopy cover, the reduced importance of lower herbaceous strata and decreasing plant species diversity described by Kruger and Bigalke (in press). During the senescent phase of post-fire succession in fynbos - over about 30 years - these authors show that mortality among shrubs is high, the canopy opens and some seed regeneration may occur. A species such as Rhabdomys presumably again finds adequate food and "grassy" ground cover while the accumulated litter may be an important factor favouring Myosorex.

Recolonisation Rates

Rates of small mammal recolonisation of burns in fynbos appear slower than in other southern African ecotypes. The present study did not include habitats of less than 2 years post-fire age, but trapping on a burn at Duthie Reserve, University of Stellenbosch (33°56'S; 18°52'E; ± 100m), Bigalke and Pepler (unpubl.) found no small mammals to be present until Rhabdomys pumilio moved in 11 months after the fire. Toes (1972) sampled 1-year-old vegetation at Jonkershoek and found only 2 species to be present. In contrast, a number of studies in other regions have shown post-fire pioneer species to be present immediately after burning (Christian 1977; Kern 1978; Meester and others 1979; Mentis and Rowe-Rowe 1979), and as many as 5 species may be present 7 months after fire in Terminalia-Dichrostachys savanna (Kern 1978). These observations presumably reflect the slower rate of regeneration of fynbos relative to other vegetation types. It is of interest in this respect that of the species sampled in this study, 2 may be present immediately after fire in other ecotypes (Mus minutoides and Myosorex varius at Midmar Dam Nature Reserve, Natal - Meester and others 1979; Myosorex varius in the Natal Drakensberg-Mentis and Rowe-Rowe 1979). Other species in which post-fire pioneer status has been documented (Desmodillus auricularis, Gerbillurus paeba, Malacothrix typica - Christian 1977; Tatera leucogaster - Kern 1978; Praomys natalensis - Meester and others 1979, Mentis and Rowe-Rowe 1979) do not occur in the S.W. Cape. Further study may show that Aethomys namaquensis, which as noted above is adapted to low cover densities (Bond and others 1980), survives on fresh burns. Its dominant position 2 years after fire (fig. 2) at least suggests that it recolonizes burns soon after fire. This species did not occur in the vicinity of Duthie Reserve, which represents a small fynbos "island" surrounded by disturbed and largely exotic vegetation.

Refuge Habitats

The data presented above indicate that riverine habitats are more important as refuges during and immediately following fire than are rocky outcrops. The occurrence in riverine vegetation of all 10 species found in the fynbos habitats suggests that recolonisation of burns at the appropriate stage of vegetative regeneration may occur from such refuges rather than surrounding areas of unburned fynbos, where species diversity may be low. In contrast, extensive recolonisation of fynbos from rocky outcrops would be expected to be undertaken only by Aethomys namaquensis.

Conservation

The conservation status of the majority of southern African small mammals is unknown, but 4 species dealt with here (Acomys subspinosus, Otomys laminatus, O. saundersae, Praomys verreauxi) are rare (Dean 1978) S.W. Cape endemics (Davis 1974). Acomys and Praomys are pollinators of geoflorous proteas such as Protea amplexicaulis and P. humiflora (Wiens and Rourke 1978). It seems reasonable to propose, therefore, that the local status of these species (at least) should be ascertained prior to prescribed burning, with a view to their conservation.

It has been shown that the abundance of francolin in the Natal Drakensberg is increased by burning small rather than large areas of veld, thus creating a fine mosaic of vegetation of different post-fire ages (Mentis and Bigalke 1979). Such a policy would appear to have much to recommend it, especially if consideration were given to the question of fire accessibility (Mentis and Rowe-Rowe 1979), so that naturally fire-accessible areas were burnt prior to reaching the moribund phase of vegetative succession, and succession was allowed to proceed ad infinitum in naturally fire-inaccessible areas. In the long term this would be expected to increase overall diversity, abundance, and biomass of small mammals, and hence to encourage proliferation of small carnivores and other predators which feed on them.

Acknowledgements: Financial assistance provided under the Fynbos Biome Project, National Programme of Environmental Sciences, C.S.I.R., is gratefully acknowledged. We thank the Directorate of Forestry, Department of Water Affairs, Forestry and Environmental Conservation for permission to trap mammals on State Forests. Jennifer Willan typed manuscripts with skill and patience.

REFERENCES

Bigalke, R.C.; K. Willan. Effects of fire regime on faunal composition and dynamics. In: P. de V. Booysen, ed. The ecological effects of fire in South African ecosystems. In press.

Bond, W.; M. Ferguson; G. Forsyth. Small mammals and habitat structure along altitudinal gradients in the southern Cape mountains. S. Afr, J. Zool. 15:34-43; 1980.

Christian, D.P. Effects of fire on small mammal populations in a desert grassland. J. Hamm. 58:423-427; 1977.

Davis, D.H.S. The distribution of some small southern African mammals (Mammalia: Insectivora, Rodentia). Ann. Transvaal Mus. 29(9): 135-184; 1974.

Dean, W.R.J. Conservation of the white-tailed rat in South Africa. Biol. Conserv. 13:133-140; 1978.

Delany, M.J. The ecology of small rodents in tropical Africa. Mamm. Rev. 2:1-42; 1972.

Delany, M.J.; D.C.D. Happold. Ecology of African mammals. London: Longmans; 1979.

Elton, C.S. Animal ecology. London: Sidgwick and Jackson; 1927.

Kern, N.G. The influence of fire on populations of small mammals in the Kruger National Park. Unpubl. M.Sc. Thesis, Univ. of Pretoria; 1978.

Kingdon, J. East African Mammals. Vol. IIB. (Hares and Rodents). London: Academic Press; 1974.

Kruger, F.J.; R.C. Bigalke. Fire in Fynbos. In: P. de V. Booysen, ed. The ecological effects of fire in South African ecosystems. In press.

Lewis, C.S. The influence of fire on small mammal populations in the Western Cape, with special reference to Jonkershoek. M.Sc. Thesis, Univ. of Stellenbosch; in prep.

Meester, J.A.J.; C.N.V. Lloyd; D.T. Rowe-Rowe. A note on the ecological role of *Praomys natalensis*. S. Afr. J. Sci. 75:183-184; 1979.

Mentis, M.T.; D.T. Rowe-Rowe. Fire and faunal abundance and diversity in the Natal Drakensberg. Proc. Grassld. Soc. S. Afr. 14:75-77; 1979.

Mentis, M.T.; R.C. Bigalke. Some effects of fire on two grassland fracolins in the Natal Drakensberg. S. Afr. J. Wildl. Res. 9:1-8; 1979.

Roberts, A. The mammals of South Africa. Johannesburg: Central News Agency; 1951.

Stewart, C.T. A report on the progress of the rodent and insectivore survey of the Andries Venter Research Station, Jonkershoek Valley. Cape Town: Unpubl. Report C.P.A. Dept. of Nature Conservation; 1972.

Toes, E. Tellengen van kleine zoogdieren en vogels in de Jonkershoek Vallei, Zuid Afrika. Unpubl. Report, Landbouwhogeschool te Wageningen; 1972.

Vesey-Fitzgerald, D.F. The habits and habitats of small rodents in the Congo river catchment region of Zambia and Tanzania. Zool. Afr. 2: ; 1966.

Wiens, D.; J. Rourke. Rodent pollination in southern African *Protea* spp. Nature 276(5683): 71-73; 1978.

Willan, K. Design and field tests of a modified small mammal livetrap. S. Afr. J. Tool. 14: 81-84; 1979.

The Influence of Disturbance (Fire, Mining) on Ant and Small Mammal Species Diversity in Australian Heathland[1]

Barry J. Fox[2]

Abstract: Multiple linear regression equations describe responses for both taxa to temporal, floristic and structural vegetation change. Mammal succession is a replacement of dominant species, ant succession is a replacement of groups of species. Many plant species show adaptations to frequent burning and a high proportion of resprouters ensures a rapid recovery, reflected in the mammal community. Mammal recolonization is slower when mining destroys the soil profile and plant regeneration occurs from seed. High-diversity sites support more fire-adapted mammal species. Species diversity is linearly related to habitat diversity. Management for maximum species diversity requires vegetation of all seral stages to accommodate many different taxa.

This paper draws on a number of closely related studies to make comparisons between different disturbance effects in the one area, and from this come to some more general conclusions using information available in the literature.

To monitor post-disturbance changes I have chosen two taxa, small mammals and ants, to represent the range of animals affected. The area considered is in coastal heathland in Myall Lakes National Park (32°28'S, 152°24'E), experiencing a sub-mediterranean climate with peak precipitation in early winter (May-June), and reduced and unpredictable rain during the summer months.

The study sites regenerating after strip-mining cover a time span from four to eleven years and provide a range of simplified habitats from very sparse vegetation cover, progressing towards cover similar to the surrounding plant community. Detailed descriptions of these sites are provided in Fox and Fox (1978). Detailed information at one heathland site (ML), before, and for 5 years after fire, is provided for a species-rich small mammal community (Fox 1980). A study of regenerating sites of different ages in the heath understorey of nearby open forest provides similar information and conclusions (Fox and McKay 1981).

There are few studies dealing specifically with the effects of disturbance on heathland small mammal communities. Cockburn (1978) found the abundance of the Heath Mouse (<u>Pseudomys shortridgei</u>), in the Grampian Mountains of Victoria, to be strongly correlated with sites that had burned 6 to 9 years previously and had high plant species diversity. Fox (1980) found that seven species of small mammals in coastal heathland formed a secondary succession following fire. Although largely a study of forest fire, Newsome and others (1975) did include some heathland sites, recording the post-fire appearance of the opportunistic House Mouse (<u>Mus musculus</u>), not previously recorded there. There is considerably more in the literature dealing with the effects of fire on forest small mammals; these are reviewed in Fox and McKay (1981).

The effects of disturbance on ants in Australia is much less well known. Fox (1978) deals with the effects of strip-mining in eastern Australian heathlands, as do Fox and Fox (in press), while Majer (1978) and Majer and others (in press) have studied the effects of bauxite mining in western Australian forests.

MINING

Sequential replacement of top soil, on sand, strip-mined for heavy minerals, produces a regenerating ribbon of heathland where position is a function of time since mining. Mining results in the complete removal of vegetation, destruction of the soil profile and complete homogenization of the overburden

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Senior Tutor in Zoology, University of New South Wales, Kensington, N.S.W., 2033, Australia.

before its replacement; plant regeneration must occur from seed. A full description of the mining and rehabilitation procedures for the Hawks Nest study sites (HN) is given in Fox and Fox (1978), together with descriptions of the methods used to monitor changes along this mining path.

Structural changes in vegetation were monitored with a light meter, using a method developed to estimate the amount of vegetation present in a number of layers (Fox 1979). There is an overall increase in the amount of vegetation in each layer as a function of time, except for the marked decrease in the lowest 20 cm after eight years. There was little vegetation present above 1 m until after this time (Fig. 1). Plant species

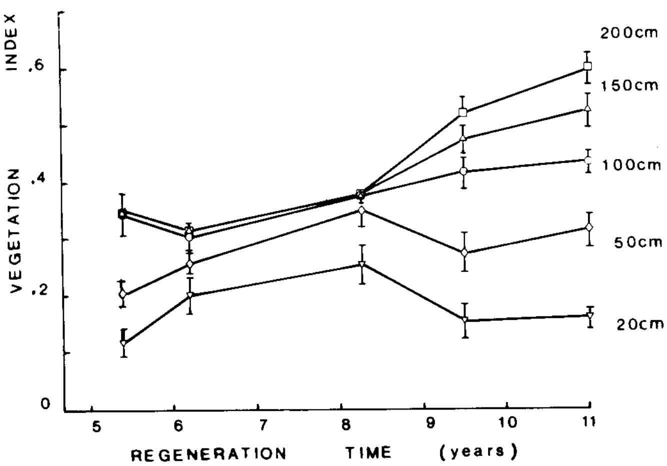


Figure 1--Changes in vegetation structure with regeneration age for five study sites on the Hawks Nest sand mining path. Error bars at the top of each layer are ± 1 s.e.m. for that layer.

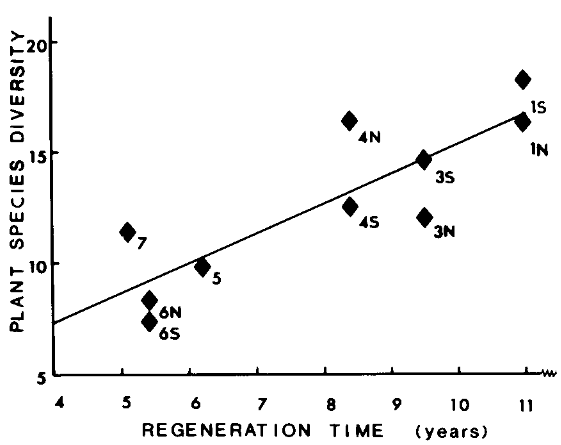


Figure 2--Changes in plant species diversity (Δ_3) with regeneration time for the same mining path ($\Delta_3 = [\Sigma(P_1)^2]^{-1}$, P_i = proportion of cover contribution by species i).

diversity showed a significant linear increase with regeneration time (Fig.2) ($r=0.80$, $n=10$, $p<0.01$). A total of 30 environmental variables were measured for inclusion in a multivariate analysis; from these a subset of 10 variables was selected for further analysis (see Fox and Fox 1978 for full details).

Small Mammals

Small mammals were simultaneously trapped on the 10 mined and 4 control plots, using 25 traps per plot, set on a 5x5 grid with 20 m spacing. Using multiple linear regression and path analysis (see Fox and Fox 1978) a path diagram can be constructed to illustrate which variables contribute significantly to the variance of the biomass of the New Holland Mouse (*Pseudomys novaehollandiae*) on the mined sites (Fig.3). Plant species diversity at each site makes the greatest contribution, followed by a

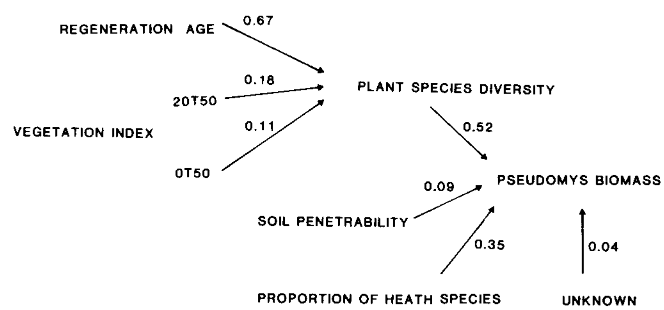


Figure 3-- A path diagram showing factors contributing to changes in *Pseudomys* biomass (PNHBIOM) on sand mined plots. Variables are plant species diversity (PLSPDIV), proportion of heath plant species (HEATHNES), soil penetrability (PENOTIS) and a vegetation index for two structural layers 0 to 50 cm (OT50) and 20 to 50 cm (20T50).

measure of the proportion of those plant species present which are true heath species and then a measure of the soil hardness on the site. Plant species diversity is itself dependent on regeneration age and to a lesser extent on the vegetation structure. From this I can summarize that the New Holland Mouse is associated with areas having a wide variety of heath plants, with vegetation cover below 50 cm on softer substrates and that abundance increases with increasing regeneration age.

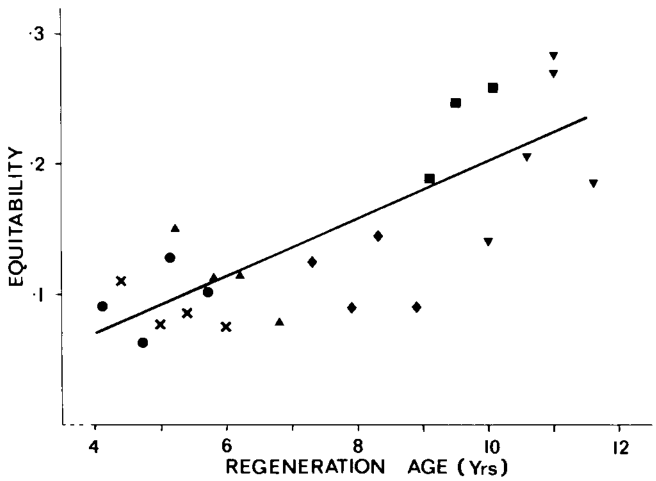


Figure 4--The equitability component (E) of ant species diversity for each mined plot, measured at each of 4 collections during two years, as a function of regeneration age ($E = 4_3/S, S$ = ant species richness). The circled point represents the community changeover.

Ants

A similar analysis was performed for ants collected by simultaneously sampling all study sites using fifteen 2.5 cm (1") pitfall traps per site on a 3x5 grid with 20 m spacing. Sampling was carried out 4 times over 2 years. It is the equitability component of ant species that shows a significant linear relationship with regeneration time (Fig.4) ($r=0.65$, $n=24$, $p<0.01$). Increasing amounts of vegetation in the layers 20 to 50 and 50 to 100 cm are the variables contributing to ant species richness (Fig.5B), while 93 percent of the variance in ant abundance can be attributed to the presence of a group of heath plant species, low foliage height diversity and a soft substrate (Fig.5A).

Analysis of the species composition of the ant communities at each site reveals distinctly different communities: one most strongly associated with plots minted less than 8 years ago; a second most strongly associated with plots mined more than 8 years ago; and a third, most prominent on control plots.

The changeovers can be abrupt and are well illustrated by the frequency changes in the numerically dominant species: Tapinoma minutum and 5 species of Iridomyrmex (Fig.6). This represents replacement of the dominant species in a successful manner, *I*. sp C → *I*. sp A → *T*. *minutum*, as one moves along the mining path from younger to older and then to

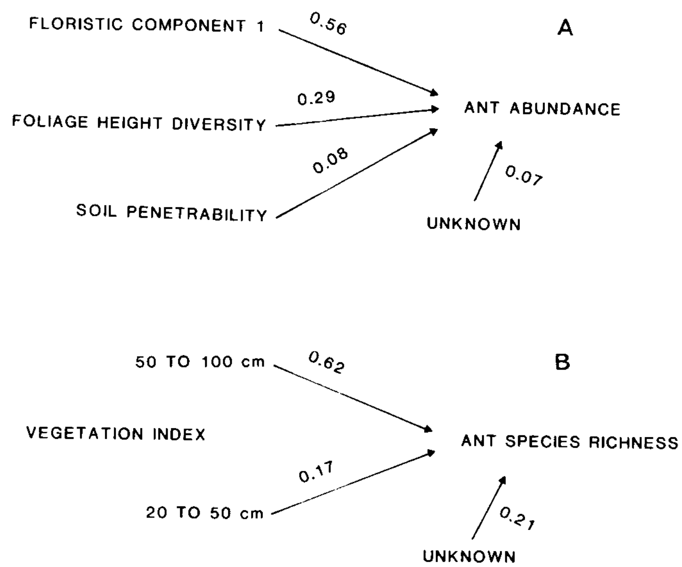


Figure 5--Multiple linear regression path diagrams showing significant contributions to the variance in A) ant abundance ($p<0.001$) and B) ant species richness ($p<0.001$).

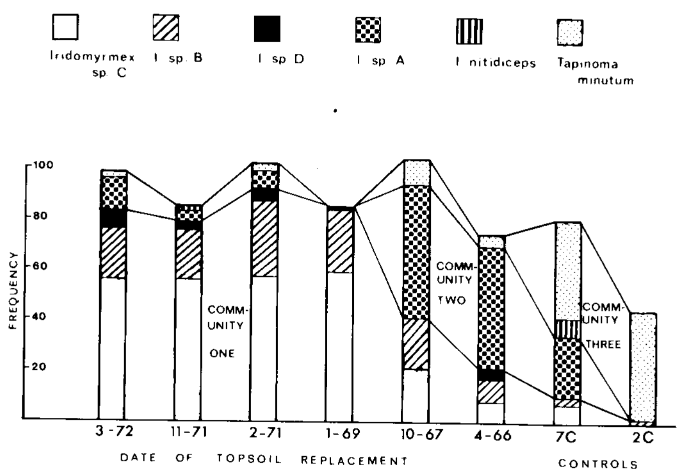


Figure 6--Changes in relative importance of dominant ant species as a function of time. Each large column contains four collections, of increasing age. The time of replacement of top soil is shown for mined plots and time of last fire on control plots. Species associated with younger plots are arranged from the bottom and those for older plots from the top. (Maximum frequency possible on any plot is 15).

unmined heath. There is good evidence that these changes result from competitive interactions between the dominant species (Fox and Fox, in press).

FIRE

The 7 ha ML site was trapped using the same 20 m grid spacing. The site comprised a range of heathland habitats ranging from swamp, through wet and dry heath, to heath (closed scrub) with emergent mallee-form eucalypts. Seven species of small mammals were regularly encountered and the site was monitored for 6 months before a major wildfire and at about 2 monthly intervals for 5 years after the fire. Some species such as the Eastern Chestnut Mouse (Pseudomys gracilicaudatus) showed a marked increase (sixfold) over their pre-fire abundance, while others such as the Eastern Swamp Rat (Rattus lutreolus) were unable to reoccupy the area for more than 4 years after the fire. The resulting mammalian secondary succession is best summarized in terms of taxonomic groupings that match the ecological grouping into early, mid and late seral stage species (Fig.7). Species are not usually completely excluded, rather there are marked changes in relative abundance as each species reaches its peak abundance at a time when the regenerating vegetation best meets that species habitat requirements.

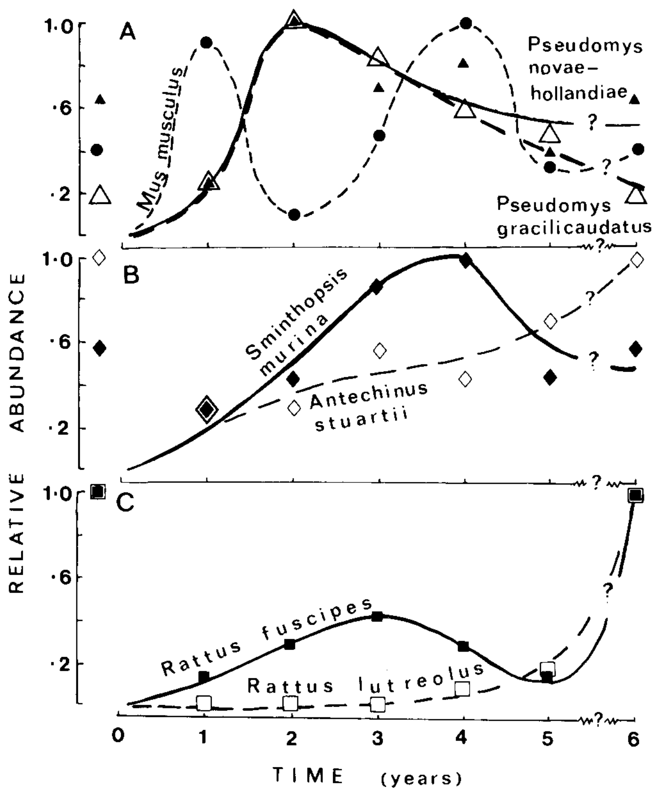


Figure 7--The maximum abundance for each small mammal species in each year since fire, relative to the maximum abundance for that species. Pre-fire abundance is plotted at 6 yrs, the time estimated since the previous fire.

Almost identical results were obtained in a nearby forest (Fox and McKay 1981) using study sites burnt at five different times from 1 to 9 years previously and techniques similar to those used in the mining study (Fox and Fox 1978). Changes in the vegetation structure and plant species diversity of the understorey were similar to those observed on the heath plot (Ml) and shown for the HN mined plots (Fig. 1 and 2).

A COMPARISON OF FIRE AND MINING DISTURBANCE

Making use of the results from the 5-year study on ML it is possible to interpret the relative effects of fire and mining in the area. The three control plots used for the HN mining study had each burnt at a different time (4½, 8½ and 15+ yrs) so that direct comparisons can be made. In isolation the two sets of results for New Holland Mouse density from the mining study appear contradictory; however when combined with the results from ML it can be seen that the differences are due to a drastic shift in the time scale (Fig.8). After fire, New Holland Mouse density, on ML, peaked around two years before returning to pre-fire levels. Given that there are different baseline densities at the ML and HN sites, the HN fire curve would appear to be covering the return to baseline (15+ yrs) density, having peaked earlier as indicated by dashes. By analogy the mining curve not only shows a much slower rate of increase (2 animals $ha^{-1}y^{-1}$ versus 5 animals $ha^{-1}y^{-1}$ for the ML fire curve), but there appears to be a threshold at 5 years. Before this, regenerating mined sites do not appear to be suitable for New Holland Mice. Although not certain, it would appear that the mining curve may overshoot, as indicated by the dashed line, before returning to the baseline density.

The difference in recolonisation rates following the two types of disturbance reflects the different modes of vegetation regeneration. Vegetation on mined plots must come from seed, while burned plots afford much more rapid regeneration from resprouting species whose rootstock survive the fires.

Ant species richness shows a similar discordance in changes following fire or mining disturbance (Fig.8B). Again, this may result from differing recovery rates, but it is more complex and without more information on ant recolonization following fire it is impossible to do more than record the difference.

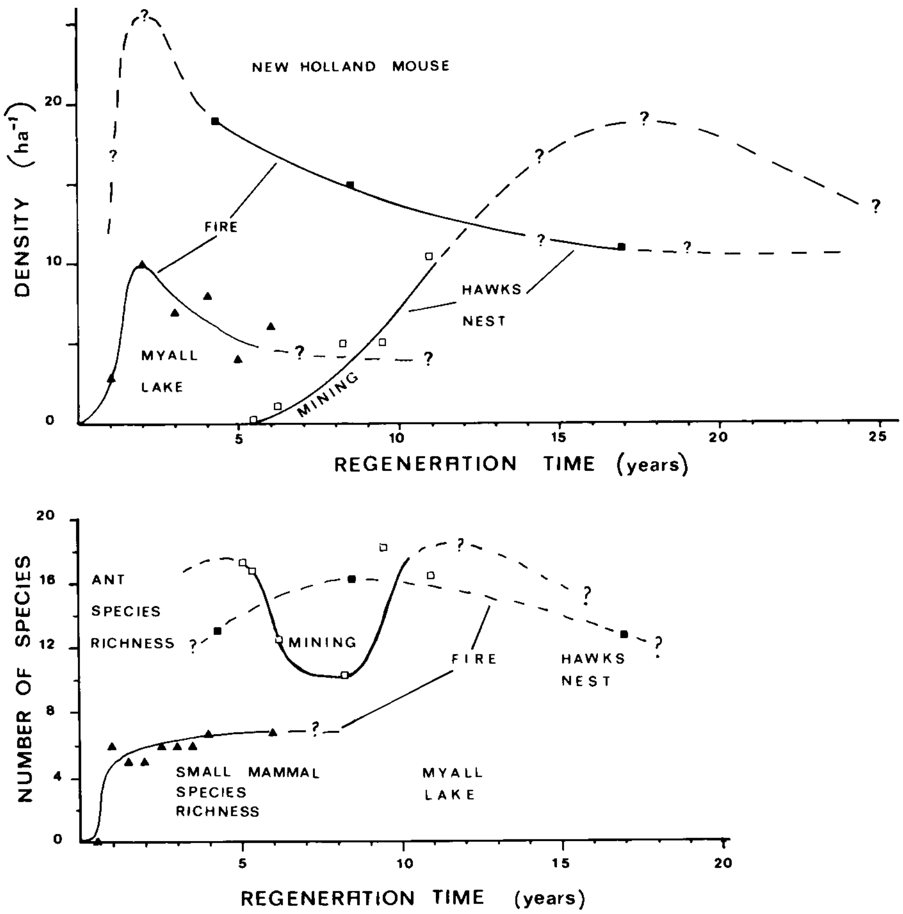


Figure 8-- A) Changes in the density of the New Holland Mouse with time on study sites regenerating after disturbance. Simultaneous data from Hawks Nest sites following mining (❑) and fire (■) are shown, together with annual maxima for a five-year record on the Myall Lake site (▲); dashed lines represent inferred extrapolations.

B) The mean number of ant species per collection for each HN plot, mined and controls. Symbols as for A).

DISCUSSION

Several points emerge that have important implications for the management of heathland areas subject to disturbance, or where some form of disturbance is used as a management tool:
1) the abundance of individual species is a function of regeneration time and they reach maximum values at different times;
2) this results in a secondary succession or species replacement series occurring for each taxa;
3) different groups of species will be present at different times after disturbance;
4) species richness or diversity is a function of regeneration time;
5) ants and mammals show different responses;
6) the response of each taxa is different for each type of disturbance.

It is clear that there can be no single procedure for managing heathland following disturbance. Management procedures must be determined by the aim for which the area is being managed. For example, management of an area to benefit early successional species may require a frequent burning regime, but this will be at the expense of those species that do not reappear until late in a succession. This can occur within a taxa and the problem is exacerbated when trying to manage for a large number of different taxa. A management objective to maintain high species diversity, an often sought aim, would encompass all of these problems. The difficulty with this objective is, it requires that a wide range of different seral stages should always be available in the managed area. The best way to obtain this objective is to maintain a habitat mosaic comprising patches of sufficient size to support populations in each different seral stage, as ready sources of colonists. Evidence supporting this approach is available from the mammal communities of the Myall Lakes National Park.

Species Diversity

Small mammal species diversity (MSD) in Myall Lakes N.P. show the typical asymptotic form of the species-area curve (Fig. 9A). The Victorian sites shown fall well below this line, and show a similarly reduced habitat diversity (HD) in relation to the area of the plot examined (Fig. 9B). An examination of the relationship between MSD and HD shows a very strong linear relationship for the Myall Lakes sites (Fig. 10) (r=0.95, n=10, p 0.001), and the Victorian sites also lie close to this regression line. This would appear to be good evidence for species diversity being directly dependent on habitat diversity and both increasing with increasing area.

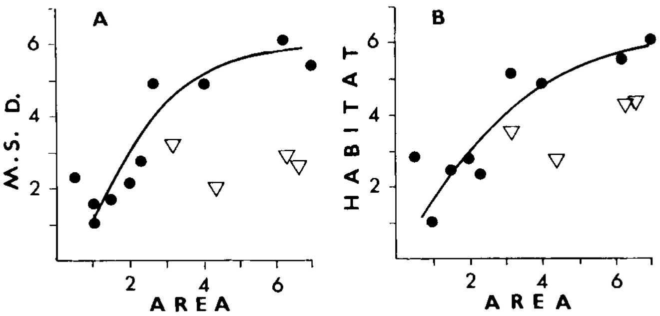


Figure 9-- A) Small mammal species diversity (Δ_3) as a function of area and B) Habitat diversity (Δ_3) as a function of area. Solid symbols from areas in Myall Lakes National Park, N.S.W. (author's data), open symbols from Victorian sites from Braithwaite and Gullan (1978) and Braithwaite, Cockburn and Lee (1978).

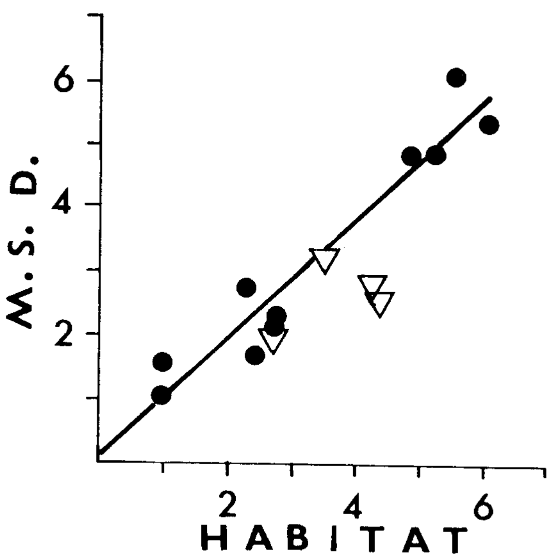


Figure 10--Small mammal species diversity as a function of habitat diversity (symbols as for Figure 8).

The increased MSD in some New South Wales (N.S.W.) sites results from an increased species richness when compared to Victorian sites (Table 1). Close examination reveals that the additional richness is provided by the presence of early successional species that are able to benefit

Table 1. The number of species (including bandicoots) advantaged (F^+) and not advantaged (Non-F^+) by fire, that contribute to the total small mammal species richness of local and regional areas in Victoria and N.S.W. (Data sources as for Fig.9 and from Fox 1980).

	F^+ Species	Non-F^+ Species	Total Species
VICTORIA			
Mt. William	1	4	5
Mirranatwa	1	4	5
Bemm River	1	4	5
Kentbruck	1	4	5
Syphon Road	2	3	5
Cranbourne	2	3	5
Regional Total	4	9	13
N.S.W.			
Marley, Royal N.P.	2	4	6
Brisbane Waters N.P.	2	5	7
Port Stephens	3	4	7
Myall Lakes N.P.	4	4	8
Regional Total	4	5	9

from the vegetation changes following fire (F^+ species, from the genera *Pseudomys* (Native Mice), *Sminthopsis* (Dunnarts) and Isoodon (Bandicoots), see Fox 1980). There is a core of 4 non-F^+ species in both states, to which 2, 3 or 4 F^+ species are added in N.S.W., while only 1 (or 2 with a reduction of 1 core species) may be added in Victoria. This is despite the fact that regionally, there are equal numbers of F^+ species inhabiting heathlands in both states, and almost twice the number of non-F^+ species inhabiting heathland in Victoria (Table 1). This evidence supports the hypothesis that high habitat diversity (resulting from a mosaic of patches with different fire histories in Myall Lakes N.P.) has meant that patchily distributed early successional species have been able to survive, along with mid and late seral stage species, to ensure the maintenance of high local species diversity.

I feel these observations on existing systems provide a good basis on which management decisions can be taken with an objective of maintaining high species diversity.

Acknowledgement: I was able to carry out this analysis by drawing on several earlier studies carried out with my colleague Marilyn Fox; I thank her for this, and for reading the manuscript.

LITERATURE CITED

Braithwaite, R.W.; Gullan, P. Habitat selection by small mammals in Victorian heathland. Aust. J. Ecol. 3: 109-127; 1978.

Braithwaite, R.W.; Cockburn, A.; Lee, A.K. Resource partitioning by small mammals in lowland heath communities of south-eastern Australia. Aust. J. Ecol. 3: 423-445; 1978.

Cockburn, A. The distribution of Pseudomys shortridgei (Muridae: Rodentia) and its relevance to that of other heathland Pseudomys. Aust. Wildl. Res. 5: 213-219; 1978.

Fox, Barry J. An objective method of measuring the vegetation structure of animal habitats. Aust. Wildl. Res. 6: 297-303; 1979.

Fox, Barry J. The ecology of a small mammal community : secondary succession, niche dynamics, habitat partitioning, community structure and species diversity. Unpublished Ph.D. Thesis, Macquarie University; 1980.

Fox, Barry J.; Fox, Marilyn D. Recolonization of coastal heath by Pseudomys novaehollandiae (Muridae) following sand mining. Aust. J. Ecol. 3: 447-465; 1978.

Fox, Barry J.; McKay, G.M. Small mammal responses to pyric successional change in a eucalypt forest. Aust. J. Ecol. 6: 29-42; 1981.

Fox, Marilyn D. Changes in the ant community of coastal heath following sand mining. Bull. Ecol. Soc. Aust. 8: 9; 1978.

Fox, Marilyn D.; Fox, Barry J. Evidence for interspecific competition influencing ant species diversity in regenerating heathland. In: Buckley, R., ed. Ant-Plant interactions in Australasia. Aust. Nat. Univ. Press (in press).

Majer, J.D. Preliminary survey of the epigaeic invertebrate fauna with particular reference to ants in areas of different land use at Dwellingup, Western Australia. For. Ecol. and Manage. 1: 321-334; 1978.

Majer, J.D.; Day, J.E.; Kabay, E.D.; Perriman, W.S. Recolonisation by ants in bauxite mines rehabilitated by a number of different methods (in press).

Newsome, A.E.; McIlroy, J.; Catling, P. The effects of an extensive wildfire on populations of twenty ground vertebrates in S.E. Australia. Proc. Ecol. Soc. Aust. 9: 107-123; 1975.

An Ecological Comparison of Small Mammal Communities in California and Chile[1]

William E. Glanz and Peter L. Meserve[2]

Abstract: Our studies in similar scrub habitats in California and Chile reveal some interesting differences between these two regions in the structure of their small mammal communities. The Chilean fauna is less diverse, with fewer species per site, and possibly more extreme density fluctuations. Chilean rodents are more strongly associated with areas of high shrub and rock cover, while California species show a greater variety of habitat preferences. Chile has more insectivorous species, and California has more seed-eating specialists. Some of these differences may be related to biogeographic and climatic factors, while others may reflect a longer history of human disturbance in Chile.

Similar climates often seem to favor the evolution of similar organisms, and the Mediterranean-climate regions of the world have provided numerous examples of such evolutionary convergence. Of the five regions with this climate, California and Chile have been compared very extensively (Mooney 1977), particularly in terms of the morphological, physiological, and ecological attributes of their dominant organisms. Striking similarities between these two regions have been found in their vegetation structure and community patterns (Mooney and Dunn 1970; Parsons and Moldenke 1975; Parsons 1976), their birds (Cody 1973 and 1974), and their lizards (Fuentes 1976).

In a variety of projects during the past decade (Meserve 1972, 1976a, 1976b, 1981a, 1981b; Glanz 1977a and 1977b; Meserve and Glanz 1978), we have studied certain communities of small mammals in the Mediterranean zones of California and Chile. In this paper we will summarize our results by comparing our three best-documented sites on each continent. We will outline some aspects of these communities that suggest convergence in morphology and ecology. Our emphasis, however, will be on the ecological differences that we have found between the two regions, especially those relating to community diversity, habitat use, and diet. These dissimilarities suggest some major differences in the functional roles of mammals in these communities, some contrasting responses of these animals to vegetation structure, natural predators, and human disturbance, and some potentially important differences in the evolutionary histories of the two regions. We hope that our discussion of these topics will stimulate further research on these ecosystems and their small mammal faunas.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Professor of Zoology, University of Maine, Orono, Maine 04469; and Assistant Professor of Biological Sciences, Northern Illinois University, DeKalb, Illinois 60115.

FIELD SITES AND METHODS

We have ecological data from a variety of communities in each region, but will restrict our discussion here to results from three vegetational types which we have studied intensively: dry coastal scrub, moist coastal scrub, and evergreen chaparral. For each of these, the vegetation structure and life forms at our sites were closely matched between continents.

The dry coastal scrub localities were studied by Meserve near Irvine, Orange County, California in 1970-71 and at Fray Jorge National Park, Coquimbo Province, Chile in 1973-74. Detailed descriptions were provided by M'Closkey (1972) and Meserve (1972 and 1976a) for the California site, and by Fulk (1975) and Meserve (1981a) for the Chilean site. Both study areas were at about 200 m elevation, within 5 km of the coast, and were located on sandy, well-drained soils. Although mean rainfall at the California site (about 300 mm) was considerably greater than at the Chilean site (127 mm), their similar topography, seasonality, and soils apparently produced remarkably convergent vegetation, with approximately 60 percent shrub cover dominated by drought-deciduous species.

The moist coastal sites studied by Glanz (1977a and 1977b) were at Camp Pendleton Marine Base, San Diego County, California, and at Zapallar and Los Molles (two sites), Aconcagua Province, Chile. Although the rainfall at these localities (225 to 350 mm) was comparable to that of the California dry coastal site, they were on slopes more directly facing the ocean and received more coastal fog. This greater moisture plus the higher clay content of the soils resulted in greater average shrub cover (74 percent), also dominated by drought-deciduous species, but including more evergreen shrubs than the dry coastal sites. All study areas were between 20 and 60 m elevation and within 1 km of the coast.

The evergreen chaparral sites sampled by Glanz (1977a and 1977b) were at Echo Valley, near Descanso, San Diego County, California, and

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

at Fundo Santa Laura, near Tiltil, Santiago Province, Chile. Both were at 900 to 1000 m elevation, had 550 to 600 mm mean annual rainfall, and were dominated by evergreen sclerophyllous shrubs. Plots trapped at these sites averaged 75 percent shrub cover. Many additional aspects of the evergreen chaparral and moist coastal sites were studied during the Mediterranean Scrub Project of the International Biological Program, and are described in detail in Thrower and Bradbury (1977).

Our field techniques were designed to sample most mammal species up to 500 gm body size in each community. Populations were live-trapped on large (1.4 to 2.2 ha) grids at all sites except the Chilean moist coastal localities, and snap-trapped on small (usually 0.4 ha) grids at all sites except to California dry coastal area. Population densities were determined by mark-recapture techniques, and by correlating snap-trap success with live-trapping results. A variety of physical and vegetational measurements were used to characterize the habitat preferences of each species. Meserve (1976b, 1981b) categorized each trap station according to its shrub, herb, and bare ground cover values, and then conducted 2 x k association analyses (Simpson, Roe, and Lewontin 1960) between presence/absence data of each species at trap stations and categories of vegetation cover. Glanz measured 30 habitat variables at each trap station, scored each mammal capture for the characteristics of that trap station, and then compared the habitat measures of stations selected by each mammal species with those of all stations trapped at each site. To assess the degree of habitat differentiation among species at each site, Glanz also conducted discriminant analyses using capture records and programs in the SPSS computer library.

Meserve compared arboreal vs. terrestrial habitat utilization at the dry coastal sites using smoked cards placed on the grant and at 25, 50, 100 and 200 cm above ground in the most common shrub species. Tracks on the cards were identified to species and individual using foot characteristics and toe-clip marks (Meserve 1976b and 1981b).

Food habits were assessed by microscopic examination of stomach contents and fecal pellets at most sites, and by fecal analysis only at the California dry coastal site. Meserve (1976a and 1981a) homogenized the sample first, subsampled and boiled the material in Hertwig's solution (Baumgartner and Martin 1939), and then identified cell fragments under a microscope at 100X. Glanz (1977) quantified stomach content fractions first at 40X, subsampled each fraction, and then followed the above procedure. These variations in methods may limit the precision of our comparisons, but should not alter the general conclusions we present in this paper.

Table 1. Occurrence of each small mammal species at the California (above) and Chilean (below) sites. Sites are dry coastal (DC), moist coastal (MC), and evergreen chaparral (EC). Abundance values are: X = present, but uncommon; L = locally common; C = common or abundant. Species Codes are used in figures 1 and 2.

	Community Type		
Species (and Code)	DC	MC	EC
CALIFORNIA			
INSECTIVORA			
Soricidae			
Notiosorex crawfordi	X	X	
RODENTIA			
Sciuridae			
Eutamias merriami			X
Spermophilus beecheyi		L	L
Geomyidae			
Thomomys bottae		X	X
Heteromyidae			
Dipodomys agilis (Dpa)	C		C
Perognathus californicus (Pgc)		X	X
Perognathus fallax (Pgf)	X	C	
Perognathus longimembris (Pgl)	C		
Cricetidae			
Microtus californicus (Mcc)	X	C	X
Neotoma fuscipes (Ntf)	L	C	C
Neotoma lepida (Ntl)	X	C	X
Peromyscus boylii (Pmb)			L
Peromyscus californicus (Pmc)	C	C	C
Peromyscus eremicus (Pme)	C	C	X
Peromyscus maniculatus (Pmm)	C	C	C
Reithrodontomys megalotis (Rtm)	C	X	X
Muridae			
Mus musculus	X	X	
Total Species	12	13	13
Common Species	7	8	6
CHILE			
MARSUPIALIA			
Didelphidae			
Marmosa elegans (Mae)	X	C	X
RODENTIA			
Abrocomidae			
Abrocoma bennetti (Abb)	X		C
Octodontidae			
Octodon degus (Ocd)	C	X	C
Octodon lunatus (Ocl)		L	L
Spalacopus cyanus		L	X
Cricetidae			
Akodon longipilis (Akl)	C	C	C
Akodon olivaceus (Ako)	C	C	X
Oryzomys longicaudatus (Orl)	X	X	X
Phyllotis darwini (Phd)	C	X	X
Muridae			
Rattus rattus (Rra)			L
Total Species	7	8	10
Common Species	4	5	5

FAUNAL COMPOSITION AND DIVERSITY

The species of small mammal recorded from each community are listed in table 1. Several points are obvious from this list. First, both faunas are dominated by rodents; the only exceptions are one shrew, Notiosorex crawfordi, in California and one mouse opossum, Marmosa elegans in Chile. Next, the two faunas are phylogenetically distinct. Among the rodents, only one native family (Cricetidae) is shared between the two regions, although each also contains species of murid rodents introduced by humans from Eurasia. The cricetid rodents of the two areas, moreover, are quite distantly related. Following Hershkovitz (1969), all the Chilean cricetids are placed in the tribe Sigmodontini, while the genus Microtus is in the subfamily Microtinae, and all California species are in the tribe Peromyscini. Similarities between these unrelated groups, then, may be considered evidence for evolutionary convergence; dissimilarities, however, may be due to either phylogenetic or ecological factors.

It is also evident from this list that the California fauna is much more diverse, including 17 species at these sites in contrast to only 10 species at the Chilean sites. This difference was not unexpected, as Greer (1965) and Baker (1967) have noted that the regional faunas of Chile are depauperate in comparison with those of similar areas in North America. They related this low diversity primarily to the geographic isolation of Chile, and to the restricted area of temperate biomes in southern South America.

If similar ecological opportunities are available in the two Mediterranean climate regions, one might expect similar numbers of small mammal species in analogous communities. This prediction is not supported, however, as each Chilean site produced fewer species than its counterpart in California (table 1). Thus, the Chilean fauna is less diverse even when comparing local communities.

POPULATION DENSITIES

Given this pattern of a depauperate Chilean mammal fauna with fewer species per community, one might predict that individual species in Chile might be replacing several analogous species in California, and that total densities of all species in comparable communities would be similar. Such "density compensation" (MacArthur and others 1972) is difficult to test on these Mediterranean-climate communities, as total densities at certain sites varied by more than 10X between years. Nevertheless, the evergreen chaparral and moist coastal sites appear to refute this prediction, as the average densities per snap-trapping grid were significantly lower in Chile for each vegetation type ($p<.05$ for both comparisons; Mann-Whitney U-test). The evergreen chaparral live-trapping densities were also lower in Chile (mean = 5.3/ha) than in California (mean = 9.6/ha), but because of great seasonal variability they were insignificantly different ($p>.05$). Density compensation, however, may be occurring at the dry coastal sites, as average total densities were actually higher in Chile (mean = 58.7/ha) than in California (mean = 41.4/ha), and insignificantly different between the two continents ($p>.10$; U-test). The Chilean site had more extreme variations (coefficient of variation = 48.9 in Chile, 16.8 in California), with Akodon olivaceus declining from high densities (32/ha) early in the study and Octodon degus reaching 120/ha near the end (Meserve 1981b). Fulk (1975) live-trapped the Fray Jorge site in 1972-73 (prior to Meserve's study), and found even higher populations, with A. olivaceus and Phyllotis darwini densities combined exceeding 300/ha. Glanz (1977) also found higher average densities and much greater variability at another Chilean dry coastal site (near Guanaqueros, Coquimbo Province) than at its climatic counterpart in North America. Pefaur and others (1979) reported on a rodent outbreak in north-central Chile in 1972-73, which was dominated by Oryzomys longicaudatus and P. darwini. These data, then, indicate that small mammal densities are highly variable in these Mediterranean-type ecosystems, but that the fluctuations in Chile may be more extreme. Some Chilean sites never achieved densities as high as their California counterparts, but we have data from at most two years for each site, and further long-term studies may find that these populations also occasionally show rodent outbreaks.

MORPHOLOGICAL COUNTERPARTS

Several of the Chilean small mammal genera strikingly resemble certain California genera in morphological characters. The Chilean leaf-eared mouse, Phyllotis darwini, and the rice rat, Oryzomys longicaudatus, are very similar to the North American Peromyscus species, all being small mice with large eyes, large ears, and long tails. All are in the family Cricetidae, however, and also resemble other genera that inhabit other habitats, so their morphological similarity may not necessarily indicate convergence. A more striking example of morphological convergence involves the California woodrats, genus Neotoma, and the Chilean hystricognath rodents of the genera Abrocoma and Octodon. These large rodents are very distantly related, but are very similar in ear and tail length, body size, and coloration. The most obvious morphological counterparts are the fossorial rodents of these regions, the gopher Thomomys bottae in California and the coruro Spalacopus cyanus in Chile. Both have reduced eyes, ears, and tail, elongated claws, and stout incisors and cranial structure, all of which are characteristics found in unrelated groups of burrowing rodents throughout the world. They therefore exhibit convergence, but in a way that is not specific to Mediterranean-type ecosystems.

Most other small mammals of the two regions are more difficult to match with a morphological counterpart on the other continent. The shrew Notiosorex and the mouse opossum Marmosa show virtually no anatomical resemblance, but both have dental adaptations for handling insects and other animal prey. The Chilean cricetid mice of the genus Akodon vaguely resemble North American meadow mice, genus Microtus, both having relatively short ears and tails, stocky bodies, long claws, and little dorso-ventral countershading. Microtus, however, is much more extreme in all of these features and has a highly specialized herbivorous dentition, while most Akodon species are morphologically generalized mice, showing no major differences from other cricetids. The California Sciuridae, including the chipmunks (Eutamias) and the ground squirrels (Spermophilus) have no obvious morphological equivalents in Chile. The Chilean hystricognath Octodon degus is diurnal, social, and a rough ecological analog of many North American ground squirrels (Fulk 1976; Glanz 1977b), but is much smaller in size, and more similar to the woodrats in body proportions. Perhaps the most conspicuous absences from the Chilean fauna are counterparts for the North American kangaroo rats and pocket mice, family Heteromyidae. No Chilean rodent has the cheek pouches, large auditory bullae, and adaptations for bipedal locomotion of the California heteromyids, nor their specializations for seed-eating and water retention (Glanz 1977a; Meserve 1978).

This brief review suggests that although some groups on each continent are morphologically convergent, the Chilean fauna has a lower diversity of structural adaptations. The California communities have more species with morphological characteristics that have no counterpart in Chile. A more rigorous morphological analysis (Glanz 1977a) confirms these general conclusions.

HABITAT SELECTION

Although the data on species diversity and morphological adaptations suggest some important differences between the small mammals of California and Chile, they do not deal directly with the ecological roles of these animals in their communities. In the next sections we will discuss the patterns of resource use by small mammals in the two regions, focusing primarily on the utilization of habitat and food.

Intercontinental comparisons of habitat selection can be difficult if great differences exist in the available habitat features. In our studies, for example, Chilean sites often had more herbaceous cover and a higher proportion of spiny shrubs than their California counterparts, and therefore selective use of these habitat types may have been more likely to evolve in Chile. To simplify our discussion here, we will consider only certain features that were comparable between analogous sites.

Percent shrub cover was virtually identical between our analogous sites, but the community response to this habitat variable was noticeably different in the two regions. Meserve's (1976b and 1981b) 2 X k association analysis of the dry coastal sites found that Peromyscus californicus and P. eremicus were associated with trap stations having high shrub cover (>75 percent) in California.

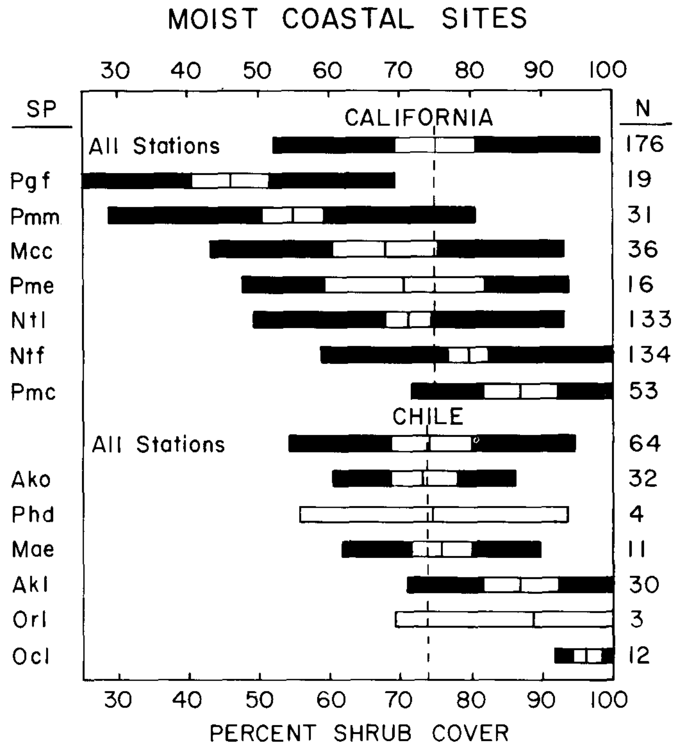


Figure 1. Comparison of shrub cover values (mean, 2 standard errors, and 1 standard deviation) of capture locations for each species with those of all trap stations at each moist coastal site. Species codes are from Table 1.

P. californicus and a third species, Neotoma fuscipes were much more common in dense shrublands adjacent to the more open study site, which also implies preferences for high shrub cover. In contrast, stations with low shrub cover (<50 percent) were significantly preferred by two other species, Dipodomys agilis and Peromyscus maniculatus. At the Chilean dry coastal site, two species, Akodon longipilis and Phyllotis darwini, showed associations with moderate to high cover (51 to 100 percent), but no species preferred stations with low shrub cover.

Shrub cover selection by small mammals at the moist coastal sites (Glanz 1977a) is depicted in figure 1, and it shows a similar intercontinental pattern. At the California site, P. californicus and N. fuscipes chose trap stations with shrub cover significantly higher than the site average, while two other species, Perognathus fallax and P. maniculatus significantly preferred stations with low shrub cover. At the corresponding Chilean sites, two species, A. longipilis and Octodon lunatus, were trapped at stations with shrub cover significantly above the site mean, while no species significantly chose low-cover stations. An analysis of shrub cover selection at the evergreen chaparral sites (Glanz 1977a) produced similar results. Preferences for high cover stations were significant for certain species on both continents, with Peromyscus boylii,

P. californicus, and N. fuscipes selecting such habitats in California, and Rattus rattus, A. longipilis, O. lunatus, and O. degus doing so in Chile. Preferences for low-cover stations, however, were again evident only in California, by D. agilis and P. maniculatus.

Several consistent patterns emerge from these data. First, species that prefer dense cover are relatively predictable from site to site within continents; these usually include some of the larger mice (notably P. californicus in California and A. longipilis in Chile) and the large woodrat N. fuscipes or its analogs (especially O. lunatus). Most of these high-cover species have ranges closely associated with Mediterranean scrub and associated forest and scrub ecosystems. Next, Chile very obviously lacks species that prefer low-cover habitats, while California has several. Finally, at all the California sites the species that choose open habitats always include one heteromyid (Dipodomys or Perognathus species) and one small cricetid, P. maniculatus. Heteromyids are dominant members of desert rodent communities in North America, while P. maniculatus is very widespread on the continent and frequently occupies arid and marginal habitats.

Rocky habitats also provide important cover to many species. The dry coastal sites had very few rocky stations and this variable was not studied there. At the moist coastal sites, three Chilean species (O. lunatus, P. darwini, and A. longipilis) were usually trapped near rocks, but these preferences were not significant, possibly because of few rocky trap stations. More rocky habitats were sampled at the evergreen chaparral sites, and the two communities showed contrasting trends. While both localities had species with significant preferences for rocky cover (P. boylii, P. eremicus, and Perognathus californicus in California, O. lunatus and M. elegans in Chile, California had two that significantly avoided rocky stations (D. agilis and P. maniculatus) and Chile had none. Other evidence from the small snap-trap plots suggests Chilean mammals favor rocky areas. Average density on these grids in Chile tended to increase with percent rock cover ($r=.51$; $.05<p<.10$), while no such relationship was evident in California ($r=-.09$).

Meserve's smoked-card tracking data (1976b, 1981b) revealed differences in another pattern of habitat use, arboreal activity. In California, 20.4 to 28.5 percent of all tracking records were in the shrub foliage, while only 3.1 percent of all Chilean records were above ground, a striking difference in the utilization of these habitat zones.

These patterns in the use of shrub cover, rocky cover, and above-ground habitats suggest that Chilean communities of small mammals utilize a smaller range of habitats, preferring those with greatest cover, and that individual species may be more similar in their habitat preferences than in California. Detailed analyses of habitat overlap by Meserve (1981b) and Glanz (1977a) support this generalization. Glanz's discriminant analyses of microhabitat selection, for example, found that 93 percent of all species pairs in California showed significant differences in habitats used, while only 68 percent of all Chilean pairs could be significantly distinguished by habitat features alone.

FOOD HABITS

Assuming that the similar vegetation patterns and climates of these regions produce similar varieties of potential foods for mammals, one would expect to find similar dietary patterns in these communities. Our analyses of mammal food habits, however, show some remarkable contrasts. Meserve (1976a, 1981a) compiled dietary data throughout the annual cycle at the dry coastal site, while Glanz (1977a) restricted his analyses to spring and summer seasons only. Since food habits vary considerably over the seasons, we will restrict our comparisons here to just spring and summer results. Figure 2 summarizes the diets of most species at the three site types. Spring and summer results have been averaged, and the food types have been combined into three general categories: vegetative parts of plants, seeds and fruits, and animal material. In this figure, each apex represents a diet composed entirely of that food type. The further a species is from an apex, the lower the proportion of that food type in the diet.

Several points are immediately apparent from these diagrams. First, most communities had one to three leaf-eating species, and these always included the larger genera Abrocoma, Octodon, and Neotoma. The diets of these "woodrat" analogs, thus, seem to have converged on leaves, particularly shrub foliage, as the principal food. The Octodon species, however, ate more herb leaves, and in some seasons seeds and fruits comprised up to 45 percent of their diet (Glanz 1977a; Meserve 1981a).

Most communities also included species that fed largely on seeds, but California sites usually had more species in this category. The heteromyid genera Dipodomys and Perognathus were always seed specialists at these sites, as they usually are in most arid communities. Most California Peromyscus were more omnivorous, but still fed extensively on seeds, particularly at the evergreen chaparral site. Two species, P. eremicus and P. maniculatus, ate substantial proportions of leaves or insects at each of the coastal sites, but averaged between 45 and 70 percent seeds in every community. In contrast to the emphasis on granivory in California, only two Chilean species, O. longicaudatus and P. darwini, fed primarily on seeds. Neither was as specialized on seeds as the heteromyid species at comparable California sites, and Phyllotis was seasonally very herbivorous at the evergreen chaparral site. Thus, in food habits as in the comparisons of habitat use, Chilean Mediterranean scrub communities seemed to lack an analog for the kangaroo rats and pocket mice of North America.

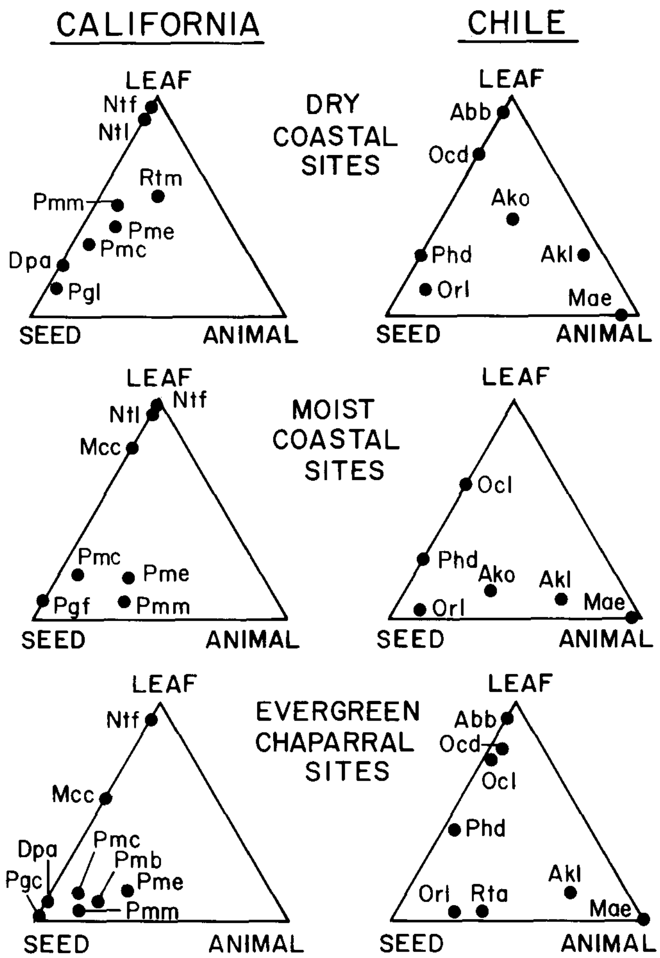


Figure 2. Food habits of small mammals at each site expressed as proportions of diets for each food type. See text for detailed discussion. Species codes are from Table 1.

A final point is even more obvious from Figure 2. California had no primarily insectivorous species, while Chile had two. The mouse opossum, M. elegans, was almost entirely insectivorous, while A. longipilis fed seasonally from 33 to 73 percent on invertebrates. A. olivaceus showed similar, but more omnivorous feeding trends, with insects comprising from 13 to 55 percent of its seasonal diets. In addition to invertebrates, small lizards were occasionally found in the diets of both M. elegans and A. olivaceus. These Chilean species, then, are trophically distinct from the small mammals studied in California.

DISCUSSION

The preceding data outline some possible examples of ecological convergence, but emphasize some interesting cases of "nonconvergence" in the organization of these mammal communities. These patterns raise numerous questions regarding the evolutionary pathways followed by the different mammal lineages, and-the relative importance of environmental vs. phylogenetic factors on such evolution. We would now like to present several major questions raised by our data and speculate on some alternative answers to these questions.

First, why are small mammals in Chile so insectivorous? Conceivably other animals could be assuming this trophic role in California. Shrews, for example, are the dominant insectivorous mammals elsewhere in North America, and we certainly did not sample adequately our one species, Notiosorex crawfordi. Considering how infrequently we trapped, sighted or found evidence of this species, however, we doubt that it is as common as Marmosa and Akodon species are at corresponding sites in Chile, but we urge further study of this interesting shrew. Insects may be more abundant and more predictable in Chile, and therefore may offer more opportunities for dietary specialization by mammals. Comparative data on flying insects of the two regions (Mooney 1977, p. 174) seem to support this idea, but more data on ground-dwelling species would be helpful. Alternatively, Chilean small mammals may represent lineages that tend toward insectivory irrespective of available resources. Elsewhere in South America, most small marsupials and many akodont rodents are also insectivorous (Hershkovitz 1969; Glanz 1977a; Pizzimenti and DeSalle 1980), but the diets of relatively few species have been studied. Morton (1979), in his comparison of North American and Australian desert mammals, found a strong bias toward insectivory in the marsupial-dominated Australian fauna.

Why is the Chilean fauna less diverse? We have mentioned above the hypotheses of Baker (1978) relating faunal size to geographic isolation and the relatively small area of temperate South America. The mammal fauna of Chile's scrub zone, then, may be a subsample drawn from a more depauperate zoogeographic source than for the California fauna. Clearly, more studies of their phylogenetic relationships to other temperate and tropical faunas will be necessary to properly test this idea. Equally important will be studies of faunal isolation through time. The Chilean Mediterranean zone is currently separated from other scrub habitats by the Atacama desert, the Andes, and the Valdivian forests, but it is unclear how important these barriers have been in limiting dispersal by different mammal groups. Speciation patterns within Chile may also have limited mammal diversity (Fuentes and Jaksić 1979) and certainly require more study.

Finally, why have no Chilean mammals evolved into a heteromyid analog, specializing on seeds and open habitats? First, Mares (1976) has found that no South American rodents are as morphologically specialized for open habitat as the heteromyids, and that historical factors provide plausible explanations for this contrast. Nevertheless, some rodents of other South American scrub areas, such as Eligmodontia typus of Argentine deserts, show more arid adaptations than any Chilean rodent, so additional factors may have influenced the Chilean fauna. Perhaps the extreme fluctuations of rainfall in the semi-arid zones of Chile (Fulk 1975; Mooney 1977) produce less dependable food supplies in open habitats than in California. More likely, the availability of these open areas may have been different through evolutionary history. The California flora has many fire-adapted species (Mooney 1977), and fires have probably been frequent in the past, creating open habitats with which many rodents have coevolved (Quinn 1980). In contrast, the Chilean flora has few fire adaptations, fire has probably been less important there, and no rodents have coevolved with such disturbance. Most open habitats in the present scrub zones of Chile may be associated with recent land use practices by humans (see Bahre 1979; Mooney 1977), and the local mammals have not specialized on these disturbances. Finally our data show that certain opportunistic species (especially *P. darwini* and *A. olivaeus*) do use these open habitats, but primarily at peak densities, when other habitats are also occupied. They thus may be analogs of the similarly opportunistic and eruptive *P. maniculatus*, which occupies low-cover habitats in California. Additional ecological and behavioral comparisons of these species might prove very interesting.

The small mammal faunas of California and Chile, thus, show some striking differences in certain ecological features. We hope that our discussion of these examples of "nonconvergence" will stimulate further research on these animals.

ACKNOWLEDGMENTS

Dissertation work by Glanz was supported by NSF grant GB-31195 to Robert K. Colwell; by the University of California, Berkeley; and by the IBP Mediterranean Scrub Project. Meserve's thesis work was supported by the University of California, Irvine, and an NIH traineeship. In Chile Meserve was an assistant professor in the Laboratorio de Ecología, Universidad Católica de Chile, Santiago. We thank Eddie Albright for preparing the manuscript and Clarence Barber for drawing the figures.

LITERATURE CITED

Bahre, Conrad J. Destruction of the natural vegetation of north-central Chile. Univ. California Publ. Geography 23:1-117; 1979.

Baker, Rollin H. Distribution of Recent mammals along the Pacific coastal lowlands of the Western Hemisphere. Systematic Zoology 16:28-37; 1967.

Cody, Martin L. Competition and the structure of bird communities. Princeton, N.J.: Princeton Univ. Press; 1974.

Fuentes, Eduardo R. Ecological convergence of lizard communities in Chile and California. Ecology 57:3-17; 1976.

Fulk, George W. Population ecology of rodents in the semiarid shrublands of Chile. Occasional Papers, Museum, Texas Tech Univ. 33:1-40; 1975.

Glanz, William E. Comparative ecology of small mammal communities in California and Chile. Ph.D. dissertation. Univ. California, Berkeley; 1977a; 300 p.

Glanz, William E. Small mammals. *In*: Thrower, Norman J.W.; Bradbury, David E., eds. Chile-California Mediterranean scrub atlas: a comparative analysis. Stroudsburg, Penna.: Dowden, Hutchinson & Ross; 1976b:232-237.

Greer, John K. Mammals of Malleco Province, Chile. Publ. Museum, Michigan St. Univ., Biol. Series 3:49-152; 1965.

Hershkovitz, Philip. The Recent mammals of the Neotropical region: a zoogeographic and ecological review. Quarterly Rev. Biol. 44:1-70; 1969.

MacArthur, Robert H.; Diamond, Jared M.; Karr, James R. Density compensation in island faunas. Ecology 53:330-342; 1972.

Mares, Michael A. Convergent evolution of desert rodents: multivariate analysis and zoogeographic implications. Paleobiology 2:39-63; 1976.

M'Closkey, Robert T. Temporal changes in populations and species diversity in a California rodent community. J. Mammalogy 53:657-676; 1972.

Meserve, Peter L. Resource and habitat utilization by rodents of the coastal sage scrub community. Ph.D. dissertation. Univ. California, Irvine; 1972. 248 p.

Meserve, Peter L. Food relationships of a rodent fauna in a California coastal sage scrub community. J. Mammalogy 57:300-319; 1976a.

Meserve, Peter L. Habitat and resource utilization by rodents of a California coastal sage scrub community. J. Animal Ecology 45:647-666; 1976b.

Meserve, Peter L. Trophic relationships among small mammals in a Chilean semiarid thorn scrub community. J. Mammalogy; 1981a, in press.

Meserve, Peter L. Resource partitioning in a Chilean semiarid small mammal community. J. Animal Ecology; 1981b, in press.

Meserve, Peter L.; Glanz, William E. Geographical ecology of small mammals in the northern Chilean arid zone. J. Biogeography 5:135-148; 1978.

Mooney, Harold A., ed. Convergent evolution in Chile and California. Stroudsburg, Penna.: Dowden, Hutchinson & Ross; 1977. 224 p.

Mooney, Harold A.; Dunn, E. Lloyd. Convergent evolution of mediterranean-climate evergreen sclerophyll shrubs. Evolution 24:292-303; 1970.

Morton, S.R. Diversity of desert-dwelling mammals: a comparison of Australia and North America. J. Mammalogy 60:253-264; 1979.

Parsons, David J. Vegetation structure in the Mediterranean scrub communities of California and Chile. J. Ecology 64:435-447; 1976.

Pefaur, Jaime E.; Yañez, Jose L.; Jaksić, Fabian M. Biological and environmental aspects of a mouse outbreak in the semi-arid region of Chile. Mammalia 43:313-322; 1979.

Pizzimenti, John J.; DeSalle, Rob. Dietary and morphometric variation in some Peruvian rodent communities: the effect of feeding strategy on evolution. Biol. J. Linnean Soc. 13:263,-285; 1980.

Quinn, Ronald D. Evolution of habitat selection in Heteromyid rodents in California chaparral. Bull. Ecol. Soc. America 61(2):110 (abstract); 1980.

Simpson, George G; Roe, A.; Lewontin, R.C. Quantitative zoology. New York: Harcourt, Brace & World; 1960.

Plant Patterning in the Chilean Matorral: Are the Roles of Native and Exotic Mammals Different?[1]

Eduardo R. Fuentes and Javier A. Simonetti[2]

Abstract: Native and exotic mammals have different effects on the matorral vegetation. (A) Large mammals (guanacos vs goats) differ in that native guanacos are only minor browsers, whereas goats use shrubs more extensively. Differences between goats and shrub-defoliating insects provide additional evidence that goats are a novel perturbation on the matorral vegetation. (B) European rabbits and their native counterparts differ in their effects on shrub seedlings and on native perennial herbs. Native small mammals affect only the periphery of antipredator refuges. Rabbits are infrequently preyed upon, do not exhibit such habitat restriction, and show a more extensive effect. Implications for matorral renewal are discussed.

Mammals and the matorral vegetation have reciprocal effects on each other's distribution and abundance. On the one hand, shrubs, herbs, and grasses provide food and cover for matorral mammals (Jaksić and others 1980; see also the chapter by W. Glanz and P. Meserve in this volume). On the other hand, the use that mammals make of the habitat can have several consequences for the plants, affecting their distribution and abundance.

Here, we will examine the question: are the roles played by native matorral mammals the same as the ones shown by alien species recently introduced?

There are at least two reasons why it is important to know the answer to this question. First, the introduced mammals we will be referring to, goats and rabbits, are of economic importance for the subsistence of a relatively large human population in central Chile (Fuentes and Hajek 1979).

Different management procedures would be derived depending on the degree of similarity one discovered. At one extreme, exotic species could produce consequences similar to those of their original "analogues," but at the other extreme, effects induced by both types of herbivores could be completely different. Whereas in the first case the effects of the introduced mammals would, within certain limits, fall within the naturally evolved resilience (Rolling 1973) of the system, in the second case the mammalian effects would be a novel perturbation from an evolutionary point of view. In this latter case, extreme care should be taken, since the system might exhibit very little tolerance to the new species. Here, only preadaptative traits would account for any resilience of the system.

The second reason why the question is important relates to the coupling of herbivores to the ecosystem structure.

Herbivores as a link between producers and carnivores have been selected not only for their capacity to eat tissues of certain plants but also for their ability to avoid predation. Hence, only a fraction of all _a priori_ possible links between plants and mammals are usually observable in any given ecosystem. However, since in a field situation there are usually no "controls," it is not possible to disentangle those links related to feeding preferences and from those associated with constraints imposed by predators, the plants, or abiotic factors. We believe that the comparison of native and exotic species of herbivores, with the latter acting somewhat as evolutionary controls, can aid in the understanding of these relationships.

In this paper, we first discuss the role of the European rabbit (_Oryctolagus cuniculus_), recently introduced to Chile (Housse 1953). This rabbit is compared with its native counterpart, the diurnal rodent degu (_Octodon degus_) and to some extent with vizcacha (_Lagidium viscacia_). There are no native rabbits in Chile (see Osgood 1943). After these comparisons, we will discuss some differences between the present ecological impact of introduced goats and the impact of guanaco (_Lama guanicoe_), a counterpart of goats. Finally, we will discuss the role of mammals within a more general framework of matorral herbivory.

COMPARISON BETWEEN SMALL MAMMALS

Degus as well as vizcachas, two analogues in body size, general food habits, and habitat of the rabbit, are known to exhibit a strong preference for microhabitat in the neighborhood of rock outcrops and large protecting bushes (Pearson 1948, Le Boulengé and Fuentes 1978) (fig. la, b). Chin-

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor and Instructor of Biological Sciences, respectively, at Pontificia Universidad Católica de Chile. Casilla 114-D, Santiago, Chile.

chilla rat (Abrocoma bennetti) is the third possible native counterpart to rabbits by size and food habits, but since its density is usually quite low and it is generally found at the same trapping spots as degus (Jaksić and others 1980), its effect is also likely to be very similar to the one we will describe for degus.

Although all the above animals venture short distances away from these refuges, they do so for very short times and apparently incur great predation risks. Vizcachas are taken by foxes (Dusicyon culpaeus) (Pearson 1948), and other carnivores (Pearson 1951) whereas degus and chinchilla rat are frequently preyed upon by two species of foxes and several raptors (for a review, see Jaksić and others 1981).

The European rabbit, on the other hand, exhibits a somewhat different behavior contrasting to that of the native species (fig. 1a, b). In the matorral, adult rabbits tend to use the open spaces far from the above—mentioned refuges (Jaksić and others 1979). Simonetti and Fuentes (1981) confirmed these results and have also shown that small, juvenile rabbit individuals tend to use the neighborhood of refuges, just like degus, and that as they become progressively larger they concomitantly become users of the open spaces (fig. 1b, c). Nevertheless, in the Chilean matorral actual predation upon rabbits seems negligible (Jaksić and others 1979, Jaksić and Soriguer 1981) in spite of the existence of a conspicuous array of potential predators. That is, there are potential predators but these do not eat rabbits.

On the other hand, in Spain where the rabbit is native, its microdistribution pattern is similar to that exhibited by degus and vizcachas in Chile; it is restricted to the neighborhood of protecting refuges (Jaksić and Soriguer 1981). In Spain, rabbits are known to be heavily preyed upon by several predators (Jaksić and Soriguer 1981). Moreover, whereas in Spain rabbits strongly prefer habitats with high shrub cover, presumably protecting them from predators, in Chile they exhibit just the opposite trend (Fuentes and Jaksić 1980, Jaksić and Soriguer 1981). It therefore seems that juvenile rabbits born in Chile behave as they would in the Spanish maquis and only later use the open, predation—safe spaces of central Chile (Simonetti and Fuentes 1981).

These differences between rabbits and native matorral species, plus the differences exhibited by rabbits in similar habitats in Chile and Spain, but under different predation pressures, suggest that in Chile rabbits exhibit habitat release associated with reduced predation pressure (Fuentes and Jaksić 1980, Jaksić and Soriguer 1981). Thus, the lack of an effective coupling between Chilean predators and rabbits can be related to an important extension in the pattern of microhabitat use by rabbits in Chile. This habitat release also occurs in zones where degus are absent, indicating that it is not competition that drives rabbits out of the refuges.

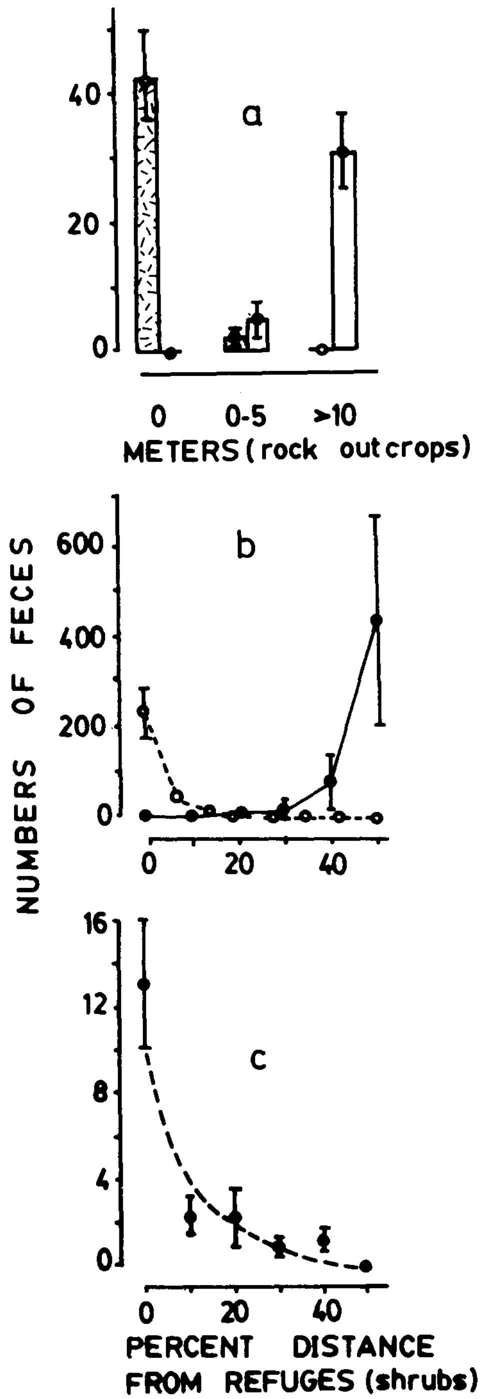


Figure 1--Relative activity of small mammals. Ordinate is density of feces ±2 SE of the mean, whereas abscissa is distance to nearest refuge (rock outcrop or large shrub). (a) Vizcachas (dark columns) versus adult rabbits (light columns). (b) Degus (light dots) versus adult rabbits (black dots) (redrawn from Jaksić and others 1979a). (c) Small rabbits under 250 mm length (re—drawn from Simonetti and Fuentes 1981). Curves were drawn by eye. Notice that vizcachas, degus, and small rabbits tend to use the neighborhood of refuges preferentially, whereas adult rabbits do exactly the opposite. See the text for discussion.

We will now discuss the question: are the preferences of these two mammals for the vegetation the same or not? The significance of this question lies in that both niche dimensions, microhabitat use, and food preferences are important in comparing the potential impacts of the species on the vegetation.

The answer to the above question was obtained through pairwise "cafeteria tests" using four common species of matorral shrubs: Colliguaya odorifera (Euphorbiaceae), Kageneckia oblonga (Rosaceae), Lithraea caustica (Anacardiaceae), and Quillaja saponaria (Rosaceae). Methods as well as results are explained in detail by Fuentes and Etchégaray (1980) and Fuentes and Simonetti (unpublished manuscript). In brief, results show that rabbits and degus eat mature leaves of all four shrub species, although they clearly exhibit different preferences in the pairwise comparisons (table la). In addition Simonetti and Montenegro (1980), following a somewhat different methodology, report that degus distinguish less between young leaves of these species than between old leaves, and they do discriminate between new and mature leaves within one species. The extent to which this latter pattern holds for rabbits is unknown, but it is not unlikely that its preferences for young tissues are broader than for the older sclerified ones.

At any rate, the cues used by these animals in selecting leaves are likely to be different. Moreover, both mammals seem capable of eating a broad spectrum of shrub species.

How do the above-mentioned differences in microhabitat use and leaf preferences express themselves in the field?

Jaksić and Fuentes (1980) proved experimentally that in Chile rabbits exhibit a preference for native perennial herbs over the mediterranean grasses, and consequently are capable of removing all unprotected native herbs before their reproduction. Only the native herbs growing under bushes with ground level branches, which can be reached only with difficulty by rabbits, attain sexual maturity and reproduce. That is, where degus are absent, rabbits restrict native herbs to the areas under bushes, whereas spaces between these shrubs are occupied by introduced grasses (Keely and Johnson 1977). Where degus are present, they remove native perennials only from under the shrubs or at most from their periphery (personal observations). Before this effect of rabbits on native herbs was known, the microhabitat restriction of native herbs, clearly differentiating the California chaparral and the Chilean matorral, was thought to be a discrepancy in convergent evolution.

It is not known what effect vizcachas have on the herb cover surrounding the large outcrops where they live, although preliminary observations at Cajón del Maipo, east of Santiago, suggest that they might have an effect that is distinguishable from the microclimatic effect produced by the rock outcrops.

In addition to the effect on herbs, rabbits and degus modify the distribution of shrubs by altering the survival chances of some seedlings. Simonetti and Fuentes (unpublished data), by planting protected and unprotected Q. saponaria seedlings on equator-facing, ridgetop, and polar-facing slopes, were able to show that even here rabbits do have an important effect on shrub renewal. On north-facing slopes, where rabbit densities are highest, their killing effect is considerably higher than on the high cover south-facing slope, where rabbits are known to be scarcer. Moreover, the ridgetop situation is intermediate in both effect and rabbit density (see fig. 2).

In sum, the evidence available at present suggests that degus have a different effect on the vegetation from that produced by rabbits. The main difference is that predator efficiency at hunting degus confines their effect to the periphery of protecting refuges, whereas predation on rabbits does not impose on them such a restriction. It is reasonable then to suggest that before the recent introduction of rabbits (Greer 1965), seedlings growing beyond 6 m from protecting shrubs or rock outcrops were safe from predation, but that this is no longer the case. Now, all seedlings have high predation risks. Field experience in the matorral shows that in fact very few seedlings can be found, and these are only on mesic slopes with high plant cover, where rabbits are less common. Thus, whereas on these polar-facing slopes few seedlings and very few small plants can be found, on the drier north-facing slopes they are almost nonexistent. Generation time for shrubs may be too long and rabbit introduction too recent for us to know exactly what the future fate of the matorral will be. The situation is complex, however, because we do not know if changes in the plants' physical and chemical composition, or modifications in potential rabbit predators (by becoming more efficient) will occur first and thus modify the whole process. Our present knowledge does not allow us to make an extrapolation.

LARGER MAMMALS

The effects of goats and guanacos have been studied only as far as they concern large, mature shrubs. Studies of their comparative roles on seedling removal are still in progress. Therefore, we mention only one clearcut example that suggests seedling removal is also important here and that it can be measured.

The only place where guanacos are now kept in a semiwild setting, within the matorral type of ecosystem, is in the Forest Reserve at Penuelas, approximately 90 km west of Santiago. Here, the Forest Service (CONAF) keeps two males and three females within a large fenced area of approximately

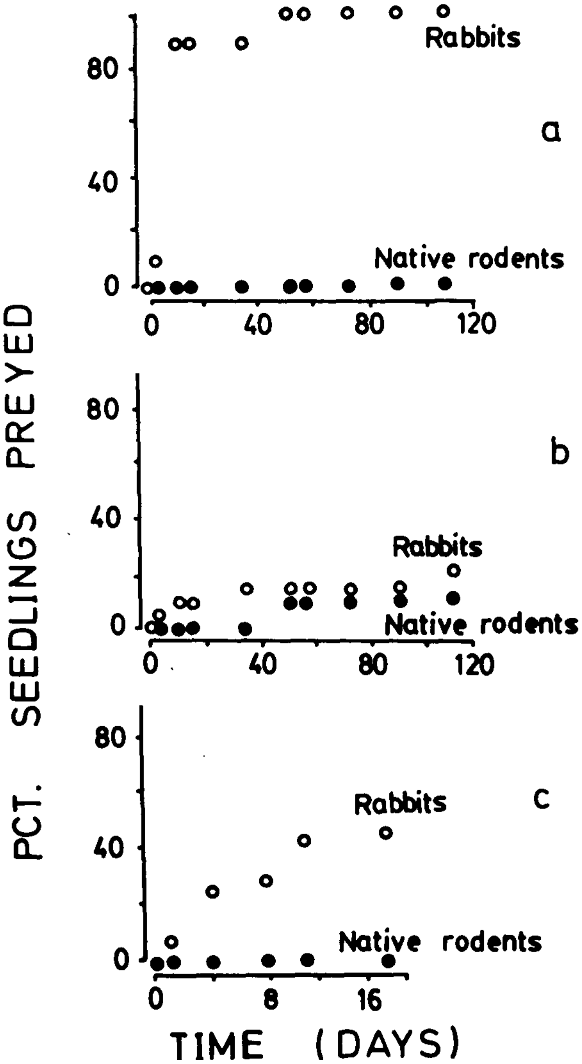


Figure 2--Seedling predation by small mammals. (a) Equator-facing slope. Points shown indicate only results in areas far from refuges where only rabbits are present. No degus effect could be detected here. (b) Polar-facing slope. Here the slope is covered by vegetation. Rabbits kill approximately twice as many seedlings as native rodents (chinchilla rat, degus). Even so, about 70 percent of the seedlings survive herbivore attacks. See text for discussion. (c) Ridgetop. Rabbit effect is intermediate between (a) and (b), but native rodents show no detectable effect.

12 ha. A recent comparison made by us (unpublished observations) shows that within the fenced area there are no seedlings or small plants of the matorral tree Maitenus boaria (Celastraceae), whereas outside the fence and where the vegetation is otherwise similar, these seedlings are common. "Cafeteria tests" showed that unlike what happens with other matorral shrubs and trees (see later discussion), guanacos eat M. boaria avidly. Moreover, within the fenced area there are large individuals of M. boaria, but all their leaves up to "guanaco height" have been eaten, whereas the large M. boaria individuals outside the fence do have leaves below that level. These larger individuals were probably established in the area before the guanacos were introduced. Since other browsers like rodents and rabbits are equally abundant on both sides of the fence, it is reasonable to suggest that it is L. guanicoe that produces the difference in the seedlings of M. boaria. It is important that there are no cattle, horses, sheep, or goats in this part of the Reserve, since we have observed that these animals eat M. boaria with the same willingness as guanacos. Moreover, they seem capable of producing exactly the same effects we just described for guanacos.

The effects of mammals on large plants are generally not as direct as they are on seedlings or herbs. Whereas grasses, herbs, and seedlings are killed in one or at most a few contacts with the herbivore, thus producing a modification in the distribution of adult plants, in the case of browsing on larger plants the consequence is generally mediated by shrub-shrub competition and takes considerably more time (Fuentes and Etchégaray 1981). This is not to say that the effect cannot be immediate, as when overstocking produces direct elimination of the shrub cover of an area (see Fuentes and Hajek 1979), but as we said above, in general, the influence is more subtle.

If individual shrubs were independent of each other--for example, if there were no competition--the fate of individual phenotypes would, for a given mammal density, depend largely upon relative palatability and capacity to recover from contacts with the browsers. In fact, matorral shrubs differ not only in the amount of new leaves produced after defoliation but also in the pattern of such production (Torres and others 1980). Thus, for example, L. caustica and C. odorifera exhibit strong dissimilarities in their production of new leaves at 25 and 66 percent defoliation levels, but not at 100 percent. Whereas L. caustica exhibits a compensatory response to 25 percent defoliation, not to 66 percent but then again to 100 percent, the second species, C. odorifera, responds only to the two higher levels of defoliation.

However, as Gutiérrez and Fuentes (1979) and Fuentes and Gutiérrez (1981) have shown, matorral shrubs also exhibit intraspecific as well as interspecific competition. Furthermore, competitive interactions seem to account for some of the successional patterns observed in the matorral (Fuentes and Gutiérrez 1981).

For example, on mesic slopes species like L. caustica and Q. saponaria have stronger effects on species like C. odorifera, Baccharis rosmarinifolia or Muehlenbeckia hastulata than vice versa, although they all interact with each other and with themselves (see Fuentes and Gutiérrez 1981).

That is, in addition to the previously mentioned individual responses to defoliation, browsing pressures also modify the competitive performance of shrubs. Defoliation then not only reduces the leaf area and consequently the future energy pool of a given shrub, but has also an opportunity cost related to unrealized root and shoot growth, with an eventual reduction in the competitive performance, and ultimately exclusion from the community (see Fuentes and others 1981, Fuentes and Etchégaray 1981). Fuentes and Etchégaray (1981) present evidence suggesting that shrub herbivory by insects, which are the most important defoliators in the matorral under natural conditions, acts on shrub density by altering interspecific competitive equilibrium. That is, because insects can reduce the photosynthetic apparatus of shrubs, such shrubs exhibit several defense mechanisms which in general keep damage at low levels. .As long as the actual level is low enough, the plant is part of the community; otherwise it is excluded by less damaged competing phenotypes.

In the following paragraphs, we will summarize some of the evidence regarding the role that native guanacos might have had and the significance that goats might be having today in the dynamics of matorral plants. This hypothetical approach was taken because guanaco is now extinct in central Chile (Miller and others 1973), except for the recently established Reserve of Penuelas. By contrast, since colonial times goats have been part of the domestic stock of low-income people in this part of the country (Fuentes and Hajek 1979).

The ideal experiment to compare guanacos and goats would be to have large separate areas with only one of these in each area, with otherwise comparable vegetation. This however cannot be done. On the one hand, there are no extensive areas in central Chile where either goats, woodcutting, or artificial fires, singly or in combination, have not been present within the last 30 years or so. In addition to the rabbits mentioned earlier, introduced hares (Lepus europeus) are more or less common everywhere and their effect is only partially understood. Moreover, presently existing herds of goat have large fluctuations in number between locations and between years, without any reliable record of them.

On the other hand, the few guanacos existing in the matorral in a semiwild state are at Penuelas Reserve. But here there exist no detailed records, either on the initial and past vegetation, or on the guanaco loads at various times. Because of these constraints, we have approached the question of differences between the two mammals by analyzing (a) relative amounts of browsing and grazing, (b) preferences for various shrub species during browsing, and (c) field densities of the two herbivores.

(a) Browsing/grazing ratios. The best known studies of guanacos feeding were made by Raedecke (1978) in Patagonia. He describes these animals as mostly grazers that use the taller vegetation mostly for cover. Along the same lines, direct observations of guanacos feeding during late summer in the matorral Reserve of Penuelas show that at most 37 percent of the bites of the average feeding sequence are on shrubs, with the remaining 63 percent being very selective feeding on herbs. This 37 percent is likely to be the maximum proportion of browsing, since during the summer the relative attractiveness of the herb cover over shrubs is at its minimum (Fuentes and Jaksić 1981).

In contrast to guanacos, goats have a much higher browsing percentage. Measurements at a matorral site with high shrub cover reveal an average 87 percent of bites on shrubs. At Penuelas reservation, with a lower shrub cover, the corresponding figure is 62 percent, but still considerably higher than the percentage given above for guanacos.

In sum, the evidence available suggests a strong difference in the browsing/grazing preferences exhibited by goats when compared with guanacos.

(b) Shrub preferences. "Cafeteria tests" similar to those previously reported for rabbits and degus are shown in table lb. It can be seen that preferences by the two herbivores are clearly dissimilar. Both species prefer C. odorifera over L. caustica, but whereas the guanaco does not distinguish between the other shrub species pairs, goats exhibit a stronger dislike for L. caustica.

Notice that these are preferences, when eating shrubs, but do not refer to consumption rates. Actually, during the experiments goats ate shrubs 5 to 10 times faster than guanacos, even if there was nothing else to eat. Guanacos frequently preferred to nibble the surrounding Eucalyptus fence instead of the shrubs.

(c) Field densities. We do not have direct evidence on the former densities of guanacos in the matorral, but they seem to have been relatively low compared with the present densities of goats (see Gay 1847). Goats are managed at very high densities.

In sum, there is little reason to expect that browsing effects of goats are comparable to those of guanacos. The high goat densities we see today, and their broad dietary preferences compared with guanacos, are too different. It is not surprising, therefore, that the traditional, uninformed "management" of such a novel evolutionary perturbation as goats has had such disastrous effects on the matorral vegetation. The evergreen/drought-deciduous matorral mixtures north of Santiago have been turned into a desert like vegetation, to a large extent due to overstocking with goats (UNCOD 1977, Fuentes and Hajek 1979). This is an unfortunate example of the desertification process where solutions are still to come. Further south, however, in the mostly evergreen

Table 1--Relative preferences for shrubs in cafeteria tests on native and exotic species[1]

(a) SMALL MAMMALS	CQ	CK	CL	QK	QL	KL
O. degus	+1	0	0	0	-1	0
O. cuniculus	0	0	-1	0	-1	0
(b) LARGER MAMMALS	CQ	CK	CL	QK	QL	KL
L. guanicoe	0	0	+1	0	0	0
C. hircus	0	0	+1	0	+1	+1

[1]Each entry shows the result of a pairwise comparison. (Goat data from Fuentes and Etchégaray 1980.) Statistically significant preferences are indicated by either +1 or -1. An entry with 0 means differences are not statistically significant. C = Colliguaya odorifera, Q = Quillaja saponaria, K = Kageneckia oblonga, L = Lithraea caustica. Entries are to be read as follows: +1 means the preference detected favors the first species in the plant species pair shown above; -1 means the second species is preferred. Thus, O. degus prefers Colliguaya odorifera over Quillaja saponaria, but prefers Lithraea caustica over Quillaja saponaria. None of the four species coincide in their preferences, and there are no closer similarities by either the native/exotic nor the size similarity criterion. See text for discussion.

matorral, more recent overstocking is also starting to show its effects. In areas around Casablanca and Melipilla (Fuentes and Hajek 1979), there is already some heavy destruction of vegetation up to the point of strong sheet and gully erosion.

Even in the few places where goats have been introduced only recently and in comparatively low densities, there are still concomitant changes in the vegetation. These are partly related to selective feeding but are also a by-product of the earlier-mentioned competitive equilibrium between shrubs.

THE TWO KINDS OF EFFECTS OF MAMMALS ON THE VEGETATION

Mammals, either large or small, are capable of exerting important effects on the matorral structure.

One the one hand, by selectively removing seedlings or small individuals of some species from exposed areas, herbivores can modify the "seedling shadow" and thus the later distribution of adult individuals. The available evidence here points towards different roles for native and introduced herbivores.

The situation with larger shrubs is more complex. As we described earlier, the effects produced by browsers depend upon relative palatabilities, response patterns to defoliation, and overall competitive performance under browsing pressure. In the matorral, where mammalian browsing does not seem to have been evolutionarily important, these factors do not all follow parallel trends.

On the other hand, the evolutionary responses of shrubs to insect herbivory are most likely to be tied to the insect's actual and potential damage to the shrub's photosynthetic apparatus. Lithraea caustica and C. odorifera are the two extreme species in terms of insect damage to leaves. In the former, about 13 percent, and the latter only about 2 percent of the yearly produced photosynthetic apparatus is eliminated by insects. Based on these results, Torres and others (1980) hypothesized that L. caustica, but perhaps not C. odorifera, should exhibit compensatory responses at low defoliation levels comparable to the ones naturally experienced during their evolutionary history. This was shown to be the case. Moreover, species that are intermediate with regard to insect defoliation also seem to exhibit intermediate responses to defoliation.

Thus, before the arrival of goats, the shrubs usually exhibiting the largest damage on their leaves also compensated the most and thus an equilibrium was established. But goats are a truly new perturbation in the evolutionary sense. Not only were there no comparable mammalian browsers before, but goat attack on shrubs is completely different from that of insects. Whereas insects attack L. caustica the most and C. odorifera the least, goats prefer to eat C. odorifera and all the other available shrub species over L. caustica. In addition, L. caustica is the strongest plant competitor in mesic matorral slopes (Fuentes and Guti4rrez 1981). It is not surprising therefore that on mesic slopes goats initially produce a strong modification in the plant community by favoring an overdominance of L. caustica (Torres and others 1980). Later, after their browsing pressure has even eliminated L. caustica, the less palatable cacti (Trichocereus spp.) are favored as dominants (Fuentes and Hajek 1979). This sequence at its various stages is a common phenomenon throughout distributional range of matorral.

Clearly then, goats, even if managed at low densities, are likely to change the composition of matorral. Moreover, Fuentes, Espinosa, and García (unpublished manuscript) provide evidence that overgrazing can accelerate erosion of the rather steep slopes where goats are kept. This is a second process that, when added to the ones described earlier for plant cover, also points in the direction of matorral degradation. In addition, Yates and Valencia (1980) have shown that the plant composition of the matorral has an important effect on the goats' rate of weight increase and on their milk's fat content (Yates and Valencia 1980). Therefore, the degradation of the vegetation produced by these mammals in turn affects the goats' productivity and their economic return. More research is therefore needed to establish a viable long-term goat management technique, or if it ultimately becomes necessary, to replace goats with some other source of income.

ACKNOWLEDGMENTS

We are grateful to J. Filp and to R. Quinn for their comments on the manuscript. Ricardo Mesa and Juan Lanzarotti (Corporación Nacional Forestal) provided us with logistic support at Reserva de Penuelas. Financial aid was obtained from Conaf (V Region), DIUC 75/81 to E. R. Fuentes and the Andean Project. This study is part of the Chilean contribution to the Andean Project (UNEP-UNESCO [MAB], 1105-77-01).

LITERATURE CITED

Fuentes, E. R.; Etchégaray J. Preferencias de cabras por arbustos: ensayos con cuatro especies del matorral. Ciencia Inv. Agric.: accepted; 1980.

Fuentes, E. R.; Etchégaray J. Defoliation patterns in matorral ecosystems. In: Kruger, F.; Siegfried, F., eds. Proceedings of the 3d international conference on Mediterranean-type ecosystems, South Africa. In press; 1981.

Fuentes, E. R.; Gutiérrez, J. R. Intra and interspecific competition between matorral shrubs. Oecologia: accepted; 1981.

Fuentes, E. R.; Hajek, E. R. Patterns of landscape modification in relation to agricultural practice in central Chile. Environ. Conserv. 6:265-271; 1979.

Fuentes, E. R.; Jaksić, F. M. Consideraciones teóricas para el control biológico del conejo europeo en Chile central. Medio Ambiente 4: in press; 1980.

Fuentes, E. R.; Jaksić, F. M. The role of the European rabbit (Oryctolagus cuniculus) in the Chilean matorral: shrub species and refuge effects. J. Appl. Ecol.: accepted; 1981.

Fuentes, E. R.; Etchégaray, J.; Aljaro, M. E.; Montenegro, G. Shrub defoliation by matorral insects. In: Di Castri, F.; Goodall, D. W.; Specht, R. L., eds. Ecosystems of the World 11: Mediterranean-type shrublands. New York: Elsevier; 1981:345-359.

Gay, C. Historia física y política de Chile. Zoología 1. Paris; 1847.

Greer, J. K. Mammals of Malleco province, Chile. Publ. Michigan State Univ., Biol. Ser. 3:51-151; 1965.

Gutiérrez, J. R.; Fuentes, E. R. Evidence for intraspecific competition in the Acacia caven (Leguminosae) savanna of Chile. Oecol. Plant. 14:149-156; 1979.

Holling, C. S. Resilience and stability of ecological systems. Ann. Rev. Ecol. Syst. 4:1-23; 1973.

Housse, F. Animales salvajes de Chile. Santiago: Ed. Universidad de Chile; 1953. 189 p.

Jaksić, F. M.; Fuentes, E. R. Why are native herbs in the Chilean matorral more abundant beneath bushes: microclimate or grazing? J. Ecol. 68: 665-669; 1980.

Jaksić, F. M.; Soriguer, R. C. Predation upon the European rabbit (Oryctolagus cuniculus L.) in Mediterranean habitats of Chile and Spain. J. An. Ecol. 50:269-281; 1981.

Jaksić, F. M.; Fuentes, E. R.; Yánez, J. L. Spatial distribution of the Old World rabbit (Oryctolagus cuniculus) in central Chile. J. Mamm. 60:207-209; 1979.

Jaksić, F. M.; Yánez, J. L.; Fuentes, E. R. Assessing a small mammal community in central Chile. J. Mamm. 61: in press; 1980.

Jaksić, F. M.; Greene, H. W.; Yánez, J. L. The guild structure of a community of predatory vertebrates in central Chile. Oecologia: in press; 1981.

Keeley, S. C.; Johnson, A. W. A comparison of the pattern of herb and shrub growth in comparable sites in Chile and California. Am. Midl. Nat. 97:120-132; 1977.

Le Boulengé, E.; Fuentes, E. R. Quelques données sur la dynamique de population chez Octodon degus (Rongeur Hystricomorphe) du Chile Central. Terre et Vie 32:325-341; 1978.

Miller, S.; Rottmann, J.; Taber, R. D. Dwindling and endangered ungulates of Chile: Vicugna, Lama, Hippocamelus and Pudu. In: Transactions of the thirty-eighth north american wildlife and natural resources conference, Washington: 1973; 55-68.

Osgood, W. H. The mammals of Chile. Field Mus. Nat. Hist., Zool. Ser. 30:1-268; 1943.

Pearson, O. P. Life history of mountain viscachas in Peru. J. Mamm. 29:345-374; 1948.

Pearson, O. P. Mammals in the highlands of Southern Peru. Bull. Mus. Comp. Zool. 106:117-174; 1951.

Raedecke, K. El guanaco de Magallanes, Chile. Su distribución y biología. Santiago: Corporación Nacional Forestal. Publicación Técnica No.4; 1978.

Simonetti, J. A.; Fuentes, E. R. Microhabitat release by European rabbits (Oryctolagus cuniculus) in central Chile: adult vs juvenile patterns. Oecologia: submitted; 1981.

Simonetti, J. A.; Montenegro, G. Preferencias por arbustos de Octodon degus (Rodentia: Octodontidae). Arch. Med. Biol. Exper. 13:112; 1980.

Torres, J. C.; Gutiérrez, J. R.; Fuentes, E. R. Vegetative responses to defoliation of two Chilean matorral shrubs. Oecologia 46:161-163; 1980.

UNCOD (United Nations Conference on Desertification). Case-study on desertification, region of Combarbalá, Chile. Kenya: A. Conference 74/9; 1977.

Yates, L. R.; Valencia, J. Efecto de la vegetación sobre el crecimiento del ganado caprino en zonas áridas y semiáridas de Chile. Congreso Internacional de Estudio de Zonas Aridas y Semiáridas, La Serena, Chile; 1980.

Postburn Insect Fauna in Southern California Chaparral[1]

Don C. Force[2]

Abstract: Extremely little is known about succession of insects in postfire chaparral. This 4-year postfire study in the San Gabriel Mountains of southern California showed that pollen-nectar feeders and predatory insects can be very abundant beginning the first spring after a burn. Annual plants in bloom appeared to entice flower feeders, and hence predators, into the area. Phytophagous insects (other than flower feeders) and parasitic insects more slowly established in the burn. Insect biomass tended to peak annually in June and July. There was no obvious correlation between insect biomass and yearly rainfall. Fourth-year insect richness and diversity showed a dramatic increase after an overall 3-year decreasing trend.

Ecological studies of chaparral insects have been badly neglected. With the exception of a handful of papers (see Force 1981b) stimulated by the Mediterranean Scrub Project of the International Biological Program (IBP), there is a dearth of published information on the subject. Those studies that are in print deal largely with comparisons between certain matorral insects from Chile and chaparral insects from California. This neglect is somewhat surprising in that a variety of chaparral plant and vertebrate animal investigations have been published. It appears that more interest might have been shown in the insect fauna since, ostensibly, it is so intimately involved with these other groups of organisms. Certainly we should be interested in how and how much insects affect such things as (a) the pollination of chaparral flora, (b) the growth of this flora by their feeding, (c) the disposition of chaparral plant seeds, (d) the postfire succession of the chaparral community and (e) the food chains of higher animals found in chaparral. Conversely, we would like to know how insects are themselves affected by various other chaparral elements. As it is, we know very little about variations in even such fundamental elements as insect identities, abundance, biomass, richness and diversity in chaparral of various kinds and of different ages.

I have reviewed what literature I could find pertaining to the relationships of chaparral insects with the community ecology of this vegetation (Force 1981b). Also, I have reviewed the postfire floral and faunal succession of chaparral, including certain aspects of my own study on the early (first 3 years) postfire succession of insects in the San Gabriel Mountains of southern California (Force 1981a,b). The present report will cover other aspects of the same study and extend previously reported data to a total of 4 years, when the project was terminated.

STUDY AREA: METHODS

From May 1976 to December 1979 I conducted a study of postfire insect succession within the San Dimas Experimental Forest located in the south-central San Gabriel Mountains, approximately 45 km east of Los Angeles. The actual study site was in the northeast section of the Forest (see Mooney and Parsons 1973) that burned November 1975. Specifically, I measured those gross insect changes that occurred annually in relation to the plant changes. Insect sampling consisted of periodic net collections and observations of insects (numbers of families and individuals) along a 1.5 km section of unmaintained contour trail at 1250 m elevation, as well as collections and observations from a series of 100 m^2 plots situated along the trail. Plant sampling was undertaken only once a year (early summer) and consisted of line intercept counts (numbers of species and individuals) in addition to plot counts (Force 1981a,b).

RESULTS

Trophic Groups

Figure 1 shows the relative abundances of various insect trophic groups during the 4-year period of postfire succession at San Dimas. These data can tell us something about the availability of resources for, and the utilization of resources by insects, as well as availability of insects as resources themselves for other animals. Another part of the story can be observed from biomass calculations, which will be treated later.

Predators tended to peak each year some time during the spring months (samples were not taken until May in 1976), mainly because of the great

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Biological Sciences, California State Polytechnic University, Pomona, California 91768.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

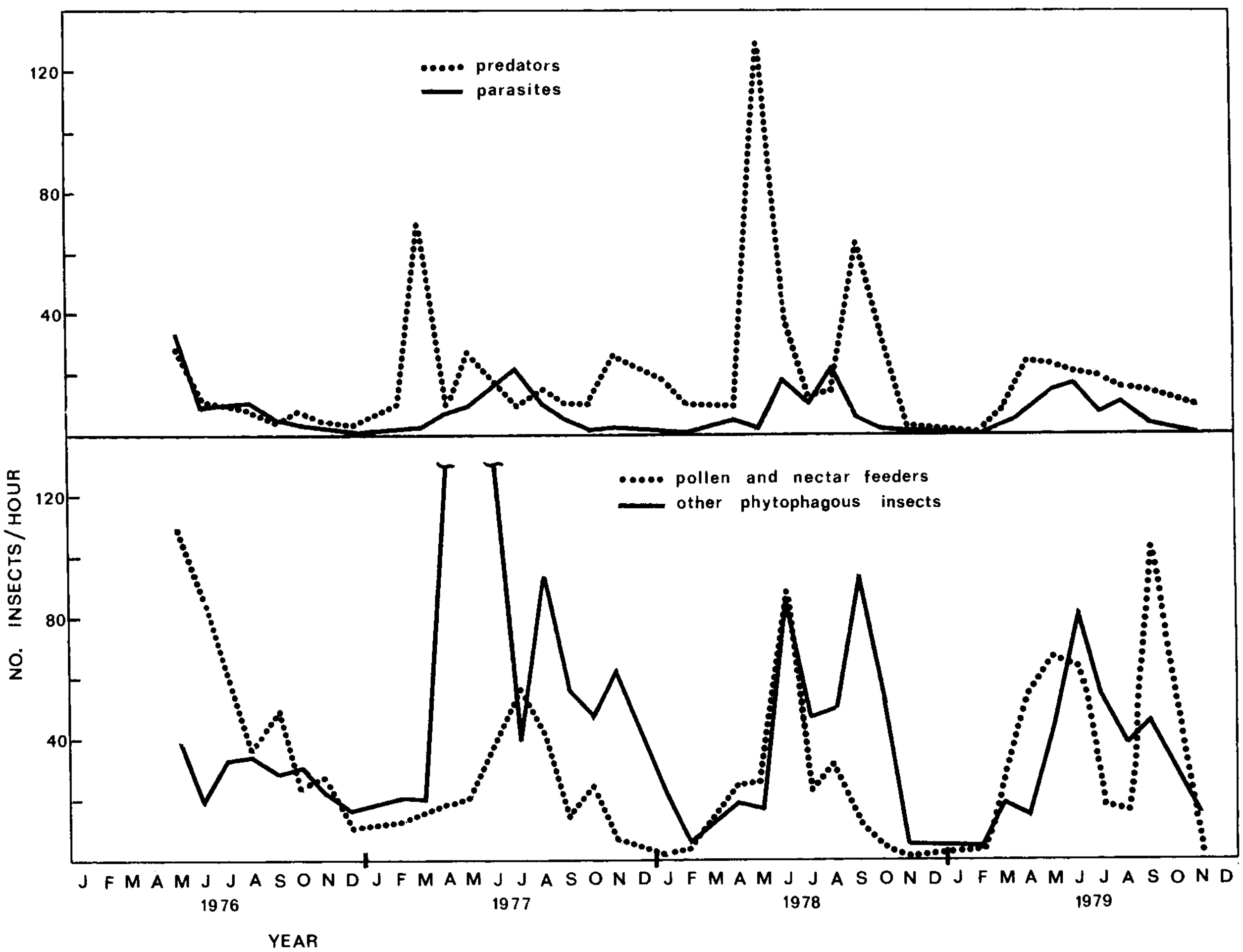


Figure 1--Relative abundances of various insect trophic groups during 4 years of postfire chaparral succession in the San Dimas Experimental Forest. The data are in numbers of insects collected and/or observed per man/hour.

numbers of Coccinellidae that emerged from hibernation in the lower mountains at this time. Many of these beetles began to feed immediately if prey were available, whereas others appeared to be migrating to lower altitudes. The earlier activity in 1977 (numbers peaked in March) as compared to 1978 (numbers peaked in May) was possibly related to weather. The winter of 1976-77 was very dry with an abundance of warm weather in early spring; whereas in 1977-78 precipitation was much above normal and early spring temperatures were low. The beetles may, therefore, have been stimulated into emerging from hibernation earlier in 1976-77. Coccinellids were much less numerous in 1979 than in the two preceding years. The secondary peaks of predators seen in November 1977 and September 1978 reflect the abundance of vespid wasps, which gather prey to stock their nests. These particular wasps, however, were interested primarily in what appeared to be extrafloral nectaries of oak (Quercus), and perhaps were not acting as predators at this time. They were most numerous in 1978. Asilid flies were abundant in May 1976 and were never so abundant again. These insects must have migrated into the burn in great numbers from outside sources. They were observed preying on the extraordinary numbers of flower-visiting insects (especially Hymenoptera) that were also attracted to the burn to take advantage of the extensive bloom of annual plants that normally occurs the first spring following fire.

Parasitic insects reached their 1977 and 1978 peak abundances in midsummer. In 1976, however, the peak was in May, and in 1979 in May and June. The great majority of these parasites were bombyliid flies, the larvae of which are parasitic on wild bees for the most part, whereas the adults are flower visitors and good pollinators. It is difficult to know for certain what these flies were doing at various times in chaparral. It is my guess, however, that at the time of their highest numbers (May 1976) they were responding to the abundance and variety of blooming annual plants, since they were observed feeding on this resource extensively. They were also likely drawn from outside the burn by the profuseness of blooming. Of course, numerous wild bees were also present and the bombyliids may have later parasitized bee nests within the burn. (The Bombyliidae was included in both the parasitic and the flower visiting trophic groups.) In June 1978 a moderate number of blood-feeding rhagionid flies was present. The number of Chalcidoidea and Ichneumonoidea (Hymenoptera) whose larvae are parasitic on other insects was extremely small in 1976 and 1977. The Ichneumonoidea were more abundant in 1978 but the Chalcidoidea were still very sparse. In 1979 both groups were slightly more numerous. They appeared to respond slowly to the abundant host resources that were available in the early postfire years.

I am aware of no other published data on chaparral insect predators and parasites that are directly comparable with those reported here. Atkins (1977) published a 1-year (1973) survey of chaparral insects from San Diego County, California; but he combined predators with parasites, reported the data as diversity indices, and sampled in a completely different manner.

Flower visitors (pollen and nectar feeders) are naturally influenced by plant-blooming periods. These insects were extremely abundant in May 1976 when sampling was first initiated and at a time when blooming of annual plants was very profuse. Some flower visitors were in the burn area even earlier before regular sampling was begun; bombyliid flies and honey bees (Apis mellifera) were moderately common early in February. By late February wild bees and wasps of several families were present. These insects also must have been attracted into the burn by the profuse bloom of annual plants. Many honey bees were probably originating from domestic colonies maintained within several km of the area by apiculturalists; however, wild colonies are not uncommon in these mountains. The majority of flower visitors in May and June of 1976 were bombyliid flies, honey bees, and anthophorid bees. Flower visitors subsequently declined greatly during the summer months as blooming subsided. By midsummer bees of all kinds were less common but more families were represented. Butterflies became more abundant at this time, especially the families Nymphalidae and Pieridae. By October and November of 1976 syrphid flies were the most common flower visitors along with a number of honey bees. In 1977 a few syrphid flies were present early in the spring. Syrphids appear to be important early spring pollinators, but there was very little blooming in 1977 until well into June. By July bombyliid flies were common flower visitors, honey bees were even more abundant, and anthophorid bees were common in early August. These three groups represented the majority of flower visitors in 1977. By September and October about the only flower insects remaining were a few honey bees. The very late, and seemingly rather poor, bloom this year may have been caused by the greatly subnormal amount of precipitation that fell during the 1976-77 winter. Again in 1978 syrphid flies were the earliest flower visitors, appearing in April and becoming even more abundant in May. In June bombyliid flies were abundant and several butterfly families were common (Hesperiidae, Lycaenidae, and Pieridae), but by far the most abundant insect (and the one responsible to a large degree for the height of the June peak) was the Chalcedon checkerspot butterfly (Euphydryas chalcedona), a common nymphalid species. Honey bees, bumble bees, and anthophorid bees were common in June and July and several other bee families were represented in lesser numbers. Bombyliid flies, anthophorid bees, and honey bees were still common in August of 1978. The April-May-June peak of flower visitors in 1979 was dominated by bombyliid flies, anthophorid bees, honey bees, lycaenid butterflies and nymphalid butterflies. Megachilid bees and bumble bees were also common. The later peak in September and October was caused by great numbers of honey bees and more moderate numbers of syrphid flies; however, they were not visiting flowers but rather were interested in extrafloral nectaries on scrub oak. Bombyliid flies were abundant throughout the season. Flower visiting Hymenoptera were more abundant and diverse in 1976 and 1979 than in 1977 and 1978.

Moldenke (1976, 1977) has reported richness (number of species) and abundance (number of individuals) of flower-visiting insects in chaparral. He found bees especially rich and abundant in both mature and burned chaparral, perhaps because of the sparseness of low ground cover, thus providing ample space for ground nesting. Bees are also by far the most important chaparral pollinators, followed by bombyliid flies. Moldenke (1976) reports, however, that much of the postburn annual flora is self-compatible and, therefore, not dependent on pollinators for reproduction. It is interesting, then, that in the San Dimas study such a large influx of pollinators (both bees and bombyliid flies) occurred the first year postfire. Apparently the annual plants were providing ample nectar and pollen for these flower feeders in order to draw them from outside sources. But why should these plants expend so much energy for this purpose if they are self-compatible? Perhaps self-compatibility is a mechanism to insure their reproductive capabilities just in case pollinating insects are not available for one reason or another. Since many of these annual plants bloom for only one season between fires, perhaps they cannot afford to depend upon insects for their continued survival. However, cross pollination by insects may substantially increase seed set over self-pollination. If this is the case, these plants would benefit by producing large quantities of high quality nectar to attract pollinators into burn areas. If seed set is increased by cross pollination, then it is clear that pollinating insects could be affecting the plant population dynamics of the chaparral ecosystem, in addition to producing more food for all kinds of seed-feeding animals.

The other phytophagous insects (all those except nectar and pollen feeders) were less abundant in 1976 than in the following years. This group in 1976 comprised a large number of families, but none was very large in numbers of individuals. In 1977 a tremendous outbreak of Aphididae occurred on Lupinus from March to June. Counts of these insects were hopeless because of their excessive numbers; the broken peak in figure 1 represents how their numbers might look when graphed. By May of 1977 many Lupinus plants in the area were wilting from the effects of aphid feeding. Coccinellid beetles were moderately numerous also (see predators in fig. 1) and were feeding on the aphids, but the former could not begin to affect the aphid numbers. Acridid grasshoppers were abundant throughout most of 1977, possibly because of the extremely dry, warm spring weather. The high numbers of phytophagous insects from August to November were largely because of acridid grasshoppers, although the family Miridae (Hemiptera) was also very common in August, and vespid wasps became abundant in November. These vespids appeared to be feeding on extrafloral nectaries on scrub oak. (Vespids were arbitrarily put into both the predator and phytophagous groups since they feed their young on animal material, whereas adults feed on various plant material. Extremely few vespids were observed visiting flowers, however.) Again in 1978, the phytophagous insect fauna was quite varied. Most abundant in midsummer were chrysomelid beetles and acridid grasshoppers. The peak in September was caused mostly by anthomyiid flies, vespid wasps, and acridid grasshoppers. These grasshoppers were scarce in 1979, however. The peak in June and July of that year was largely the consequence of large numbers of chrysomelid beetles and butterflies in the families Nymphalidae and Lycaenidae. (Butterflies were put into both the pollen-nectar feeding group because of adult habits, and the "other" phytophagous group because of larval habits.) Vespid wasps were common in September. Phytophagous ants were more common in 1978 than in the two previous years and became still more abundant in 1979.

Overall, there may be certain structural characteristics that one can discern in the early development of trophic groups within the chaparral insect community after fire. In general, parasitic forms are scarce except for bombyliid flies, whose members may be more interested at this stage of floral development in gathering nectar than parasitizing bee nests. Parasitic hymenopterans are extremely scarce at first, but become more numerous by the fourth postfire year. Biting flies (e.g., Tabanidae, Hippoboscidae) that are reported to be fairly common in mature chaparral are very scarce after fire. Predatory insects are much more abundant and active than parasitic forms. This observation reinforces the hypothesis that predators are more r-selected than parasites and, therefore, naturally tend to be more abundant and important immediately after a habitat disturbance. Flower visitors are mostly bombyliid flies and bees of various families. They appear in numbers that match the profuseness of blooming and probably migrate into burn areas to take advantage of the nectar and pollen provided by the "fire annuals" especially. The nonflower visiting phytophagous insects may be greatly influenced by year to year weather changes. Aphids may explode in numbers during a warm, dry spring; acridid grasshoppers are perhaps abundant following a dry winter and spring. More data are needed before any of the above observations can be verified.

Biomass

Figure 2 shows the relationship of insect biomass (below) to rainfall (above) at the project site in the San Dimas Experimental Forest for the 4-postfire years, 1976-1979. Biomass is shown as dry weight of the total insects collected and/or observed per man/hour each month; these weights were estimated from the weight of a representative sample of each variety of insect. The rainfall data (centimeters/month) were taken from Forest Service records gathered at Tanbark Flat near the project site.

The 1976 peak in biomass occurred in May when sampling was first initiated. An average of about half of the total insect biomass during the months of May through September was composed of hymenopterans--especially the families Apidae and Anthophoridae. Nearly a quarter of the total biomass in May was comprised of bombyliid flies. These figures, along with the trophic group statistics given earlier, indicate the dominance of flower visitors during the spring and summer months of the first postfire year. Almost the entire bloom consisted of annual plants, which apparently enticed these flower visitors into the burn with their reward of nectar and pollen. By the last three months of 1976, acridid grasshoppers made up the greater part of the biomass and continued to comprise most of the biomass through the early months of 1977, augmented by coccinellid beetles in March. The broken peak from March through June of 1977 is the estimated contribution to biomass made by a massive buildup of aphids on Lupinus. These insects were neither counted nor weighed, but I estimate their weight easily doubled the total biomass of other insects during these months. The 1977 biomass peak in August and September was due largely to acridid grasshoppers, although anthophorid bees and a variety of Lepidoptera contributed significantly in August to the total. Acridids and vespid wasps contributed the main biomass from September through November.

There is a slightly bimodal biomass peak in 1978 and a very definite one in 1979. However, the insects contributing the main biomass in the two years are somewhat different. In 1978 the June-July peak was because of nymphalid butterflies and bumble bees, and the August-September-October high was mainly vespid wasps and acridid grasshoppers. The 1979 May-June peak was caused partially by nymphalid butterflies again, and also a mixture of Hymenoptera, particularly anthophorid bees. The well-differentiated September peak was comprised of vespid wasps, honey bees, and syrphid flies. Surprisingly, acridid grasshoppers were a very small part of the biomass the second half of 1979 from July until the end of the year.

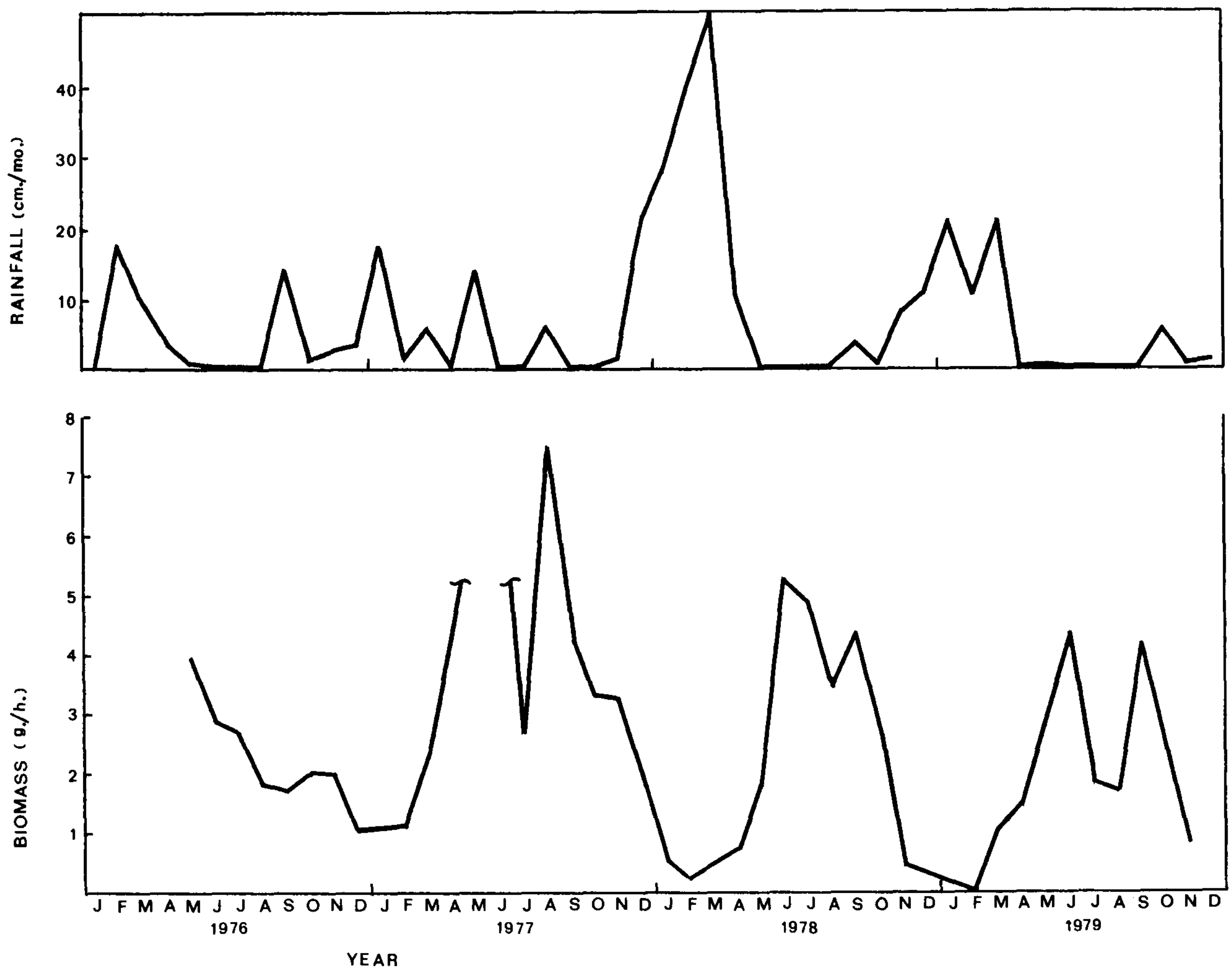


Figure 2--Seasonal distribution of rainfall and insect biomass during 4 years of postfire chaparral succession in the San Dimas Experimental Forest. The biomass data are shown as dry weight of the total insects collected and/or observed per man/hour each month.

A comparison of insect biomass found by Atkins (1977) in San Diego County with that at San Dimas indicates certain differences. Of course, the sites and conditions were also quite different. Atkins' location (Echo Valley) is considerably south of San Dimas, and at a lower elevation than the San Dimas research site. His sampling was done in mature rather than postfire chaparral, his sampling methods were completely different, and he sampled for only one year (1973). The Echo Valley biomass peaks at a much earlier date (March-April) in 1973 than any year at San Dimas (June-July), a difference that would probably be expected because of latitudinal and altitudinal differences. Additionally, the "fall" biomass (September-October) appears to be proportionally much lower at Echo Valley than at San Dimas.

The effect of weather on chaparral insects is still to be determined. A search for correlations between rainfall and biomass in figure 2 is largely enigmatic. (Temperature data were not available for the immediate research area.) The winter of 1976-77 was comparatively dry with rather warm temperatures. Whether this weather had anything to do with the mass buildup of aphids and grasshoppers that ensued during 1977 is uncertain. The winters of 1977-78 and 1978-79 were quite different in the amount of rain that fell, and yet there appeared to be no great difference in the total biomass pattern, although the insects comprising the larger part of the biomass were rather different each year. Further analysis of the effects of weather on chaparral insects will have to await additional data from other studies.

Richness, Diversity, and Abundance

I have reported elsewhere (Force 1981a,b) richness and diversity changes in plants and insects, and abundance changes in insects only, for the first 3 postfire years (1976-78) at the San Dimas study site. Richness was reported as number of insect families and plant species, diversity as Simpson's Diversity Index, $\underline{D} = \frac{1}{\Sigma \underline{p}_{\underline{i}}^2}$ (Simpson 1949), using insect families and plant species, and abundance as average number of insects observed per unit of time. A general decline in all categories was observed over the 3-year period, and it was noted that the successional trends of insects appeared to parallel those of chaparral plants. It was also noted that declining trends in these kinds of statistics are unusual in successional sequences; usually richness, diversity, and abundance increase during the early years after a disturbance. Also discussed in those papers were the following hypotheses: (1) that the comparatively high richness and abundances of insects in a chaparral area the first year following a burn are due to immigration from outside sources, (2) that the size of the burn influences the magnitude of these numbers because of the variable dilution factor involved, (3) that the decreasing trends shown in my data could be temporary, and (4) that various kinds of weather may influence trends of this sort.

For comparative purposes, table 1 gives the same statistics as reported in earlier papers (Force 1981a,b) for the first 3 postfire years (1976-78), but also incorporates recently analyzed data for the fourth year (1979). It is obvious from table 1 that the overall decreasing trends seen the first 3 years are dramatically broken the fourth year. Insect family richness rises even higher than during the first postfire year, which presumably means that by the fourth year additional slow-to-colonize insect families were finding their way into the burn. Insect diversity also makes a large gain partly because of the increase in richness, but mostly because of the more balanced numbers of individuals among the various families. There were no disproportionate number increases among any of the insects in 1979, and this more equitable distribution greatly influenced the calculation of diversity. Average insect abundance, on the other hand, was no different in 1979 from the preceding 2 years and was only slightly less than in 1976. In fact, it is surprising that abundance changed so little in the course of the 4-year study. Abundance was greatest the first postfire year with the large influx of opportunistic feeders that apparently migrated into the burn to take advantage of the annual plant bloom.

The most surprising observations from the 1979 data are the increases from 1978 in plant richness and diversity. These statistics would be expected to decline with the continued disappearance of annual plant species as succession proceeds. However the small difference in plant richness could easily have been sample error, and most of the gain in diversity was, as in the case of the insects, because of more equitable distribution of individuals among plant species. Several questions immediately come to mind at this juncture. (1) The insect data appear to parallel the plant data throughout the study; i.e., insect richness and diversity rise or fall in correlation with plant data. The question is whether this correlation was cause and effect or merely coincidental. (2) Does the abrupt switch in direction of statistics the fourth year indicate that the decline in richness and diversity were temporary and that, henceforth, increases would prevail? This condition would tend to agree better with conventional theories of succession and would perhaps explain Moldenke's (1977) finding of higher insect pollinator richness and abundance in mature chaparral than in postfire chaparral (see Force 1981a,b). (3) Do weather conditions have any deciding influence on chaparral successional events? None of these questions can be answered without additional studies in chaparral burn situations.

Table 1--Richness, diversity, and abundance indices for insects and plants in southern California chaparral the first three years following fire

	1976	1977	1978	1979
Insect family richness[1]	85	72	82	90
Insect family diversity[2]	13.3	10.9	9.1	16.0
Plant species richness[1]	29	26	23	26
Plant species diversity[2]	7.6	2.4	6.0	9.5
Insect abundance[3]	90.0	80.2	77.9	80.6

[1]Total no. of insect families; plant species.

[2]Calculated from $\underline{D} = \frac{1}{\Sigma \underline{p}_{\underline{i}}^2}$ (Simpson 1949).

[3]Avg. no. insects collected/observed per man/hr.

WHAT NEEDS TO BE DONE

Research on chaparral insects is still in its infancy. Because of the attributes of chaparral (e.g., pulse stable perturbation by fire, unique plant recovery characteristics), there are undoubtedly new and bizarre phenomena to be discovered about how insects deal with it. At present, however, we do not know even such basic things as what insects are there in what numbers at what times. After we have these answers, perhaps it will be easier to determine why the insects are where they are and what they are doing there. More exploratory questions concern (1) the amount of movement of insects from outside sources into new burns of various sizes, (2) what factors (floral or otherwise) are responsible for this immigration into burns, (3) whether the trends I have found in insect richness, diversity, and abundance during one postfire succession are commonplace, (4) whether insect feeding and pollination significantly affect chaparral postburn succession, (5) whether floral or vegetational characteristics significantly affect insect succession in chaparral, and (6) what effect weather perturbations have on insect populations and insect community structure in chaparral.

Acknowledgments: The author's work in the San Dimas Experimental Forest was funded by grants from the U. S. Forest Service.

LITERATURE CITED

Atkins, Michael D. Insect biomass and diversity. In: Thrower, Norman J.W.; Bradbury, David E., eds. Chile-California Mediterranean scrub atlas. Stroudsburg, Pennsylvania; Dowden, Hutchinson and Ross, Inc.; 1977; 180-183.

Force, Don C. Postfire insect succession in southern California chaparral. Am. Nat.; 1981a; 117:575-582.

Force, Don C. Ecology of insects in California chaparral. In: Symposium on the classification and distribution of California chaparral ecosystems. Sixtieth annual meeting of the Western Soc. of Naturalists; 1979; December 28; Pomona, Calif.: USDA, Forest Service; 1981b in prep.

Moldenke, Andrew R. California pollination ecology and vegetation types. Phytologia; 1976; 34:305-361.

Moldenke, Andrew R. Insect-plant relations. In: Thrower, Norman J.W.; Bradbury, David E., eds. Chile-California Mediterranean scrub atlas. Stroudsburg, Pennsylvania; Dowden, Hutchinson and Ross, Inc.; 1977; 199-217.

Mooney, Harold A.; Parsons, David J. Structure and function of the California chaparral--an example from San Dimas. In: di Castri, F.; Mooney, Harold A., eds. Mediterranean-type ecosystems: origin and structure. New York; Springer-Verlag; 1973; 83-112.

Simpson, E. H. Measurement of diversity. Nature; 1949; 163:688.

Postfire Community Structure of Birds and Rodents in Southern California Chaparral[1]

W. O. Wirtz II[2]

Abstract: Changes in rodent and avian community structure were documented for 42 months following a major fire in southern California chaparral. Rodent species richness, biomass per ha, and diversity reached levels equal to, or exceeding, those in 16 to 20 year old chaparral within 15 to 24 months post-fire. Heteromyids and meadow mice contributed significantly to biomass per ha in early post-fire seres; wood rats and *Peromyscus* species contributed significantly in older stands. Productivity and diversity of rodents were higher in post-fire seral stages than in older stands. Avian species richness and diversity increased in early post-fire seral stages, probably reflecting an increase in availability of both insect and plant food resources. No significant shifts in feeding guild utilization were noted. A few rodent species may take several years to recolonize burned areas, but avian repopulation is rapid, limited chiefly by the availability of suitable nesting sites.

The chaparral community of southern California is associated with nearly two million years of fire history (Hanes 1971). In recent centuries major fires have occurred at intervals of 20 to 40 years (Byrne and others 1977; Philpot 1977). Post-fire plant succession has been described by Patric and Hanes (1964), Hanes and Jones (1967), and Hanes (1971). Short-term effects of fire on birds and small mammals in the chaparral have been reported by Lawrence (1966), Quinn (1979), and Wirtz (1977, 1979). Wirtz (1977) summarized the work of earlier authors concerning conditions in small vertebrate microhabitats during fire, vertebrate behavior during fire, and survival of small vertebrates exposed to fire. Both Lawrence (1966) and Quinn (1979) studied rodent populations before and after a burn, in addition to documenting microhabitat conditions during the fire.

The Village Fire of November 1975 consumed 1619 ha of the San Dimas Experimental Forest, Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service, in the San Gabriel Mountains of southern California approximately 45 kin east of Los Angeles. Following this fire, permanent study plots were established in 16-year--old chaparral at 975 m and in newly burned areas at 975 and 1280 m with the intention of documenting the post-fire succession of rodents and birds for a long period. This paper discusses changes in community structure of rodents and birds on these plots for the first 42 months post-fire.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Professor of Biology, Pomona College, Claremont, California, 91711.

STUDY AREA

The Experimental Forest encompasses 6,885 ha at elevations from 458 to 1,678 m (Hill 1963). It is dissected by several north-south drainages, and its topography is generally quite steep, the average slope of the land being 68 percent, with nearly half of the slopes having angles greater than 70 percent (Bentley 1961). Mooney and Parsons (1973) describe the Experimental Forest in considerable detail, including its fire history.

The study plot at 975 m in Bell 3 burned last in July 1960. Its present dense cover is composed principally of chamise (*Adenostoma fasciculatum*) and hoary leaf ceanothus (*Ceanothus crassifolius*). Species present in lesser numbers include hairy ceanothus (*C. oliganthus*), black sage (*Salvia mellifera*), bigberry manzanita (*Arctostaphylos glauca*), California buckwheat (*Eriogonum fasciculatum*), mountain mahogany (*Cercocarpus betuloides*), scrub oak (*Quercus dumosa*), silktassel (*Garrya Veatchii)*, toyon (*Heteromeles arbutifolia*), and thickleaf yerba santa (*Eriodictyon crassifolium*).

The recently burned plot at 975 m (Oak) had a pre-fire shrub cover dominated by hairy and hoary-leaf ceanothus, mountain mahogany, scrub oak, chamise, and bigberry manzanita. Toyon and silktassel were more abundant here than at Bell 3, and there were scattered stands of interior live oak (*Quercus wislizenii*). This plot is 0.25 km north of Bell 3, and has a slightly more northerly aspect. All but the live oak had recovered to heights of 1-2 m within 36 months post-fire. Additional shrub species present post-fire included yerba santa, southern honeysuckle (*Lonicera subspicata*), coffeeberry (*Rhamnus californica*), sugar bush (*Rhus ovata*), elderberry (*Sambucus caerulea*), and poison oak (*Toxicodendron diversilobum*).

The burned plot at 1280 m (Sunset) had a pre-fire shrub cover dominated by deerbrush (*Ceanothus integerrimus*), chaparral whitethorn (*C. leucodermis*), hoaryleaf ceanothus, chamise, scrub oak, and bigberry manzanita. This area has experienced a post-fire succession quite different from Oak, presumably due to its higher elevation. The area was dominated by low herbs and grasses (chiefly *Cryptantha intermedia, Stephanomeria virgata, Chaenactis artemisaefolia, Eschscholzia californica, Penstemon spectabilis, Sisymbrium altissimum, Emmenanthe pendulifera, Chichorium intybus, Bromus tectorum*) and a shrubby lupine (*Lupinus excubitus*) in 1976, the first spring post-fire. By 1977 the lupine was extremely abundant (frequency - 92 percent), herbs were decreasing in relative abundance, and shrub species were resprouting vigorously. By spring 1978 the area had regained its shrubby nature, with ceanothus, chamise, scrub oak, bigberry manzanita, and thickleaf yerba santa being the most common species.

METHODS

Square grids of 100 stations at 15 m intervals were established on each of the three study areas. Large Sherman traps were used in a mark and release study to obtain information on rodent populations. Determination of mean distance traveled between captures permitted estimation of the actual area sampled per species per plot. Population density was estimated for each trapping period by the Hayne (1949) equation, and animals per ha determined per species. Mean weights were calculated separately for each species, plot, and trapping period. These values were used with density estimates to determine gm per ha for each species and trapping period. Percent of total biomass per ha per species is used in this paper. Brillouin (1956) diversity indices were calculated for each trapping period and plot.

Birds were censused for each trapping period and on some occasions when trapping was not conducted. Both sightings and sounds were noted as the observer walked the entire grid; individuals overhead were also noted. These observations were converted to individuals per species per man-hour and also to percent of total sightings per species per month, providing indices of relative abundance rather than actual density estimates. Brillouin diversity indices were calculated for each area and sampling period. Wirtz (1979 and in press) divided the avifauna of the San Gabriel Mountain chaparral community into 13 feeding categories or guilds, based on field observations and data in Martin and others (1951). The percentage of species observed per area per period in common feeding guilds was calculated to ascertain whether shifts in food availability occurred during post-fire succession.

RESULTS

Rodents

The rodent fauna of this chaparral community consists of 11 species in 8 genera representing 3 families. The Beechey ground squirrel (*Spermophilus beecheyi*) and Merriam chipmunk (*Eutamias merriami*), family Sciuridae, are seldom seen or trapped. The California pocket mouse (*Perognathus californicus*) and Pacific kangaroo rat (*Dipodomys agilis*) represent the family Heteromyidae. The remaining species are in the family Cricetidae, including the western harvest mouse (*Reithrodontomys megalotis*), California mouse (*Peromyscus californicus*), deer mouse (*P. maniculatus*), brush mouse (*P. boylii*), dusky-footed wood rat (*Neotoma fuscipes*), desert wood rat (*N. lepida*), and California meadow mouse (*Microtus californicus*).

Total rodent biomass varied considerably on the unburned site, from a low of 333 gm/ha in September 1976 to highs of 1896 and 1547 gm/ha in December 1976 and May 1979, respectively (fig. 1). Total biomass was low on both burned plots for 12 months post-fire, increased rapidly from 15 to 30 months post-fire, and by 34 months post-fire had exceeded the maxima on the unburned plot (fig. 1). Seasonal fluctuations in total biomass did not occur on either burned or unburned plots.

Wood rats (*N. fuscipes* and *N. lepida*) contributed 40 to 90 percent of total biomass per ha on the unburned plot (fig. 2). The contribution of both Pacific kangaroo rats and California pocket mice declined from 16 to 20 years post-fire, while that of brush and California mice combined increased (fig. 2).

Only Pacific kangaroo rats, California pocket mice, and *Peromyscus* (*maniculatus, californicus,* and *boylii*) were present on the burned plot at 975 m for 20 months post-fire (fig. 3). Kangaroo rats contributed a major portion of the biomass per ha for 25 months post-fire, but declined to

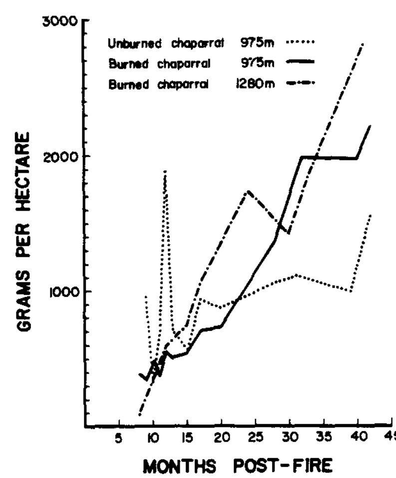


Figure 1: Total rodent biomass, gm/ha, for burned and unburned plots.

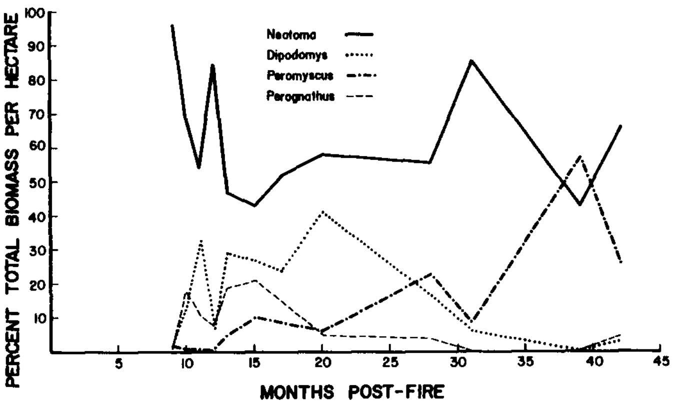


Figure 2: Percent total biomass per ha for rodent genera on the unburned plot at 975 m.

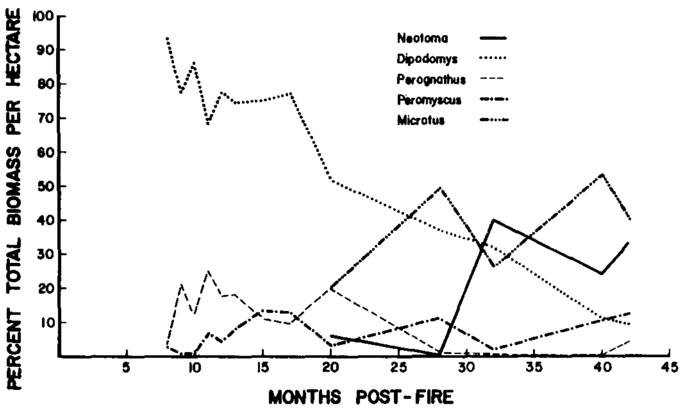


Figure 3: Percent total biomass per ha for rodent genera on the burned plot at 975 m.

contribute less than 10 percent by 42 months post-fire. Wood rats (both *N. fuscipes* and *N. lepida*) and California meadow mice first appeared on this plot at 20 months post-fire, and contributed 25 to 50 percent of biomass per ha between 30 and 42 months post-fire (fig. 3). California pocket mouse populations declined on the plot from 20 to 42 months, and *Peromyscus* populations remained low throughout the entire period (fig. 3).

Pacific kangaroo rats contributed 40 to 95 percent of biomass per ha on the burned plot at 1280 m throughout the entire period (fig. 4). Wood rats (both *N. fuscipes* and *N. lepida*) were present on the plot by 10 months post-fire, and contributed 15 to 40 percent of biomass per ha from 15 to 41 months post-fire (fig. 4). California pocket mice and *Peromyscus* (*maniculatus* and *californicus*) contributed 2 to 22 percent biomass per ha. between 10 and 41 months post-fire, and California meadow mice were present in very low numbers from 33 to 41 months post-fire (fig. 4).

The number of rodent species has been highest on the burned plot at 975 m since 17 months post-fire, and more species have been present on both

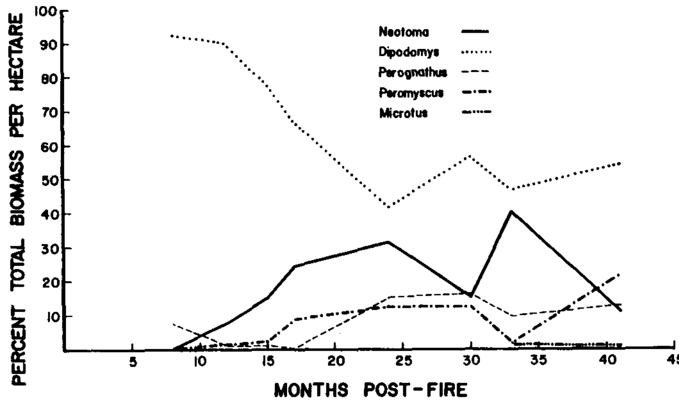


Figure 4: Percent total biomass per ha for rodent genera on the burned plot at 1280 m.

burned plots than on the unburned plot since 30 months post-fire (fig. 5). There was little difference in diversity between unburned and burned plots at 975 m for 28 months post-fire (fig. 5). Diversity on the higher elevation burned plot was lower than that of lower elevation unburned and burned plots for 32 months post-fire, and both burned plots were more diverse than the unburned area from 32 to 42 months post-fire.

Birds

A total of 73 diurnal bird species were observed on the three study plots during the period, but only 23 species occurred regularly (see Wirtz 1979 and in press for a detailed description of the avifauna of the chaparral of the San Gabriel Mountains). Common feeding guilds represented were raptors (7 species), omnivores (2 species), nectar-feeders (5 species), seed-eaters (6 species), insect and fruit eaters (9 species), insect and seed eaters (13 species), those gleaning insects from vegetation (14 species), and those taking insects from the air (8 species).

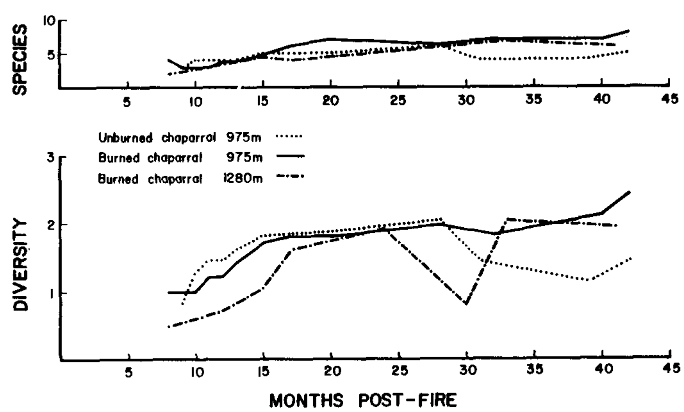


Figure 5: Number of rodent species present (upper) and Brillouin diversity indices (lower), for burned and unburned plots.

The unburned plot at 975 m had the greatest number of species in the spring of 1976, 5 to 6 months post-fire, but by summer more species were present on the burned plot at 1280 m (fig. 6). More species were also present on the unburned plot in spring 1977, 17 to 18 months post-fire, but both burned plots had more species than the unburned plot in spring 1978 and 1979, 29 to 30 and 41 to 42 months post-fire, respectively, with the higher elevation burned plot having more species in both of these years (fig. 6). Omnivorous species were more prevalent on the higher elevation burned plot than on the unburned plot in spring 1976, more prevalent on the unburned site than on either burned site in fall and winter 1976-77 and again in winter 1978, but there was little difference in occurrence of omnivores during the rest of the period studied (fig. 7A). More seed-eating species were normally found on burned areas than on the unburned site; the greatest difference was in the first year post-fire, and there was more fluctuation in the presence of seed-eating species at the higher elevation burned site (fig. 7B). Insect-and fruit-eating species fluctuated in their presence on burned sites, and did not equal or exceed numbers on the unburned site until the fourth year post-fire (fig. 7C). Insect and seed-eating species were much more prevalent on burned sites in the first year post-fire; subsequent occurrence varied but was similar to that on the unburned site (fig. 7D). Those species gleaning insects from vegetation were not common on the higher elevation burned site in the first year post-fire; burned an unburned areas did not show significant differences in occurrence during the next three years (fig. 7E). Species taking insects from the air, or on the wing, such as flycatchers, were less common, and more erratic in occurrence, at all sites (fig. 7F). There are no striking differences between burned and unburned sites.

Brillouin diversity indices for avian occurrence on unburned and burned plots indicate greater diversity on burned plots (fig. 8). This difference is more pronounced for the first two years post-fire, and less for the latter two.

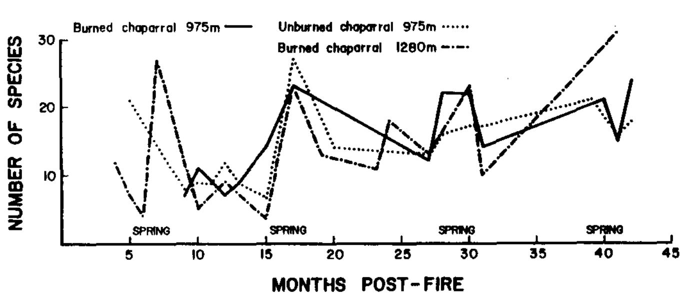


Figure 6: Number of bird species present on burned and unburned plots.

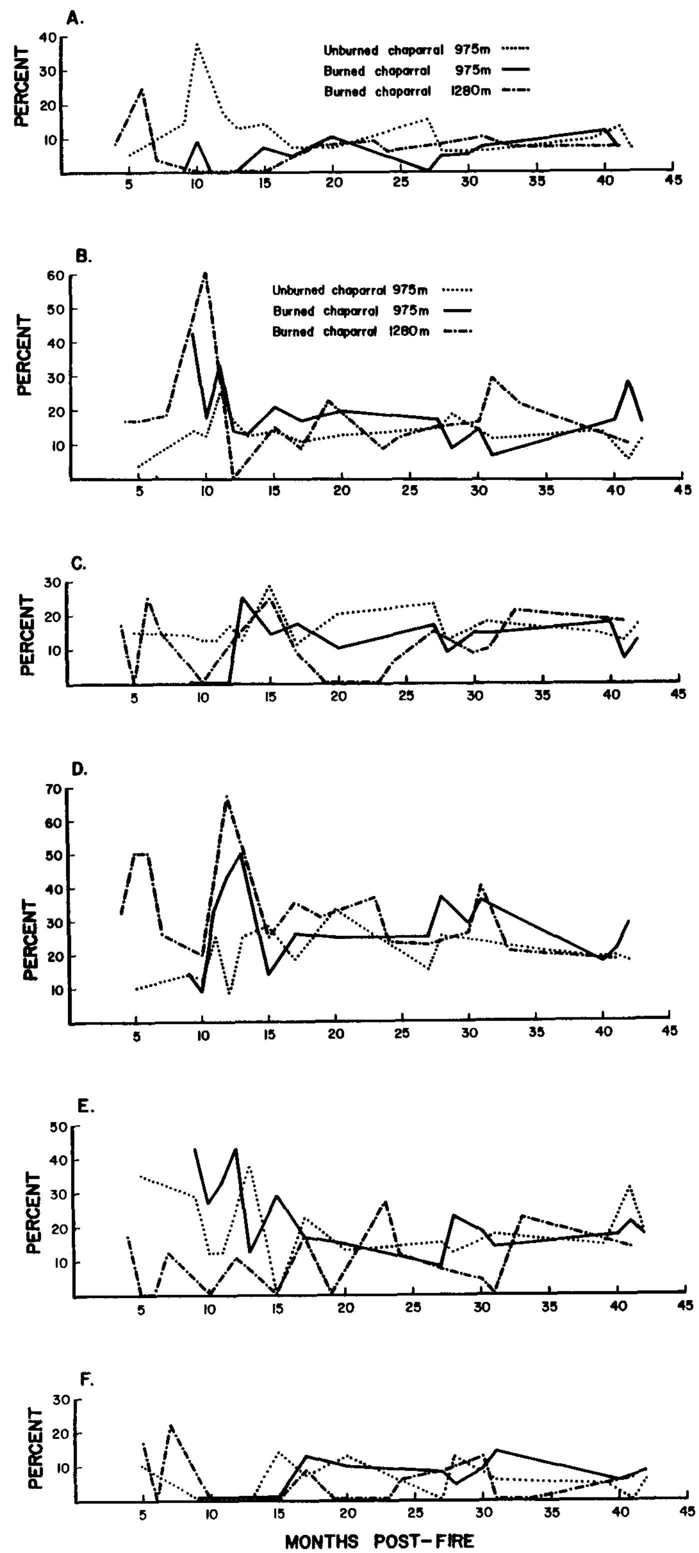


Figure 7: Presence of different feeding guilds on burned and unburned plots, as percent of total species present: A) omnivores, B) seed eaters, C) insect and fruit eaters, D) insect and seed eaters, E) gleaners of insects from vegetation, F) insects taken from air.

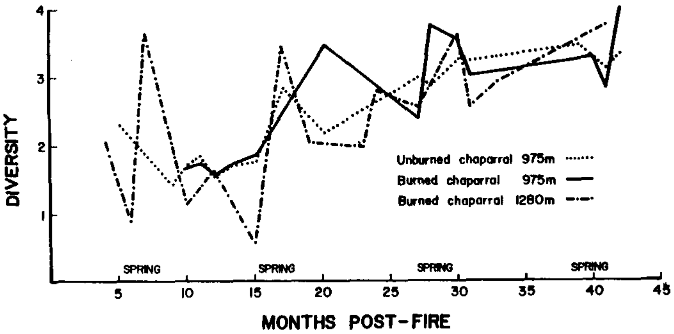


Figure 8: Brillouin diversity indices for avian populations on burned and unburned plots.

DISCUSSION

Only 6 rodent species are commonly found in older chaparral stands in the San Gabriel Mountains: California pocket mouse, Pacific kangaroo rat, California mouse, brush mouse, dusky-footed wood rat, and desert wood rat. Western harvest mouse, deer mouse, and California meadow mouse inhabit disturbed habitats in this region, whether they be grassland conversions (Wirtz 1977) or post-fire seral stages.

The burrowing habit enhances rodents' ability to survive fire (Howard and others 1959; Lawrence 1966; Quinn 1979). Thus, post-fire rodent communities in this region are dominated by kangaroo rats (figs. 3 and 4; Quinn 1979) and, to a lesser extent, pocket mice. Rapid post-fire plant succession reduces habitat suitability for burrowing heteromyids, and their abundance and contribution to total biomass declines (figs. 3 and 4). Pacific kangaroo rats exhibit a significant preference for open space in their habitat, most likely associated with their saltatorial mode of locomotion.

Utilization of above-ground stick nests by wood rats makes them particularly susceptible to fire (Horton and Wright 1944; Quinn 1979), and they may not successfully recolonize burned areas until 1-2 years post-fire (figs. 3 and 4). Deer mice and California meadow mice colonize burned areas within 1-2 years post-fire (figs. 3 and 4).

Though rodent communities may be decimated by wildfire, recolonization and subsequent reproduction bring species numbers, biomass per ha, and diversity to levels equal to, or exceeding, those in 16 to 20 year old chaparral within 15 to 24 months post-fire (figs. 1 and 5). Productivity and diversity of rodents is higher in post-fire seral stages than in older stands, and data collected in this study suggest that both begin to decline when the stand reaches 18 to 20 years of age (figs. 2 and 5).

Wood rats, because of their large size, contribute significantly to biomass per ha in older chaparral stands (fig. 2). Their contribution on burned areas increases slowly between 2 and 3 years post-fire (figs. 3 and 4). *Peromyscus* abundance and biomass contribution increases as stands age from 16 to 20 years (fig. 2).

Both bird species richness and species diversity increased during 42 months post-fire (figs. 6 and 8). The increase in richness most likely reflects the addition of rare species with more observer time on the study plots, as the phenomenon occurred on unburned as well as burned plots. An increased number of species present on the higher elevation burned plot in the first spring post-fire may reflect increased richness in both insect and plant food resources associated with the great plant species richness that occurred in that spring. Lawrence (1966) reports increased diversity of bird species following a controlled burn in the chaparral of Sierra Nevada foothills, and Bock and Lynch (1970) report increased richness and diversity on burned plots in Sierra Nevada coniferous forest. Higher diversity indices for burned plots in all springs post-fire (fig. 8) reflect changes in population size of species already present rather than addition of species. No increase was noted in the number of omnivorous species present on burned areas (fig. 7A), but increases were noted in the number of seed-eating (fig. 7B) and insect-and seed-eating (fig. 7D) species. These differences are most pronounced in the first year post-fire. Insect-and fruit-feeding species exhibit an initial decrease in use of burned areas (fig. 7C), presumably because fruits are not available. Species that glean insects from vegetation also exhibit an initial decrease in utilization of burned areas (fig. 7E), presumably due to lack of vegetation, while species that take insects from the air exhibit little response to fire (fig. 7F). No significant shifts in feeding guild utilization of burned habitats is noted, and therefore it is assumed that shifts also do not occur in food type availability in burned habitats.

Rodent populations are initially decimated by wildfire. Only burrowing forms survive in any numbers. Post-fire recovery is rapid, however, with biomass per ha exceeding that in 16 to 20 year old chaparral within two years. Species lost in the fire, like wood rats, may not return to the site for two years. It is assumed that some refugia always remain for these species, due to the normally patchy nature of burns. Species that thrive in disturbed areas, like the deer mouse (Williams 1955), or herbivorous forms like the California meadow mouse, colonize early post-fire seral stages. Brush-tolerant species, such as wood rats and California and brush mice, assume a greater role in the community as it returns to shrub seral stages. By 20 years post-fire early successional forms like deer mouse and meadow mouse have vanished, burrowing heteromyids have declined in abundance as the shrub canopy closes in and ground level open space is eliminated, and shrub-tolerant species like wood rats and brush and California mice predominate.

Fire reduces both food availability and nesting cover for bird species. Post-fire plant and insect succession rapidly restores food availability. Avian species diversity is enhanced slightly in early post-fire seral stages due to food resource diversity. Numbers of individuals are greater on early post-fire seral stages, resulting in higher diversity indices. Rapid replacement of early herb and grass seral stages by shrub-dominated stages reduces this diversity within four years post-fire.

Though individuals are lost in wildfires, few species are lost. Surviving individuals are able to repopulate quickly as plant succession occurs. A few rodent species may take several years to recolonize burned areas, but avian repopulation is rapid, perhaps limited chiefly by the availability of suitable nesting sites.

ACKNOWLEDGMENTS

The author is indebted to the Pacific Southwest Forest and Range Experiment Station, and to Pomona College, for financial support for this project, and to C. Eugene Conrad, Project Leader, San Dimas Experimental Forest, for his continual cooperation. Dr. Paulette Bierzychudek provided helpful criticism of the manuscript. Many present and former students have helped with field work, especially Sharon L. Booth, C. Eric Orr, John A. Lubina, and Joel S. Brown. All figures are by Helen J. Wirtz, who also frequently participated in field work.

LITERATURE CITED

Bentley, Jay R. Fitting brush conversion to San Gabriel watersheds. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., Misc. Paper 61; 1961; 1-8.

Bock, Carl E.; Lynch, James F. Breeding bird populations of burned and unburned conifer forest in the Sierra Nevada. Condor 72(2):182-189; 1970.

Brillouin, Leon. Science and information theory. New York; Academic Press; 1956; 1-320.

Byrne, Roger; Michaelsen, Joel; Soutar, Andrew. Fossil charcoal as a measure of wildfire frequency in southern California: A preliminary analysis. ***IN***: Mooney, Harold A.; Conrad, C. Eugene, eds. Proc. symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. USDA Forest Service, Gen. Tech. Report WO-3; 1977; 361-367.

Hanes, Ted L. Succession after fire in the chaparral of southern California. Ecol. Mono. 41(1): 27-52; 1971.

Hanes, Ted L.; Jones, Harold W. Post-fire chaparral succession in southern California. Ecol. 48(2):259-264; 1967.

Rayne, Don W. Two methods of estimating population from trapping records. J. Mamm. 30(4): 399-411; 1949.

Hill, Lawrence W. The San Dimas Experimental Forest. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.; 1963; 1-24.

Horton, John S.; Wright, Jerome T. The wood rat as an ecological factor in southern California watersheds. Ecol. 25(3):341-351; 1944.

Howard, Walter E.; Fenner, R. L.; Childs, Henry E., Jr. Wildlife survival on brush burns. J. Range Mgmt. 12(5):230-234; 1959.

Lawrence, George E. Ecology of vertebrate animals in relation to chaparral fire in the Sierra Nevada foothills. Ecol. 47(2):278-291; 1966.

Martin, Alexander C.; Zim, Herbert S.; Nelson, Arnold L. American wildlife and plants: A guide to wildlife food habits. New York; Dover Publ.; 1961; 1-500.

Mooney, Harold A.; Parsons, David J. Structure and function of the California chaparral - an example from San Dimas. ***IN***: di Castri, Francesco; Mooney, Harold A., eds. Mediterranean type ecosystems. New York; Springer-Verlag; 1973; 83-112.

Patric, James J.; Hanes, Ted L. Chaparral succession in a San Gabriel Mountain area in California. Ecol. 45(2):353-360; 1964.

Philpot, Charles W. Vegetative features as determinants of fire frequency and intensity. ***IN***: Mooney, Harold A.; Conrad, D. Eugene, eds. Proc. symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. USDA Forest Service, Gen. Tech. Report WO-3; 1977; 12-16.

Quinn, Ronald D. Effects of fire on small mammals in the chaparral. Cal-Neva Wildlife Transactions; 1979; 125-133.

Williams, Olwen. Distribution of mice and shrews in a Colorado montane forest. J. Mamm. 36(2): 221-231; 1955.

Wirtz, William O., II. Vertebrate post-fire succession. ***IN***: Mooney, Harold A.; Conrad, C. Eugene, eds. Proc. symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. USDA Forest Service, Gen. Tech. Report WO-3; 1977; 46-57.

Wirtz, William O., II. Effects of fire on birds in chaparral. Cal-Neva Wildlife Transactions; 1979; 114-124.

Wirtz, William O., II. Seasonal distribution, habitat utilization, and reproductive phenology of avifauna in southern California chaparral. Proceedings of the symposium on classification and distribution of California chaparral ecosystems, Pacific Southwest Forest and Range Experiment Station, Forest Serv., U.S. Dep. Agric., Berkeley, Calif.; in preparation.

Management of Chaparral Habitat for Mule Deer and Mountain Sheep in Southern California[1]

Vernon C. Bleich and Stephen A. Holl[2]

Abstract: Mule deer (Odocoileus hemionus) and mountain sheep (Ovis canadensis) occur in chaparral habitats of the San Gabriel and San Bernardino mountains, California. While they inhabit similar vegetation types, differences in the physical characteristics of their habitats result in a general allopatry of these species. Management options applicable to deer habitat are not always practical in sheep habitat. A series of models which will assist managers with the design of projects to benefit these species is presented. Options for achieving these goals are presented, and constraints with which managers must deal are detailed and discussed.

> There is a huge crevasse that separates the zoological field of wildlife management from the botanical field of wildlife-habitat management. Despite the fact that each field is greatly dependent upon the other, each marches on his own side, not aware that they should do more than gaze coyly at the other from a distance.
>
> F. E. Egler, 1974

In southern California, vegetation most commonly referred to as "chaparral" dominates wildland ecosystems. Chaparral generally occurs on cismontane slopes, primarily between 1,200 and 2,500 meters elevation. The species composition of chaparral is diverse, and most species are fire-adapted (Gill 1977), or otherwise adaptable to the application of chemical and mechanical management strategies (see Roby and Green 1976, Green 1977a, and Leisz and Wilson 1980).

Until recently, land management agencies approached chaparral manipulation from a fuels management aspect. Aside from the construction of fuel breaks and occasional type conversion projects, land management was dominated by fire prevention and suppression activities. The disasterous results of the 1970 fire season led to the formulation of the Laguna-Morena Demonstration Area in San Diego County (Newell 1979), and the concept of an active chaparral resource management program spread to other sites in southern California.

Because much of our public land is capable of producing more than one product, the multiple resource management philosophy is extremely important. As human populations increase, citizens place more and more demands upon public lands. Demands for commodities such as red meat, recreation sites, minerals, and energy increase daily. Consequently, intensive management of these resources is becoming increasingly important.

Wildlife biologists must be willing to provide input into all land management decisions if wildlife benefits and detriments are to be considered. Until now, predictive methods for assessing the potential impacts of vegetation management on wildlife habitat were not available. Multiple resource management needs an analytical system which allows the prediction of the effects of land management activities on wildlife habitats and, ultimately, on wildlife populations. Thomas (1979) and Salwasser and others (1980) have described the concept of a predictive wildlife habitat-oriented system which will allow more comprehensive assessments of land management actions on native wildlife species. The system in California is known as the Wildlife Habitat Relationships Program, and is a joint endeavor of many Federal and State agencies, as well as some private organizations. What follows is being developed as an aspect of the Wildlife Habitat Relationships Program, and is presented only in an exemplary manner.

In southern California, two large ungulates, mule deer (Odocoileus hemionus) and mountain sheep (Ovis canadensis), are major faunal elements of chaparral ecosystems. The objectives of this paper are to describe briefly the distribution and habitat requirements of these species, provide examples of various habitat management models which are being developed for the Wildlife Habitat Relationships Program, and discuss options and constraints in managing chaparral for wildlife.

Mule deer occur throughout the mountain ranges of southwestern California. Both resident and migratory populations are present. Winter ranges are generally between 400 and 2,500 meters elevation, and summer ranges between 2,000 and 3,600 meters (Longhurst and others 1952). Deer inhabit

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Wildlife Biologist, California Department of Fish and Game, Hemet, Calif.; and Wildlife Biologist, San Bernardino National Forest, U.S. Department of Agriculture, Fontana, Calif.

diverse land forms, on slopes generally less than 60 percent. South aspects are preferred during winter, north aspects during summer (Taber and Dasmann 1958). A variety of vegetation types are utilized by deer (Longhurst and others 1952, Taber and Dasmann 1958). Chamise (*Adenostoma fasciculatum*) and mixed chaparral stands commonly are used below 2,400 meters elevation (Cronemiller and Bartholomew 1950). Water generally is available within 800 meters of occupied habitats.

Mountain sheep occur in the San Gabriel and San Bernardino Mountains. Both resident and migratory populations are present (Weaver and others 1972, DeForge 1980). Winter ranges generally are between 1,200 and 2,400 meters elevation and summer ranges between 2,000 and 4,500 meters. Approximately 70 percent of the observations (Holl and others 1980) showed mountain sheep used slopes from 50-90 percent, having south or southeast aspects, and supporting vegetation dominated by chaparral whitethorn (*Ceanothus leucodermis*), mountain mahogany (*Cercocarpus betuloides*), and chamise. Mean shrub cover is approximately 30 percent and herbaceous cover is less than 5 percent (Light and Weaver 1973). Water usually is available within 400 meters of occupied habitats.

DISCUSSION OF HABITAT MODELS

Background

While we cannot accurately predict the number of deer or sheep which a given vegetation type supports, we can predict population responses of these species to changes in the conditions of their habitats. The models presented here predict relative changes in deer and sheep populations with respect to the potential capabilities of chaparral vegetation (table 1). A high capability habitat would potentially support a relatively dense population, or a population of lesser density but which exhibits a high recruitment rate. Because of environmental resistance, the actual population in a high capability habitat may not exhibit high productivity, but this does not alter the habitat's (i.e., the vegetation's) potential. A low capability habitat would not support a dense, self-sustaining population; if it contains a population, some individuals would, by definition, be immigrants from other higher capability habitats.

There are several important management implications in the concept of defining seasonal habitat capability in terms of its contribution to population recruitment. Each seasonal range has a finite supply of forage and cover resources. If that supply is sufficient to support a deer population, any excess individuals will disperse to other available habitats. Among sheep, the tendency to disperse appears to be more limited (Geist 1971). There is, however, increasing evidence that mountain sheep may occupy newly available suitable habitats (Bleich and others 1980, Campbell and Remington 1979, Holl and others 1980, Riggs and Peek 1980), and this could be of paramount importance in future sheep habitat management decisions.

Table 1--Habitat capability as described by selected population parameters.

Habitat Capability	Population Parameters: Density	Recruitment / Mortality	Emigration
High	Increasing or stable	≥ 1	Yes
Moderate	Stable	~ 1	No
Low	Decreasing	<41	No

Where deer find other adjacent, unstocked but high capability habitat, they may increase to their tolerance density and produce more dispersers. On deer summer ranges, this leads to rapid colonization of newly available habitats, but only when there are sufficient high-capability ranges to produce dispersers. When high capability summer ranges are missing, new habitats may not be readily colonized for lack of dispersers.

On winter ranges of both species, carrying capacity may be exceeded because there often is no other suitable habitat available. Managers should attempt to balance the capacities of all seasonal ranges. High capability winter ranges are able to support positive recruitment only if the summer ranges provide healthy animals.

Perhaps the most significant implication of this concept for land management is the importance of identifying high capability seasonal ranges and either maintaining or recreating their characteristics. This is a distinct alternative to applying non-site-specific prescriptions to all lands within a herd's seasonal range. Moderate capability ranges should be targeted for enhancement. Low capability ranges should be treated only if they have a reasonable potential for improvement and they are adjacent to high capability habitat.

Within each seasonal range there are distinct habitat elements and attributes which determine its capability. Selected aspects of these attributes will be addressed in the habitat models. We will focus on the following:

Vegetation Stage: A designation of the existing vegetation, its age class and canopy cover.

Canopy Cover of Dominant Plants: Percent canopy cover of plants describing the vegetation type.

Stand Size: The area, in hectares, of a distinct stand of vegetation.

Cover and Forage Proportions: The proportion of an area in vegetation stands that meet cover standards, and the proportion in vegetation stands that provide forage but do not meet cover standards. The proportions apply to stands within a delineated seasonal range. Standards for thermal and hiding cover differ by vegetation type and season of use. Stand area, canopy cover of dominant plants, and species composition of stands qualifying for cover designation must be stated for each seasonal habitat model.

In order to understand the models, it is necessary to consider the following definitions:

Forage Area: A vegetation stand, or group of stands, that provides high quality forage, but lacks structure which meets thermal or hiding cover requirements.

Thermal Cover Area: A vegetation stand, or group of stands, containing shrubs or trees that, because of their growth form, height, and canopy cover, are able to moderate temperature extremes. Such stands may also provide forage.

Deer Hiding Cover: Any stand of vegetation that is capable of hiding 90 percent of an adult deer from human view at a distance of less than or equal to 70 meters.

Sheep Escape Terrain: An area of steep, rocky terrain, lacking dense vegetation and which allows a sheep an unobstructed view for at least 100 meters.

Because chaparral vegetation is such an important component of the habitats of mountain sheep (Roll and others 1980) and mule deer (Longhurst and others 1952), it was selected as the example for which management models would be presented. That chaparral is so important from the standpoint of fire management (Philpot 1979) and the numerous techniques available for manipulation (Menke and Villasenor 1977, Green 1977a, Green 1977b, Biswell 1977) are additional factors which influenced our selection. We have further limited our discussion to the winter and spring, and we use the following dates and characteristics to describe these seasons:

Winter: December 22-March 21; highest rainfall and coolest temperatures. Grasses are green and growing.

Spring: March 22-June 21; little rain and warming temperatures. Grasses are drying, forbs are flowering, and browse species are initiating new growth and flowering.

Chaparral Habitat Models

On chaparral ranges, forage values generally are high during the spring and moderate during the winter. Deer hiding cover is high year round, and winter-spring thermal cover is considered high for both deer and sheep. The value of a chaparral range as sheep escape terrain is related to the geomorphology of the area and is an inverse function of shrub density. As such, it is difficult to rate chaparral vegetation as escape terrain for sheep, except to say that less dense stands are better than higher density stands. High quality deer hiding cover is poor quality sheep escape terrain; the converse also is true.

The following models (figures 1-5)are based on our personal experiences and a review of the literature, and portray the relative value of chaparral ranges to deer and sheep populations. Sheep escape terrain, rather than deer hiding cover, was considered when evaluating vegetation parameters for sheep populations.

Relative to percent canopy cover, thermal and hiding cover values are similar year round on chaparral ranges, but marked seasonal differences occur in the relative forage value to deer on a seasonal basis (fig. 1). During winter and spring, forage value peaks at perhaps 20 percent canopy cover and then declines gradually. This is a function of the large amount of herbaceous material produced on these ranges, particularly at low densities of perennial plants. The relative forage value for deer remains relatively high up to about 50 percent canopy cover. Because percent canopy cover is closely related to age class, and concomitantly to forage quality, relative forage value to deer declines rapidly as canopy cover exceeds 50 percent. Cover values are not high until a minimum of 50 percent cover is attained.

The relative forage value of chaparral winter and spring ranges to mountain sheep is nearly identical to that of deer, except that value decreases more rapidly as crown closure increases (fig.1). The relative value of hiding and thermal cover is greatest when canopy cover is less than 15 percent. These values reflect the decided preference of mountain sheep for open shrub stands.

The relative value of chaparral habitat as a function of age class is shown in figure 2. Cover values are highest in mature, but not decadent chaparral. Forage value on winter and spring ranges are highest during early successional stages. This is related to the fact that young, vigorous chaparral shrubs have a higher forage value than do old, decadent shrubs (Taber and Dasmann 1958). Young, vigorous chaparral shrubs most commonly are found within five years of a fire.

For deer, relative value of chaparral habitat as a function of stand size is shown in figure 3. Thermal cover value is maximized between one and 8 hectares, while forage and hiding cover values peak at about 6 hectares and decline rapidly thereafter with increasing stand size. This primarily is a function of the stand becoming too large for deer to make effective use of ecotonal areas, where highly productive herbaceous habitats may provide additional high quality forage.

Vegetation patch size may not be a determinant of habitat quality for mountain sheep, owing to their affinity for steep, rocky terrain. Therefore, we have used the distance of vegetation stands from escape terrain in our model (fig.4). Forage value is greatest within 150 meters of escape terrain. Geomorphic features are the primary determinants of sheep thermal cover value; however, their value can be enhanced with a few large, scattered shrubs, up to about 15 percent canopy cover. Again, this reflects the preference of sheep for open terrain.

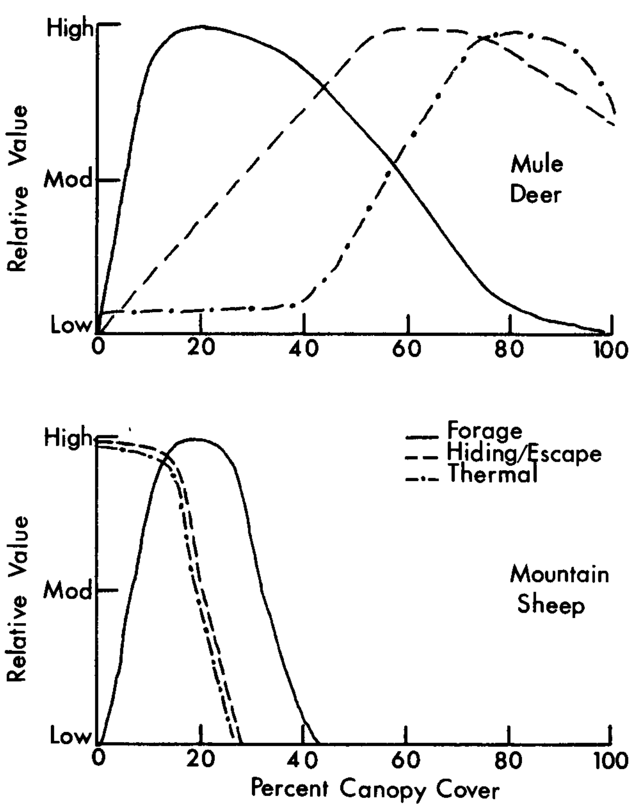


Figure 1. Relationship of percent canopy cover of chaparral vegetation to meet forage and cover requirements of mule deer and mountain sheep.

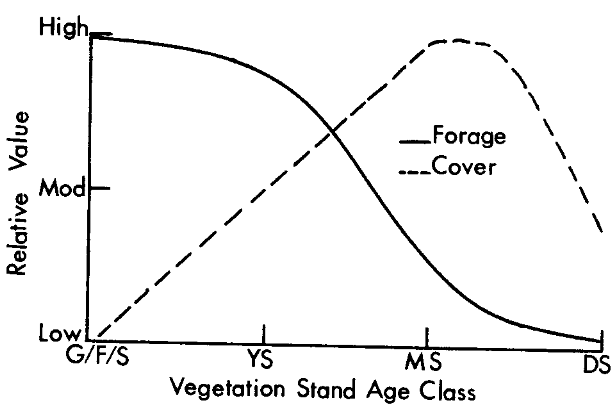


Figure 2. Relationship of vegetation stand age class of chaparral vegetation to meet forage and cover requirements of mule deer and mountain sheep.
G/F/S=Grass, forb, seedling
YS= Young shrub
MS= Mature shrub
DS= Decadent shrub

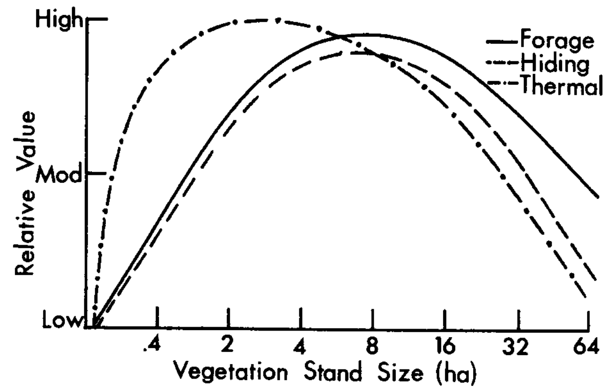


Figure 3. Relationship of size of chaparral vegetation stand to meet forage and cover requirements of mule deer.

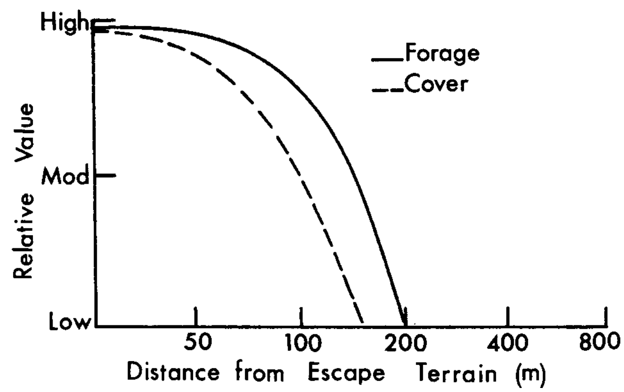


Figure 4. Relationship of distance of vegetation stand from escape terrain to meet forage and cover requirements of mountain sheep.

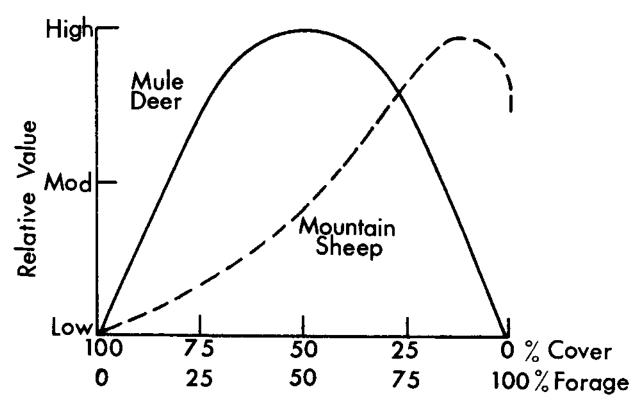


Figure 5. Relationship of cover/forage proportion of chaparral vegetation to meet forage and cover requirements of mule deer and mountain sheep.

The relative value of chaparral ranges for deer and sheep as a function of proportions in cover and forage is reflected in figure 5. It has been previously estimated (Taber and Dasmann 1958) that a cover and forage proportion of 50 percent of each is ideal for deer, while Thomas and others (1979) have suggested proportions of 40 percent and 60 percent.

The relative value of chaparral ranges as a function of the cover proportion is skewed to the right of that for deer (fig. 5). In this context, a shift to the right reflects a lower shrub density or lower percent crown cover. With a lower cover proportion a greater degree of openness is expected, thereby increasing the value to sheep because of their decided preference for more open habitats.

MANAGEMENT OPTIONS AND CONSTRAINTS

Managers can effectively manipulate wildlife populations through direct population manipulation or habitat modification (Caughley 1977, Scotter 1980). Direct population manipulation usually requires modification of existing harvest strategies; this subject will not be covered here. Habitat manipulation may be categorized as: (1) direct rehabilitation of ranges whose capability has declined because of natural processes or past management strategies; (2) direct enhancement of existing habitat; and (3) modification of other resource management practices (Scotter 1980).

Several methods of vegetation manipulation are available to the land manager interested in featuring deer or sheep. Each method produces varying effects and has different cost factors (table 2). The preferred method must be capable of producing the desired objectives for the wildlife population and vegetation structure and, whenever possible, be compatible with other resources.

Mechanical treatments such as disking, crushing, chaining, raking, and railing can be used to improve the productivity of desired forage species. However, the costs are relatively high (Roby and Green 1976, Green 1977a, and Yoakum and others 1980).

Erosion potentials following treatment are dependent on the method and the amount of vegetation removed. Brushrakes and ball and chain treatments may produce high erosion potentials, while a modified chain and disking treatment will produce the least. Additional treatments may be necessary following mechanical manipulation. Generally, mechanical treatments are desirable only on slopes less than 30 percent; however, a ball and chain may be used on slopes greater than 30 percent in suitable terrain (Roby and Green 1976, Green 1977b).

Properly planned mechanical treatments can result in irregular edges and leave islands of cover (Yoakum and others 1980). They are particularly suitable for chaparral ranges inhabited by deer, where optimum openings are 5-15 hectares in size. Mechanical treatment of vegetation on mountain sheep ranges generally is impractical because of the steep slopes and rugged terrain they inhabit.

Herbicides offer possibilities for improving wildlife habitat and some positive results have been obtained. However, wildlife habitats are composed of a variety of plant species which respond differently according to chemical concentrations and time of application. This often makes the use of sprays unpredictable in terms of their overall effect (Scotter 1980, Yoakum and others 1980). Chemical treatment of vegetation on chaparral ranges can be used as a preparation for burning, density reduction of impenetrable brush stands, or maintenance of low density brush stands.

The application of herbicides can be relatively inexpensive. They can be aerially broadcast or

Table 2--Some management options for vegetation manipulations in chaparral habitats, and predicted results.

	Approximate Cost/Hectare[1]		Probability of Successful Treatment[2]		Probability of Method Resulting in Conflicts With[2]	
Method	Light Fuel (<50 ton/hec.)	Heavy Fuel (>50 ton/hec.)	Deer Range	Sheep Range	Deer	Sheep
Mechanical	200-275	225-500	H	L	L	L
Chemical	50-75	125-190	H	H	L	L
Handwork	1125-3000	3500-6250	M	H	L	L
Livestock[3]			M	L	M	H
Burning	75	115	H	H	L	L

[1]Recent U.S. Forest Service Estimates (Dollars)

[2]H=High; M=Moderate; L=Low

[3]Costs vary with the species involved. Cattle often create a positive cashflow for the landowner; goats often create a negative cash flow.

selectively sprayed by hand in a variety of terrains. Close supervision is necessary to assure that target species are treated and drift is minimized (Roby and Green 1976, Green 1977b).

Indiscriminant application of herbicides can result in a loss of both cover and forage. Although no cases have been documented of lethal effects of herbicides when properly applied, certain chemicals possibly may cause abnormalities in some animals It is possible that legal restrictions on the widespread use of herbicides will prevent their future application (Scotter 1980).

Handwork includes cutting shrubs and trees, grubbing root crowns, selectively applying herbicides, and planting. These treatments are feasible in all terrains and reduce soil disturbance to a minimum. Handwork is usually carried out in conjunction with other vegetation manipulation projects. This may include selectively spraying stumps and root crowns following prescribed burns or mechanical manipulation, or cutting control lines around prescribed burns. High manpower requirements and slow progress severely limit the practicability of handwork (Green 1977b).

Grazing practices and vegetation manipulation for domestic livestock can have significant effects on native ungulates. The effects may be positive or negative, depending on the timing and level of stocking, current range conditions, or the amount of habitat manipulated.

Competition for limited forage usually occurs among the most palatable species (Bryant and others 1979). On low capability chaparral ranges, competition for palatable species would be greatest with goats (Bryant and others 1979), moderate with domestic sheep (Longhurst and others 1979) and least with cattle. Heavy utilization of herbaceous forage by cattle may be detrimental to deer (Bowyer and Bleich, unpubl. data); however, as long as sufficient forage of all categories are available, competition is not likely to occur (Longhurst and others 1979).

Modification of grazing practices may be one of the best tools for improving deer forage. For example, Biswell and others (1952) discussed the use of domestic sheep to augment control of shrub regrowth on disturbed ranges where the deer population was inadequate to do so. This would maintain an open shrub community interspersed with grasses and forbs. Longhurst and others (1979) concluded that deer grazing alone did not maintain herbaceous ranges in the most productive condition for deer and that livestock could be utilized to achieve this objective. Additionally, the judicious use of cattle can be used to provide flexibility and control of browsing on deer ranges (Gibbens and Schultz 1962). Thus, both livestock and wild ungulate grazing are useful to maintain the desired seral stage of a plant community (Longhurst and others 1976, Scotter 1980).

We recommend caution when attempts are made to integrate grazing practices with mountain sheep. The rugged terrain inhabited by mountain sheep inhibits herding of domestic stock, and the low forage production of many sheep ranges increases the possibility of competition. Additionally, mountain sheep are extremely susceptible to diseases of domestic stock, and these diseases have been implicated in several recent, major die-offs of mountain sheep (Foreyt and Jessup 1980, Jessup 1981).

Prescribed burning is recognized as a viable and economical tool for vegetation management on wild ungulate ranges (Yoakum and others 1980). Prescribed burning is applicable in a variety of vegetation types and in a variety of terrains. Not only do fires create a mosaic of vegetation structures between vegetation types, they will also create a mosaic within types (Lyon and others 1978). With the advent of the helitorch, prescribed burning can now be conducted under conditions which in the past would have been impossible.

Early work on northern California chaparral ranges documented the beneficial effects of prescribed burning on the productivity of deer populations (Biswell and others 1952, Taber and Dasmann 1957, Taber and Dasmann 1958). More recently, Longhurst and Connolly (1970) have also shown an increase in deer harvest within recently burned ranges. The value of burning on mountain sheep ranges has also now been recognized (Stelfox 1971, Peek and others 1979, Riggs and Peek 1980, Holl and others 1980).

While burning may be a highly desirable management tool, it may not be applicable under all circumstances (Leisz and Wilson 1980). Additionally, Longhurst and others (1976) questioned the cost/benefit ratio of burning chaparral ranges solely to benefit wildlife. These authors concluded that additional multiple use benefits should accrue to make prescribed burning economically justifiable.

SUMMARY

A cursory analysis of habitat utilization of mule deer and mountain sheep shows that their preferences are different. Different models are necessary to describe the habitat requirements of these two species. The models designed for management of deer habitat stressed vegetation structure and composition. Models designed for management of mountain sheep habitat emphasized both geomorphic and vegetative features. Management opportunities are more liberal for mule deer; however, the preferred habitat management technique for either species should be integrated with other resource management objectives.

LITERATURE CITED

Biswell, H. H. Prescribed fire as a management tool. In: Mooney, H. A.; Conrad, C. E., tech. coords. Proc. Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Sta., Forest Service, U.S. Dep. Agric.:1977; Gen. Tech. Rep, WO-3:151-162.

Biswell, H. H., R. D. Taber, D. W. Hedrick and A. M. Schultz. Management of chamise brushlands for game in the north coast region of California. Calif. Fish and Game 38:453-484; 1952.

Bleich, V. C., L. J. Coombes and J. H. Davis. Big game guzzler evaluations: progress report II. Long Beach, Calif.: California Dep. Fish and Game; 1980. 19p.

Bryant, F. C., M. M. Kothman and L. B. Merrill. Diets of sheep, angora goats, Spanish goats, and white-tailed deer under excellent range conditions. J. Range Manage. 32:412-417; 1979.

Campbell, B. H. and R. Remington. Bighorn use of artificial water sources in the Buckskin Mountains, Arizona. Desert Bighorn Council, Trans. 1979:50-56; 1979.

Caughley, G. Analysis of vertebrate populations. New York: John Wiley and Sons; 1977. 200p.

Cronemiller, F. P. and P. S. Bartholomew. The California mule deer in chaparral forests. Calif. Fish and Game 36:343-365; 1950.

DeForge, J. R. Ecology, behavior, and population dynamics of desert bighorn sheep, Ovis canadensis nelsoni, in the San Gabriel Mountains of California. Unpubl. M.S. Thesis, California Polytechnic State Univ., Pomona; 1980. 133 p.

Egler, F. E. Wildlife habitat management, and deer. Ecology 55:684-685; 1974.

Foreyt, W. and D. A. Jessup. Fatal pneumonia of bighorn sheep following introduction of domestic sheep. J. Wildl. Dis.: submitted; 1981.

Geist, V. Mountain sheep. Chicago, Ill.: Univ. Chicago Press; 1971. 383 p.

Gibbens, R. P. and A. M. Schultz. Manipulation of shrub form and browse production in game range improvement. Calif. Fish and Game 48:49-64; 1962.

Gill, A. M. Plant traits adaptive to fires in Mediterranean land ecosystems. In: Mooney, H. A.; Conrad, C. E., tech. coords. Proc. Symp. Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U. S. Dep. Agric.: 1977; Gen. Tech. Rep. W0-3:17-26.

Green, L. R. Fuel reduction without fire--current technology and ecosystem impact. In: Mooney, H. A.; Conrad, C. E., tech. coords. Proc. Symp. Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1977a; Gen. Tech. Rep. WO-3:163-171.

Green, L. R. Fuelbreaks and other fuel modification for wildland fire control. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1977b; Agric. Handb. 499. 79 p.

Holl, S. A., V. C. Bleich, B. Rios and M. Brayton. San Gabriel bighorn sheep project, annual report. San Bernardino, Calif.: Forest Serv., U.S. Dep. Agric.: San Bernardino Nat. Forest; 1980. 42 p.

Jessup, D. A. Pneumonia in bighorn sheep: effects on populations. Cal-Neva Wildl., Trans. 1981: in press; 1981.

Leisz, D. R. and C. C. Wilson. To burn or not to burn: fire and chaparral management in southern California. J. For. 78:94-95; 1980.

Light, J. T. and R. A. Weaver. Report on bighorn sheep habitat studies in the area for which an application was made to expand the Mount Baldy facility. San Bernardino, Calif.: Forest Serv., U.S. Dep. Agric.: San Bernardino Nat. Forest; 1973. 39 p.

Longhurst, W. M. and G. E. Connolly. The effects of brush burning on deer. Cal-Neva Wildl., Trans. 1970:139-155; 1970.

Longhurst, W. M., G. E. Connolly, B. M. Browning and E. O. Garton. Food interrelationships of deer and sheep in parts of Mendocino and Lake counties, California. Hilgardia 47:191-247; 1979.

Longhurst, W. M., E. O. Garton, H. F. Heady and G. E. Connolly. The California deer decline and possibilities for restoration. Cal-Neva Wildl., Trans. 1976:74-103; 1976.

Longhurst, W. M., A. S. Leopold and R. F. Dasmann. A survey of California deer herds. Sacramento, Calif.: California Dep. Fish and Game: 1952; Game Bull. 6. 136 p.

Lyon, L. T., and others. Effects of fire on fauna. Washington, D. C.: Forest Serv., U.S. Dep. Agric.: 1978; Gen Tech. Rep. WO-6. 41 p.

Menke, J. W. and R. Villasenor. The California Mediterranean ecosystem and its management. In: Mooney, H. A.; Conrad, C. E., tech coords. Proc. Symp. Environmental Consequences Fire and Fuel Management in Mediterranean Ecosystems. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U. S. Dep. Agric.: 1977; Gen. Tech. Rep. WO-3:257-270.

Newell, L. A. Managing chaparral. San Diego, Calif.: Forest Serv., U.S. Dep. Agric.: Cleveland Nat. Forest; 1979. 55 p. + appendices.

Peek, J. M., R. A. Riggs and J. L. Lauer. Evaluation of fall burning on bighorn sheep winter range. J. Range Manage. 32:430-432; 1979.

Philpot, C. W. Fire dynamics in chaparral. Cal-Neva Wildl., Trans. 1979:102-103; 1979.

Riggs, R. A. and J. M. Peek. Mountain sheep habitat-use patterns related to post fire succession. J. Wildl. Manage. 44:933-938; 1980.

Roby, G. A. and L. R. Green. 1976. Mechanical methods of chaparral modification. Washington, D.C. Forest Serv., U.S. Dep. Agric.: 1976; Agric. Handb. 487. 46 p.

Salwasser, H., J. C. Capp, H. Black, Jr., and J. F. Hurley. The California wildlife habitat relationships program: an overview. In: DeGraff, R., tech. coord. Proc. Workshop Management Western Forests and Grasslands for Nongame Birds. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen Tech. Rep. INT-86:369-378.

Scotter, G. W. Management of wild ungulate habitat in the western United States and Canada: a review. J. Range Manage. 33:16-27; 1980.

Stelfox, J. C. Bighorn sheep in the Canadian Rockies: a history 1800-1970. Can. Field-Nat. 85:101-122; 1971.

Taber, R. D. and R. F. Dasmann. The dynamics of three natural populations of the deer Odocoileus hemionus columbianus. Ecology 38:233-246; 1957.

Taber, R. D. and R. F. Dasmann. The black-tailed deer of the chaparral. Sacramento, Calif.: California Dep. Fish and Game: 1958; Game Bull. 8. 163 p.

Thomas, J. W., tech. ed. Wildlife habitats in managed forests. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1979; Agric. Handb. 553.

Thomas, J. W., H. Black, Jr., R. J. Scherzinger and R. J. Pedersen. Deer and elk. In: Thomas, J. W., tech. ed. Wildlife habitats in managed forests. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1979; Agric. Handb. 553:104-127.

Weaver, R. A., J. L. Mensch, W. Timmerman and J. M. Hall. Bighorn sheep in the San Gabriel and San Bernardino Mountains. Sacramento, Calif.: Calif. Dep. Fish and Game: 1972; Wildl. Manage. Admin. Rep. 72-2. 38 p.

Yoakum, J. W., and others. Habitat improvement techniques. In: Schemnitz, S. D., ed. Wildlife Management Techniques Manual. Washington, D.C.: The Wildlife Society; 1980; 329-403.

Response of Deer to Fuel Management Programs in Glenn and Colusa Counties, California[1]

Bill Thornton[2]

Abstract: Seven years of an active, coordinated, fuel management program on the Mendocino National Forest has led to a 300 percent increase in the deer population, improvement in their condition, increase in their available range and redistribution of populations. It has not led to significant increases in hunter numbers nor serious conflicts with other resource uses of the same area.

Deer are the most numerous and popular big game animal in the State of California, with a reported hunting harvest of 32,377 in 1980. Herd populations statewide have suffered long-term declines since 1954 when a high of 75,602 animals were harvested. This report deals specifically with Columbian blacktail (Cervidae Odocoileus Columbianus) of the Coast Range Mountains of California, not the mule deer species of the Sierra Nevadas and south coast, even though many requirements and management implications are similar.

Glenn and Colusa Counties are located on the western side of the Sacramento Valley, about 100 air miles north of San Francisco. The western parts of the counties are largely public lands, varying from oak-grass foothills at lower elevations through large expanses of chaparral into timber-covered higher mountains. For management reasons, the deer are biologically grouped into what is known as the Alder Springs Herd.

The Alder Springs Herd suffered the same decline in population experienced by most of the herd units statewide. Historically, this Herd annually harvested 1,300 to 1,500 animals during the 1950's and early 1960's, falling steadily to 300 to 400 during the 1970's. Deer need a proper mix of season-long forage, escape and thermal cover, useable water, and a degree of solitude during fawning periods to maintain or increase their populations. By 1970, the Herd Unit was characterized by large stands of over-mature chaparral that had developed from large wildfires of the late 1940's and early 1950's, mature stands of old-age conifers or thickets of sapling-sized conifer regeneration where logging had occurred, and even-aged stands of blue-oak, high-lined through browsing. This habitat situation had developed over time, due primarily to a fire protection policy that has suppressed all fires at the smallest possible acreage and timber policies that allowed slash to accumulate in unnatural amounts and minimized surface disturbance. Such policy inexorably led to old-age stands of vegetation exhibiting little diversity, with occasional large-acreage wildfires that burned intensely.

Most of the local chaparral and timber-related browse species require fire as a rejuvenating part of their life cycles and provide excellent deer forage when young. A large wildfire increases the amount of forage (brush sprouts and forbs) dramatically but sets up a "feast or famine" situation. Animal populations start to rise dramatically after a fire, only to quickly return to previously low levels as the brush species mature, forbs are eliminated by brush, and protein levels decline (3 to 5 years). Also, deer do not have the biotic potential to effectively use all the forage created by the large fire, and finally, forage is only one of the requirements of their life cycle. Mature, heavy stands of vegetation also significantly lower supplies of available water, another important need of all wildlife.

The Department of Fish and Game and the Mendocino National Forest began in 1973 to try to change the essentially unmanaged, custodial situation into an actively managed one. Our goal was to increase overall land productivity and managerial effectiveness, with objectives specifying increased populations of wildlife, more available water, additional cattle grazing and less large wildfires. Today, we actively pursue four programs, always cooperatively on the ground.

Specifically

1. Prescribed burning of chaparral stands, keyed to individual 20-to 50-acre (8-to 10-hectare) burns occurring over a 25-to 30-year rotation. This program has annually treated an average of 2,000 acres (800 hectares) per year since 1973.

2. Prescribed burning of summer dormant perennial grass fuelbreaks and type conversions established within the chaparral type in the late 1950's and early 1960's. This program started in 1978 and treats 500 to 600 acres (200 to 400 hectares) annually, with a rotation (reburn) occurring at 10 years.

3. Underburning of conifer stands with disposal of logging slash.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Unit Manager, California Department of Fish and Game, Willows, California 95988.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

4. Coordination of management activities of other programs, i.e., fuel reduction, timber management, range, recreation, etc. with deer management program objectives.

Deer Response To These Four Programs Has Been As Follows:

1. Deer population, measured through utilization studies and license returns, has increased by approximately 300 percent since 1973 on over half of the herd range (the half that has received the highest level of project work).

2. The condition of the deer has visibly improved. Fawn production has increased; spring fawn survival is high; deer are fat and "clean" with few parasites and even less disease; the average weight per buck taken has increased approximately 20 percent field-dressed; 3 point and better horn classes have increased by 18 percent.

3. Deer ranges have both expanded and modified.

4. There has been an increase in public use of the land.

What has caused these responses? Naturally, the four programs have been responsible, but why? To the best of our ability to measure, specifically:

1. Prescribed burning of chaparral results in a flush of nutritious forage with high protein levels for about 3 years, then returning to levels associated with "old brush", high enough to maintain life but little else. Our small burns, recurring within each watershed each year, build and hold a forage level that is available for the increased populations during the time of each year that it is needed.

2. Prescribed burning of perennial grasses removes dry matter and evidently supplies nutrients for the plant. Available forage doubles the first year and holds for at least 3 years (we don't know how much longer yet; the first grass burns occurred 3 years ago). The ashes also cause the grass to begin growth about two weeks earlier, important for a deer range. Also, we know that a prescribed burn of an annual grass type stimulates and increases filaree and clover, preferred by deer over grass. This also comes earlier, increases deer use per land unit by about 25 percent and is an important early spring feed.

3. The scattered nature of smaller prescribed burns creates maximum edge, but also as importantly, keeps escape cover handy, almost 100 percent available at any time.

4. Each acre (4 hectares) of chaparral burned produces an additional 100,000 gallons (380,000 liters) of water the first year, declining to normal (pre-burn) yield at about 15 years. About half the increase comes as extended season supplies for springs, seeps, and intermittent streams. Water sources increase, in good location to available forage, often including an increase in riparian vegetation, especially important for fawning.

5. Deer populations have moved into treated areas previously unused, even sometimes leaving cultivated fields for improved foothill range. More use is made of transition ranges, saving summer range. Our work has tended to redistribute the increased population, probably an important factor in the low incidence of disease within the Alder Springs Herd.

6. Large wildfires have been kept from the Herd Unit since the start of the programs. This is partially due to recognition of the fact that such fires are not desirable for managing a deer population. Once this is agreed, it is easy for the biologist to support larger first entry burns that do not maximize edge but prioritize protection against the large fire. Second and third entry burns are smaller, serving to maximize edge, water increase, etc. once the overall fire threat is significantly abated via the first entry.

7. Use of, and products from, the land increase. The same area that supports the 300 percent increase in deer, also grazes almost 4 times the original numbers of cattle, sheep and goats for carefully selected periods of the year. Sheep and goats are considered as tools for deer management by the biologist. Research shows that carrying capacity for deer and soil productivity is higher when sheep forage the same area under controlled conditions.

Users get to see more wildlife and we have a hunter success rate calculated at 27 percent. Also, public safety is increased for the users.

The things we knew and have recently learned were embodied in the Alder Springs Deer Herd Management Plan developed in 1979. This Plan deals with both the deer and their habitat and was approved by the Department of Fish and Game and Mendocino National Forest. It describes the existing situation; sets herd goals for numbers, conditions, level of use; analyses what work is needed to reach them; and develops an action plan. A key part of the Plan is Habitat Models describing the condition desired for chaparral and conifer vegetation types. The four programs previously mentioned are some of the ways we seek to reach the agreed Models. The responses we have measured indicate movement toward goals.

HABITAT MODELS PER 1,000 ACRES (400 HECTARES)

Chaparral Vegetation Type - 50 Percent Cover

5 percent thermal (overstory).

25 percent hiding (including chamise If years old),

10 percent fawning in 8 to 10 acre cells (55 percent palatable grass and forbs), 30 percent accessible brush (50 to 70 percent crown closure), and 15 percent dispersed overstory (10 to 30 percent crown closure).

10 percent optional (to be treated on a case-by-case basis toward the limiting factor for that management unit).

Chaparral Vegetation Type-- 50 Percent Forage

10 percent perennial grass and forbs.

15 percent annual grass and forbs.

10 percent oaks (oak and grass type).

15 percent new brush (1 to 3 years).

Chaparral Vegetation Type

Water within one-third mile (.53 kilometers) radius (essentially a non-linear supply situation).

Solitude for the fawning period (starting May 1 at lower elevations, continuing to June 15 at higher elevations).

Mixed Conifer Forest Vegetation Type (includes transition range)

10 percent meadow or glade.

15 percent browse.

15 percent immature timber (shrub, seedlings, saplings).

20 percent open timber (less than 50 percent crown closure).

Closed stand of mature timber (50 to 100 percent crown closure).

Oaks (a minimum of 200 square feet per 40 acres), (18 square meters per 16 hectares).

Water (three sources) (essentially a linear supply situation).

Solitude (June 1 at lower elevations, to July 15 at upper elevations).

In conclusion, 7 years of experience with an active fuel management program has resulted in a significant increase in the deer herd, healthy, larger, animals in better condition, more evenly distributed throughout their natural range. The hunter success rate is high and everyone is pleased with the results to date. An economic analysis based on the 7 years of project costs, compared to values of deer, water, livestock forage and fire suppression savings, shows an 8.1 benefit cost ratio at a 10 percent discount rate.

Equally significant are the things that have not happened. We have not experienced an overwhelming increase in hunters. Serious conflicts with other uses and users have not developed, and finally, the public continues to actively support, and cooperate with the program.

Seasonal Changes in Chaparral Composition and Intake by Spanish Goats[1]

Ahmed E. Sidahmed, James G. Morris, Steven Radosevich, and Ling J. Koong[2]

Abstract: Seasonal changes in utilization of one year regrowth of chaparral by Spanish goats was investigated. Esophageal and fecal samples were obtained during spring, summer and fall of 1979. Preference of Spanish goats was highly directed towards oak (50%) and chamise (30%) in all seasons. Correlation of use and availability indicated that goats may be generalist but select between the dominant species. Tannins were at low concentrations and did not appear to be affecting utilization. Predictive equations for intake and digestibility were derived. Recently burnt chaparral provides a maintenance diet for Spanish goats during spring and summer only.

Browse may contribute a major portion of goat's diet (Davis and others 1974, Wilson and others 1975). Reports on diet selection by goats in different regions of the world (McCammon-Feldman 1980) suggests a great variation in feeding habits of goats in different ecological zones. According to Coblentz (1977) and Kay and others (1980), goats are adaptable mixed feeders rather than browsers.

The objectives of this paper were to study the seasonal variations in intake, digestibility and composition of a recently burnt chaparral community by Spanish goats. Correlations between these variables were examined. The response of consumption to availability and its effect on grazing strategies by goats are discussed.

MATERIALS AND METHODS

Site Description--This study was conducted in a chaparral community burnt June 1978 at Hopland Field Station located on the southeastern part of Mendocino County of the northern coastal area of California (latitude 39°N, longitude 123°W). The climate is mild with rainy winters and dry summers. Mean annual rainfall is 112.0 centimeters.

Immediately after burning, the area (3.2 ha) was enclosed by a deer proof fence. Five 0.20 to 0.26 ha plots were constructed inside the fenced area and one of these (0.26 ha) was chosen to conduct the seasonal study reported in this paper. This plot was dominated by four shrub species and a very thin cover of some grasses and forbs. Initial vegetation composition (% cover) was measured at the beginning of each sampling period using the line-intercept technique as described by Cox (1972). Cover measurements represented the spread of the twigs (with or without leaves) over the soil surface (Table 1). The shrub species in order of dominance during the spring season measurement were chamise (*Adenostoma fasciculatum*), oak (*Quercus dumosa* and few *Q. wislizenii*), manzanita (*Arctostaphylos glandulosa*, and ceanothus (*Ceanothus cuneatus* and *Q. foliosus*).

Forage yield was not measured on the seasonal study plot. The regression of cover on yield (kg DM) measured on four adjacent plots was highly correlated ($P<.001$) and justified our use of cover as an index of availability. Daily temperature means during sampling were 19, 18 and 12°C for the spring, summer and fall periods respectively.

Table 1--Mean percentage cover during spring, summer and fall seasons.

	Spring	Summer	Fall
Oak	10.5	11.7	4.5
Chamise	10.9	11.5	9.2
Manzanita	1.1	1.3	0.5
Ceanothus	1.1	1.4	1.6
Green herb	7.6	0.2	0.4
Dead herb	0	2.5	0
Dead shrub leaves	0	3.6	4.4

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Ph.D. Candidate and Research Assistant, Animal Science Dept., University of California, Davis; Professor of Animal Science and Physiological Sciences, University of California, Davis; Associate Professor of Botany, University of California, Davis; and Research Leader, Production Systems, US Meat Animal Research Center, Clay Center, Nebraska.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Animals and Sampling Procedure

Eight esophageal fistulated Spanish goat wethers (1 to 2 years of age purchased from Southern California and weighing 23.4 ± 2.6 kg) were used in a grazing trial to collect dietary and fecal samples during spring, summer and fall of 1979. Winter grazing trial was not conducted as the site (985 m elevation) was considered unsuitable for grazing activity during the cold months. Prior to sampling, the animals were adapted to the vegetation by grazing for 10 days inside the experimental plots. All animals were drenched for internal parasites at approximately seven week intervals during the study. Daily samples were collected in the following sequence: 15 days in each of the spring and summer seasons (June 4-19 and August 21 - September 4), and for 12 days in fall (October 8-20). The fall trial was terminated 3 days earlier than scheduled because of cold and stormy weather.

Four goats were used for each seasonal study (Table 2). Goats were confined overnight prior to daily fecal collection at 0700 hr which was followed by a 1 to 2 hr collection of esophageal fistula samples. Once diet samples were collected, the fistulae were closed and the goats were left to graze until sunset. Drinking water, salt and dicalcium phosphate were made available *ad libitum* in the holding pen and in the experimental plot.

Table 2--Live weight of goats and sample collection schedule.

Season	Animal #	Sample Count	Live weight (kg) Initial	Live weight (kg) Final
Spring	1	5	20.4	24.0
	2	5	22.9	22.7
	3	5	24.0	24.9
	4	5	24.3	23.8
Summer	4	5	23.4	23.1
	5	4	23.4	23.1
	6	5	28.1	23.6
	7	5	24.0	23.6
Fall	3	4	23.1	16.3
	5	4	25.0	19.0
	7	4	24.5	19.5
	8	4	17.2	15.4

[1]Count: a unit represents compounded average of 3 days collection (feed or feces) by the same animal.

Leaves and twigs of young regrowing green shoots were clipped at the middle of each seasonal grazing period. These clipped samples, together with esophageal samples, were frozen, freeze-dried and ground in a wiley mill (1 mm screen) preparatory to analysis. The fecal samples were oven dried at 55°C and moisture contents were recorded.

Analytical Procedures

Diet samples collected from each animal over a 3-day period were compounded in equal proportions. Rumen contaminated samples were excluded. Five composited dietary samples per goat were obtained to represent spring and summer periods and four samples per goat for the fall (Table 2). From each compounded sample, as well as from the clipped shrubs, microscopic slides were prepared for microhistological identification (Sparks and Malecheck 1968). Use was calculated as the % of each species in fistulae samples on a dry matter basis. Kjeldahl nitrogen (N) was measured by the AOAC (1975) procedure. Esophageal and clipped samples were incubated with rumen liquor collected from a donor goat fed 65% shrub and 35% alfalfa hay feed mixtures in order to estimate *in vitro* digestibility values (Tilley and Terry 1963). Fiber components and tannins were estimated by the sequential detergent system (Van Soest and Robertson 1980). The clipped samples were analyzed similarly, and a further parallel sequential analysis to estimate tannins and cutins was performed based on the method described by Horvath (1980) with modifications of Van Soest (personal communication). Intake (I) was calculated by dividing average daily fecal dry matter output (F) for samples collected in either 3 or 6 days over the apparent indigestible coefficients (Ra) obtained *in vitro* for dietary samples; I = F/Ra. Statistical analyses were performed using the methods described by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Dietary Botanical Composition

Botanical composition of the esophageal samples for each season are shown in Table 3. There was no significant change in dietary preference with seasons (P>.1). Oak comprised over half the diet in all three seasons, followed by chamise (35% of the dry matter). The selective behavior of the goats was examined by correlating use and availability (Nudd 1980, Westoby 1980). Use (% in the diet) for the 4 shrub species was significantly associated (r = .85, P<.005) with availability (Tables 1 and 3). This relationship may imply a generalistic strategy where resources are restricted and fitness is attained by maximizing energy intake (Schoner 1971). Within the esophageal samples there was a reciprocal relationship between oak and chamise (r = -.89, P<.005) as shown in figure 1. Use was poorly associated with availability (r = -.13) when oak and chamise were

Table 3--Mean]. percentage botanical composition of esophageal samples.

Season	Oak	Chamise	Manza-nita	Ceano-thus	Others
Spring	57±4	34±3	1±1	1±1	6±2
Summer	59±4	35±3	3±1	2±1	1±1
Fall	51±4	38±4	6±2	4±1	1±1
Mean of all 3 seasons	56±4	36±3	3±1	2±1	3±1

1 ± SE $\hat{p}$.

considered separately, and preference for oak and chamise coincided with dominance. However, in a previous study (Sidahmed and others 1981a) conducted in southern California, we observed a similar preference for oak and chamise in a plot dominated by manzanita and ceanothus. This suggests that goats exhibit a specialized behavior for oak and chamise.

The herbaceous species were of minor importance both in the plot and in the diet during summer and fall (Tables 1 and 3). In the spring, the diets selected contained about 6% herbaceous species while availability was 7.6%. This finding may suggest that consumption of the herbaceous plants was restricted by availability. But, Westoby (1980) reported that consumption of particular foods was constrained by availability only at cover values below 0.5%.

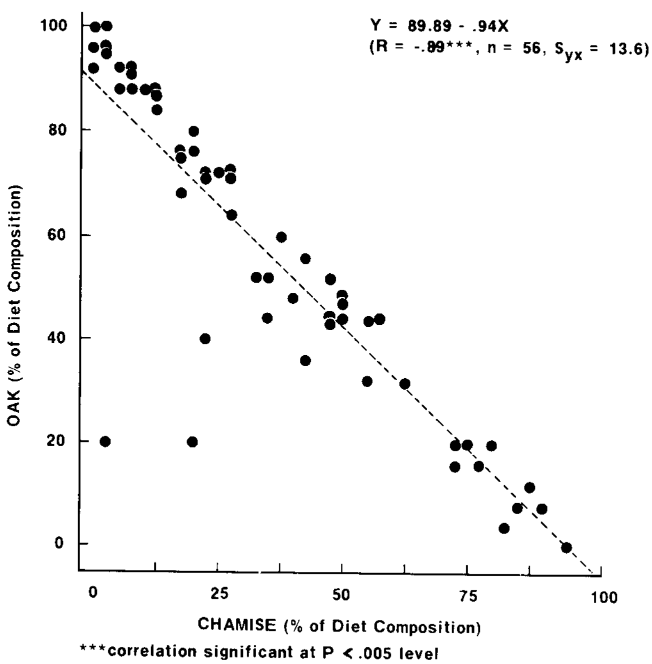


Figure 1--The relationship between the % composition of oak and chamise in esophageal samples collected by goats.

Table 4--Chemical constituents and IVOMD of clipped shrubs.[1]

Chemical constit-uents (%)	Oak	Chamise	Manzani	Ceanothus
CWC	59±4	55±7	41±2	60±4
NAD	42±3	40±4	34±3	46±.9
NADLk	9±.3	8±2	10±1	9±1
Cutin	4±2	7±.8	9±2	7±2
Ash	4±.5	3±.4	3±.4	3±.5
N	1±.4	1±.3	1±.1	1±.2
Tannins	2±.5	4±5	0	2±2
IVOMD	34±5	28±6	30±4	26±5

[1]Means ± SD.

See text below for key to abbreviations.

Nutritional Characteristics of Clipped Shrubs

The chemical composition of the shrubs was estimated from samples clipped during each season. Regression of *in vitro* digestibility (IVOMD) on chemical constituents (Table 4) showed positive and linear relationships with nitrogen (r = .69, P<.05) and ash (r=.77, P<.005). Although there were negative relationships with fiber components for data pooled from all shrub species (r = -.41 to -.56), these relations were not significant. Also, it was observed that the correlation coefficients of fiber components in oak and chamise were greater (r = -.40 to -.67) than in all shrub species. Sequential neutral-acid detergent fiber (NAD) was more closely associated with IVOMD than other fiber components. With herbaceous feeds, Van Soest and others (1978) suggested that acid detergent fiber and lignin depress digestibility more than cell wall content (CWC) or cellulose. Permanganate lignin ($NADL_K$) had an insignificant effect on depression of IVOMD of the shrub samples (r = -.14). However, cutin and sulphuric lignin (NADLs) had a more pronounced association (r = -.41 and -.31, respectively). These correlations suggest that cutin would depress digestibility of shrubs more than true lignin (permanganate lignin). However, Van Soest (1969) suggested on limited data that cutin had a lesser and quantitatively different effect than permanganate lignin on depression of digestibility of sunflower and caster seed hulls.

The difference between acid detergent fiber (ADF) and NAD gives a presumptive estimate of condensed tannins (Van Soest and Robertson 1980). The correlation of ADF-NAD tannins and IVOMD was low for all shrubs and for oak and chamise together (r=.19 and .43, respectively).

Comparison of clipped versus esophageal samples showed that goats selected a diet higher in digestibility (22-39 versus 39-47%) and N (1 versus 1.47%) than the clipped samples (Tables 4 and 5). However, the association of N with digestibility was higher for clipped samples and fall diets (r = .69 and .77) than spring and summer diets (r = .43 and .25, respectively). This indicates either -a N limiting effect on digestibility or the high correlation of N with plant age.

Seasonal Changes in Intake and Digestibility

No significant difference (P>.05) was observed between intake values estimated from average fecal output of 3 or 6 days. Therefore, intake values based on calculations using 3 days fecal excretion were used throughout the following discussion. Animal-season interactions could not be determined by two-way analysis of variance because of missing cells resulting from replacing goats during the study (Table 2). Therefore, the variation between animals within each season was examined first. From 13 parameters (IVOMD, intake, N, tannins, CWC, NAD, NADC, $NADL_S$, NADHC, $NADL_S$:NAD, ash and fecal moisture), there were significant differences between animals in intake during spring and fall (P<.05, P<.001, respectively) but not in summer. Also, different animals consumed diets containing different N levels (P<.05) in summer, and cellulose (P<.05) in the fall. It was assumed that between-animal variation was not significant except for intake.

Table 5--Percentage dietary chemical constituents, in vitro organic matter digestibility (IVOMD) and fecal moisture content.[1]

Dietary constituents (%)	Spring n=20	Summer n=20	Fall n=16	All seasons n=56
IVOMD	47 ± 3[a]	44 ± 6[a]	39 ± 5[b]	43 ± 6
Intake	60 ± 17[a]	57 ± 11[ab]	36 ± 11[c]	52 ± 17
N	1.8 ± .2[a]	1.4 ± .2[b]	1.2 ± .2[c]	1.5 ± .3
Tannin (ADF-NAD)	1 ± 1[a]	2 ± 2[a]	3 ± 2[a]	2 ± 2
CWC	46 ± 3[a]	48 ± 4[a]	50 ± 6[a]	48 ± 4
NAD	31 ± 2[a]	34 ± 3[a]	36 ± 4[b]	34 ± 4
NADC	18 ± 2[a]	19 ± 3[a]	19 ± 3[a]	18 ± 2
NADLs	11 ± 1[a]	12 ± 1[ab]	15 ± 3[c]	13 ± 2
NADHC	15 ± 2[a]	14 ± 1[a]	15 ± 2[a]	14 ± 2
NADLs : NAD	36 ± 4[a]	34 ± 2[a]	37 ± 3[b]	35 ± 4
Ash	10 ± 1[a]	9 ± 4[a]	8 ± 3[a]	9 ± 3
Fecal Moisture	45 ± 2[a]	46 ± 2[a]	46 ± 4[a]	45 ± 3

[a,b,c,] Means with different superscripts are significantly different (P<.05 - P<.001).

[1] ± SD.

Seasonal means of intake, digestibility and chemical composition of diet samples, and results of the paired t-test comparisons are summarized in Table 5. Daily feed intake (g $DM/BW^{.75}$) during spring and summer was significantly (P<.005, P<.01, respectively) higher than during fall. Spring and summer intakes (Table 5) were comparable to the NRC (1975) requirements for sheep, and to recorded values for Spanish goats in a digestion trial (Sidahmed and others 1981b). The reduction in intake from 2.7% of body weight during spring and summer to 1.7% during the fall period was reflected in more than 20% decline in live weight (Table 2). Similarly, IVOMD and N in esophageal samples declined from 47% in the spring to 39% in the fall and from 1.76% to 1.23%, respectively. Also, there was a significant increase in $NADL_S$ of diet samples as seasons advanced. It was suggested that decreasing N and increasing lignin-cutin levels in browse as it matures would contribute to reduction in its utilization by goats. These results agree with conclusions reported by Smith and others (1971) that cellulose availability and rate of cell wall digestion were adversely affected by increase in forage lignin concentrations. There was a nonsignificant increase in dietary ADF-NAD tannins between spring, summer and fall. However, tannins levels were generally low (2%).

Browse Characteristics Related to Intake and Digestibility

Dietary fiber components (CWC, NAD, NADC, $NADL_S$, NADHC, and $NADL_S$:ADF ratio), tannins, N, fecal moisture content and mean daily temperature were regressed against intake and digestibility individually (Table 6) and combined in a stepwise analysis.

Predictive equations obtained for intake (DMI) and digestibility (IVOMD) were:

1. $\widehat{DMI} = -25.67 + 1.80\ IVOMD$
   $(n=56,\ S_{yx} = 17.72,\ r = .59,\ P<.005).$

2. $\widehat{IVOMD} = 56.98 - .46\ CWC - .45\ NADL_S + .65\ N + .09\ DMI$
   $(n = 56,\ S_{yx} = 2.77,\ r = .88,\ P<.005).$

The correlation between digestibility and intake was significant when all data points (n=56) were considered (equation 1). However, when intake and digestibility were regressed individually for each season (Table 6 and Figure 2) the coefficients varied. Intake and digestibility were poorly related in the spring (r=.13), but significantly related in summer (r=.73) and fall (r=.45). It was reported by Lippke (1980) that only when digestibility is closely correlated with factors limiting intake (for example CWC) will it show a high relationship to intake. In this study, digestibility was weakly correlated with fiber components during the spring and highly correlated during

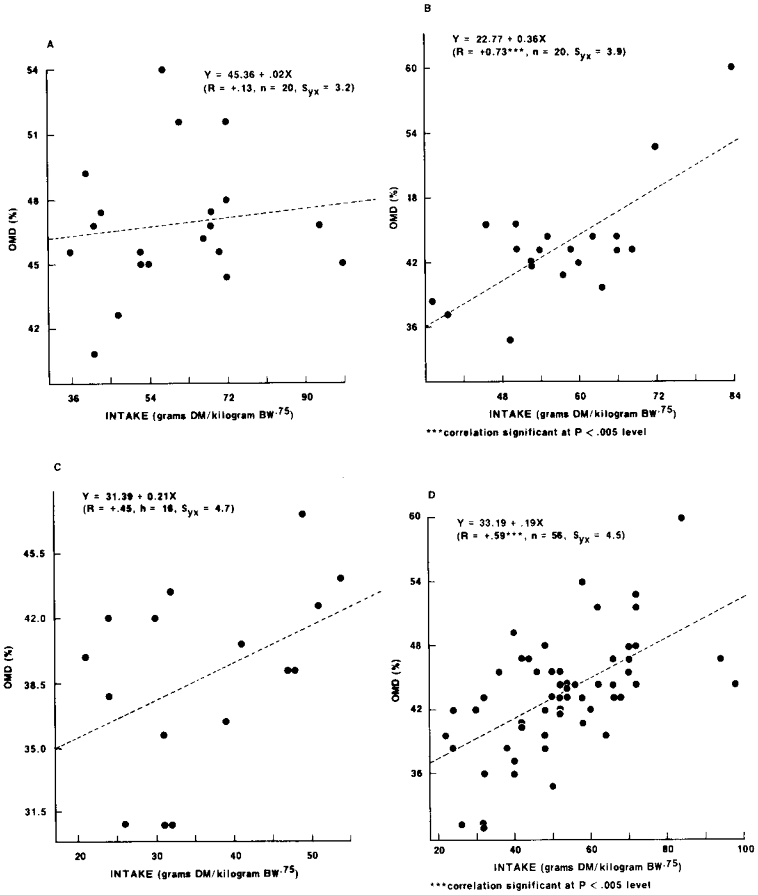


Figure 2. The relationships between digestibility (IVOMD) and intake (a = spring, b = summer, c = fall and d = pooled data points for all three seasons).

summer and fall. The effect of N on digestibility was more significant during fall season and on intake during spring season. The contribution of CWC, $NADL_S$, N and intake to the variation in digestibility of browse diets was 77% (equation 2).

The effect of dietary ash on intake and digestibility was not significant. This contrasted to the strong relationship between ash and digestibility of clipped samples (r=.77, p<.005). The correlation between intake or digestibility with temperature was positive (r=.30 and .66, respectively) but not significant. The decline in temperature from 19°C in spring to 12°C in the fall depressed digestibility more than intake. The decline in temperature during the fall was accompanied by storms which restricted the browsing and selection by the goats.

ADF-NAD tannins were poorly correlated with intake (Table 6) and did not exhibit a pronounced effect on digestibility except during the fall (r=-.66, P<.01). In vitro digestibility studies indicated that digestibility was inhibited at tannin levels above 4% (Mika 1978, Horvath 1980). Therefore, low levels of tannin as reported in the present study (2%) would not likely be responsible for the low IVOMD values of the immature shrub diets. The fecal moisture contents were comparable in all seasons (Table 5) and correlated poorly with intake (Table 6). Similarly, no significant relationship was found between digestibility and fecal moisture. This was in contrast to that reported by Zimmerman (1980) who concluded that high fecal moisture reflects better dietary quality of grazing cattle.

In conclusion, it is suggested that recently burnt chaparral vegetation would provide only a maintenance diet for goats during spring and summer and a submaintenance diet during fall.

ACKNOWLEDGEMENTS

This research comes from a doctoral dissertation for the Department of Animal Science at the University of California, Davis. Partial support was provided by research grants from the Chaparral R&D Program, USDA, Forest Service, and the Institute of Ecology, UCD (OPER-4791). Appreciation is extended to Mr. Al Murphy, Superintendent, Hopland Field Station, for generous assistance and for performing the prescribed burning for the study site. Mr. Norman Hinman helped in statistical analysis, and Mr. John Bryan in laboratory analysis.

Table 6--Relationship between *in vitro* organic matter digestibility (IVOMD), intake and dietary chemical constituents and fecal moisture content.

Dietary constituent (%)	% IVOMD All seasons n=56	Intake ($g/w^{.75}$) All seasons n=56
IVOMD	1.00	.59***
Intake	.59***	1.00
N	.65***	.26
Tannins (ADF-NAD)	-.50***	-.20
CWC	-.74***	-.45***
NAD	-.75***	-.49***
NADC	-.54***	-.29*
NADL	-.75***	-.46***
NADHC	-.43***	-.18
NADLs:NAD	-.24*	-.17
Ash	.15	.15
Fecal Moisture	-.19	.05

*, **, *** Correlations significant at P<.05, P<.01, P<.005 levels, respectively.

LITERATURE CITED

A.O.A.C. Official method of analysis. 12 Edition. Association of Official Agricultural Chemists. Washington, D.C.; 1978.

Coblentz, B. E. Some range relationships of feral goats on Santa Catalina Island, California. J. Range Manage 30:415-419; 1977.

Cox, G. W. Laboratory manual of general ecology. 2nd Edition. Dubuque: Wm. C. Brown; 1972:45-49.

Davis, G. G.; Lawrance, E. B.; Cook, C. W. Control of gamble oak by goats. J. Range Manage. 28:216-218; 1974.

Horvath, P. J. The nutritional and ecological significance of Acer-tannins and related polyphenols. M.S. Thesis. New York: Cornell University; 1980.

Kay, R. N. B.; Engelhardt, W. von; White, R. G. The digestive physiology of wild ruminant. *In*: Buckebusch, Y.; Thivend, P., eds. Proc. Vth Int. Symp. Ruminant Physio. Lancaster, England: MTP Press Ltd. Falcon House; 1980: 743-758.

Lippke, H. Forage characteristics related to intake, digestibility and gain by ruminants. J. Anim. Sci. 50:952-961; 1980.

McCammon-Feldman, B. A critical analysis of tropical savanna forage consumption and utilization by goats. Ph.D. Thesis. University of Illinois, Illinois; 1980.

Mika, V. CSc. The influence of some antiquality components on the digestibility of forages *in vitro*. *Scientia Agriculturae Bohemoslovaca Tomus* 10(XXVII), No. 1:33-40; 1978.

NRC. Nutrient requirements of Domestic Animals. No. 5. Nutrient Requirements of Sheep. Fifth Edition. National Academy of Science. National Research Council, Washington, D.C.; 1975.

Nudd, D. T. Forage "preference": Theoretical considerations of diet selection by deer. J. Wildl. Manage. 44:735-740; 1980.

Schoener, T. W. Theory of feeding strategies. Annual Rev. of Ecol. and Systematics 2:369-404; 1971.

Sidahmed, A. E.; Morris, J. G.; Radosevich, S. R. Summer diet of Spanish goats grazing chaparral. J. Range Manage. 34:33-35; 1981a.

Sidahmed, A E.; Morris, J. G.; Koong, L. J.; Radosevich, S. R. The contribution of three chaparral shrubs to the protein and energy requirements of Spanish goats. J. Anim. Sci.; 1981b. (submitted).

Smith, L. W.; Goering, H. K.; Waldo, D. R.; Gordon, C. H. *In vitro* digestion rate of forage cell wall—components. J. Dairy Sci. 54:71-76; 1971.

Sparks, D. R.; Malecheck, J. C. Estimating percentage dry weight of diets using a microscopic technique. J. Range Manage. 21:264-265; 1968.

Steel, R. G. D.; Torrie, J. H. Principles and Procedures of Statistics. New York: McGraw-Hill Book Co.; 1960.

Tilley, J. M. A.; Terry, R. A. A two-stage technique for *in vitro* digestion of forage crops. J. British Grassl. Soc. 18:104-111; 1963.

Udén, P. Comparative studies on rate of passage, particle size, and rate of digestion in ruminants, equines, rabbits and man. Ph.D. Thesis. New York: Cornell University; 1978.

Van Soest, P. J. 1969. The chemical basis for the nutritive evaluation of forages. Proc. of the National Confr. on Forage Quality Evaluation and Utilization. Univ. Nebraska, Lincoln.; p. U1-U19.

Van Soest, P. J.; Mertens, D. R.; Deinum, B. Preharvest factors influencing quality of conserved forages. J. Anim. Sci. 47:712-720; 1978.

Van Soest, P. J.; Robertson, J. B. Systems of analysis for evaluating fibrous reeds. *In*: Pigden, W. J.; Balch, C. C.; Graham, M., eds. Standardization of Analytical Methodology for Feeds. Pub. 1DRC-134e, Internal Develop. Res. Cent., Box 8500, Ottawa, Canada, K1G 3H9; 1980; 49-60.

Westoby, M. Black tailed jack rabbit diets in Curlew Valley, Northern Utah. J. Wildl. Manage. 44:942-948; 1980.

Wilson, A. D.; Leigh, J. H.; Hindley, N. L.; Mulhan, W. E. Comparisons of the diets of goats and sheep on a *Casuarins cristatta Heterodendrum oleifolium* woodland community in Western N.S. Wales. Aust. J. of Exp. Agr. and Anim. Husb. 15:45-53; 1975.

Zimmerman, I. Predicting diet quality from measurement of nitrogen and moisture in cattle dung. S. Afr. J. Wildl. Res. 10:56-60; 1980.

Angora Goats for Conversion of Arizona Chaparral: Early Results[1]

O. D. Knipe[2]

Abstract: Use of goats to convert chaparral to brush-grass to increase water and forage may be an alternative to chemical and mechanical means. Results indicate that trampling of grass seed by goats in burned-over chaparral promotes germination and establishment. Because shrubs constitute a large percentage of the goats' diet, sprouting is retarded. Goats prefer about the same shrub species as other domestic livestock and big game herbivores. Since goats relish young grasses, areas must be protected during grass establishment.

This study is part of the Rocky Mountain Forest and Range Experiment Station program researching methods of effective, economical, and environmentally safe methods of converting chaparral to brush-grass mosaics.

Research over the last quarter century has shown that conversion of Arizona chaparral to grass significantly increases water and forage yields, reduces fire hazard, and may increase wildlife values (Hibbert et al. 1974).

Total rainfall and its distribution throughout the range of Arizona chaparral is adequate for establishment of seeded grasses. Precipitation ranges from 16 to 30 inches annually, with about 55 percent falling primarily from November through April and the remaining 45 percent from May through October (mostly during the growing season from July through September). However, to date, the only entirely effective and environmentally acceptable means of controlling shrubs and promoting grass establishment is the root plow. Its use is limited to less than 8 percent of the chaparral acreage because of rugged topography and the rocky character of soils. Fire is effective for opening up mature stands, but the only important shrub species killed are manzanita (Arctostaphylos pringleii and A. pungens) and desert ceanothus (Ceanothus greggii), and germination of their seeds is stimulated by fire. The major dominants, shrub live oak (Quercus turbinella) and mountain mahogany (Cercocarpus betuloides and C. breviflorus), sprout vigorously and regain dominance before herbaceous plants can become established. Foliage spray herbicides[3] of the phenoxy group, such as 2,4-D,2,4,5-T, and silvex and mixtures thereof, have been used, but they do not provide adequate control without several successive annual applications. Soil-applied herbicides previously tested, such as fenuron, picloram, and karbutilate, are potent brush killers but, being nonselective, they are also toxic to, and may delay establishment of, herbaceous plants. Even when shrubs are controlled by herbicides, grass establishment requires several years because it is not possible to plant the seeds. The terrain is too rugged and rocky for use of conventional seedbed preparation and seed planting equipment. Thus, conversion by techniques presently in use leaves much to be desired.

In view of the foregoing, and since public concern about environmental quality has become a powerful force in resource management, we need more efficient, economical, and environmentally safe methods for conversion of chaparral.

Following prescribed burning and seeding, browsing with goats to trample seeded grasses into the soil and to retard recovery rate of the sprouting shrubs might be an effective tool for use in chaparral conversion. If goat use will hold the shrubs in check until a grass cover that will carry fire becomes established, the conversion can be maintained by periodic prescribed burning, or possibly by continued goat browsing.

The objective of this study is to determine if prescribed burning, seeding, and goat browsing in the fall can be a useful tool for conversion of Arizona chaparral.

PRIOR RESEARCH

Goats are primarily browsers and, given a choice, prefer woody species, as studies in East Africa (Wilson 1957), Texas (Fraps and Cory 1940, McMahan 1964), and Australia (Wilson et al. 1975; Wilson, Mulham, and Leigh 1976) have shown. In Mexico, Carrera (1971) observed 1,728 goat bites and found 83 percent browse and forbs and 17

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2] Range Scientist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station located at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University. Headquarters is in Fort Collins, in cooperation with Colorado State University.

[3] The herbicides discussed in this report have been used experimentally; their use does not imply that they are recommended or registered for watershed use. The use of any herbicide for project or commercial purposes must conform with regulations of the Environmental Protection Agency and be registered for the intended use.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

percent grass bites. Huss et al. (1970) and Zertuche (1970) noted that goats preferred browse even when there was an abundance of grass. Wilson, Mulham, and Leigh (1976) found that goats show a definite preference for certain shrubs and tree leaves over others.

"Goats eat a wider range of available vegetation than do sheep and should make better use of the vegetation as a whole. At the same time the quality of their diet is equivalent to that of sheep so that the greater production from the land should be obtained from goats than sheep. It is clear that the effect of goats on the woody species in a community will be dependent on the acceptability to goats of the particular species present. Some will be controlled and, depending on species composition, possibly eliminated while others may be relatively untouched and become more dominant" (Wilson et al. 1975).

Fraps and Cory (1940) found that cattle fed on the smallest numbers of different kinds of plants, sheep on a somewhat larger variety, while the diet of goats was quite diversified.

Davis, Bartel, and Cook (1975) used goats to control Gambel oak (Quercus gambelii) sprouts in Colorado and observed that "the goat diet was usually composed of over 85 percent oak leaves, about 10 percent forbs, and 5 percent grasses" (no values regarding relative species composition were given). However, another research study indicated that goats consumed large portions of grass and forbs and that Spanish goats consumed significantly less grass and more browse than angora goats (Taylor 1975).

Because many food habit studies failed to determine relative forage availability, it is not possible to state with certainty whether a particular class of forage was used because of preference or because little or no other kinds were available. Malechek and Leinweber (1972) measured botanical composition of angora goats' diets and the forage available for consumption; they found that grass was the major class of forage consumed during the growing season (June to mid-October). The proportion of browse in diets increased rapidly in late October and November, and remained relatively high through May (greatest use of browse was from mid-March to mid-April). Although Malechek and Leinweber (1972) did not say this, it is likely that the peak in browse use corresponded with the period of initiation of shrub shoot growth and the period prior to initiation of grass growth.

Du Toit (1972) investigated the role of goats in controlling sprout regrowth after sprouting had begun, following chopping of shrubs in a brush-grass community (no data was presented on composition of the stand). The time goats spent browsing shrubs was about equal to the time they spent grazing grass. Basal cover of grass increased significantly in the 3-year period, and shrub regrowth was negligible. Cattle-carrying capacity was greater than in similar areas grazed by sheep, where shrub regrowth was double that in the goat use pastures.

In a study within the Edwards Plateau region of Texas, Bryant et al. (1979) found that goat diets were nearly equal in percent grass and browse consumed.

STUDY AREA

The study area is a 210-acre exclosure (roughly 3,000 square feet) located on the Tonto National Forest, 10 miles northeast of the town of Payson, Arizona. This area was selected because of accessibility, the presence of permanent water, and the dominance of a mature stand of shrub live oak-mountain mahogany--the most widespread and dominant associate of the Arizona chaparral (Knipe et al. 1979). Other important shrub species common to the type are also represented, such as manzanita, desert ceanothus, yellowleaf and Wright silktassel (Garrya flavescens and G. wrightii), skunkbush (Rhus trilobata), sugar sumac (R. ovata), hollyleaf buckthorn (Rhamnus crocea), and cliffrose (Cowania mexicana). Average annual precipitation at Payson (elevation 5,000 feet) is 21 inches; the study area is 300 to 800 feet higher so it is likely that annual precipitation is about 23 inches.

Elevation gradually rises from 5,300 feet at an east west channel near the southern boundary to 5,800 feet at the crest of Diamond Rim at the north boundary (fig. 1). There is a north slope comprising about 20 acres (10 percent of the area) south of the main channel, and about 190 acres (southerly exposure) above and north of the channel. This area is dissected north to south

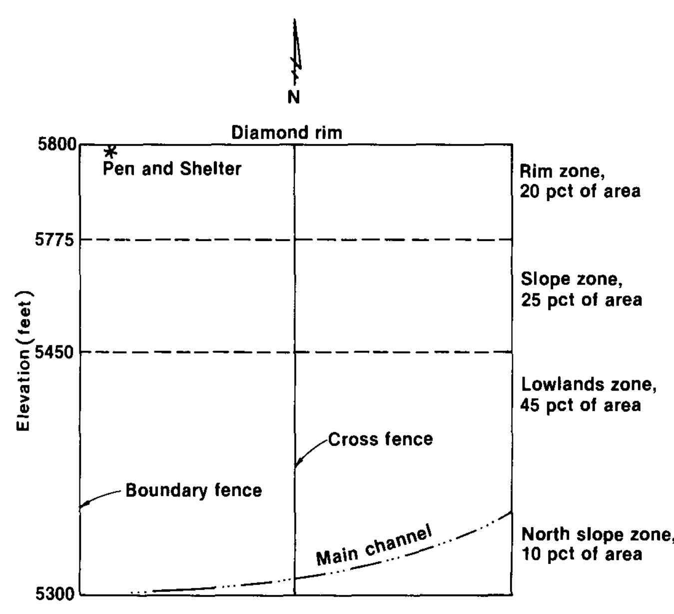


Figure 1--Schematic description of study area (not to scale).

by several branch channels which flow into the main east-west channel. The 20-acre north slope is shrub live oak-mountain mahogany, with sparse Wright silktassel. Mountain mahogany dominates the higher elevation (rim zone), but sparse shrub live oak and Wright silktassel are also present. This zone comprises about 20 percent of the total acreage.

Elevation decreases rapidly from the rim through an intermediate elevation zone of shrub live oak-mountain mahogany with sparse Wright silktassel, sugar sumac, and skunkbush. This intermediate zone comprises about 25 percent of the area.

Between the base of the rim slope and the channel is a lowland zone, ranging in elevation from 5,300 feet at the main channel to 5,450 feet at the base of the rim slope. This zone is shrub live oak-mountain-mahogany; manzanita is codominant in a few small pockets, and Wright silktassel, sugar sumac, and skunkbush are sparsely scattered throughout. The main channel is occupied by pine (*Pinus ponderosa*), Emory oak (*Quercus emoryi*), and walnut (*Juglans major*), with a sparse mixed shrub understory.

PROCEDURES

Starting from a random sample point, four permanent sample lines were established at 600-foot intervals across the area (upslope to downslope). Cover percentages (total and by individual shrub species) were determined by 100-foot intercept segments along these lines in September 1979 and again in 1980. Percent of individual species utilized was determined along the intercept lines at regular intervals for several weeks after introduction of the goats by:

1. Selecting a random number between 1 and 100 for each 100-foot segment of each line.
2. Beginning at the random point, tallying the first 10 plants of each species as browsed or not browsed.

The height of the tallest sprout of each plant sampled for utilization was also noted.

At the end of the growing season (Sept. 30, 1980), the percent biomass removed by goat browsing was estimated visually. The area had been burned the first week of October 1979, which was a departure from the norm since controlled burning in the Arizona chaparral had always before been conducted in the spring. The area was burned in the fall this time because

1. Winter rains are cyclonic in nature (low intensity, long duration) and are less apt to result in erosion of the freshly bared soil than would convectional summer storms which are of short duration and high intensity. Summer rains typically result in 1-1/2 inches precipitation in 15 minutes.
2. Burning of chaparral imparts a hydrophobic property to the soil which restricts infiltration. This property may be less detrimental in the winter because the precipitation is less intense, and trampling by goats, chemical, microbial, and root activity, leaching, and freezing and thawing prior to the start of the summer rains may dissipate the hydrophobic layer.

The burn eliminated top growth over 80 percent of the area, leaving 20 percent in a mosaic pattern for wildlife cover and esthetic purposes. The main channel is dotted with large ponderosa pine, Arizona walnut, junipers (*Juniperus monosperma*, *J. deppeana*, *J. osteosperma*, *J. scopulorum*) and Emory oak trees which were retained for wildlife habitat.

The area was broadcast seeded with weeping lovegrass (*Eragrostis curvula*) in the fall immediately after burning, at a rate of 1 pound pure live seed per acre.

The area was fenced with a seven-wire electric fence which uses smooth, 12-1/2 gauge wire, and fiberglass posts. The fence is operated by a 12-volt wet cell battery (charged by a solar cell) attached to a high-powered low-impedance energizer which pulsates a 5,000-volt current 60 times per minute; each pulse lasts 3/10,000ths of a second. The fence is designed not only to keep livestock in but to keep predators out. Wires are spaced close together near the ground and increasingly further apart toward the top. The height of the fence was limited to 54 inches so that deer and elk movement into the area was not restricted. A 200-foot strip was left outside the grazed area for measuring shrub recovery without grazing.

In an attempt to preclude overuse and because of problems that would be present if numbers had to be reduced, approximately one goat unit per acre was decided upon as the stocking rate. In June, 242 angora wethers[4] were introduced into the area. Wethers are being used for three reasons. First, kidding is a highly specialized operation; second, wethers are larger than nannies and less susceptible to predation; and third, if wethers were to escape, they would be unable to establish a self-perpetuating feral population.

The plan was to burn, seed, and, when the shrubs had started to sprout, introduce goats to trample the grass seed into the soil and suppress shrub growth through browsing. It was anticipated that the young, tender, and presumably palatable shrub sprouts would be preferred over establishing grasses. Three weeks after their

[4]Of the 242 wethers, 42 were 3 years of age and equal to 1 goat unit each, 100 were 2-year olds considered 0.90 goat units each, and 100 were yearlings considered 0.75 goat units each, so that the area was stocked with 217 goat units.

introduction, when grasses were beginning to grow, the goats were eating or pulling up a high percentage of grass seedlings. The area was immediately divided into two 105-acre pastures and the goats were kept in one pasture until the end of the growing season. Thus, this pasture was used from June 11 to November 1, 1980. Except for the period from June 11 to July 1, the other pasture was deferred during the 1980 summer growing season.

A fair stand of grass resulted in the summer-deferred pasture; at the end of the growing season (about November 1, 1980), after the grasses had matured and set seed, the goats were moved to this pasture. This summer-deferred pasture will be grazed until about June, at which time the summer 1980 grazed pasture will be seeded and the goats put in it long enough to trample the seeds into the soil. When the summer rains start, the herd will be removed from the experimental area for the duration of the 1981 growing season.

RESULTS AND DISCUSSION

Shrub Response

The heaviest used shrubs during the first 16 days after introduction of the goats were shrub live oak, sugar sumac, and skunkbush (table 1). Heavy use of the palatable skunkbush was expected, but it was also expected that the goats would take mountain mahogany and Wright silktassel more readily than shrub live oak and sugar sumac.

During the first 3 weeks of use, the values were estimated, with the exception of sugar sumac, to also be representative of percent biomass removed. A high percentage of the plants of this species were browsed, but only the tips of the sprouts were taken so that very little biomass was removed (table 1). The use pattern had changed by the fourth week after introduction of the goats; by this time the use of mountain mahogany had increased and was being heavily used both with respect to percentage of plants and biomass removed. Heavy use of the relatively palatable Wright silktassel did not occur until about 2 months after introduction of the goats. Thereafter, use of this species was about equal to that of mountain mahogany. The reasons for the relatively heavy use of shrub live oak and light use of mountain mahogany and silktassel during the first few weeks may be these:

1. Mountain mahogany and Wright silktassel do not grow in Texas and they were new to the goats.
2. Mountain mahogany and Wright silktassel growth had started earlier in 1980 than shrub live oak, and they may have been somewhat coarser by June when the goats were introduced.
3. During the first 3 weeks after introduction, the goats concentrated in and grazed a strip about 100 yards wide across the area along the base of the rim (fig. 1). Vegetation within this zone is predominantly shrub live oak.

Number 3 above is probably the best explanation although number 2 may also have some merit.

Table 1--Percent of important plant species browsed (Summer 1980)

	Species										
	Shrubs					Forbs		Half shrubs		Grass[1]	Tree
Date	Shrub live oak	Mtn.-mahog.	Wright silk-tassel	Sugar sumac	Skunk-bush	Lambs-quarter.	Morning glory	Snake-weed	Rough meno-dora		Juni-per
6/1/80[2]	0	12	14	0	0	45	41	0	0	25	0
6/11/80	Goats introduced										
6/19/80	29	18	16	T	13	70	80	0	0	50	10
6/27/80	82	55	26	75	83	100	90	0	0	85	10
7/8/80	93	89	59	98	100	100	100	20	0	93	23
7/23/80	95	93	60	99	100	100	100	68	10	98	38
8/8/80	100	100	90	100	100	100	100	90	15	100	62
8/20/80	100	100	100	100	100	100	100	92	20	100	73
9/30/80	100	100	100	100	100	100	100	100	30	100	100
Percent biomass[3] reduction	60	80	75	10	80	95	90	40	20	95	15

[1]Primarily weeping lovegrass with traces of native sideoats grama (Bouteloua curtipendula), red threeawn (Aristida longiseta), and squirreltail (Sitanion hystrix).

[2]Prior to introduction of goats; deer and elk use.

[3]Visually estimated on 9/30/80.

Species preferences described above, for the pasture used during the summer, appeared to be the same when the goats were turned into the summer-deferred pasture in November, the only exceptions being that the dry grass and forbs were not used as heavily as during the growing season.

The palatable forbs--lambsquarter (Chenopodium album) and morning glory (Ipomea hirsutula)--and grass were all heavily used during the growing season.

Of the two important half shrubs in the area, snakeweed (Xanthocaphalum sarathrae) and rough menodora (Menodora scabra), snakeweed received the heaviest, though only moderate, use. The relatively light use of rough menodora is surprising as this species is relished by deer, elk, and cattle; it was anticipated that it would be highly palatable to goats.

Juniper was taken readily by the goats, but actual removal of foliage is light (table 1) because most is out of reach of the animals.

Percent reduction in height of the three most important shrub species (shrub live oak, mountain-mahogany, and Wright silktassel) as a result of goat browsing varied appreciably (table 2). These measurements, the percent browsed plants by species discussed above, and the estimates of biomass removal indicate a strong preference for mountain mahogany and Wright silktassel over shrub live oak. Heavy use of Wright silktassel did not begin until late in the summer; after October it appeared that use of the species was about equal to that of mountain mahogany.

Other Observations

Because of restrictions imposed by topography and accessibility, the holding pen and shelter were placed in one corner of the area (fig. 1). It was believed that the herd should be penned nightly as a precaution against predation losses, so the goats were salted in the pen and shelter area to induce them into the pen at night. (Because of topography and labor limitations, it would not have been possible to herd the goats to the pen daily.) This resulted in an undesirable use pattern; a quarter circle area extending about 400 feet out from the penning area became a heavily used "sacrifice zone"; the problem was magnified because the vegetation composition within the zone was predominantly mountain mahogany (fig. 1), which is more palatable than the other major dominant (shrub live oak). This "sacrifice zone" could have been reduced or possibly prevented had it been possible to centrally locate the pen-shelter site and salt the goats in outlying areas. It appears that the electric fence is effective against predation (no losses have occurred), and it may not be necessary to pen the herd nightly.

Treatment (prescribed burning and goat browsing) resulted in decreased shrub cover, increased herbaceous cover, and an apparent reduction in fire hazard and improvement in water yield (table 3).

There was a fair stand of grass over the entire study area by the end of the second week in July. Some of the seedlings were from spring emergence and some were from late June and early July rains. Precipitation in the area totaled 8 inches during the growing season (May through September)--about 7 inches fell from June 20 through September. Almost 16 inches fell during the 1980-81 winter months (October through April). Grass production increased in the summer-deferred pasture--the stand was better than is characteristic of seedings in the Arizona chaparral following burning. It is believed that this is due, in part, to "seed planting" as a result of trampling by the goats during the 3 weeks before the herd was excluded from this pasture. It remains to be seen if goat browsing during the winter months will result in sufficient control of shrubs to maintain and/or increase the grass stand. This will depend on the degree of shrub cover reduction from browsing pressure prior to initiation of spring growth, at which time utilization of grasses may necessitate removal of the herd from the pasture.

Table 2--Average height (feet) of important shrubs as related to browsing.

	Species								
	Shrub live oak			Mountain-mahogany			Wright silktassel		
Date	Browsed	Not browsed	Pct. reduction	Browsed	Not browsed	Pct. reduction	Browsed	Not browsed	Pct. reduction
6/11/80[1]	1.70	1.68		0.92	0.93		1.34	1.36	
7/23/80	1.47	--		0.89	--		1.60	--	
9/11/80	1.59	--		0.74	--		1.43	--	
11/1/80	1.56	2.17	28	0.49	1.50	67	1.17	2.10	44

[1]Prior to introduction of goats.

Table 3--Characteristics of the study area, October 1979 to November 1980.

	Pretreatment	End of first growing season: Summer-grazed pasture	End of first growing season: Summer-deferred pasture
Shrub cover (pct.)	70	10	28
Estimated grass production (no./acre)	25	0	200
Water production	Intermittent	Continuous	No summer or fall flow
Fire hazard	High	None	None
Wildlife	?	Heavy deer and elk use	Very heavy deer and elk use
	No quail	4 coveys quail	2 coveys quail
	No cottontail	Sparse cottontail	Cottontail numerous

CONCLUSIONS

Conversion of chaparral by goat browsing will require some form of put-and-take system of grazing management to protect the area during the critical period of grass establishment. Results to date indicate that it may be possible to control shrub cover sufficiently to result in increased water yield. Whether or not this can be accomplished while establishing an acceptable grass cover remains to be seen. It appears that trampling does effectively "plant the seed" and enhance seedling establishment.

Goats utilized a far wider range of vegetation in the Arizona chaparral than other domestic livestock and resident big game. Species such as snakeweed, juniper, and sugar sumac appear to be used more heavily by goats than by other animals common to the area. Chaparral species most preferred by goats are comparable to those of other domestic livestock and resident big game. Thus, goat browsing in the Arizona chaparral can be expected to result in heaviest use of species also preferred by cattle, deer, and elk.

LITERATURE CITED

Bryant, F. C.; Kothmann, M. M.; Merrill, L. B. Diets of sheep, angora goats, Spanish goats, an (white-tailed deer under excellent range conditions. J. Range Manage. 32:412-417; 1979.

Carrera, C. Tripos de plantas que consume el ganado caprino. XII. Informe of Investigacion Div. de Ciencias Ogape cu rias y Maritimas, I.T.E.S.M. Monterrey, Mexico: 1971. p. 168-169.

Davis, F. G.; Bartel, D. L.; Cook, C. W. Control of Gambel oak sprouts by goats. J. Range Manage 28:216-218; 1975.

Du Toit, P. F. The goat in brush-grass community Proceedings of Grassland Society, South Africa. 7:44-50; 1972.

Fraps, G. S.; Cory, C. L. Composition and utilization of range vegetation of Sutton and Edwards counties. Texas Agric. Exp. Stn., U.S. Dep. Agric.: 1940; Bulletin 586. 39 p.

Hibbert, Alden R.; Davis, Edwin A.; School, David G. Chaparral conversion potential in Arizona. Part I: Water yield response and effects on other resources. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Pap. RM-126. 36 p.

Huss, D. L.; Zertuche, J. M.; De Leon Juarez, J. L.; Carrera, C. Informe solbre progecto de experimentación para el approvechamiento con ganado caprino de zonas con vegetación tipo matorral alto subperenifolia en la Región de Linares. N. L. Deptl. Zootechia I.T.E.S.M. Monterrey, Mexico: 48 p.

Knipe, O. D.; Pase, C. P.; Carmichael, R. S. Plants of the Arizona chaparral. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1979; Gen. Tech. Rep. RM-64. 54 p.

Malechek, J. C.; Leinweber, C. I. Forage selectivity by goats on lightly and heavily grazed ranges. J. Range Manage. 25:105-111; 1972.

McMahan, C. A. Comparative food habits of deer and three classes of livestock. J. Wildlife Manage. 28:798-808; 1964.

Taylor, G., Jr. Spanish versus angora in controlling browse. The Ranch Mag. p. 16-17; 1975 October.

Wilson, A. D.; Leigh, J. H.; Hindley, N. L.; and Mulham, W. E. Comparison of the diets of goats and sheep on a _Casuarina_ _cristata_-_Heterodendrum_ _oleofolium_ woodland community in western New South Wales. Aust. J. Exp. Agric. and Anim. Husb. 15:45-53; 1975.

Wilson, A. D.; Mulham, W. E.; Leigh, J. H. A note on the effects of browsing by feral goats on a Belah (_Casuarina_ _cristata_)-Rosewood (_Heterodendrum_ _oleofolium_)woodland. Aust. Rangeland J. 1:17-21; 1976.

Wilson, P. N. Studies of the browsing and reproductive behavior of the East African dwarf goat. East Africa J. 23:138-147; 1957.

Zertuche, J. H. Effecto de rodillo y quema en el control of arbustos y prefencias en pastoreo de las cobras. Tesis. I.T.E.S.M. Monterrey, Mexico: 1970; 67 p.

Grazing Management of Evergreen Brushlands in Greece[1]

Leonidas Liacos[2]

Abstract: Evergreen brushlands in Greece occupy 783,000 ha. Their main use in the past and at present is for grazing by livestock, especially goats. Irrational long grazing has lowered brush cover and density of the most productive and desirable species. Now kermes oak is the dominant species, represented by various browse types. Production of natural kermes oak stands of 100 percent cover was found to be 30 kg meat/ha/yr. Improvement experiments have shown that meat production can be doubled if brush composition and management form are improved, and increased by four times if brush is partly converted to grass.

Greece is an east mediterranean country. Its climate is typically mediterranean, ranging from the arid to the perhumid of Emberger's (1955) classification. The most significant of its features from the standpoint of production and management is that water is the main limiting and regulating factor for plant growth. This is especially true in the maquis zone. Increase in soil water storage could contribute to an increase in biomass production, particularly in the driest zones, through improved evapotranspiration efficiency and greater precocity of plant growth (precipitation is concentrated in winter and early spring).

Maquis vegetation occupies a great part of the territory of Greece. A considerable part of Greece's land area is covered by evergreen brush vegetation, the dominant species of which is kermes oak (*Quercus coccifera* L.), and this species is also the most abundant plant in the typical maquis formation. Kermes oak brushlands outside the maquis zone are a degraded state of former productive high forests, mainly deciduous broad-leaf oaks. These formations, covering 783,000 ha, and making up 15.4 percent of the total area of Greece, are the typical browse rangelands.

The main use of these brushlands during the long past of Greece's history was grazing by livestock, especially goats. Their use for fuelwood production was also quite intensive. Irrational use of these natural resources over long periods, coupled with frequent wildfires, has greatly lowered their productivity. Therefore bedrock now extends over a large part of the ground surface, leaving a relatively small area to shallow poor soils.

At present, the usefulness of Greece's sclerophyllous evergreen brushlands is multiple. The following uses should be emphasized:

a) Fuelwood: The increased cost of heating houses with oil or electric energy has forced people, especially in small towns and villages, to return to wood for heating. Thus, an old market has been reopened, making fuelwood production a viable economic operation in managing maquis.

b) Production of Energy: The energy crisis, especially distressing in the countries that, like Greece, are poor in traditional energy resources, brings about the use of maquis biomass for energy production (Margaris 1980). Certainly, relative research must specify the conditions under which such utilization could be feasible and justified.

c) Landscape and Recreation: Maquis vegetation has great esthetic and recreational value. It extends over the low-elevation land of Greece along and around its sea shores and beaches, which are great tourist attractions. This fact might even justify the exclusion of any other use.

d) Soil Protection: Evergreen brush vegetation effectively protects the soil against erosion. Under Greece's climatic conditions, particularly, with heavy rains during the winter, evergreen brush plays an important role in soil stability.

e) Water Production: Under the intensive economic development of Greece, the availability of the required water in relatively high quantity (to supply the cities, for irrigation, and for industry) is of paramount importance. Therefore, the use and management of evergreen brush vegetation, covering a considerable part of the watersheds around crowded beaches, big cities, and industrial centers, must guarantee the maximum possible production of usable water.

f) Forage: Goat raising, and to some extent sheep raising also, depends greatly on browse and grass produced on evergreen brushlands. This is especially true for the period from late autumn to late spring, when the upland ranges are not ready to be grazed. However, under proper management these evergreen brushlands might be profitably used by grazing goats throughout the year, and thus protect the productive forests, especially fir, from the damaging effects of goat grazing pressure.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Range Management, School of Agriculture and Forestry, Aristotelion University, Thessaloniki, Greece.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

GRAZING USE OF EVERGREEN BRUSHLANDS

Sclerophyllous evergreen vegetation under present use is the basis of goat grazing for a period of 6 to 7 months from late autumn to late spring. In summer, the majority of grazing goats move to higher elevation rangelands, covered, mainly, with deciduous oak or fir forests. Goat operators, mostly nomads, believe that goats cannot live in lowlands during the hot dry season.

Feeding requirements of grazing goats during the cold, humid winter are met mainly by browsing evergreen brush species, among which kermes oak is most important from a production standpoint. Between individual brush plants are found some grass species, which contribute to the diet selected by grazing animals. It is certain that goats cannot meet all their feeding requirements for maximum production from such browse and forage. It could even be said that in most instances the diet consumed is well below the maintenance requirements of goats.

In the past, grazing management practices in evergreen brushlands were mainly circumscribed by the needs and perspectives of goat operators, governed by their desire to increase their income to the maximum. This was attempted almost entirely by increasing the number of goats; the result has been a pronounced deterioration of brush cover. With time, brush height has been lowered and brush cover reduced in proportion to the intensity of grazing pressure. Now, the brush community is usually composed of the less palatable and less productive species and types. Very often, soil erosion is evident between brush clumps because of overuse of grass species growing there, and heavy trampling (fig. 1).

Often, fire is used by goat raisers in an irrational way, to improve browse production and particularly, palatability. This is done without permission of responsible administration authorities. Goat operators have found by experience that by burning the aboveground part of brush plants they can rejuvenate them, and thus obtain a significant improvement of the browse produced. They do not realize, however, that this uncontrolled and irrationally practiced burning leads gradually to a severe deterioration of the site.

Management working plans and grazing control are applied in a very limited area. The responsible authorities are limited to deciding whether or not the various brushland units should be protected from grazing. The areas burned by accidental wildfires or dry fires started by goat operators are protected for 3 to 5 years from goats. When brushlands fall within the limits of a torrent watershed, the period of protection against any grazing can be prolonged according to the specifications of the watershed management plan.

Improvement practices to increase browse and forage production in the brush-covered areas are at present limited to an experimental scale. The main reason is the great difficulty of changing the customs of the goat raisers, who are strongly attached to traditional practices. It is almost impossible to persuade the small operators (100-200 head) to group their animals in common herds and lead them to graze in specific brushland units at particular times, under the control of a management plan. The improvements they are interested in and ask for are range development works, such as roads to facilitate transportation of supplements, animal products, etc., and animal watering facilities. It is worthwhile to note that such development works, in the absence of any management plan, have led to more intensive misuse and overuse of brushlands, with resulting heavier deterioration of the site, and more pronounced decrease in their carrying capacity.

Fig. 1--Kermes oak clumps with grass-covered surfaces between them, in a brushland north of Thessaloniki. Soil erosion between clumps is evident.

PROPER USE AND MANAGEMENT

From the above discussion, it is rather obvious that proper management of maquis vegetation, and in general, of sclerophyllous evergreen brushlands in Greece, must be based upon the principle of multiple use. The management form and the vegetational structure which respond to this need might vary according to existing specific conditions. The various products and services expected from evergreen brushlands could be obtained either simultaneously from every small piece of land under a complex management scheme over the total area, or separately. If separately, each product or certain selected products would be obtained from small surface subunits, each under a specific management plan. Thus a mosaic of vegetation types would be created over the total brushland area. This second type of management scheme seems to be more suitable in Greece for the following main reasons:

a) It is better adapted to the extremely diversified topography, rockiness, soil depth and fertility, etc. of the land.

b) It fulfills more efficiently the esthetic requirements and the necessary conditions for development of recreation facilities.

c) It offers the possibility of securing protection against soil erosion by conserving a thick brush stand on steep slopes and susceptible sites, and at the same time improving usable water production by establishing low water-consuming plant cover on less vulnerable sites.

d) It renders easy the task of balancing browse and grass forage production according to the diet requirements of grazing animals.

In a considerable portion of evergreen brushland, the soil is relatively fertile and sufficiently deep to support productive forests, while the most productive sites can be used for olive or almond-tree orchards. Unfortunately, inventory data about the acreage of such sites are not available; it is estimated as 10 to 15 percent of the total brushland area of Greece.

The main forest species used in reforestation work in this area are aleppo pine (Pinus halepensis), brutia pine (P. brutia), maritime pine (P. maritima) and parasol pine (P. pinaster). All are light-demanding species. Therefore, their stands remain open, in general, during most of the rotation time, promoting an understory of brush or grass, or both (fig. 2).

Under the specific conditions governing the functioning of the ecosystems within the bioclimatic zones in question, the competition for water (the limiting factor in plant growth) exercised by this understory vegetation against the plants of the forest floor is extremely high. The result is (a) considerable decrease in stand annual increment; (b) rapid depletion of soil moisture; and (c) pronounced desiccation of biomass for a comparatively longer period of time during the dry and hot summer, and hence, increased fire hazard.

No doubt, proper browsing or grazing of the understory vegetation will diminish all these undesirable effects. In addition, such control of the understory vegetation, which is effective and inexpensive, and of considerable benefit, will permit intensification of the silvicultural treatment of the forest tree floor for maximum wood production (Liacos 1980). The International Meeting of Scientists held in Palermo, Sicily (Oct. 6-11, 1980) on "Conservation and Restoration of Forest Cover in Mediterranean Regions" concluded with this recommendation: "In some cases the rational silvo-pastoral use of mediterranean forests might even improve their productive function and better secure their protection."

Figure 2--Thick brush understory vegetation in a 70-year-old natural stand of brutia pine.

In the major part of Greece's brushlands, soils are steep, shallow, and rocky. Because this area is more suitable for livestock grazing, its vegetation cover must meet the feeding requirements of grazing animals to the greatest extent possible. It is rather obvious that the kind of animals most adapted to evergreen brushlands are goats (domestic or wild) and roe deer. However, goats and roe deer as well cannot be entirely satisfied with browse alone, and thus they cannot reach their productive potential. They also need some grass forage, which for domestic goats amounts to about 40 percent of their daily requirements. Consequently, the composition and structure of the vegetation cover on brushlands would be ideal if it could offer to grazing animals the daily required quantity of forage composed of about 60 percent browse and 40 percent grass. Besides, such a diversified plant cover is more appropriate. By relative control trials (Nastis and Liacos 1981) it has been found that the assimilated N of kermes oak foliage is almost zero, although the digested N is about 40 percent, when goats are fed only kermes oak foliage harvested during the dormant season of plant growth.

The browse production of evergreen brushlands in Greece is quantitatively and qualitatively low at present. An experiment carried out in the subhumid zone, with good soil conditions and a brush cover of 100 percent, has shown that annual browse production varies greatly (Liacos and Moulopopoulos 1967). Five kermes oak types were identified, differentiated by their botanical characteristics such as color of new leaves, shape and size of adult leaves, size and peduncle of acorns, scales of acorn-cups, etc. The browse produced annually by the different types varied, with 762 kg/ha for the least productive type, which is usually dwarf and of very low palatability for goats. Differences were also found in browse nutritive value, specifically in crude protein content. Again, the browse of the least productive and least palatable type has the lowest nutritive value. It is interesting to report here that browse preference by domestic goats was similar to host preference noticed for the larvae of gypsy moth (Lymandria dispar), which is the most damaging pest of all oak species in Greece.[3] The less productive, less palatable, and less nutritive type of kermes oak is now the most abundant in the evergreen brushlands of Greece, misused and overused for many centuries.

Herbaceous vegetation cover in the evergreen brushland area is more productive than brush cover. An experiment to convert brush to grass was carried out in the semiarid bioclimatic zone by seeding grass forage species: hardinggrass (Phalaris tuberosa), orchardgrass (Dactylis glomerata-palestina), rose clover (Trifolium hirtum). Data show that forage production went up to 4500 kg/ha (fig. 3). That means that forage could be increased by 7 to 10 times when brushlands are converted to grasslands.

Certainly, this kind of improvement can be applied only on good sites with gentle topography (slope 15 percent) and good conditions. Considerable improvement could be obtained even on rough areas, however, by applying the proper technique in each case. Liacos and others (1980), in a conversion experiment, carried out in the subhumid bioclimatic zone in rough country (40 percent slope), used controlled burning to clear the ground and then seeded valuable forage species on the ash--primarily orchardgrass, smooth brome (Bromus inermis), hardinggrass (Phalaris tuberosa) and birdsfoot trefoil (Lotus corniculatus). Italian ryegrass (Lolium multiflorum) was also used with the hope of depressing the kermes oak sprouts by its strong competitive effect. During the first year after burning, Italian ryegrass was expected to grow vigorously, because the soil was well fertilized by the ash, and it was relatively rich in N from rich brush humus mineralization over a long period before burning.

The effectiveness of this conversion technique in rough country was compared, under the same experimental design, to improved brush cover in which all undesirable and less desirable species and types of brush were eliminated. Additionally, all brush plants were cut down to 0.40 m high, and then left for two years to recover. The structure of the cover was also improved to secure the proper utilization by goats of all browse produced. Yearling goats were used in both treatments to check the effectiveness of the improvement techniques applied. The annual grass and browse production of the conversion treatment was found to be 3400 kg/ha and 2000 kg/ha respectively on the average for three consecutive years. Meat production of the yearling goats used

Figure 3--High forage production in the brushland area of the semiarid zone after conversion to grass. Brush cover was removed mechanically and grass forage species were seeded.

in the experiment was about 120 kg/ha for the conversion treatment and 60 kg/ha for the improved brush cover, while meat production in unimproved brush stands of 100 percent cover was found not to exceed 30 kg/ha (Liacos and Moulopoulos 1967).

The brushland improvement experiments have shown that the production of Greece's evergreen brushlands, used for livestock grazing, can be at least doubled by the proper improvement of brush cover, and increased by four times by partial conversion to grass.

Up to the present, the experimental data, although very limited, show that the possibility for improvement of Greece's evergreen brushlands and the increase in forage and grazing animal production is relatively high. To make this more concrete and meaningful, it would be useful to say that in Greece, within the evergreen brushlands suitable for livestock grazing, meat production could be increased by at least three times, on the average, after the appropriate improvement of brush cover and the application of proper management. Thus, the estimated present meat production of 18,000 ton/year could reach the amount of 72,000 ton/year. Greece's evergreen brushlands suitable for grazing are estimated at 600,000 ha out of a total area of 783,000 ha. Moreover, it is the author's belief that the opportunity for further improvement of forage production and an increase of animal products from brushlands is great.

Management techniques to be applied in evergreen brushlands, to secure the highest possible sustained yield of forage and livestock products, are not well defined. It is not yet known which structure and form of vegetation is most productive. A series of experiments are underway to approach the solution to the problem. The following three forms

[3] The palatability differences noted among the various kermes oak types are now being investigated by the author's associates.

Figure 4--Improved brushland with controlled burning of brush cover and seeding of valuable forage species on the ash.

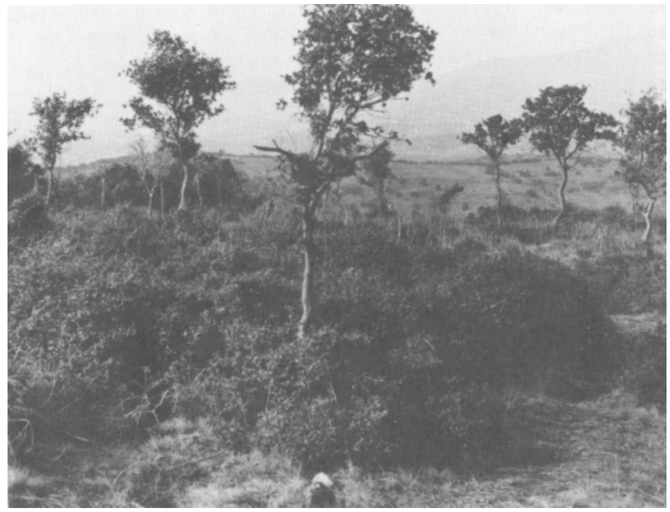


Figure 6--Dwarf brush stands with grass-covered soil between brush patches and small tree-like individuals of kermes oak interspersed, to support spreading shoots and produce acorns for animal food.

are being investigated to evaluate their compatibility for the various brushland sites:

b) A vegetation form that seems quite promising for relatively good sites is that shown in figure 4. Brush plants are low, spreading on the ground surface, with grasses growing between in large or small patches, occupying 30 to 40 percent of the total area.

c) A brush form which is suitable for relatively poor and rocky sites is shown in figure 5. Under this form the individual brush plants are evenly distributed all over the area at a height within the reach of goats. The browse produced is organized vertically over all the depth of the brush stand. Grass forage produced under this form is very limited. Therefore, in order to secure the forage required by the livestock, the brush-covered land should be incorporated in the same management allotment with the required grass-covered area.

Figure 5--Brushland improved by eliminating undesirable brush plants and limiting the brush to a height within the reach of browsing goats.

a) The third form, which has high esthetic value, is an improved form of the first (fig. 6). Under this form, a number of kermes oak shoots evenly distributed all over the area are left to grow as high as small trees. The main advantages expected under this diversified form are (1) betterment of microclimatic conditions with the aim of retaining a greater quantity of water and improving the evapotranspiration efficiency in the system; (2) conservation of the vigor of spreading brush sprouts which are heavily browsed; (3) production of a considerable quantity of acorns, which are a valuable feed for livestock during the most critical season for browsing animals--late summer and early autumn; and (4) a very significant improvement of the landscape and the recreation conditions in an area falling within the most touristically important zone of Greece.

REFERENCES

Emberger, L. Une classification biogeographique des climats. Serie Bot. 7. Montpellier, France: Rec. Tray. Lab. Bot. Geol. Zoo. Natural, Fac. Sc. Montpellier; 1955; p.3-45.

Le Houerou, H. N. Fire and vegetation in the Mediterranean basin. Proceedings of the Tall Timbers Fire Ecology Conference 13; Tallahassee, Fla.; 1973; p. 237-277.

Liacos, L. Present studies and history of burning in Greece. Proceedings of the Tall Timbers Fire Ecology Conference 13; Tallahassee, Fla.; 1973; p. 65-95.

Liacos, L. Fire and fuel management in pine forest and evergreen brushland ecosystems in Greece. Mooney, Harold A.; Conrad, C. Eugene, coord. Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, August 1-5, 1977, Palo Alto, Calif. USDA Forest Service Gen. Tech. Rep. WO-3. Washington DC: U.S. Department of Agriculture; 1977; 498 p.

Liacos, L. Livestock grazing in Mediterranean forests. Proceedings International Meeting--Soil, Vegetation, Fauna; Palermo, Italy; 1980. In press.

Liacos, L.; Moulopoulos, Ch. Contribution to the identification of some range types of Quercus coccifera L. (in Greek). Thessaloniki, Greece: F.S.--N.G.F.R.C.

Liacos L.; Papanastasis, V; Tsiouvaras, C. Contribution to the conversion of kermes oak brushlands to grasslands and comparison of their production with improved brushlands in Greece. Thessaloniki, Greece: F.S.--I.F.R. In press.

Margaris, N. Harvesting before a fire: how much energy and organics Greece can gain? Proceedings International Meeting--Soil, Vegetation, Fauna; Palermo, Italy; 1980. In press.

Nastis, A.; Liacos, L. Consumption, digestion and utilization by yearling goats of oak (Quercus coccifera) foliage at different phenological stages. Proceedings of the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981; San Diego, California.

Research and Management of Animals in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Ronald D. Quinn[2]

Summarizing a session as diverse as this one has been challenging. The papers deal with animals as different as insects and Mountain Sheep, from five different parts of the world, both domestic and feral, and from the perspective of both research scientists and land managers. The only thing these papers have in common is that they all deal with animals in Mediterranean-type ecosystems. In the summary that follows I have drawn inferences which may not be in accordance with the professional opinions of all session participants. It is my intention to stimulate further thought on the subject at hand, not to have the last word, and I am solely responsible for what follows.

This session has accomplished its two major goals: 1) it has been a truly international exchange of ideas bringing together researchers from all five parts of the world having Mediterranean-type ecosystems and 2) in the presentations there has been a productive balance between research and the application of that research to management situations.

The summary and discussion below treat topics in approximately the order they were presented, with small mammals first, followed by insects, deer and Mountain Sheep, and finally domestic goats. I conclude with a few remarks about future research on the animals of Mediterranean-type ecosystems.

SMALL MAMMALS

The influence of fire on small mammal communities was analyzed for Australia (Fox; Catling, Newsome and Dudzinski), and South Africa (Willan and Bigalke). Using a most innovative approach, Fox showed that despite being members of distant phyla both small mammals and ants can be used as indices of disturbance in Australian heathlands. In both cases the patterns of replacement of one species by another showed the importance of the changing structure of the plant community in ordering corresponding changes in the structure of the animal community. This relationship between the habitat structure and the community structure of small mammals was stressed by Catling, Newsome and Dudzinski for the dry sclerophyll forests of southeastern Australia, by Willan and Bigalke for the montane fynbos of South Africa, and by Glanz and Meserve for the sclerophyll shrublands of both southern California and central Chile. In the case of Catling and coworkers, fire intensity was also found to be important to the structure of the small mammal community, but this too was interpreted in terms of the resulting structure of the plant community rather than the direct effects of the heat of a fire on the animals.

This consistent connection between the structure of the habitat and the structure of the small mammal community is interesting in two respects. First, to the researcher it suggests that in Mediterranean-type ecosystems it is the physical structure of the habitat, not the presence of particular species of plants, that causes the presence or absence of particular species of animals. Secondly, to the manager it suggests that when the successional changes in the community of small mammals are well understood, as they are in California chaparral and southeastern Australian heath, diversity and abundance of the small mammal community can be predicted from measurement of readily determined parameters of the habitat, such as the size of the plants, age of the plant community, or the presence of rock outcrops. Conversely, the condition of the habitat can be assessed by sampling the community of small mammals, which in some cases may be more easily accomplished than more direct measurements of the environment.

In montane fynbos Willan and Bigalke found that diversity, abundance, and biomass for the community of small mammals peaked within the first several years after fire. This finding is typical for fire-prone, Mediterranean-type ecosystems. Similar post-fire population peaks are reported in this session for southeastern Australia by both Fox and Catling and coworkers, and for southern California by Wirtz. The remarkable thing about the South African pattern, however, was a second peak in these community characteristics in very old (38 years) fynbos. This increase seemed to be related to a secondary recovery of the plant community after earlier senescence, which in turn caused it to once again develop those attributes which supported the first peak.

Bigalke and Willan emphasized the importance of nearby refugia as centers of dispersal for small mammals back into recently burned areas. Dispersal between patches of vegetation of different ages was also discussed by Catling, Newsome and Dudzinski. This dispersal phenomenon has management implications, suggesting that not only the time interval between fires but also the size and pattern of patches burned (or unburned) are important in the community dynamics of small mammals. Catling and

[1]Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Biological Sciences, California State Polytechnic University, Pomona, California 91768, U.S.A.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

coworkers also arrived at the rather surprising conclusion that intense fires in the sclerophyll forests of southeastern Australia, rather than the cooler fires favored by managers, are the best way to maximize the abundance and diversity of the small mammal community!

Glanz and Meserve made comparisons between the structure of small mammal communities in the sclerophyll shrublands of central Chile and southern California. They found that convergence of community structure between paired communities of the two continents was rather weak, with differences being more notable and intriguing than similarities. This lack of close convergence amongst the small mammals is consistent with the general conclusions of comparisons of many other taxa between these two ecosystems. There were differences in trophic organization and the range of habitat preferences between the two faunas. They also reported low and highly variable population densities in Chile when compared to California, and lesser community diversity as well. It is interesting that Catling and coworkers also found low densities and diversity in the sclerophyll forests of southeastern Australia, as did Bigalke in some circumstances in montane fynbos. The relatively high diversity and abundances found by Wirtz in California chaparral were comparable to the findings of Glanz and Meserve for the same region. It may be that for small mammal communities in Mediterranean-type ecosystems, low abundance and diversity are the rule with California as an exception.

Wirtz observed a pattern of resilience and stability in a community of birds and small mammals following a chaparral wildfire. Although some species appeared and others disappeared, and the relative abundances between species changed rapidly, there was a steady increase in biomass to 2-3 kg/ha after three-and-one-half years. By contrast Catling and coworkers reported a small mammal biomass of 1.5-2.5 kg/ha, which was reached 5 years after fire. In Wirtz' study if either rodent (or bird) diversity or biomass is used as an index of community recovery, the burned plots exceeded the controls in less than 2 years. The changes that Wirtz found are consistent with the structural habitat preferences of the individual species of small mammals.

Fuentes and Simonetti found that mammals in the Chilean matorral not only responded to the structure of the plant community, but also played a rather important role shaping that structure. Furthermore, the impact of exotic herbivores was quite different than that of native species. These phenomena, although not surprising, have not received sufficient attention by researchers. It is important for both pure and applied ecologists working in Mediterranean areas to remember that herbivores, including small mammals, can act as agents of change within an ecosystem. Fuentes and Simonetti presented evidence that herbivores, especially goats, exert pressures upon the plant community which are potentially drastic and undesirable.

INSECTS

The opening statement of Force's paper is the most important--the study of insects in chaparral (and other Mediterranean-type ecosystems) has been largely neglected. In view of the strong influences insects have over the plant community (especially reproduction), and their importance as a food resource, this oversight is unfortunate. Force clearly showed that some groups of insects responded with remarkable rapidity to the equally rapid changes in the plant community after chaparral fire. In the early years after fire these insects were sufficiently abundant to constitute an important food resource for birds, as was shown by Wirtz, and for phytophagous insects to damage plants as was found by Force for aphids on lupines. Wirtz reported that of 55 species of chaparral birds, 35 belonged to guilds that feed largely or exclusively upon insects. Fuentes and Simmonetti mentioned that insects, not vertebrates, are the most important defoliators of matorral shrubs to the extent that they change shrub densities by altering the competitive equilibrium between populations of shrubs.

In Australian heath slowly recovering from mining disturbance, Fox found that groups of ant species replace one another in response to changes in the plant community, and that this replacement process is influenced by competition between the dominant species of ants.

CHAPARRAL DEER AND MOUNTAIN SHEEP

Thornton described a herd of black-tailed deer (*Cervus hemionus columbiana*) living in chaparral that, after a long period of decline, experienced a 300-percent increase in numbers over a period of 7 years. This increase was the result of a fuel management program which, among other things, greatly improved the extent and quality of deer habitat. This highly successful management program has produced numerous benefits at a relatively low cost.

Bleich and Holl emphasized the importance of the physical environment, rather than vegetation type in defining desirable habitat for the Mule Deer (*Cervus hemionus*) and the Mountain Sheep (*Ovis canadensis*). They presented models which predict the potential of habitats to support populations of these two species, and provide guidelines for the systematic improvement of habitat for either species through manipulation of the vegetation.

DOMESTIC GOATS

Recently goats have been used experimentally to manage vegetation in the chaparral of California and Arizona. The interactions between the goat herds and the vegetation were reported by Knipe, and Sidahmed and coworkers. The emphasis in both studies was to use goats as a tool for reducing fuels and for type conversion of the vegetation on public lands. Knipe has found that under careful management, herds of goats can assist in fuel reduction, type conversion from shrubs to grasses, improvement of water output, and even in the planting of grass seeds by trampling: Although goat herders may profit from such a project by selling goat products, these economic benefits were secondary to the study.

Sidahmed and coworkers clearly showed that goats are selective herbivores that both browse and graze. These feeding habits were also shown by Knipe's data, and both studies emphasized that regular goat grazing can be a powerful agent of change in the composition of plant communities. Liacos pointed out that in Greece, where goat grazing practices have been determined by tradition and short-term economic gains, there has been degradation of the forage value of the plant community over the long term. Only recently have scientists like Liacos analyzed the changes in management practices that would be necessary to improve the forage value of the brushlands in which goats graze, so that the scope and magnitude of long-term economic benefits could be increased.

Fuentes and Simonetti described the desertification of the more arid parts of Central Chile from long-term goat grazing. More recently the introduction of large numbers of goats into evergreen matorral has caused shifts in the composition of that plant community due to selective feeding. In more extreme situations, matorral degradation has been accompanied by soil erosion and by a declining economic return from goat products. Fuentes and Simonetti agreed with Liacos; additional research and more careful management practices are needed if goat grazing is to continue indefinitely as a productive economic activity.

THE FUTURE

The Mediterranean climate areas of the world are places that already have relatively high population densities, and these populations are growing rapidly. A pleasant climate, growing urban areas and productive agriculture will continue to attract ever more people to these areas during the forseeable future. The cultural history of the Mediterranean Basin has shown us repeatedly that neither the pristine nor modified ecosystems of Mediterranean-type areas are especially resilient. The dismal cycle of deforestation, overgrazing, soil and watershed degradation, deterioration of plant communities, and wildlife loss has been seen all too often to be ignored. In regions where the vegetation has been less degraded, there is the problem of destructive and uncontrollable wildfires raging through sclerophytic vegetation in close proximity to densely urbanized areas.

With all of the above in mind, it is altogether proper that the attention of research scientists and managers should be devoted to the understanding and management of these ecosystems, and that public agencies should sponsor international symposia of this kind. It is appropriate that the greater part of these research and management activities should be focused on the pressing problems of fire management, watersheds, soils, nutrients, and vegetation, so long as this approach does not overlook the effects of management practices upon the fauna.

These communities of animals are an indispensable element of our understanding of Mediterranean-type ecosystems. A few animals are relatively well studied because they are of particular interest to the public, such as the spectacular and endangered California condor (*Gymnogyps californianus*), the hunted Mule Deer (*Cervus hemionus*), and the admired and rare Mountain Sheep (*Ovis canadensis*). These species and a handful of others like them, however, are exceptions. We remain woefully ignorant of the biology of most vertebrates in Mediterranean-type ecosystems and know next to nothing about the invertebrates. Many of these species do not simply respond to the condition of the plant communities in which they live, they also influence both its structure and function. Animals influence plant reproductive patterns as pollinators and by their dispersal and consumption of seeds. Animals can greatly modify the structure of plant communities by selective herbivory, as was shown by several of the papers in this session. Additionally, animals are frequently useful as indices of the condition of the community as a whole.

All management activities are an expression of values. I would like to conclude with a plea for a value that rests in the heart of many of us who call ourselves scientists and managers, but one which is more difficult than the others to reduce to an annual budget item, cost benefit analysis, or research proposal. We must always remember that the presence of native animals in Mediterranean-type ecosystems is an important goal for its own sake. Many people enjoy seeing these animals or even just knowing that they are there, unseen. What importance they might have in maintaining the integrity of the ecosystem is often unknown. That is not the point. Even if they play no known role in the system they are nevertheless important, for their own sake. In the press of what we believe to be more immediate and therefore more important issues, we must not lose sight of the right that other species have to exist. In the grand scheme of things they have lived in these marvelous, small, fragile, Mediterranean-type ecosystems far longer than we--and if we are wise they will be present long after we have departed.

Acknowledgements: I thank D. Force and W. Edmonds for their comments on the manuscript.

Soils

Soils

Atmospheric Precipitation as a Source of Nutrients in Chaparral Ecosystems[1]

William H. Schlesinger and John T. Gray[2]

Abstract: Precipitation and dry fallout were collected over a 2-year period at a remote site in the Santa Ynez Mountains, Santa Barbara County, California, USA and analyzed for nutrient content. Mean annual depositions of Ca (2.2 kg/ha), K (0.7 kg/ha), NH_4-N (0.5 kg/ha), and NO_3-N (1.5 kg/ha) were largely derived from dryfall; depositions of Na (7.2 kg/ha) and Mg (1.2 kg/ha) were important in both rainfall and dry fallout. These inputs are equal to or larger than the typical losses reported in runoff from mature chaparral, but these values imply that long periods are necessary to replace losses measured in volatilization and exacerbated runoff after fire.

During fires a large quantity of essential plant nutrients, particularly nitrogen, may be lost from terrestrial ecosystems to the atmosphere (Raison 1979). These losses have been quantified in chaparral ecosystems (DeBano and Conrad 1978, DeBano et al. 1979), as have the losses in erosion and runoff following fire (DeBano and Conrad 1976). The marked response of *Adenostoma* chaparral to nitrogen fertilization (Hellmers et al. 1955) has led to the widespread recognition of nutrient limitations to growth in chaparral soils. If fires are frequent, large losses could deplete chaparral sites of nitrogen at a more rapid rate than it is replenished by atmospheric deposition and by nitrogen-fixing species such as *Ceanothus*.

Over the past several years we have studied the rate of deposition of nutrients from the atmosphere in the chaparral near Santa Barbara, CA. The goal of these studies was to compare the annual deposition of nutrients to the typical losses in runoff and to the nutrient requirements for growth in mature chaparral. Our data also allow a calculation of the time needed to replenish the exacerbated losses which occur as a result of fire. In our early studies, we collected rainfall and dry fallout together in open funnels (Schlesinger and Hasey 1980); more recently we have separated these deposition processes by collections using an automatic rain collector. Here we report on our recent work, and we review sources of similar data in California.

METHODS AND MATERIALS

We established a research site on the south slope of the Santa Ynez Mountains (Los Padres National Forest) at 850 m elevation and approximately 10 km north of the Pacific Ocean near Santa Barbara, CA. The site was 3 km west of the transect of sites used for precipitation collections in related studies (Schlesinger and Hasey 1980, 1981). While these sites are close to the ocean, the south slope of this mountain range receives little direct deposition of salt spray and marine aerosols (Ogden 1975, p. 205-206). Direct on-shore winds are predominant only during the arrival of winter synoptic storms from the Pacific Ocean. The site is remote from anthropogenic sources of atmospheric constituents.

Over a 25-month period we measured precipitation in individual rainstorms using a standard U.S. Weather Bureau 8" (20.3 cm) diameter raingage. Monthly total airflow was measured with a recording 3-cup anemometer mounted 2 m above ground-level. A continuous record of air temperature and relative humidity was obtained using a sheltered hygrothermograph (Weathermeasure Model H311), but these data are not reported in the present paper.

We used an automatic rain collector (Aerochem Metrics Model 101), electronically sensitive to precipitation events, to collect nutrient deposition in rainfall and dry fallout in separate (28-cm diameter) plastic buckets. This rain collector was originally designed by the U.S. Atomic Energy Commission and tested favorably in the trials reported by Galloway and Likens (1976) and Bogen et al. (1980). The plastic buckets were washed with 50 percent HC1 and rinsed 5 times with deionized water. They were transported to the field in plastic bags. At the end of each storm and at the end of each month, the wetfall bucket was replaced with a clean collector, the volume of precipitation was recorded, and an aliquot of the precipitation was saved for analysis. At the end of each month, the dryfall collector was rinsed with 250 ml of glass-distilled water which was saved for analysis; thus, our analyses include only those ions that are dissolved when dryfall is leached with distilled water (fraction 2 of Lewis and Grant 1978). A clean dryfall bucket was placed in the rain collector at this time.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Professor of Botany, Duke University, Durham, N.C. 27706; and Research Assistant, Department of Biological Sciences, University of California, Santa Barbara, CA 93106

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

During 15 months of the study, we also collected bulk precipitation using the rain collector designed and tested by Likens et al. (1967, 1977) to collect a composite sample of rainfall and dry fallout at the Hubbard Brook Ecosystem in New Hampshire. This collector consisted of a 10-cm diameter polypropylene funnel connected to a 1-liter polypropylene bottle with tygon tubing. It was acid-washed, rinsed, and replaced in the field after each storm. It was also rinsed at the end of each month.

The various samples were analyzed for Ca, Mg, K, and Na as described in Schlesinger and Hasey (1980). During the second year of study, the samples were also analyzed for NH_4^+-N and NO_3^--N as described in Schlesinger and Hasey (1980). Analyses for the nitrogen constituents were performed as soon as possible after collection, usually within 24 hours; thus, no preservatives were used in the collectors. For each rainfall event, concentrations of ions (mg/1) in the wetfall and in the Hubbard Brook collector were multiplied by the volume of precipitation, converted to $1/m^2$ based on the area of the collector surface, to calculate total deposition (mg/m^2). Concentrations in the water used to rinse the dryfall collector were converted to dry deposition based on the volume of rinse water and the area of the collector.

In this paper we use the term "bulk precipitation" to refer to collections made using the Hubbard Brook collector. "Total deposition" refers to the sum of "wet deposition (wetfall)" and "dry deposition (dry fall)," as collected in the automatic rain collector. When data are treated as monthly depositions, it should be remembered that these are derived from summing the collections and calculations for the individual rainstorms during the month.

RESULTS AND DISCUSSION

Long-term measurements compiled by the National Oceanic and Atmospheric Administration for Santa Barbara (elevation 3 m) indicate a mean annual rainfall of 45 cm. Sites in the coastal mountains of southern California generally receive greater rainfall than lower elevations along the coast (Bauer 1936, Miller and Poole 1979, Schlesinger and Hasey 1980), but the influence of local topography on rainfall patterns often results in only a weak correlation of increasing rainfall with increasing elevation in the mountains. Santa Barbara County records show a mean annual rainfall of 77 cm for a 33-year period at San Marcos Pass (700 m elevation), along the ridgetop of the Santa Ynez Mountains 2.5 km west of our study site. During the 2 years of study, we recorded 76 and 111 cm of rainfall in the U.S. Weather Bureau gage.

Because of progressive atmospheric cleansing during large storms, the concentrations of ions in precipitation often decrease during the duration of rainfall (Junge 1963, Georgii and Wotzel 1970, Gatz and Dingle 1971, Kennedy et al. 1979). Thus, concentrations are higher in rainfall collections from small storms than from larger storms. To express rainfall concentrations, many workers use weighted average concentrations, calculated by dividing the total deposition in a collection period (mg/m^2) by the total volume of precipitation recorded ($1/m^2$). Table 1 shows the annual weighted average concentrations (mg/1) in wetfall for the various ions for the 2 years of study. Not surprisingly for this coastal site, Na and Mg are dominant ions, reflecting their abundance in sea water from which aerosols and rainfall nuclei are commonly formed (Gorham 1961).

We found only non-significant negative linear correlations between the ionic concentrations in the wetfall collections and increasing precipitation volume. The correlations between log-concentration and precipitation were usually stronger (higher _r_); these correlation coefficients (r) were -0.60* for Ca, -0.01 for Mg, -0.53* for K, +0.12 for Na, -0.82* for NH_4^+-N and -0.60 for NO_4^--N. Thus, those ions derived from continental and terrestrial sources (e.g., Ca and K, Gorham 1961) show a stronger tendency to be cleansed from the atmosphere during rainfall than those derived from the ocean. This conclusion is directly opposite from that of Kennedy et al. (1979) in an analysis of rainfall chemistry in northern California; however, we feel that our results are likely to be more typical for precipitation derived from maritime aerosols.

In most regions the concentrations of Na and Cl in precipitation can be used as an index of the relative importance of the sea as a source of dissolved constituents in rain and of aerosols for raindrop nuclei. Sodium may be slightly preferred over Cl, for some Cl is apparently also derived from continental or anthropogenic sources (Likens et al. 1977, Kennedy et al. 1979). Recognizing the possibility that various ions might be fractionated during the production of marine aerosols (e.g., Glass and Matteson 1973), one assumes that all Na is ocean-derived and that the oceanic contribution of other ions will be in a ratio similar to sea water. In the present study the Ca/Na ratio for the weighted average concentrations of these ions in wetfall suggests slight enrichment of the Ca ion in rainfall; Ca/Na is 0.06 in wetfall _vs_. 0.04 in sea water (Mason 1966, p. 195). Ratios for Mg/Na (0.13) and K/Na (0.03) in wetfall show no indication of enrichment of these ions compared to sea water ratios of 0.13 and 0.04, respectively. Comparisons using ratios of nitrogen are not usually made because of the labile nature of these constituents. Further indication of the enrichment of Ca from continental sources is shown in figure 1, which includes the concentrations of Ca and Na in individual wetfall samples. For most samples, the Ca values lie above a line representing the Ca/Na ratio in sea water, especially in small storms with rela-

* significant at $P<0.05$'

Table 1--Concentrations and depositions of nutrient ions in wet- and dryfall from the atmosphere in the Santa Ynez Mountains. All calculations have been rounded.

	Rainfall	Ca	Mg	K	Na	NH_4^+-N	NO_3^--N
Weighted average concentrations in wetfall (mg/1)							
1978-1979		0.03	0.06	0.01	0.44	-	-
1979-1980		0.03	0.06	0.02	0.49	0.02	0.03
Annual depositions in wetfall (mg/m^2)							
1978-1979	76	24	43	5	336	-	-
1979-1980	111	28	70	24	542	17	25
Annual deposition in dryfall (mg/m^2)							
1978-1979		123	45	46	185	-	-
1979-1980		256	74	60	384	35	128
Total deposition ($mg/m^2/yr$)							
1978-1979		147	88	51	521	-	-
1979-1980		284	144	84	926	52	153
Mean annual deposition, this study (mg/m^2)		216	116	68	724	52	153
Mean annual deposition, extrapolated from Schlesinger and Hasey (1980) (mg/m^2)		140	80	40	610	10	90
Overall mean annual deposition (mg/m^2)- 3 years		190	104	58	688	31	121

[1] data in cm.

tively high concentrations of Ca. In comparison, the Mg values lie closer to the Mg/Na ratio in seawater over the full range of concentrations recorded.

In an earlier study (Schlesinger and Hasey 1980), very strong enrichment of Ca and K and slight enrichment of Mg were observed in bulk precipitation (rainfall + dry fallout) collections in the Santa Ynez Mountains. While our present data for wetfall show enrichment for Ca, it is now obvious that most of the enrichment in the bulk precipitation values was due to contributions from dryfall in those collections.

Total annual deposition of ions in wetfall and dryfall collections is given for the 2 years of study in table 1. In accordance with our interpretation of the sources of ions in wetfall collections, the depositions of Ca, K, NH_4^+-N and NO_3^--N in dry fallout are much larger than the deposition in wetfall, while for Na and Mg the opposite is true. The semi-arid climate of southern California allows for long periods of

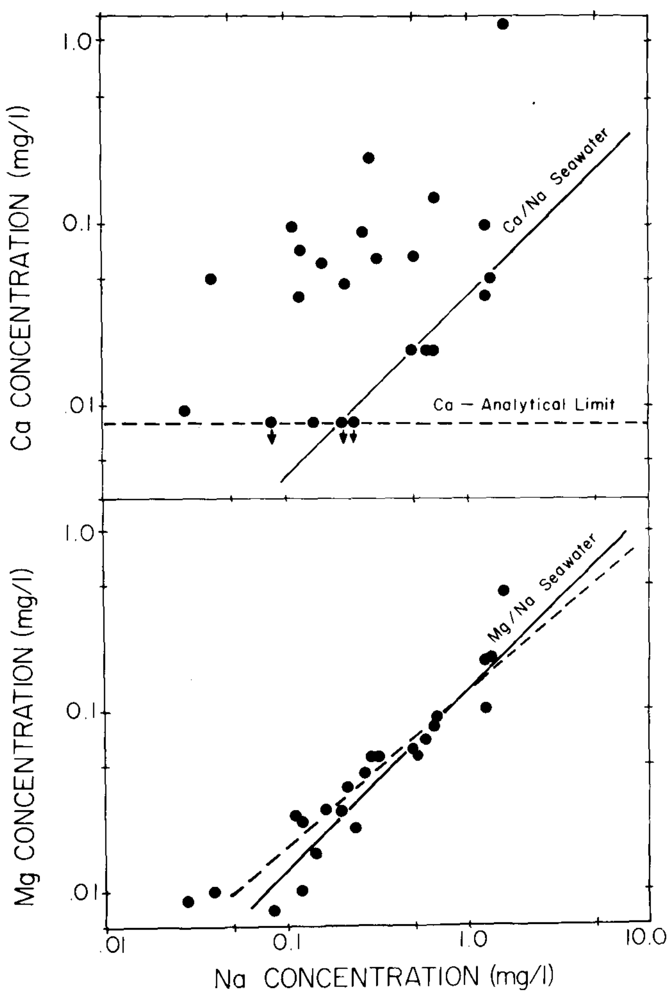


Figure 1--(Right) Concentrations of Ca and Mg in the wetfall precipitation of individual storms in the Santa Ynez Mountains, California, plotted as a logarithmic function of Na concentrations. In both cases the solid line represents the ratio of these ions to Na in seawater. For Mg, the dashed line is the least-squares-fit linear regression to the data (F = 143, P(0.0001, r^2=0.88). The equivalent regression for Ca is not significant.

soil drying and dispersion of soil dust by wind. Thus, there is a strong terrestrial influence on deposition which is manifest in the abundance of dryfall as well as in the enrichment of Ca and K in wet deposition. The large amount of NO_3^--N in dryfall confirms earlier reports of its importance as a form of nutrient deposition from the atmosphere in chaparral systems (Christensen 1973, Schlesinger and Hasey 1980, also Hart and Parent 1973).

Dry fallout is derived from a number of processes including long range atmospheric transport and the suspension of soil particles from the local environment. We attempted to separate the importance of the suspension of soil dust from the local area, by expressing monthly dryfall deposition as a function of monthly windflow and using the Y-intercept of this regression to represent dry sedimentation in conditions of no wind (cf. Munn and Rodhe 1971). Unfortunately, none of these regressions was statistically significant. During the course of our study there were few fires in the Santa Ynez Mountains; we noted no unusual depositions of nutrients during one large fire in October 1979, such as have been reported in studies in other regions (Clayton 1976).

Monthly deposition in wetfall and dryfall is summed to give monthly total deposition. Total monthly depositions are significantly correlated with monthly precipitation for most ions; the correlation coefficients are higher for Mg (r = 0.89* ± .17) and Na (r = 0.93* ± .12) than for Ca (r = -0.06 ± .20), K (r = 0.77* ± .12), NH_4^+-N (r = 0.52 ± .30) and NO_3^--N (r = 0.69* ± .20), though the 95 percent confidence intervals show overlap among some pair-wise comparisons. The magnitude of these coefficients suggests the extent to which monthly depositions vary between the wet and dry seasons in California. Thus, Na and Mg, which are not diluted by increasing rainfall volume, tend to be derived from precipitation in winter storms, whereas dryfall is important for the latter group. The low correlation coefficient for Ca suggests substantial deposition in months with little or no rain, presumably as a result of more airborne dust from local soils.

Total monthly deposition values were summed to give yearly deposition (table 1). Depositions are higher during 1979-1980, reflecting the greater rainfall received, but also as a result of greater dryfall. Together with the annual deposition values extrapolated from 1977 collections by Schlesinger and Hasey (1980), these values give an indication of the annual range in deposition to be expected in the chaparral of the Santa Ynez Mountains. As shown later, the variation is relatively insignificant when the importance of atmospheric deposition is assessed in terms of other nutrient fluxes in these ecosystems.

*P< 0.05

Comparison Between Collectors

The Hubbard Brook collector as developed by Likens et al. (1967, 1977) has been widely used in their ecosystem studies in New Hampshire to collect "bulk precipitation," the composite of wet and dry processes as defined by Whitehead and Feth (1964). As a result of the reliability of the Hubbard Brook collector and other advantages, Galloway and Likens (1976, 1978) advocate its use and employ it as a standard for the comparison of more elegant collectors. In the present study, the volume of precipitation per storm measured by the U.S. Weather Bureau raingage was highly correlated with the volume measured by both the wetfall bucket of the automatic rain collector (r = 0.99) and the Hubbard Brook collector (r = 0.99), but these collectors underestimated the volume by an average of 6 percent and 8 percent, respectively, over the range of storms sampled. In a recent comparative study, Bogen et al. (1980) also found that this model of automatic rain collector underestimated rainfall by 4 percent.

For ions other than Na and Mg, we found poor correlations between the total monthly deposition as measured in the Hubbard Brook collector and the sum of wet and dry depositions in the automatic rain collector (table 2). An initial interpretation of the data suggests that the Hubbard Brook gage and the automatic rain collector differ mainly as a result of different efficiency of collection for elements with a strong dryfall component. For most ions the automatic rain collector records higher depositions at the lower range of depositions, but the opposite is true at higher levels of deposition (cf. magnitudes of slope and intercept

Table 2-- Correlation between monthly depositions (mg/m^2) received in the Hubbard Brook collector (bulk precipitation) and in the sum of wet and dry fall (total deposition) in the automatic raingage. Slope and intercept are the factors "m" and "b" in the linear equation:

"Total deposition = m (bulk precipitation) + b."

The converse model offers no different interpretations of data. Also given are weighted average concentrations (mg/1) in bulk precipitation.

	Ca	Mg	K	Na	NH_4^+-N	NO_3^--N
r	0.48	0.98*	-0.10	0.95*	0.48	0.84*
Slope	0.32	0.70*	-0.03	0.79*	1.17	0.84*
Intercept	13.44	2.10	7.51	2.16	1.49	4.07
Weighted Average Concentrations	0.20	0.15	0.14	0.94	0.02	0.12

* P < 0.05

Table 3-- Sources and loss of nutrients from chaparral ecosystems.

Process	Ca	Mg	K	N	P
Input:	------kg/ha/yr--------				
Precipitation[1]	1.9	1.0	0.6	1.5	-
N-fixation[2]	-	-	-	1.1	-
Outputs, mature stand:					
Runoff[3]	0.9	0.6	0.6	0.3	0.1
Outputs, post-fire:					
Runoff[3]	67	32	27	15	3.5
Volatilization[4]	-	-	48	146	-
Indicated Replacement time for first year losses after fire (yr)	35	32	125	62	

[1]Present Study

[2]Kummerow et al., 1978; Ellis, pers. comm., 1980

[3]DeBano and Conrad 1976

[4]DeBano and Conrad 1978

in table 2). For Na and Mg, however, the Hubbard Brook collector yielded higher estimates of deposition than the automatic rain collector over most of the range of depositions recorded. Bogen et al. (1980) found that for various ions the automatic rain collector recorded depositions typically 10 percent lower than other collectors. We make no presumptions as to which collector is the more accurate, but in view of the increased sophistication and interpretation to be gained from the separation of deposition processes, the automatic rain collector seems preferable despite its higher cost. Notwithstanding, the annual weighted average concentrations calculated for the bulk precipitation collector in this study (table 2) are similar to those measured using these collectors in an earlier study in the Santa Ynez Mountains (Schlesinger and Hasey 1980).

NUTRIENT BALANCE IN CHAPARRAL ECOSYSTEMS

In mature chaparral there is a large pool of most nutrients in the soil, but in the case of nitrogen, only a small portion is potentially mineralizable and available for plant uptake (Marion et al., in press). Nevertheless, atmospheric deposition can contribute only a small portion to the annual uptake of nutrients from the soil in mature chaparral. For example, in Adenostoma chaparral in San Diego County, annual uptake of nitrogen is estimated at 3.4 to 8.2 g/m^2 (Mooney and Rundel 1979, Marion et al., in press). In the Santa Monica Mountains of Los Angeles County, Gray (1981) measured 7.5 $g/m^2/yr$ nitrogen uptake from the soil to the aboveground portion of a 22-year-old stand of Ceanothus megacarpus. In both cases, the uptake greatly exceeds the estimated total atmospheric deposition of 0.1 to 0.2 $g/m^2/yr$.

If our results are representative of various chaparral areas in southern California, the total atmospheric deposition of nutrients equals or exceeds the annual losses which have been reported in runoff from mature, undisturbed chaparral (e.g., table 3). The thick charcoal-rich varves in the sediments of the Santa Barbara Basin are indicative of the large losses of debris following fires in the chaparral through many millennia (Byrne et al. 1977). DeBano and Conrad (1976, 1978) have measured the losses of nutrients by volatilization in fire and by accelerated runoff after fire for a typical stand of burned chaparral in Santa Barbara County (table 3). The losses greatly exceed the annual inputs from the atmosphere and indicate that more than 60 years may be needed to replenish the nitrogen losses from a single fire. A long replacement time is also indicated for K, based on atmospheric sources; however, substantial quantities of this element are also likely to be replenished by mineral weathering, which is not yet quantified for chaparral ecosystems. Considering chaparral ecosystems on a regional basis, it would be instructive to know the extent to which volatile losses in burned areas result in added deposition in adjacent unburned areas.

There are a number of ways in which these estimates should be improved, including continued regional monitoring and increased study of the importance of nitrogen-fixing processes. To the extent that atmospheric deposition of nutrients is derived from soil dust suspended from the local area, estimates of the atmospheric deposition of ions are greater than the actual input of new quantities of these elements for plant growth. Unfortunately, there is no obvious way to eliminate this overestimate. On the other hand, estimates of deposition derived from open collectors are underestimates to the extent that chaparral shrubs intercept aerosols and fog water from the horizontal airstream (Schlesinger and Hasey 1980).

Atmospheric pollution by oxides of nitrogen which are later deposited as NO_3^--N in rainfall may have a stimulating effect on chaparral growth in nutrient-poor sites. Morgan and Liljestrand (1979) reported rainfall concentrations for a variety of sites in the Los Angeles Basin; in the San Gabriel Mountains, concentrations of NH_4^+-N and NO_3^--N in wetfall were 25 and 10 times higher than our values for the Santa Ynez Mountains. The effects of this additional nutrient input, balanced against deleterious effects such as rainfall acidity, have yet to be evaluated.

ACKNOWLEDGMENTS

We thank Mavis Hasey for help in field and laboratory aspects of this project and Norman L. Christensen, Leonard F. DeBano and Lochlan Rose for critical reviews of an earlier draft of this manuscript. We thank owners and personnel of Laurel Springs Ranch for their kindness in allowing us to maintain the weather station on their property. These investigations were supported by grants from the Academic Senate of the University of California and NSF Grant DEB-79-11753 to the University of California, Santa Barbara.

LITERATURE CITED

Bauer, H.L. Moisture relations in the chaparral of the Santa Monica Mountains, California. Ecol. Monogr. 6: 409-454; 1936.

Bogen, D.C.; Nagourney, S.J.; and Torquato, C. A field evaluation of the HASL wet-dry deposition collector. Water, Air, Soil Poll. 13: 453-458; 1980.

Byrne, R; Michaelsen, J.; Soutar, A. Fossil charcoal as a measure of wildfire frequency in southern California: A preliminary analysis. In: Mooney, H.A.; Conrad, C.E., eds. Symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. Washington: U.S. Forest Serv; 1977: 361-367.

Christensen, N.L. Fire and the nitrogen cycle in California chaparral. Science 181: 66-68; 1973.

Clayton, J.L. Nutrient gains to adjacent ecosystems during a forest fire: an evaluation. Forest Science 22: 162-166; 1976.

DeBano, L.F.; Conrad, C.E. Nutrients lost in debris and runoff water from a burned chaparral watershed. In Proceedings of the third federal interagency sedimentation conference Denver, Colorado; 1976.

DeBano, L.F.; Conrad, C.E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59: 489-497; 1978.

DeBano, L.F.; Eberlein; G.E.; Dunn, P.H. Effects of burning on chaparral soils. I. Soil nitrogen. Soil Sci. Soc. Amer. J. 43: 504-509; 1979.

Galloway, J.N.; Likens, G.E. Calibration of collection procedures for the determination of precipitation chemistry. Water, Air and Soil Poll. 6: 241-258; 1976.

Galloway, J.N.; Likens, G.E. The collection of precipitation for chemical analysis. Tellus 30: 71-82; 1978.

Gatz, D.F.; Dingle, A.N. Trace substances in rain water: concentration variations during convective rains, and their interpretation. Tellus 23: 14-27: 1971.

Georgii, H -W.; Wötzel, D. On the relation between drop size and concentration of trace elements in rainwater. J. Geophys. Res. 75: 1727-1731; 1970.

Glass, S.J.; Matteson, M.J. Ion enrichment in aerosols dispersed from bursting bubbles in aqueous salt solutions. Tellus 25: 272-280; 1973.

Gorham, E. Factors influencing supply of major ions to inland waters, with special reference to the atmosphere. Bull. Geol. Soc. Amer. 72: 795-840.; 1961.

Gray, J.T. Comparative nutrient relations in adjacent stands of chaparral and coastal sage scrub. Proceedings of the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

Hart, G.E.; Parent, D.R. Chemistry of throughfall under Douglas fir and rocky mountain juniper. Amer. Midi. Natur. 92: 191-201; 1974.

Hellmers, H.; Bonner, J.F.; Kelleher, J.M. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80: 189-197; 1955.

Kennedy, V.C.; Zellweger, G.W.; Avanzino, R.J. Variation of rain chemistry during storms at two sites in northern California. Water Resour. Res. 15: 687-702; 1979.

Kummerow, J; Alexander, J.V.; Neel, J.W.; Fishbeck, K. Symbiotic nitrogen fixation in *Ceanothus* roots. Amer. J. Bot. 65: 63-69; 1978.

Lewis, W.M.; Grant, M.C. Sampling and chemical interpretation of precipitation for mass balance studies. Water Resour. Res. 14: 1098-1104; 1978.

Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Pierce, R.S. The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem. Ecology 48: 772-785; 1967.

Likens, G.E.; Bormann, F.H.; Pierce, R.S.; Eaton, J.S.; Johnson, N.M. Biogeochemistry of a forested ecosystem. New York: Springer; 1977. 146 p.

Marion, G.M.; Kummerow, J; Miller, P.C. Predicting nitrogen mineralization in chaparral soils. Soil Sci. Soc. Amer. J., in press.

Mason, B. Principles of geochemistry. 3rd. ed. New York: Wiley; 1966. 329p.

Miller, P.C.; Poole, D.K. Patterns of water use by shrubs in southern California. Forest Science 25: 84-98; 1979.

Mooney, H.A.; Rundel, P.W. Nutrient relations of the evergreen shrub, *Adenostoma fasciculatum*, in the California chaparral. Bot. Gaz. 140: 109-113; 1979.

Morgan, J.J.; Liljestrand, H.M. Measurement and interpretation of acid rainfall in the Los Angeles Basin. Final report to the California Air Resources Board, Mimeographed: 1980. 54 p.

Munn, R.E.; Rodhe, H. On the meteorological interpretation of the chemical composition of monthly precipitation samples. Tellus 23: 1-13; 1971.

Ogden, G.L. Differential response of two oak species to far inland advection of sea-salt spray aerosol. Univ. Calif., Santa Barbara: Ph.D. Dissertation; 1975 230p.

Raison, R.J. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: a review. Plant Soil 51: 73-108; 1979.

Schlesinger, W.H.; Hasey, M.M. The nutrient content of precipitation, dry fallout, and intercepted aerosols in the chaparral of southern California. Amer. Midi. Natur. 103: 114-122; 1980.

Schlesinger, W.H.; Hasey, M.M. Decomposition of chaparral shrub foliage: losses of organic and inorganic constituents from deciduous and evergreen leaves. Ecology 62: in press; 1981.

Whitehead, H.C.; Feth, J.H. Chemical composition of rain, dry fallout, and bulk precipitation at Menlo Park, California, 1957-1959. J. Geophys. Res. 69: 3319-3333; 1964.

Biological Dinitrogen Fixation in Chaparral[1]

Mark Poth[2]

Abstract: Presently available data indicate that biological dinitrogen fixation is responsible for the greatest proportion of nitrogen entering chaparral ecosystems. Dinitrogen fixation by the Rhizobium-legume symbioses is relatively unimportant in chaparral when compared to the possible substantial fixation by free-living soil bacteria and the Frankia-woody shrub (Ceanothus) symbioses. At present, estimates of these processes are scant. Site degradation is possible if management practices adversely affect biological dinitrogen fixation.

Nitrogen is lost from Mediterranean-type ecosystems through many mechanisms. These include fire-induced volatilization, sediment and erosional losses (DeBano and Conrad 1978), nitrate-nitrogen lost in runoff and leaching waters (Riggan and Lopez 1981, Vitousek and Melillo 1979), and denitrification. Some of these processes have been studied extensively. For example, more is known of the magnitude of fire volatilization losses and the effects of variables such as fire intensity and time of year in which the burn occurs (DeBano and Conrad 1978, Christensen and Muller 1975, Hanes 1971), than of any other mechanisms of nitrogen loss, such as denitrification, which remains unquantified in the Mediterranean ecosystems. Historical records, ocean cores, and geological evidence indicate that in southern California chaparral these loss mechanisms have been operating for millennia (Byrne and others 1977, Vogl 1977). The flux of nitrogen out of chaparral ecosystems is evidently large and ongoing; yet chaparral, though low in nitrogen, is not completely impoverished, as might be expected. Nitrogen inputs into the system then must be high enough to allow for this degree of ecosystem resiliency. Consequently, nitrogen inputs are one of the important factors which determine the resiliency of Mediterranean-type ecosystems to various management manipulations.

Ecosystem nitrogen inputs fall into three general categories. The first is the industrial-commercial synthesis of nitrogen fertilizers via the Haber-Bosch process (Finneran and Czuppon 1979). This process consumes large amounts of energy, usually in the form of natural gas or electricity, which renders the widespread use of fertilizers on Mediterranean-type ecosystems economically unfeasible--both now and in the future. The second major category is aerial inputs, discussed elsewhere in this Proceedings. Lastly, there is biological dinitrogen fixation.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Microbiologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

ENZYMOLOGY

Only specific bacteria, blue-green algae, and actinomycetes (all procaryotic microorganisms) are able to synthesize the nitrogenase enzyme and fix dinitrogen. The active enzyme consists of two protein subunits: the smaller subunit is the iron protein, the larger is the molybdenum-iron protein. The intact enzyme catalyzes the reduction of atmospheric dinitrogen to ammonium, which can then be used in biosynthetic pathways to produce proteins, nucleic acids, and other biomolecules as required. Nitrogenase is not highly specific and will reduce other substrates, for example, hydronium ions to dihydrogen. This represents a net energy loss if the dihydrogen is evolved to the atmosphere. Azide, nitrous oxide, acetylene, and many other substrates may be reduced by nitrogenase (Burris 1979). The reduction of acetylene to ethylene forms the basis of the most widely used technique for the determination of nitrogenase activity (Hardy and others 1971); the reduction is quantified by standard gas chromatography. The technique is advantageous in that it is very sensitive and fairly simple to use (Sprent 1979). Acetylene reduction rates can be used as an index of dinitrogen fixation for relative comparisons.

The heavy isotope of nitrogen ^{15}N can also be used to measure dinitrogen fixation. This technique requires much more time, technical skill, and access to a mass spectrometer. Some work has been done with the radioactive isotope of nitrogen ^{13}N, but its use is severely hampered by a short (10.5 min) half-life; the laboratory must be very close to a cyclotron producing the isotope, and few laboratories are so situated (Sprent 1979).

Several factors affect nitrogenase activity and biosynthesis. The partial pressure of oxygen must be low. Oxygen may be low in the environment or may be regulated by the synthesizing organism. Oxygen diffusion into the site of nitrogenase activity may be restricted by specialized structures such as the heterocysts of blue-green algae, or it may be sequestered by specialized compounds such as leghemoglobin. Ammonium and nitrate levels must be low, since mineral nitrogen inhibits nitrogenase activity. The organism must have a readily available energy source since the reduction of dinitrogen is a highly energy-demanding

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

process (Gutschick 1978). Finally, moisture, pH, and temperature conditions must be favorable for the organism.

DINITROGEN FIXATION BY LEGUME-RHIZOBIUM SYMBIOSES

Legumes (members of the family Fabaceae) form symbiotic associations with bacteria of the genus *Rhizobium.* Root nodules are formed by a complex infection process, involving the production by *Rhizobium* of enzymes that degrade the plant cell wall and of plant hormones (Dart 1977). The host specificity of the rhizobia is used as a major taxonomic criterion (Vincent 1977). Once the bacteria have infected the root cells, these proliferate to form the root nodule. Many nodule cells are filled with rhizobia. Most of the bacteria within the root cell convert to the bacteroid form: enlarged, pleomorphic rhizobia which contain nitrogenase. Bacteroids have not been cultured on laboratory media. In this symbiosis, the plant supplies carbohydrate energy to the bacteria in the root nodules. The bacteria use a portion of this carbohydrate to "fix" atmospheric dinitrogen into forms which are usable by the plant. Historically, this symbiosis has been used to improve fertility through crop rotation systems (Delwiche 1978). Recently, much effort has been spent to maximize dinitrogen fixation by agronomic species as well as to encourage the use of new and different legume species as crops (Delwiche 1978, Hardy and others 1971). The most notable success in improving dinitrogen fixation of a crop has been achieved with soybeans. The annual fixation by many agronomic legume species is substantial (table 1).

Table 1--A comparison of dinitrogen fixation by agronomic and chaparral legumes.

Plant	Acetylene reduction rate[1]	Total N fixed
		kg/ha/yr
Agronomic species:[2]		
Glycine max	7.3	103
Medicago sativa	15.1	54 to 463
Pisum sativum	17.4	52 to 77
Chaparral species:[3]		
Lotus scoparius	0.17	9 to 40
Lupinus excubidus	0.66	24
Lupinus longifolius	0.25	--
Lupinus polycarpus	0.32	--

[1]Expressed as micromoles/hr/g fresh weight nodule.

[2]From Torrey (1978).

[3]From Poth (1980).

Legumes are common in chaparral postfire, and extensive stands may develop (Poth 1980, Hanes 1971). The genera *Lotus* and *Lupinus* are often observed. As time progresses, these species became increasingly rare. *Lupinus arboreus* Sims stands in New Zealand have been shown to fix between 84 and 107 kg-N/ha/yr (Sprent and Sylvester 1973, Gadgil 1971). Lupines and other legumes in chaparral are routinely well nodulated. These nodules have the pink color of leghemoglobin and demonstrate the ability to reduce acetylene, which is indicative of nodulation with an effective strain of *Rhizobium* (Hardy and others 1973, Vincent 1970). In a recent study summarized in table 1, four chaparral legume species--Lupinus *excubidus* Jones var. *Hallii*, *Lupinus longifolius* Abrams, *Lupinus polycarpus* Greene, and *Lotus scoparius* ssp. *scoparius* Nutt. in T. and G.--were assayed for their ability to fix nitrogen under greenhouse conditions (Poth 1980).

The estimated total nitrogen fixed by these chaparral legume species is much lower than that of agronomic legume species. The reason may lie in the agronomic species themselves. Considerable effort by agronomists and plant geneticists has gone into artificially selecting plants and rhizobial strains for optimum dinitrogen fixation (Delwiche 1978, Gutschick 1978). Alternatively, the selective forces in the chaparral environment are such that a high dinitrogen fixation rate is not a primary selection criterion. Legumes are most abundant in chaparral immediately following a fire, and their numbers decline as the stand matures (Poth 1980, Hanes 1971). In the postfire environment, soil mineral nitrogen levels are at their highest (Christensen and Muller 1975, DeBano and Conrad 1978). Nitrogen does not limit plant growth during the first few years following fire (Hellmers and others 1955), and there is apparent luxury consumption of this nutrient (Rundel and Parsons 1980). Legumes using the readily available soil mineral nitrogen pool and not expending energy to fix nitrogen would be able to put more energy into reproduction, and hence be at a selective advantage. In addition, mineral nitrogen depresses nitrogen fixation activity (Burris 1979). This would most likely result in the selection of rhizobial strains which would be readily infective, easily forming nodules, but there would be no selection for dinitrogen fixation. Legumes are rare in chaparral stands during the period between fires. Rhizobia must then exist for extended periods as free-living soil bacteria. Selection then occurs for those organisms best able to survive as free-living soil bacteria.

The overall contribution by the prevailing legumes at a particular site depends on water availability (Sprent 1976). A dry year substantially reduces net nitrogen fixation. Soil temperature also affects net fixation. Lower soil temperatures decrease nitrogen fixation. With all environmental factors considered, chaparral legumes are able to fix only a small proportion of the nitrogen that is lost in fire, erosion, denitrification, runoff, and leaching.

DINITROGEN FIXATION BY ANGIOSPERM-*FRANKIA* SYMBIOSES

Symbiotic associations are found between soil bacteria belonging to the family Actinomycetes (*Frankia* sp.) and a large and diverse group of woody dicotyledonous plants (Torrey 1978). Some of the plants involved and their distribution are summarized in table 2. *Ceanothus*, a common genus throughout western North America, forms symbioses with *Frankia* sp. In forests of the Pacific Northwest, *Ceanothus velutinus* Dougl. has been shown to fix 56 kg-N/ha/yr (Youngberg and Wollum 1976). Kummerow and others (1978) investigated dinitrogen fixation by *Ceanothus greggii* var. *perplexans* and *Ceanothus tomentosus* in southern California chaparral. First-year seedlings of *C. tomentosus* were found to be infrequently and poorly nodulated with no dinitrogen fixation capacity. This is most likely due to the elevated soil ammonium and nitrate levels after fire (Christensen 1973, Christensen and Muller 1975, Hellmers and others 1955). Both ammonium and nitrate are inhibitors of nodulation and dinitrogen fixation (Burris 1979). These elevated levels of available mineral nitrogen have been shown to promote luxury consumption of nitrogen in *Adenostoma fasciculatum* H. & A. and *Ceanothus leucodermis* Greene (Rundel and Parsons 1980). A 25-year-old stand of *C. greggii* was shown to fix but 0.1 kg-N/ha/yr, an amount comparable to the leaching loss (Kummerow and others 1978). This low level may be caused by the general loss of vigor in these older plants.

Excavations of *Ceanothus crassifolius* Torr. seedlings have been made every year since 1976 in the area burned by a November 1975 wildfire. In 1976, 1977, and 1978, few nodulated plants were found. Those plants that were nodulated typically had but one nodule, and these were very small, in all cases being less than 0.5 g fresh weight. This situation changed dramatically in spring 1979. Excavations at that time revealed that nearly all seedlings were nodulated. The plants had from two to five nodule clusters each. The fresh weight of each cluster was in the 2 to 5 g range; the largest nodules approaching 10 g fresh weight. Field acetylene reduction assays showed these nodules to be actively fixing dinitrogen.

The point at which dinitrogen fixation drops to 0.1 kg-N/ha/yr observed by Kummerow and others (1978) is crucial to any overall estimates of dinitrogen fixation by *Ceanothus* spp. in chaparral. At present, this remains to be investigated. *Ceanothus* fixation may prove to be substantial. An estimation of the magnitude of *Ceanothus* fixation in chaparral can be gained from the data of Zinke (1969) (table 3). These data indicate a net fixation of 49 kg-N/ha/yr for lysimeter-grown *C. crassifolius* over a 13-year period. As is characteristic of plants that form nitrogen-fixing symbioses, the tissue levels of nitrogen in *C. crassifolius* are high. This is reflected in the larger amounts of nitrogen sequestered in the stems and leaves of *C. crassifolius* than in the leaves and stems of other

Table 2--Plants that form root nodules following actinomycete infection, with their relationships and distribution (From Torrey 1978).

Genus (family)	Species nodulated/ total species in genus	Geographical distribution	Ecological sites
Alnus (Betulaceae)	33/35	Europe, Siberia, N. America, Japan, Andes	Poor soils, sand hills/ dunes, glacial till, wet bogs, mine dumps, gravel, wasteland, volcanic ash
Casuarina (Casuarinaceae)	24/45	Australia, tropical Asia, Pacific Islands, widely introduced elsewhere	Sand dunes, salt marshes, tropical forests, desert areas
Ceanothus (Rhamnaceae)	31/55	N. America especially western U.S.	Dry forest and chaparral, subalpine zones
Cercocarpus (Rosaceae)	4/20	Western U.S. and Mexico	High altitudes poor soils
Colletia (Rhamnaceae)	1/17	S. America (cf. Bond 1976)	
Comptonia (Myricaceae)	1/1	N. America	Disturbed sandy or gravelly areas
Coriaria (Coriariaceae)	13/15	Mediterranean to Japan, New Zealand, Chile, to Mexico	Lowlands and subalpine, sandy, or gravelly soils or clay
Discaria (Rhamnaceae)	2/10	Andes, Brazil, New Zealand, Australia	gravelly soils, arid zones
Dryas (Rosaceae)	3/4	Alaska, Canada, circumpolar	Postglacial areas, sandy, gravelly soils
Elaeagnus (Elaeagnaceae)	16/45	Asia, Europe, N. America	Disturbed areas, sand dunes, poor soils
Hippophae (Elaeagnaceae)	1/3	Asia, Europe, from Himalayas to Arctic Circle	Sand dunes, coastal areas
Myrica (Myricaceae)	26/35	Many tropical, subtropical, and temperate regions, extending to Arctic Circle	Acidic bogs, sand dunes, mine wastes
Purshia (Rosaceae)	2/2	Western N. America	Dry sandy soils, as understory plant in *Pinus* forest

species (table 3). Should fixation occur in natural stands at a rate of 49 kg-N/ha/yr, fire losses would be alleviated by Ceanothus fixation gains.

DINITROGEN FIXATION BY FREE-LIVING MICROORGANISMS

Bacteria and blue-green algae (Cyanobacteria) are able to fix dinitrogen. For fixation by these organisms to occur, the following conditions must be met: there must be a sufficient supply of available carbohydrate, or light to produce carbohydrate as the case of Cyanobacteria; levels of ammonium and nitrate must be low; oxygen must be at low partial pressures; and moisture, temperature, and pH must fall within acceptable ranges (Mulder 1979, Granhall 1979, Gutschick 1978, Peters 1978). These conditions might be met in chaparral with the first rains of the winter. Carbon availability would be at its peak after the spring and summer litter fall. The water of the first rains would immediately stimulate rapid growth of the soil microflora (Winn 1977). With this growth, much of the available ammonium and nitrate would be immobilized. Oxygen tension would become reduced as a result of rapid respiration. These factors could combine to promote transient free-living dinitrogen fixation in chaparral. This is one possible explanation for the nitrogen gains in lysimeter studies with Quercus dumosa Nutt. and Eriogonum fasciculatum Benth. (Zinke 1969) (table 3). The nitrogen accumulations seen in chaparral soils under E. fasciculatum and Q. dumosa support the hypothesis that free-living soil bacteria fix substantial amounts of dinitrogen in chaparral. Zinke's data indicate free-living bacterial dinitrogen fixation rates of 38 kg-N/ha/yr in soil under Q. dumosa, and 32 kg-N/ha/yr in soil under E. fasciculatum.

CONCLUSION

Nitrogen is one of many factors which will determine the resiliency of chaparral to various management practices. Nitrogen management must be considered in prescribed burning plans. Should ecosystem nitrogen levels be allowed to drop, water quality (Riggan and and Lopez 1981), erosion, and browse quality could all be adversely affected. If nitrogen inputs can be managed in such a fashion that they equal or exceed losses, then the ecosystem should be highly resilient, allowing land managers greater flexibility in proposed management programs.

The data I have presented seem to support the following hypotheses concerning dinitrogen fixation in chaparral:

1. Symbiotic dinitrogen fixation by chaparral legumes is insignificant in relation to ecosystem losses, because chaparral legumes are inherently poor dinitrogen fixers and their presence is short lived. (Lotus scoparius may be an exception since it is present for up to 10 years.)

2. Nodulation and dinitrogen fixation by Ceanothus spp. in the first few years following fire is repressed to very low levels by elevated soil mineral nitrogen. Once soil mineral nitrogen

Table 3--Nitrogen balance of chaparral stands in San Dimas lysimeters after 13 years (From Zinke 1969).

Part of system	Nitrogen balance, by cover type					
	Original soil	Barren	Adenostoma fasciculatum	Eriogonum fasciculatum	Quercus dumosa	Ceanothus crassifolius
	Grams-N/m2[1]					
Vegetation:						
Leaves	0	0	2.4	1.6	1.9	11.5
Stems	0	0	2.8	9.0	4.2	18.1
Total	0	0	5.2	10.6	6.1	29.6
Leaf litter	0	0	3.2	30.0	17.9	32.4
Mineral soil to 122 an	318.0	283.8	278.5	318.8	343.6	320.1
Total	318.0	283.8	286.9	359.4	367.6	382.1
Change from original condition		-34.2	-31.1	+41.4	+49.6	+64.1

[1]To convert to kg/ha, multiply by 10; to lb/acre, multiply by 11.2.

levels have dropped, symbiotic dinitrogen fixation by Ceanothus is substantial.

3. Dinitrogen fixation by free-living soil and litter bacteria associated with scrub oak (Quercus dumosa) and California buckwheat (Eriogonum fasciculatum) is substantial.

LITERATURE CITED

Bond, G. The results of the IBP survey of root-nodule formation in nonleguminous angiosperms. In: Nutman, P. S., ed. Symbiotic nitrogen fixation in plants. Cambridge: Cambridge Univ. Press; 1976: 443-474.

Burris, Robert H. Inhibition. In: Hardy, R. W. F.; Bottomley, Frank; Burns, R. C., eds. A treatise on dinitrogen fixation, sec. I and II. New York: John Wiley and Sons; 1979: 569-604.

Byrne, Roger; Michaelsen, Joel; Soutar, Andrew. Fossil charcoal as a measure of wildfire frequency in southern California: a preliminary analysis. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. W0-3; 1977; 361-367.

Christensen, Norman L. Fire and the nitrogen cycle in California chaparral. Science 181:66-68; 1973.

Christensen, Norman L.; Muller, C. Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45:29-55; 1975.

Dart, P. Infection and development of leguminous nodules. In: Hardy, R. W. F.; Silver, W. S., eds. A treatise on dinitrogen fixation, sec. III. New York: John Wiley and Sons; 1977: 367-472.

DeBano, Leonard F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

Delwiche, C. C. Legumes--past, present, and future. Bioscience 28(9):565-570; 1978.

Finneran, J. A.; Czuppon, T. A. Economics of production and consumption of ammonia. In: Hardy, R. W. F.; Bottomley, Frank; Burns, R. C., eds. A treatise on dinitrogen fixation, sec. I and II. New York: John Wiley and Sons; 1979: 333-379.

Gadgil, R. The nutritional role of Lupinus arboreus in coastal sand dune forestry. III. Nitrogen distribution in the ecosystem before tree planting. Plant Soil 35:113; 1971.

Granhall, Ulf. Nitrogen fixation by blue-green algae in temperate soils. In: Stewart, W. P. D., ed. Nitrogen fixation by free-living micro-organisms. Cambridge: Cambridge Univ. Press; 1979: 189-198.

Gutschick, V. P. Energy and nitrogen fixation. Bioscience 28(9):571-575; 1978.

Hanes, T. L. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41(1):27-52; 1971.

Hardy, R. W. F.; Burns, R. C.; Herbert, R. R.; Holsten, R. D.; Jackson, E. K. Biological nitrogen fixation: a key to world protein. Plant and Soil Spec. Vol.; 1971: 561-590.

Hardy, R. W. F.; Burns, R. C.; Holsten, R. D. Application of the acetylene-ethylene assay for measurement of nitrogen fixation. Soil Biol. and Biochem. 5:47-81; 1973.

Hellmers, Henry; Bonner, James F.; Kelleher, John M. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80(3):189-197; 1955.

Kummerow, Jochen; Alexander, James U.; Neel, James W.; Fishbeck, Kathleen. Symbiotic nitrogen fixation in Ceanothus roots. Am. J. Bot. 65(1): 63-69; 1978.

Mulder, E. G. Physiology and ecology of free-living nitrogen-fixing bacteria. In: Stewart, W. D. P., ed. Nitrogen fixation by free-living micro-organisms. Cambridge: Cambridge Univ. Press; 1979: 3-28.

Peters, Gerald A. Blue-green algae and algal associations. Bioscience 28(9):580-585; 1978.

Poth, Mark. Legume N_2 (C_2H_2) fixation and nitrogen cycling in chaparral ecosystems. Fullerton, Calif.: Calif. State Univ.; 1980. 23 p. Dissertation.

Riggan, Philip J.; Lopez, Ernest. Nitrogen cycling in the chaparral ecosystem. In: Quinn, R.; Conrad, C. E., eds. Proceedings of the symposium on ecology and management of chaparral ecosystems, December 27-29, 1979, Pomona, California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep.; 1981; [in press].

Rundel, Philip W.; Parsons, David J. Nutrient changes in two chaparral shrubs along a fire-induced age gradient. Am. J. Bot. 67(1):51-58; 1980.

Sprent, Janet I. Water deficits and nitrogen fixing root nodules. In: Water deficits and plant growth, Vol. IV, Soil-water measurement, plant responses, and breeding for drought resistance. New York: Academic Press; 1976: 291-315.

Sprent, Janet I. The biology of nitrogen-fixing organisms. London: McGraw-Hill Book Co.; 1979. 196 p.

Sprent, Janet I.; Sylvester, W. B. Nitrogen fixation by Lupinus arboreus grown in the open and under different aged stands of Pinus radiata. New Phytol. 73:991-1003; 1973.

Torrey, John G. Nitrogen fixation by actinomycete-nodulated angiosperms. Bioscience 28(9):586-592; 1978.

Vincent, J. M. A manual for the practical study of root nodule bacteria. Blackwells, London: IBP Handb. 15; 1970. 164 p.

Vincent, J. M. Rhizobium microbiology. In: Hardy, R. W. F.; Silver, Warren S., eds. A treatise on dinitrogen fixation, sec. III. New York: John Wiley and Sons; 1977; 277-366.

Vitousek, Peter M.; Melillo, Jerry M. Nitrate losses from disturbed forests: patterns and mechanism. For. Sci. 25(4):605-619; 1979.

Vogl, Richard J. Fire frequency and site degradation. In: Mooney, H. A.; Conrad, C. E., eds.

Proceedings of the symposium on environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. W0-3; 1977; 193-201.

Winn, C. D. Litter decomposition in the California chaparral. Fullerton, Calif.: Calif. State Univ.; 1977. 59 p. Dissertation.

Youngberg, C. T.; Wollum, A. Nitrogen accretion in developing Ceanothus velutinus stands. Soil Sci. Soc. Am. J. 40:109-112; 1976.

Zinke, Paul J. Nitrogen storage of several California forest soil-vegetation systems. In: Biology and ecology of nitrogen. Washington, D.C.: Nat. Acad. Sci.; 1969: 40-53.

Productivity and Nutrient Cycling in the Early Postburn Chaparral Species *Lotus scoparius*[1]

Erik Tallak Nilsen[2]

Abstract: The frequent fires in southern California have a pronounced influence on many aspects of chaparral shrub communities, particularly nutrient relationships. Nutrient accumulation, and productivity were studied for the post fire species Lotus scoparius. This stand of Lotus scoparius was approaching maximum biomass yet there was significant net production and a large transfer of nutrients to the detrital compartment. These productivity and nutrient relationships suggest that early post-burn dominance by fast-growing deciduous perennials may be important for nutrient conservation following fire.

Nutrient circulation through the biomass of Southern California chaparral is most heavily influenced by frequent fires. The fire cycle of 20- to 40-year interval (Byrne et al., 1977) significantly disrupts the chaparral nutrient circulation (Gray & Schlesinger, 1981). Considerable quantities of nutrients, particularly carbon and nitrogen, are lost through volatilization and smoke during these frequent fires (DeBano and Conrad, 1978). The remaining nutrients are deposited on the soil surface as ash. These post-burn nutrients are in available forms subject to export from the community by leaching or by erosion (Christensen and Muller, 1975; DeBano and Conrad, 1978).

The nitrogen cycle is critical to the development of chaparral stands because chaparral soils tend to be poor in available nitrogen, and productivity of mature stands may be nitrogen-limited (Hellmers et al., 1955). Chaparral stands receive only limited inputs of nitrogen from atmospheric sources (1.0 kg of ha^{-1} yr^{-1}, Schlesinger and Hasey, 1980) and nitrogen fixation (0.1 kg ha^{-1} yr^{-1}, Kummerow et al., 1078). During a fire over 100 Kg ha^{-1} of nitrogen can be lost by volatilization and an additional 15 Kg ha^{-1} of nitrogen can be lost by erosion in the first year following a fire in a chaparral community with a biomass of 3000 g/m^2 (DeBano and Conrad, 1978). The nitrogen remaining on the site after volatilization is only a small portion of the nitrogen in a mature chaparral stand. Even though the total soil pool of nitrogen is large in chaparral regions, the concentrations of available soil nutrients below the surface ash are characteristically low. Since inputs of nitrogen into chaparral stands after a fire are small, the limitation of nitrogen export following a fire can be critical for later community development.

Deerweed was chosen for this investigation because of its ubiquitous distribution in southern California burn sites and because this species often dominates young post-burn chaparral regions. This investigation examined productivity and nutrient accumulation by deerweed in a four-year old post-burn site. The seasonality of productivity, phenology, and nutrient accumulation was evaluated, and a yearly nutrient budget was compiled for Lotus scoparius. These investigations were conducted to evaluate deerweed as a nutrient conserving agent in chaparral following fire. The nitrogen cycle in particular was investigated because of its critical influence on later community development.

SITE DESCRIPTION

A four-year-old post-burn site was chosen for this investigation in the Santa Ynez Mountains 10 km north of the Pacific Ocean near Santa Barbara, California. This was a southeast-facing slope of 15° at 800 m elevation. The soil texture was a sandy loam (65% sand, 25% silt and 10% clay) of sandstone parent material. Kjeldahl nitrogen content of the upper 10 cm was 1.6%, nitrate and ammonium ion concentrations were less than 1 $\mu g.g^{-1}$ dry weight, and organic matter was 8% by loss-on-ignition. Before the most recent fire in 1974 the site was dominated by Adenostoma fasciculatum (chamise). During this 1979 investigation, Lotus scoparius accounted for 40% cover and 22 other shrub species accounted for 45% cover. Annuals were of very low importance.

METHODS AND MATERIALS

Climatic measurements were made at 910 m elevation on a south slope 3 km east of the research site. Temperature and relative humidity were recorded with a hygrothermograph (Weathermeasure Model H311) and rainfall was measured with a standard 8-inch raingauge. Photoperiod

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-June 26, 1981, San Diego, California.

[2] Postdoctoral Researcher, University of California, Irvine, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

was calculated as the number of hours with an irradiance greater than 100 $\mu E \cdot m^{-2} \cdot sec^{-1}$.

A 0.5-ha plot was chosen in the center of the burn site and divided into 5 x 5 m quadrats. Three of these quadrats were randomly chosen to be used as permanent quadrats for phenology measurements. Within these permanent quadrats two to four canopy branches on each Lotus scoparius plant were labeled for phenological measurements. This resulted in 125 monitored canopy branches. Measurements of plant growth characteristics were made every two weeks from January 1979 to August 1979. Relative plant water relations were measured by determining predawn xylem pressure potential of Lotus scoparius at 2-week intervals on 25 canopy branches collected in the immediate proximity of the permanent quadrats.

Standing biomass and productivity were measured with a sequential harvest technique. Fifteen randomly chosen 1 x 1 m quadrats were harvested on five occasions from August 1978 to November 1979. All the Lotus scoparius plants were collected at ground level in each quadrat and the harvested quadrats were labeled to prevent resampling. Each harvest was separated into live wood, leaves, dead wood, and reproductive tissue, dried at 70°C in a forced air oven for 48 h, and weighed to obtain dry weight/area. Productivity was calculated from the increments in standing live biomass.

On each phenology sampling date, plant material was collected for tissue nutrient analysis. Five canopy branches were collected from 10 plants in each permanent quadrat. These were oven-dried at 70°C for 48 h and ground in a Wiley Mill. Phosphorus was determined by the molybdovanadate reaction and the cationic concentrations were determined by atomic absorption spectrophotometry (Likens and Bormann, 1970).

In addition, concentrations of nitrogenous compounds were analyzed in both dried and fresh samples. Immediately after milling, the dried samples were assayed for NO_3^-, NH_4^+, and total (Kjeldahl) nitrogen. Nitrate was determined by the "known addition" technique (Orion, 1977) using a nitrate-specific ion electrode (Orion Model 93-07). Total free and exchangeable ammonium ion was measured with an Orion ammonia electrode (Model 95-10). Kjeldahl nitrogen (total nitrogen less NO_3^-) was extracted with a micro-Kjeldahl technique (McKenzie and Wallace, 1954). The concentration of nitrogen in the digest was measured with the Orion ammonia-specific electrode.

RESULTS

Climatic conditions during 1979 were characteristic for this region of southern California. Temperature gradually increased from a mean minimum of 4°C in January to a mean maximum of 29°C in July (Figure 1). Along with the increase in temperature, vapor pressure deficit also increased to a maximum in July of 2.90 KPa. Rainfall began in December and continued through March resulting in a total of 37 cm. No precipitation occurred after March. The pre-dawn xylem pressure potential (a relative indication of water availability) increased to its least negative value in March indicating high moisture availability. After the precipitation stopped and the vapor pressure deficit began to increase, plant pre-dawn xylem pressure potential slowly decreased to the lowest value in August. These climatic data indicate low physiological stress from January to May and high physiological stress from June through August.

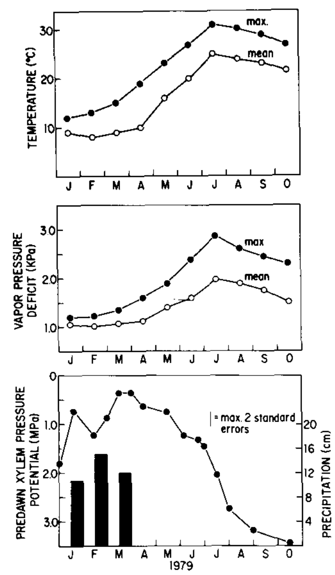


Figure 1. Climatic conditions for an elevation of 910 m in the Santa Ynez Mountains of southern California. Pre-dawn xylem pressure potentials are for a 4-year-old stand of Lotus scoparius subject to the represented climatic conditions.

One of the primary environmental cues for growth in deerweed is water stress (Nilsen and Muller, 1980a) as is shown by the phenology results (Figure 2). The number of leaves per branch is a general indication of the plants ability to capture carbon for biomass production in the absence of limiting environmental factors. The leaf number per branch increased to maximal values from May through June during the warmest period of the year (Figure 2).

Indexes of relative plant activity can be found through measurements of the rates of certain plant growth characteristics. The rate of leaf production indicates maximal plant activity in late February and May. The high leaf production rate in February is due to bud burst of many small leaves. Therefore maximum leaf production occurred during May. Similarly maximal shoot elongation occurred during May and early June as well as maximal flower production. These relative indicators of plant activity point to May through June as the period of greatest plant growth. Leaf abscission occurred very synchronously during late June and early July when the dawn xylem pressure potential reached -2.0 mPa. Previous experiments with deerweed phenology indicated that -2.0 mPa is a critical predawn xylem pressure potential for leaf abscission (Nilsen and Muller, 1980b). All the phenology indices indicate a precipitous decrease in plant activity functions incident with hot and dry climatic conditions.

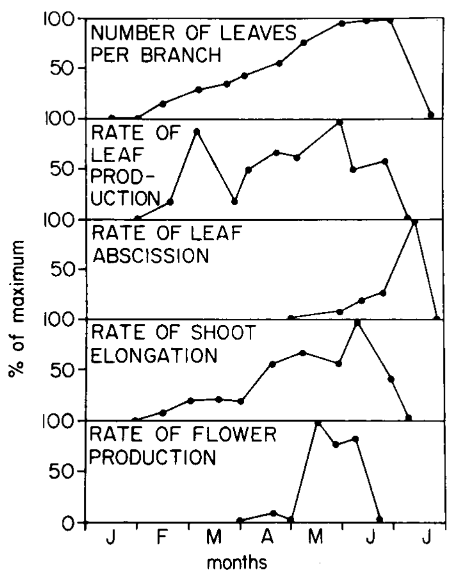


Figure 2. Phenological characteristics for a population of Lotus scoparius in the Santa Ynez mountains of Southern California, 1979.

The seasonal progression of biomass components (Figure 3) indicate a slow increase in biomass during the beginning of the growing season (January-March) followed by a sudden jump in deerweed biomass in May through June. The rapid increase in total biomass during May was due to the rapid increase in leaf biomass. Woody biomass increased at a constant rate from January through May. Following the dry season from July through October total biomass decreased to a value similar to the initial November biomass. The reduction in total biomass during the dry season is due to leaf fall and die hack of the woody compartment. These data indicate that this 4-year old stand of deerweed is close to a steady state biomass condition where net production is similar to litter fall.

Primary production of deerweed at this research site was characterized by similar magnitudes of stem-wood and leaf production (Table 1). Production of reproductive tissues

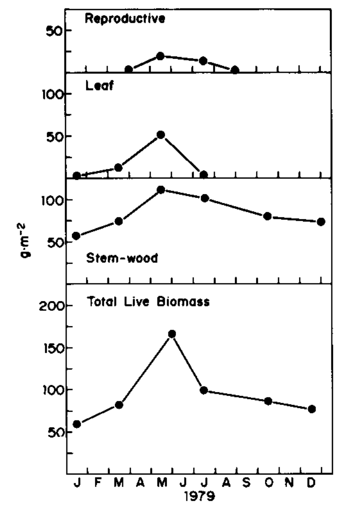


Figure 3. Seasonal changes in biomass components for a stand of Lotus scoparius in the Santa Ynez mountains of southern California, 1979.

was only one third that of stems and leaves. Detrital production (biomass of each component entering the litter layer) was a large portion of net production. All the leaf and reproductive biomass entered the litter layer in July and 28.5 OIL of stem wood died and entered the standing dead wood or the litter layer between July and October. This resulted in a small true increment of biomass equal to only 16.5% of net production (% retention in Table 1). The high productivity in relation to biomass results in a low biomass accumulation ratio. Indicating that the total biomass of this four-year-old (close to steady state) stand of deerweed can be turned over into the litter layer every 1.57 years.

Table 1. Net production characteristics of a 4-year-old post-burn Lotus scoparius population

Characteristic	Stem	Leaf	Fruit	Total
Max. Biomass (g/m^2)	105.6	42.1	16.7	164.4
Net Primary Production($g/m^2/yr$)	45.7	42.1	16.7	104.5
Detrital Production ($g/m^2/yr$)	28.5	42.1	16.7	87.3
True increment ($g/m^2/yr$)	17.2	0.0	0.0	17.2
% Retention ($g/m^2/yr$)	37.6	0.0	0.0	16.5
Biomass accumulation ratio (years)	2.31	—	—	1.57

$$\text{Biomass accumulation Ratio} = \frac{\text{maximum biomass}}{\text{net primary production}}$$

$$\% \text{ Retention} = \frac{\text{True increment}}{\text{net primary production}} \times 100$$

Yearly seasonal nutrient concentrations are shown in Figure 4 on a leaf area basis. The specific leaf weight increased dramatically from May through June when the vapor pressure deficit was highest and the plants were enduring greater water stress. The increase in specific leaf weight had significant influences on all nutrient concentrations. In particular Ca, Mg, and K increased greatly during this specific leaf weight increase. Nitrogen and phosphorus were the only measured nutrients which decreased in concentration during January through April. This decrease in N and P indicates that these nutrients were being diluted in the biomass, therefore, accumulation of N and P from root and soil resources may be limited later in the growing season.

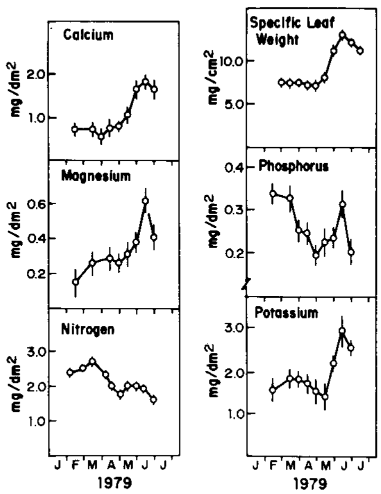


Figure 4. Seasonal concentrations of major nutrients in leaves of <u>Lotus scoparius</u> during 1979.

Stem nutrient concentrations show only small gradual seasonal nutrient changes. For this reason average nutrient concentration for stems and reproductive tissues are represented along with average leaf, deadwood, and abscissed leaf nutrient concentrations (Table 2). Only winter concentrations of N in stems were significantly higher than summer concentrations. Also, nutrient content of deadwood was insignificantly different from summer stem nutrient concentrations. Abscissed leaf concentrations of N, P, and K are significantly lower than the average leaf content on the plant, while calcium concentration is higher in abscissed leaves. This indicates that significant reabsorption of N, P, and K may occur from pools of these nutrients allocated to leaves before leaf abscission.

Nitrogen components were investigated separately because nitrogen may be an important limiting factor in chaparral vegetation (Figure 5). Total protein decreased throughout the growing season in accordance with total nitrogen.

Table 2. Average nutrient concentrations in above-ground biomass components for <u>Lotus scoparius</u>

Component	Ca	K	Mg	N	P
		% oven-dry weight			
Leaves	1.12 (0.17)	2.16 (0.15)	0.34 (0.05)	2.1 (0.54)	0.30 (0.06)
Abscised Leaves	1.53 (0.28)	1.30 (0.07)	0.46 (0.14)	1.0 (0.05)	0.07 (0.1)
Stem (summer)	0.38 (0.02)	0.75 (0.05)	0.12 (0.01)	0.85 (0.11)	0.09 (0.01)
stem (winter)	0.48 (0.04)	0.88 (0.10)	0.14 (0.01)	1.42 (0.24)	0.09 (0.01)
Dead wood	0.40 (0.02)	0.0 (0.05)	0.10 (0.01)	0.88 (0.10)	0.09 (0.01)
Flowers and Fruits	0.63 (0.20)	1.74 (0.20)	0.26 (0.06)	0.76 (0.25)	0.24 (0.06)

(   ) = 2 standard errors.

Ammonium ion content remained unchanged until the leaf specific weight increased. The seasonal cycle of nitrate ion concentration contrasted with that of the other components. During the end of the growing season nitrate increased in concentration more than the increase in specific leaf weight. Nitrate concentration in abscissed leaves was higher than leaves in July even though

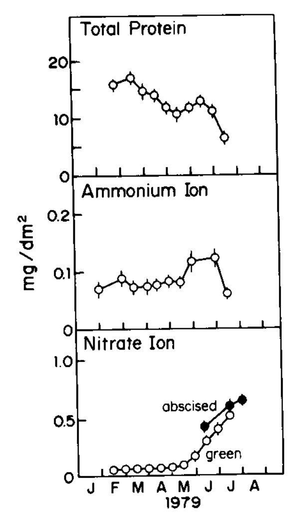


Figure 5. Seasonal concentrations of nitrogenous compounds in leaves of <u>Lotus scoparius</u> during 1979.

the specific leaf weight of abscissed leaves was lower than that of the leaves on the plant in July.

The ability of Lotus scoparius to accumulate nutrients in above-ground biomass and litter is an important part of this investigation. Table 3 represents the combination of net primary productivity and tissue nutrient concentration; yielding nutrient accumulation characteristics for this stand of Lotus scoparius. Accumulation of nutrients by this stand are lower than accumulation rates of local chaparral and coastal sage communities (Gray and Schlesinger, 1981a; Schlesinger and Gill, 1980) but they are higher than a stand of chamise chaparral (Mooney and Rundel 1979) which had a far greater biomass. The true increment of nutrients for Lotus scoparius at this site was low in all cases and the detrital production of nutrients was a large part of the total accumulation. Only P, N, and K had a percent retention in standing biomass close to 50% of the yearly accumulation. The less mobile Ca and Mg had very low retention in the standing live biomass.

Nitrogen and phosphorus are thought to be critical limiting factors for chaparral development (Hellmers et al., 1955) and large amounts of these nutrients are lost from chaparral following fire (DeBano and Conrad 1978). Therefore, a nitrogen and phosphorus budget has been composed for this stand of deerweed (Figure 6). Flux rates (transfers between compartments) for N and P were large in comparison to the pool size of each compartment. For example the N accumulation ratio in above-ground parts (biomass N-pool/N accumulation) was 1.78 years indicating that the above ground N-pool is replaced rapidly. Also, 0.65gm^{-2}of nitrogen was introduced as litter into the chaparral system and 41% of the accumulated nitrogen was transferred into the roots at the end of the growing season. This nitrogen and phosphorous budget then indicates

Table 3. Net production, maximum pool size, true increment, and total detrital production for dry weight and nutrients in a 4-year-old stand of Lotus scoparius.

Nutrients and units	Net primary production and nutrient accumulation				True increment	Detrital	% Retention
	stem	leaf	fruit	total			
Dry Weight ($g/m^2/y$)	45.7	42.1	16.7	104.5	17.2	87.3	16.5
Ca ($g/m^2/y$)	0.18	0.49	0.11	0.78	0.07	0.69	12
R	0.35	0.94	0.29	1.58	0.13	0.86	46
Mg	0.07	0.15	0.04	0.26	0.03	0.21	19
N	0.41	0.84	0.13	1.38	0.16	0.75	53
P	0.02	0.13	0.04	0.19	0.08	0.09	53

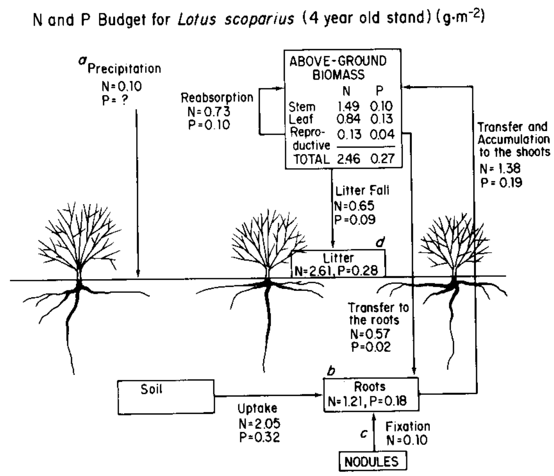


Figure 6. Nitrogen and Phosphorus budget for a stand of Lotus scoparius in the Santa Ynez Mountains of southern California, 1979. a = data from Schlesinger & Hasey 1980; b = Root biomass calculated from a lab derived Root to Shoot Ratio; c = data from Kummerow et al. 1978; d = assuming a litter residence time of 4 yr.

a nutrient cycle with short residence time in biomass components but considerable nutrient uptake from the environment.

DISCUSSION

The phenology, productivity, and nutrient accumulation data presented in this investigation clearly indicate that maximal plant activity occurs during the latter part of the growing season. Although the initial plant activity of deerweed occurs in February most productivity and nutrient accumulation occurs in May through June. Nitrogen and phosphorus are the only nutrients which indicate an initial accumulation in February through March and a dilution in the biomass during the maximum productivity period. High productivity during the late growing season is closely associated with increasing temperatures. Although deerweed has favorable water relations characteristics early in the growing season only limited productivity occurred during the period of low temperatures. Temperature has previously been found as a factor speeding physiological functions in deerweed (Nilsen 1980a).

There have been only few investigations of productivity and nutrient accumulation in southern California chaparral (Mooney and Rundel 1979, Schlesinger and Gill 1980, Gray & Schlesinger 1981). In these studies, chamise productivity ranged from 362 to 67 g • m^{-2} • yr^{-1}, Ceanothus productivity was 850 g • m^{-2} • yr^{-1} with considerable year to year variation, aril coastal sage productivity was 255 g • m^{-2} • yr^{-1}. These productivity values are greater than that of Lotus scoparius (105 g • m^{-2} • yr^{-1}) but

Lotus scoparius is a small shrub (biomass = 164 g m^{-2}) in comparison to chaparral shrubs (2,127 g m^{-2} Mooney and Rundel to 7,506 g m^{-2} Cray and Schlesinger 1981b) and coastal sage scrub (1,417 g m^{-2} Cray & Schlesinger 1981). Lotus scoparius also has a shorter growing season (3-4 months) in comparison to chamise chaparral (6-8 months, Mooney and Rundel 1979) and coastal sage scrub (4-6 months, Gray & Schlesinger 1981). Taken together, the productivity, biomass and growing season data from this investigation indicate that this early post-burn shrub rapidly replaces its biomass with newly accumulated tissues. The low biomass accumulation ratio (BAR) for this stand of deerweed (1.57) in comparison to other chaparral communities (BAR = 3 to 10, Cray & Schlesinger 1981h) further supports the rapid replacement of biomass.

Nutrient circulation in a community with rapid biomass turnover, such as this 4-year old burn site, should also have high nutrient flux rates from the environment to the detrital layer. These high flux rates in comparison to nutrient pool sizes were found in Lotus scoparius (Figure 5). Therefore, even though deerweed has a small biomass in relation to other chaparral shrubs the rapid nutrient cycling fluxes in stands of Lotus scoparius can accumulate considerable quantities of nutrients from the environment in standing biomass and litter. This capacity to accumulate nutrients following fire may be particularly important for nitrogen and phosphorous. The ability of Lotus scoparius to grow in high density after fire, the high nutrient uptake and flux rates, and the potential N-fixation ability of deerweed all point to the importance of nutrient accumulation by Lotus scoparius in latter chaparral community development. Lotus scoparius is particularly suited for rapid nutrient accumulation because of its deciduous phenology and high productivity in relation to biomass. Post-burn annuals are of lesser importance to nutrient accumulation following fire because they only have short term residence following fire due to germination requirements. Young evergreen species are also of lesser importance because their density is lower and growth rates are slower than that of the deciduous perennials in early post burn environments. Even though the quantitative importance of Lotus scoparius as a nitrogen source (by fixation) has yet to be evaluated, the role of Lotus in the conservation of mobile nutrients may be very important to later community development in southern California chaparral.

Many thanks are due to Dr. W.H. Schlesinger for assistance with nutrient analysis techniques, collection of climatic data, and many helpful comments and conversations and Dr. P.W. Rundel for an early review. Thanks are also due to the Los Padres National Forest for the use of the research site. This research was supported by a grant from the California Native Plant Society and the University of California, Santa Barbara Committee on Research.

References

Byrne, R., Michaelsen, J. and Soutar, A.: Fossil charcoal as a measure of wildfire frequency in southern California: A preliminary analysis. In: Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems (H.A. Mooney and C.F. Conrad, eds.) pp. 361-367. Washington, D.C.: US Forest Service. (1977)

Christensen, N.L. and Muller, C.H.: Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45, 29-55 (1975)

DeBano, L.F. and Conrad, C.F.: The effect of fire on nutrients in a chaparral ecosystem. Ecology 59, 489-497 (1978)

Gray, J.T., and W.H. Schlesinger: Biomass, production, and litter fall in the coastal sage scrub of Southern California. Am. J. of Bot. 68, 24-33 (1981b)

Cray, J.T. and Schlesinger, W.H.: Nutrient cycling in Mediterranean ecosystems. In: Resource utilization in two Mediterranean type ecosystems. (P.C. Miller, ed.) New York: Springer-Verlag. in press (1981h)

Hellmers, H., Bonner, J.F. and Kelleher, J.M.: Soil fertility: A watershed management problem in the San Gabriel Mountains of southern California. Soil Science 80, 189-197. (1955)

Kummerow, J., Alexander, J.V., Neel, J.W. and Fishbeck, K.: Symbiotic nitrogen fixation in Ceanothus roots. Amer. J. Bot. 65, 63-69 (1978)

Likens, G.F. and Bormann, F.H.: Chemical analysis of plant tissues from the Hubbard Brook Ecosystem in New Hampshire. New Haven, Conn.: Yale Univ. School of Forestry Bulletin 79 (1970)

McKenzie, H.A. and Wallace, H.S.: The Kjeldahl determination of nitrogen: A critical study of digestion conditions - temperature, catalyst, and oxidizing agent. Aust. J. Chem. 7, 55-70 (1954)

Mooney, H.A., and P.W. Rundel. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum in the California chaparral. Bot. Gaz. 140: 109-113 (1979)

Nilsen, E.T.: Phenology of Lotus scoparius: Climatic control and adaptive significance. Ph.D. Thesis, Dept. Biol. Sci., Univ. Calif., Santa Barbara. (1980a)

Nilsen, F.T. and Muller, W.H.: An evaluation of summer deciduousness in Lotus scoparius Nutt. (T. & G.). Amer. Midl. Natur. 103, 88-95 (1980b)

Schlesinger, W.H. and Hasey, M.M.: The nutrient content of precipitation, dry fallout, and intercepted aerosols in the chaparral of southern California. Amer. Midl. Natur. 103, 114-122 (1980)

Schlesinger, W.H., and D.S. Gill: Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61, 781-789 (1980)

Fertility Element Storage in Chaparral Vegetation, Leaf Litter, and Soil[1]

Paul J. Zinke[2]

Abstract: This study was conducted on various chaparral sites sampled throughout California in the range of the following species: chamise, Adenostoma fasiculatum; scruboak, Quercus dumosa; and Ceanothus cuneatus, & C. crassifolius. Data for elemental composition, total vegetation and leaf litter weights, and elemental storage weights for each of these species were determined. These data are aggregated and presented as tables of cumulative probability values for composition and storage weight of nitrogen, phosphorus, calcium, magnesium, potassium, sodium, iron, manganese, and zinc in chaparral. These tables can be used by the land manager to give a percentile rank to any values for vegetation analyses or to assess probable values to expect for fertility storage in the soil or vegetation of chaparral stands.

Knowledge of the total storage of material in chaparral stands is of interest to land managers because of its utility in solving a variety of problems. The total weight of the stand is related to fuel content and thus to relative fire hazard of the stand. The elemental content of the chaparral vegetation and total site fertility are affected by brush removal, as for example, where harvest is planned for fuel utilization. Chaparral species vary in their elemental content and it is wise to favor species which enhance site fertility. Ashing vegetation by burning returns elements to the site in soluble form. These elements are subject to immediate use by herbaceous vegetation. In addition, the elemental composition of the surface litter and soil relates to these total site fertility problems. Knowledge of these factors may increase management options, and offer a more sound basis for decisions.

This paper reports results of a study in which data have been gathered on vegetal and litter weights and elemental compositions and storages from various chaparral sites. These were sampled throughout the range of the following species in California: chamise, Adenostoma fasiculatum; scrub oak, Quercus dumosa; and the Ceanothi, Ceanothus cuneatus and C. crassifolius.

The data from the various sampling sites will be aggregated into probability distributions for total weights of constituents, and their elemental compositions and storages. This will allow the manager to determine the probable variation in chaparral properties, as well as to rank any data at hand as a site specific application of the data.

LITERATURE

Chaparral literature concerned with weights, areal extent, and fertility has been mainly in the context of forestry and range management applications. These came about because of the practical necessity of conducting surveys of areal extent, assessing fire hazards and watershed influences of chaparral cover; and determining the relation of chaparral as browse to range carrying capacity for domestic and game animals.

The extent of chaparral vegetation types was assessed by Wieslander (1935) who began an early map of the vegetation of California in which the chaparral vegetation types were mapped over the entire state. The vegetation survey has since been expanded to include relevant soil information as part of the California Soil-Vegetation survey. The areal extent of chamise chaparral is 3,099,300ha (9,866,000 acres). Various measures have been made of total weight of chaparral in relation to fuel assessment. Specht (1969), determined weights of chaparral and elemental contents at various time intervals following fire on the San Dimas Experimental forest. Trabaud (1977) published data for litter and biomass for garrique in France composed mainly of Quercus coccifera, similar to Q. dumosa in California chaparral. Kittredge (1955) published a thorough study of litter weights and rates of accumulation under various chaparral species on the San Dimas Experimental Forest. The probability tables that will be presented in this paper allow a percentile ranking of any of these data within the range of weights, nutrient compositions, and total nutrient storage found in California chaparral.

METHOD OF STUDY

Site Selection

In this study, the sampling sites were chosen to represent the range of conditions over which three representative California chaparral species;

[1] Presented at the Symposium on Dynamics and Management of Mediterranean -Type Ecosystems, June 22-26, 1981, San Diego, Calif.

[2] Assoc. Prof. of Forestry, University of California, Berkeley.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

chamise, scrub oak, and Ceanothus grow. Sampling sites were selected over gradients of annual rainfall, in mountain areas of similar geologic soil parent material in San Diego, Los Angeles, and Glenn Counties. Other sites were chosen to represent additional conditions of soil parent material conditions, and annual rainfall extremes in Lake, Mariposa, Tehama, and Shasta Counties.

Sample sites and their characteristics are listed in table 1.

Table 1-- Sample site locations

Location	Species	Age (yr)	Precip. (mm)
San Diego Co.			
nr San Marcos	Af,Qd	15	305
Descanso	Af,Cc,Qd	20	635
Sunrise	Af,Cc,Qd	25	965
Scissors Jct.	Af,Qd	50	229
Los Angeles Co.			
Griffith Pk.	Af,Qd	25	356
El Prieto Can.	Af,Qd	25	635
Tanbark Fl.	Af,Ccr,Qd	39	990
Glenn Co.			
Elk Cr.	Af,Cc	17	356
Sanhedrin Rd	Af	20	457
Sanhedrin Rd	Af	20	889
Sanhedrin Rd	Af	20	1520
Miscellaneous			
Bear Val. Marip. Co.	Af,Cc	23	500
Kiethly Rch. Lake Co.	Af,Cc,Qd	30	500
Pattymocus Bt. Tehama Co.	Af,Cc	15	1520
Delta Pt. Lkt. Shasta Co.	Af	20	1650
Tanbark Fl. Lysimeters	Af,Ccr,Qd	20	990

Af, *Adenostoma fasiculatum*; Cc, *Ceanothus cuneatus*; Ccr, *Ceanothus crassifolius*; Qd, *Quercus dumosa*.

Vegetation Sampling

Dominant shrubs of the desired species were selected for sampling at each site. Either a single large shrub, or a rectangular area of 2.22m^2 (4' x 6') was chosen, marked by stakes, and the shrubs cut at ground level. When a single large shrub was chosen, the crown projectional area was used to relate the subsequent weight measurements to an areal basis. Vegetation weights and elemental storage were calculated on a square meter basis.

Age was determined at the time of cutting the shrubs by counting annual rings. It was recognized that this represented age since sprouting or growth following fire.

Vegetation Weights

The cut shrubs were further sectioned into 38 cm (one ft) height increments, and fresh field weights obtained for each. These were taken to the laboratory to dry and separate oven dry weights of foliage and stems were obtained on each sample. For some sites with very large shrubs or dense growth, the drying was done on subsamples of known field weight. Moisture contents were determined by oven drying at 80°C.

Leaf Litter and Soil Sampling

Leaf litter, and soil samples were obtained directly beneath the center of the canopy radius of the shrub. The leaf litter and organic detritus was sampled from a unit area, usually 0.1 square meter.

Soil samples were taken from a pit dug to rock bottom; sampling at uniform depth intervals at each site of 0-2.5 in.(6.4 cm), 2.5-6 in.(15.2 cm), 6-12 in. (30.4 cm), 12-24 in.(61 cm.), and 24-48 in.(121.9 cm). The calculations of storage of soil elemental composition were made on the basis of the square meter area to the depth of rock, or to one meter depth if no rock bottom was encountered.

Soil Preparation

Soil samples of known volume were obtained in the field, and bulk densities determined. Samples were oven dried, and the oven dry weight divided by volume of the sample was used as a bulk density figure. Also; roots were sieved from this known volume sample to obtain root weights by volume. The soil coarse fraction greater than 2 mm was sieved out, and percent by weight calculated. A bulk sample of soil for chemical analysis was collected uniformly through each depth increment. These roots were weighed and saved for subsequent chemical analysis. Coarse mineral fragments remaining were considered devoid of available fertility element storage, and their weights were deducted from the calculated storage for the square meter soil volume.

Chemical Analyses

Vegetation and litter samples were analyzed after grinding in a wiley mill through a 50 mesh stainless steel sieve. Nitrogen was determined on this material by microKjeldahl method. Perchloric acid digestates were used for the remaining elements analysed. Phosphorus was analysed by molybdenum blue method, and the remaining elements; calcium, potassium, sodium, iron, manganese, and zinc were determined by atomic absorption spectrometry, methods described by Johnson and Ulrich (1959). Elemental contents were calculated on a weight percent basis for nitrogen, calcium, potassium, sodium; and weight per million basis for phosphorus, iron, manganese and zinc.

Soils analyses were conducted on the fine earth fraction (less than 2 mm) soil material. Total organic nitrogen content was determined by macro-Kjeldahl analyses; phosphorus was determined in a water extract; exchangeable cations were determined in 1 N ammonium acetate extracts buffered to pH 7.0; and exchange capacity was determined by the total ammonium remaining on the soil after such extraction and rinsing with methyl alcohol. These standard methods of soil analysis reported in Black (1965). Nitrogen was calculated on a weight percent basis, phosphorus on a weight per million basis, and exchangeable cation data on a milliequivalent per hundred grams basis. These data are the basis for the intensity factor of soil storage, which when multiplied by the capacity factors of bulk density, volume of the square meter depth increment minus coarse fragments, determines total soil fertility storage.

These composition and storage values were arrayed in order of magnitude and fitted to the cumulative probability function described by Weibull (1949) in application to variation in organism properties. A modification developed by Bailey and Dell (1973) was used in this study. An application to foliar analysis is described by Zinke and Stangenberger (1981).

The form of the Weibull cumulative probability distribution used in this paper is as follows:

$$F(x) = 1 - e^{-\left(\frac{x-A}{B}\right)^{C}} \qquad (1)$$

This function is determined by factor A, which is a threshold value related to the lowest value obtained; B, which is a scale value related to the magnitude of the units used in describing the respective property of the vegetation, litter or soil; and C, which is a shape factor. C ranges from values of one or lower for exponential distributions with data peaking at low values skewed toward high values, to 3.25 for normal bell shaped distributions about a central value. The flexibility of the Weibull function allows the fitting of diverse data with the same computer program developed by Dr. Alan Stangenberger. The fitted probability functions were then used to develop tables of probable values to be expected for cumulative percentiles of the field population of chaparral sites for each property. These can be considered to be preliminary rating tables for chaparral sites, their vegetation weights, elemental compositions, and total elemental storages.

The results will be presented as capacity and intensity factors evaluated for elemental storage for each species at each sampling site. The capacity factor for vegetation is the oven dry weight of vegetation per unit area of horizontally projected land surface, with the vegetation subdivided into categories of foliage, stems, and roots, and surface litter and detritus. The intensity factor is the weight fraction elemental composition. The total elemental storage in the vegetation is the sum of the products of the capacity and the elemental intensity factors for each vegetation subdivision.

Similarly, for the soil, the intensity factors will be the respective available elemental weight fractions for each element of concern, multiplied by capacity factors derived from bulk density, coarse fraction percent, and volume of each sampling depth increment.

RESULTS and DISCUSSION

Foliage & Stem Weights (table 2)

The capacity factor (weight per unit area) for the individual shrubs or stands were determined at each sampling site for foliage, stems, leaf litter, and roots. These form the storage capacity for the retention of elements, and are a measure of the fuel content of the stand.

Data on the foliage, stem, and foliage plus stem weights were determined for each site. These individual site data were arrayed by the Weibull equation in probability functions, and the data tables are developed from this function. The data in table 2 are presented as equal to or less than values of weight for each cumulative percentile class of the population. This allows the manager to rank any data within the range of values in these tables. Thus a determination of 180 gm/m^2 for chamise foliage would be in the lower 1% of the range of that species according to this table. Likewise, a value of 3 kg/m^2 for foliage plus stems of mixed chaparral would be in the 40% class of these data.

These data indicate that foliage weights range from a low 9f 0.15 kg per square meter to more than 2 kg/m^2, with a 50% value of 474 gm/m^2. Generally, chamise has the least foliage weight and Ceanothus the most per unit area; with scrub oak intermediate.

Table 2— Chaparral foliage and stem weight cumulative probabilities (oven dry grams/m^2).

Component	Foliage				Stems				Foliage +Stems			
Species	All	Af	Qd	Cc	All	AF	Qd	Cc	All	Af	Qd	Cc
Cumul. Pct.												
≤1	156	185	175	151	823	734	962	1556	1065	965	1021	1636
5	178	192	186	186	1085	870	1130	2052	1374	1137	1303	2244
20	262	235	244	244	1739	1312	1698	2817	2132	1665	2097	3212
40	394	322	365	382	2507	1935	2525	3455	3009	2382	3110	4039
50	474	383	449	490	2914	2299	3013	3741	3472	2792	3383	4413
60	570	462	558	632	3366	2722	3587	4030	3983	3265	4306	4795
80	861	729	928	1125	4576	3947	5267	4707	5345	4610	6069	5695
95	1420	1323	1760	2268	6555	6170	8365	5624	7554	6997	9090	6931
99	2047	2108	2826	3773	8488	8544	11700	6385	9699	9499	12200	7969
Sample n	32	16	8	8	32	16	8	8	32	16	8	8

[1]Af, Adenostoma fasiculatum; Qd, Quercus dumosa; Cc, Ceanothus cuneatus and C. crassifolius. (Divide by 100 for metric tons/ha; multi-ply by .00446 for tons/acre)

Stem weights are 7 to 8 times the foliage weights. Stem weights range from 0.7 to 11.7 kg/m^2, with 50% 2f the population having approximately 3000 gm/m^2 or less. Stem weights are highest for Ceanothus at 3.7 kg/m^2, lowest for chamise with 2.2 kg/m2.

Combining the foliage and stem weights accentuates the relative ranking of the species at the 50% level. Ceanothus has the greater weigh at 4.4 kg/m^2, and chamise is low with 2.8 kg/m^2.

Leaf Litter Weights (table 3)

Leaf litter weights obtained in this study were also fitted to cumulative probability functions. The derived data are presented in table 3. These data indicate that litter weights can be almost as great as the vegetation weights in the stand. Thus they will be an important storage component for nutrient elements, as well as an important fuel component of stands. Typical values for all species sampled indicate 50% of the population weigh 2.0 kg or less per square meter. This is in contrast to the 3.5 kg/m^2 for foliage and stems recorded in the previous table.

Table 3—Leaf litter weight probabilities in chaparral stands (oven dry gms/m^2).

Cumul. Pct.	All	Af	Qd	Cc
<1	156	279	954	306
5	419	316	1025	674
10	648	375	1119	956
20	1021	523	1328	1377
30	1356	710	1566	1728
40	1685	944	1847	2058
50	2026	1239	2179	2386
60	2399	1621	2588	2732
70	2830	2140	3118	3120
80	3373	2914	3869	3591
90	4190	4322	5163	4273
95	4913	5816	6464	4855
99	6373	9532	9508	5982
Sample n	75	30	13	22

Af, *Adenostoma fasiculatum*; Qd, *Quercus dumosa*; Cc, *Ceanothus cuneatus* and *C. crassifolius.* (Divide weights by 100 for metric t/ha; multiply by .00446 for tons per acre)

As with the other probability tables in this paper, the manager can use table 3 to rank litter weight data at hand. For example, Kittredge (1955) found that the weight of litter of *Quercus dumosa* litter in Bell Canyon on the San Dimas Experimental forest to be 17.7 metric tons per acre, or 43.7 metric tons per hectare. This value would rate between 80-90% on the cumulative probability presented in table 3. The value of 4.7 metric tons per acre for chamise chaparral obtained by Kittredge for Fern Canyon on the same forest was 1160 gm/m^2, ranking at approximately the 50% level for chamise in table 3.

Elemental Composition

To determine total elemental storage on the site, the capacity factor of weight and the elemental composition as an intensity factor are needed. In addition to their use as intensity factors elemental composition values may be used in rating the fertility of a site by foliar analysis, and for assessing possible elemental deficiencies. The data obtained for elemental composition of foliage, stems, litter, and roots for the various sampling sites and chaparral species were also fitted to cumulative probability functions, and probability tables derived for weight fractions of each element analysed.

Foliage Analyses (table 4)

The cumulative probability percentile ranking of foliage analyses by order of magnitude for chaparral species studied are presented in table 4.

Nitrogen contents of chamise foliage are generally lower than for scrub oak or Ceanothus. The higher nitrogen content of the scrub oak foliage in general is a surprise because of the demonstrated nitrogen fixation ability of the Ceanothi (Delwiche, *et al*. 1965). However, as will be seen later, this added nitrogen is stored in stem storage in the Ceanothi.

Phosphorus, iron, and zinc contents in contrast to nitrogen are much higher at the 50% level in chamise than in scrub oak, and Ceanothus. Calcium contents in scrub oak foliage are lower than in either chamise or Ceanothus foliage. Magnesium amounts are higher in Ceanothus than in chamise or scrub oak.

These tables may be used to rank foliar analyses which may be at hand. Thus, if a foliar analysis has been made for a chamise sample which shows 0.7% calcium, the table indicates that this is a very low value, found in the lower 5% of the population.

Stem Analyses (table 5)

The data for cumulative probability percentiles of the population of stem analyses for the same elements are presented in table 5. These data are for stemwood plus bark. Most of the composition values are much lower for stems than for foliage. Exceptions are sodium in Ceanothus, and calcium in scrub oak stemwoods.

Nitrogen values are highest for Ceanothus stems. This indicates that lower values in scrub oak and chamise stems. This indicates that much of the nitrogen fixed by Ceanothus is stored in high nitrogen content stems.

Table 4-Elemental composition of chaparral foliage. (oven dry basis)

Probability Cumul. Pct.	N Pct.	P ppm	Ca Pct.	Mg Pct.	K Pct.	Na Pct.	Mn ppm	Fe ppm	Zn ppm
Chamise									
≤5	.397	673	.715	.079	.184	.011	42	168	26
20	.627	1102	.844	.096	.277	.019	85	210	34
40	.810	1455	.980	.127	.371	.025	125	279	49
50	.891	1611	1.049	.146	.417	.028	145	324	58
60	.971	1769	1.123	.171	.466	.031	165	379	71
80	1.156	2137	1.314	.247	.591	.038	216	550	113
95	1.402	2632	1.609	.403	.778	.047	289	896	205
Sample n	20	20	20	20	20	16	20	20	20
Scrub oak									
≤5	1.007	1010	.569	.085	.283	.020	121	112	20
20	1.240	1186	.671	.096	.362	.021	133	129	21
40	1.394	1351	.765	.109	.417	.023	166	164	23
50	1.455	1429	.810	.115	.439	.024	194	189	25
60	1.514	1510	.856	.123	.460	.027	233	221	27
80	1.639	1709	.970	.142	.505	.037	389	331	37
95	1.789	1996	1.132	.173	.561	.068	820	579	63
Sample n	8	8	8	8	8	7	8	8	8
Ceanothus									
≤5	1.038	538	.850	.106	.248	.006	27	93	17
20	1.110	975	1.044	.130	.326	.007	41	105	19
40	1.213	1363	1.173	.159	.412	.009	54	140	21
50	1.273	1542	1.224	.174	.457	.011	60	168	21
60	1.343	1727	1.273	.192	.506	.014	67	208	22
80	1.546	2169	1.378	.239	.634	.028	82	364	25
95	1.916	2789	1.503	.318	.837	.067	105	782	28
Sample n	12	11	11	11	11	8	12	12	12

Table 5--Elemental composition of chaparral stems (oven dry).

Probability Cumul. Pct.	N Pct.	P ppm	Ca Pct.	Mg Pct.	K Pct.	Na Pct	Mn ppm	Fe ppm	Zn ppm
Chamise									
≤5	.119	110	.288	.023	.084	.009	11	48	16
20	.179	191	.385	.028	.101	.015	20	84	22
40	.240	288	.471	.035	.127	.022	29	144	34
50	.270	340	.510	.039	.143	.026	33	182	43
60	.302	398	.551	.044	.162	.030	38	229	55
80	.384	554	.646	.058	.218	.040	51	373	95
95	.506	811	.780	.085	.323	.056	70	661	188
Sample n	72	72	72	72	72	67	72	71	72
Scrub oak									
≤5	.195	43	.573	.030	.072	.013	26	39	8
20	.267	92	.801	.039	.087	.019	35	53	13
40	.332	178	.968	.051	.110	.026	49	75	17
50	.363	232	1.037	.057	.122	.030	57	90	18
60	.395	300	1.105	.064	.137	.034	66	107	20
80	.473	514	1.257	.085	.181	.044	93	160	24
95	.584	951	1.448	.120	.260	.061	142	264	30
Sample n	36	36	35	35	35	32	36	36	36
Ceanothus									
≤5	.277	40	.488	.026	.054	.015	9	36	41
20	.328	86	.603	.031	.072	.018	11	58	5
40	.389	172	.725	.040	.107	.022	14	80	8
50	.422	230	.787	.046	.131	.025	16	91	10
60	.459	304	.854	.053	.162	.028	18	103	12
80	.558	546	1.026	.075	.266	.039	27	132	17
95	.724	1068	1.292	.121	.495	.061	46	177	26
Sample n	39	39	38	39	39	26	38	37	37

Table 6: Elemental composition of chaparral roots (oven dry).

Probability Cumul.Pct.	N Pct.	P ppm	Ca Pct.	Mg Pct.	K Pct.	Na Pct.	Mn ppm	Fe ppm	Zn ppm
Chamise									
≤5	.299	222	.297	.044	.039	--	25	718	12
20	.432	358	.604	.076	.068	--	46	1317	15
40	.583	485	1.012	.114	.110	--	87	2128	24
50	.662	545	1.241	.135	.134	--	115	2591	34
60	.748	608	1.505	.158	.163	--	152	3125	48
80	.978	762	2.248	.221	.246	--	277	4642	115
95	1.348	984	3.549	.324	.397	--	553	7332	335
99	1.704	1178	4.897	.426	.559	--	905	10147	724
Sample n	57	38	45	46	46	--	38	39	38
Scrub oak									
≤5	.345	180	.514	.050	.031	--	23	454	9
20	.501	312	1.068	.100	.067	--	42	1158	13
40	.677	486	1.611	.147	.107	--	79	1961	23
50	.769	583	1.875	.170	.128	--	104	2381	31
60	.869	695	2.154	.194	.150	--	135	2844	42
80	1.133	1006	2.849	.253	.209	--	238	4070	84
95	1.554	1548	3.879	.340	.301	--	456	6043	195
Sample n	41	28	37	37	37	--	28	27	28
Ceanothus									
≤5	.306	605	.794	.063	.062	--	72	662	26
20	.598	638	1.025	.098	.077	--	77	919	29
40	.871	793	1.328	.142	.112	--	96	1711	37
50	1.001	955	1.498	.166	.138	--	115	2394	43
60	1.136	1293	1.692	.193	.173	--	145	3390	51
80	1.468	2545	2.235	.267	.298	--	279	7454	80
95	1.947	7440	3.180	.392	.601	--	721	19166	153
Sample n	22	9	12	12	12	--	8	9	8

Table 7--Elemental composition of chaparral litter (oven dry).

Probability Cumul. Pct.	N Pct.	P ppm	Ca Pct	Mg Pct.	K Pct.	Na Pct,	Mn ppm	Fe ppm	Zn ppm
Chamise									
≤5	.372	495	.842	.079	.106	.007	206	1359	44
20	.543	629	1.056	.164	.124	.015	289	3192	76
40	.697	755	1.278	.263	.157	.024	377	5407	131
50	.769	816	1.388	.316	.179	.029	421	6599	165
60	.843	878	1.507	.374	.206	.036	468	7932	208
80	1.023	1032	1.811	.530	.293	.046	590	11545	340
95	1.276	1255	2.275	.786	.474	.067	778	17547	606
Sample n	30	30	29	29	29	25	29	29	29
Scrub oak									
≤5	.685	375	.954	.123	.073	.013	228	3377	39
20	.741	448	1.156	.182	.101	.021	301	4428	52
40	.826	551	1.299	.244	.137	.028	397	5158	76
50	.877	611	1.357	.275	.156	.031	451	5456	91
60	.937	681	1.414	.309	.178	.034	514	5744	110
80	1.117	884	1.539	.395	.239	.041	689	6372	169
95	1.456	1252	1.694	.528	.343	.051	995	7145	291
Sample n	13	13	13	13	13	8	13	13	13
Ceanothus									
≤5	.671	312	1.044	.163	.077	.014	136	2868	41
20	.877	526	1.261	.217	.127	.016	187	3583	72
40	1.029	707	1.478	.281	.180	.020	235	5063	111
50	1.094	788	1.585	.315	.206	.023	258	6107	132
60	1.158	870	1.698	.354	.235	.027	282	7464	156
80	1.300	1063	1.984	.457	.307	.038	342	12087	223
95	1.482	1327	2.412	.627	.417	.062	429	22559	337
Sample n	22	22	22	22	21	16	21	21	21

Phosphorus contents are much higher in chamise stems than in Ceanothus or scrub oak. This is coupled with higher phosphorus contents in chamise foliage.

Calcium, magnesium, and manganese contents are highest in scrub oak stemwood, while in contrast, potassium, iron, and zinc are lowest; while the reverse is true for chamise stemwood contents.

The reader can make similar comparisons at the 50% level in table 5.

Root Composition (table 6)

Cumulative probability values derived from the root analyses are presented in table 6. These values are for roots sieved from the soil samples, and cleaned by blowing air, but not washed. Most

Table 8--Chaparral soil surface properties (in top 31n., 7.6 cm.).

Property	Bd g/cc	pH	C Pct.	N Pct,	C/N	P ppm	CEC	Ca^{++} milliequivs./100grams	Mg^{++}	K^{+}	Na	M^{++}
Chamise												
≤5	.90	5.2	.49	.036	10.7	.07	5.5	4.6	.6	.1	.0	.0
20	1.04	5.6	.95	.063	14.3	.19	7.3	6.5	1.0	.2	.0	.1
40	1.15	5.9	1.69	.099	17.3	.46	9.5	8.4	1.7	.3	.0	.1
50	1.20	6.0	2.15	.120	18.5	.67	10.7	9.2	2.1	.4	.1	.1
60	1.26	6.1	2.70	.144	19.8	.96	12.0	10.1	2.6	.4	.1	.2
80	1.38	6.3	4.40	.213	22.8	2.01	15.7	12.2	4.1	.5	.1	.3
95	1.56	6.6	7.71	.337	26.7	4.61	22.0	15.2	7.1	.7	.3	.6
Sample n	70	71	71	71	71	71	70	70	65	70	70	70
Scrub oak												
≤5	.74	5.2	.60	.050	11.6	.12	6.1	5.1	1.0	.1	.0	.0
20	.88	5.5	1.13	.078	13.9	.22	8.0	6.9	1.4	.2	.0	.1
40	1.00	5.8	1.84	.113	15.7	.56	10.2	8.6	2.0	.4	.1	.1
50	1.05	5.9	2.23	.133	16.5	.84	11.3	9.5	2.3	.5	.1	.1
60	1.11	6.1	2.69	.155	17.2	1.26	12.5	10.5	2.7	.6	.1	.2
80	1.24	6.4	3.95	.217	19.0	2.96	15.9	12.9	4.0	.8	.2	.3
95	1.42	6.9	6.16	.324	21.3	7.86	121.2	16.6	6.3	1.3	.6	.6
Sample n	48	48	48	48	48	48	48	48	47	48	48	47
Ceanothus												
≤5	.98	5.5	.36	.031	10.2	.18	7.1	9.8	1.8	.1	.0	.1
20	1.03	5.7	.67	.048	12.1	.26	11.6	8.2	2.3	.2	.0	.1
40	1.12	5.8	1.35	.086	14.0	.62	13.9	9.6	3.2	.3	.0	.2
50	1.17	5.9	1.83	.114	14.9	.97	15.2	10.4	3.8	.4	.1	.2
60	1.24	6.0	2.47	.153	15.8	1.52	16.7	11.4	4.6	.5	.1	.3
80	1.44	6.2	4.66	.289	18.2	4.08	121.0	14.1	7.0	.8	.1	.4
95	1.83	6.5	9.73	.620	21.7	12.77	28.6	19.0	12.0	1.8	.3	.6
Sample n	25	25	25	25	25	25	25	25	20	25	25	24

(Bd . bulk density)

Table 10 -- Root weights and elemental storage contents (gm/m^2).

All Species: Chamise. Scruboak, Ceanothus.

Cumul.	Weight	N	P	Ca	Mg	K	Mn	Fe	Zn
≤5	18	.1	.008	.11	.02	.02	.001	.04	.0001
20	54	.3	.03	.58	.06	.08	.003	.1	.001
40	126	.8	.07	1.67	.16	.17	.009	.3	.004
50	177	1.1	.10	2.55	.24	.23	.010	.4	.006
60	241	1.6	.14	3.77	.34	.31	.022	.6	.009
80	460	3.2	.29	8.43	.72	.58	.054	1.2	.020
95	948	7.2	.68	20.70	1.64	1.17	.140	2.9	.048
Sample n	27	27	22	26	26	26	22	22	22

Table 12-Total elemental storage in top 5 cm of chaparral soils

Probability Cumul. Pct.	C Kg/m^2	N g/m^2	P mg/m^2	CEC	Ca^{++} gram-equivalent wts./m^2	Mg^{++}	K^{+}	N^{+}	Mn^{++}
Chamise									
≤5	.5	29	3	3.28	2.37	.43	.09	.00	.07
20	1	50	7	4.24	2.81	.49	.13	.00	.09
40	1.4	67	11	5.46	3.56	.70	.17	.01	.11
50	1.6	75	13	6.13	4.05	.88	.19	.01	.13
60	1.7	84	15	6.90	4.65	1.14	.21	.02	.14
80	2.2	103	20	9.02	6.53	2.22	.26	.04	.20
95	2.8	130	30	12.66	10.34	5.36	.33	.11	.31
Scrub oak									
≤5	.2	24	6	2.76	2.34	.64	.09	.01	.06
20	.5	37	6	3.05	3.28	.66	.11	.01	.08
40	.9	53	8	3.74	3.96	.75	.15	.01	.10
50	1.1	61	9	4.26	4.24	.85	.18	.01	.12
60	1.3	71	10	4.96	4.52	1.01	.22	.01	.14
80	1.8	97	15	7.48	5.14	1.81	.36	.04	.19
95	2.6	140	27	13.65	5.92	4.79	.66	.26	.29
ALL SPECIES									
≤5	.3	21	3	3.13	2.49	.44	.08	.00	.07
20	.6	41	6	4.26	3.25	.59	.11	.01	.09
40	1.0	59	8	5.58	4.15	.93	.16	.01	.12
50	1.2	67	10	6.27	4.62	1.18	.18	.02	.13
60	1.4	76	12	7.05	5.14	1.53	.22	.03	.15
80	1.9	98	17	9.12	6.54	2.80	.31	.07	.19
95	2.7	129	27	12.51	8.81	5.91	.50	.26	.26

(For gram weights of exchangeable cations multiply by equivalent weights: Ca, 20; Mg, 12; K, 39; Na, 23; Mn, 27.4.)

Table 9-- Total elemental storage in chaparral foliage plus stems (gm/m^2).

Probability Cumul.	N	P	Ca	Mg	K	Na	Mn	Fe	In
Chamise									
≤5	5.6	0.7	9.7	1.0	1.8	.4	.05	.23	.06
20	6.9	0.8	11.2	1.0	2.9	.5	.06	.35	.08
40	9.1	1.2	14.0	1.3	4.5	.6	.10	.59	.12
50	10.5	1.4	16.0	1.5	5.4	.7	.13	.74	.15
60	12.2	1.7	18.5	1.8	6.5	.8	.16	.93	.20
80	17.5	2.7	26.8	3.0	9.6	1.2	.28	1.56	.37
95	28.0	5.0	44.8	6.6	15.1	1.9	.58	2.86	.79
Scrub oak									
≤5	7.2	1.0	14.5	1.2	1.5	0.7	.12	.14	.03
20	11.3	1.1	22.3	1.5	2.5	1.0	.16	.20	.04
40	16.5	1.3	31.0	2.1	4.3	1.2	.23	.32	.05
50	19.4	1.5	35.6	2.4	5.6	1.3	.29	.40	.07
60	22.7	1.8	40.6	2.8	7.2	1.4	.36	.50	.08
80	31.8	2.8	53.8	4.1	12.5	1.7	.62	.84	.12
95	47.4	5.5	75.0	6.5	24.1	2.1	1.22	1.56	.20
Ceanothus									
≤5	14.5	.5	20.2	1.0	2.5	.4	.05	.23	.02
20	18.4	.6	26.1	1.3	3.4	.5	.06	.28	.03
40	22.4	.9	32.4	1.9	5.3	.6	.08	.41	.03
50	24.3	1.2	35.5	2.4	6.7	.8	.09	.50	.04
60	26.4	1.7	38.8	3.0	8.6	.9	.11	.61	.06
80	31.6	3.7	47.5	5.2	15.1	1.4	.17	1.03	.31
95	39.4	9.8	60.7	10.5	30.4	2.5	.31	2.01	.54

Table 11-Total elemental storage in chaparral litter (gm/m^2).

Probability Cumul. Pct.	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
Chamise									
≤5	2.1	.2	4.4	.5	.4	.2	.12	.9	.03
20	3.5	.4	7.6	1.3	.8	.3	.22	2.5	.06
40	6.8	.8	13.8	3.1	1.9	.4	.43	6.2	.14
50	9.2	1.1	18.0	4.4	2.7	.5	.56	8.9	.22
60	12.5	1.4	23.2	6.1	3.7	.6	.74	12.6	.33
80	24.4	2.6	40.5	12.0	7.5	.9	1.31	25.3	.81
95	53.6	5.1	77.4	25.8	16.9	1.6	2.54	55.8	2.24
Scrub oak									
≤5	10.0	0.9	13.5	2.3	1.3	.2	.58	5.9	0.7
20	11.6	1.1	18.0	4.5	2.0	.3	.70	8.3	.10
40	15.3	1.5	25.2	6.7	3.2	.5	.92	11.5	.18
50	18.1	1.7	29.6	7.9	3.8	.7	1.07	13.4	.25
60	21.9	1.9	35.0	9.1	4.7	.9	1.26	15.6	.33
80	35.6	2.6	51.5	12.1	7.2	1.5	1.88	21.8	.62
95	69.5	4.0	83.8	16.7	12.1	2.7	3.20	33.0	1.32
Ceanothus									
≤5	6.2	.3	7.7	1.5	.6	.1	.13	.9	.03
20	13.9	.8	19.2	3.8	1.9	.2	.32	3.7	.11
40	21.9	1.4	32.1	6.4	3.8	.4	.53	9.7	.24
50	25.9	1.8	38.8	7.9	4.9	.5	.64	14.0	.32
60	30.2	2.3	46.1	9.4	6.2	.6	.76	19.6	.41
80	41.2	3.5	65.4	13.5	10.0	1.0	1.08	38.7	.70
95	57.9	5.6	96.1	20.0	16.8	1.5	1.59	82.5	1.25

Table 13-Summary of 50 Pct, probability values for nutrient storage (gm/m^2) in chaparral stands.

	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
Chamise									
Fol.+stems	10.5	1.4	16.0	1.5	5.4	0.7	0.13	0.74	0.15
Roots	1.1	0.1	2.6	0.2	0.2	--	0.01	0.4	0.01
Litter	9.2	1.1	18.0	4.4	2.7	0.5	0.56	8.9	0.22
Total	20.8	2.6	36.6	6.1	8.3	1.2	0.7	10.0	0.38
Soil/5 cm	75	0.013	81	11	7	0.2	3.6		
Scrub oak									
Fol.+stems	19.4	1.5	35.6	2.4	5.6	1.3	0.29	0.40	0.07
Roots	1.1	0.1	2.6	0.2	0.2	--	0.01	0.4	0.01
Litter	18.1	1.7	29.6	7.9	3.8	0.7	1.07	13.4	0.25
Total	38.6	3.3	67.8	10.5	9.6	2.0	1.4	14.2	0.33
Soil/5 cm	61	.009	85	10	7	0.2	3.3	--	
Ceanothus									
Fol.+stems	24.3	1.2	35.5	2.4	6.7	0.8	0.09	0.50	0.04
Roots	1.1	0.1	2.6	0.2	0.2	--	0.01	0.4	0.01
Litter	25.9	1.8	38.8	7.9	4.9	0.5	0.64	14.0	0.32
Total	51.3	3.1	71.9	10.5	11.8	1.3	0.7	14.9	0.37
Soil/5 cm	67	.010	92	14	7	0.4	3.6	--	

•(All chaparral soils values used for Ceanothus) likely this definition entails some rhizosphere material.

Nitrogen contents of chaparral roots were highest for Ceanothus roots, although at the lower ranges all species were similar. Phosphorus values are also higher in association with Ceanothus roots, being nearly double those of the other species. Magnesium values are slightly higher in chamise roots than in other species, a contrast with the lower magnesium contents in chamise stems and foliage.

Root manganese contents are similar at the 50% level for all species. Iron contents of roots are much higher for all the species than for any other plant component analyzed.

Zinc contents for roots are in the range of other plant parts analyzed. The much higher foliage and stem values for chamise do not carry through to the roots except in the extreme values in the upper 30% of the population.

Chaparral litter composition (table 7)

The litter analyses were fitted to probability functions for each species and element and the data in table 7 derived from this function.

The litter accumulated under the various chaparral species reflects some of the compositional differences previously observed in stem and foliage.

Iron and zinc contents as weight per million are highest in chamise litter. However as will be seen later, this does not necessarily mean higher total storage amounts on the site since total litter weights may have different rankings between species.

Soil Surface Properties (table 8)

The basic laboratory weight composition data for surface soils were also arrayed in probability tables for each property by species as shown in table 8 to show expected ranges. Thus in general, pH has a similar 50% value of 6.0. The percent carbon content is highest under scrub oak, although, it reaches higher extremes under Ceanothus. Nitrogen values also reach greater extremes under Ceanothus, but are generally higher over the population of samples under scrub oak. Ceanothus tends to maintain lower C/M ratios in the surface soil, and higher water soluble phosphorus contents. In general the cation exchange capacity is higher in soils under Ceanothus, as well as having higher amounts of exchangeable calcium and magnesium on that exchange complex.

TOTAL ELEMENTAL OTORAGF

The values for elemental storage for each component of chaparral stands were obtained by multiplying the intensity factor of elemental composition by the capacity factor of total weight. These individual component storage values for each species and sampling site were fitted to cumulative probability functions and the data derived for elemental storage are presented in tables 9-12.

Foliage and Stem Elemental Storage (table 9)

Nitrogen storage quantities for various percentiles of the expected field population are shown in table 9. The nitrogen quantities stored in stands of Ceanothus are highest. Scruboak stands have nearly as much stored nitrogen, while chamise stands have half these amounts.

Phosphorus storage values are similar for all three species. Although chamise vegetation had greater phosphorus weight composition, the greater weights of vegetation in Quercus and Ceanothus stands resulted in equivalent stand weights of phosphorus present.

The data in table 9 can be used to rank any calculation on total elemental storage which the forester or manager of chaparral may have at hand. Comparisons between species are also apparent in the data.

Root Elemental Storage (table 10)

Root storage contents are grouped for all species because of gaps in the data. The quantities are presented in table 10 as cumulative probability values for all chaparral species.

All the storage amounts are about one tenth the corresponding elemental storage in the tops, except for iron which has a high root storage quantity related to the high intensity of storage as shown in table 6. The generally low storage values are due to the low root weights per unit area, since, most elements are high in weight per—cent in roots.

Leaf Litter Elemental Storage (table 11)

Elemental storage quantities in leaf litter may be as great as those in the foliage and stem storage because of high litter weights coupled with high weight percent compositions. Table 11 presents the data obtained from the cumulative probability functions fitted to the sample site data for the litter storage of nine elements.

The nitrogen storage values of 25.9 gm/m^2 in Ceanothus are the highest of the three species. These are comparable to the quantities stored in vegetation reported in table P. The litter storage of phosphorus is similar for all the species compared. Calcium storage in litter is similar in quantity to that stored in the vegetation storage in foliage plus stems. However magnesium storage amounts in litter are much higher than the foliage plus stem storage. These values are roughly four times vegetation storage, indicating that magnesiumis being accumulated in the litter.

Potassium storage in litter is highest under Ceanothus at 5 gm/m^2, least under chamise at 2.7 gm/m^2, half the amount in the vegetation, attesting to the ready leaching of potassium. Sodium storage amounts are the same in the hitter of all the species. The values of 0.5 gm/m^2 are half the content of vegetation storage indicating ready leaching as in the case of potassium.

Manganese and iron contents are definitely enriched in litter. Manganese contents are highest in oak litter, and second highest in that of Ceanothus litter. Iron storage quantities are generally highest in the Ceanothus, and the scrub oak litters, and least in the chamise litter.

Zinc quantities are generally 0.2 to 0.3 gm/m^2 in all the litters without wide differences, although there is a tendency to higher extremes in chamise litter.

<u>Elemental Storage in Surface Soil Layers</u> (<u>table 12</u>)

The calculated data for elemental storage quantities in the top 5 cm layer of the soil were arrayed and fitted to cumulative probability functions to derive the data in table 12. Elemental storage in the surface soils tend to have less variation related to species influences than the vegetation and litter values. Nitrogen storage in the top 5 cm of soil whether associated with chamise or Ceanothus is very nearly 60-75 gm/m^2, despite a much wider variation in the associated litter and vegetation. Available phosphorus storage in soil (water soluble) is much lower than the total storage in litter and vegetation. Calcium storage amounts are nearly the same, at the 50% level from 4.0-4.6 equivalents per square meter (multiply by 40 for grams). Thus, the soil storage quantities in the top 5 cm alone are four times those in the vegetation and liter. Manganese storage of the soil at 50 gm/m^2 in the top 5 cm of soil is nearly fifty times that contained in the vegetation and the litter above. No iron or zinc analyses were made of the soil. The data indicate that for many of the elements in the chaparral stand the soil has the major storage amount.

<u>Elemental Storage Distribution Between Stand Components</u> (<u>table 13</u>)

The total elemental storage on a chaparral site will be distributed variously between the vegetation, leaf litter, and the soil. This partly depends upon the age of the stand of course, but since these were all stands of about 20-25 years of age, they will be considered to be mature stands of chaparral. The data for the fifty percentile class of total storage amounts have been collected in table 13.

At a glance one finds that storage values in the leaf litter are frequently as much or more than the storage in the live vegetation. Some elements such as magnesium have much greater quantities in litter storage. Leachable elements such as potassium and sodium have much less storage in the litter. Manganese, iron, and zinc are present at orders of magnitude greater in litter storage.

Soil storage values in the top 5 cm of the soil alone are much greater than most of the storage quantities in vegetation, indicating the importance of even the loss of a small portion of top soil in erosion associated with brush removal as a major process of nutrient loss from chaparral stands. This is particularly the case in chamise stands where nitrogen storage amounts in the top 5 cm of the soil are more than three times the storage amounts in vegetation and leaf litter combined. Vegetation storage quantities of phosphorus represent a large proportion of the readily available phosphorus in the stand and its associated soil, and the processes involved upon liberation of this phosphorus back to the soil may be important in determining its availability. Magnesium and potassium storage quantities in vegetation are also a substantial proportion of total storage on the site including the surface soil.

ACKNOWLEDGMENT

Computer programs designed by A. Stangenberger, Assistant Programmer University of California, Berkeley, were a major contribution to this work.

LITERATURE CITED

Bailey, R.L. and Dell, T.R. Quantifying diameter distributions with the Weibull function. Forest Science 19:97-104; 1973

Black, C. A.,. ed. Methods of soil analyses. pt. 2 Chemical and microbiological methods. No. 9 Agronomy Series, pp 771-1572, Madison, Wisc., Amer. Soc. of Agron., 1965.

Delwiche, C.; Zinke, P.; and C. M. Johnson Nitrogen fixation by Ceanothus. Plant Physiol. 40(6): 1045-1047;1965

Johnson, C. M.; and Ulrich, A. analytical methods for use in plant Analyses. Bul. 766 Pt.II Calif. Ag. Exp. Sta.; 1959: 26-77.

Kittredge, J. Litter and forest floor of the chaparral in parts of the San Dimas Exp. Forest, California. Hilgardia 23(13) : 563-596 1955.

Specht, R. L. A comparison of the sclerophyllous vegetation characteristics of Mediterranean type climates in France, California, and southern Australia. II, Dry matter, energy, and nutrient accumulation. Aust. J. Bot. 17:293-308; 1969.

Trabaud, L. Materiali combustibili e fitomasse epigee di alcuni popolamenti del Mediterraneo francesi. Monti e Boschi 28(4):45-49;1977.

Weibull, W. A statistical analysis of the size of Cyrtoideae in Albatross cores from the East Pacific Ocean. Nature 164:1047-1048; 1949.

Wieslander, A.E. A vegetation type map of California. Madrono 3:140-144; 1935.

Zinke, P. and A.G. Stangenberger Ponderosa pine and Douglas fir foliage analyses arrayed in probability distributions. p. 221-225 in Proc. Forest Fertilization Conf.; 1979, Sept.26;Alderbrook, Wash. Univ. of Wash. Inst. of For. Res. Contr. #40.

Comparative Nutrient Relations in Adjacent Stands of Chaparral and Coastal Sage Scrub[1]

John T. Gray[2]

Abstract: Productivity and nutrient cycling parameters were measured in mature stands of chaparral and coastal sage scrub in the Santa Monica Mountains, California, USA. Net annual production and the magnitude of annual nutrient transfers were much greater in the evergreen chaparral. The chaparral had considerable stores of nutrients in wood biomass, low leaching rates, and a conservative and efficient use of most mineral elements. The drought-deciduous community was characterized by a high annual turnover of nutrients, high leaching rates, and considerable variation in foliar nutrient concentration during the year.

Several attributes of mediterranean-type ecosystems make them attractive systems in which to study plant nutrition, including low soil fertility, the predominance of sclerophylly, and the recycling of minerals by fire. Nutrient studies in these plant communities have traditionally focused on one or more of these attributes (e.g., Beadle 1966, Christensen and Muller 1975, Hellmers et al. 1955a, Specht and Groves 1966). However, our understanding of the complete nutrient cycle in mediterranean-type ecosystems is very limited, especially in comparison to forested ecosystems (Gray and Schlesinger 1981a). There is a conspicuous need for detailed studies of nutrient pools, transfers, and regulating processes in mature scrub communities.

In response to this situation, a nutrient study was conducted in the chaparral of southern California (Gray 1981). The goal of this research was twofold: (1) to quantify nutrient pools and annual transfers in the chaparral for several years; and (2) to compare and contrast the pattern of nutrient cycling and nutrient resource-use in two communities dominated by shrubs with different leaf types. The communities were evergreen chaparral and drought-deciduous coastal sage scrub, which are closely associated with one another in the coastal mountains of southern California.

SITE DESCRIPTION AND METHODS

The research site was located in the Santa Monica Mountains, 100 km north of Los Angeles, Calif., USA. Adjacent stands of chaparral and coastal sage were found at 150 meters elevation, 3 km inland. The two communities established after a fire 22 years ago on the same aspect, slope, soil, and rock formation (Gray 1981).

It is generally recognized that coastal sage scrub and chaparral are distributed along a moisture gradient in the southern California mountains (Harrison et al. 1971, Mooney and Dunn 1970). The drought-deciduous growth form appears to be an adaptation to very dry, seasonal conditions, and is normally found at low elevations. At mid-elevations a mosaic may be formed as coastal sage species are replaced by evergreen chaparral, the well-known mediterranean-type sclerophyllous vegetation of California.

The chaparral community chosen for this study was a pure stand of Ceanothus megacarpus. This species establishes only by seed after a fire and forms dense, rapidly-growing stands with a closed canopy of 3-4 meters height (Schlesinger and Gill 1980). In contrast, the coastal sage stand was co-dominated by two shrubs, Artemisia californica and Salvia leucophylla. Other occasional species include Yucca whipplei and Eriogonum parvifolium, and scattered herbs and grasses (Gray and Schlesinger 1981b). The two "sage" shrubs establish by seeds and resprouting after a fire, and form a relatively low, open community that is essentially leafless during the dry summer months.

The standing biomass in each community was determined by harvesting large samples of each shrub species and forming dimension analysis regressions (Whittaker and Woodwell 1968). Net annual aboveground production was measured for the dominant species for two years. A random sample of each species was harvested monthly and the dry weight of all plant parts was determined. Net production was calculated as the sum of positive biomass increments during the year on an areal basis, using the "mean-tree" approach (Ovington and Pearsall 1957, Gray and Schlesinger 1981b). Litterfall was collected monthly for two years in randomly-placed trays beneath the canopy of both stands.

The nutrient pool in the standing vegetation was determined by standard analysis of all harvested tissues in the lab. Nitrogen was measured as total Kjeldahl-N with an ion-specific electrode (NH_4); phosphorus by an ammonium metavandate colorimetric technique; and the major cations by atomic absorption spectrophotometry (Gray 1981). Nutrient analysis of the monthly harvested tissues provided a measurement of annual nutrient accumulation.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Associate, Department of Biological Sciences, University of California, Santa Barbara, California, 93109.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Nutrient return was measured as the nutrient content of the monthly litterfall, and the elemental content of throughfall and stemflow collections following the techniques of Eaton et al. (1973), using randomly-placed collectors.

STANDING BIOMASS AND NUTRIENT POOLS

The peak aboveground live biomass of the *Ceanothus* chaparral was greater than the coastal sage by a factor of six (Table 1). The biomass of these two stands represent the highest and lowest values of 14 mediterranean-type ecosystems from around the world as summarized in Gray and Schlesinger (1981a). Dead wood accounted for 15 and 21 percent of the aboveground biomass in the chaparral and coastal sage, respectively. The coastal sage had a greater proportion of its peak standing biomass in foliage than in the chaparral (Table 1). However, during the summer months of August and September, only 15-30 percent of the deciduous foliage biomass remains (Gray and Schlesinger 1981b).

In the coastal sage scrub, 39-42 percent of the total nutrient pool in the vegetation was present in the foliage. In contrast, this value was only 12-23 percent for all elements in the chaparral. The smaller allocation of nutrients to the foliage compartment in the chaparral is due in part to the large amount of wood accumulation, and to the low concentration of mineral elements in the evergreen foliage.

Unlike forest ecosystems, where 60-70 percent of the aboveground nutrient pool is stored in the litter layers (Lang and Forman 1978), a comparatively smaller nutrient pool was found in the litter of the chaparral and coastal sage (Table 1). Non-limiting elements such as calcium and magnesium accumulated in the litter layer, while potassium which is easily leached from litter by rainfall was only present in small quantities. The relative impoverishment of nitrogen and phosphorus in the litter layers may be a result of a greater retranslocation of these elements before abscission. Schlesinger and Hasey (1981) have shown that in chaparral ecosystems, rates of decomposition are relatively rapid, preventing the accumulation of large nutrient pools in the litter.

ANNUAL PRIMARY PRODUCTION AND NUTRIENT ACCUMULATION

In the mediterranean climate of southern California, both evergreen and drought-deciduous shrubs begin their aboveground growth soon after the winter rains (Mooney et al. 1977). This period of measurable growth varies for each species and from year to year. For the drought-deciduous shrubs, there is a 5-8 month period of leaf production, followed by a short period of flowering, and 2-4 months of drought dormancy (Gray 1981, Gray and Schlesinger 1981b). The evergreen shrub, *Ceanothus*, produces flowers and leaves in the spring, while woody increment may extend throughout the summer. The possession of evergreen foliage in *Ceanothus*

Table 1-- Peak aboveground standing biomass and nutrient pools in the chaparral and coastal sage.

	Dry Matter	Nutrient Pool				
		N	P	K	Ca	Mg
		g/m^2				
CHAPARRAL						
Live aboveground biomass	6482	40.8	2.8	16.0	33.5	4.2
Percent foliage	8	20	13	12	13	23
Community aboveground total[1]	9651	68.6	3.9	23.4	65.2	11.5
Percent litter layer	21	30	15	19	39	58
COASTAL SAGE SCRUB						
Live aboveground biomass[2]	925	5.5	0.7	5.6	4.1	1.0
Percent foliage[2]	12	39	39	40	42	39
Community aboveground total[1]	2034	12.5	1.5	9.2	15.0	5.1
Percent litter layer	30	37	26	20	60	60
MEDITERRANEAN-TYPE ECOSYSTEMS[3]						
Mean, aboveground biomass	3729	21.1	1.6	13.4	25.5	3.8

[1]Includes dead wood, litter layer mass, and biomass of subordinate species.
[2]Values for the dominant shrubs *Salvia* and *Artemisia* only.
[3]From Gray and Schlesinger (1981a).

Table 2-- Annual production, litterfall, nutrient accumulation, and nutrient return in the chaparral coastal sage. Values are a mean of two years.

	Dry Matter	N	P	K	Ca	Mg
				$g/m^2/yr$		
ANNUAL ACCUMULATION[1]						
Chaparral	1056	13.11	0.74	4.61	7.39	1.38
Coastal Sage[3]	291	3.19	0.42	3.58	2.39	0.51
ANNUAL RETURN[2]						
Chaparral	801	7.30	0.32	4.06	9.54	1.77
Coastal Sage[3]	199	2.01	0.18	3.14	3.87	0.99

[1]Accumulation = peak nutrient content of annual production.

[2]Return = nutrient content of litterfall, throughfall, and stemflow.

[3]Values for the dominant shrubs, *Salvia* and *Artemisia* only.

allows for the potential of year-round photosynthesis (Gray 1981, Mooney and Dunn 1970).

The annual aboveground production was greater in the *Ceanothus* chaparral than in the coastal sage as shown in Table 2. In the chaparral, 52 percent of the production (1056 $g/m^2/yr$) was foliage, compared to 38 percent of the production (291 $g/m^2/yr$) in the coastal sage. Both communities allocated 50 percent of total production to twig growth and radial wood increment. This relatively high rate of wood accumulation in both communities is reduced partially by the death of attached stems, estimated at 74 and 20 $g/m^2/yr$ in the chaparral and coastal sage, respectively (Gray 1981).

Not surprisingly, nutrient accumulation in the annual production was greater in the chaparral (Table 2). Nutrient accumulation in *Adenostoma fasciculatum* (chamise), another evergreen chaparral dominant, appears to be much less than found in *Ceanothus*. Annual accumulation of nitrogen and phosphorus in a chamise community was only equivalent to that found in the coastal sage scrub (Mooney and Rundel 1979).

In both the chaparral and coastal sage, 60-70 percent of the annual primary production was returned in litterfall (Table 2). The majority of the annual nutrient return was contained in this litterfall; potassium is a notable exception because it is so easily leached from plant leaves (Tukey 1970). The time and magnitude of leaching by winter rains vary from year to year, but generally coincide with the appearance of new, nutrient-rich leaves on all the shrubs.

NUTRIENT RELATIONS

Foliar Concentrations

The concentration of mineral elements, particularly nitrogen and potassium, is usually lower in coniferous and evergreen foliage (van den Driessche 1974). For all the major elements, *Ceanothus* had a lower concentration than either *Artemisia* or *Salvia* as shown in Table 3. *Ceanothus megacarpus* had much higher values for nitrogen and phosphorus than reported in the needle-like leaves of *Adenostoma fasciculatum* (chamise), the most wide-

Table 3-- Mean elemental concentrations (pct. dry weight) in leaves of the dominant shrubs. Mean derived from 24 monthly collections, 8 samples per month; coefficient of variation in parentheses.

Species	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Artemisia californica	1.88 (29)	0.225 (29)	1.42 (33)	0.94 (25)	0.267 (19)
Salvia leucophylla	1.85 (31)	0.200 (30)	1.54 (44)	1.41 (16)	0.298 (19)
Ceanothus megacarpus	1.69 (12)	0.081 (20)	0.45 (22)	0.87 (12)	0.160 (12)

spread chaparral shrub in California (Mooney and Rundel 1979). Ceanothus also had moderately high concentrations compared to six other chaparral shrubs in San Diego County where nitrogen and phosphorus concentrations ranged from 0.91-1.61 and 0.06-0.13 percent, respectively (Mooney et al. 1977).

The nitrogen:phosphorus ratios in the drought-deciduous shrubs were between 8 and 9, while in Ceanothus, it was 20. The optimal ratio for productivity in many agricultural plants is between 15-20 (van den Driessch 1974). The high ratio in Ceanothus implies that nitrogen is probably not limiting at this site.

Symbiotic nitrogen fixation occurs in the genus Ceanothus (Delwiche et al. 1965), although no nodules were observed on the roots of the shrubs at the research site. Kummerow et al. (1978) suggest that nodulation of the roots of C. greggii in the chaparral is rare because of xeric soil conditions; they estimate that symbiotic nitrogen fixation contributes less than 0.01 $g/m^2/yr$ in the chaparral.

Thus, in comparison to the drought-deciduous species, and many other evergreen chaparral shrubs, Ceanothus appears to have a relatively high nitrogen requirement. It also appears that in the chaparral, Ceanothus may not depend upon nitrogen fixation to meet this requirement, although this suggestion deserves careful attention in the future.

The monthly variation of nitrogen and phosphorus concentration in the leaves of the three species is presented in Figure 1. This fluctuation is due primarily to the production of new, nutrient-rich leaves and the subsequent reduction in their concentration as they age. In the evergreen shrub, Ceanothus, the annual variation was lower; the coefficient of variation for all elements over two years was only 12-20 percent (Table 3). In Salvia and Artemisia, the concentration of elements in the leaves varied greatly throughout the year, depending primarily upon the season in which the leaves were produced. Coefficients of variation for the drought-deciduous shrubs ranged from 16-44 percent (Table 3).

Turnover Rates

Turnover rates of dry matter and nutrients are primarily a function of the magnitude of the standing biomass and the nutrient pools. In the high biomass chaparral, the percent of the total biomass returned to the environment each year was only 12 percent, compared to 22 percent in the coastal sage as shown in Table 4. In both communities, the order of nutrient turnover from fastest to slowest was Mg, Ca, K, N, and P. The essential elements nitrogen and phosphorus were both closely coupled to dry matter turnover. The nutrient turnover rates in the chaparral were twice that found in the coastal sage. The turnover rates of non-limiting elements, calcium and magnesium were very rapid in the coastal sage community.

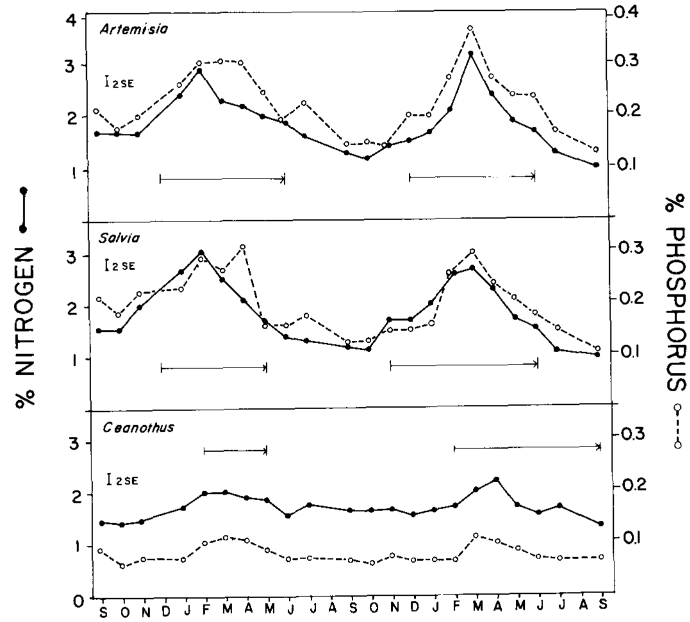


Figure 1--Monthly nitrogen and phosphorus concentrations (pct. dry weight) in the foliage of the dominant shrubs of the coastal sage and chaparral. The largest two standard errors for any month are shown. The spring period of leaf production is indicated by the lines with arrows.

Leachability

Plant foliage is subject to nutrient losses by leaching, although the magnitude differs depending upon the leaf morphology and the element in question (Tukey 1970). The leachability of each community, expressed as the total nutrient loss in throughfall and stemflow as a percent of the nutrient pool in the canopy (i.e., leaves and flowers) during the winter months is presented in Table 4. The coastal sage showed a high leaching rate for all elements: the leachability ratio was 2-3 times greater than in the chaparral. The overall rate of leaching in the coastal sage community was surprisingly high in light of the fact that the canopy was open and sparse. In contrast, the canopy of the chaparral was closed and over 50 percent of the incident precipitation was intercepted (Gray 1981).

Redistribution of Mineral Elements

Mobile mineral elements are translocated from leaves into living stems before abscission (Williams 1955). The extent of this recovery process varies, depending upon the plant species and the plant nutrient status (Chapin 1980). Clearly, in nutrient-limiting situations, greater redistribution would be of a selective advantage. Using the mass balance relationships defined by Turner et al. (1976), the amount of the annual nutrient accumulation provided by redistribution can be calculated for the species in the chaparral and coastal sage scrub. As presented in Table 4, only the

Table 4-- Elemental characteristics of the chaparral and coastal sage scrub. All values represent a mean of two years.

	Dry Matter	N	P	K	Ca	Mg
TURNOVER RATE[1]						
Chaparral	12	17	11	25	28	42
Coastal Sage	22	36	26	56	94	99
LEACHABILITY[2]						
Chaparral	-	3	0	41	17	29
Coastal Sage	-	8	0	76	54	59
REDISTRIBUTION[3]						
Chaparral	-	44	56	12	0	0
Coastal Sage	-	36	57	12	0	0
EFFICIENCY RATIO[4]						
Chaparral	-	86	1944	156	66	358
Coastal Sage	-	72	805	46	37	146

[1]Total annual nutrient return/nutrient pool in the standing biomass.
[2]Annual leaching losses/ leaf and flower nutrient pool during winter months.
[3]Percent of annual nutrient accumulation provided by retranslocated minerals.
[4]Annual dry matter production of leaves and flowers/annual nutrient return.

common limiting elements, nitrogen and phosphorus, were conserved to any significant degree. There was no redistribution of calcium and magnesium, the former being associated with cell wall deposition and not freely transported within the plant (Clarkson and Hanson 1980). Magnesium has a multiplicity of roles in plant metabolism and is relatively mobile. Any redistribution of magnesium may have been masked by the high leaching rate of this element, particularly in the coastal sage.

Although _Ceanothus_ had a high nitrogen requirement and did not appear to be nitrogen-limited, the shrub showed a high dependency on internal sources of nitrogen and a great capacity for the storage of this nutrient. The redistribution values for _Ceanothus_ can be compared to chamise, where redistribution of nitrogen and phosphorus has been estimated at only 24 and 46 percent, respectively (Mooney and Rundel 1979). Values reported for other wild plants in the literature range from 0-83 percent and no consistent relationship between growth form and redistribution ability is evident yet.

Efficiency Ratio

Nutrient-use efficiency can be defined in a variety of ways, depending upon which nutrient process of the plant being investigated (i.e., acquisition, transport, or utilization). On a community level, a production efficiency ratio can be defined as the annual production of dry matter per amount of mineral element returned to the environment each year. This is a composite index across the species in the community that incorporates production with nutrient uptake, accumulation, and loss (Gray 1981). To the extent that greater production leads to greater reproduction and/or longevity, this index may be a measure of the potential competitive abilities under nutrient-limited conditions.

For all the major elements, the evergreen shrub, _Ceanothus_, had a greater production efficiency (Table 4). This is particularly true for phosphorus, potassium, and magnesium. _Ceanothus_ had a very low requirement for these three elements, and was less susceptible to leaching of the latter two nutrients than _Salvia_ or _Artemisia_.

DISCUSSION AND CONCLUSIONS

Chaparral ecosystems are relatively short-lived because of recurring fires. Ecologists have traditionally thought that in the absence of fire, many chaparral communities become "senescent" (Hanes 1977). In these communities, it has been suggested that as more of the soil mineral resources are tied up in the vegetation and litter layer, production will become nutrient-limited (Rundel and Parsons 1980).

However, the present work indicates that in mature stands of _Ceanothus_ chaparral and coastal sage, there is considerable net production and nutrient accumulation. The high foliar concentrations in the two drought-deciduous shrubs and in Ceanothus are equal to or greater than the levels in most chaparral shrubs (Mooney et al. 1977) and suggest no nutrient limitation. This conclusion is similar to that of Schlesinger and Gill (1980), who found no decline in foliar nitrogen concentrations in stands of C. megacarpus from 6-22 years near Santa Barbara, California.

With regard to the coastal sage scrub, there was considerable turnover of dry matter and nutrients each year; 26-36 percent of the standing nitrogen and phosphorus pools were returned annually to the soil. The stand was relatively productive and did not appear to be impoverished of mineral elements. This high rate of nutrient turnover and productivity implies that there may be a close coupling of nutrient release (i.e., decomposition and mineralization) and nutrient uptake by the plants. Drought-deciduous shrubs like Artemisia and Salvia are well adapted to form this type of nutrient cycle by virtue of their shallow roots (Hellmers et al. 1955b), rapid response to winter rains (Gray and Schlesinger 1981b, Harvey and Mooney 1964), and fast, inherent growth rates (Gray 1981).

The Ceanothus chaparral was more productive than the coastal sage community, and the magnitude of the nutrient transfers was considerably larger. Also, in contrast to the rapid turnover of nutrients in the coastal sage, the nutrient cycle in the chaparral was characterized by several important differences.

First, there were considerable stores of nutrient in the biomass of the chaparral. Therefore, only a small turnover of minerals occurred annually. Second, the evergreen shrub had low leaching rates, a high redistribution ability, and an efficient use of nutrients in the production of dry matter. These attributes of the evergreen shrub made it very conservative in its use of nutrients, particularly nitrogen and phosphorus. Third, because of the great extent to which Ceanothus used internal sources of nitrogen and phosphorus, it may have been less dependent upon soil nutrient availability during any given year compared to the coastal sage.

In the early development of a Ceanothus community the high nutrient-use efficiency may favor the rapid accumulation of biomass and nutrients typical of this species (Schlesinger and Gill 1980). This same conservative and efficient use of mineral elements in a mature stand may also permit the formation of a comparatively balanced and self-regulated nutrient cycle, which in turn may lead to the high rate of biomass accumulation found in these mature stands. The extent to which this nutrient cycle is characteristic of other evergreen chaparral communities is unknown and deserves future attention before management questions involving chaparral nutrient relations can be fully answered.

ACKNOWLEDGEMENTS

I thank William H. Schlesinger for the valuable advice and scientific insight that he provided throughout the research project. I thank Kim Wagner for her help and understanding during the study. I also thank the California Department of Parks and Recreation for the kind use of Leo Carrillo State Beach Park for this work. This research has been supported in part from grants from Sigma-Xi and the Academic Senate of the University of California; and by NSF Grant DEB-79-11753 to W.H. Schlesinger.

LITERATURE CITED

Beadle. N.C.W. Soil phosphate and its role in molding segments of the Australian flora and vegetation, with special reference to xeromorphy and sclerophylly. Ecology 47: 992-1007. 1966.

Chapin, F.S. The mineral nutrition of wild plants Ann. Rev. Ecol. Syst. 11: 233-260; 1980.

Christensen, N.L. and C.H. Muller. Effects of fire on factors controlling plant growth in Adenostoma fasciculatum chaparral. Ecol. Monogr. 45: 29-55; 1975.

Clarkson, D.T. and J.B. Hanson. The mineral nutrition of higher plants. Ann. Rev. Plant Physiol. 31: 239-312; 1980.

Delwiche, C.C., P.J. Zinke, C.M. Johnson. Nitrogen fixation by Ceanothus. Plant Physiol. 40: 1045-1047; 1965.

Eaton, J.S., G.E. Likens, F.H. Bormann. Throughfall and stemflow in a northern hardwood forest. J. Ecology 61: 495-508; 1973.

Gray, J.T. Productivity, nutrient-cycling, and nutrient-resource-use in the chaparral and coastal sage scrub of southern California. Ph.D. Dissertation. Univ. of Calif. Santa Barbara. 1981.

Gray, J.T. and W.H. Schlesinger. Nutrient cycling in mediterranean-type ecosystems. In P.C. Miller, ed., Resource Utilization in Two Mediterranean-Type Ecosystems. Chapter 10. Springer-Verlag, New York. 1981a.

Gray, J.T. and W.H. Schlesinger. Biomass, productivity, and litterfall in the coastal sage scrub of southern California. Amer. J. Bot. 68: 24-33; 1981b.

Hanes, T.L. California chaparral. In M.G. Barbour and J. Majors, eds., Terrestrial Vegetation of California. Wiley & Sons, Inc., New York. 1977.

Harrison, A.T., E. Small, H.A. Mooney. Drought relationships and distribution of two mediterranean-climate California plant communities. Ecology 52: 869-875; 1971.

Harvey, R.A. and H.A. Mooney. Extended dormancy of chaparral shrubs during severe drought. Madrono 17: 161-163; 1964.

Hellmers, H., J.F. Bonner, J.M. Kelleher. Soil fertility: a watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80: 189-197. 1955a.

Hellmers, H., J.S. Horton, G. Juhren, J. O'Keefe. Root systems of some chaparral plants in southern California. Ecology 36: 667-678. 1955b.

Kummerow, J., J.V. Alexander, J.W. Neel, and K. Fishbeck. Symbiotic nitrogen fixation in Ceanothus roots. Amer. J. Bot. 65: 63-69;1978.

Lange, G.E. and R.T.T. Forman. Detrital dynamics in a mature oak forest: Hutcheson Memorial Forest, New Jersey. Ecology 59: 580-598; 1978.

Mooney, H.A. and P.W. Rundel. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum in the California chaparral. Bot. Gaz. 140: 109-113; 1979.

Mooney, H.A., J. Kummerow, A.W. Johnson, D.J. Parsons, S. Keeley, A. Hoffman, J. Gilberto, R.I. Hays, and C. Chu. The producers--their resources and adaptive responses. In H.A. Mooney, ed., Convergent Evolution in Chile and California, Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa. 1977.

Mooney, H.A. and E.L. Dunn. Photosynthetic systems of mediterranean-climate shrubs and trees of California and Chile. Amer. Nat. 104: 447-453; 1970.

Ovington, J.D. and W.H. Pearsall. Production ecology. II. Estimates of average production by trees. Oikos 7: 202-205; 1956.

Rundel, P.W. and D.J. Parsons. Nutrient changes in two chaparral shrubs along a fire-induced age gradient. Amer. J. Bot. 67: 51-58; 1980.

Schlesinger, W.H. and M.M. Hasey. Decomposition of chaparral shrub foliage: losses of organic and inorganic constituents from deciduous and evergreen leaves. Ecology (In Press); 1981.

Schlesinger, W.H. and D.S. Gill. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61: 781-789; 1980.

Specht, R.L. and R.H. Groves. A comparison of the phosphorus nutrition of Australian heath plants and introduced economic plants. Aust. J. Bot. 14: 200-221; 1966.

Tukey, H.B. The leaching of substances from plants. Ann. Rev. Plant Physiol. 21: 305-324; 1970.

Turner, J., D.W. Cole, S.P. Gessel. Mineral accumulation and cycling in a stand of red alder (Alnus rubra). J. Ecology 64: 965-974; 1976.

van den Driesshe, R. The prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40: 347-397; 1974.

Whittaker, R.H. and G.M. Woodwell. Dimension and production relations of trees and shrubs in the Brookhaven forest, New York. J. Ecology 56: 1-25; 1968.

Williams, R.F. Redistribution of mineral elements during development. Ann. Rev:- Plant Physiol. 6: 25-42; 1955.

Nutrient Mineralization Processes in Mediterranean-Type Ecosystems[1]

G. M. Marion[2]

Abstract: The objective of this paper is to assess the role of mineralization processes (pyrolysis, decomposition, and weathering) on nutrient (N, P, K, Ca, Mg, and S) release in mediterranean-type ecosystems. Decomposition is the most important process for N release. Decomposition and pyrolysis are both significant in the release of K, Ca, and Mg. Too little is known concerning the mineralization of P and S to allow generalizations. Also, generalizations about weathering are difficult because of the high site specificity of nutrient release through weathering. Environment is as important as substrate in estimating mineralization rates; these mineralization rates should be more sensitive to moisture than to temperature fluctuations.

Mineralization is a general term referring to processes that convert complex organic and inorganic materials into soluble ions available for plant uptake. Three mineralization processes are potentially important in mediterranean-type ecosystems; these are (1) pyrolysis of organic matter, (2) decomposition of organic matter, and (3) chemical weathering of inorganic minerals (fig. 1). These three mechanisms are the key processes controlling nutrient availability in terrestrial ecosystems. The rate of nutrient release through these processes is largely a function of substrate quantity and quality, temperature, and moisture.

The objectives of this review are to (1) assess the magnitude and relative importance of pyrolysis, decomposition, and weathering on macronutrient (N, P, K, Ca, Mg, S) flux in mediterranean-type ecosystems and (2) assess the importance of substrate quantity and quality, temperature, and moisture in determining nutrient flux.

PYROLYSIS OF ORGANIC MATTER

The importance of fire as a mineralizing agent in mediterranean-type ecosystems is generally recognized (Naveh 1975, Groves 1977, Zinke 1977, Trabaud 1981). Fire can affect mineralization processes in both direct and indirect ways. The direct ashing of organic matter releases significant quantities of N, P, K, Ca, Mg, and S (table 1). The release is particularly large for K, Ca, and Mg. This "pulse" nutrient addition is important for the rapid reestablishment of chaparral vegetation following fire (Naveh 1975, Christensen and Muller 1975). Work in the *Quercus coccifera* garrigue has also shown that fire leads to an immediate increase in available P, K, Ca, and Mg (Trabaud 1981). The actual release depends largely on the quantity of organic matter, temperature, and moisture. Laboratory studies have shown that NH_4 and NO_3 formation begins at 200°C and peaks between 300 and 350°C; beyond 500°C, nitrogen is completely volatilized (Dunn and DeBano 1977). The formation and loss of available nitrogen depends on soil moisture content. Moist soils stay cooler during fires because the heat energy can be dissipated by evaporating moisture. As a consequence, there is generally less release of available N during fires over moist soils (table 1).

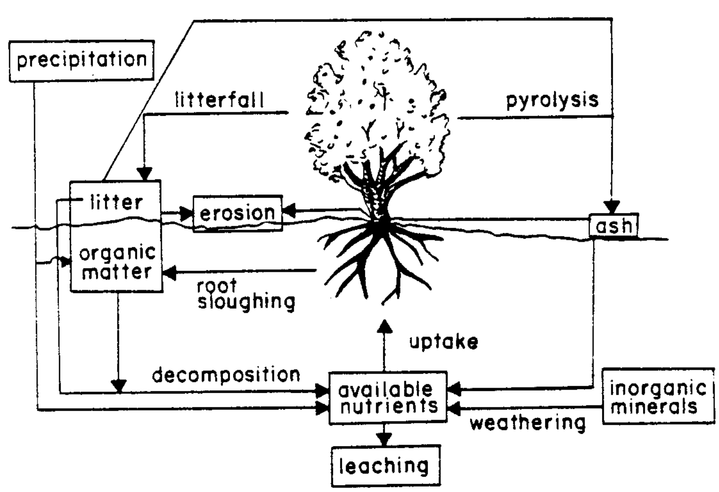


Figure 1--The ecosystem nutrient cycle.

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26 1981, San Diego, California.

[2]Research Professor of Ecology, Systems Ecology Research Group, San Diego State University, San Diego, California 92182

Table 1--Nutrient mineralization from pyrolysis of organic matter in selected mediterranean-type and forest ecosystems.

Ecosystem: Location (Reference)	Experimental conditions	Nutrient					
		N	P	K	Ca	Mg	S
		$g\ m^{-2}$					
Chamise chaparral: California (Christensen and Muller 1975)	Laboratory ashing of vegetation	0.04	0.01	5.1			0.4
	Laboratory: Burning treatments						
Chamise chaparral	Intense-dry	0.29					
Ceanothus chaparral	Intense-dry	0.88					
Chamise chaparral	Intense-moist	0.36					
Ceanothus chaparral	Intense-moist	0.13					
Chamise chaparral	Moderate-moist	0.17					
Ceanothus chaparral	Moderate-moist	0.14					
Chaparral: California (DeBano et al. 1979)	Field: prescribed fire	1.0-2.4					
Adenostoma-*Ceanothus*-*Salvia* chaparral: California (DeBano and Conrad 1978)	Field: prescribed fire			4.1	11	6.6	
Coniferous forest: Washington (Grier 1975)	Field: wildfire			3.2	31	4.5	

Fire can indirectly affect mineralization by creating a more favorable environment for mineralization processes following fire. Available NH_4, NO_3, and P are generally higher on burned sites than on unburned sites for periods up to 2 years following fire (Christensen and Muller 1975). Factors present following fire that can lead to a more favorable microbial environment include the high content of organic N added with the ash, higher soil temperatures, more favorable moisture conditions, and the destruction of allelopathic compounds during the fire (Naveh 1975, Christensen and Muller 1975). However, the presence of high levels of available nutrients for long periods following fire is not always evidence of improved mineralization. The high available nutrient levels may simply reflect a low vegetative uptake during the establishment phase.

Although fire is generally considered a beneficial agent in releasing nutrients tied up in organic matter, there is evidence that burning too frequently can lead to site nutrient degradation (Groves 1977, Trabaud 1981, Schlesinger and Gray 1981). Frequent fires can exacerbate an already nutrient deficient situation favoring the growth of shrubby sclerophyllic species instead of the more herbaceous species and thus "deflect" succession in mediterranean-type ecosystems (Specht 1973, Groves 1977).

DECOMPOSITION OF ORGANIC MATTER

Annual Nutrient Fluxes

Decomposition of organic matter is an important process leading to the release of N, P, K, Ca, Mg, and S into forms available for plant growth. However, decomposition and mineralization are not generally synonymous. Decomposition refers to the breakdown, or disappearance, of organic matter. For a nonstructural nutrient, such as K, decomposition and mineralization are synonymous. Structural nutrients, such as N, P, and S, are frequently converted into soluble organic forms during decomposition; an additional step is required to break the organic molecules into soluble inorganic ions before plant uptake can occur. As a consequence, litter decomposition data cannot be directly used to estimate mineralization rates with the exception of K. The annual nutrient mineralization from decomposition of organic matter falls in the order: N ≈ Ca > K > Mg ≈ S > P (table 2). The magnitude of this release is significant with respect to plant requirements. In fact, N mineralization from organic matter is the primary source of available N for plant uptake in terrestrial ecosystems (Rosswall 1975, Ellenberg 1977).

Nitrogen Mineralization

Nitrogen is of special importance because it is the nutrient which most frequently limits growth in terrestrial ecosystems (Ellenberg 1977, Gray and Schlesinger 1981). Substrate quantity and quality, temperature, and moisture largely control N availability. The quantity of N within an ecosystem can be easily measured; however, such point-in-time measurements are poorly correlated to N availability (Harmsen and van Schreven 1955). Soil incubations are considered the best technique for assessing substrate quality with respect to N availability (Harmsen and van Schreven 1955, Stanford and Smith 1972).

Accumulative nitrogen mineralized (N_t) with time (t) under optimal temperature (35°C and moisture (0.2 bar soil moisture tension) in the laboratory can be described with a three-parameter logarithmic equation:

$$\text{Log } (N_O - N_t) = \text{Log } N_O - kt^b \qquad (1)$$

where N_O is potentially mineralizable N, k is the rate constant, and b is the time exponent (Marion and others 1981). Nitrogen mineralization parameters for chaparral and matorral soils show considerable variation between soils, particularly in the potentially mineralizable nitrogen (table 3); the latter parameter is an estimate of substrate quality.

The laboratory nitrogen mineralization equations can be used to estimate field nitrogen mineralization by adjusting for suboptimal moisture and temperature. Stanford and others (1973) found a Q_{10} of 2.0 for the N mineralization rate constants (k; table 3); that is, the rate constant is halved for every 10°C drop below 35°C. Stanford and Epstein (1974) found that relative N mineralization with respect to moisture (N mineralized at field moisture/N mineralized at optimum moisture) was equal to relative moisture content [field moisture content/optimum moisture content (approximately field capacity)]. Nitrogen mineralization under optimal moisture and temperature for the Cieneba-mixed soil (table 3) is 5.4 ppm N/week. Using the above relationships to adjust the optimal equation (table 3) to field temperature and moisture (measured at the Echo Valley research site), one can calculate the relative effect of field temperature and moisture on N mineralization (fig. 2). Moisture is optimum for N mineralization during the winter months; temperature optimums for N mineralization are reached in the summer. However, the relative N mineralization attributable to temperature fluctuates by a factor of less than three, while the relative N mineralization attributable to moisture fluctuates by a factor of ten (fig. 2). As a consequence, the combined moisture and temperature curve, which assumes that moisture and temperature are acting independently, more closely follows the moisture fluctuations.

Table 2--Nutrient mineralization from decomposition of organic matter in selected mediterranean-type and forest ecosystems.

Ecosystem: Location (Reference)	Material	Nutrient					
		N	P	K	Ca	Mg	S
		$g\ m^{-2}\ yr^{-1}$					
Coastal sage: California (Gray and Schlesinger 1981)	Litter			[1]1.1			
Ceanothus chaparral: California (Gray and Schlesinger 1981)	Litter			[1]3.4			
Chamise chaparral: California (Mooney and Rundel 1979)	Soil and litter	3.3					
Mixed chaparral: California (Marion et al. 1981)	Soil and litter	8.0					
Banksia scrub: Australia (Maggs and Pearson 1977)	Litter			[1]0.9-2.1			
Quercus ilex forest: France (Lossaint 1973)	Litter	2.6	0.2	0.7	5.3	0.3	
Deciduous forest: U.S.A. (Likens et al. 1977)	Soil and litter	7.0		2.0	4.2	0.6	0.6

[1]Calculated from litterfall data assuming the ecosystem litter is in a steady state (input = output).

Table 3--Nitrogen mineralization parameters for the equation, $\text{Log}(N_O - N_t) = \text{Log } N_O - kt^b$, determined under optimal conditions for temperature (35°C) and moisture (0.2 bar moisture tension) (Marion et al. 1981).

Location: soil	Horizon	Total nitrogen	Potential mineralizable nitrogen (N_o)	Rate constant (k)	Time exponent (b)	r^2
		%	ppm	$week^{-1}$		
San Diego County, California, U.S.A.:						
[1]Cieneba-chamise	A	0.043	9.8	0.141	0.61	0.94
	C	0.016	0.4	[2]0.39	[2]0.70	---
[1]Cieneba-mixed	A	0.098	24.5	0.109	0.72	0.77
Tollhouse	A	0.083	14.8	0.104	0.65	0.96
	AC	0.035	4.0	[2]0.50	[2]0.70	--
La Posta	A	0.186	50.7	0.070	0.73	0.95
	C	0.075	11.9	0.142	0.69	0.97
Las Posas	A	0.123	54.0	0.104	0.87	0.99
	B	0.040	3.0	0.147	0.62	0.94
Sheephead	A	0.107	20.3	0.127	0.73	0.98
	C	0.050	3.4	[2]0.87	[2]0.70	--
Fundo Santa Laura, Chile:						
Ridgetop--near ravine	A	0.223	73.0	0.027	1.09	0.94
Ridgetop	A	0.141	37.6	0.082	0.87	0.99

[1]The Cieneba-chamise and Cienaba-mixed are Cieneba soils under pure chamise and mixed chaparral vegetation, respectively.

[2]Calculated indirectly because of too few points for a statistical fit.

Nitrogen mineralization is more sensitive to moisture than to temperature fluctuations in this mixed chaparral ecosystem; this high sensitivity to moisture conditions agrees with previous chaparral work (Schaefer 1973, Mooney and Rundel 1979). Nitrogen mineralization should theoretically peak in the winter and be at a minimum in the summer. The simulated weekly N mineralization ranged from 3 to 27 percent of the optimal amount (5.4 ppm N). Clearly, quantification of the mineralization environment, particularly temperature and moisture, is as important as quantification of substrate quantity and quality in estimating N availability in terrestrial ecosystems.

These field temperature and moisture effects are based on a theoretical model of the N mineralization process developed from laboratory studies. There exists field data to support this theoretical model. Using the N mineralization equations for optimal conditions (table 3), the previously mentioned relationships to adjust N mineralization to field moisture and temperature, and field moisture and temperature measurements, one can calculate the annual N mineralization by integrating the mineralization equations at weekly time steps over the plant rooting zone. The predicted annual N mineralization for a chamise and a mixed chaparral ecosystem were 3.2 and 7.4 g N m^{-2} yr^{-1}, respectively; these estimates agree reasonably well with independent estimates using a mass balance equation of 3.3 and 8.0 g N m^{-2} yr^{-1}, respectively (Marion and others 1981).

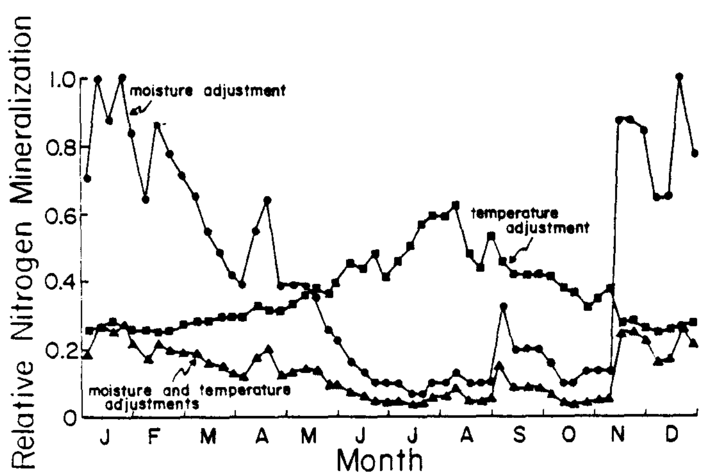


Figure 2--The simulated effect of seasonal field soil temperature and moisture on relative nitrogen mineralization for a surface soil in a mixed chaparral ecosystem.

Table 4--Nutrient mineralization from chemical weathering in selected mediterranean-type and forest ecosystems.

Ecosystem type: Location (Reference)	Rock type	Nutrient				
		P	K	Ca	Mg	S
		$g\ m^{-2}\ yr^{-1}$				
Fynbos: South Africa (Day 1981)	Sandstone	0.025	6.0	3.5	2.0	
Oak-pine forest: New York, U.S.A. (Woodwell and Whittaker 1967)	Outwash sands		1.0-1.2	2.3-2.6	0.7-1.0	
Scrub pine-oak forest: Maryland, U.S.A. (Cleaves et al. 1974)	Serpentinite		tr	tr	3.4	
Forest: Maryland, U.S.A. (Cleaves et al. 1970)	Shist		0.23	0.13	0.17	
Oak-beech forest: Luxembourg (Verstraten 1977)	Shale		0.02	0.87	1.6	
Northern hardwood forest: New Hampshire, U.S.A. (Likens et al. 1977)	Moraine/gneiss		0.71	2.1	0.35	0.08
Douglas-fir forest: Oregon, U.S.A. (Fredricksen 1972)	Tuffs/breccias		0.16	4.7	1.2	
Northern hardwood forest: Michigan, U.S.A. (Adams and Boyle 1979)	Outwash sands		0.1-0.3	0.1	0.1	

Table 5--The primary minerals and mean annual temperature and precipitation for five selected sites within mediterranean-type ecosystems.

Ecosystem: Location (Reference)	Rock type: Primary minerals	Mean annual	
		Temperature	Precipitation
		°C	mm
Chaparral: Echo Valley, California (Thrower and Bradbury 1977)	Quartz diorite: plagioclase, quartz, orthoclase	17	440
Matorral: Fundo Santa Laura, Chile (Thrower and Bradbury 1977, Miller et al. 1973)	Andesite: plagioclase, augite. Quartz diorite: Hornblende quartz, plagioclase, biotite	16	550-600
Garrigue: Montpellier, France (Lossaint 1973)	Limestone: calcite	14	770
Fynbos: Jonkershoek, South Africa (Kruger 1977, 1979)	Quartzite: quartz	16	1270
Heath: Dark Island Soak, Australia (Specht and Rayson 1957)	Aeolian sand: quartz	15	460

CHEMICAL WEATHERING OF INORGANIC MINERALS

Many igneous, metamorphic, and sedimentary rocks were formed under high temperatures, high pressures, and in the absence of air and water; their exposure to the low temperatures, low pressures, and the presence of air and water at the Earth's surface causes their chemical breakdown into stable secondary minerals. A by-product of this chemical transformation is the release of essential nutrients for plant growth. Primary mineral weathering is an important process releasing Ca, Mg, and K, and to a lesser extent, P and S for plant growth.

Watershed level studies using mass balance techniques provide the best estimates of nutrient release from rock weathering (Clayton 1979). A mass balance equation can be written as:

precipitation + weathering = plant uptake + leaching + Δ soil storage (2)

Accurate estimates of weathering rates require accurate estimates of precipitation, plant uptake, leaching, and changes in soil storage. Although there are a few gaged watersheds within mediterranean-type ecosystems, none have been used to estimate rock weathering rates. The only estimate of nutrient release from rock weathering in a mediterranean-type ecosystem was developed by assuming a weathering rate of 1 cm/100 years for a sandstone (table 4); since details of this estimate are not available, it is impossible to critically assess its validity. However, the weathering data from forested ecosystems are adequate to demonstrate the high inherent variability likely to be found from site to site (table 4). Under the right circumstances, significant amounts of K, Ca, and Mg can be released, but generalizations are difficult because of the highly variable mineral suites (tables 4 and 5).

Both temperature and moisture affect weathering rates. The weathering diagram (fig. 3) depicts the relative effect of temperature and moisture on chemical weathering intensity. At the average temperature and precipitation typical of mediterranean-type ecosystems, the chemical weathering intensity should be weak to moderate (fig. 3). Because moisture regimes are more likely than temperature regimes to be different between sites within mediterranean-type ecosystems (fig. 3), differences in chemical weathering intensity between sites are more likely to be due to moisture than to temperature. Climate also plays an indirect role on weathering intensity through its effect on vegetative growth. Carbon dioxide from root and microbial activity in the soil can react with water to form carbonic acid which can react with primary minerals. Carbon dioxide levels may ultimately control weathering in soils (Johnson and others 1975, Routson and others 1977).

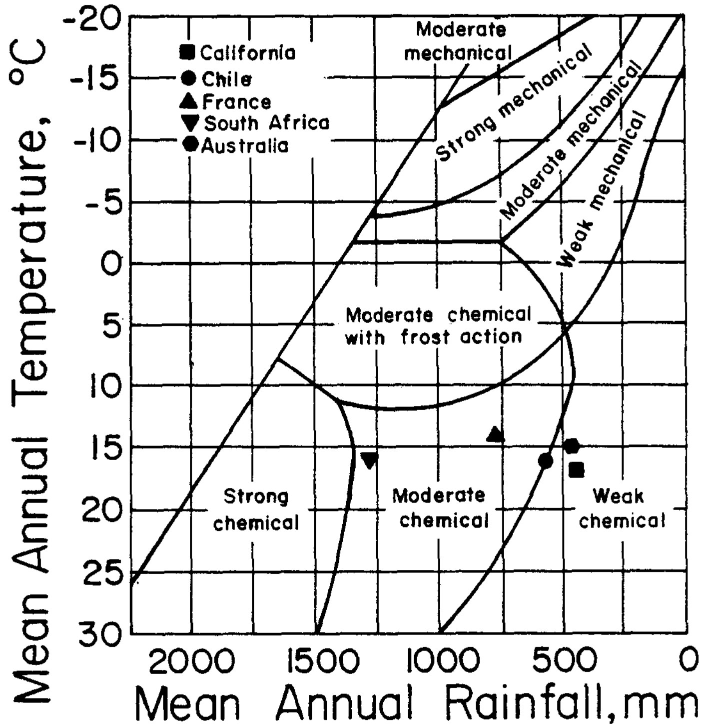


Figure 3--Relative mechanical and chemical weathering rates as influenced by mean annual temperature and rainfall (adapted from Peltier 1950).

An alternative to the empirical measuring of chemical weathering rates is to develop a theoretical model based on chemical thermodynamics. Adequate thermodynamic data exist to develop such models (Sillen and Martell 1964, Robie and Waldbaum 1968, Wagman and others 1968, Lindsay 1979). The solubility of simple compounds, such as calcite and gypsum, have been used in theoretical soil models (Dutt and others 1972). More complex primary mineral weathering models have been developed for arid watersheds (Routson and others 1977) and humid watersheds (Cleaves and others 1970, 1974); however, it remains to be seen whether or not equilibrium thermodynamic relationships can be used to quantitatively predict the release of nutrients from complex suites of primary minerals.

SUMMARY

Decomposition is the most important process rendering N available for plant growth in mediterranean-type ecosystems. Although important quantities of available N are added through pyrolysis (0.04-2.4 g m^{-2} yr^{-1}), more available N can be expected through decomposition on an annual basis (2.6-8.0 g m^{-2} yr^{-1}). The pulse addition through pyrolysis of K, Ca, and Mg (3.2-31 g m^{-2} yr^{-1}) will probably exceed annual additions through either decomposition or weathering (tr-6.0 g m^{-2} yr^{-1}); however, release of K, Ca, and Mg through decomposition will certainly play an important role in cycling of these nutrients. It is difficult to generalize about chemical weathering release of K, Ca, and Mg because of the highly variable primary mineral suites present in the different mediterranean-type ecosystems (table 5) and the highly variable moisture regimes (fig. 3). Decomposition and chemical weathering both can play an important role in the cycling of P; however, because of the highly immobile nature of P, it is quite difficult to separate decomposition and weathering releases. Too little is known about S release to allow generalizations at this time.

Although substrate quantity and quality play an important role in the mineralization processes, the environment in which these transformations take place is of equal importance (figs. 2 and 3). Although both temperature and moisture are important, both organic matter decomposition and chemical weathering rates in mediterranean-type ecosystems are more likely to be influenced by moisture fluctuations than by temperature fluctuations (figs. 2 and 3).

Two serious gaps exist in our current understanding of nutrient mineralization processes in mediterranean-type ecosystems. Phosphorus limits growth in many mediterranean-type ecosystems (Gray and Schlesinger 1981, Read and Mitchell 1981). In part, because P is highly immobile in soils and, in part, because of the many processes controlling P availability, our understanding of the controls on P availability is not good. A simple P mineralization model relating substrate quantity and quality, temperature, and moisture, analogous to the N mineralization model, does not exist. More complex P models exist (Cole and others 1977), but they generally require too much information to be useful for practical purposes. Our current understanding of the importance of chemical weathering in mediterranean-type ecosystems is poor. Experimental work on chemical weathering would be a valuable contribution to furthering our understanding of nutrient cycling in mediterranean-type ecosystems.

ACKNOWLEDGEMENTS

I would like to thank P. C. Miller, P. J. Riggan, and W. H. Schlesinger for critical reviews of an earlier draft of this manuscript. The assistance of P. M. Miller, B. Sigren and R. Watson in preparing the manuscript was appreciated. This work was supported by NSF Grant DEB- 77-13944.

LITERATURE CITED

Adams, P. W.; Boyle, J.R. Cation release from Michigan spodosols leached with aspen leaf extracts. Soil Sci. Soc. Am. J. 43:593-596; 1979.

Christensen, N. L.; Muller, C. H. Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45:29-55; 1975.

Clayton, J. L. Nutrient supply to soil by rock weathering. Proceedings of a symposium on impact of intensive harvesting on forest nutrient cycling; College of Environmental Science and Forestry, Syracuse, New York; 1979; 75-96.

Cleaves, E. T.; Fisher, D. W.; Bricker, O. P. Chemical weathering of serpentinite in the eastern Piedmont of Maryland. Geol. Soc. Am. Bull. 85:437-444; 1974.

Cleaves, E. T.; Godfrey, A. F.; Bricker, O. P. Geochemical balance of a small watershed and its geomorphic implications. Geol. Soc. Am. Bull. 81:3015-3032; 1970.

Cole, C. V.; Innis, G. S., Stewart, J. W. B. Simulation of phosphorus cycling in semiarid grasslands. Ecol. 58:1-15; 1977.

Day, J. (ed.). Medcon workshop report. Proceedings of a workshop held at Hermanus, South Africa. In press.

DeBano, L. F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59:489-497; 1978.

DeBano, L. F.; Eberlein, G. E.; Dunn, P. H. Effects of burning on chaparral soils. I. Soil nitrogen. Soil Sci. Soc. Am. J. 43:504-509; 1979.

Dunn, P. H.; DeBano, L. F. Fire's effect on biological and chemical properties of chaparral soils. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. U.S. For. Serv. Gen. Tech. Rep. WO-3; 1977; 75-84.

Dutt, G. R.; Shaffer, M. J., Moore, W. J. Computer simulation model of dynamic bio-physiochemical processes in soils. Agric. Expt. Stn. Tech. Bull. 196. Tucson, Arizona: The University of Arizona.

Ellenberg, H. Stickstoff als Standortsfaktor, insbedsondere fur mitteleuropaische Pflanzengesellshaften. Oecol. Plant. 12:1-22; 1977.

Fredriksen, R. L. Nutrient budget of a Douglas-fir forest on an experimental watershed in western Oregon. Proceedings--research on coniferous forest ecosystems--a symposium. Portland, Oregon: U.S. For. Serv.; 1972; 115-131.

Gray, J. T.; Schlesinger, W. H. Nutrient cycling in mediterranean type ecosystems. In: Miller, P. C., ed. Resource use by chaparral and matorral: A comparison of vegetation function in two mediterranean type ecosystems. New York: Springer-Verlag; in press.

Grier, C. C. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Can. J. For. Res. 5:599-607; 1975.

Groves, R. H. Fire and nutrients in the management of Australian vegetation. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. U.S. For. Serv. Gen. Tech. Rep. WO-3; 1977; 220-229.

Harmsen, G. W.; van Schreven, D. A. Mineralization of organic nitrogen in soil. Adv. Agron. 7:299-398; 1955.
Johnson, D.; Cole, D. W.; Gessel, S. P. Processes of nutrient transfer in a tropical rain forest. Biotropica 7:208-215; 1975.
Kruger, F. J. Ecology of Cape fynbos in relation to fire. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. U.S. For. Serv. Gen. Tech. Rep. WO-3; 1977; 230-244.
Kruger, F. J. South African heathlands. In: Specht, R. L., ed. Ecosystems of the world. Vol. 9A: Heathlands and related shrublands. Amsterdam: Elsevier Scientific Publishing Company; 1979; 19-80.
Likens, G. E.; Bormann, F. H.; Pierce, R. S.; Eaton, J. S.; Johnson, N. M. Biogeochemistry of a forested ecosystem. New York: Springer-Verlag; 1977.
Lindsay, W. L. Chemical equilibria in soils. New York: Wiley-Interscience; 1979.
Lossaint, P. Soil vegetation relationships in mediterranean ecosystems of southern France. In: di Castri, F.; Mooney, H. A., eds. Mediterranean type ecosystems: Origin and structure. New York: Springer-Verlag; 1973.
Maggs, J.; Pearson, C. J. Litter fall and litter layer decay in coastal scrub at Sydney, Australia. 0ecologia 31:239-250; 1977.
Marion, G. M.; Kummerow; J., Miller, P. C. Predicting nitrogen mineralization in chaparral soils. Soil Sci. Soc. Am. J.; in press.
Miller, P. C.; Bradbury, D.'E.; Hajek, E.; LaMarche, V.; Thrower, N. J. W. Past and present environment. In: Mooney, H. A., ed. Convergent evolution in Chile and California. Stroudsburg, Pennsylvania; Dowden, Hutchinson & Ross, Inc.; 1977; 27-72.
Mooney, H. A.; Rundel, P. W. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum, in the California chaparral. Bot. Gaz. 140:109-113; 1979.
Naveh, Z. Effects of fire in the mediterranean region. In: Kozlowski, T. T.; Ahlgren, C. E., eds. Fire and ecosystems. New York: Academic Press; 1974; 401-434.
Peltier, L. The geographic cycle in periglacial regions as it is related to climate geomorphology. Ann. Assoc. Am. Geog. 40:214-236; 1950.
Read, D. J.; Mitchell, D. T. Decomposition and mineralization processes in mediterranean-type ecosystems and in heathlands of similar structure. In: Kruger, F. J.; Siegfried, W. R., eds. Nutrients as determinants of the structure and functioning of mediterranean type ecosystems. New York: Springer-Verlag; in press.
Robie, R. A.; Waldbaum, D. R. Thermodynamic properties of minerals and related substances at 298.15°K (25.0°C) and one atmosphere (1.013 bars) pressure and at higher temperatures. Geol. Surv. Bull. 1259; 1968.
Rosswall, T. The internal nitrogen cycle between microorganisms, vegetation, and soil. Ecol. Bull. 22:157-167; 1976.
Routson, R. C.; Wildung, R. E.; Garland, T. R. Mineral weathering in an arid watershed containing soil developed from mixed basaltic-felsic parent materials. Soil Sci. 124:303-308; 1977.
Schaefer, R. Microbial activity under seasonal conditions of drought in mediterranean climates. In: di Castri, F.; Mooney, H. A., eds. Mediterranean type ecosystems: Origin and structure. New York: Springer-Verlag; 1973; 191-198.
Schlesinger, W. H.; Gray, J. T. Atmospheric precipitation as a source of nutrients in chaparral ecosystems. In: Proceedings of the symposium on dynamics and management of mediterranean-type ecosystems. U.S. For. Serv., this conference; 1981.
Sillen, L. G.; Martell, A. E. Stability constants of metal-ion complexes. London: The Chemical Society, Special Publ. No. 17; 1964.
Specht, R. L. Structure and functional response of ecosystems in the mediterranean climate of Australia. In: di Castri, F; Mooney, H. A., eds. Mediterranean type ecosystems: Origin and structure. New York: Springer-Verlag; 1973; 113-120.
Specht, R. L.; Rayson, P. Dark Island heath (Ninety-Mile Plain, South Australia). I. Definition of the ecosystem. Aust. J. Bot. 5:52-85; 1957.
Stanford, G.; Epstein, E. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38:103-107; 1974.
Stanford, G.; Frere, M. H.; Schwaninger, D. H. Temperature coefficient of soil nitrogen mineralization. Soil Sci. 115:321-323; 1973.
Stanford, G.; Smith, S. J. Nitrogen mineralizaton potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472; 1972.
Trabaud, L. Changes in soil nutrient levels in a Quercus coccifera garrigue according to different fire regimes. In: Kruger, F. J.; Siegfried, W. R., eds. Nutrients as determinants of the structure and functioning of mediterranean type ecosystems. New York: Springer-Verlag; in press.
Thrower, N. J. W.; Bradbury, D. E., eds. Chile-California mediterranean scrub atlas. Stroudsburg, Pennsylvania; Dowden, Hutchinson & Ross, Inc.; 1977.
Verstraten, J. M. Chemical erosion in a forested watershed in the Oesling, Luxembourg. Earth Surf. Processes 2:175-184; 1977.
Wagman, D. D.; Evans, W. H.; Parker, V. B.; Halow, I.; Bailey, S. M.; Schumm, R. H. Selected values of chemical thermodynamic properties. Nat. Bur. Stan. Tech. Note 270-3; 1968.
Woodwell, G. M.; Whittaker, R. H. Primary production and the cation budget of the Brookhaven Forest. In: Symposium on primary productivity and mineral cycling in natural ecosystems. Orono, Maine: University of Maine Press; 1967; 151-166.
Zinke, P. J. Mineral cycling in fire-type ecosystems. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. U.S. For. Serv. Gen. Tech. Rep. WO-3; 1977; 85-94.

Microbial Activity After Fire in a Phryganic East Mediterranean Ecosystem[1]

M. Arianoutsou-Faraggitaki and N. S. Margaris[2]

Abstract: Soil microbial activity, measured as dehydrogenase activity, nitrification, and CO_2 release from the soil, showed that decomposers of phryganic ecosystems are adapted to fire, since no serious perturbations occur. Nitrifying capacity is increased while total soil metabolism remains constant during the first postfire year but in—creases during the second year.

Fire occurrence is generally accepted as a natural and inevitable event in Mediterranean—type ecosystems. High summer temperatures combined with water deficiency provide ideal conditions for fire outburst.

Although information concerning adaptive strategies and recovery of producers is available in a sufficient degree, the same is not true for consumers and decomposers. Preliminary results of a research project started some years ago, dealing with the effect of fire on decomposers in a phryganic (coastal sage) ecosystem in Greece, were presented during the Palo Alto Symposium (Margaris 1977). Additional data now available are concerned with processes such as microbial activity, nitrification, and total soil metabolism.

MATERIALS AND METHODS

The area under study is located close to the Athens University Campus, in Mt. Hymettus, 400 meters above sea level. Data on the structure and function of this system are already presented by Margaris (1976). Part of the site was burned accidentally in July 1976.

Throughout a 2—year postfire period, burned and control sites were frequently surveyed.

For the estimation of soil microbial activity, dehydrogenase activity was taken as parameter (Lenhard 1955).

Nitrate content of the soil was estimated using the phenoldisulphonic method (Barker 1974). For the determination of nitrifying capacity, dried soil samples weighing 20 g each were placed in beakers, brought to 60 percent of field water capacity, and kept in the dark (25±1° C) for 21 days. The nitrifying capacity was calculated from the difference in the nitrate content at the beginning and the end of the 21—day period; it was estimated every second month.

Soil metabolism was measured by the inverted boxes technique (Witkamp 1966, Coleman 1973). We used aluminum cylinders, 20 cm high and 10 an in diameter, in which a 50—m1 beaker contained 20 ml 1 N KOH. Ten 24—hour measurements were made every 20 days in the burned and unburned sites.

RESULTS AND DISCUSSION

Microbial Activity

Using as parameter dehydrogenase activity, we found that microbial activity (fig. 1) in the first 3 an of soil shows no difference between burned and unburned soils. However, the disadvantages of this method must be always taken into account, since general biological parameters are involved, such as activity of free enzymes re—leased by lysed microorganisms or plant roots, or enzymes excreted by integral microbial cells, and meso— and microfauna.

Nitrification

The monthly changes in the nitrate content of the upper 3 to 5 cm of the soil is shown in figure 2. In general, the burned soil contains more nitrates than the unburned, during the whole period of measurements. This difference can be interpreted in terms of either a more intense nitrification process in the burned site or in—creased nitrate removal due to the higher plant biomass absorbing it in the unburned site.

In order to test these two hypotheses, we estimated the soil nitrifying capacity in the laboratory. The results given in figure 3 show that immediately after fire the nitrifying capacity is low; but soon it increases and remains higher in the burned site throughout the 2—year postfire period.

In conclusion, the nitrification process is active and even more intense after fire; this contradicts results by Christensen (1973) and Christensen and Muller (1975), but agrees with data provided by DeBano's research team (DeBano and others 1979, Dunn and others 1979).

Total Soil Metabolism

Results dealing with total soil metabolism, measured as CO_2 released from the soil, are

[1]Presented at the Symposium on Dynamics and Management of Mediterranean—type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Lecturer and Professor of Ecology, respectively, University of Thessaloniki, Thessaloniki Greece.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

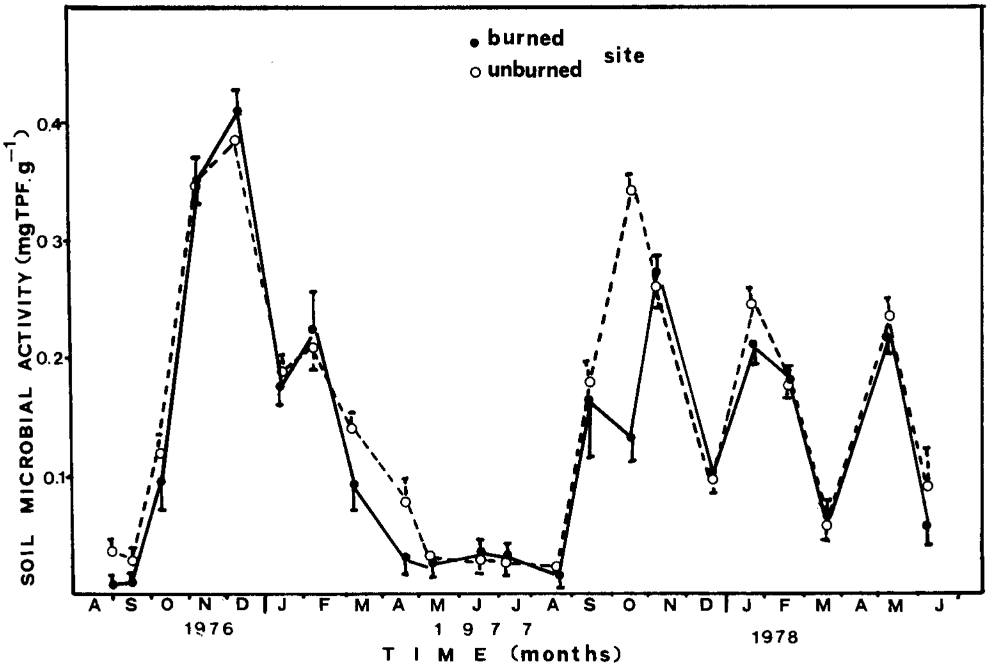


Figure 1--Soil microbial activity of a phryganic ecosystem (burned and unburned) during the period of August 1976 to June 1978.

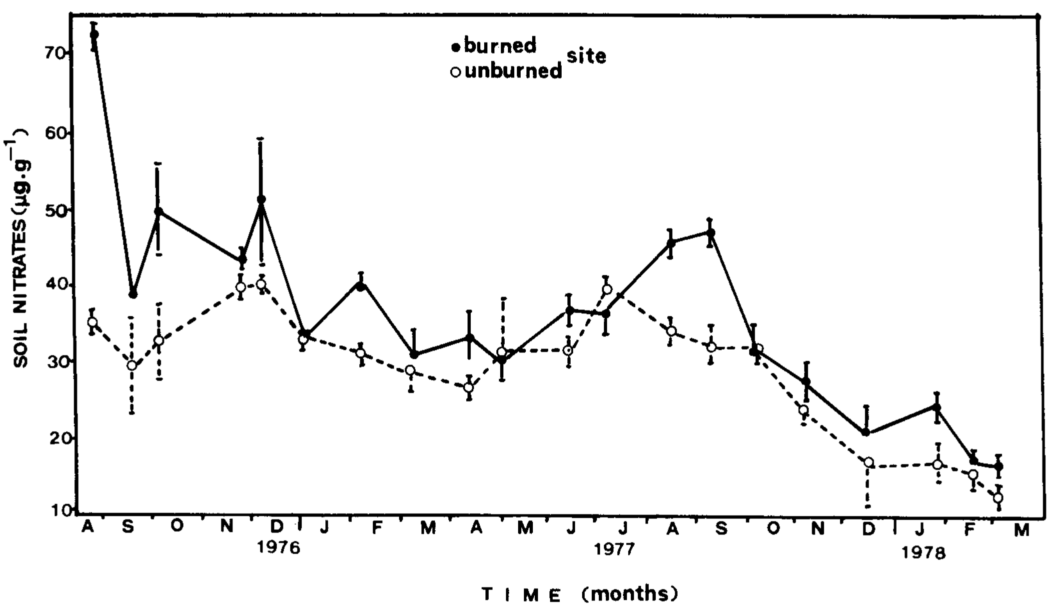


Figure 2--Nitrate content in the upper 3 cm of the burned and unburned soil of a phryganic ecosystem.

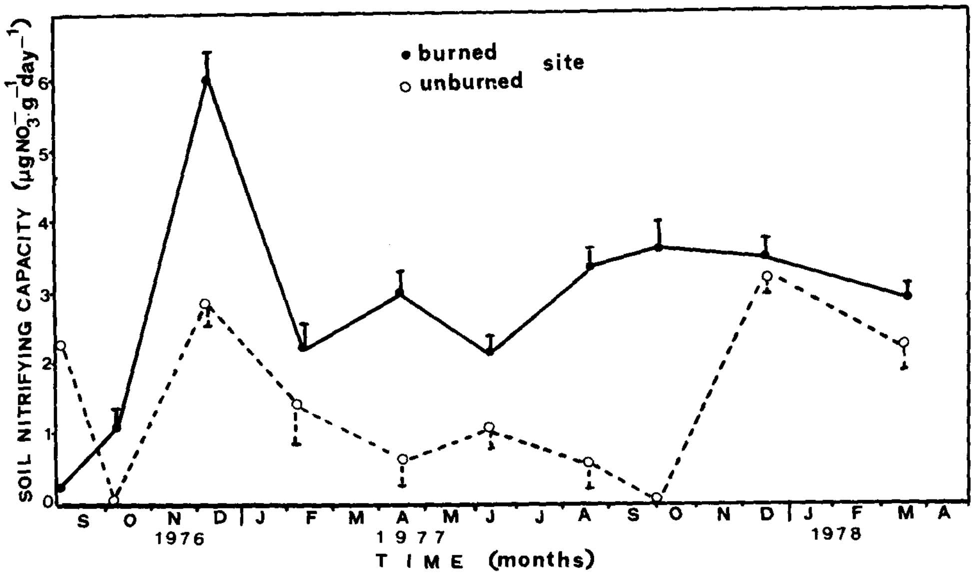


Figure 3--Nitrifying of the burned and unburned phryganic soil.

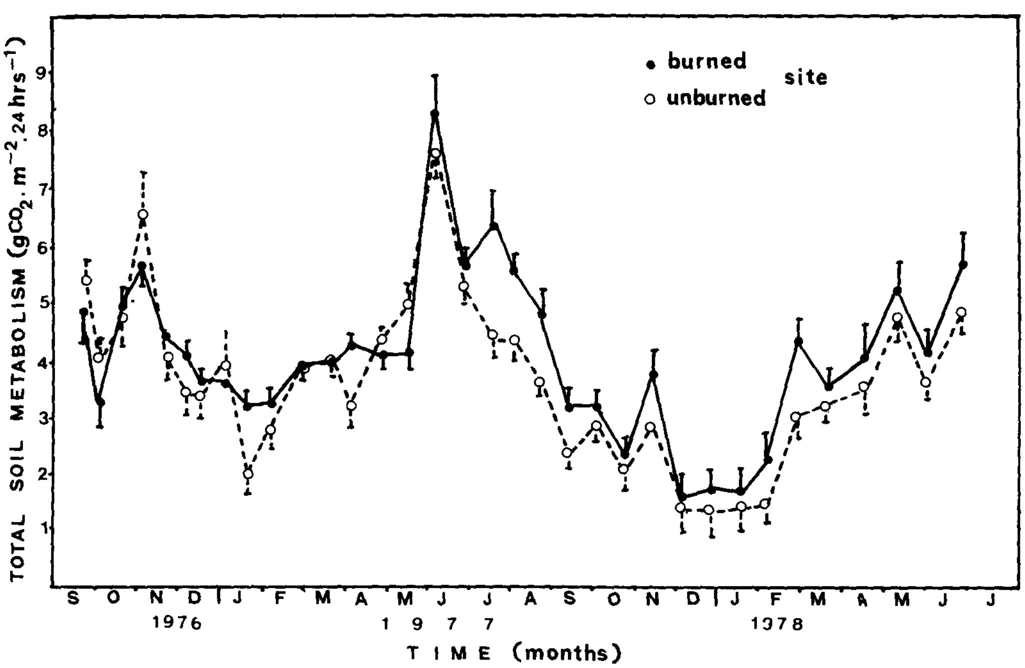


Figure 4--Total soil metabolism measured as CO_2 released from the burned and unburned site of the phryganic ecosystem.

are presented in figure 4. A strong seasonality is observed, characterized by high values at the end of spring (when temperature ceases being a limiting factor) and autumn (when drought is no more a limiting factor).

Statistical tests (t-paired) have shown that soil respiration in the first postfire year does not differ in the burned and unburned sites. Herman and Kucera (1975) came to the same conclusion for Missouri grasslands. During the second postfire year, total soil metabolism is higher in the burned site. If we consider the outgrowth of herbaceous plants during the first postfire year and the subsequent production of easier decomposable litter offered to the decomposers subsystem, we can explain in some degree the above-mentioned increase in the total soil metabolism.

LITERATURE CITED

Barker, A. V. Nitrate determination in soil, water and plants. Mass. Agric. Exp. Stn., College of Food and Natural Resources. Univ. of Massachusetts Bull. 611; 1974; 5-9.

Christensen, N. L. Fire and the nitrogen cycle in Adenostoma chaparral. Science 181:66-68; 1973.

Christensen, N. L.; Muller, C. H. Effects of fire on factors controlling plant growth in Adenostoma chaparral. Ecol. Monogr. 45:29-55; 1975.

Coleman, D. C. Soil carbon balance in a successional grassland. Oikos 24:195-199; 1973.

DeBano, L. F.; Eberlein, G. E.; Dunn, P. H. I. Soil nitrogen. Soil Sci. Soc. Amer. J. 43:504-509; 1979.

Dunn, P. H.; DeBano, L. F.; Eberlein, G. E. II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Amer. J. 43:509-514; 1979.

Herman, R. P.; Kucera, C. L. Vegetation management and microbial function in a tallgrass prairie. Iowa State J. Res. 50:255-260; 1975.

Lenhard, D. Die dehydrogenase aktivitat des Bodeus als Mass fur Microorganismentatigkeit in Boden. Z. Phlernahr. Dung. Bodenk 73:1-11; 1955.

Margaris, N. S. Structure and dynamics in a phryganic (East Mediterranean) ecosystem. J. Biogeogr. 3:246-259; 1976.

Margaris, N. S. Decomposers and the fire cycle in Mediterranean ecosystems. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems; Palo Alto, Calif.; 1977; 37-45.

Witkamp, M. Rates of carbon dioxide evolution from the forest floor. Ecology 47:492-494; 1966.

Nutrients and Water Relations in Mediterranean-Type Ecosystems[1]

Philip C. Miller[2]

Abstract: Mediterranean regions of the world are characterized by winter rain, summer drought precipitation cycles and by their generally low nutrient status. This paper reviews concepts relating to water and nutrient use by vegetation in these regions.

The broad correspondence between the sclerophyllous shrub form and the climate in mediterranean-type ecosystems indicates a climatic control over the vegetation particularly with respect to the summer drought, but all five regions are noted for nutrient deficiencies, especially Australia and South Africa. As studies of these ecosystems are completed, divergences related to the control of community structure, function, and form are becoming apparent. Differences in species composition and growth form are apparent on nutrient poor and base rich sites (Specht and Moll 1981). The mediterranean type ecosystems in South Africa and Australia are generally considered nutrient poor relative to the mediterranean-type ecosystems in Chile, the United States, and the Mediterranean Area. In Australia phosphorus limitation is assumed to have selected for sclerophylly, which preadapted the flora to the more recent summer drought climate (Beadle 1954, Specht 1979 Moll and others 1981). In South Australia the overstory vegetation is believed to be evergreen because of climate, while the understory is evergreen because of nutrient impoverishment (Specht 1972). In California the overstory is believed to be evergreen because of climate, and the understory is deciduous because of microclimate near the soil surface (Miller 1981). Nutrient deficiencies have been suggested to explain other aspects of the community structure in the mediterranean-type ecosystems; such as succession following fire (Specht 1972), species richness in South Africa aid Australia (Kruger 1979), the distribution of fynbos and heathlands in South Africa aid Australia over a wide range of annual precipitation (300-3000 mm/yr) (Specht 1979), and specialized morphological structures (Lamont 1972, 1973, 1980, 1981).

In contrast, in California and Chile the length of the summer drought is thought to control sclerophylly (Miller 1981). Evergreen sclerophyllous shrubs are believed to occur in California where the length of the soil drought is about 100 days or less (Miller and Mooney 1974). In California the leaf area index develops until water use by the chaparral creates a drought lasting about 100 days (Miller and Poole 1981). In Australia evergreen shrubs moderate water use so that the period of summer soil drought is minimized (Specht 1972); water is then available throughout the summer to support photosynthesis and growth in summer. In some regions of high annual precipitation in South Africa and Australia, the soils are either rocky and sandy or are underlain by a hardpan, so periodic drought is possible in spite of high rainfall.

The objective of this paper is to review concepts of nutrient aid water relations in mediterranean-type ecosystems, indicate interactions between the two, and suggest possible needs for future research.

SOIL-PLANT NUTRIENT RELATIONS IN MEDITERRANEAN-TYPE ECOSYSTEMS

The role of nutrients, especially phosphorus, in determining the vegetation in mediterranean-type ecosystems has been emphasized in Australia and South Africa (Kruger 1979, Specht 1979). Specht (1979) argues that nutrients, rather than light or soil moisture, cause succession in mediterranean-type ecosystems. In South Australia, the herbaceous component in heath increased after fertilizing with phosphorus (Specht 1963). In California, fertilizing with nitrogen aid with nitrogen plus phosphorus increased shrub and herb growth. Fertilizing with phosphorus alone had no effect (Hellmers and others 1955, Kummerow unpublished data, Miller unpublished data). Nitrogen fixation by Ceanothus species may be important in northern California (Delwiche and others 1965, Gray and Schlesinger 1981) aid may increase Ceanothus abundance on nitrogen poor sites. But in mature chaparral in southern California

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22 26. 1981 San Diego, California

[2]Director, Systems Ecology Research Group, San Diego State University, San Diego, California 92109

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

nitrogen fixation by C. greggii is negligible (Kummerow and others 19786). Christensen and Muller (1975a) concluded that nutrients enhanced seedling survival but not seed germination. They also showed that nitrate was washed from the canopy with the first rain in the fall and that, following fire, nutrients were most available near the soil surface. The nitrate washed into the soil in the fall is subject to leaching by the winter rains before root growth and nitrogen uptake begin. In the chaparral root growth occurs after February and nitrogen uptake occurs in March and April (Kummerow and others 1978b, Mooney aid Rundel 1979, Shaver 1981). The soil chemistry affecting leaching is unknown in chaparral. Nitrification occurs in chaparral soils (Marion and others 1981).

The few experiments that exist on species interactions in chaparral indicate competition for nutrients. In a stand composed mainly of C. greggii and A. fasciculatum, eliminating all A. fasciculatum increased herb production, but eliminating C. greggii and leaving A. fasciculatum gave no change in herb production. Eliminating C. greggii increased A. fasciculatum production slightly but decreased the growth of individual shoots (Kummerow unpublished data). In fertilizer experiments, nitrogen addition also increased shrub production but decreased the individual shoot growth (Kummerow et al. unpublished data). These experiments taken together indicate that higher available nitrogen, either from fertilization or from eliminating competitors, increases production not by increased shoot growth but by increased numbers of individual shoots per square meter. Additionally, it appears that C. greggii may suppress the growth of A fasciculatum by more effective nitrogen capture, while the opposite does not appear to occur. The latter conclusion is consistent with a higher nitrogen capture ability of C. greggii relative to A. fasciculatum (Zinke 1977, Miller 1981) but was unexpected because Ceanothus species can fix nitrogen under some conditions (Delwiche and others 1965, Cray aid Schlesinger in press). Because of their capacity to fix nitrogen, Ceanothus species could be poor at taking up mineralized nitrogen. Adenostoma fasciculatum tends to occur on low nitrogen sites (Zinke 1977, Marion aid others 1981).

SOIL-PLANT WATER RELATIONS IN MEDITERRANEAN TYPE ECOSYSTEMS

The annual pattern of soil drought and air temperature along an elevational transect from 0 to 2 000 m in southern California was calculated from the annual courses of precipitation and potential evapotranspiration (Miller 1979). Such a pattern was postulated by Mooney and others (1972) and Mooney and Dunn (1970a, b). Xylem pressure potentials, which were measured to check the calculations (Poole and Miller 1981), decreased earlier in the summer at the coastal and desert edges of the chaparral and later toward the center of the chaparral. Poole and Miller (1975) showed that xylem pressure potentials of Rhus spp. and Heteromeles arbutifolia decreased earlier at the coast than in the center of chaparral. The pattern of drying was affected by the vegetation cover (Miller aid Poole 1980). At the edges of the distribution, water use was about 200 mm/yr per unit leaf area index (A_1) which occurred with precipitation of about 400 mm/yr. Soil evaporation aid interception losses account for the remainder of the precipitation. With higher precipitation the leaf area index increases until the resulting transpiration rate decreases to about 200 mm/yr/A_1 Without disturbance, chaparral vegetation should develop until the water use per unit leaf area and the duration of the summer soil drought are similar throughout the distribution of the chaparral. The resulting period of summer drought should be about 3 months long. This hypothesis is consistent with the patterns of water and soil drought measured under the vegetation of pole- aid equator-facing slopes at Echo Valley (Miller and Poole 1979; Ng and Miller 1980) and with the pattern of several leaf properties (Poole and Miller 1981).

A pattern of moderate water use would allow sufficient water throughout the drought period for photosynthesis to offset maintenance respiration and allow for growth (Specht 1972a,b). Walter (1973) pointed out the evenness of water potentials in deep rooted evergreen shrubs in mediterranean type regions. These findings are consistent with the pattern of water use on the equator-facing slope at Echo Valley (Ng and Miller 1980) which was dominated by a single species, A. fasciculatum, with the pattern of water use in Q. dumosa and R. ovata, aid with the pattern of water use in the Chilean shrubs. Rhus ovata also has a high temperature requirement for growth, similar to Australian shrubs (Specht 1969a, b). The Chilean shrubs appear to have low temperature requirements for growth (Jacobson and others 1981). Specht's suggestion is not consistent with the pattern of soil moisture on the pole-facing slope which is dominated by several evergreen species including A. glauca and C. greggii. Thus, the patterns of water use must he viewed in the context of various physiological characteristics and the floral history of the area. The Australian mediterranean vegetation has no cool temperate species, but such species are present in the chaparral aid matorral because of the migrations of the flora during the Pleistocene (Axelrod and Raven 1978; Solbrig and others 1977). The need for conserving water is more important for species with high temperature requirements for growth.

In Californian chaparral, transpiration in the evergreen shrubs varied seasonally (Miller and Poole 1979). Although leaf conductances were high in winter, transpiration was low because net radiation was low and vapor density deficits were small. In the spring, transpiration increased because of increased daylength, since leaf conductances and vapor density deficits were nearly constant. In June and July, transpiration decreased because leaf conductances decreased, even though vapor density deficits increased. Arctostaphylos glauca showed a complete cessation of transpiration for almost 2.5 months. Rhus ovata, H. arbutifolia, and C. greggii showed no transpiration for about 1 month. Similar annual patterns were shown for heath in South Australia (Specht 1957a). In mature shrubs transpiration during spring was 0.7-2.0 mm day^{-1} m^{-2} of leaf area. Annual water use on a square meter of leaf basis was 150-190 mm/yr from A. fasciculatum, 145-195 from C. greggii, 280-290 from A. glauca, and 127 from R. ovata (Miller and Poole 1979).

Several sets of measurements and calculations indicate that chamise chaparral, grasslands, and bare soil lose water similarly while mixed chaparral loses more water (Shachori and Michaeli 1965, Miller and Poole 1979, Miller and Stoner 1979, Ng and Miller 1980, Patric unpublished data). In simulations transpirational water loss increased with foliage area. Soil evaporation decreased with foliage area and was 200-300 mm/yr in southern California and about 200 mm/yr in central Chile. Total evapotranspiration from the vegetation and soil increased with foliage area index in species which had high transpiration rates but remained constant in species which had moderate or low transpiration rates. In these latter species increased transpirational losses were compensated by decreased soil evaporation. Nitrogen release decreased as foliage area increased, because the additional foliage area increased transpiration which decreased the available soil moisture and therefore the length of the decomposition season.

With relatively low precipitation (<400 mm/yr) only low foliage areas can be maintained (< 2.0 m^2/m^2), soil evaporation is high, and the transpiration:precipitation ratio is low. In simulations as the foliage area index increased from 0 to 2 m^2/m^2, soil evaporation decreased to two-thirds. A similar relation between transpiration and annual precipitation has been noted for grasslands and other semiarid lands (Fischer and Turner 1978; Sims and Singh 1978). Based on field observation in southern California and theory, an annual precipitation of 400-450 mm/yr is required to maintain a foliage area index of about 2 in the chaparral (Miller and Poole 1981). Thus, with precipitation below about 400 mm/yr transpiration can be expected to decrease rapidly with decreasing precipitation. Above 450 mm/yr precipitation the foliage area which can be maintained is limited by the photosynthesis-light responses of the species and leaf turnover during the drought. Transpiration is limited by foliage area, and the transpiration:precipitation ratio decreases while drainage increases as precipitation increases above 450 mm/yr.

The low transpiration:precipitation ratio (transpiration efficiency) of chamise chaparral at low elevations and an drier sites and the higher ratio of mixed chaparral at mid-elevations and on more mesic sites are consistent with the theoretical trends. The matorral stands at Fundo Santa Laura have relatively low transpiration efficiencies because of relatively high precipitation and low net radiation in winter. Because of its shade intolerance, chamise chaparral has a relatively low foliage area index, high soil evaporation, and relatively low transpiration efficiency. The low transpiration efficiency of matorral is caused by the low foliage area. Similar constraints are expected to reduce transpiration efficiencies in other Southern Hemisphere mediterranean climate regions compared to Northern Hemisphere regions. In contrast to the evergreen shrubs, the transpiration efficiency of the drought semideciduous shrubs decreases with increasing precipitation. With respect to elevation, the maximum transpiration efficiency of a species occurs at elevations below those at which the maximum abundance of the species occurred, supporting the generality for mediterranean-type ecosystem that water is the limiting factor at the lower elevational limit of a species.

Year-to-year variations in precipitation affect transpiration efficiencies because leaf growth occurs after the period of receipt of the precipitation and varies less than does precipitation. The simulated response of production to precipitation was flatter than the usual production-precipitation relations in arid regions (Chang 1968, Whittaker 1975) and was flatter at Fundo Santa Laura than at Echo Valley. The flatness of the response was partly due to the low fraction of annual precipitation received during the growing season.

Other plant characteristics should correlate with the precipitation gradient. Transpiration and the transpiration:precipitation ratio increase with high leaf conductances, steeply inclined leaves, narrow leaves, high leaf reflectances, and high leaf area to dry weight ratios, which increase soil shading. With low precipitation (< 400 mm/yr) and low foliage area index, rapid use of water by plants is advantageous because otherwise the water is evaporated. Because the soil drought is lengthened by the soil evaporation and high transpiration rate, drought deciduous species are favored. The advantage of steep leaf inclination is balanced against the advantage of shading the soil surface and reducing soil evaporation. At higher precipitation levels (> 550 mm/yr) water is lost by drainage; transpiration is increased with higher leaf conductances; the length of the drought is short. Leaf width, inclination, and color can be more variable without affecting water loss. At intermediate precipitation levels (400-550 mm/yr) the composition of the vegetation changes the length of the soil drought by changes in the abundance of species with different leaf conductances and different leaf area indices. The transpiration:precipitation ratio is controlled by the vegetation composition and can be relatively high.

The expected trends in water relations occur in chaparral and matorral species (table 1). Maximum leaf conductances of Californian species arranged from highest to lowest were: A. californica, Salvia apiana, A. glauca, C. greggii, A. fasciculatum, Q. dumosa, and R. ovata. The sequence of species was similar for the minimum xylem pressure potentials, for the duration of low pressure potentials, and the variability of pressure potentials through the year. Osmotic concentrations at turgidity were similar aid moderate, ranging from -2.0 to -3.0 MPa. The depth of rooting probably also increases in the same sequence. Artemisia californica, S. apiana, C. greggii, and A. glauca are recognized as shallow rooted, while Q. dumosa and R. ovata are thought to be deep rooted (Hellmers and others 1955; Kummerow and others in press). The sequence of species also segregate obligate seeders aid sprouting shrubs. The sequence occurs along a gradient of increasing annual precipitation. Different patterns of reproduction may reinforce the patterns of water-use characteristics. Seedlings and resprouts have different water environments when young. Schlesinger and Gill (1980) showed lower water potentials during the summer in seedlings than in mature individuals of Ceanothus megacarpus. Radosevich and others (1977) indicated that resprouts of A. fasciculatum generally had higher water potentials than the unburned control vegetation. The higher soil moisture under Banksia ornata (Specht 19576) and decreased water use with reduced stem densities of Acacia aneura (Pressland 1976) appear to be consistent with the expected interaction between leaf area, leaf conductance, aid water loss.

The Chilean species, arranged by maximum leaf conductance from highest (about 0.5 cm/s) to lowest (about 0.15 cm/s), are S. gilliesii, T. trinervis, C. odorifera, Q. saponaria, C. alba, and L. caustica. The sequence was similar for the lowest xylem pressure potentials measured but was not as consistent as with the Californian species. Rooting depth may be similarly arrayed in the Chilean species (Avila and others 1975, Giliberto and Estay 1978). The sequence is not as clearly related to reproductive patterns as with the Californian shrubs.

The maximum leaf area index which could be maintained with different annual precipitation amounts was estimated by simulations (Miller 1981). These leaf area indices increased as precipitation increased to about 400 mm/yr with the Californian shrubs aid to 350 mm/yr with the Chilean shrubs. The calculated steady state leaf area indices were similar to those measured in the field (Miller aid Poole 1980).

INTERACTIONS BETWEEN NUTRIENTS AND WATER

The available nutrients and water and the rate of turnover of leaves and stems affects the biomass that can be supported. The steady state biomass (B) can be expressed in terms of the precipitation (Ppt), transpiration efficiency (Tr/Ppt), water-use efficiency (P_S/Tr), maintenance and growth respiratory costs (r_m, r_g) and leaf longevity ( ) by

$$B = (Ppt)\ (Tr/Ppt)\ (P_S/Tr)/(r_m + r_g\ ) \qquad \text{Eq. 1}$$

Annual precipitation and nitrogen taken up by the vegetation should be interrelated. In the steady state nitrogen taken up must equal that lost as plant parts are shed. Thus,

$$B = (N_{up})/[(N_d)\ ] \qquad \text{Eq. 2}$$

where N_{up} is the nitrogen taken up, and N_d is the nitrogen content of plant parts at death. Equations 1 and 2 indicate that the steady state biomass should increase by 400-500 g/m^2 for every 100 mm/yr increase in annual precipitation and by about 400 g/m^2 for every additional g N m^{-2} yr^{-1} taken up. Increasing leaf longevities more than 2 years have smaller effects on the steady state biomass than increasing leaf longevities from 1 to 2 years. Within a precipitation regime leaf longevity should increase in accordance with nitrogen limitation because turnover rate is more closely related to nitrogen uptake than to precipitation.

Interactions between water and nitrogen availability can be calculated. A gram of nitrogen taken up and incorporated into aboveground tissue yields an increment of about 166 g dry weight/g N of new biomass. Leaf area is increased by about 0.004 $m^2{}_1$/g dry weight although some of the new biomass is in stems. This increment of leaf area increases transpiration by about 0.67 kg day^{-1} g^{-1} N, Allowing for the dry weight and water costs involved in the growth of the leaf area, the net increase in transpiration is about 0.33 kg day^{-1} g^{-1} N. The increased transpiration decreases the length of the season in which soil moisture is available. The length of the growing season changes with transpiration according to the amount of water available divided by the square of the daily evapotranspiration rate. Thus, the reduction in the growing season because of added nitrogen would be about 0.33 x 38 or 12 days per gram nitrogen taken up by the chaparral in southern California and by about 10 days per gram nitrogen taken up by the matorral in central Chile. This shortening of the growing season should reduce growth by about 48 g dry weight m^{-2} yr^{-1} in southern California and by 20 g dry weight $m^{-2}yr^{-1}$ in central Chile, while the increased nitrogen should increase growth by about 166 g dry weight. Thus, net growth should increase about 118 g dry weight/g N taken up in California and 146 g dry weight/g N taken up in

Chile, even though the growth period is limited by temperature aid water.

Long leaf duration, from whatever cause, affects the availability of nitrogen. The presence of ligneous and herbivore defense compounds can reduce the quality of the substrate for decomposition and mineralization. The selection of evergreen leaves by the seasonal patterns of temperature and water availability favors leaves of about 1-year duration but does not necessarily favor leaves with more than 1-year duration. The evergreen leaves should have structural modifications to maintain rigidity under water stress and to reduce the intensity of water stress (Beadle 1966; Cutler and others 1977). According to heat transfer theory, such leaves should be rigid, narrow, steeply inclined, and light colored to reduce cellular distortion, plant temperatures, and transpiration rates. Small cell size is advantageous (Cutler and others 1977). Leaf longevities may increase with nitrogen limitation (Monk 1966). Although evergreenness caused by nitrogen limitation does not require the adaptations to survive drought (Beadle 1966), the general biochemical composition of nitrogen-limited leaves may be similar to that of water-limited leaves, resulting in similar sclerophyll indices, which are, based on lignin, cellulose, and nitrogen content (Loveless 1961). Water limitation creates a direct need for sclerophyllous tissue, while the nitrogen or phosphorus limitation may reduce protein formation due to low nutrient availability, which may increase cellulose and lignin formation because of excess carbohydrate (Loveless 1961, Beadle 1966, Steubing and Alberdi 1973).

Specht and others (1981) discuss the seasonality of leaf growth and leaf drop in Australia and South Africa. Their opinions are similar to opinions developed in studies of chaparral and matorral in California and Chile. The indications are that if water limits biomass, leaf drop will follow leaf growth, which occurs in most evergreen shrubs in California and Chile (Mooney 1977). But if nutrients limit biomass and growth, leaf drop will be synchronous with leaf growth, as occurs in *Quercus* sp. and in Australia and South Africa (Specht and Moll 1981).

Of the five mediterranean regions of the world, the mediterranean region of central Chile is relatively nutrient rich. Vegetation is climatically selected, and leaf turnover rates are relatively high. In southern California and southern Europe, soils are less nutrient rich, but climate is still a strong selective agent; leaf turnover is slower than in central Chile. In the mediterranean regions of Australia and South Africa where old, nutrient poor soils occur, leaf turnover is lower than in California (Kruger 1979, Specht 1979, Miller and others unpublished data), and the climatic effect is reinforced by nutrient limitations.

In South Africa, pines are rapidly invading undisturbed fynbos, and pine plantations on unfertilized fynbos soils have higher productivity than the native fynbos or than the pines in their native Northern Hemispheric habitats (Van der Zel and Kruger 1975, Hall and Boucher 1977). Rough estimates indicate that annually the pines take up three times the nitrogen as does the fynbos on the same soil (Miller and others unpublished data). The Proteaceae and Restionaceae lack mycorrhizal associates (Lamont 1981). Experiments with tree seedlings show a nearly 50-fold increase in growth when the seedlings are inoculated by mycorrhizae. Proteoid roots may merely compensate for the reduced nutrient and water uptake caused by the lack of mycorrhizae. The introduced pines have mycorrhizae. In South Africa at least, the apparent nutrient impoverishment may not be due to the soil supplying ability but to the plant uptake ability.

The low production in South African fynbos and Australian heath may also be due to high temperature requirements for growth (Specht 1972). Because these temperatures occur during the summer drought, the growing season is severely truncated. In both countries the flora in the mediterranean regions has evolved from a tropical flora, which has not been invaded by more polar elements. In Chile, California, and the Mediterranean Sea regions, a more polar floral element with cooler temperature requirements for growth has mixed into the vegetation (Raven 1973, Axelrod and Raven 1978). Temperature limitations on growth in South Africa and Australia could have allowed excessive leaching of nutrients resulting in the current nutrient impoverishment of mediterranean-type ecosystems in these countries. The Southern Hemisphere mediterranean regions receive less spring precipitation than the Northern Hemisphere mediterranean regions, which speeds the onset of summer drought in the Southern Hemisphere (Miller 1981). The low production in South African and Australian mediterranean regions may also be due to high cloudiness and low solar irradiance during the winter which reduce photosynthetic rates. A limitation on photosynthesis by solar irradiance was indicated for central Chile (Miller 1981). Thus, the plants in the Southern Hemisphere may enter the spring with lower carbohydrate reserves and lower growth potential.

RESEARCH NEEDS

In spite of the recognition of divergent causes of vegetation form in mediterranean-type ecosystems, functional measurements of nutrient and water availability have not been carried out with identical techniques. A direct functional comparison is needed. Static comparative soil statistics, which are now becoming available, do not show great differences in soil organic matter content, total nitrogen, available nitrogen, total phosphorus, available phosphorus, percent base saturation, and pH between South Africa, Australia, California, and Chile (Thrower and Bradbury 1977, Miller et al. 1977, Kruger 1979, Boone unpublished data). Earlier measurements of available nitrogen and phosphorus in California and Chile, which are often cited in comparing mediterranean-type regions, are rejected because of the length of time between collection and processing of the samples.

Direct comparable measurements on soil nutrient supplying power and plant uptake ability are needed to define the controls on the composition and form of mediterranean-type ecosystems in the five mediterranean regions of the world. In addition, a synthesis of these measurements and existing data is needed and should lead to a quantification of nutrient cycling, its control, and an explanation of how nutrient cycling processes deviate in mediterranean-type ecosystems. Such a synthesis is timely. Much descriptive information has been collected and is being published (Specht 1979, Kruger 1981, Miller 1981). Some functional relations have been established for some mediterranean-type ecosystems and collated in original and review papers (Kruger and Siegfried 1981, Miller 1981). The communication and cooperation among investigators in the mediterranean-type ecosystems is good. The synthesis should clarify whether the similarity in vegetation form is only coincidently associated with the mediterranean-type climate but is caused by differences in soil and climate in the five mediterranean regions.

LITERATURE CITED

Avila, G.; Aljaro, M.; Araya, S.; Montenegro, G. The seasonal cambium activity of Chilean and Californian shrubs. Am. J. Bot. 62:473-478; 1975.

Axelrod, D. I.; Raven P. H. Late Cretaceous and Tertiary vegetation history of Africa. In: Werger, M. J. A., ed. Biogeography and ecology of southern Africa. The Hague, Netherlands: Dr. W. Junk Publishers; 1978:77-130.

Beadle, N. C. W. Soil phosphate and the delimitation of plant communities in eastern Australia. Ecology 35:370-375; 1954.

Beadle, N. C. W. Soil phosphate and its role in molding segments of the Australian flora and vegetation, with special reference to xeromorphy aid sclerophylly. Ecology 47:992-1007; 1966.

Bingham, G. E.; Coyne, P. I. A portable, temperature-controlled, steadystate porometer for field measurements of transpiration and photosynthesis. Photosynthetica 11:148-160; 1977.

Chang, C. Climate and agriculture, an ecological survey. Chicago: Aldine Publ. Co.; 1968. 304 PP.

Christensen, N. L.; Muller, C. H. Effects of fire on factors controlling plant growth in *Adenostoma* chaparral. Ecol. Monogr. 45:29-55; 1975.

Cutler, J. M.; Rains, D. W.; Loomis, R. S. The importance of cell size in the water relations of plants. Physiol. Plant. 40:255-260; 1977.

Day, J. (ed.). Nutrients in mediterranean type ecosystems. Proceedings of the MEDCO workshop; 1980 September 24-26; Pretoria: Republic of South Africa; CSIR; 1981.

Day, J.; Siegfried, W. R.; Louw, G. N.; Jarman, M. L., eds. Fynbos ecology: A preliminary synthesis. Pretoria, Republic of South Africa: CSIR, S. African Nat. Sci. Progr. Rept. No. 40.

Deacon, H. J. The comparative evolution of mediterranean-type ecosystem: A southern perspective. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981.

Delwiche, C. C.; Zinke, P. J.; Johnson, C. M. Nitrogen fixation by *Ceanothus*. Plant Physiol. 40:1045-1047; 1965.

Fischer, R. A.; Turner, N. C. Plant productivity in the arid and semiarid zones. Annu. Rev. Plant Physiol. 29:277-317; 1978.

Gray, J. T.; Schlesinger, W.H. Nutrient cycling in mediterranean-type ecosystems. In: Miller, P. C., ed. Resource use by chaparral and matorral: A comparison of vegetation function in two mediterranean-type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag; 1981: in press.

Giliberto, J.; Estay, H. Seasonal water stress in selected shrub species in the mediterranean region of central Chile. Bot. Gaz. 139:236-240; 1978.

Hall, A. V.; Boucher, C. The threat posed by alien vegetation to the Cape flora. In: Proceedings of the second national weeds conference; Stellenbosch, Republic of South Africa; 1977:35-46.

Heddle, E. M.; Specht, R. L. Dark Island heath (Ninety-Mile Plain, South Australia). VIII. The effect of fertilizers on composition and growth, 1950-1972. Aust. J. Bot. 23:151-164; 1975.

Hellmers, H.; Bonner, J. F.; Kelleher J. M. Soil fertility: A watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80:189-197; 1955.

Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Proceedings of the international symposium on ecology and revegetation of drastically disturbed areas. University Park, Pa.: New York-Paris-London: Gordon and Breach; Vol. 1.

Jacobson, M. B.; Stoner, W. A.; Richards, S. P. Models of plant and soil processes. In: Miller, P. C., ed. Resource use by chaparral and matorral. New York-Heidelberg-Berlin: Springer-Verlag; 1981.

Kruger, F. J. South African heath lands. In: Specht, R. L., ed. Heathlands aid related shrublands. Part A: Descriptive studies. Amsterdam-Oxford-New York: Elsevier Scientific Publ. Co.; 1975:19-80.

Kruger, F. J. Structural and functional characteristics of mediterranean-type plants.

In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981a.

Kruger, F. J. Plant community diversity and dynamics in relation to fire. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 19816.

Kruger, F. J.; Siegfried, W. R., eds. Nutrients as determinants of the structure and functioning of mediterranean type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag; 1981.

Kummerow, J.; Krause, D.; Jow, W. Seasonal changes of fine root density in the southern California chaparral. 0ecologia 37:201-212; 1978.

Lamont, B. The effect of soil nutrients on the production of proteoid roots by Hakea species. Aust. J. Bot. 20:27-40; 1972a.

Lamont, B. The morphology and anatomy of proteoid roots in the genus Hakea. Aust. J. Bot. 20:155-174; 1972b.

Lamont, B. Factors affecting the distribution of proteoid roots within the root systems of two Hakea species. Aust. J. Bot. 21:165-187; 1973.

Lamont, B. Specialized roots of non-symbiotic origin in heathlands. In: Specht, R. L., ed. Heathlands and related shrublands of the world. Amsterdam: B. Elsevier; 1980.

Lamont, B. B. Specialized roots of non-symbiotic origin in heathlands. In: Specht, R. L., ed. heathland aid related shrublands. Ecosystems of the World. Vol. 9. Amsterdam-Oxford-New York: Elsevier Scientific Publ. Co.; 1981.

Lamont, B. B. Strategies for maximizing nutrient uptake in mediterranean-type ecosystems. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981.

Loveless, A. R. A nutritional interpretation of sclerophylly based on differences in the chemical composition of sclerophyllous and mesophytic leaves. Ann. Bot. 25:168-184; 1961.

Marion, G. M.; Kummerow, J.; Miller, P. C. Predicting nitrogen mineralization in chaparral soils. Soil Sci. Soc. Am. J. in press; 1981.

Martin, H. A.; Specht, R. L. Are mesic communities less drought resistant? A study of moisture relationships in dry sclerophyll forest at Inglewood, South Australia. Aust. J. Rot. 10:106-118; 1962.

Miller, P. C. Quantitative plant ecology. In: Horn, D.; Stairs, G. R.; Mitchell, R. D., eds. Analysis of ecosystems. Columbus: Ohio State Univ. Press; 1979:179-232.

Miller, P. C.; Mooney, H. A. The origin and structure of American arid-zone ecosystems. The producers: Interactions between environment, form, and function. Proceedings of the first international congress of ecology; The Hague, Netherlands; 1974:201-209.

Miller, P. C.; Poole, D. K. Patterns of water use by shrubs in southern California. For. Sci. 25:84-98; 1979.

Miller, P. C.; Stoner, W. A. Canopy structure and environmental interactions. In: Solbrig, 0.; Jain, S.; Johnson, G. B.; Raven, P. H., eds. Plant population biology. New York: Columbia Univ. Press; 1979:163-173.

Miller, P. C.; Bradbury, D. E.; Hajek, E.; La Marche, V.; Thrower, N. J. W. Past and present environment. In: Mooney, H. A., ed. Convergent evolution in Chile and California mediterranean climate ecosystems. Stroudsburg, Pa: Dowden, Hutchinson & Ross; 1977:27-72.

Miller, P. C.; Stoner, W. A.: Tieszen, L. L. A model of stand photosynthesis for the wet meadow tundra at Barrow, Alaska. Alaska 57:411-430; 1976.

Moll, E. J.; Specht, R. L., Manders; P. T. The role of woody underground parts in survival and growth. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981.

Monk, C. D. An ecological significance of evergreenness. Ecology 47:504-505; 1966.

Mooney, H. A., ed. Convergent evolution in Chile and California mediterranean climate ecosystems. Stroudsburg, Pa.: Dowden, Hutchinson & Ross; 1977. 224 p.

Mooney, H. A.; Dunn, E. L. Convergent evolution of mediterranean climate evergreen sclerophyll shrubs. Evolution 24:292-303; 1970a.

Mooney, H. A.; Dunn, E. L. Photosynthetic systems of mediterranean climate shrubs and trees of California and Chile. Am. Nat. 104:447-453; 19706.

Mooney, H. A.; Rundel, P. W. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum, in the California chaparral. Bot. Gaz. 140:109-113; 1979.

Mooney, H. A.; Dunn, E. L.; Shropshire, F.; Song, L., Jr. Land-use history of California and Chile as related to the structure of the sclerophyll scrub vegetations. Madrono 21:305-319; 1972.

Ng, E.; Miller, P. C. Soil moisture relations in southern California chaparral. Ecology 61:98-107; 1980.

Orshan, G. The mediterranean type plant form: A definition. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republics of South Africa; 1981.

Poole, D. K.; Miller, P. C. Water relations of selected species of chaparral and coastal sage communities. Ecology 56:1118-1128; 1975.

Poole, D. K.; Miller, P. C. The distribution of plant water stress and vegetation characteristics in southern California chaparral. Am. Midi. Nat. 105:32-43; 1981.

Poole, D. K.; Roberts, S. W.; Miller, P. C. Water utilization. In: Miller, P. C., ed. Resource use by chaparral and matorral: A comparison of vegetation function in two mediterranean type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag; 1981: in press.

Pressland, A. J. Effect of stand density on water use of mulga (Acacia aneura F. Muell.)

woodlands in southwestern Queensland. Aust. J. Rot. 24:177-191; 1976.
Radosevich, S. R.; Conrad, S. C.; Adams, D. R. Regrowth responses of chamise following fire. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems; 1977 August 1-5; Palo Alto, CA: U.S. Dept. Agric., For. Serv. and U.S. For. Serv. Gen. Tech. Rep. WO-3.
Raven, P. H. The evolution of mediterranean floras. In: di Castri, F.; Mooney, H. A., eds. Mediterranean type ecosystems: Origin and structure. New York-Heidelberg-Berlin: Springer-Verlag; 1973:213-224.
Read, D. J.; Mitchell, D. T. Decomposition and mineralization processes in mediterranean-type ecosystems and in heathlands of similar structure. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981.
Shachori, A. Y.; Michaeli, A. Water yields of forest, maquis, and grass covers in semiarid regions. A literature review. In: Eckardt, F. D., ed. Methodology of plant ecophysiology. Paris: UNESCO; 1965.
Shaver, G. R. Mineral nutrient and nonstructural carbon utilization. In: Miller, P. C., ed. Resource use by chaparral aid matorral: A comparison of vegetation function in two mediterranean type ecosystems. New York-Heidelberg-Berlin: Springer-Verlag; 1981: in press.
Sims, P. L.; Singh, J. S. The structure and function of ten western North American grasslands. II. Intra-seasonal dynamics in primary producer compartments. J. Ecol. 66:547-572; 1978.
Solbrig, O. T.; Cody, M. L.; Fuentes, E. R.; Glanz, W.; Hunt, J. H.; Moldenke, A. R. The origin of the biota. In: Mooney, H. A., ed. Convergent evolution in Chile and California, mediterranean climate ecosystems. Stroudsburg, Pa.: Dowden, Hutchinson & Ross; 1977:13-26.
Specht, R. L. Dark Island heath (Ninety-Mile Plain, South Australia). IV. Soil moisture patterns produced by rainfall interception and stem-flow. Aust. J. Bot. 5:137-150; 1957a.
Specht, R. L. Dark Island heath (Ninety-Mile Plain, South Australia). V. The water relationships in heath vegetation and pastures on the Makin Sand. Aust. J. Bot. 5:151-172; 1957b.
Specht, R. L. Dark Island heath (Ninety-Mile Plain, South Australia). VII. The effect of fertilizers on composition aid growth, 1950-60. Aust. J. Bot. 11:67-94; 1963.
Specht, R. L. A comparison of the sclerophyllous vegetation characteristic of mediterranean type climates in France, California, and southern Australia. I. Structure, morphology, and succession. Aust. J. Bot. 17:277-292; 1969a.
Specht, R. L. A comparison of the sclerophyllous vegetation characteristic of mediterranean type climates in France, California, and southern Australia. II. Dry matter, energy, and nutrient accumulation. Aust. J. Bot. 17:293-308; 19696.
Specht, R. L. Water use by perennial evergreen plant communities in Australia and Papua New Guinea. Aust. J. Bot. 20:273-299; 1972.
Specht, R. L., ed. Heathlands and related shrublands. Part A: Descriptive studies. Amsterdam-Oxford-New York: Elsevier Scientific Publishing Co.; 1979. 498 p.
Steubing, L.; Alberdi, M. The influence of phosphorus deficiency on the sclerophylly. Oecol. Plant. 8:211-218; 1973.
Specht, R. L.; Moll, E. J. Nutrients as determinants of the structural and functioning of mediterranean-type ecosystems. In: Proceedings of the third international conference on mediterranean-type ecosystems; 1980 September 22-23; Stellenbosch, Republic of South Africa; 1981.
Thrower, N. J. W.; Bradbury, D. E., eds. Chile-California mediterranean scrub atlas: A comparative analysis. Stroudsburg, Pa.: Dowden, Hutchinson & Ross; 1977. 237 p.
Walter, H. Vegetation of the earth in relation to climate and the eco-physiological conditions. (Trans. from 2nd German ed. by Joy Wieser). New York-Heidelberg-Berlin: Springer-Verlag; 1973. 237 p.
Whittaker, R. H. Communities and ecosystems. 2d ed. New York: MacMillan Co.; 1975.
Van Der Zel, D. W.; Kruger, F. J. Results of the multiple catchment experiments at the Jankershoek Research Station, South Africa. 2. Influence of protection of fynbos on stream discharge in Langrivier. For. S. Africa 16:13-18; 1975.
Zinke, P. J. Mineral cycling in fire-type ecosystems. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems; 1977 August 1-5; Palo Alto, Ca.: U.S. Dept. Agric., For. Serv. and U.S. For. Serv. Gen. Tech. Rep. WO-3.

Stream Water Nutrient Changes Associated With the Conversion of Arizona Chaparral[1]

Edwin A. Davis[2]

Abstract: Increased streamflow obtained by converting chaparral watersheds to grass is associated with increased nitrate concentrations in the stream water. Undisturbed chaparral watersheds are tight with respect to nitrogen, losing very little nitrate-nitrogen in streamflow; nitrate concentrations are usually less than 0.5 ppm. Converting chaparral watersheds from deep-rooted shrubs to shallow-rooted grasses through the use of herbicides allows the escape of nitrate ions through the soil mantle. Nitrate concentrations of 45-80 ppm occurred in stream water from treated watersheds; nitrate concentrations remained above normal for 10 years or longer.

Streamflow from chaparral watersheds in Arizona can be increased under certain conditions by converting brush to grass (Hibbert and others (1974). In conjunction with water yield investigations I am studying the effects of chaparral manipulation practices on stream water chemistry. The objective of the water chemistry studies is to identify the short- and long-term effects of the various water improvement treatments on the chemical composition of the stream water and of the watershed soil in order to assess their environmental and ecological impacts.

A mature chaparral ecosystem is normally tight with respect to plant nutrients, recycling them through the vegetation, organic debris, microorganisms, available nutrient supply, and the soil-rock compartments of the ecosystem. Killing the brush could prevent the normal uptake of nutrients by that vegetation and allow the dissolved nutrients to escape to bedrock and into subsurface runoff.

I found that major disruptions occurred in the nitrogen cycle of a converted chaparral watershed, causing marked increases in nitrate concentration above those found for the untreated control watershed. The accelerated loss of nitrogen was not accompanied by an increased loss of cations. Although all major anions and cations are being studied and play important roles in understanding the biogeochemical processes involved in a chaparral conversion, only major aspects of stream water nitrogen losses are presented.

EXPERIMENTAL AREA

The experimental chaparral watersheds are on the 3-Bar Wildlife Area in the Mazatzal Mountains of central Arizona at an elevation of 4,000-5,000 feet. The chaparral is predominately shrub live oak (*Quercus turbinella*) with a mixture of other sclerophyllous species such as birchleaf mountain-mahogany (*Cercocarpus betuloides*), yellowleaf silktassel (*Garrya flavescens*), sugar sumac (*Rhus ovata*), hollyleaf buckthorn (*Rhamnus crocea*), palmer oak (*Quercus chrysolepis* var. *palmeri*), Emory oak (*Quercus emoryi*), pointleaf manzanita (*Arctostaphylos pungens*), and desert ceanothus (*Ceanothus greggii*). Sprouting shrubs predominate with minor occurrence of nonsprouting species, producing a brush crown cover of about 70 percent. The precipitation pattern is biseasonal: summer and winter precipitation (with occasional snow) and spring and fall droughts. The driest months, May and June, are followed by summer monsoons beginning in July. Annual precipitation at the study area averaged 29 inches over the past 24 years.

The soils are very gravelly sandy loamy derived from granitic parent material. They are classified as Udic Ustochrepts, from the loamy skeletal, mixed, mesic family. The soils are slightly acid and very permeable with infrequent surface runoff. Seismic exploration on the watershed indicated the coarse-grained granite was weathered and fractured 20 to 40 feet deep.

METHODS

Nutrient losses associated with chaparral conversions are being studied in conjunction with water yield experiments using the paired watershed approach. Comparisons between treated and untreated watersheds provide a basis for determining treatment effects. After a wildfire swept over the 3-Bar watersheds in June 1959, watersheds D and F were allowed to recover for 10 years, at which time brush cover was about 90 percent of its prefire crown cover. The biomass had not recovered to the same extent. Watershed F contains 68.39 acres and D contains 80.47 acres. The pretreatment streamflow calibration period began in 1964

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Plant physiologist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Forestry Sciences Laboratory, Arizona State University, Tempe, Ariz. 85281. Station headquarters is in Fort Collins in cooperation with Colorado State University.

and lasted for 5 years prior to the treatment of 3-Bar F in February 1969. 3-Bar D serves as an untreated control. Precipitation and streamflow data are based on an October-September water year. 3-Bar F soil was treated with karbutilate granules (20 lb. active ingredient per acre) by helicopter. After 3 years, by which time brush control was excellent, soil bioassays indicated that karbutilate residues in the soil had declined substantially, and the watershed was seeded with weeping lovegrass (Eragrostis curvula).

Streamflow samples were collected weekly at the gaging station weir, and more frequently during stormflow periods. Bulk precipitation samples (the composite of wet and dry fallout) were collected in a plastic pail within the housing of a recording rain gage. The samples were analyzed for the major cations and anions including nitrate and ammonium. Only nitrate results will be reported because it was the only ion that increased significantly after treatment.

Nitrate was determined with a Technicon AutoAnalyzer II utilizing a colorimetric method in which nitrate is reduced to nitrite, which then reacts with sulfanilamide to form a diazo compound. This compound then couples with N-1-naphthylenediamine dihydrochloride to form an azo dye.

Eleven years of posttreatment results are presented, which include a wide range in annual precipitation: 2 years of below-average amounts (15.7 and 16.9 inches), 5 years of nearly normal amounts (19.8-30.8 inches), and 4 years of very high amounts (44.3-53.1 inches).

RESULTS

Rainfall following the February 1969 treatment was ideal for leaching the karbutilate into the soil. Rain began within 2 hours after the application, and showers continued for the next 5 days. Rainfall after the treatment totaled 2.59 inches in February and 1.64 inches in March. The rainfall pattern was ideal for producing rapid injury to the brush in the spring.

Although the actual treatment year was from mid-February to mid-February, aberrations in nitrate concentration did not occur until November 1969, well into the treatment year. Data are presented, therefore, on the basis of the standard October-September water year.

The pretreatment data indicate that stream water chemistry for the paired watersheds was very similar. With 26.3 inches rainfall, the annual weighted mean nitrate concentrations were 0.18 ppm for 3-Bar F, and 0.10 ppm for 3-Bar D; nitrate losses were 0.06 lb/A from both watersheds (table 1). During six years of pretreatment calibration data, including one year in which chemical composition was measured, 3-Bar D outyielded 3-Bar F by a factor of 1.8 although it is just 1.2 times larger.

By May, following the February treatment, the brush, grasses, and forbs on 3-Bar F were severely injured, and an early treatment-response increase in streamflow became noticeable and continued throughout the spring drought. The increase in streamflow resulted from a less rapid recession of base flow for 3-Bar F than for 3-Bar D. Because there was a soil moisture deficit during the spring drought, the small amounts of rain received during the summer had no immediate effects on streamflow, and the stream water nitrate concentrations remained normal. The first increases in nitrate concentration came as flushes in November and December 1969 (1970 water year). Nitrate flushes of 10 ppm and 30 ppm were associated with 1.8-inch and 2.1-inch rainstorms. Subsequently during the year, seven additional rainstorms of 1.0 to 7.4 inches produced elevated nitrate concentrations. The maximum concentration was 56 ppm, caused by a 7.4-inch storm in September 1970. Annual precipitation during 1970 was 30.4 inches. The dramatic difference in nitrate release patterns that occurred as a result of controlling the brush is tabulated in the form of concentration frequency distributions (table 2). Nitrate concentrations in the 0-5 ppm range occurred on 72 percent of the days. The annual weighted mean nitrate concentration was 16.1 ppm (table 1). By contrast, the mean nitrate concentration in stream water from the untreated watershed (3-Bar D) was 0.24 ppm. The annual nitrate loss from 3-Bar F was 12.8 lb/A, while that from untreated 3-Bar D was only 0.06 lb/A.

During the second year (1971), there was 20.1 inches of rain and only four major nitrate flushes. The annual mean nitrate concentration was 5.6 ppm; 79 percent of the daily concentrations were less than 5 ppm (tables 1 and 2). The maximum concentration was 30 ppm. Nitrate losses from 3-Bar F and D were 3.4 lb/A and 0.04 lb/A, respectively.

During the third year (1972), the area received only 15.7 inches of rain and experienced an unusual 5-month drought from January through May. A 4.2-inch storm during the last 2 days of the 1971 water year (September 29 and 30) produced a flush of nitrate with a peak concentration of 69 ppm that dominated the entire year. The annual mean concentration increased to 26.5 ppm, and 71 percent of the daily concentrations ranged from 5 to 40 ppm (tables 1 and 2). The annual nitrate losses in streamflow were 17.9 lb/A from 3-Bar F and 0.03 lb/A from 3-Bar D.

During the fourth year (1973), the area received a record-breaking 53.1 inches of rainfall and provided conditions for what was to be the maximum annual nitrate loss from 3-Bar F (table 1). Nitrate concentrations in the stream water remained high during the entire year; 75 percent of the daily nitrate concentrations ranged from 20 to 60 ppm (table 2). The maximum concentra-

Table 1--Streamflow nitrate concentrations and losses from converted (3-Bar F) and untreated (3-Bar D) chaparral watersheds[1]

Year[2]	Converted (3-Bar F) Precipi-tation[3]	Converted (3-Bar F) Stream-flow	Converted (3-Bar F) Nitrate Concn.[4]	Converted (3-Bar F) Nitrate Loss	Untreated (3-Bar D) Precipi-tation[3]	Untreated (3-Bar D) Stream-flow	Untreated (3-Bar D) Nitrate Concn.[4]	Untreated (3-Bar D) Nitrate Loss	F/D Nitrate ratio Concn.	F/D Nitrate ratio Loss
	- - - inches - - -		ppm	lb/A	- - - inches - - -		ppm	lb/A	ppm	lb/A
Pretreatment										
1969	26.30	1.40	0.2	0.06	26.60	2.63	0.1	0.06	2	1
Posttreatment										
1970	30.80	3.52	16.1	12.84	30.61	1.15	0.2	0.06	80	214
1971	20.06	2.66	5.6	3.35	19.50	0.46	0.4	0.04	14	84
1972	15.74	2.99	26.5	17.90	15.50	0.39	0.4	0.03	66	597
1973	53.08	15.07	33.0	112.66	52.68	11.44	0.6	0.74	110	152
1974	19.83	2.36	12.8	6.82	19.50	1.40	0.6	0.20	21	34
1975	29.85	3.21	13.2	9.58	29.12	1.64	0.6	0.20	22	48
1976	30.18	3.53	13.8	11.02	30.24	1.86	0.3	0.11	46	100
1977	16.92	0.82	5.2	0.97	16.86	0.37	0.6	0.05	9	19
1978	44.29	8.75	13.5	26.72	44.54	8.55	1.0	1.88	14	14
1979	49.20	13.66	13..8	42.69	49.59	14.46	0.6	1.92	23	22
1980	43.38	11.01	8.3	20.70	43.61	9.84	0.6	1.45	14	14
Posttreatment annual means	32.12	6.14	[5]14.7	24.11	31.98	4.69	[5]0.5	0.61	[6]29	[6]40

[1]Watershed areas: 3-Bar F, 68.39 acres; 3-Bar D, 80.47 acres

[2]Oct.-Sept. water year

[3]Weighted precipitation on watershed

[4]Annual volume-weighted mean concentrations

[5]Arithmetic mean of annual volume-weighted concentrations

[6]Based on the 11-year posttreatment annual means

tion was 60 ppm, and the annual mean was 33 ppm. This annual mean was not approached again during the course of the study. During this high rainfall year, the nitrate level in the stream water from the untreated watershed remained low (0.3 ppm). Nitrate exported in streamflow from the converted watershed amounted to 112.7 lb/A, whereas that from the untreated watershed was only 0.7 lb/A. This was a landmark year in the study, and nitrate concentrations did not drop below 1 ppm for the next 3 years.

For the next 3 years (1974-1976), precipitation was about normal, and 80-95 percent of the daily nitrate concentrations had fallen back to the 5-20 ppm range (table 2). Maximum concentrations were 16.1 to 19.5 ppm; annual mean nitrate concentrations ranged from 12.8 to 13.8 ppm; and annual nitrate losses were 6.8 to 11.0 lb/A (table 1). During these years stream water from the untreated watershed maintained normally low annual mean concentrations (0.3 to 0.6 ppm), and annual nitrate losses were 0.1 to 0.2 lb/A.

The eighth year (1977) was very dry (16.9 inches rainfall), and streamflow volume (0.82 inches) was less than it had been since the start of the study (table 1). Seventy-five percent of the daily nitrate concentrations were in the 1-10 ppm range, and the maximum concentration was 9.4 ppm (table 2). The annual mean nitrate concentration was 5.2 ppm, in contrast to 0.6 ppm for the untreated watershed. Nitrate loss from the converted watershed dropped to 1 lb/A, chiefly due to the lack of adequate rainfall to flush nitrate through the watershed. Likewise, nitrate loss from the untreated watershed was low (0.05 lb/A).

The 3 most recent years of the study (1978-1980) had extremely high amounts of precipitation (44.3, 49.2, and 43.4 inches, respectively). Precipitation and streamflow for these years was exceeded only by those for 1973 (table 1).

Table 2--Streamflow nitrate concentration frequency distributions for a converted chaparrll watershed (3-Bar F) during the period 1969-1980[1]

Nitrate concn. (ppm)	Year and posttreatment year number											
	1969[2]	1970 1	1971 2	1972 3	1973 4	1974 5	1975 6	1976 7	1977 8	1978 9	1979 10	1980 11
	Number of days per year											
0- 1.0	365	190	154	70	5	0	0	0	91	101	0	5
1.1- 5.0		73	135	27	4	18	27	68	115	3	35	118
5.1-10.0		37	38	31	3	91	142	83	159	104	108	219
10.1-20.0		28	29	96	78	256	196	215		157	222	24
20.1-30.0		24	9	108	97							
30.1-40.0		6		25	57							
40.1-50.0		2		4	53							
50.1-60.0		5		2	68							
60.1-70.0		0		3								
≥45.0		6		6								
	ppm											
Max. nitrate concn.	0.3	56.0	30.0	69.0	60.0	16.1	18.3	19.5	9.4	17.6	18.3	10.6
	inches											
Precipitation	26.3	30.8	20.1	15.7	53.1	19.8	29.8	30.2	16.9	44.3	49.2	43.4

[1]Oct.-Sept. water year

[2]Pretreatment year

Because of the 3 consecutive years of high rainfall, nitrate flushing continued, and the annual mean nitrate concentrations were 13.5, 13.8, and 8.3 ppm, respectively. These concentrations, in conjunction with high streamflow volumes, combined to produce the 3 largest nitrate-loss years of the study except for 1973. Maximum nitrate concentrations for 1978-1980 were 17.6, 18.3, and 10.6 ppm, respectively (table 2). Seventy-two percent of the daily nitrate concentrations during 1978 and 1979 ranged from 5-20 ppm, while in 1980 (the eleventh posttreatment year) 92 percent of the samples had concentrations in the 1-10 ppm range. For the untreated watershed, the 1978-1980 years were also among the highest for precipitation and streamflow, average nitrate concentrations, and annual nitrate losses. Even so, annual mean nitrate concentrations were only 0.6 to 1.0 ppm, with nitrate losses of only 1.4 to 1.9 lb/A (table 1).

The arithmetic mean of annual volume-weighted nitrate concentrations in stream water from the converted watershed for the 11-year posttreatment period is 14.7 ppm, whereas that for the untreated watershed is 0.5 ppm, or 29-fold greater overall (table 1). After 3-Bar F was treated, the nitrate concentration of the stream water gradually shifted upward. For the first 4 years after treatment, a greater proportion of days of each succeeding year had concentrations in the higher nitrate concentration ranges (table 2). The third and fourth posttreatment years had the highest mean nitrate concentrations, the greatest proportion of samples in the 20-60 ppm range, and the two highest concentrations encountered during the study (tables 1 and 2). Interestingly, the third year (1973) had the least precipitation of the study, and the fourth year had the most precipitation. High streamflow and high nitrate concentrations during the fourth year combined to produce the maximum nitrate loss of the study (112.7 lb/A). Although the high nitrate concentrations were directly related to high rainfall amounts, they undoubtedly were also related to the length of time from treatment as it relates to the increasing availability of nitrogen from decaying organic matter in the soil, including the residual soil organic matter, and the organic matter from decaying shrub roots, leaves, twigs, and the more slowly decomposing branches.

Nitrate levels exceeded the current EPA standard for drinking water of 45 ppm on 6 days during

Table 3--Annual net gains and losses of nitrate-nitrogen associated with the conversion of a chaparral watershed to grass

Year[1]	Precipitation[2]	Nitrate-nitrogen		
		Loss (streamflow)	Gain (bulk precip.)	Net gain (+) or loss (-)[3]
	Inches	lb/A		
Pretreatment				
1969	26.30	0.01	3.21	+ 3.20
Posttreatment				
1970	30.80	2.90	4.74	+ 1.84
1971	20.06	0.76	4.59	+ 3.83
1972	15.74	4.04	2.92	- 1.12
1973	53.08	25.45	4.12	-21.33
1974	19.83	1.54	4.54	+ 3.00
1975	29.85	2.16	3.66	+ 1.50
1976	30.18	2.49	4.65	+ 2.16
1977	16.92	0.22	3.14	+ 2.92
1978	44.29	6.04	2.63	- 3.41
1979	49.20	9.64	2.16	- 7.48
1980	43.38	4.68	4.61	- 0.07
Posttreatment				
Totals		59.92	41.76	-18.16
11-Yr. ann. mean		5.45	3.80	- 1.65
10-Yr. ann. mean[4]		3.45	3.76	+ 0.31

[1]Oct.-Sept. water year.

[2]Weighted precipitation on watershed.

[3]Calculated as the difference between input in bulk precipitation and output in streamflow.

[4]1973 data is excluded.

each of the first and third years, and on 97 days during the fourth year. Thereafter, nitrate levels did not exceed 20 ppm (table 2).

Although nitrogen was exported from the watersheds in streamflow, it was also added in bulk precipitation. The net nitrate-nitrogen gain and loss budget for the converted watershed for 12 years is calculated as the difference between input in bulk precipitation and output in streamflow (table 3). For the pretreatment year (1969), there was a net gain of nitrate-nitrogen of 3.2 lb/A. For the 11-year posttreatment period, there was a net loss of 18 lb/A, or an average yearly net loss of 1.6 lb/A. Although this overall net loss figure is relatively small, it is somewhat misleading in that it is heavily biased by the 21.3 lb/A net loss in 1973. If the aberrant 1973 year is omitted from the budget, then there is an average yearly net gain of 0.3 lb/A. This average includes the 3 unusually high rainfall years of 1978, 1979, and 1980, for which 99 percent of the loss occurred in 1978 and 1979. Based on this budget, it is apparent that in spite of the 40-fold greater loss of nitrate-nitrogen from the converted watershed than from the untreated watershed (table 1), the input of nitrate-nitrogen in bulk precipitation largely offset the loss in streamflow.

DISCUSSION

Elevated nitrate concentrations accompanied death and decomposition of the brush and increased water yield. For the first few years, the pattern of nitrate concentration followed a wave form in which nitrate increased only after rainstorms of sufficient duration and amount to leach nitrates through the regolith into base flow. Between storms, during the early posttreatment years, the nitrate concentration returned to pretreatment baseline levels (0-1 ppm). As the treatment became older, the reservoir of decaying soil organic matter in the regolith probably increased. During this second stage, nitrate concentrations in the stream water remained 10 to 100 times above normal, with rainfall conditions adequate to sustain increased water yields. The nitrate release pattern can be likened to a series of waves of increasing height and breadth in which wave height cannot exceed a certain level but wave breadth is unlimited. In this analogy, wave height corresponds to nitrate concentration, and wave breadth to duration of the increased concentrations. The frequency of the nitrate waves, or flushes, is determined by the frequency and magnitude of rainstorms, and by the nitrogen reservoir in the soil. Nitrogen supply in the soil is limited by the supply and quality of decomposable organic matter and by the release of nitrates through the process of nitrification. This process is regulated by the supply of organic matter, the abundance of nitrifying bacteria, and the temperature and moisture content of the soil. A third stage should ultimately be reached when the reservoir of nitrogen below the root zone of the established grass cover is exhausted and the nitrogen within the grass root zone is recycled between soil and grass. When this new steady state is reached, the nitrate concentration of the stream water should return to pretreatment levels. Eleven years after the treatment of 3-Bar F this stage has not been reached.

Some possible side effects of the nitrate-release phenomenon which have ecological or environmental implications are eutrophication of streams and reservoirs, loss of watershed soil fertility, and unsuitability of stream water for drinking purposes. Of these possible consequences, eutrophication of watercourses is probably of greatest practical concern. Its effects can be reduced, however, by designing projects so that streams from conversion areas are diluted by streams from untreated areas. If reservoirs or other water impoundments already contain near maximum allowable levels of nitrate, however, an added burden of nitrogen in entering streamflow could be undesirable. Soil fertility of converted areas may be reduced by the extent that nitrogen is exported in streamflow. However, since grass production on converted areas is generally good, and vastly superior to that on natural areas (Cable 1975, Pase and others 1967), there may be no reason for concern. The slow release of nutrients from decomposing aboveground vegetal material is a compensating factor in supplying nutrients for the developing grass cover. The nitrate content of stream water from converted areas is unlikely to represent a health hazard (Parsons 1977). Although there are occasional concentrations greater than 45 ppm in streams from converted areas during the first few years, downstream mixing and dilution with streams from natural areas would reduce the occasional flush of high nitrate.

LITERATURE CITED

Cable, Dwight F. Range management in the chaparral type and its ecological basis: The status of our knowledge. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1975; Res. Paper RM-155. 30 p.

Hibbert, Alden R.; Davis, Edwin A.; Scholl, David G. Chaparral conversion potential in Arizona; Part I: Water yield response and effects on other resources. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Paper RM-126. 36 p.

Parsons, M. L. Current research suggests the nitrate standard in drinking water is too low. J. Environ. Health 40:140-143; 1977.

Pase, C. P.; Ingebo, P. A.; Davis, E. A.; McCulloch C. Y. Improving water yield and game habitat by chemical control of chaparral. International Union of Forestry Research Organization. 1967 Sept. 4-9; XIV. IUFRO-Kongress; V. I, Sect. 01-02-11:463-486.

Net Primary Productivity of Some California Soils Compared to Those of the Santa Catalina Mountains, Arizona[1]

Earl B. Alexander[2]

Abstract: Soil properties and climatic parameters were used to develop above-ground net primary productivity equations from published data for the Santa Catalina Mountains, Arizona, and for annual grassland and chamise-chaparral sites in California. An equation with soil properties only had nearly as low a standard error of estimate (SE) as the best equation (i.e. lowest SE) with estimated actual evapotranspiration included, and is more widely applicable.

Net primary productivity (NPP) is the rate of biomass (or energy) accumulation by autotrophic plants (Whitaker, 1975). In green plants, which are the major sources of primary productivity in terrestrial ecosystems, NPP is the difference between organic matter produced by photosynthesis and that consumed by respiration. NPP of natural unmanaged vegetation is the most suitable index for comparing the inherent productivity of all land. Yields of cultivated crops are not such universally suitable indices, because no single plant species grows on all soils. Although the natural vegetation varies in species composition from one soil to another, it is not arbitrary. Each soil, under natural conditions, supports the particular vegetation that is characteristic for it and its environment. Natural conditions include disturbances responsible for cyclical changes in the vegetation (White, 1979).

Little data on NPP are available, because they are difficult to obtain. Even in annual plant communities, where the data are relatively easy to obtain, the productivity is so variable from year to year that it must be averaged over a number of years in order to derive reasonable estimates. Lieth (1973) has reviewed historical developments in the field of predicting the NPP of terrestrial ecosystems. He has settled on actual evapotranspiration (AET) and mean annual air temperature (MAT) for predicting world-wide NPP. Most attempts to predict NPP rely solely on climatic data. Even when utilizing AET, a single value is usually assumed for the plant available water capacities of all soils.

Soils are important not only for their physical properties, which affect root distribution and water supply, but also for their fertility, which is the effect of plant nutrient supply on productivity. Since soils are so important to plant growth, it should be possible to improve the predictions of NPP by adding soil properties, as well as climatic factors, in predictive equations. However, there is little soils data from sites where NPP has been determined. Therefore, in testing the applicability of soil parameters, only the most basic properties (for example, particle-size distribution or clay content, pH, plant available water-holding capacity, and C/N ratio) which have either been measured at sites of NPP determinations or can be inferred from data for similar soils near the sites are utilizable. Data from California (Fig. 1) and the Santa Catalina Mountains of southern Arizona were used to develop equations for predicting NPP from both soil properties and climatic parameters.

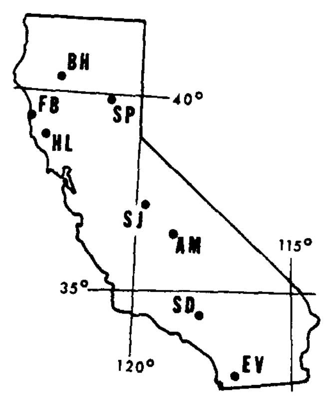


Figure 1—A map of California with the locations of the sites with NPPa data. The site names (Table 1) are Hopland (HL), San Joaquin (SJ) Bald Hills (BH), San Dimas (SD), Ash Mountain (AM), Echo Valley (EV), Spanish Peak (SP), and Fort Bragg (FB, 15 sites).

MODEL

NPP is estimated by measuring the rate of carbon or organic matter accumulation in living autotrophic plants. When plants die, most of their organic matter remains in the same ecosystem for some time, generally until the organic matter decomposes to inorganic compounds. During this process some organic matter is stored above ground and some is stored in the soil. A model for predicting NPP from soil properties and climatic factors can be developed if the amount of organic matter stored in the soil can be related to the amount produced by autotrophic plants in the ecosystem.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-25, 1981, San Diego, California.

[2]Soil Scientist, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

In early stages of stand development (secondary succession), a large proportion of the production accumulates in living plants. As succession progresses, increasingly larger proportions of the production are returned by way of fallen leaves, dead stems, and discarded root tissues to the pool of non-living organic matter subject to decomposition. Finally, in mature stands, the recharge to this pool is equal to the NPP and the temporal change in non-living organic matter (OM) which is subject to decay is equal to the gains from primary production (NPP) minus the losses due to decomposition. Thus

$$d(OM)/dt = NPP - k\ (OM) \qquad (1)$$

where k is a general decay constant which integrates the effects of different decay rates resulting from different kinds of organic matter in different ecosystem microenvironments. This equation follows a more general formulation of Olsen (1953). Sometime after a stand reaches maturity, organic matter contents reach steady state values throughout the ecosystem and the overall change in organic matter content ceases, or at least becomes so negligible that essentially d(OM)/dt = O. Hence, equation 1 becomes

$$NPP = k\ (OM) \qquad (2)$$

in mature ecosystems.

Since the decay constant (k) has different values in different ecosystems with different environments, it must be related to soil properties and environmental parameters before the steady state equation can be used for predicting NPP. According to Meentemeyer (1977), the logarithm of the decay constant for leaf litter is proportional to AET; that is, Ln(k) = a + b AET, when a and b are constants. Without contrary information for the decay constants of other ecosystem organic matter components, assume that they too are related to AET by an equation of the same form. Then, taking logarithms of equation 2, Ln(NPP) = Ln(k) + Ln(OM), and substituting Meentemeyer's relationship for Ln(k),

$$Ln(NPP) = a + b\ AET + Ln(OM). \qquad (3)$$

Equation 3 might be used for predicting NPP if data were available for determining the constants. They will be different from the constants determined by Meentemeyer who dealt with leaf litter only rather than all ecosystem organic matter not in living plants. Since much of the data for NPP does not include below ground productivity, above ground net primary productivity (NPPa) is substituted for total NPP. Also, it is convenient to substitute soil organic carbon (OC) for all ecosystem organic matter not in living plants, because more data are available for soil organic carbon, it is easier to obtain, and it is affected less by short-term ecosystem disturbances or human manipulations. The justification for this substitution is that there must be a close relationship between soil organic carbon and ecosystem organic matter production, because large proportions of the organic matter in stems, branches, roots, and leaves which accumulate on the ground are incorporated into the soil before they are completely decomposed to inorganic carbon. With substitutions of NPPa for NPP and a constant (c) times Ln(OC) for Ln(OM) into equation 3,

$$Ln(NPPa) = a + b\ AET + c\ Ln(OC). \qquad (4)$$

Although these substitutions are based more on analogies than on precise relationships, it is the utility of equation 4 and its derivatives for predicting NPPa that is the primary concern rather than rigid derivations. This was tested by least squares regression analyses. Other soil parameters were added to equation 4 as linear variables, assuming that the decay constant is related to them much as it is related to AET, unless the regression analyses indicated that other forms are obviously better.

MODEL DEVELOPMENT AND EVALUATION PROCEDURE

NPPa data were obtained from published sources (Table 1). Most of these sources have data on surface soils but lack subsoil data, which generally had to be derived from other sources. Soil bulk densities were calculated from organic carbon contents (Alexander, 1980). Available water capacities were estimated from soil textures and depths. Climatic data for the Santa Catalina Mountains were extrapolated from the data of Sellers and Hill (1974) and data for California sites were extrapolated from various sources.

A large part of the data are from 13 sites in the Santa Catalina Mountains, Arizona. Chow's test (Chow, 1950) was used to determine the suitability of combining data for the 13 Arizona and 7 California sites (Fig. 1) and treating them as one data set. Westman and Whittaker (1975) have published net primary productivity data for 15 sites near Fort Bragg, California, which are not listed separately in Table 1.

The independent variables used in various combinations to predict NPPa (t/ha) were (1) the logarithm of organic carbon content in mineral soil to one meter depth (kg/m^2m); (2) mean annual air temperature (MAAT, $^\circ C$); (3) actual evapotranspiration (AET, cm/yr) calculated by the Thornthwaite procedure; (4) a function of evapotranspiration (FET) equal to AET/(1-Ln(AW/AWC)), ($AW/AWC \geq 0.01$), where AW is the mean monthly plant available water and AWC is the available water capacity of a soil; (5) mean carbon to nitrogen ratio (C/N) in the upper 10 cm of soil; (6) mean clay content (percent) in the upper 25 cm of soil; and (7) mean pH in the upper 10 cm of soil. Coastal California soils of the Fort Bragg area are in four soil drainage classes, which were considered as discrete independent variables. The best equations for predicting Ln(NPPa), the dependent variable, were considered

Table 1--Site information, above ground net primary productivity, soil properties, and sources of data. [4]

Site[1]	Lat.	Alt.	Vegetation	Soil Series	NPPa	Stand[2] Age Span	MAAT	AFT	Soil Organic Carbon	Surface Soil Clay	Surface Soil C/N	Surface Soil pH
	N	meters			t/ha	yr	°C	cm/yr	kg/m^2m	pct		
44, SCM	32.5°	2720	Subalpine Fir Forest	-	8.7	mature, last 5	7.6	53.9	19.0	21	36	6.0
46, SCM	32.5°	2640	Douglas-fir Fir Forest	-	11.2	"	8.1	51.5	14.5	9	23	5.2
47, SCM	32.5°	2650	Douglas-fir Forest	-	8.4	"	8.1	51.3	17.1	9	23	5.2
48, SCM	32.5°	2470	Mixed Pine Forest	-	6.2	"	7.5	46.9	4.9	3	12	4.5
49, SCM	32.5°	247	Ponderosa Pine Forest	-	5.8	"	9.3	51.7	9.3	9	22	4.8
50, SCM	32.5°	2180	Pine-Oak Forest	-	5.0	"	11.2	51.7	10.9	10	25	5.5
51, SCM	32.5°	2040	Pine-Oak Woodland	-	4.5	"	12.2	50.3	9.4	10	19	6.8
52, SCM	32.5°	2040	Pygmy Conifer-Oak Scrub	-	1.9	"	12.2	49.6	2.1	6	16	6.2
53, SCM	32.5°	1310	Open Oak Forest	-	1.5	"	17.1	40.4	4.2	12	16	6.8
54, SCM	32.5°	1220	Desert Grassland	-	1.4	"	17.1	41.6	3.5	6	12	7.5
55, SCM	32.5°	1020	Spinose-Suffrut. Shrub	-	1.3	"	19.0	34.3	3.2	12	12	7.0
56, SCM	32.5°	870	Paloverde-Busage Shrub	-	1.0	"	20.0	31.1	2.8	12	11	7.0
57, SCM	32.5°	760	Creosotebush Des. Shrub	-	0.9	"	20.8	27.8	3.2	18	6	7.0
Hopland	38°59′	300	Annual Grassland	Laughlin-Sutherlin	2.3	mean, 16 ann.	14.4	39.3	7.5	22	12	5.4
S. Joaquin	37°01′	335	Annual Grassland	Ahwahnee	2.4	mean, 35 ann.	15.3	20.3	3.8	8.5	11	6.4
Bald Hills	40°25′	335	Annual Grassland	Sehorn	2.6	mean, 4 ann.[3]	15.3	34.5	6.9	48	10	6.2
San Dimas	34°10′	900	Chamise Chaparral	Cieneba	1.5	0-18	14.3	27.4	2.1	4.5	14	5.6
Ash Mtn.	36°30′	800	Chamise Chaparral	Sierra	2.0	0-20	13.8	35.6	7.4	13	14	5.8
Echo V.	32°54′	1000	Chamise Chaparral	Vista	3.6	current, 22-24	13.5	29.5	5.5	15	13	6.5
Spanish Pk.	39°55′	2070	Red Fir Forest	Waca	8.4	0-120	4.8	29.8	14.7	5	28	5.8
Ft. Bragg	39.5°			-		mature, last 5						

[1]Numbers 44 through 57 are Whittaker's, SCM = Santa Catalina Mountains.

[2]Stand age for NPPa determinations.

[3]Two sites with two years of data from each.

[4]Data sources by site for NPPa, surface soil and subsoil properties, respectively: Santa Catalina Mountain sites - Whittaker and Nierinq (1975), Whittaker et al. (1968) and Martin and Fletcher (1943): Hopland - Murphy (1970), Zinke and Stanqenberqer (1975); San Joaquin - Duncan and Woodmansee (1974), Duncan (1975) with soil descriptions by K. Chang; Bald Hills - Powell (1965), Zinke and Stanqenberqer (1975); San Dimas - Specht (1969) plus litter production from Kittredge (1955), Mooney and Parsons (1973) plus SCS (1973); Ash Mountain - Rundel and Parsons (1979), Parsons (1976) and SCS (1973); Echo Valley - Mooney and Rundel (1979), Bradbury (1977); Spanish Peak - Stanqenberqer (1978), Stanqenberqer (1978) and SCS (1973); Fort Bragg - Westman and Whittaker (1975), Westman (1971) and Gardner and Bradshaw (1954) plus Zinke and Stangenberger (1975).

to be those with the lowest standard errors of estimate (SE).

RESULTS AND DISCUSSION

Ln(OC) was included in every equation considered, because it is essential to the model. Although NPPa is highly correlated with MAAT, the temperature coefficients in predictive equations are negative, which is opposed to the expected temperature effect on the decay constant. This anomaly is due to increasing precipitation and its greater effectiveness with increasing altitude and decreasing temperature in Arizona and California. AET incorporates air temperature and is a more satisfactory independent variable because it does not increase indefinitely with increasing altitude. Equations with MAAT greatly over estimate the NPPa at the Spanish Peaks site, which is the only one at relatively high altitude in California. Therefore, AET was used as an independent variable, instead of MAAT, because the predictive equations using it are more likely applicable to a wider range of environments.

The results of regression analyses are presented in Table 2. Adding more than three independent variables for the Arizona set and more than four for the combined set of Arizona and inland California site data increases the standard errors of estimate. Chow's test indicates that the best equation for the 13 Arizona sites, $Ln(NPPa) = 0.0260 + 0.5330\ Ln(OC) + 0.0376\ AET - 0.2548\ pH$, is not appropriate for the combined set of Arizona and seven inland California soils ($F = 8.35$, $p<0.01$). However, none of the best equations, with up to five independent variables (Table 3), for the combined set of Arizona and inland California soils are statistically differentiable from equations for the Arizona soils only. The NPPa and soil organic matter decay rates of the soils in the Fort Bragg area are so dependent on soil drainage, which cannot be confidently determined from information in the published sources, that no equations were developed for the coastal California soils. All the 13 Arizona and the seven inland California soils are well drained.

Table 2-Degrees.,of freedom (DP), coefficients of determination (R^2), and standard errors of estimate (SE) for equations to predict NPPa. All variable combinations were tested, but the Napierian logarithm of soil organic carbon content (OC) was retained in all equations. Following Ln(OC), variables are listed in the orders that they contribute to reductions of the standard errors of estimate.

	Arizona Sites			Arizona and Inland California		
Variable	DF	R^2	SE	DF	R^2	SF
Ln(OC)	11	.790	.4352	18	.739	.4139
AET	10	.939	.2454			
pH	9	.975	.1655	17	.831	.3425
Clay				16	.952	.3197
C/N				15	.872	.3177

Table 3--Constant and coefficients of variables in equations for predicting NPPa from the 13 Arizona and 7 inland California soils. Each column represents the best equation for the specified number of independent variables, including the constant. The dependent variable is Ln(NPPa).

	Number of Independent Variables			
Variable	5	4	3	2
Constant	1.4846	1.4824	1.6971	-0.6515
Ln(OC)	0.6731	0.8481	0.7899	0.9799
pH	-0.2952	-0.2941	-0.3329	
Clay	-0.0103	-0.0147		
C/N	0.0194			
OF	15	16	17	18
R^2	0.872	0.962	0.831	0.739
SE	0.3177	0.3197	0.3426	0.4139
[1]F	3.06	2.70	2.55	0.75

[1]Values of F for Chow's test are nonsignificant (p = 0.05), indicating that equations developed for the 13 Arizona sites are statistically undifferentiable from these equations.

The Arizona sites can be divided into two groups, each with linear but distinctly different AET-NPPa relationships: (1) a group of seven sites with forest cover (NPPa = -51.74 + 1.123 AET, r^2=0.952) and (2) a group of six sites with open woodland, scrub, or desert vegetation (NPPa = -.33 + .044 AET, r^2=0.954). The discrepancy between these two groups was eliminated by substituting for AET a function of evapotranspiration (FET) equal to the sum of twelve monthly values of AET/(1-Ln(AW/AWC)). This function implies that the ratio of NPPa to evapotranspiration decreases as soil water is depleted and becomes less readily available to plants. It is analogous to the expression AET/(1-H), when 4 is relative humidity, used by Arkley and Ulrich (1953) for predicting crop yield. With FET as an independent variable, Ln (NPPa) = -.6574 + 0.0761 FET (r^2=0.913, SE = 0.2794) for the 13 Arizona sites. Although FET is better than AET alone for predicting NPPa, its advantage is greatly diminished when more independent variables are utilized.

With the set of 13 Arizona soils and 7 inland California soils, the equation for predicting NPPa from Ln(OC), pH, clay content, and C/N ratio is best (Table 2). AET is not one of the most useful independent variables for this set of data. The regression coefficients for pH and clay are negative and the coefficient for C/N is positive (Table 3).

The negative coefficient for pH implies that the rate of organic matter decay increases as the soil pH decreases. However, the negative coefficient reflects the very high negative correlation between NPPa and soil pH (Table 4), thus invalidating the implied effect of soil pH on the decomposition of soil organic matter. The correlation of increasing NPPa with decreasing soil pH is probably related to the contributions of precipitation to both NPPa and leaching of bases. The trend to greater NPPa with lower pH is reversed on the extremely acid, poorly drained soils of the pygmy forests of coastal California, where the NPPa averages only 2.6 t/ha. The highest productivity is on the slightly to moderately acid (about pH 6) soils of the coastal redwood forests, where the NPPa averages 14 t/ha.

The negative coefficient for clay (Table 3) implies that soil organic matter disappears less rapidly as the clay content increases. This might be expected from the fact that clay mineral-organic matter complexes increase the stability of the organic matter. It is in accord with the findings of Harradine and Jenny (1958) that soils from mafic volcanic rocks have both more clay and more organic matter than soils from granitic rocks. The quantity of clay to one meter, or some other depth, may be the best soil textural parameter to use for predicting NPPa, but the percentage of clay in the <2 mm fraction of surface soil was utilized due to lack of more appropriate data.

The positive coefficient for C/N (Table 3) is contrary to the negative effect that a high C/N ratio might be expected to have on the decay constant (Witkamp, 1971). This apparent anomaly is probably due to the very high correlation between C/N and OC (Table 4) and the positive correlation of NPPa to OC.

Equations developed from the Arizona and inland California soils data are not good for the coastal California soils. In the Fort Bragg area, soil drainage has the greatest influence on NPPa, which is so poorly correlated with 0C that the model is not useful. The best equation for the well drained soils of Arizona and inland California (Table 3, 15 DF) overestimates the NPPa of all the pygmy forest soils, which are mostly poorly drained; it underestimates the NPPa of all but one of the Bishop pine forest soils, which are mostly moderately well drained; and it greatly underestimates the NPPa of all but one of the coastal redwood forest soils, which are well drained. The coastal fog may be an important factor too, since the NPPa predictions are poor even for the well drained soils of the Fort Bragg area.

Table 4-Correlations of continuous variables with one another. Correlation coefficients (r) for 13 Arizona and seven inland California soils are on the lower left and those for 15 coastal California soils are on the upper right. Coefficients with absolute values greater than 0.444 (0.514 for the coastal set) are significant ($p = 0.05$) and those greater than 0.561 (0.641 for the coastal set) are highly significant ($p = 0.01$).

	NPPa	OC	MART	Clay	C/N	pH
NPPa		0.502	-0.443	0.135	0.415	-0.180
CC	0.883		-0.618	0.197	0.544	-0.092
MAAT	-0.880	-0.760		0.160	-0.706	0.549
Clay	-0.154	0.068	0.246		-0.079	0.177
C/N	0.788	0.869	-0.772	-0.167		-0.658
pH	-0.612	-0.454	0.754	0.143	-0.388	
AET	0.608	0.559	-0.570	-0.142	0.597	-0.463
FET	0.787	0.705	-0.823	-0.044	0.650	-0.833

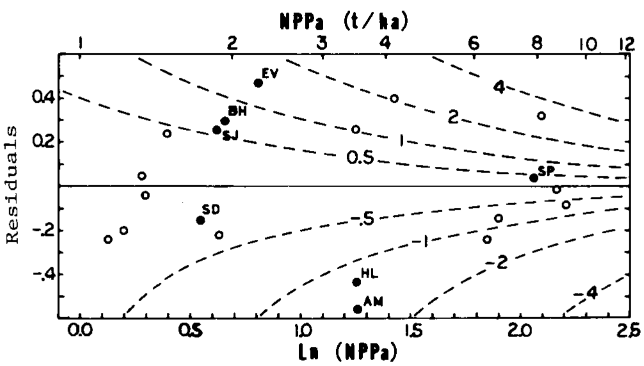


Figure 2-Residuals (actual minus predicted values) from Ln(NPPa) = 1.4846 + 0.6731 Ln(OC) - 0.2952 pH - 0.0103 Clay + 0.0194 C/N (Eq. 5) for the 13 Arizona and 7 California soils. The horizontal axis represents predicted values and the dashed lines represent conversions of residuals to NPPa by taking their antilogarithms.

A plot of the residuals (Fig. 2) shows how actual NPPa relates to values predicted from the best equation for Arizona and inland California soils (Table 3, 15 OF). The inland California values are evenly distributed between positive and negative deviations. There are positive and negative values for both annual grassland and chamise-chaparral soils. The NPPa of the Spanish Peak red fir site is based on the average productivity over the first 120 years following deforestation, whereas the NPPa of the Arizona sites are based on the current productivity averaged over the last five years, yet the residual for the Spanish Peak site is very small. However, 8.4 t/ha is only a minimum figure for the NPPa of the Spanish Peak site, because carbon lost as CO_2 from completely decomposed organic matter was not accounted for in estimating NPPa from the model of Stangenberger (1978). The NPPa of forest stands may be affected more by stand condition, as reported by Grier and Logan (1977), than by differences between successional and mature stands. In fact, it may even be more appropriate to compare sites by mean NPPa over a successional period, as for two of the chamise-chaparral stands as well as for the Spanish Peak red fir stand. Cyclical repetitions of disturbance and succession may be more a rule than an exception for plant communities (White, 1979).

CONCLUSIONS

Soil parameters were found useful for estimating the NPPa of well drained Arizona and inland California soils, assuming that the Ln(NPPa) is related to the Ln(OC) and functions of AET or soil properties which affect the rate of soil organic matter decay. Even though organic carbon in the soil is only a fraction of that in an ecosystem, its quantity may be the best organic matter parameter for estimating NPPa in all except mature ecosystems because it is less readily affected by perturbations of the environment. Soil organic matter may vary little through a cycle of disturbance and succession, whereas there may be extreme changes in the quantities of litter above ground (Turner and Long, 1975).

The best equation for predicting the NPPa of 13 Arizona and 7 California soils would be Ln(NPPa) = -.7148 + 0.6774 Ln(OC) + 0.0346 FET -.0147 clay (R^2=0.881, 5E=0.2957). However, Chow's test indicates (F=5.32, with 9 and 7 degrees of freedom) that this regression is significantly different ($p < 0.05$) from a similar regression (same variables) for the 13 Arizona soils alone. Therefore, equation 5 (Table 3, 15 OF), which is suitable for either the 13 Arizona soils alone or in combination with the 7 inland California soils, is considered to be better because it is more widely applicable:

$$\text{Ln(NPPa)} = 1.4846 + 0.6731\ \text{Ln(OC)} - 0.2952\ \text{pH} - 0.0103\ \text{Clay} + 0.0194\ \text{C/N}. \quad (5)$$

This equation appears to be good for predicting the NPPa in chamise-chaparral and annual grassland ecosystems, but there is insufficient data for judging its accuracy in estimating the productivity of forest ecosystems at higher altitudes in California. Better and more universally applicable equations can be developed only when much more soils data can be coordinated with NPPa measurements.

LITERATURE CITED

Alexander, E. B. Bulk densities of California soils in relation to other soil properties. Soil Sci. Soc. Am. J. 44: 689-692; 1980.

Arkley, R. J.; Ulrich, R. Relationships between plant growth and transpiration. Hilgardia 34: 559-584; 1963.

Bradbury, D. E. Soils. In: Thrower, M. J. W.; Bradbury, D. E., eds. Chile-California Mediterranean Scrub Atlas: A Comparative Analysis. Dowden, Hutchinson, Ross; 1977: 78-81.

Chow, G. C. A test of equality between sets of observations in two linear regressions. Econometrica 28: 591-605; 1960.

Duncan, D. A.; Woodmansee, R. G. Forecasting forage yield from precipitation in California annual rangeland. J. Range Manage. 28: 327-329; 1974.

Duncan, D. A. Comprehensive network site description - San Joaquin. USIBP, Grassland Biome, Tech. Report No. 296; 1975.

Gardner, R. A.; Bradshaw, K. E. Characteristics and vegetation relationships of some Podzolic soils near the coast of northern California. Soil Sci. Soc. Am. Proc. 18: 320-325; 1954.

Grier, C. C.; Logan, R. S. Old-growth Pseudotuga menziesii communities of a western Oregon watershed: biomass distribution and production budgets. Ecol. Monogr. 47: 373-400; 1977.

Harradine, F.; Jenny, H. Influence of parent material and climate on texture and nitrogen and carbon contents of virgin California soils. Soil Sci. 85: 235-243; 1958.

Kittredge, J. Litter and forest floor of the chaparral in parts of the San Dimas Experimental Forest, California. Hilgardia 23: 563-596; 1955.

Lieth, H. Primary production: terrestrial ecosystems. Human Ecology 1: 303-332; 1973.

Martin, W. P.; Fletcher, J. E. Vertical zonation of great soil groups on Mt. Graham, Arizona, as correlated with climate, vegetation, and profile characteristics. Univ. Arizona Agr. Exp. Sta., Tech. Bull. 99: 89-153; 1943.

Meentemeyer, V. Climatic regulation of decomposition rates of organic matter in terrestrial ecosystems. In: Adriano, D.C.; Brisbin, I. L., eds. Environmental Chemistry and Cycling Processes. U.S. Dept. Energy Symposium Series CONF-760429, Washington, D.C. 1977: 779-789.

Mooney, H. A.; Parsons, D. J. Structure and function of the California chaparral - an example from San Dimas. In: di Castri, F.; Mooney, A., eds. Mediterranean Type Ecosystems. Springer-Verlag; 1973: 83-120.

Mooney, H. A.; Rundel, P. W. Nutrient relations of the evergreen shrub, Adenostoma fasciculatum, in the California chaparral. Bot. Gaz. 140: 109-113; 1979.

Murphy, A. H. Predicted forage yield based on fall precipitation in California annual grasslands. J. Range Manage. 23: 363-365; 1970.

Olson, J. S. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44: 322-331; 1963.

Parsons, D. J. The role of fire in natural communities: an example from the southern Sierra Nevada, California. Environ.. Conserv. 3: 91-99; 1976.

Powell, W. R. Soil survey studies: No. 6 and No. 7. Calif. Dept. Forestry, Sacramento; 1965.

Rundel, P. W.; Parsons, D. J. Structural changes in chamise (Adenostoma fasciculatum) along a fire-induced gradient. J. Range Manage. 32: 462-466; 1979.

Sellers, W. D.; Hill, R. H., eds. Arizona Climate, 1931-1972. Univ. Arizona, Tucson; 1974. 616 p.

Soil Conservation Service. Soil survey laboratory data and descriptions for some soils of California. Soil Survey Investigations Report No. 24. USDA; 1973. 637 p.

Specht, R. L. A comparison of the sclerophyllous vegetation characteristic of Mediterranean type climates in France, California, and southern Australia. II. Dry matter, energy, and nutrient accumulation. Australian J. Botany 17: 293-308; 1969.

Stangenberger, A. G. Simulation of nutrient cycling in red fir (Abies magnifica A. Murr.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) forests. Ph.D. Dissertation. Univ. Calif., Berkeley; 1978.

Turner, J.; Long, J. N.; Accumulation of organic matter in a series of Douglas-fir stands. Can. J. For. Res. 5: 681-690; 1975.

Westman, W. E. Production, nutrient circulation, and vegetation-soil relations of the pygmy forest region of northern California. Ph.D. Thesis. Cornell Univ, Ithaca, N. Y. 1971.

Westman, W. E.; Whittaker, R. H. The pygmy forest region of northern California: studies on biomass and primary productivity. J. Ecol. 63: 493-520; 1975.

White, P. S. Pattern, process, and natural disturbance in vegetation. Bot. Rev. 45: 229-299; 1979.

Whittaker, R. H. Communities and Ecosystems. Macmillan; 1975. 385 p.

Whittaker, R. H.; Buol, S. W.; Nierinq, W. A.; Havens, Y. H. A soil and vegetation pattern in the Santa Catalina Mountains, Arizona. Soil Sci. 105: 440-450; 1968.

Whittaker, R. H.; Niering, W. A. Vegetation of the Santa Catalina Mountains, Arizona. V. Biomass, production, and diversity along the elevation gradient. Ecology 56: 771-790; 1975.

Witkamp, M. Soils as components of ecosystems. Ann. Rev. Ecol. Systematics 2: 85-110; 1971.

Zinke, P. J.; Stangenberger, A. California wildland soil-vegetation information system. Microfiche. Univ. Calif., Berkeley; 1975.

Assessing the Effects of Management Actions on Soils and Mineral Cycling in Mediterranean Ecosystems[1]

Leonard F. DeBano[2]

Abstract: Mediterranean ecosystems can be harvested, undergo type conversion, or be burned. Both wildfires and prescribed burning are important features of these ecosystems. All these activities affect soils and mineral cycling. Managers are concerned with assessing the impacts of different management activities. Soil, physical, chemical, and biological properties are important parts of these assessments. The implications of nutrient loss and availability on short- and long-term site productivity are lacking. Guides are needed by land managers for making assessments of their decisions.

Many land management decisions and activities concerning mediterranean-type ecosystems affect nutrient cycling processes and mechanisms. Recent legislation in the United States has mandated that the impacts of these different activities be assessed. Equally important is recognizing which treatments affecting soils and nutrient cycling may lead to soil-site degradation.

Much of the information necessary to assess these impacts of different management actions appears in research publications and documents which are not readily available to the land manager when making day-to-day decisions. This presentation discusses the possible impacts arising from different management actions and suggests some handbooks needed by land managers. Because fire is an important feature of mediterranean ecosystems, it necessarily makes up a large portion of the discussion.

THE MEDITERRANEAN ECOSYSTEM AND ITS MANAGEMENT --A BROAD PERSPECTIVE

Although mediterranean ecosystems include forests and grasslands, the most widespread vegetation type is evergreen sclerophyllous shrubs. This shrub type is known as mattoral in Chile, fynbos in Africa, maquis or garrigue in France, heath in Australia, and as chaparral in the United States. In California, chaparral occupies about 4.4 million hectares (Wieslander and Gleason 1954) and in Arizona another 1.2 million hectares (Hibbert and others this symposium)[1].

The soils and parent rock are diverse and vary widely over short distances; almost all geologic types are found in the different mediterranean environments. Soil fertility levels and nutrient pools vary widely both locally and regionally. Data on total nutrient pools of phosphorus and nitrogen shows the soils in Chile and the mediterranean zone of Europe, North Africa, and the Middle East are moderately fertile (Rundel 1978). Australia and South Africa have infertile soils, and California chaparral soils are intermediate in fertility. Little is known about the relationships between total nutrient pools and their availability to different plants.

The diverse vegetation, climate, and soils in the mediterranean ecosystems present a large number of unique management situations. However, space permits discussing only a few general activities and their impacts. Managers can either partially or completely harvest the vegetation. Forests can be logged or thinned; shrub areas can be harvested for biomass, can undergo type conversion, or can be grazed; and grasslands can be grazed or mowed. An important feature of mediterranean ecosystems is fire--both naturally occurring wildfires and prescribed burning. Managers can also either temporarily or permanently change the plant cover. Brush areas can be converted to grass, and forests can be invaded by brush or noncommercial trees after harvesting. Still other ecosystems receive minimum use and remain in nearly natural conditions, although these areas are diminishing and will be more intensively managed as the world population increases.

ASSESSING THE IMPACT OF MANAGEMENT ACTIONS

The management activities outlined above affect nutrient cycling by interrupting the flow of elements through the ecosystem, altering nutrient availability, or in some cases selectively removing significant portions of the total nutrient pool. Further, these activities also affect the physical, chemical, and biological soil properties.

Harvesting

Logging and thinning in forests, type conversion and biomass harvesting in evergreen shrub areas,

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Supervisory Soil Scientist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station located at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University. Headquarters is in Fort Collins, in cooperation with Colorado State University.

and grazing of grasslands directly and indirectly affect mineral cycling. Harvesting not only removes biomass and the nutrients contained in the crop but also can accelerate nutrient losses by erosion and leaching. Harvesting activities may also affect nutrient availability on the site.

Information on the distribution of nutrients in live vegetation (leaves, twigs, stems), litter, and soil provide an important basis for assessing the impact of harvesting because this information can be used to estimate the quantity of nutrients removed from a site. These losses can then be compared with total nutrient pools on a site and serve as the basis for judging whether these losses may have a potential impact on the area. If a substantial portion of the nutrient is removed, there may be a decrease in site productivity unless it is replaced by fertilization or some other way. A recent guide developed by Boyer and Dell (1980) outlined an approach for assessing the impact of logging and slash disposal treatment on forested areas in the Pacific Northwest. Unfortunately, the amounts of nutrients which could be removed without causing site degradation (threshold values) were not established for the different nutrients.

Some general guidance is also available on the potential impact biomass harvesting may have on chaparral sites. Chaparral sites are known to be low in nitrogen and phosphorus (Hellmers and others 1955), thus making these nutrients of the greatest concern to the land manager. Information on the distribution of different nutrients over a wide range of chaparral sites has been presented by Zinke at this symposium. This type of information when combined with the nutrient requirements of plants may provide the basis for classifying chaparral sites according to their nutrient pools and their possible vulnerability to nutrient depletion and site degradation.

Fire Effects

The physical, chemical, and microbiological properties of soil are all affected by fire. The physical properties most likely affected are soil aggregation and moisture movement (infiltration, water repellency, etc.). Soil chemical properties most readily affected are organic matter; total and available forms of nitrogen, phosphorus, and sulfur; and ion-exchange properties of the soil. The microbiological properties affecting the input, loss, and availability of nutrients may also be significantly affected by fire. These include such properties as organic matter decomposition, nitrogen fixation, and nitrification.

The changes in the soil occurring during a fire seem related to the intensity of the fire (DeBano and others 1979b). Therefore, it is essential to first characterize fire intensity and relate it to soil heating before attempting to finally assess fire effects on soil properties and nutrient cycling.

Characterizing Fire Intensity

Fire intensity is frequently described in qualitative nonstandard terms as being light, moderate, and intense because it is difficult to predict heat fluxes and time-temperature relationships during a fire (Rothermel and Deeming 1980). Two more exact expressions of fire intensity, based on fire behavior, have been proposed--fireline intensity and heat per unit area. Fireline intensity, which is related to flame length, is best suited for predicting the effect of fire on items in the flame, such as the combustion of branches, leaves, stems, etc. This parameter would be best suited for assessing the impact of fire on nutrients in the standing biomass. Heat per unit area is based on fireline intensity and the rate of spread. This parameter would better describe fire effects in the litter and duff or soil heating. Expressing fire intensity in the above terms for individual prescribed fires is complex and time consuming and, therefore, has not been widely used in the past for assessing fire effects on soils. However, utilizing flame lengths to calculate fireline intensity as outlined by Rothermel and Deeming (1980) may make these intensity indexes easier to determine and more widely used.

The difficulties described above in determining fire intensities has led to the use of more qualitative ways of classifying fire intensity. Most of these methods are based on the appearance of the postburn vegetation and litter. Classification systems have been developed for forests (Boyer and Dell 1980) and chaparral areas (Bentley and Fenner 1958, DeBano and others 1979b). Postfire seedbed appearance has been used to classify fire intensity on chaparral areas in southern California (Wells and others 1979), and these have been related to soil temperatures present during a fire (Bentley and Fenner 1958).

Relating Soil Heating to Fire Intensity

Once fire intensity has been characterized, it must be related to soil heating before fire-related changes in the soil can be assessed. Unfortunately, fireline intensity and heat per unit area have not yet been related to soil or litter heating although this may be possible by using correlation techniques (Rothermel and Deeming 1980). Developing a relationship between fire intensity and soil heating is further complicated by the litter layer because it both interferes with the transfer of heat downward in the soil and burns, releasing additional heat. These complications have lead to failure when attempts were made to develop useful duff-consumption (Van Wagner 1972) and duff-burnout models (Albini 1975). The litter presents a more formidable problem in forests than in brush areas because the litter layer is generally thicker and moister.

Until the shortcomings of the litter consumption and fire behavior models are solved, it may be necessary to measure, or estimate, soil and litter temperatures and relate them to changes in soil properties. Measured soil temperatures have been used to predict the effects of light, moderate, and intense fires on soil properties in chaparral areas of southern California (DeBano and others 1979b). When soil temperatures cannot be measured it may be necessary to obtain the best estimates possible from the literature or wherever data exists.

Wildfires Versus Prescribed Fires

When fire related impacts are being assessed in forest and brush areas, it is important to distinguish between prescribed burns and wildfires. Wildfires in both forests and brushlands usually burn intensely because the conditions are conducive to rapid propagation (high temperatures, low humidities, dry fuels). They can consume large areas in a short time while destroying most of the standing vegetation and litter on the soil surface. Fire intensities vary locally throughout an area burned by a wildfire, and some areas burn at moderate or low intensities--or in some cases are unburned. During prescribed burn fires the intensities are usually lower because more marginal burning conditions are selected. During a prescribed burn in brush the flames move through the canopy where they consume variable amounts of live vegetation and most of the dead fuels. Unburned "islands" are common during low to moderate intensity prescribed burns in brush. Prescribed burning in forests is even less severe and is designed to minimize damage to the larger standing trees and consume dead fuels and litter on the soil surface.

Assessing Fire Effects

Soil Physical Properties--The soil physical properties most likely altered by fire are: soil structure, soil wettability, and clay mineralogy. The destruction of organic matter and soil structure increases bulk density, diminishes aggregate stability, and decreases macro-pore space. When mineral soil is heated to 980°°C clay minerals are irreversibly altered (Ralston and Hatchell 1970). Alteration of organic substances starts at 200°C and 85 percent are destroyed at 300°C (Hosking 1938). Within this temperature range, hydrophobic substances responsible for decreasing soil wettability are vaporized in the surface litter and distill downward in the soil where they condense and form a water repellent layer (DeBano 1981). Temperatures of 250°C are necessary to fix the hydrophobic substance tightly to the soil particles. Above 288°C the hydrophobic substances are destroyed. The loss of soil structure and a decrease in wettability decreases infiltration and accentuates runoff and erosion.

Soil Chemical Properties--Although burning alters several soil chemical properties, the changes of most concern to the land manager are: the organic matter, nitrogen, phosphorus, and perhaps sulfur and potassium contents. Loss of organic matter decreases cation exchange capacity and diminishes the soils' ability to retain the abundant available plant nutrients released on the site during a fire. This is of greatest concern in a coarse textured soil containing small amounts of clay.

Nitrogen is probably the most important plant nutrient affected by fire because it is the nutrient most likely to be limiting (Hellmers and others 1955) and a large amount of the total nitrogen is volatilized and lost during fire (DeBano and Conrad 1978). Fire also affects organic nitrogen mineralization and may make this nutrient readily available to plants (DeBano and others 1979a). As the intensity of burning increases, the amount of nitrogen lost by volatilization increases. At temperatures above 500°C, 100 percent of the nitrogen in plant and litter material is lost (White and others 1973). Between 300° and 400°C, 50 to 75 percent of the nitrogen is lost. Between 200° and 300°C, up to 50 percent of the nitrogen may be lost, and below 200°C no measurable nitrogen is lost. The information on nitrogen losses at different temperatures can be combined with the surface and soil temperatures and used to estimate nitrogen losses at different burning intensities (fig. 1). The amount of nitrogen volatilized from the standing plants (live and dead) also depends on both the intensity of the fire and the completeness of the burn. Even when most of the standing shrub vegetation is consumed, significant amounts of nitrogen can remain in the charred branches and stems remaining after the fire. Nitrogen losses by volatilization during prescribed fires in forested areas is probably less than in chaparral because the soil, litter and duff temperatures are much lower than during brush fires (DeBano and others 1979b).

Sulfur is also volatilized but less is known about it than nitrogen. The importance of sulfur losses will require additional research. One study indicated potassium may be lost during burning (DeBano and Conrad 1978) although this may have a minor consequence because it is probably replaced by weathering of parent material during soil formation.

Many other plant nutrients contained in the organic matter, including phosphorus, are released and made readily available by burning. The abundance of available plant nutrients after fire makes the fertilization of freshly burned areas questionable. Little information is currently available on the length of time these nutrients remain in an available form before being immobilized. Although on-site movements occur, the losses from an entire watershed are not well understood. Most nutrients lost because of erosion are lost in debris rather than in runoff water (DeBano and Conrad 1976).

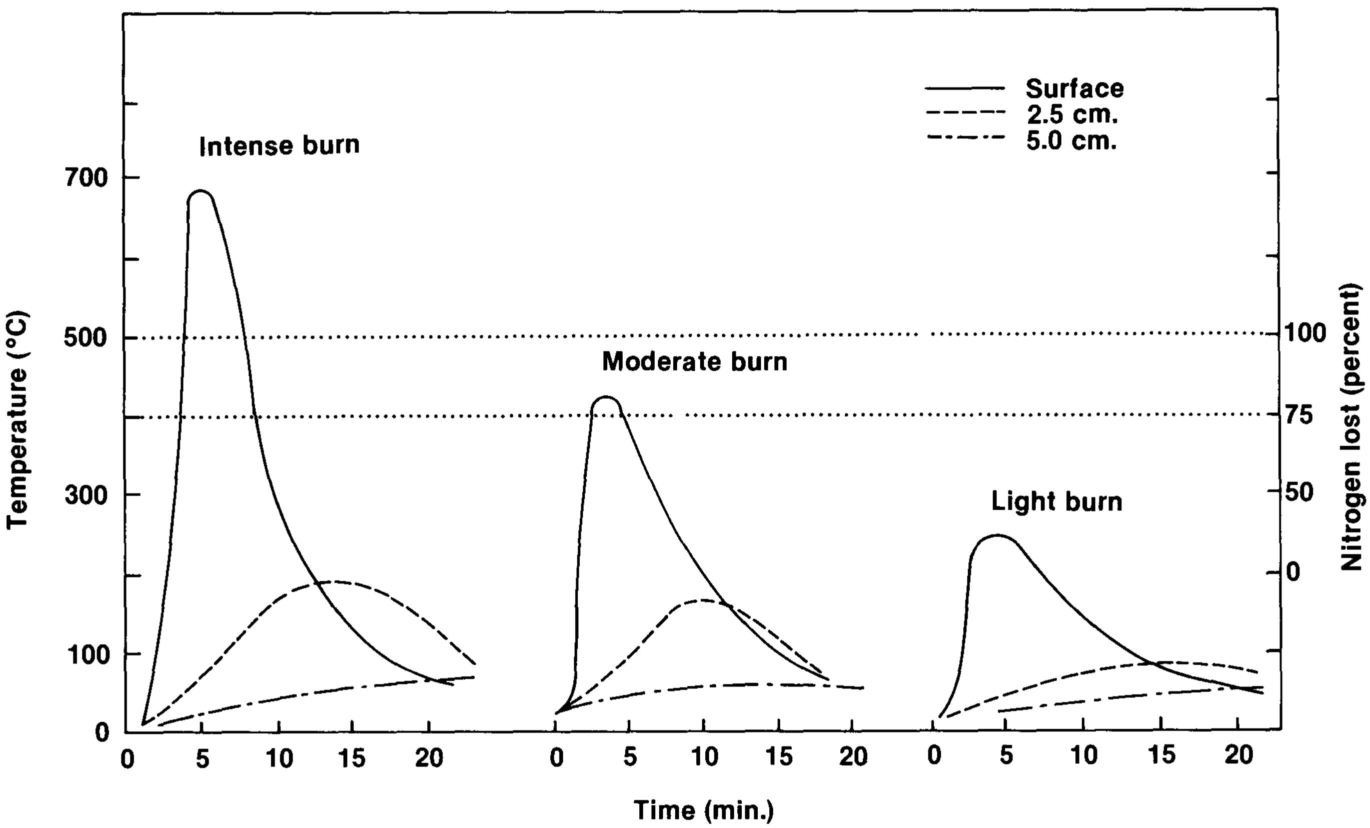


Figure 1--Surface and soil temperatures, and associated losses of nitrogen during: intense, moderate, and light intensity fires in chaparral (DeBano and others 1979).

Soil Microorganisms--Soil heating directly affects microorganisms either by killing them directly or altering their reproductive capability. Indirectly, soil heating alters organic matter, which increases nutrient availability (particularly nitrogen and carbon), and stimulates microbial growth rates. Although a complex interrelationship exists between soil heating and microbial populations in soils, it appears that duration of heating, maximum temperatures, and soil water content all may affect microbial responses (Dunn and others 1979). Generally, bacteria are more resistant to heating in both wet and dry soil than are fungi. The lethal temperature for bacteria was found to be 210° C in dry and 110° C in wet soil. Fungi have been found to tolerate temperatures of only 155° C in dry soil and 100° C in wet chaparral soils. Nitrifying bacteria appear to be particularly sensitive to soil heating, and even the most resistant of the *Nitrosomonas* bacteria can be killed in dry soil at 140°C and in wet soil at 75° C.

The sensitivity of microbial populations to burning over wet soils points to the necessity for evaluating the tradeoffs between microbial populations, soil nitrogen, and soil wettability during prescribed fires. Both soil wettability and nitrogen losses are reduced by burning over wet soils because the soil temperatures are lower, less nitrogen is lost by volatilization, and water repellency is less. Microbial populations, and possibly seeds, may be adversely affected by burning over wet soil. If the seeds of many of the short-lived perennial nitrogen-fixing plants are adversely affected by burning over moist soils, then the tradeoffs between nitrogen losses and microorganisms must be considered in terms of both short- and long-term plant succession and site productivity.

Cover Manipulation

Disturbing the vegetation on a site by type conversion may release high concentrations of nitrate nitrogen in streamflow. Type conversion resulting from logging in forests (Vitousek and Melillo 1979) land converting brush to grass (Davis this session)[1] may both release large amounts of nitrate nitrogen. It is hypothesized that the disturbance affects both the mineralization of nitrogen and its retention in the soil. The nitrogen compounds released during the decomposition, which had been returned to the surface by the deep-rooted shrubs, are not returned by the shallower rooted grasses. Therefore, the nitrates are no longer cycled from the deeper soil depths but instead percolate downward with the water through the soil profile, and later appear in the streamflow. Although large amounts of nitrogen may be lost they probably do not affect site fertility but are more important in terms of downstream water quality. This nitrate loss could become an important management consideration if large conversions were proposed above reservoirs used for domestic and recreational purposes.

Other impacts that need to be considered when making brush to grass conversions are erosion on steep slopes and the possible contamination of downstream water if herbicides are used for brush control.

RECOMMENDATIONS FOR FILLING INFORMATION GAPS

The information discussed above on the response of soils and mineral cycling to different management situations in mediterranean ecosystems needs to be presented in a format which can be used by the land manager for making on-the-ground decisions and assessments. Although state-of-knowledge publications provide excellent reviews of research findings, they do not satisfy the immediate needs of the manager. Instead guides or "handbooks" similar to the one developed by Boyer and Dell (1980) for assessing the effects of fire on Pacific Northwest soils seem to be more useful for management situations than are research reviews. These authors brought together existing information on fire effects in soils from scientific journals, state-of-knowledge publications, and by verbal communications with researchers. This material was presented in a format which could be used for assessing fire impacts under different prescribed burning conditions and residue treatments in the Pacific Northwest. Similar publications are needed for chaparral soils under the management situations discussed in this presentation. Specific handbooks needed and the information necessary for developing these are:

Handbook Relating Soil Heating to Fire Intensity--This publication should consider when: (a) fire intensity is determined by postfire visual estimation and temperatures are not measured, and (b) surface temperatures are measured. If only visual estimates are made of fire intensities, then soil temperatures must be based on data reported in the literature. Photographs of postfire conditions representing light, moderate, and intense burns would aid in classifying fire intensities. A section of the guide should also be devoted to describing the methods available for measuring soil and surface temperatures during prescribed burns. Sufficient information is currently available to write this handbook without waiting for the development of physical models relating fire intensity or behavior to soil heating. When stronger physical relationships are established, these can be used to refine and upgrade the initial handbook.

Handbook Relating Soil Heating to Changes in Soil Properties and Nutrient Cycling in Chaparral--This should be a comprehensive document outlining the effects of different degrees of soil heating on changes in: soil physical, chemical, and biological properties; nutrient availability; susceptibility to erosion; and site productivity. This handbook should consider the nutrient changes occurring when aboveground plant material is burned because these nutrients are deposited on the soil surface in a highly available form where they affect site productivity and are susceptible to loss by postfire erosion. The effect of burning over wet and dry soil and associated tradeoffs need to be addressed. The effects of repeated fire on steep slopes needs to be considered when prescribed burning is to be used to develop mosaic stands of different aged brush. Critical slope criteria already developed for brush to grass conversion need to be adapted to areas subjected to periodic burning programs.

Handbook Relating Biomass Removal to Nutrient Cycling and Site Productivity in Chaparral--The increasing interest in the potential use of chaparral biomass for energy and other uses makes it necessary to assess the impacts of crop removal on site productivity. The effect of removing an entire standing crop may be more important than merely removing tree boles during logging.

LITERATURE CITED

Albini, Frank A. An attempt (and failure) to correlate duff removal and slash fire heat. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1975; Gen. Tech. Rep. INT-24. 16 p.

Bentley, J. R.; Fenner, R. L. Soil temperatures during burning related to postfire seedbeds on woodland range. J. For. 56:737-740; 1958.

Boyer, Donald E.; Dell, John D. Fire effects on Pacific Northwest forest soils. Northwest Region, Forest Serv., U.S. Dep. Agric.: 1980; R6 WM 040. 59 p.

DeBano, Leonard F. Water repellent soils: A state-of-the-art. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981; Gen. Tech. Rep. PSW-46. 21 p.

DeBano, L. F.; Conrad, C. E. Nutrients lost in debris and runoff water from a burned chaparral watershed. In: Federal Inter-Agency Sediment. 1976: Conf. Proc. 3. p. 13-27.

DeBano, L. F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

DeBano, Leonard F.; Eberlein, Gary E.; and Dunn, Paul H. Effects of burning on chaparral soils: I. Soil nitrogen. Soil Sci. Soc. Amer. J. 43(3):504-509; 1979a.

DeBano, Leonard F.; Rice, Raymond M.; Conrad, C. Eugene. Soil heating in chaparral fires: Effects on soil properties, plant nutrients, erosion, and runoff. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1979b; Res. Pap. PSW-145. 21 p.

Dunn, Paul H.; DeBano, Leonard F.; Eberlein, Gary E. Effects of burning on chaparral soils: II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Amer. J. 43(3):509-514; 1979.

Hellmers, Henry; Bonner, James F.; Kelleher, John M. Soil fertility: A watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80(3):189-197; 1955.

Hosking, J. S. The ignition at low temperatures of the organic matter in soils. J. Agric. Sci. 38(3):393-400; 1938.

Ralston, Charles W.; Hatchell, Glyndon E. Effects of prescribed burning on physical properties of soil. In: Prescribed Burning Symposium Proceedings; 1971 April 14-16; Charleston, S.C. Asheville, N.C.: Southeastern Forest Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1971; p. 68-85.

Rothermel, Richard C.; Deeming, John E. Measuring and interpreting fire behavior for correlation with fire effects. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Tech. Rep. INT-93. 3 p.

Rundel, Philip W. Ecological impact of fires on mineral and sediment pools and fluxes. In: Fire and Fuel Management in Mediterranean Climate Ecosystems: Research priorities and programmes. 1978; MAB Technical Note 11. 1 p.

Van Wagner, C. E. Duff consumption by fire in eastern pine stands. Can. J. For. Res. 2(1):34-39; 1972.

Vitousek, Peter M.; Melillo, Jerry M. Nitrate losses from disturbed forests: Patterns and mechanisms. For. Sci. 25(4):605-609; 1979.

Wells, Carol G.; Campbell, Ralph E.; DeBano, Leonard F.; Lewis, Clifford E.; Fredriksen, Richard L.; Frandlin, E. Carlyle; Froelich, Ronald C.; Dunn, Paul H. Effects of fire on soil: A state-of-knowledge review. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1979; Gen. Tech. Rep. WO-7. 34 p.

White, E. M.; Thompson, W. W.; Gartner, F. R. Heat effects on nutrient release from soils under ponderosa pine. J. Range Manage. 26(1):22-24; 1973.

Wieslander, A. E.; Gleason, Clark H. Major brushland areas of the coast ranges and Sierra-Cascade foothills in California. Berkley, Calif.: California Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1954; Misc. Pap. 15. 9 p.

Some Recent Aspects and Problems of Chaparral Plant Water Relations[1]

Stephen W. Roberts[2]

Abstract: Current research on the water relations of shrub species in the southern California chaparral and the central Chilean matorral vegetations is reported. A fair data base is now available to characterize water potentials, stomatal conductances, and plant water use patterns in some of the more common shrubs in the chaparral and matorral vegetations. Much less is known about the water relations of the herbaceous plants, succulents, and tree species of these areas. Osmotic relations appear particularly important in understanding adaptation of these plants to the mediterranean-climate water environment.

Water is a critically important resource for plants and is often limiting with respect to plant growth, development, and distribution. Environmental water availability may also be quite variable in space and time. In view of both the significance of water to plant processes and its variability in nature, any mechanisms by which plants might stabilize their internal water environment against a changing external water regime would have great adaptive significance. Chaparral shrubs must endure droughts which occur repeatedly with varying severity over the lifetime of an individual plant (Mooney and Dunn 1970). The objective of this paper is to briefly review some current research results on the water relations of selected chaparral and matorral plants and to characterize aspects of the plant responses to developing water deficits during drought.

CHAPARRAL FIELD WATER RELATIONS

Field measurements of xylem pressure potential and leaf conductance were made through a summer drought cycle for Adenostoma fasciculatum H. & A., Ceanothus greggii var. perplexens (Trel.) Jeps. [C. p. Trel.], Quercus dumosa Nutt., and Arctostaphylos glauca Lindl. [A. g var. eremicola Jeps.], four common and widespread southern California chaparral shrub species (Munz and Keck 1959). Measurements were obtained from June through November 1978 at the Echo Valley research site in San Diego County, California. The research site has been previously described (Poole and Miller 1975, Mooney 1977, Thrower and Bradbury 1977). Measurements in A. fasciculatum, C. greggii, Q. dumosa, and A. glauca were obtained for individuals growing in close association on a north (pole-)-facing slope. Additional measurements were made in a pure stand of A. fasciculatum growing on an adjacent south (equator-)-facing slope.

Seasonal patterns of leaf water potential, measured with a pressure bomb (Scholander and others 1965), appeared to segregate by species rooting distribution (fig. 1). Ceanothus greggii and A. glauca, which tend to be shallow-rooted (Hellmers and others 1955, Miller and Ng 1977) showed similar seasonal water potentials which were increasingly more negative than the water potentials in A. fasciculatum and Q. dumosa, which tend to be deep-rooted. Site effects can override species differences, however. Adenostoma fasciculatum, measured during the same time period in a pure stand on an adjacent equator-facing slope, showed consistently more negative minimum water potentials than A. glauca and C. greggii on the pole-facing slope (fig. 1). It thus appears that particular water potential values should not in general be taken as a

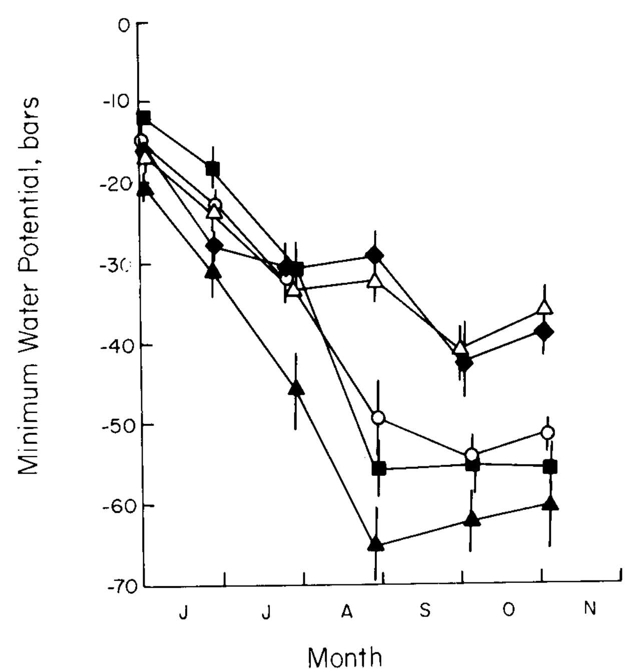


Fig. 1. Seasonal course of mean minimum leaf water potentials with standard errors estimated with a pressure bomb in Adenostoma fasciculatum on the pole- (△) and equator-facing slopes (▲), and Quercus dumosa (◆), Ceanothus greggii (■), and Arctostaphylos glauca (○) on the pole-facing slope.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Research Professor of Biology. Systems Ecology Research Group and Department of Biology, San Diego State University, San Diego, California 92182

species-specific property. The water potential measurements may serve as a relative index of drought stress among several species occupying the same local site, but the variation in water potential within a species from site to site can be often greater than the interspecific water potential variation within a site.

Additional measurements of stomatal conductance were made using the "null-balance" porometer approach (Beardsell and others 1972). Maximum conductances showed differences between species and in A. fasciculatum there were further differences by leaf age class (fig. 2). All conductances reported here are based on the total leaf surface area. Conductances based on a projected leaf area would be twice the values reported here for the broadleaf species A. glauca, C. greggii, and Q. dumosa, and approximately three times the values reported here A. fasciculatum. Early season measurements showed A. fasciculatum with the highest conductance and new A. fasciculatum leaves with conductances of about 0.8 centimeters per second in mid-June. There were no differences in maximum conductances between old and new leaves of A. glauca, which generally showed the lowest maximum conductances. Ceanothus greggii and Q. dumosa showed maximum conductances intermediate to A. fasciculatum and A. glauca. In all species maximum conductance decreased as the drought cycle progressed, reaching late season values of 0.05-0.15 centimeters per second.

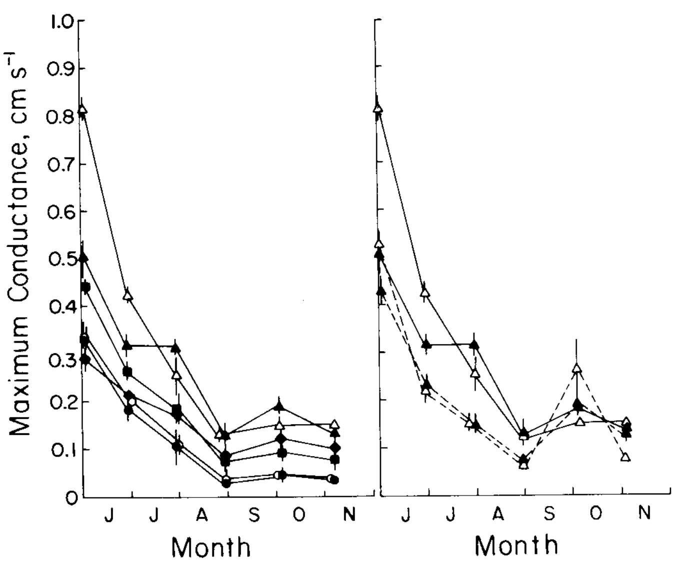


Fig. 2. A. Seasonal course of mean maximum leaf conductance with standard errors, measured on the pole-facing slope for Adenostoma fasciculatum (△ current year's leaves, ▲ old leaves), Quercus dumosa (♦ old leaves), Ceanothus greggii (■ old leaves), and Arctostaphylos glauca (○ current year's leaves, (● old leaves). B. Comparison of seasonal courses of mean maximum leaf conductance with standard errors in Adenostoma fasciculatum old (▲) and new (△) leaves, growing on the pole- (—) and equator-facing (---) slopes.

Within A. fasciculatum maximum leaf conductances differed with leaf age class and shrub exposure (fig. 2). Adenostoma fasciculatum shrubs on the pole-facing slope showed higher maximum conductances than did A. fasciculatum on the equator-facing slope and on each slope the new leaves showed higher early season maximum conductances. The early October peak in maximum conductance was associated with a short period of precipitation. The effect of precipitation was more pronounced in the conductance response of the equator-facing slope shrubs, but can be noted in the pole-facing slope shrubs as well (fig. 2).

Contrasts in leaf conductance between leaf age classes have not been studied previously in these species. Roberts and others (1979) measured consistent differences in leaf conductance in Ilex opaca Ait. early in the growing season with new tissue showing lower conductance than old tissue. These differences were gone by midseason. The controls determining conductance differences between the new and old leaves in A. fasciculatum may be related to both endogenous developmental patterns of leaf maturation and external conditions related to the water history of the tissue. For example, the early season conductance differences were greater in A. fasciculatum on the pole-facing slope than for A. fasciculatum on the equator-facing slope and the differences were maintained further into the regional drought cycle in A. fasciculatum on the pole-facing slope (fig. 2). The seasonal water potential data showed that A. fasciculatum on the equator-facing slope developed water stress sooner and to a greater degree than did A. fasciculatum on the pole-facing slope (fig. 1). This suggests that stomatal behavior becomes increasingly conditioned by the water status of the tissue as water becomes increasingly limited.

The magnitude and duration of differences in conductance between leaf age classes appears strongly influenced by the water history of the tissue. Shrubs which tend to be deep-rooted, such as A. fasciculatum, and which are located on sites producing less water stress, pole-facing slopes, showed larger age class differences in leaf conductance and maintained the differences further into the regional drought cycle. Shallow-rooted shrubs, such as A. glauca, showed much reduced leaf age class conductance differences. Age class differences in conductance were diminished earlier in the season in plants occupying sites of greater water stress (A. fasciculatum on the equator-facing slope) compared to plants of the same species occupying sites of lesser water stress (A. fasciculatum on the pole-facing slope). This may result from the earlier dominance of leaf water status on the equator-facing slope as a major control affecting stomatal behavior.

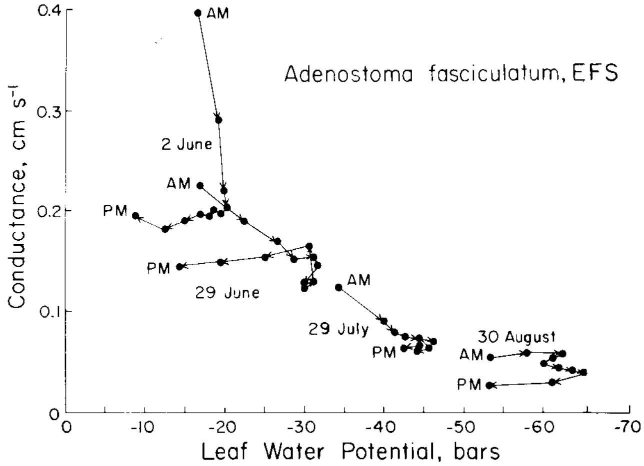


Fig. 3. Seasonal course of leaf conductance-leaf water potential relation in Adenostoma fasciculatum on the equator-facing slope, showing large hysteresis from morning (AM) to afternoon (PM) in the early season June measurements and decreasing hysteresis as the drought progresses. Environmental measurements are shown in Figure 3. Details are discussed in the text.

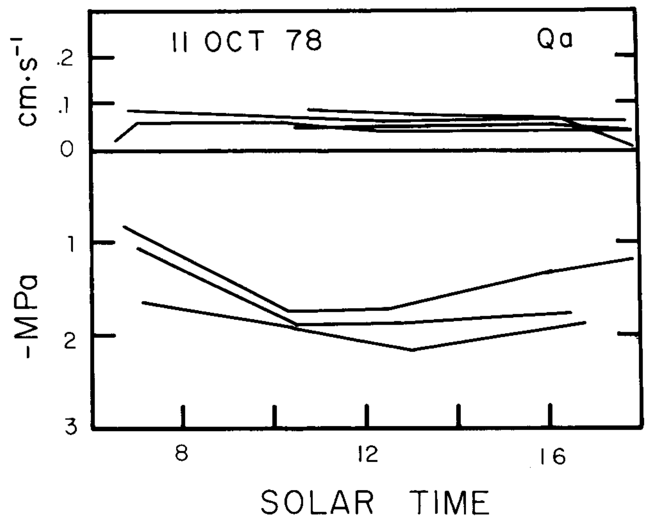


Fig. 4. Stomatal conductance and water potential in Quercus agrifolia at the Thousand Oaks site.

The increasingly dominant role of tissue water status in determining stomatal behavior as the drought cycle progresses is indicated by the seasonal course of the daily conductance hysteresis curves (fig. 3). Presumably, stomata respond to a complex of environmental factors, including light, temperature, carbon dioxide, humidity, wind, and tissue water status (Jarvis 1976). The large hysteresis in the early season leaf conductance-water potential relation indicates that several factors are operating simultaneously to determine stomatal responses and that leaf water status is only one factor functioning in concert with others to affect overall stomatal behavior. The seasonal tendency to decreasing hysteresis in the conductance-water potential relation suggests that tissue water status assumes an increasingly dominant role in controlling stomatal behavior under sustained drought conditions.

Specht (1972) has suggested that evergreen shrubs in mediterranean climates may moderate water use such that soil moisture would be conserved and processes such as photosynthesis and growth would be possible throughout the year. Miller and Poole (1979) suggest that such moderation of water use by a species may be adaptive in pure stands, but not in mixed stands due to interspecific competition for soil moisture. The present study showed that A. fasciculatum in a pure stand on the equator-facing slope had generally lower leaf conductance than did A. fasciculatum growing in a mixed stand on the pole-facing slope, supporting the suggestion of Miller and Poole (1979). However, water potentials in A. fasciculatum on the equator-facing slope were consistently more negative than for A. fasciculatum on the pole-facing slope, so that the observed conductance differences in A. fasciculatum cannot be ascribed solely to interspecific competitive effects, but must be conditioned as well by the differing water history the plants experience on the two slopes.

OAK FIELD WATER RELATIONS

Late summer measurements of water potential and stomatal conductance in Quercus agrifolia Nee and Quercus lobata Nee at a study site near Thousand Oaks, California showed conservative patterns of water use, with low stomatal conductances and water potentials much higher than values measured in the shrubs (fig. 4). Water potential measurements in Q. agrifolia and Q. lobata indicated Q. lobata undergoing slightly more negative midday water potentials compared to Q. agrifolia (fig. 5). Experimentation with partial root system removal (approximately 70% of lateral roots) showed an immediate negative shift in Q. agrifolia of approximately 1.0 MPa (fig. 6). This pattern of increased water stress persisted over time, both in terms of more negative midday values, and also in a reduced ability to recover overnight from the previous days transpirational water losses. Early morning and pre-dawn measurements in the root-cut tree were always 1.0 - 1.5 MPa more negative than those of a nearby control tree (fig. 6).

MATORRAL FIELD WATER RELATIONS

Comparative measurements in the Chilean matorral (nomenclature follows Muñoz Pizarro, 1966) showed differing species sensitivity to drought severity. Trevoa trinervis Miers, Satureja gilliesii Grah.) Brig., Lithraea

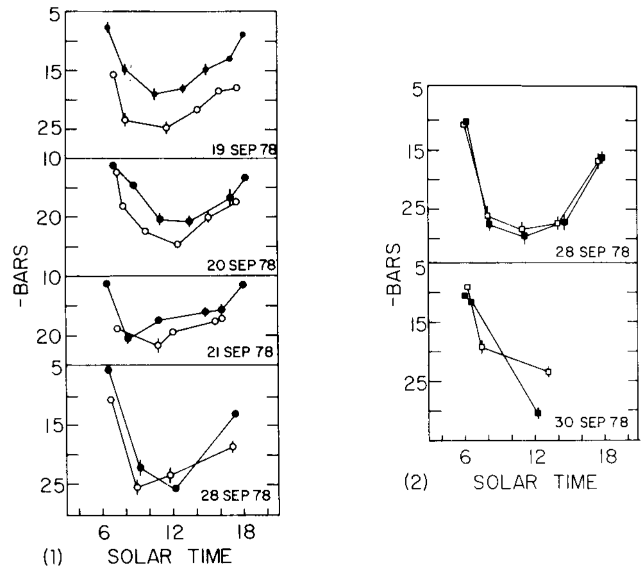


Fig. 5. Daily courses of water potential measured in *Quercus agrifolia* (A) and *Quercus lobata* (B) at the Thousand Oaks site.

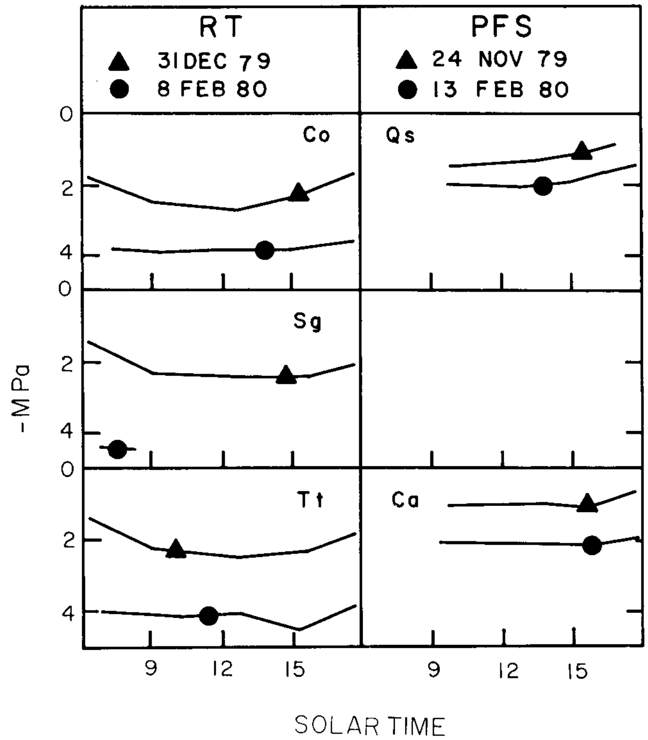


Fig. 7. Daily courses of water potential in the Chilean matorral species *Colliguaya odorifera* (Co), *Satureja gilliesii* (Sg), *Trevoa trinervis* (Tt), *Quillaja saponaria* (Qs), and *Cryptocarya alba* (Ca) on a ridge-top (RT) and a pole-facing slope (PFS).

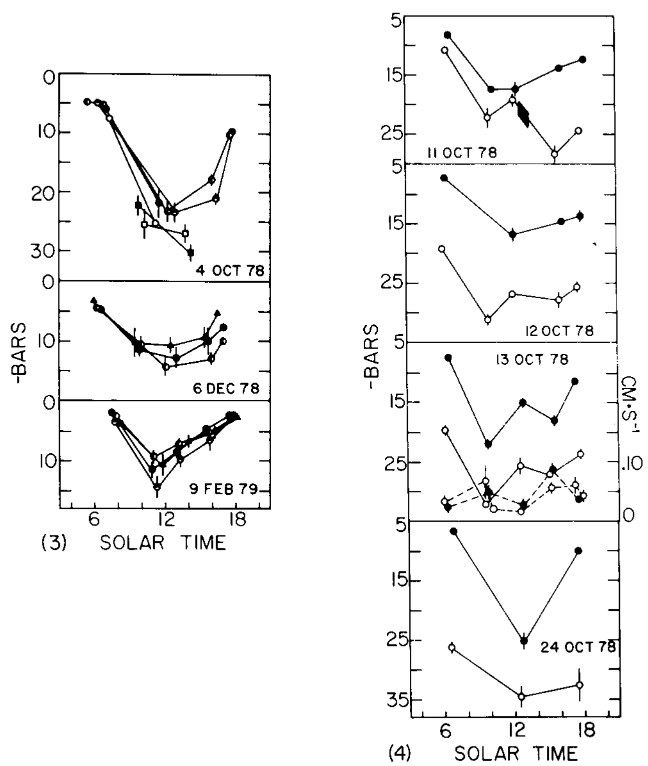


Fig. 6. Daily course of water potential and stomatal conductance measured in *Quercus agrifolia* at the Thousand Oaks site. Shaded area on 11 October 1978 indicates time of root cutting on an experimental tree.

caustica (Mol.) H. et Arn., and *Colliguaya odorifera* Mol., four shrub species located on a ridgetop site at Fundo Santa Laura, near Til-Til in central Chile (site described in Thrower and Bradbury 1977), all showed seasonal decreases in daily courses of both water potential (fig. 7) and stomatal conductance (fig. 8). *Quillaja saponaria* Mol., *Cryptocarya alba* (Mol.) Looser, and *L. caustica* on an adjacent pole-facing slope showed an opposite seasonal pattern in stomatal conductance, with higher values in February, late in the Chilean drought season, compared to measurements in November. Water potentials of pole-facing slope plants did decrease from November to February, but the decreases were less and the values were generally higher than the equator-facing slope values.

CHAPARRAL WATER POTENTIAL COMPONENTS

The capacity of many chaparral plant species to develop and endure very negative tissue water potentials is now well recognized. The question remains, however, as to just how the tissue water potential is partitioned into its turgor, osmotic, and matric components. Increasingly, the importance of characterizing the components of water potential has been recognized (Hsiao and others 1976, Fereres and others 1978) as well as the importance of understanding osmotic and

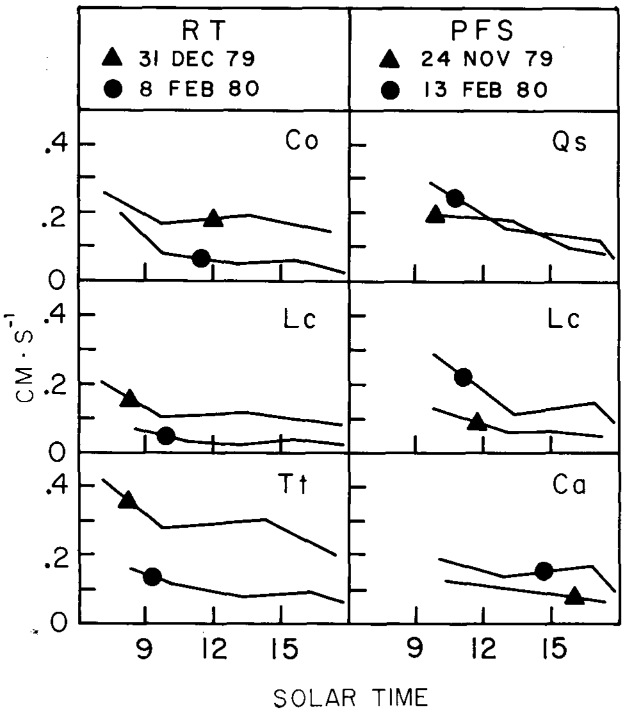


Fig. 8. Daily courses of stomatal conductances on the Chilean matorral species Colliguaya odorifera (Co), Lithraea caustics (Lc), Trevoa trinervis (Tt), Quillaja saponaria (Qs), and Cryptocarya alba (Ca), on a ridge-top (RT) and on a pole-facing slope (PFS).

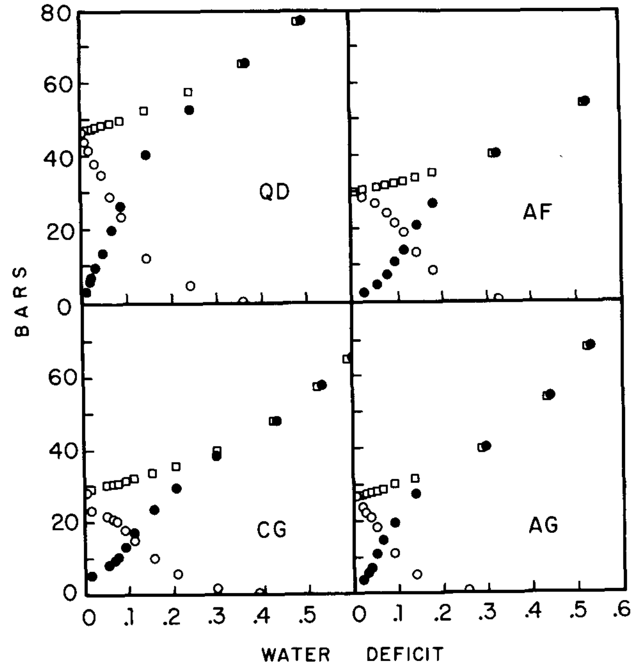


Fig. 9. Water potential component diagram for Quercus dumosa (QD), Adenostoma fasciculatum (AF), Ceanothus greggii (CG), and Arctostaphylos glauca (AG), showing water potential (●)- and its turgor (○) and non-pressure (□) components. Turgor is positive, other components are negative.

structural properties of tissue which determine the component potentials. The pressure-volume technique (Tyree and Hammel 1972, Roberts and Knoerr 1977) is an analytical approach which allows the tissue water potential to be partitioned into components.

The pressure-volume approach has been applied in several southern Californian chaparral shrub species. Water potential component diagrams (fig. 9), showing water potential with its pressure (turgor) and nonpressure (osmotic plus matric) components, indicated that osmotic potentials were unexpectedly high (approximately -3 MPa). The potentials are shown as functions of relative water deficit WD = (Turgid wt - Fresh wt)/(Turgid wt - Dry wt). Ceanothus greggii, A. fasciculatum, and A. glauca showed similar initial osmotic potentials (osmotic potential at full turgor) of approximately -2.7 to -3.0 MPa. Quercus dumosa showed an initial osmotic potential of approximately -4.6 MPa. The turgor responses were summarized by plots of the turgor component, the "volume-averaged" turgor of Tyree and Hammel (1972), versus the total water potential (Fig. 11). The rate of change of turgor per change in water potential was similar for all the species. Species differences were associated with displacements of the magnitude of the turgor component, with Q. dumosa showing the highest turgor values at any given water

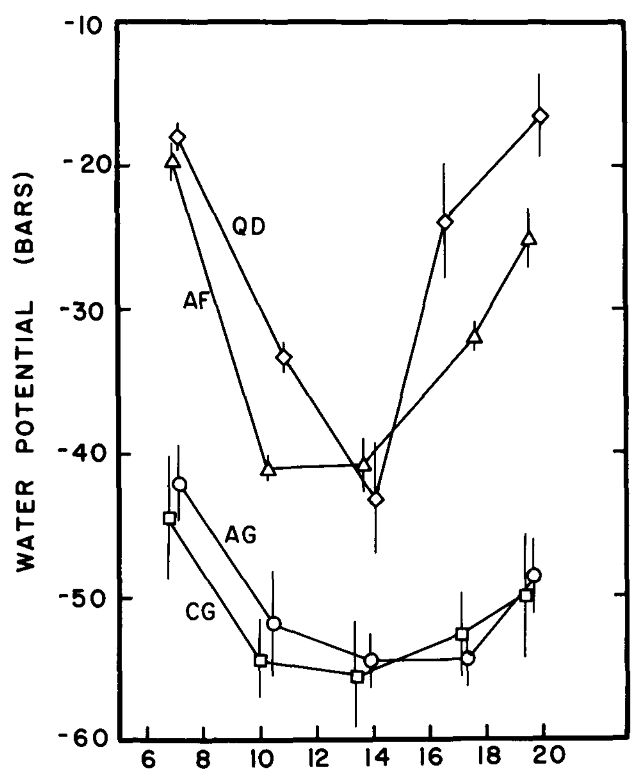


Fig. 10. Daily course of water potential measured during the late summer period when pressure-volume analyses were concurrently performed. Species symbols are as in figure 9.

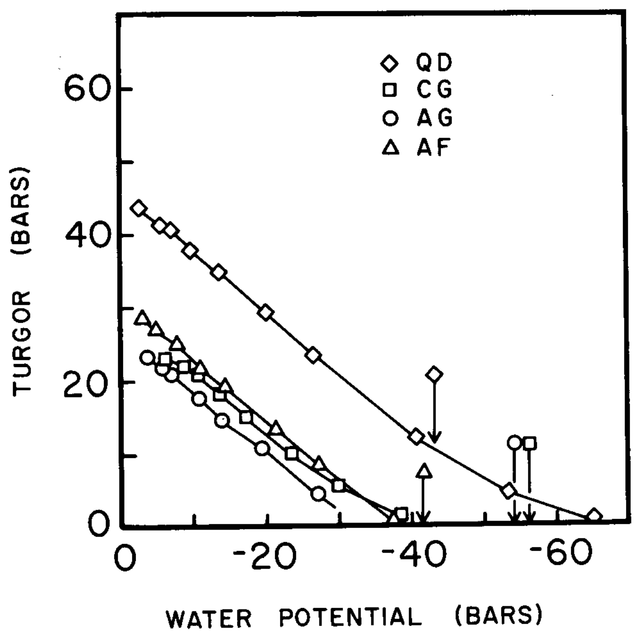


Fig. 11. Turgor pressure plotted as a function of water potential. Arrows show the point of zero turgor as determined by the pressure-volume analysis. Species symbols are as in Figure 9.

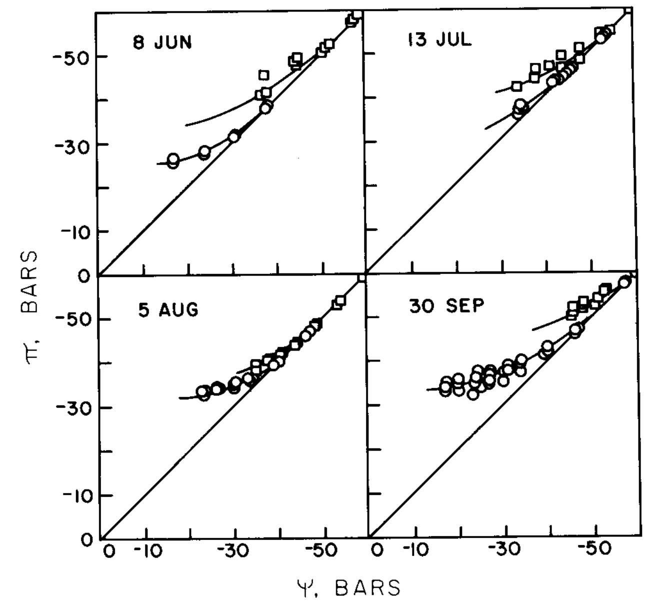


Fig. 12. Osmotic potential plotted as a function of water potential during the season for Quercus dumosa showing daily shifts in the osmotic component from morning (○) to afternoon (□).

potential, resulting largely from the more negative osmotic potentials in that species.

The high osmotic values were unexpected in regard to concurrent field measurements of water potential and stomatal conductance, which showed that the plants were regularly undergoing water potentials substantially more negative than the osmotic plus matric components estimated by pressure-volume analysis (fig. 10). Diurnal patterns of xylem pressure potentials showed clear species segregation, with C. greggii and A. glauca developing similar minimum potentials of approximately -5.5 MPa during midday, about 1.3 MPa more negative than the midday values for Q. dumosa and A. fasciculatum. In addition, Q. dumosa and A. fasciculatum showed higher early morn g potentials and more rapid water potential recovery in the afternoon compared to C. greggii and A. glauca. From the diagrams in figure 9 we would predict loss of bulk leaf turgor at a water potential of about -3.6 MPa in Arctostaphylous glauca. Yet, from daily course field data on the same plants within five days of the pressure-volume analyses we know these plants are commonly reaching -5.5 MPa in midday water potentials (fig. 10), well beyond the turgor-loss point predicted by the pressure-volume analyses. The a priori expectation was that seasonal osmotic adjustment would occur such that increasingly negative water potentials could develop, with concurrent osmotic adjustment allowing maintenance of turgor. Figure 11 shows that pressure-volume results would predict less of turgor at water potentials substantially higher than those actually measured in the field, indicating the plants would go through a large part of the day with zero turgor.

This seemed inconsistent with the notion of plant osmotic adjustment and adaptation to environment. The pressure volume results presented here reflect measurements on tissue rehydrated overnight and, thus, subjected to water availability conditions quite dissimilar from the conditions the tissue experiences in the field. If the tissue alters its osmolality or effective elasticity during the rehydration period, the analysis results will reflect tissue responses which will not be directly applicable to the field situation, at least for these species. Short-term osmotic adjustments of approximately 0.8 MPa over a few hours have been measured in field-grown maize (Acevedo 1975, Hsiao et al. 1976) and in apple (Davies and Lakso 1979). Measurements of short-term osmotic adjustments in two forest tree species (Ilex opaca and Cornus florida) showed only small (<0.1 MPa changes from morning to afternoon (Roberts et al. 1980). Thus, it appears that species may differ with regard to their ability to undergo short-term changes in tissue osmolality. The results of the present study suggest that these chaparral species may undergo daily shifts in tissue osmolality. The shifts might result from accumulation of photosynthate during the day, from a more direct response of the tissue to water deficits by interconversion of solute molecules to more osmotically active species, or by importation and accumulation of solute from the xylem stream. The possibility that the chaparral leaf samples were adjusting osmotically during the overnight rehydration period implies that the resulting analysis would not reflect osmotic and turgor properties of the *in situ* field material.

In order to resolve this question, pressure-volume curves were analyzed from leaf tissue sampled without rehydration at dawn and at midday, corresponding to times of minimum and maximum water stress, respectively. Results of these analyses with *Quercus dumosa* indicated possible 10- to 12-bar osmotic adjustments from dawn to midday (fig. 12). The morning to afternoon change in the osmotic component was always a negative shift, but varied in magnitude at different times during the season. The largest shift appeared to occur in June, where the turgor loss point (the point at which the osmotic component departs from the diagonal in figure 12) shifted from a morning value of approximately -4 MPa to an afternoon value of -5.1 MPa. These results indicate that, at least for some chaparral species, the standard pressure-volume method may not predict field performance correctly.

CONCLUSIONS

A fair amount of data are now available to characterize water potentials and stomatal conductances of some of the more common shrubs in the worlds mediterranean climate regions. Relatively little is known about the water relation of the herbaceous species or the chaparral *Quercus* tree species. Apart from a few initial studies (Hinckley and others 1980, Roberts and others 1981) nearly nothing is known about osmotic adjustments and turgor relations in mediterranean-type vegetation. Osmotic relations may be particularly important for growth and gas exchange in plants which experience recurring drought, and thus represent an important area to focus on in ecophysiological research in the worlds mediterranean regions.

LITERATURE CITED

Acevedo Hinojosa, E. The growth of *Zea mays* L. under field conditions as affected by its water relations. PhD thesis. University of California, Davis; 1975.

Beardsell, M.F.; Jarvis, P.G.; Davidson. B. A null-balance diffusion porometer suitable for use with leaves of many shapes. J. Applied Ecol. 9: 677-690; 1972.

Davies, F.S.; Lakso, A.N. Diurnal and seasonal changes in leaf water potential components and elastic properties in response to water stress in apple trees. Physiol. Plant. 46: 109-114; 1979.

Fereres, E.; Acevedo, E.; Henderson, D.W.; Hsiao, T.C. Seasonal changes in water potential and turgor maintenance in sorghum and maize under water stress. Physiol. Plant. 44: 261-267; 1978.

Hellmers, H.; Horton, J.S.; Juhren, G.; O'Keefe, J Root systems of some chaparral plants in southern California. Ecology 36: 667-678; 1955.

Hinckley, T.M.; Duhme, F.; Hinckley, A R.; Richter, H. Water relations of drought hardy shrubs: Osmotic potential and stomatal reactivity. Plant, Cell, and Environment. 3: 131-140; 1980.

Hsiao, T.C.; Acevedo, E.; Fereres, E.; Henderson, D.W. Stress metabolism. Phil. Trans. Roy. Soc. London. Ser. B. 273: 479-500; 1976.

Jarvis, P.G. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Phil. Trans. Roy. Soc. London. Ser. B. Biological Sciences. 273: 593-610; 1976.

Miller, P.C.; Ng, E. Root-shoot biomass ratios in shrubs in southern California and central Chile. Madrono. 24: 215-223; 1977.

Miller, P.C.; Poole, D.K. Patterns of water use by shrubs in southern California. Forest Science. 25: 84-89; 1979.

Mooney, H.A.; Dunn, E.L. Convergent evolution of mediterranean-climate evergreen sclerophyll shrubs. Evolution. 24: 292-303; 1970.

Mooney, H.A. (ed.). Convergent evolution in Chile and California mediterranean climate ecosystems. Dowden, Hutchinson and Ross, Inc.; 1977.

Muñoz Pizarro, C. Sinopsis de la flora chilena. (2a. edición). Ediciones de la Universidad de Chile, Santiago; 1966.

Munz, P.A.; Keck, D.D. A California Flora. University of California Press, Los Angeles; 1959.

Poole, D.K.; Miller, P.C. Water relations of selected species of chaparral and coastal sage communities. Ecology 56: 1118-1128; 1975.

Roberts, S.W.; Knoerr, K.R. Components of water potential estimated from xylem pressure measurements in five tree species. Oecologia. 28: 191-202; 1977.

Roberts, S.W.; Knoerr, K.R.; Strain, B.R. Comparative field water relations of four co-occurring forest tree species. Can. J. Bot. 57: 1876-1882; 1979.

Roberts, S.W.; Strain, B.R.; Knoerr, K.R. Seasonal patterns of leaf water relations in four co-occurring forest tree species: Parameters from pressure-volume curves. Oecologia. 46: 330-337; 1980.

Roberts, S.W.; Oberbauer, S.; Kendall, R.; Miller, P.C. Properties of internal leaf water relations in chaparral shrubs, measured by pressure-volume analysis. Oecol. Plant. (in press); 1981.

Scholander, P.F.; Hammel, H.T.; Bradstreet, E.D.; Hemmingsen, E.A. Sap pressure in vascular plants. Science. 148: 339-346; 1965.

Thrower, N.J.W.; Bradbury, D.E. (eds.). Chile-California mediterranean scrub atlas. Dowden, Hutchinson and Ross, Inc. Stroudsburg, Pa.; 1977.

Tyree, M.T.; Hammel, H.T. The measurement of the turgor pressure and the water relations of plants by the pressure-bomb technique. J. exp. Bot. 23: 267-282; 1972.

Soil and Nutrient Cycling in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Leonard F. DeBano and Paul H. Dunn[2]

The presentations at this session addressed the detailed aspects of nutrient cycling processes in Mediterranean ecosystems. Although many of these processes are reasonably well understood, some areas need further study before our current knowledge can be applied confidently by the land manager. This summary highlights some of the nutrient cycling processes discussed, points to obvious gaps in our knowledge, and lists the concerns having the most important management implications.

NUTRIENT INPUTS

Nutrients are added to Mediterranean ecosystems in several ways, including precipitation, dry fall, biological fixation, and rock weathering. Some of these processes have been discussed in detail by speakers at this Symposium. The importance of the different input mechanisms varies with the nutrient.

The cations, phosphorus, and sulfur are introduced into the ecosystem principally by precipitation, dry fall, and rock weathering. Nutrient inputs by precipitation and dry fall are well documented and vary widely, depending on the local and regional meteorological conditions, as discussed by Schlesinger (these Proceedings). The quantities of nutrients arriving in dry fall are usually greater than those contained in precipitation. Local air quality, nearby wildfires, and proximity to oceans can all influence the chemical composition of the precipitation.

The weathering of parent rock may be an important source of some nutrients. The rates of weathering of the different parent rock materials vary and affect the inherent fertility and productivity of a site. Little is known about the nutrient additions to southern California soils by rock weathering although some research on granitic soils in Idaho indicates that substantial amounts of some nutrients can be added by weathering (Clayton 1979).

Nitrogen additions to the Mediterranean ecosystems have received much attention recently because nitrogen is most susceptible to loss by leaching and volatilization and is the nutrient most likely to be limiting in Mediterranean ecosystems. Nitrogen can be replaced by both physical and biological mechanisms (table 1). Physically it is replaced by both wet and dry fall from the atmosphere (Schlesinger, these Proceedings). Dry fall is more important and contributes 1.63 kg/ha/yr as compared to 0.42 kg/ha/yr for wet fall. In areas having high levels of air pollution, such as the Los Angeles air basin, up to 6.75 kg/ha/yr may be added as wet fall (Morgan and Liljestrand 1980). The effect of additional nitrogen enrichment in heavy smog areas is not known, but nitrogen could possibly be leached from the soil and contribute to the high nitrate levels observed in the groundwater in the foothill areas of the San Gabriel Mountains in southern California.

Dinitrogen fixation by bacteria and actinomycetes is a major source of nitrogen replacement (table 1). The free-living bacteria do not seem important, however, although only a few measurements have been made. Preliminary studies have shown free-living dinitrogen fixation in chaparral soils can be stimulated by adding a carbon source such as sugar (J. Kummerow, pers. commun.), or by incubating soils for a week under moisture conditions near field capacity (Dunn, unpubl. data). Although dinitrogen-fixing bacteria present in chaparral soils are capable of rapid reproduction and can readily fix nitrogen under certain conditions, their role in natural systems is unknown.

Symbiotic dinitrogen fixation by legume-*Rhizobium* symbiosis is much better understood than the other mechanisms. Although legumes are present in abundance after a fire, they do not fix the amounts of nitrogen expected (Poth, these Proceedings)--probably because the legumes are competing with the nonleguminous plants for available nitrogen in the soil instead of satisfying their own needs by fixing nitrogen from the atmosphere (Dunn and Poth 1979; Nilsen, these Proceedings). The legumes replace less than 15 percent of the nitrogen lost from a stand by fire and only 30 percent of the nitrogen contained in their own biomass.

Nitrogen is probably also replaced by the *Ceanothus-Frankia* symbiosis and possibly the

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981. San Diego, California.

[2]Supervisory Soil Scientist, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona; and Soil Microbiologist, Pacific Southwest Forest and Range Experiment Station, Glendora, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--Amounts of nitrogen gained and lost from chaparral by different mechanisms (kg/ha/25 yr).

	Losses	Gains	
Fire (volatilization)	[1]146-[2]419	Dinitrogen fixation	
Postfire erosion		Legumes	[3]15- [4]75
Sediment	[1]10-[2]181	Shrubs	[5]2.5-[6]1225
Water	[1]0- [2]12	Free living	[7]25
Type conversion	[10]97	Atmospheric	[8]25- [9]200
Denitrification	?		

[1]Data from DeBano and Conrad (1978).

[2]Unpublished data from a prescribed burn done on the Buckhorn east of Santa Maria, Calif.

[3]Data collected on the San Dimas Experimental Forest after the 1976 Village fire on areas occupied by Lupinus spp.

[4]Fixation by Lotus scoparius (Poth, these Proceedings).

[5]Data from Kummerow and others (1978).

[6]Nutrient accumulations reported by Zinke (1969) on the San Dimas lysimeters and elsewhere in southern California.

[7]Unpublished laboratory data (P. H. Dunn).

[8]Data from Schlesinger (these Proceedings).

[9]Data from Los Angeles County air pollution (Morgan and Liljestrand 1980).

[10]Data on nitrate losses from disturbed chaparral watersheds (Davis, these Proceedings).

Cercocarpus betuloides-Frankia symbiosis in shrubs; the exact amounts are not known but are suspected to be high (table 1; Poth, these Proceedings). The Ceanothus-Frankia symbiosis seems to have poor dinitrogen fixation ability in 1-year-old stands and in mature stands older than 20 years (Kummerow and others 1978; Poth, these Proceedings). Studies of seedlings in the San Gabriel Mountains showed few nodules were developed the first 2 years after fire, but a large increase in nodular biomass occurred in the third, fourth, and fifth years. Lack of nodulation during the first year may have been related to nitrogen availability on the site. Postfire soils have high levels of available nitrogen (Christensen and Muller 1975, DeBano and others 1979a, Dunn and others 1979), which may suppress nitrogen fixation. After the large amounts of available nitrogen are immobilized it may be advantageous to the Ceanothus-Frankia symbiosis to fix nitrogen again.

The relation between seed dormancy, in legumes and other nitrogen-fixing plants, and soil heating during a prescribed fire is not fully understood. Fire breaks the dormancy and is the principal mechanism inducing germination and establishment of these plants on a site after a fire. However, prescribed burning over a moist soil may adversely affect seed germination in the soil. Data by Westermeyer (1978) showed that in seeds from some species, seed mortality was higher in moist than in dry soils heated to the same temperatures. However, the differences in heat sensitivity among species were not great enough to explain the differences in seedling crops observed on moist soils under prescribed burns and adjacent dry soils under wildfires. These contradictory seedling responses must be better understood before major prescribed burning programs are implemented. The failure to establish seedlings capable of fixing nitrogen may lead to a long-term decline in site fertility and productivity after repeated burning over moist soils.

NUTRIENT LOSSES

Nutrients can be lost from Mediterranean ecosystems by volatilization (DeBano and Conrad 1978, Ralston and Hatchell 1971), erosion (DeBano and Conrad 1976), leaching (Davis 1980; Vitousek and Melillo 1979; Riggan and Lopez),[3] and harvesting (Boyer and Dell 1980). Not all nutrients are lost at the same rates because different processes of loss are important for different elements. It is important to recognize these differences when assessing the impact of different management alternatives on a site (DeBano, these Proceedings).

Volatilization

Nitrogen is one of the nutrients most sensitive to loss by volatilization. It can be lost by heating during a wildfire or a prescribed burn (DeBano and Conrad 1978), by ammonia volatilization in acid soils (Vitousek and Melillo 1979), and possibly by denitrification under anaerobic conditions (Swank and Caskey 1980). The amount of nitrogen volatilized during a fire can be estimated reasonably well if the litter and soil temperatures are known (DeBano and others 1979b). The estimated nitrogen losses from chaparral during prescribed fires have varied from 146 to 419 kg/ha (table 1). Currently no simple method of measuring litter and soil temperatures continuously is readily available to the land manager for routine measurements for use in assessing nitrogen losses. Although maximum temperatures can be determined more easily and inexpensively than continuous measurements, they are not completely satisfactory for characterizing biological changes produced by soil heating. Research studies are needed to quantify and model soil and litter temperatures and heating during different intensities of burning (DeBano, these Proceedings). Losses of nitrogen by ammonia volatilization are not well known in Mediterranean ecosystems although some losses have been detected during chaparral fires (Dunn, pers. commun.). Ammonia losses from acid soils under coniferous forests in a Mediterranean climate have not been studied, although nitrogen could be lost in this way. It is also possible to lose nitrogen by denitrification, particularly from poorly drained, nutrient-rich soils and sediments in riparian zones. Denitrification losses have been reported from second-order mountain streams draining logged deciduous forest watersheds in the eastern United States (Swank and Caskey 1980).

During fires, sulfur volatilizes in much the same way as nitrogen, but probably at higher temperatures. Tiedemann and Anderson (1980) reported up to 6g percent of the total sulfur was lost at 11750 C; nitrogen is completely volatilized at 500° C (White and others 1973). Data on sulfur losses at different temperatures need refining and the significance of these losses for short- and long-term productivity should be established.

Unlike nitrogen and sulfur, most nutrients are not lost into the atmosphere as gases. Instead, significant amounts of calcium, magnesium, potassium, phosphorus, and sodium are transported as particulate material in smoke (Clayton 1976). This is a local or regional (in large wildfires) redistribution rather than an irreversible loss, such as the loss of nitrogen to the atmosphere.

Erosion

The quantity of nutrients lost from a site also depends on the amount and type of erosion. Accelerated erosion commonly occurs after wildfires (Rowe 1941, Sinclair 1954) when much of the eroded material is produced by surface erosion and rilling (Wells 1981). Poor infiltration and surface erosion can be caused by a water repellent soil condition formed during a fire (DeBano 1981). More nutrients are lost from the site by this surface erosion than might be expected, because large quantities of highly soluble nutrients are deposited on the soil surface during a fire. The largest nutrient losses following fire seem to be associated with the mineral sediment and organic debris rather than with water (DeBano and Conrad 1976, Campbell and others 1977). Water serves primarily as a transporting medium. The amounts of nitrogen lost in sediments and water presented in table 1 illustrate the difference in magnitude of these different erosional losses.

In assessing erosional losses of nutrients, a careful distinction must be made between on-site movement and the loss from the entire watershed. Losses from on-site movement, as measured by troughs or other small scale collection devices, may differ considerably from those measured in debris basins constructed at the mouths of larger watersheds. These relationships need to be better defined.

Leaching Losses

High concentrations of some nutrients, notably nitrates, have been reported to be lost from

---

[3] Riggan, Philip J., Lopez, Ernest. Nitrogen cycling in the chaparral ecosystem. In Proceedings of the symposium on the ecology and management of chaparral ecosystems; Western Society of Naturalists annual meeting, December 27-29, 1979. Pomona, CA. Manuscript in preparation.

some disturbed watersheds (Davis 1980; Vitousek and Melillo 1979; Riggan and Lopez).[3] The losses are most noticeable after timber harvesting and brush-to-grass conversions. Although the total nitrogen lost from a watershed as nitrates following disturbance probably does not significantly affect site productivity and fertility, it may alter downstream water quality.

Several mechanisms may be responsible for nitrate release. The most popular explanations are (1) higher nitrification rates following disturbance, (2) greater rates of mineralization and decomposition of organic litter material, and (3) the inability of new shallow-rooted vegetation occupying the site to retain the nitrate nitrogen previously cycled by deep-rooted plants (Vitousek and Melillo 1979). It is important that the dominant mechanisms contributing to nitrate production and loss from these disturbed watersheds be better understood so possible remedial measures can be developed.

Harvesting

The amount and type of biomass harvested and the postharvest residue treatment all influence nutrient removal and loss (Boyer and Dell 1980). Also, the distribution of nutrients in the leaves, stems, small twigs, boles, and litter affect the amounts removed by a given treatment. For example, removing only the boles of trees during logging would have a much different effect on nitrogen than removing both the leaves and small stems. The effect on short- and long-term site productivity of removing different amounts of nutrients is not known. Data on nutrient distributions in chaparral (Zinke 1967; Zinke, these Proceedings) and in forests (Zinke and Stangenberger 1980) may provide a basis for establishing threshold values for different plant nutrients. Also, this total nutrient distribution must eventually be expressed in terms of availability to be useful for assessing site productivity.

ACCUMULATION AND MINERALIZATION OF ORGANIC MATTER

Litter Production

Litter production is directly controlled by primary productivity, as discussed by Alexander (these Proceedings). The quantity of leaves on a plant that becomes litter each year depends partly on the amount of rainfall a site receives 2 years earlier, during bud formation (Riggan, pers. commun.). The length of time leaves remain on chaparral shrubs is shortened by drought and lengthened by more favorable climatic conditions. Some of the nutrients are translocated back into the plant stems and roots before the leaves fall; the amount varies among species. About 9 percent of the total aboveground biomass seems to be deposited in the litter each year (Gray, these Proceedings).

Decomposition

After the leaves and small twigs die they become part of the standing dead and litter biomass, and decomposition depends on several factors. First, placement of the material is important. The material remaining in the canopy (standing dead material) decomposes very slowly compared with the buried material. Material deposited on the mineral soil surface has an intermediate decomposition rate (Yielding 1978). A second factor in decomposition is moisture, particularly in young, open canopy stands where the aboveground material and litter held in the canopy dry out quickly. Temperature is a third factor. Rate of decomposition of litter on the soil surface depends on whether the canopy is open or closed, because this condition controls both temperature and moisture (Winn 1977). Moisture fluctuations are more influential than temperate fluctuations (Marion, these Proceedings). The role of stand age (Winn 1977), possible allelopathic effects (Rice and Pancholy 1973), and nutrient content of the litter (Rundel and Parsons 1980) in decomposition are still controversial points.

It is unclear whether a steady state is reached between litter deposition and decomposition. Kittredge's data (1955) support a steady-state condition, whereas Winn's results (1977) were not definitive. Schlesinger and Hasey (1981) concluded that the forest floor reached a steady state in 11 to 13 years. Decomposition rates also seem to vary among plant species. Schlesinger and Hasey (1981) found the overall decomposition rate fast, with evergreen material decomposing slower than deciduous leaves; Yielding (1978) found both rapid and slow decomposition rates for different species.

Fire as a Mineralizing Agent

Most Mediterranean ecosystems are burned regularly by either wildfires or prescribed burns, which act as active mineralizing agents (St. John and Rundel 1976). Fire is particularly influential in those ecosystems where a large portion of the nutrient pool is contained in the biomass, and where the decomposition rates of the unburned plant material between fires regulate the productivity of the system (Raison 1980). The accumulated undecomposed litter and plant material is suddenly combusted and the plant nutrients contained in it are released. This "pulse" nutrient addition may play an important role in the rapid reestablishment of vegetation following fire (Marion, these Proceedings).

Fire has variable effects on nutrient availability--it may mobilize the nutrients, induce a deficiency, or have no effect (Wells and others 1979). Although some of the nutrients contained in the plants are volatilized, or lost as airborne particulates, most of the combusted material is deposited on the soil surface. Some of the nitrogen remaining after the fire is in a highly available form as ammonia- and nitrate-nitrogen (DeBano and others 1979a, Christensen and Muller 1975). The nitrogen remaining in the uncombusted organic matter after burning is readily mineralized by microorganisms so that the level of available inorganic nitrogen is kept high (Dunn and others 1979).

Conflicting results on phosphorus availability have been reported after a fire (Wells and others 1979). In most soils the availability of phosphorus may be increased by burning (Vlamis and Gowans 1961, Vlamis and others 1955). However, some soils presumably contain significant amounts of soluble iron and aluminum, which may tie up the phosphorus and cause a phosphorus deficiency after repeated burning (Lunt 1941, Vlamis and others 1955). The basic cations (Ca, Mg, K, Na) contained in the plant material are released by burning and generally reduce soil acidity. The more frequent the burning the more pronounced the increase in pH (Wells and others 1979). The increased plant growth or "ash bed" effect observed after fire seems also to include a heating of the soil as well as greater nutrient availability (Bruce 1950, Renbuss and others 1973). The presence of highly available nutrients in the "ash bed" usually makes fertilization of freshly burned watersheds ineffective (DeBano and Conrad 1974, Vlamis and Gowans 1961).

Nutrient Availability and Uptake

Nutrient availability and uptake from burned and biologically decomposed plant material is only partly understood. Nitrogen compounds have received more study than the other plant nutrients. Decomposition plays the most important role in nitrogen release and availability--particularly during the interval between fires (Marion, these Proceedings). Although fire releases large amounts of available nitrogen, and nitrification rates are stimulated (Arianoutsou-Faraggitaki and Margaris, these Proceedings; Christensen and Muller 1975; Dunn and others 1979), more nitrogen is probably made available by decomposition during the interval between fires (Marion, these Proceedings). Decomposition and pyrolysis during fires are equally important processes for the release of potassium, calcium, and magnesium. Little is known about the factors affecting mineralization and availability of phosphorus and sulfur.

Both nitrogen mineralization and nitrification are important biological processes affecting nitrogen availability. Nitrogen mineralization is controlled largely by substrate quantity and quality, temperature, and moisture. Carbon is frequently the most limiting factor for microbial activity and the presence of highly resistant organic compounds (phenolics and lignins) may restrict the energy source available to microbes responsible for nitrogen mineralization (Marion, these Proceedings). The ammonia released by mineralization may be immobilized by decomposers, taken up by vegetation, fixed by clays, volatilized, adsorbed on cation exchange sites in the soil, or undergo nitrification (Vitousek and Melillo 1979). Nitrification can be carried out by both chemotrophic and heterotrophic microorganisms (Dunn and others 1979) which may be inhibited by parent rock material (Nakos 1981) or tannins (Rice and Pancholy 1972). The nitrates produced are highly soluble, and if not immediately immobilized by microbes (El-abyad and Webster 1968) or taken up by plants (Vitousek and Melillo 1979), may be lost to streamflow by leaching (Davis, these Proceedings).

The role of mycorrhizae in nutrient uptake by plants in Mediterranean ecosystems has not been fully clarified. Preliminary studies in chaparral show that mycorrhizae are present in all shrubs (Dunn, pers. commun.). *Quercus dumosa* has been found to have many hypogenous mycorrhizal fruiting bodies (Dunn 1980). It is possible that mycorrhizae may reduce the need for microbes in recycling nutrients before the nutrients are taken up by plants. Immediately after fire the available nutrients are probably immobilized by living microbes. As nutrient stress increases, between fires, mycorrhizae probably play a more important role in plant nutrition and site productivity. For example, in South Africa the growth rate of pine seedlings was 50 times greater on soils inoculated with mycorrhizae as compared to native untreated fynbos soils (Miller, these Proceedings). Mycorrhizal responses may also involve nutrient-water stress relationships which have evolved as features of the Mediterranean-type ecosystems (Miller, these Proceedings). Basic information on moisture stress relationships for different plant species is limited, although some information is now available for several chaparral species (Roberts, these Proceedings).

MANAGEMENT IMPLICATIONS AND KNOWLEDGE GAPS

Several of the nutrient cycling processes and mechanisms have strong management implications in addition to being intellectually enticing to the researcher. The papers presented pointed out the need to:

1. Define the trade-offs among nitrogen losses, soil wettability, and biological damage to roots, seeds, and soil microbes in burning over wet and dry soil.
2. Quantitatively assess the impacts of burning or permanent type conversion on steep slopes having different types of soils.
3. Establish spatiotemporal treatment patterns that reduce the amounts of nitrate nitrogen released from disturbed or converted watersheds.
4. Establish criteria for postfire fertili-

zation.

5. Relate on-site nutrient movement to losses from the entire watershed so realistic assessments of nutrient losses can be developed.

Many of the concerns expressed by the managers can be addressed or satisfied with existing information, but this must be prepared in a format that will be useful to the land managers when making on-the-ground decisions and assessments. Probably this task can be accomplished most effectively in handbooks and guidelines developed jointly by the managers and researchers. Additional research is needed in some areas before parts of these guidelines can be quantitatively established. Until such information is available, judgment and experience will have to fill the gaps.

Literature Cited

Boyer, Donald E.; Dell, John D. Fire effects on Pacific Northwest forest soils. Portland, OR: Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 1980. 59 p.

Bruce, David. It isn't the ashes. Res. Note SO-66. New Orleans, LA: Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 1950. 1 p.

Campbell, R. E.; Baker, M. B., Jr.; Ffolliott, P. F.; Larson, R. R.; Avery, C. C. Wildfire effects on a ponderosa pine ecosystem: An Arizona case study. Res. Paper RM-191. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1977. 12 p.

Christensen, N. L.; Muller, C. Effects of fire factors controlling plant growth in Adenostema chaparral. Ecol. Monog. 45:29-55; 1975.

Clayton, James L. Nutrient gains to adjacent ecosystems during a forest fire: an evaluation. For. Sci. 22:162-166; 1976.

Clayton, James L. Nutrient supply to soil by rock weathering. Proceedings of the symposium on impact of intensive harvesting on forest nutrient cycling; 1979 August 13-16; Syracuse, NY. Syracuse, NY: State Univ. of New York; 1979; 75-79.

Davis, E. A. Effects of converting chaparral to grass on the chemical composition of stream water. In: Western Society Weed Sci. Res. Prog. Rep. Salt Lake City, UT: 1980. p. 75-77.

DeBano, Leonard F. Water repellent soils: A state-of-the-art. Gen. Tech. Rep. PSW-46. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 21 p.

DeBano, Leonard F.; Conrad, C. Eugene. Effect of a wetting agent and nitrogen fertilization on establishment of ryegrass and mustard on a burned watershed. J. Range Manage. 27(1):57-60; 1974.

DeBano, L. F.; Conrad, C. E. Nutrients lost in debris and runoff water from a burned chaparral watershed. Proceedings of the Federal Inter-Agency Sedimentation Conference 3:13-27; 1976.

DeBano, L. F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

DeBano, Leonard F.; Eberlein, Gary E.; Dunn, Paul H. Effects of burning on chaparral soils: I. Soil nitrogen. Soil Sci. Soc. Amer. J. 43(3):504-509; 1979a.

DeBano, Leonard F.; Rice, Raymond M.; Conrad, C. Eugene. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion, and runoff. Res. Paper PSW-145. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1979b. 21 p.

Dunn, Paul H. Nutrient-microbial considerations in oak management. Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks. 1979 June 26-28; Claremont, CA: Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 149-160.

Dunn, Paul H.; DeBano, Leonard F.; Eberlein, Gary E. Effect of burning on chaparral soils: II. Soil microbes and nitrogen mineralization. Soil Sci. Amer. J. 43(3):509-514; 1979.

Dunn, P. H.; Poth, M. Nitrogen replacement after fire in chaparral. Gordon, J. C.; Wheeler, C. T.; Perry, D. H., ed. Proceedings of a workshop on symbiotic nitrogen fixation in the management of temperate forest; 1979 April 2-5; Corvallis, OR. Corvallis, OR: Forest Research Laboratory, Oregon State Univ.; 1979; 287-293.

El-abyad, M. S. H.; Webster, J. Studies on pyrophilous discomycetes. I. Comparative physiological studies. Transactions British Mycol. Soc. 51:253-267; 1968.

Kittredge, J. Litter and forest floor of the chaparral in parts of the San Dimas Experimental Forest, California. Hilgardia 23:563-596; 1955.

Kummerow, J.; Alexander, J. V.; Neel, J. W.; Fishbeck, K. Symbiotic nitrogen fixation in Ceanothus roots. Amer. J. Bot. 65:63-69; 1978.

Lunt, H. A. A pot culture experiment with undisturbed forest soil. Soil Sci. Soc. Amer. Proc. 6:403; 1941.

Morgan, J. J.; Liljestrand, H. M. Measurement and interpretation of acid rainfall in the Los Angeles basin. Final Report to the California Air Resources Board. 1980. 54 p.

Nakos, G. Humus nitrification patterns in broad-leaved evergreen mediterranean zone. Soil Biology and Biochem. 12:515-516; 1980.

Raison, R. J. A review of the role of fire in nutrient cycling in Australian native forests, and other methodology for studying the fire-nutrient interaction. Aust. Ecology 5:15-21; 1980.

Ralston, Charles W.; Hatchell, Glyndon, E.

Effects of prescribed burning on physical properties of soil. Proceedings of the symposium on prescribed burning. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U. S. Department of Agriculture; 1971; 68-85.

Renbuss, M.; Chilvers, G. A.; Pryer, L. D. Microbiology of an ashbed. Proc. Linn. Soc. New South Wales. 97:302-310; 1973.

Rice, E. L.; Pancholy, S. K. Inhibition of nitrification by climax vegetation. Amer. J. Bot. 59:1033-1040; 1972.

Rice, E. L.; Pancholy, S. K. Inhibition of nitrification by climax ecosystems. II. Additional evidence and possible role of tannins. Amer. J. Bot. 60:691-702; 1973.

Rowe, P. B. Some factors of the hydrology of the Sierra Nevada foothills. Natl. Res. Counc. Amer. Geophys. Union Trans. 1941. 90-101; 1941.

Rundel, P. W.; Parsons, D. J. Nutrient changes in two chaparral shrubs along a fire-induced age gradient. Amer. J. Bot. 67:51-58; 1980.

St. John, Theodore V.; Rundel, Philip W. The role of fire as a mineralizing agent in a Sierran coniferous forest. Oecologia 25:35-45; 1976.

Schlesinger, W. H.; Hasey, M. M. Decomposition of chaparral shrub foliage: losses of organic and inorganic constituents from deciduous and evergreen leaves. Ecology 12:(In press).

Sinclair, J. D. Erosion in the San Gabriel mountains of California. Trans. Amer. Geophys. Union 35(2):264-268; 1954.

Swank, W. T.; Caskey, W. H. Denitrification in sediments of a second order mountain stream. Agron. Abstracts. Proceedings of the 1980 Annual Meeting of the American Society of Agronomy; 1980 Nov. 30-Dec. 5; Detroit, MI. 1980; p. 162.

Tiedemann, A. R.; Anderson, T. D. Combustion losses of sulfur from native plant materials and forest litter. Proceedings of the sixth conference on fire and forest meteorology; 1980 April 22-24; Seattle, WA. 1980; 220-227.

Vitousek, Peter M.; Mellilo, Jerry M. Nitrate losses from disturbed forests: patterns and mechanisms. Forest Sci. 25(4):605-619; 1979.

Vlamis, J.; Gowans, K. D. Availability of nitrogen, phosphorus, and sulfur after brush burning. J. Range Manage. 14(1):38-40; 1961.

Vlamis, J. H.; Biswell, H. H.; Schultz, A. M. Effects of prescribed burning on soil fertility in second growth ponderosa pine. J. For. 53:905-909; 1955.

Wells, Carol G.; Campbell, Ralph E.; DeBano, Leonard F.; and others. Effects of fire on soil: A state-of-knowledge review. Gen. Tech. Rep. WO-7, Washington, D.C.: Forest Service, U.S. Department of Agriculture; 1979. 34 p.

Wells, Wade G., II. Some effects of brushfires on erosion processes in coastal southern California. In: Erosion and Sediment Transport in Pacific Rim Steeplands. International Association of Hydrologic Sciences. Publ. 132. Christ Church, N. Z.: p. 305-342; 1981.

Westermeyer, L. J. Effects of dry and moist heat shocks on seed viability and germination of Lotus strigosus and Lupinus escubitus var. Hallii. Fullerton, CA: Calif. State Univ., 1978; 42 p. M. S. Thesis.

White, E. M.; Thompson, W. W.; Gartner, F. R. Heat effects on nutrient release from soils under ponderosa pine. J. Range Manage. 26(1):22-24; 1973.

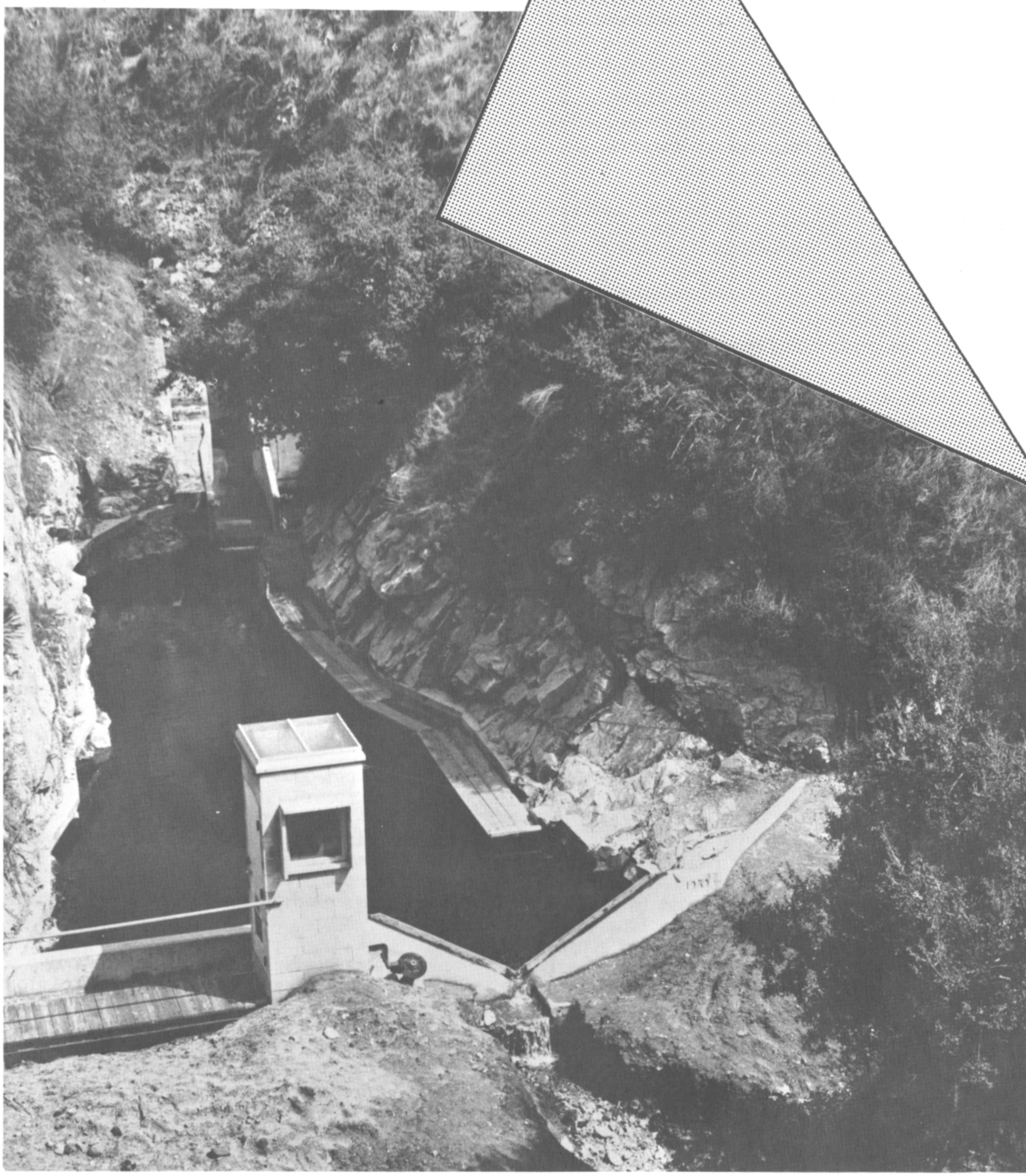
Winn, C. D. Litter decomposition in the California chaparral. Fullerton, CA: Calif. State Univ.; 1977. 59 p. M. S. Thesis.

Yielding, L. Decomposition of five fuel components of seven southern California chaparral plants. Berkeley, CA: Univ. of Calif.; 1978. 150 p. M. A. Thesis.

Zinke, Paul J.; Stangenberger, Alan G. Ponderosa pine and Douglas fir foliage arrayed in probability distributions. Proceedings of the forest fertilization conference; 1979 Sept. 25-27; Union, WA. In press.

Zinke, Paul J. Nitrogen storage of several California forest soil-vegetation systems. Proceedings of a conference on the biology and ecology of nitrogen; 1967 Nov. 28-Dec. 1; Davis, CA. Washington, D.C.: National Academy of Sciences; 1969; 40-53.

Hydrology



Hydrology

Slope Stability Effects of Fuel Management Strategies—Inferences From Monte Carlo Simulations[1]

R. M. Rice, R. R. Ziemer, and S. C. Hankin[2]

Abstract: A simple Monte Carlo simulation evaluated the effect of several fire management strategies on soil slip erosion and wildfires. The current condition was compared to (1) a very intensive fuelbreak system without prescribed fires, and (2) prescribed fire at four time intervals with (a) current fuelbreaks and (b) intensive fuelbreaks. The intensive fuelbreak system caused a slight increase in soil slip erosion and a reduction of about 12 percent in average annual wildfire area associated with each of the prescribed fire intervals. All of the prescribed fire strategies greatly reduced wildfires, but resulted in substantial increases in soil slip erosion, with the greatest increase, 282 percent, for the 15-year prescribed fire interval.

Chaparral fires have been an important land management problem in southern California for at least the past 50 years. The fires themselves are a threat to life and property, but post-fire erosion is often a greater threat. Fire suppression efforts have been the principal response to these threats. In recent years fire suppression has been supplemented by two vegetation management strategies: fuelbreaks to aid directly in suppression, and prescribed fire to mimic the presumed natural mosaic of age classes and fuel loads, thereby inhibiting fire spread. Neither tactic is expected to eliminate the threat of wildfire; rather, both are aimed at reducing the size of wildfires and making the resultant fire and erosion damage smaller, more predictable, and more manageable.

The probability that fuelbreaks, either alone or with prescribed burning, will accomplish their fire management objectives is relatively high. Whether they will also reduce erosion is uncertain. Both tactics nay increase the risk of soil slip erosion on steep slopes that are partially dependent on (roots for their stability. Soil slips are shallow failures of colluvial soil and ravine fill. Soil slip erosion increases on the areas converted to fuelbreaks because most of the deep-rooted 'vegetation has been eliminated. Prescribed fire, by reducing the mean age of vegetation, and hence root biomass, may also increase soil slip erosion. The severity of soil slip erosion has been linked to storm size and to the state of the chaparral with respect to its burn and regrowth cycle at the time of the storm (Rice 1974).

The outcome of any fire management strategy therefore, depends on the prescribed burning interval, the area maintained in fuelbreaks, the chance occurrence of wildfire, and the timing of landslide-producing storms. Since the chance of fire and its eventual size, as well as the timing and severity of storms, interact stochastically, their joint interaction with fire management strategies is unknown with respect to both erosion and burned area.

In the face of sparse data concerning most of the relevant parameters in the fire-chaparral-storm interactions, this paper reports insights into the soil slip erosion consequences of various fire management strategies, as gained through a Monte Carlo simulation. Our simulation included functions defining the growth and decay of chaparral roots following fires. These phenomena are key links between age and amount of vegetation, storm size, fire occurrence, and soil slip erosion rate. Our model was as eclectic as necessary in order to give a quantitative basis to what is principally a qualitative appraisal of the problem. The path we charted can be widened and straightened by others as better data become available.

MODEL PROCESSES

Vegetation

Plant roots can increase the stability of slopes by anchoring a weak soil mass to fractures in bedrock, by crossing zones of weakness to more stable soil, and by strengthening soil with long fibrous hinders. When vegetation is killed, as by fire or herbicides, the root system decays and root reinforcement of the soil decreases until new roots reoccupy the soil.

In chaparral fires, the aboveground biomass is burned, but the root system remains intact. Some chaparral species such as chamise (*Adenostoma fasciculatum* H. & A.) have a large root curl which sprouts after. fire. There is adequate carbohydrate reserve in this burl to keep the root system alive for several years. In our model we have assumed the root system will live for 2 years following

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Hydrologists and Computer Specialist, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Arcata, California.

fire before it dies back to be in balance with photosynthate production. The net soil reinforcement by roots is the sum of reinforcement by decaying dead roots and by newly expanding roots of the sprouting brush.

Landslide frequency has been shown to increase after vegetation is removed from metastable slopes (Croft and Adams 1950; Kawaguchi and Namba 1956; Bishop and Stevens 1964; Rice and Foggin 1971; Burgy and Papazifiriou[3]). _In situ_ measurements have shown that soil strength increases as root biomass increases (Endo and Tsuruta 1969; O'Loughlin 1972; Ziemer 1981).

Little is known about the rooting habits of chaparral plants. Hellmers and others (1955) hydraulically excavated the root system of 57 plants at six sites in the San Gabriel Mountains of southern California and reported maximum root length, depth, and radial spread. Information on root biomass in chaparral-covered slopes is scant. Miller and Ng (1977) reported that root biomass of 21-year-old chaparral excavated near Echo Valley in San Diego County ranged from 100 to 1400 g/m^3. Near the same location, Kummerow and others (1977) excavated a 70 m^2 plot and found an average root biomass of 626 g/m^3. In the more humid Mediterranean climate of northwestern California, root biomass of 12- to 20-year-old snowbrush (_Ceanothus_ _velutinus_ Dougl.) fields averaged 1050 g/m^3 (Ziemer 1981).

Information on changes in root biomass following fire is lacking. There is better understanding of changes in aboveground biomass following fire (Rothermel and Philpot 1973). Miller and Ng (1977) reported an average root:shoot biomass ratio of 0.58 for chamise; Kummerow and others (1977) reported 0.57. When the root:shoot ratio is applied to the aboveground live brush biomass model of Rothermel and Philpot (1973), an approximation of root biomass changes following fire can be made (fig. 1). This approximation compares favorably with observed root biomass densities in excavated 20-year-old chaparral stands. We have assumed the maximum density of roots in old-growth chaparral is 1270 g/m^2.

In our model, the live and dead root biomass at the time of a fire is based on the age of the chaparral (the number of years since the last fire). The total dead root biomass after a fire is made up of roots that were dead before the fire and live roots that were killed by the fire. These dead roots decay exponentially with time (eq. 1). (Note: all numbered equations referred to are given in the Appendix.) Growth of the remaining live root fraction follows a logistic curve with time

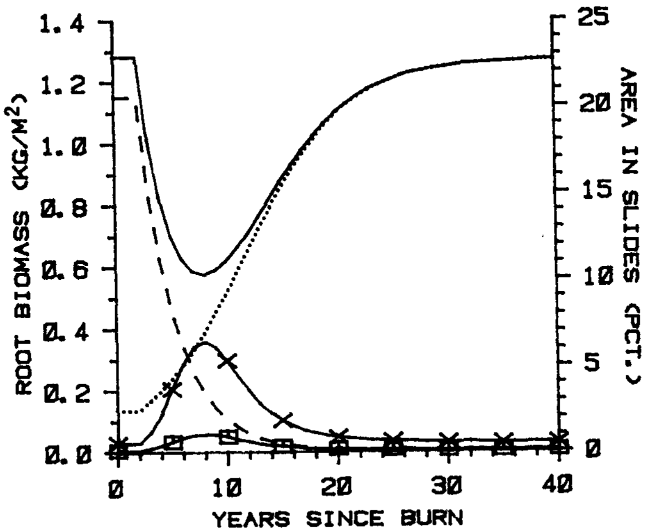


Figure 1--Change in live (······), dead (---), and total (——) root biomass following fire and percent of area in soil slips following fire for a 32-year storm (X——X) and a 9-year storm (□——□).

(eq. 1). The sum of the live and dead root biomass is the total root biomass (BMASS) in a cell.

Storm Severity

Precipitation data used in our model were obtained from Tanbark Flat on the San Dimas Experimental Forest (Reimann and Hamilton 1959). The record seems to be appropriate since the raingage is located at about the median elevation for chamise and at a middle latitude for the chaparral of southern California. We extended the published data (Reimann and Hamilton 1959) through hydrologic year 1980[4]. From the 47 years of record, we used 176 storms yielding more than 50 mm of precipitation.

It is difficult to define exactly what constitutes a soil slip producing storm. Undoubtedly a large number of site conditions and storm sequences could result in soil slips. We have based our model on an extrapolation of the work of Caine (1980), who analyzed 73 descriptions of storms that caused landslides on slopes unmodified by construction, agriculture, or stream erosion at their bases. His data spanned a great variety of climates and vegetative types and included eight observations from southern California chaparral. He found that the landslide threshold was defined by the function

$$I = 14.82\ D^{-0.39}$$

where I is the mean storm rainfall intensity (mm/hr) and D is the storm duration (hr). It seemed reasonable to us that if, in fact, Caine's

[3]Burgy, Robert H.; Z. G. Papazifiriou. Effects of vegetation management on slope stability, Hopland Experimental Watershed II. Unpublished paper presented at Water Resources Advisory Council Meeting, January 25, 1971, Los Angeles, California, 10 p.

[4]Precipitation data provided by Eldora M. Negley, engineering technician, San Dimas Experimental Forest, Forest Service, U.S. Department of Agriculture, April 20, 1981.

function is the threshold of slope failure, a good index of storm severity might be the distance of a storm from the line defined by Caine's landslide threshold function in the intensity/duration space. We found that with this new function (eq. 2) our 176 storms were lognormally distributed, with the threshold storm approximately one standard deviation above the mean.

Landslide Erosion

The amount of soil slip erosion following fire is related to storm severity and to the degree of vegetation recovery. Following a 9-year return period storm, about 1 percent of an area burned 6 years earlier was in soil slips (Rice and Foggin 1971; Rice 1974), whereas there were no soil slips in a comparable area not burned for 50 years. Three years later the same area was subjected to a much larger storm with an estimated return period of 32 years. About 6 percent of the previously burned area slipped in this storm while 0.7 percent of the 50-year-old chaparral land slipped. There was very little difference between soil slip rate in the old chaparral and that in an area which burned the previous year. In nearby areas which had been converted to grass following the fire, 7 percent of the land slipped in the 9-year storm and 18 percent in the 32-year storm. The amount of slippage observed following the 32-year storm probably underestimates that which would have occurred had there been no 9-year storm 3 years earlier. Some of the most vulnerable areas failed during the previous storm and were not susceptible to re-sliding only 3 years later. However, soil slip scarps often predispose adjacent areas to additional slippage. For purposes of our model we have assumed soil slip susceptibility of previously failed sites (RESID) to follow an exponential recovery rate of the form, e^{-kt}, where $k = 0.23$ and t is the number of years since the area slipped. The amount of soil slips produced by our model (fig. 1) is a function of storm severity (SEVR), root biomass (BMASS), and the residual effect of previous soil slips (RESID) in the cell (eq. 3).

Fire Occurrence

This portion of our model produces a random sequence of fires which conforms to the current frequency and size distribution of chaparral fires in southern California. The number of fire occurrences in each annual cycle of the model was determined by randomly sampling a distribution having the same mean and standard deviation as annual fire occurrences observed on the Angeles, Cleveland, and San Bernardino National Forests during the fire seasons of 1976 through 1980[5].

The point of origin of each fire was located at random. Our model included no variation due to topography or culture, and fire starts on fuel-breaks were not permitted. Consequently, every chaparral location in the model had an equal probability of being the origin of a fire, in contrast to the real-world situation where areas adjacent to roads and development and especially uphill from them, have a higher probability of burning. Given that there was a fire start (eq. 4), the next step in the simulation was to determine the ultimate size of the fire. The probability of burning each cell in our model was based on the size of the approaching fire (eq. 5, 6) and the elapsed time since the previous fire (eq. 7, fig. 2). The elapsed-time function is based on the effect that the age of an average chamise stand has on the rate of spread of a fire driven by a 32 km/hr wind (Rothermel and Philpot 1973). During the first decade following fire, spread of a new fire is assumed to be dependent upon herbaceous vegetation (Rothermel and Philpot[6]). In our model, the rate of spread of a fire in 5-year-old grass or herbaceous vegetation was approximately equal to the rate of spread in 21-year-old chamise. The coefficient of variation of our fire-spread function was assumed to decrease as the mean rate of spread increased (fig. 2). This assumption derives from the expectation that in the early postfire years the amount of fuel present varies considerably and that, as time passes, variation diminishes as the site approaches its ecological potential.

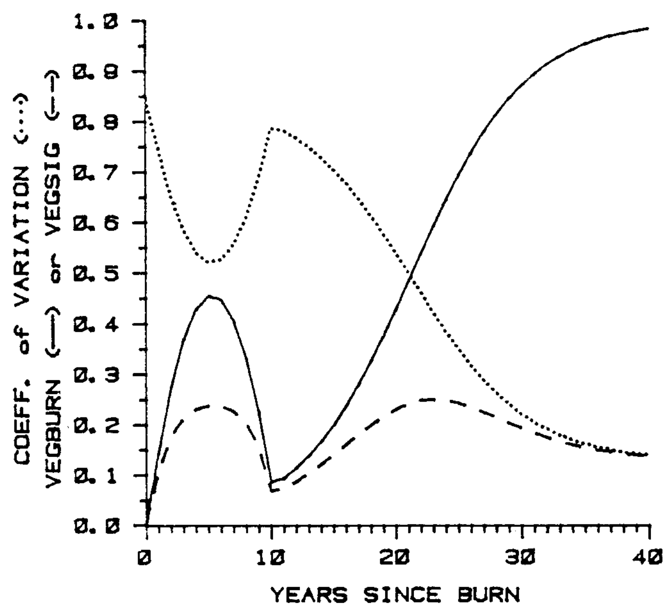


Figure 2--The effect of vegetation age on the mean probability of burning a model cell (VEGBURN) and its standard deviation (VEGSIG) (adapted from Rothermel and Philpot, 1973).

---

[5]Fire occurrence data provided by Lynn R. Biddison, director of aviation and fire management, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture, May 1, 1981.

[6]Rothermel, Richard C.; Charles W. Philpot. Mathematical models for predicting chaparral flammability. Unpublished paper, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, Montana, 1972.

Rate of spread was further regulated by a fire-size function (eq. 5), which determined whether the next model cell would be consumed by the fire. Large model elements being approached by small fires have a low probability of burning and, conversely, small elements being approached by large fires have a high probability of burning.

In the computer simulation, once the location of a fire start has been determined, the ignition (eq. 4) and vegetation (eq. 7) functions are consulted to determine if the first cell will be burned. If not, the ignition is ignored and a new random fire start is generated. If the first cell is consumed, the rate-of-spread function (eq. 5), the fire-size function (eq. 6), and the vegetation function (eq. 7) for the adjacent cell are employed to determine the probability that the next cell will also be consumed. This portion of the model is repeated until the fire goes out. If the cell being approached by the fire is a fuelbreak, whether the fire will be contained is determined by reference to an assumed probability that the fire can be stopped at the fuelbreak. That probability (0.8) is an amalgam of the chances of a fuelbreak holding the head, flanks, and rear of a fire; it is based on reported experience of fuelbreak success. Considering the planned simplicity of our model, we do not feel that this treatment of fuelbreaks and other vegetative elements is unwarranted.

MODELS TESTED

Ten models were tested. The one representing current conditions was most important, as only this could be tested against reality. The modeled area represented approximately 80,000 ha divided into "watersheds" of 400 ha or more. (The capabilities of our computer dictated the 400-ha minimum watershed size.) We adjusted our fire functions to increase the probability of burning a 400-ha watershed in order to compensate for the model's inability to explicitly consider smaller fires (eq. 6). This adjustment yielded an annual wildfire area distribution (Table 1A) in agreement with historical records (Philpot 1974). Initially we assumed that the vegetation had an average age of 27.5 years and a standard deviation of 15 years. After several trial runs we found that, <u>in our model</u>, the current fire regime yielded a mean vegetation age of 32 years, and a standard deviation of 27.5 years. For all subsequent runs the model was initialized based on these parameters. The model had a random distribution of cell clusters ranging in size from 1200 to 8000 ha. Ages were randomly assigned which reproduced the appropriate distribution of age classes.

Watersheds were assumed to be rectangular and twice as long as wide. Fuelbreak area was taken to be 100 meters in width times half the perimeter of the watershed (assuming that adjacent watersheds supply the other half-perimeter of fuelbreaks). In our model of current conditions, fuelbreaks surrounded randomly located watersheds having areas typical of fuelbreaked watersheds on the Angeles, Cleveland, and San Bernardino National Forests. The fire- and landslide-producing capabilities of the current condition were contrasted with those of nine other conditions: regularly-spaced fuelbreaks enclosing watersheds of 2000 ha without prescribed fires, and prescribed fire intervals of 15, 20, 25, and 30 years with the current fuelbreak system and the 2000-ha fuelbreak system.

DISCUSSION

The ability of a model to predict actual conditions depends on the assumptions used to construct the model. In a complex natural ecosystem, such as the fire subclimax chaparral, model assumptions are imperfect, at best. As knowledge of the parameters influencing the ecosystem improves, the model can evolve to convey actual conditions more accurately. As a first approximation, however, even an imperfect, simple model, such as ours, may identify the potential result of planned management strategies, given the set of assumptions which land managers now use and the current state of knowledge of ecosystem interactions.

From our 10 model runs, several trends emerged regarding the influence of prescribed fires and fuelbreaks on wildfires and soil slip erosion.

<u>Prescribed Fires</u>

In our model all prescribed fires were assumed to be uniformly successful in reducing fuel volume and none escaped. Prescribed fires dramatically modified the amount of area burned by wildfires each year. Under the current fuelbreak system with no prescribed fires, the long-term average area burned annually by wildfires was estimated to be about 2.2 percent (fig. 3). The average annual wildfire area dropped as prescribed fire intervals

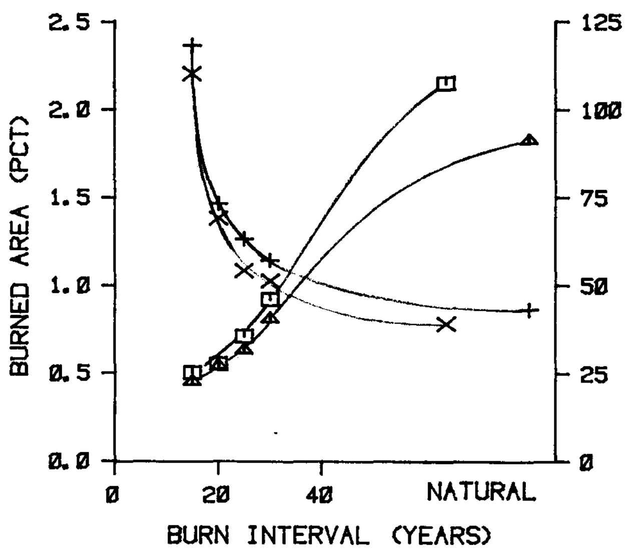


Figure 3--Prescribed fire interval effects on wildfire area with current (❑) and 2000-ha (Δ) fuelbreak densities and annual soil slip erosion rates with current (x) and 2000-ha (+) fuelbreaks.

Table 1--Interval between prescribed burns related to expected frequency of area burned annually by wildfire.

Annual Wildfire Area(pct)	Prescribed Fire Interval (years)				
	(†)	30	25	20	15
	--Expected Frequency (years/century)--				
	A. Current Fuelbreak System				
0.0	16.5	30.7	37.6	43.5	45.7
0.0-1.5	30.9	42.8	43.4	44.0	43.5
1.5-3.0	25.7	19.7	15.9	10.7	9.5
3.0-4.5	15.1	5.5	2.5	1.5	1.0
4.5-6.0	4.8	0.7	0.2	0.2	0.0
6.0-7.5	3.3	0.3	0.1	0.1	0.1
7.5-9.0	1.4	0.0	0.0	0.0	0.0
>9.0	2.3	0.1	0.2	0.1	0.1
	B. 2000-ha Fuelbreak System				
0.0		32.2	36.8	42.6	48.3
0.0-1.5	41.5	52.5	54.4	50.6	47.1
1.5-3.0	23.4	12.4	7.5	6.1	4.0
3.0-4.5	12.6	2.3	1.1	0.5	0.4
4.5-6.0	3.8	0.4	0.1	0.1	0.1
6.0-7.5	2.0	0.2	0.1	0.1	0.1
7.5-9.0	1.1	0.0	0.0	0.0	0.0
>9.0	0.3	0.0	0.0	0.0	0.0

(†) Prescribed burning not done.

were more frequent and the average age of the chaparral decreased. A prescribed fire interval of 30 years produced an expected average annual wildfire burn of 0.9 percent of the area, or about 43 percent of the average annual area burned by wildfires under the current system. With a prescribed fire interval of 15 years, the average annual wildfire area averaged only 0.5 percent of the area, or about 23 percent of the current average annual wildfire area.

Not only was average annual wildfire area reduced by prescribed fire, but the distribution of fire sizes shifted to smaller fires (table 1A). For example, with the current system, there were no wildfires larger than 400 ha in 16.5 years per century, whereas with a 15-year prescribed fire interval there were no wildfires larger than 400 ha in 45.7 years per century. With the current system, in 11.8 years per century, wildfires burned more than 4.5 percent of the area and in 2.3 years per century, more than 9 percent of the area. Using a 15-year prescribed fire interval, wildfires burned more than 4.5 percent of the area only twice in a millennium.

Prescribed fire had an erosional penalty. Under the current fuelbreak system, the long-term soil slip erosion rate was about 39 m^3/ha/year (fig. 3). This rate increased to 110 m^3/ha/year when a 15-year prescribed burn interval was employed, which is a 282 percent increase in average annual soil slip erosion.

Table 2--Interval between prescribed burns related to expected frequency of annual slip soil erosion rate.

Annual Erosion Rate (m^3/ha)	Prescribed Fire Interval (years)				
	(†)	30	25	20	15
	--Expected Frequency (years/century)--				
	A. Current Fuelbreak System				
0	54.0	53.1	54.0	53.4	54.4
0-50	22.8	19.5	18.6	17.1	14.3
50-100	9.8	9.5	7.9	6.6	5.7
100-200	8.3	10.2	10.4	9.3	6.1
200-400	4.0	6.1	7.4	9.6	9.5
400-600	0.5	1.1	1.3	3.2	4.7
600-800	0.3	0.2	0.2	0.6	2.9
800-1000	0.0	0.2	0.1	0.2	1.1
>1000	0.1	0.0	0.0	0.1	1.2
	B. 2000-ha Fuelbreak System				
0	55.0	52.5	53.6	54.2	54.2
0-50	21.9	20.0	18.2	16.9	15.0
50-100	7.4	7.8	7.3	6.3	4.5
100-200	9.6	9.8	9.3	8.4	6.3
200-400	4.9	7.9	8.7	9.4	8.7
400-600	0.8	1.7	2.4	3.6	5.7
600-800	0.2	0.2	0.2	0.6	2.8
800-1000	0.0	0.1	0.2	0.2	1.8
>1000	0.1	0.0	0.0	0.1	1.2

(†) Prescribed burning not done.

The effect of prescribed fire on the distribution of soil slip erosion rates is more complex (table 2). The distribution of storm severities fixes the frequency of soil-slip-producing storms. Thus, the frequency of years with no soil slips is independent of fire management strategy. The important change in the distribution of soil slips is the marked increase in the frequency of larger events as the prescribed fire interval decreases--especially in the strategy utilizing a prescribed fire interval of 15 years. That strategy increased the number of years with soil slip erosion greater than 200 m^3/ha by almost fourfold to almost 1 year in 5. This prescribed fire interval concentrates the age distribution of the chaparral around the trough of minimum root strength (fig. 1), resulting in extreme sensitivity to storms having soil-slip-producing potential.

Fuelbreaks

The addition of a very intensive fuelbreak system, isolating each 2000-ha watershed, had much less effect on the distribution of average annual wildfire area than the various fire management strategies (table 1), but it shifted the fire-size distribution toward the smallest fires. The intensive fuelbreak strategies are also associated with an average reduction of about 12 percent in the long-term average annual wildfire area (fig. 3).

The intensive fuelbreak system had little effect on the distribution of erosion rates associated with the various prescribed fire intervals (table 2). Neither did it seem to have an appreciable effect on the average annual soil slip erosion rate associated with various prescribed burn intervals (fig. 3).

CONCLUSIONS

In common with most land management decisions, the choice of a fire management strategy requires careful evaluation of trade-offs. Generally, those strategies achieving the greatest reduction in area burned by wildfires also carry the greatest soil slip erosion penalties. This is because reduced root strength and slope instability accompany managed reductions in fuel volumes.

A hypothetical 2000-ha fuelbreak system appears to add only modest fire management benefits to the various prescribed fire strategies, and has negligible effect on soil slip erosion. Consequently, it appears that increases in fuelbreak density beyond the present state will have to be justified mainly on bases other than reduction of burned area or erosion.

It should be kept in mind, however, that the increased erosion rate we have estimated applies to areas having a distribution of slopes matching the average for chaparral in southern California. If the various strategies we have discussed were applied exclusively to the 30 percent of the chaparral area having slopes steeper than 50 percent, the erosion rates would be approximately three times greater. On the other hand, if the manager can restrict his activities to the 70 percent of the chaparral growing on slopes less than 50 percent, the erosional consequences that we have estimated for the various fuel management strategies will almost vanish. Planning a fuel management strategy which capitalizes upon this dichotomy, is the challenge facing chaparral land managers.

LITERATURE CITED

Bishop, Daniel M.; Stevens, Mervin E. Landslides on logged areas in southeast Alaska. Juneau, Alaska: Northern Forest Exp. Sta., Forest Serv., U.S. Dep. Agric.: 1964; Res. Paper NOR-1. 18 p.

Caine, Nel. The rainfall intensity-duration control of shallow landslides and debris flows. Geogr. Ann. 62A(1-2):23-27; 1980.

Croft, A. R.; Adams, John A. Landslides and sedimentation in the North Fork of Ogden River, May 1949. Ogden, Utah: Intermountain Forest and Range Exp. Sta., Forest Serv., U.S. Dep. Agric.: 1950; Res. Paper 21. 4 p.

Endo, Taizo; Tsuruta, Takeo. The effect of the trees' roots upon the shear strength of soil. 1968 Annual Report of the Hokkaido Branch, Forest Exp. Sta.; Sapporo, Japan: 1969; 157-182.

Hellmers, H.; Horton, J. S.; Juhren, G.; O'Keefe, J. Root systems of some chaparral plants in southern California. Ecology 36(4):668-678; 1955.

Kawaguchi, Takeo; Namba, Senshi. Landslides and erosion control. Rin-Go-Shiken-Hokoku 84:43-66; 1956.

Kummerow, Jochen; Krause, David; Jow, William. Root systems of chaparral shrubs. Oecologia (Berl.) 29:163-177; 1977.

Miller, Philip C.; Ng, Edward. Root:shoot biomass ratios in shrubs in southern California and central Chile. Madrono 24:215-223; 1977.

O'Loughlin, Colin Lockhart. The stability of steepland forest soils in the Coast Mountains, southwest British Columbia. Vancouver, British Columbia: Univ. of British Columbia; 1972; Ph.D. thesis. 147 p.

Philpot, Charles W. The changing role of fire on chaparral lands. Proceedings of the symposium on living with the chaparral; 1973 March 30-31; Riverside, California: Sierra Club; California Div. Forestry; U.S. Forest Serv.; 1974; 131-150.

Reimann, Lyle F.; Hamilton, Everett L. Four hundred sixty storms--data from the San Dimas Experimental Forest. Pacific Southwest Forest and Range Exp. Sta., Forest Serv., U.S. Dep. Agric.: 1959; Misc. Paper 37. 101 p.

Rice, R. M. The hydrology of chaparral watersheds. Proceedings of the symposium on living with the chaparral; 1973 March 30-31; Riverside, California: Sierra Club; California Div. Forestry; U.S. Forest Serv.; 1974; 27-34.

Rice, R. M.; Foggin, G. T., III. Effect of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resources Research 7(6):1485-1496; 1971.

Rothermel, Richard C.; Philpot, Charles W. Predicting changes in chaparral flammability. J. For. 71(10):640-643; 1973.

Ziemer, R. R. Roots and the stability of forested slopes. Proceedings of the erosion and sediment transport in Pacific rim steeplands symposium; 1981 January 25-31; Christchurch, New Zealand: Int. Assoc. Hydrol. Sci. Pub. 132; 1981; 343-361.

APPENDIX

Eq. 1. Root biomass as a function of time since last burn and live and dead root biomass at last burn.

For chaparral:

$$LIVE(t) = 1270/(1 + C * e^{-0.22T})$$

$$DEAD(t) = 0.905 * LIVE(0) * e^{-0.3T} + DEAD(0) * e^{-0.5T}$$

where: $C = (1270 - L_O)/L_O$,
$L_O = 0.095 * LIVE(0) + 12$,
t = years since last burn,
T = t-2, for $t \geq 2$, and
= 0, for t < 2.

For fuelbreaks:

$$LIVE(t) = DEAD(t) = 0$$

Eq. 2 Storm severity as a function of storm duration and rainfall amount.

$$SEVR = \log(0.081 * I^{0.93} * D^{0.36})$$

where: I is the mean rainfall intensity in mm/hr,
D is the storm duration in hours.

Eq. 3 Percent of area in landslides given storm severity, SEVR, residual slide effects, RESID, and summed live and dead root biomass, BMASS.

$$P = \frac{(2.2 * 10^9) * SEVR^{1.13}}{BMASS^{3.6} + (2.4 * 10^9)} - RESID$$

and

$$RESID(new) = RESID(old) + P$$

Eq. 4 Probability of the first cell igniting if cell is of average age.

$$SPREAD = 5.74 * SIZE(CELL)^{-0.577}$$

where: SIZE(CELL) is the area of the cell where the possible ignition occurs.

Eq. 5 Probability of fire spreading to the next cell if it is of average age.

$$SPREAD = \left[\frac{FIRAREA + SIZE(CELL}{SIZE(CELL)}\right]$$

where: FIRAREA is the current size of the fire.

Eq. 6 Fire-spread function adjusted to compensate for area burned in fires smaller than minimum cell size (applies to second cell of a fire only).

$$SPREAD = 0.556 * SPREAD$$

Eq. 7 Fire-spread function adjusted for age of vegetation.

$$SPREAD = 1.284 * SPREAD * N(VEGBURN, VEGSIG)$$

where: N(VEGBURN, VEGSIG) is a normal random variable having the mean and the standard deviation corresponding to the age of the vegetation in figure 3.

Runoff and Sedimentation Potentials Influenced by Litter and Slope on a Chaparral Community in Central Arizona[1]

John H. Brock and Leonard F. DeBano[2]

Abstract: Runoff and sediment was measured for a chaparral community on the Prescott National Forest in the summer of 1979. Simulated rainfall intensities of 12.5 cm/hr were applied to steep, moderate, and gentle sloped plots covered with none, light, moderate and heavy litter. Infiltration capacity was highest (10.8 cm/hr) on heavy litter plots giving low runoff potentials. Highest sediments (1466 kg/ha) were from bare soils. Litter cover significantly reduced sediment losses and decreased runoff potentials.

The chaparral type is an important watershed resource in Arizona where it covers about 3-1/2 million acres at mid-elevations throughout the central part of the state (Hibbert and others 1974). These brush-covered areas are potential sources of increased streamflow when the deep.-rooted brush plants are replaced with shallower-rooted grasses and forbs (Hibbert 1979). The possibility of large-scale treatments of this vegetation type makes it essential to better understand the potential on-site runoff-sedimentation relationships. This study reports the results of infiltrometer trials which were used to establish the effect of different litter and slope conditions on runoff and associated on-site sediment movement in an undisturbed stand of Arizona chaparral.

Several factors affect the runoff-sedimentation relationships in chaparral, including vegetation cover and density, litter, slope, and the infiltration capacity of the soil. In chaparral areas receiving 22 inches or more of precipitation annually the brush cover is usually moderate to dense with a sparse understory of native herbaceous plants (Hibbert and others 1974). The amount of litter on the soil surface varies widely depending partly on the brush density. For example, in an oak-mountain mahogany stand the weight of L- and F-material (current and partly decomposed litter) on the forest floor varied from 9.2 to 27.1 metric tons per ha (Pase 1972).

The physical properties and infiltration characteristics of the chaparral soils vary widely depending upon the parent rock material. In many areas the parent rock is granite which weathers into a coarse-textured soil having a high infiltration capacity but which can be highly erosive on steep slopes because it lacks soil structure.

[1]Presented at the International Symposium on Dynamics and Management of Mediterranean-type Ecosystems: June 22-26, 1981, San Diego, California.

[2]Assistant Professor, Division of Agriculture Natural Resource Management, Arizona State University, Tempe, Arizona 85281; and Supervisory Soil Scientist, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, Arizona State University, Tempe, Arizona 85281.

Although the infiltration capacity in chaparral soils is usually high, it may be restricted by water-repellent substances present in the litter and underlying soil. Water repellency is most likely a problem after fire although it may also be present in unburned chaparral litter and soil (DeBano and others 1979).

When fully vegetated, chaparral watersheds seldom show overland flow (Rice 1974). Both surface litter and plant canopy promote infiltration by reducing raindrop impact and impeding overland flow, thereby providing temporary storage for periods of high-intensity rainfall. Litter material in an oak-mountain mahogany stand in Arizona was found to retain from 4.8 to 5.1 mm of precipitation against free drainage (Pase 1972). High infiltration rates and the storage capacity of the chaparral soil and litter leave little water available for overland flow (DeBano and others 1979).

METHODS

The study area was located in a chaparral community about 2 miles S.W. of the Goodwin, Arizona, townsite on the Prescott National Forest. The cover on the study area was composed mainly of shrub liveoak (*Quercus turbinella*) and Wright mountain mahogany (*Cercocarpus breviflorus*). These species are typical of much of Arizona chaparral (Cable 1972, Carmichael and others 1978).

Twelve study sites were selected on different slopes and litter conditions in the area. Three slope categories selected were (1) gentle 0-19 percent, (2) moderate 20-39 percent, and (3) >40 percent. Within each slope category, four different litter conditions were selected for study. The litter classes included (1) none, (2) light, (3) moderate, and (4) heavy amounts on the soil surface. The litter was visually classified into these four classes when study sites were selected; amounts of litter were measured after completion of the infiltrometer trials. Two replicates of each slope-litter combination were used for the study.

Infiltrometer trials were run on each of the twelve plots. Infiltration rates were measured using a drip infiltrometer (Blackburn and others

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

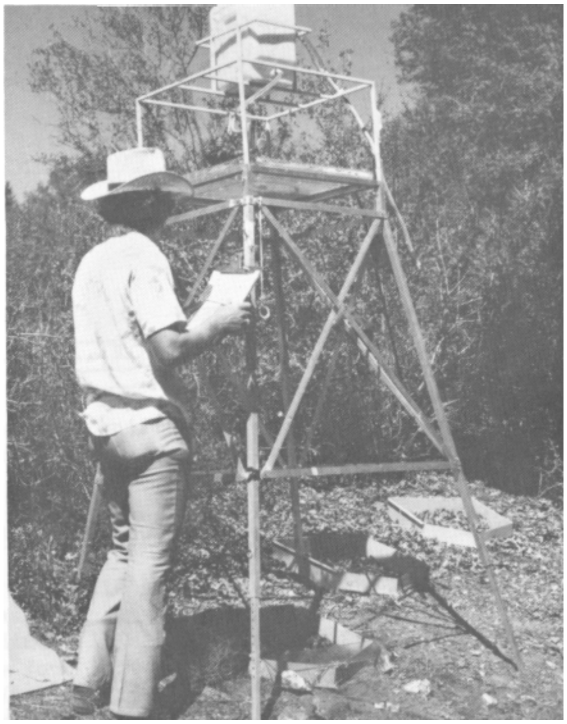


Figure 1--Modified rainfall infiltrometer.

1974) modified to improve portability in rugged terrain (fig. 1). Simulated rainfall was applied from 0.36 m^2 modules to a 0.25 m^2 sample plot at a rate of 12.5 cm/hr for 30 minutes. The four litter plots within each slope category received simulated rainfall from the infiltrometer in a single day. Following the initial application, the plots were covered with plastic to retard evaporation, and after six hours of drainage the plot received simulated rainfall with the soil in a wet condition.

Antecedent soil water was determined gravimetrically from samples of surface soil (0-5 cm) taken immediately adjacent to the plots. Following each wet soil infiltrometer trial the litter was removed from the plot using a fine rake, and oven-dried at 80°C for 48 hours. Rocks were removed, and litter weighed. A soil sample from the surface 0-5 cm depth was collected for subsequent analysis. Soil organic matter was determined by chromic acid oxidation (Jackson 1958) and soil texture by the hydrometer method (Day 1965).

Runoff water drained through a miniature flume and was collected in a 10-liter plastic bottle. The quantity of runoff was measured in a 1-liter graduated cylinder at 5-minute intervals and recorded to the nearest milliliter. Data was converted to centimeters of runoff per area and used to calculate infiltration rates for 5-minute time intervals. The infiltration rates reported in this paper are for wet soils during peak runoff.

After runoff stopped, a 1-liter aliquot of the runoff water was saved for sediment analysis. The amount of sediment lost in the runoff water was determined by filtering it through No. 41 filter paper and oven-drying the residue at 105°C for 24 hours before weighing. Sediment losses are reported in kilograms per hectare.

The sediment yield data were normalized by using a common logarithmic transformation prior to statistical analysis. The data was analyzed using the Statistical Analysis System (SAS) software package (Barr and others 1976). Analysis of variance (Steele and Torrie 1960) was used to test for differences in runoff, sediment, litter and soil characteristics. Duncan's new multiple range test (P = 0.05) was performed when F-values were significant. Stepwise multiple regression analyses were used to isolate the effect of slope, litter classes, and soil characteristics on infiltration rates and sediment production. Variables included in the regression models if significant at P = 0.10.

RESULTS AND DISCUSSION

Litter and Soil Conditions

The slope of the individual plots selected for study ranged from 6 to 67 percent (table 1). Mean litter ranged from none on the bare plots to 36074 kg/ha on the sites having heavy litter accumulations (table 2). The quantities of litter measured in this study were similar to those reported by Pase (1972) in Arizona and DeBano and Conrad (1978) in California where both the F- and H-layers (humus) were reported as litter. In the study area about 10 percent of the surface was bare soil, 17 percent covered with light, 31 percent moderate, and 42 percent with heavy accumulations of litter. The average amounts of litter on the gentle, moderate and steep slopes were 14073, 11326, and 14600 kg/ha, respectively, but were not statistically different at the 0.05 level. Soil organic matter was greater on the heavy litter plots, as expected, but only significantly different from plots having no litter (table 2).

Table 1--Slope (percent) characteristics of plots used for studying runoff and sedimentation potentials of a chaparral community in central Arizona.

	Slope Category		
Category Data	Gentle	Moderate	Steep
Category Limits	0-19	20-39	>40
Observed Ranges	6-15	20-33	55-67
Mean Slope	8.9	25.0	58.2

Table 2--Surface soil properties of a chaparral community in central Arizona.

Soil Cover	Litter (kg/ha)	Organic Matter Percent	Sand	Percent Silt	Clay
None	[1]0c	2.2b	51.9a	31.0b	17.0a
Light	3,804c	3.2ab	52.0a	33.5ab	14.4ab
Moderate	13,454b	4.8ab	50.7a	34.3ab	14.9ab
Heavy	36,074a	8.5a	49.2a	36.6a	14.0b

[1]Means followed by the same letter are not significantly different at P = 0.05 percent.

Generally, organic matter increased in the soil as the thickness of the litter layer increased.

The surface soils were classified as silt loams for all slope and litter combinations. There were no significant differences in the sand fraction among the four litter classes. In contrast, the silt and clay fractions were statistically different (table 2). Silt increased with increasing amounts of litter. Clay content was 2.6 percent higher in soils on bare plots compared to those having some litter cover.

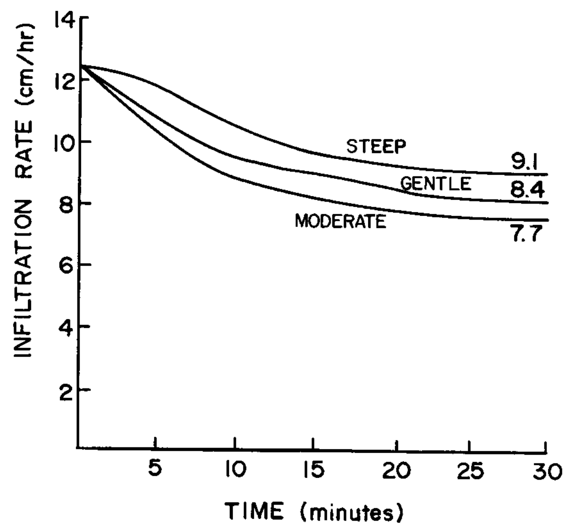


Figure 2--Terminal infiltration rates (cm/hr) for wet soils as influenced by slope in a chaparral community in central Arizona.

Infiltration Rates

The terminal infiltration rate, or infiltration capacity, is defined as the stable rate which is attained during a 30-minute infiltrometer trial. The terminal infiltration rate for the dry soil averaged 9.4 cm/hr and was significantly greater ($P = 0.05$) than the 8.4 cm/hr rate in the wet soils.

No significant differences in terminal infiltration rates were found in the wet soils among the different slope classes (fig. 2). The steep slopes had the highest infiltration rates (9.1 cm/hr). This may have occurred because the steep slopes had shallow soils which contained numerous fractures in the unweathered granitic parent material. On the more gentle slopes, the surface soils probably developed from colluvial material which produced a deeper soil containing more clay and silt than those on steeper slopes (table 3). Consequently, infiltration rates were slower on the gentle and moderate slopes compared to the steep slopes (fig. 2). The major feature governing infiltration into chaparral soils appears to be the amount of litter accumulating on the soil surface. The infiltration capacities of plots having the greatest amounts of litter (36074 kg/ha) was 10.8 cm/hr after 30 minutes of simulated rainfall (fig. 3). Moderate quantities of litter (13454 kg/ha) had an average infiltration capacity of about 2 cm/hr less than those plots covered with a heavy litter accumulation.

On plots having light amounts of litter, or no litter, the infiltration capacities were 30 to 40 percent less (and statistically significant) than on plots having heavy amounts of litter.

The influence of litter, or its decomposed counterpart-soil organic matter, on water movement into chaparral soils was further verified by the regression analysis. The best three-variable equation describing the infiltration capacity of dry soils (Y_1) was:

$$Y_1 = 13.0388 + 0.3325 \text{ organic matter} - 0.0564 \text{ silt} - 0.2234 \text{ clay}$$

This model accounted for 75 percent of the variation observed in the infiltration capacity of the dry soil. The first variable in the model, organic matter, yielded a coefficient of determination of 0.48. In the wet soil, slightly more of the variation in infiltration capacity (Y_2) was accounted for by a three-variable model. The equation for the wet soil was:

$$Y_2 = 0.4457 + 0.0008 \text{ litter} + 0.02287 \text{ organic matter} + 0.1123 \text{ sand}$$

This equation had a coefficient of determination of 0.84 and the first variable in the model, litter, accounted for 66 percent of the variation observed in infiltration capacity.

Table 3--Soil textural properties of soils on gentle, moderate and steep slopes in an Arizona chaparral community.

Slope Category	Sand Percent	Silt Percent	Clay Percent
Gentle	[1]52.4a	33.5a	14.1b
Moderate	44.6b	36.2a	19.1a
Steep	55.9a	31.9a	12.2b

[1]Means in columns followed by the same letter are not significantly different at P = 0.05 percent.

Sediment Production

The sediment losses from the three slope classes were not statistically different. However, sediment losses were significantly different among the four litter classes. The greatest loss (1466 kg/ha) was from bare soils that were wet (fig. 4). Even small amounts of litter on the soil surface significantly decrease the sediment lost in the runoff water. The lowest sediment loss (20 kg/ha) was measured on plots having a heavy litter layer.

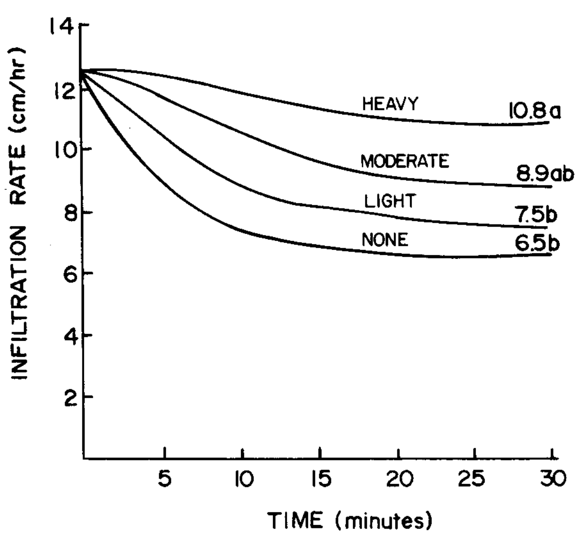


Figure 3--Infiltration capacity (cm/hr) for wet soils as influenced by litter class. Means for terminal infiltration rate followed by the same letter are not significantly different at P = 0.05 percent.

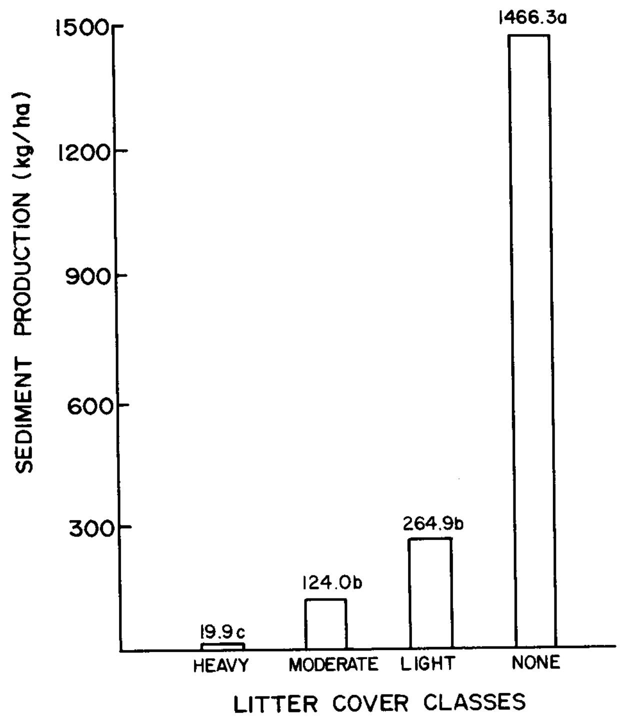


Figure 4--Sediment production from wet soils after 30 minutes at 12.5 cm/hr rainfall intensity as influenced by litter class. Column means with the same letter are not significantly different at P = 0.05 percent.

The on-site movement of sediment measured during the infiltrometer trials reported here are comparable to a long-term sediment rate of 0.7 m^3/ha reported for a nearby watershed (Hook and Hibbert 1979). If the volume-weight of the sediment is assumed to be 1121 kg/m^3 (Megahan 1972), then the mass of sediment moving off this watershed was 812 kg/ha per year. The sediment rates measured in this study were also comparable to those reported on other small plots or infiltrometer trials. In southern California, on-site sediment movement rates of 210 kg/ha were measured on small plots in untreated chaparral on a 50 percent slope (DeBano and Conrad 1976). Recent studies on Texas grasslands using a similar type infiltrometer showed that maximum sediment losses from untreated short-grass ranges were 252 kg/ha (Brock and others 1981), 196 kg/ha on heavily continuously grazed pastures during years of favorable moisture (Woods 1980), and over 1000 kg/ha following a summer drought on heavily grazed areas (Knight and others 1980).

Sediment production rates measured by infiltrometers, or on small plots, should be used with extreme caution when assessing the long-term erosion rates from large watersheds. The measurements may not be comparable because many of the on-site erosional processes are altered down-slope or completely different in the channels draining larger watershed areas. However, small plots and infiltrometers are useful tools for isolating some of the factors affecting on-site erosion such as litter, soil physical properties, localized slope conditions, effect of fire, water repellency, and a host of other small-scale processes. These small-scale studies provide a much better chance of rigorously testing some variables while controlling others.

Sediment losses were also related to organic matter, litter and soil properties in dry and wet soils by regression analysis. Litter and soil organic matter were related to sediment loss as was the case for infiltration capacity, but the regression coefficients were reversed in sign. The prediction equation for the log of sediment losses (Y_3) from dry chaparral soil was

$$Y_3 = -2.8797 - 0.2614 \text{ organic matter} + 0.0962 \text{ sand} + 0.02706 \text{ clay}$$

This three-variable model accounted for 65 percent of the variation observed in the log of sediment yield. When only one variable, organic matter, was used, only 48 percent of the observed variation was accounted for in the regression. The regression model for the log of sediment losses of wet soils (Y_4) was

$$Y_4 = 6.2423 - 0.0006 \text{ litter} - 0.1841 \text{ organic matter} + 0.0417 \text{ clay}$$

The coefficient of determination for the three variables was 0.76 and litter accounted for 67 percent of the variation.

CONCLUSIONS

Infiltration capacity of chaparral soils was found to be influenced more by soil surface characteristics than by steepness of slope. The infiltration capacities were lowest on bare soils and increased when litter and soil organic matter content increased. Sediment losses were greatest on unprotected soils. However, even small amounts of litter on the surface greatly reduced the on-site erosion potential of these chaparral soils. The results of this study provided some information concerning the important site factors that affect on-site erosion, particularly if they are affected by chaparral treatments. For example, treatments in chaparral communities which bare the soil and leave it unprotected should be avoided. When mineral soil is exposed by mechanical treatments or overly intense fires, revegetation or surface modifications such as contour furrowing and revegetation should be undertaken immediately to reduce potential soil movement and loss.

Acknowledgments: Support for this research was in part from the Rocky Mountain Forest and Range Experiment Station, under Cooperative Agreement Number 16-882-CA; Arizona State University, Faculty Grant-In-Aid Program, ERC-P-80139; and from the Division of Agriculture, Arizona State University. Paper layout and preparation by Shanyn Owens-Mathieu.

LITERATURE CITED

Barr, A. J.; Goodnight, James H.; Sall, John P.; and Helwig, Jane T. A users guide to SAS 76. Raleigh, North Carolina: Sparks Press; 1976. 329 p.

Blackburn, Wilbert H.; Meeuwig, Robert O.; and Skau, C. M. A mobile infiltrometer for use on rangeland. J. of Range Management 27:322-323; 1974.

Brock, John II.; Blackburn, Wilbert H.; and Haas, Robert H. Effects of brush control on infiltration and sediment production on a hardland range site in North Central Texas. (In press) J. of Range Management; 1981.

Cable, Dwight R. Range Management in the chaparral type and its ecological basis: The status of our knowledge. Rocky Mountain Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1975; Research Paper RM-155. 30 p.

Carmichael, Robert S.; Knipe, O. Duane; Pase, Charles P.; and Brady, Ward W. Arizona chaparral: Plant associations and ecology. Rocky Mountain Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1978; Research Paper RM-202. 16 p.

Day, Paul R. Particle fractionation and particle size analysis. In: Methods of Soil Analyses. Am. Soc. Agron.: 1965; Agron. Monogr. No. 9, part 1; 545-567.

DeBano, Leonard F.; and Conrad, E. Eugene. Nutrients lost in debris and runoff from a burned chaparral watershed. Proceedings of the Third Inter-agency Sedimentation Conference; 1976 March; Denver, Colorado; 3:13-27.

DeBano, Leonard F.; and Conrad, C. Eugene. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

DeBano, Leonard F.; Rice, Raymond M.; and Conrad, C. Eugene. Soil heating in chaparral fires: effects on soil properties, plant nutrients, erosion, and runoff. Berkeley, California: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1979; Res. Paper PSE-145. 21 p.

Hibbert, Alden R.; Davis, Edwin A.; and Scholl, David G. Chaparral conversion potential in Arizona Part I: Water yield response and effects on other resources. Rocky Mountain Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1974; Research Paper RM-126. 36 p.

Hibbert, Alden R. Managing vegetation to increase flow in the Colorado River Basin. Fort Collins, Colorado: Rocky Mountain Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1979; Gen. Tech. Rep. RM-66. 27 p.

Hook, Thomas E.; and Hibbert, Alden R. Sediment production from a chaparral watershed in central Arizona. In: Hydrology and water resources in Arizona and the Southwest. Proceedings of 1979 Meetings of the Arizona Sect.-Amer. Water

Resource Assn., and the Hydrol. Sect., Ariz.-Nev. Acad. Sci.; 1979 April 13; Tempe, Arizona: 9:31-36.

Jackson, Michael L. Soil chemical analysis. Englewood Cliffs, New Jersey: Prentice Hall Inc.; 1958. 498 p.

Knight, Robert W.; Blackburn, Wilbert H.; and Merrill, Leo B. Impacts of selected grazing systems on hydrologic characteristics, Edwards Plateau, Texas. Meeting of the Society for Range Management; 1980; San Diego, California; Abstract.

Megahan, Water F. Volume weight of reservoir sediment in forested areas. J. Hydraulics Division, ASCE, 98:1335-1342; 1972 August; Proc. Paper 9129, No HY8.

Pase, Charles P. Litter production by oak-mountain mahogany chaparral in central Arizona. Fort Collins, Colorado: Rocky Mountain Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1972; Res. Note RM-214. 7 p.

Rice, Raymond M. The hydrology of chaparral soils. Proceedings of the Symposium on Living with the Chaparral; 1973 March 30-31; Riverside, Calif.: Sierra Club; 1974; 27-34.

Steel, Robert G. D.; and Torrie, James H. Principles and procedures of statistics. New York: McGraw-Hill Book Co., Inc., 1960. 481 p.

Woods, M. Karl. Impacts of grazing systems on watershed values. Proceedings of Grazing Management Systems for Southwest Rangelands Symposium; 1980; Las Cruces, New Mexico: New Mexico State University, Range Improvement Task Force; 163-170.

Role of Fungi in Postfire Stabilization of Chaparral Ash Beds[1]

Paul H. Dunn, Wade G. Wells II, Juliana Dickey, and Peter M. Wohlgemuth[2]

Abstract: Raindrop impact is a major agent of soil erosion, and any reduction in its effectiveness reduces sediment production from burned watersheds. A chaparral soil treated with heat-shock fungi in three combinations was compared to sterile soil to test the ability of postfire heat-shock fungi to diminish raindrop impact erosion. Two to three times as much sediment was detached from sterile soil as from any of the three fungal treatments. A 1-month incubation period was sufficient to allow all fungal treatments to resist raindrop impact.

Wildfire and flooding after wildfire in chaparral have been problems to land managers for many years. Because postfire floods frequently take the form of mudflows, the problem is complex, involving sediment management and ecosystem management as well as protection of lives and property. It is unrealistic to expect to stop postfire sedimentation completely, but reducing the size of individual events and minimizing potential damage are attainable goals.

Solutions to the sediment production problem take one of two approaches: engineering and biological. Crib dams, debris basins, flood control dams, and flood control channels are examples of the engineering approach. These structures function by trapping or diverting sediments that would otherwise damage developed areas. Although all these structures are essential to sediment management, they do have drawbacks. They are expensive to build and maintain, and they divert sediments formerly transported to the ocean where they replenished beach sand constantly eroded by wave action (Brownlie and Taylor 1981).

One biological approach, in use for several years, has been to seed burned areas with grass, particularly to annual ryegrass (Lolium spp.). This treatment is of questionable value for erosion reduction and has definite drawbacks, and land managers are presently seeking biological alternatives. One such alternative is the use of heat-shock soil fungi, a group indigenous to chaparral. This group, long known to be present but without an identified ecological function, occurs in most ecosystems associated with fire. They require a period of heating before their spores will germinate, yet the organisms are not thermophilic since they will not grow at the elevated temperatures characteristic of thermophiles. The heat-shock fungi in ash beds are adapted to the high ammonium and pH conditions of the ash and are capable of very rapid growth rates. They are, however, unable to compete against other saprophytic fungi (El-Abyad and Webster 1968a,b) and are only active during the period following a fire. Fire kills the nonheat-shock saprobes, but they later reinvade from outside areas. There is also a possibility that heat-shock fungi will be eliminated or their numbers seriously reduced if a fire is extremely hot over dry soil or hot over a wet soil (Dunn and DeBano 1977).

Many fungi, including heat-shock fungi, are capable of soil aggregation (Tisdall and others 1978, Harris and others 1966). The mycelium surrounds the soil particles and intertwines among them to form aggregates. The aggregates show a high degree of stability (Harris and others 1966) and thus are resistant to soil detachment by falling raindrops, one of the major soil erosion processes (Mutchler and Young 1975, Wells and Palmer 1981). Heat-shock fungi form definite crusts on the surface of ash beds, and often produce fruiting bodies on this surface or on charred twigs and grass blades poking up through it (Zak and Wicklow 1978, 1980).

In southern California chaparral, there are five principal heat-shock fungi: Pyronema omphalodes (Bull. ex St.-Amans) Fuckel, Aspergillus fischeri var. glaber Fennell and Raper, Gelasinospora cerealis Dowding, Humicola fuscoatra Traaen, and A. fumigatus Fresenius. These fungi seem to be distributed throughout southern California chaparral soils, although local dominance by a given species tends to vary.

This paper examines the ability of heat-shock fungi to stabilize the ash layer and prevent soil erosion by raindrop impact.

MATERIALS AND METHODS

The soil used was a Soper loam, an argixeroll, collected in Bluebird Canyon on the San Dimas Experimental Forest in southern California. Litter was collected from the soil surface, and soil was collected from the upper 5 cm of mineral

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Microbiologist, Hydrologist, Soil Microbiologist, and Geomorphologist, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

soil. The litter was ashed until black, but still recognizable. The ash was then sieved to remove soil and large particles and then ground to pass the 0.5-mm sieve of a Wylie Mill. The soil sample was sieved at 2 mm.

The soil was given two treatments. First, moist soil was heat-shocked by oven heating the soil to 60° C and maintaining that temperature for 30 minutes, conditions typical of subsurface layers during fire. The time and temperatures for heat-shocking were chosen on the basis of moisture content (Dunn and DeBano 1977). The second treatment, sterilization, was done by steam autoclaving for 90 minutes on four successive days. Sterility was tested by plating on tryptic soy agar (DIFCO).

All soil was handled under sterile conditions. Soil was moistened to field capacity, placed in petri dishes (100 mm by 15 mm), leveled at approximately 13 mm with a spatula, and sprinkled with ash to a 1-mm thickness. For inoculated samples, 1 ml of the inoculum solution was placed dropwise over the surface of the ash layer. Lids were placed on petri plates and plates were incubated 30 days at 24° C. Plates were watered by misting with sterile water every Monday and Thursday. Before testing, all plates were allowed to dry to 10 percent moisture.

Inoculum Preparation

Soil from Monroe Truck Trail on the San Dimas Experimental Forest was heat-shocked for 1.5 hr in a 60° C oven and plated on Martin's II, an agar with penicillin and streptomycin, each at 50 units per ml agar. Aspergillus fischeri var. glaber was isolated and cultured on Czapek solution agar, which induces production of conidia and ascospores. Conidia were suspended in 0.04 percent sterile saline solution by disturbance with sterile glass beads. Spore counts were made with a hemocytometer and inoculum diluted to 2.2×10^6 spores per ml.

Rain Tower Testing

A 5-m enclosed rain tower, designed by two of the authors[3], and built by Keck Engineering Laboratory, California Institute of Technology, was used for testing. Waterdrops were produced individually under a constant head, and a collimator of 90 percent fused alumina was installed near the bottom to screen out drops falling off center. A 19-gauge needle with a square-cut point produced a 3.3-mm waterdrop with a mass of an 18.5 mg.

The samples in 100-mm petri dishes were placed in the bottom of the tower on a small platform which had a 35-percent slope. A thin piece of plastic 110 mm in diameter, with a 10-mm hole in the center, was placed on the surface of the ash to keep it from sticking to the bottom of the sample cup. This was an aluminum cup (resembling a Dixie cup) fabricated with a 10-mm hole in the cup bottom and placed on the plastic with the holes aligning. The aluminum cup was handled with alcohol-rinsed tweezers.

Three drops of water were allowed to strike the exposed 10-mm circle of soil and ash. Any soil or ash splashed was caught in the aluminum cup. The aluminum cup was ovendried at 105° C for 24 hr and weighed to the nearest 0.01 mg. The cup was rinsed with alcohol and redried, and then a tare weight was taken. At the time of testing, a portion of the sample in the petri dish was removed for soil moisture determination.

Experimental Layout

Four treatments were tested in the rain tower: (1) sterile soil and ash, (2) sterile soil and ash inoculated with A. fischeri var. glaber, (3) heat-shocked soil and ash, and (4) heat-shocked soil and ash inoculated with A. fischeri var. glaber. Treatment 1 represented the condition where the soil was sterilized with a hot burn over moist soil. Treatment 2 represented the same conditions with an inoculation of A. fischeri var. glaber as might be used by management. Treatment 3 represented the normal field condition following wildfire. Treatment 4 represented the normal conditions plus a simulated inoculation to enhance the effect of heat-shock fungi.

RESULTS

The number of observations per treatment varied from 21 to 47. Means and standard deviations are shown in table 1. It is clear from the table that the two treatments involving Aspergillus fischeri var. glaber are effective in reducing soil detachment by raindrop impact. The data gathered were not found to be sufficiently normal to permit the use of parametric statistics such as a t-test for

Table 1--Amount of soil suspended by raindrop splash.

Treatment	Number of observations	Soil	
		Mean	S.D.
Sterile	47	0.49	0.28
A. fischeri	47	0.16	0.15
Heat-shock/A.f.	28	0.17	0.19
Heat-shock	21	0.30	0.19

[3]Wells, W. G. II; Dunn, P. h.; Wohlgemuth, P. M. A 5 meter rain tower for testing soil treatments for surface stability. (Unpublished manuscript).

comparative analysis. Results were compared using the nonparametric rank-sum test, employing the rank-sum statistic T' (Dixon and Massey 1969). The null hypothesis for this test was $(T_O' - \overline{m}_{T'} + 0.5)/\sigma_{T'} = 0$, where $\overline{m}_{T'}$ is the mean of the sum of the ranks for two test samples, $\sigma_{T'}$ is this rank-sum standard deviation, and T_O' is the sum of the ranks of the observations in the smaller of the two samples.

Production of rain-splashed sediment was two to three times greater on the sterile soil than on any of the soils with fungi (table 1). When compared with the other treatments, it was significantly different from them at a 99-percent confidence level (table 2).

The natural heat-shock flora reduced the amount of rain-splashed sediment by 40 percent over the sterile treatment. Enhancement with additional *A. fischeri* var. *glaber* produced even greater reductions, 45 percent over the heat-shock treatment and 65 percent over the sterile soil. There was no difference between the two treatments in which *A. fischeri* var. *glaber* was inoculated.

DISCUSSION

Two questions must be answered before heat-shock fungi can be suggested as a supplement to or replacement for postfire ryegrass seeding: do fungi stabilize the postfire ash bed, and if so, can this effect be enhanced by applying supplemental heat-shock mycoflora? The results show that heat-shock fungi do stabilize the postfire ash bed against rain-splash erosion and that stabilization against rain-splash erosion can be enhanced. The normal heat-shock fungal flora was not as effective as the heat-shock fungal flora enhanced with additional *A. fischeri* var. *glaber* or sterile soil so enhanced. Since there was no difference between the two *A. fischeri* var. *glaber* treatments, we infer that the effects of the natural heat-shocked fungi and additional *A. fischeri* var. *glaber* are complementary and not additive. All treatments with fungi were superior to sterile soil in reducing rain-splash erosion.

Table 2--Results of comparative analysis of data for four soil treatments, shown as normalized Z scores.

Treatment	Sterile	Heat-shock	Heat-shock/A.f.[1]	A.f.
Sterile	X			
Heat-shock	-2.89	X		
Heat-shock/A.f.	-5.65	-2.89	X	
A.f.	-6.32	-3.03	[2]Nonreject	X

[1]*A. fischeri* var. *glaber*.

[2]For a two-tailed test at the significance level $\alpha = 0.01$, the null hypothesis is rejected when $-2.58 > Z > 2.58$.

All test plates were incubated for 1 month at 24° C under field capacity moisture conditions. In the field, such conditions rarely exist and the time, temperature, and moisture conditions required for optimal growth must still be determined. It is known that the pH and nitrogen conditions found in chaparral ash beds are near optimum for all known heat-shock fungi. The ability of heat-shock fungi to respond to a wide range of growth conditions requires further study.

The fungal inoculation described in this paper is effective in reducing erosion caused by raindrop impact, a major erosional process (Mutchler and Young 1975). The effect of this treatment on other postfire processes, such as dry ravel and rill formation, has not been tested. It has been hypothesized that these two processes are initiated below the soil surface because of small local changes in the intergranular friction of the soil particles (Wells 1981). It is possible that treatments with fungi may cause slight increases in soil shear strength near the surface and, as a result, mitigate erosion by these processes.

Complete control of erosion in mountainous terrain is not attainable and probably not desirable. Steep slopes must maintain their equilibrium with gravity. Oversteepened (>60 percent) slopes must reestablish their equilibrium. Erosion, ultimately, is the only way that this equilibrium can be maintained. Although erosion cannot be prevented, it must be managed to protect lives and property. These fungi cannot prevent erosion, but their ability to reduce the effectiveness of raindrop impact suggests that they can make a useful contribution to our erosion and sediment management efforts. They should be inexpensive to produce and easy to apply, and they have, at present, no known harmful effects on the ecology of the chaparral.

LITERATURE CITED

Brownlie, William R.; Taylor, Brent D. Coastal sediment delivery by major rivers in southern California. Part C, Sediment management for southern California mountains, coastal plains, and shoreline. Pasadena, Calif.: Calif. Inst. of Tech.: 1981; Environ. Qual. Lab. Rep. 17-C. 314 p.

Dixon, W. J.; Massey, F. J., Jr. Introduction to statistical analysis. 3d ed. New York: McGraw-Hill; 1969. 638 p.

Dunn, P. H.; DeBano, L. F. Fire's effect on biological and chemical properties of chaparral soils. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on environmental consequences of fire and fuel management in Mediterranean ecosystems, 1-5 August, 1977, Palo Alto, California. Washington, D.C.: Forest

Serv., U.S. Dep. Agric. Gen. Tech. Rep. WO-3; 1977; 75-84.

El-Abyad, M. S. H.; Webster, J. Studies on pyrophilous discomycetes. I. Comparative physiological studies. Trans. Br. Mycol. Soc. 51:253-267; 1968a.

El-Abyad, M. S. H.; Webster, J. Studies on pyrophilous discomycetes. II. Competition. Trans. Br. Mycol. Soc. 51:369-375; 1968b.

Harris, R. F.; Chesters, G.; Allen, O. N. Soil aggregate stabilization by the indigenous microflora as affected by temperature. Soil Sci. Soc. Amer. Proc. 30:205-210; 1966.

Mutchler, C. K.; Young, R. A. Soil detachment by raindrops. In: Present and prospective technology for predicting sediment yield and sources. New Orleans, La.: Agric. Res. Serv., U.S. Dep. Agric. Publ. ARS-S-40; 1975; 113-117.

Tisdall, J. M.; Cockroft, B.; Uren, N. C. The stability of soil aggregates as affected by organic materials, microbial activity and physical disruption. Aust. J. Soil Res. 16:9-17; 1978.

Wells, W. G. II. Some effects of brushfires on erosion processes in coastal southern California. In: Erosion and sediment transport in Pacific Rim steeplands. Christchurch: Int. Assoc. Hydrol. Sci. Publ. 132; 1981; 305-342.

Wells, W. G. II; Palmer, N. R. The role of vegetation in inland sedimentation processes. Part D, Special inland studies. Sediment management for southern California mountains, coastal plains, and shoreline. Pasadena, Calif.: Calif. Inst. of Tech.: 1981; Environ. Qual. Lab. Rep. 17D (sec D-3) (In press).

Zak, J. C.; Wicklow, D. T. Response of carbonicolous ascomycetes to aerated steam temperatures and treatment intervals. Can. J. Bot. 56:2313-2318; 1978.

Zak, J. C.; Wicklow, D. T. Structure and composition of a post-fire ascomycete community: role of abiotic and biotic factors. Can. J. Bot. 58:1915-1922; 1980.

Water Yield Changes Resulting From Treatment of Arizona Chaparral[1]

A. R. Hibbert, E. A. Davis, and O. D. Knipe[1]

Abstract: Annual streamflow from small chaparral watersheds, in a 600-750 mm rainfall zone, was increased 75-150 mm and changed from intermittent to perennial flow by converting brush to grass with herbicides. Increases lasted up to 18 years with maintenance. At drier sites (450 mm rainfall) increases averaged less than 15 mm. Burning increased streamflow for 3-4 years while brush regrew. Both storm and nonstorm flows increased. About 85 percent of the increase occurs in 6 fall-winter months which get 60 percent of the precipitation. Yearly increases tend to be exponentially related to precipitation.

The chaparral vegetation type occupies about 1.2 million hectares (3 million acres)[3] in central Arizona (fig. 1). Average annual precipitation is 400 mm to 750 mm (16-30 inches). Chaparral shrubs transpire large amounts of water, leaving an average of only about 30 mm (1.2 inches) or 5 percent for streamflow. Transpiration can be reduced and streamflow increased by removing part or all of the shrubs and replacing them with shallow-rooted grasses and forbs. This paper updates the water yield potential portion of a detailed "status of knowledge" report (Hibbert and others 1974) on water yield improvement in Arizona chaparral.

Seven to eight years of additional research findings are reported, including several wet years, which are important in the interpretation of hydrologic relations in the chaparral.

The chaparral community in Arizona consists of a variety of deep-rooted, evergreen, sclerophyllous shrubs (fig. 2) usually dominated by shrub live oak (Quercus turbinella), or shrub live oak-mountain mahogany (Cercocarpus betuloides or C. breviflorus); manzanita (Arctostaphylos pringlei or A. pungens) may dominate locally (Carmichael and others 1978). The type occurs mostly at elevations between 1,000 m and 2,000 m and grows best where precipitation exceeds 500 mm (20 inches).

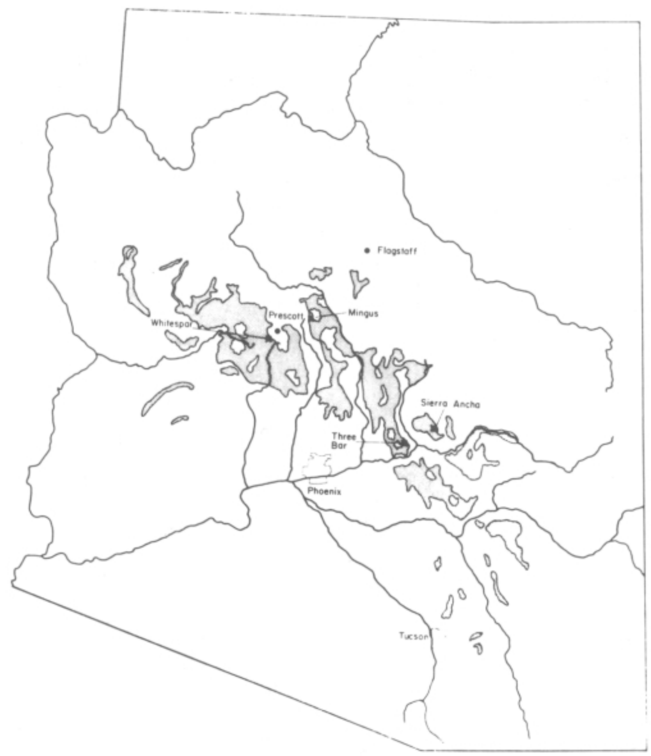


Figure 1--Distribution of chaparral in Arizona and location of experimental watersheds.

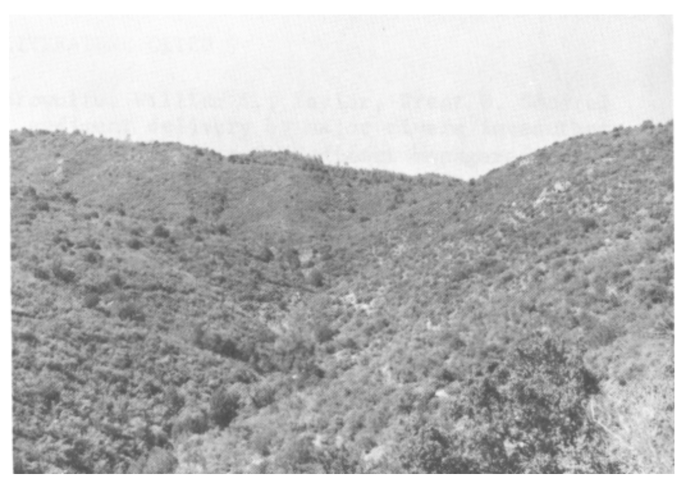


Figure 2--Mixed chaparral dominated by shrub live oak.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Authors are Research Hydrologist, Plant Physiologist, and Range Scientist, respectively, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station located at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University. Headquarters is in Fort Collins, in cooperation with Colorado State University.

[3]Estimates of chaparral area in Arizona vary widely. The most recent estimate taken from a vegetation type map by Brown and Lowe (1980) indicates nearly 3 million acres of chaparral in Arizona.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Chaparral shrubs are typically deep-rooted (Davis and Pase 1977) and usually grow on deeply weathered or fractured regoliths. Because the shrubs are evergreen, they transpire whenever atmospheric and soil moisture conditions are favorable. The climate favors high evapotranspiration rates from early spring to late fall; thus summer rains, which account for about one-third of the annual precipitation, seldom contribute to recharge. Consequently, winter rains must usually overcome soil moisture deficits before much water is available for streamflow.

The key to increasing water yield is the replacement of deep-rooted shrubs with shallow-rooted grasses and forbs that consume less water, largely because less water is available to the shallow-rooted plants. Also, interception of precipitation by grass is less than by brush, and seasonal dormancy of grass, particularly during winter, results in less water withdrawal.

WATERSHEDS AND TREATMENTS

The main objective of the chaparral watershed studies was to determine how much water yield could be improved by converting brush to grass. Studies were conducted in areas of low, medium, and high precipitation, corresponding roughly with open, medium, and dense chaparral. Treatments began in 1954 with eradication of the sparse shrub cover on two small so-called Natural Drainage watersheds on the Sierra Ancha Experimental Forest near Lake Roosevelt (fig. 1). Other treatments followed on Three Bar, Whitespar, and Mingus watersheds. Investigations of increasing complexity are now underway to achieve environmentally acceptable designs and treatment prescriptions.

Low Precipitation Areas

The Natural Drainage watersheds, at 1,420 m elevation, receive 485 mm (19.1 inches) mean annual precipitation. Exposure is southeast and slopes are moderate (15-25 percent). Total shrub cover, mostly shrub live oak, was 20 percent to 25 percent before treatment. The basal 150 mm (6 inches) of each shrub on watersheds A (5.4 ha) and C (6.9 ha) was hand sprayed in 1954-55 with a 6.6 percent solution of 2,4-D[4] and 2,4,5-T in diesel oil until the bark was saturated, and shrubs were resprayed as necessary to eradicate all shrubs. Adjacent drainages B and D were left untreated as controls. By 1959, grass production on the lower portions of the treated catchments with quartzite-derived fine-textured soils was over twice as much (420 kg/ha) as without treatment (191 kg/ha). Grass production did not change significantly on the upslope portions with diabase-derived coarse-textured soils. Forbs and half shrubs increased on all treated sites, with the greatest gain on the diabase soils. No seeding was attempted, and the watersheds were not grazed. Precipitation averaged 452 mm (17.8 inches) in the 17-year treatment period.

Mingus watersheds A and B get about the same precipitation (480 mm) as the Natural Drainages, but are at a higher elevation (1,800-2,100 m) and have greater shrub cover (47 percent). Exposure is westerly and slopes are steep (45-55 percent). Gravelly loam soils 38 cm to over 127 cm deep are derived from pre-cambrian volcanic and sedimentary rocks. Shrub live oak and mountain mahogany dominate in association with pinyon pine (*Pinus edulis*) and alligator juniper (*Juniperus deppeana*).

Prescribed burning on Mingus A (38.9 ha) and chemical brush control on Mingus B (26.8 ha) were compared as methods for improving water yield. Mingus C (17.3 ha) served as the untreated control. To minimize any treatment-induced erosion, particularly from burning, the upper halves of the watersheds were burned or chemically treated in 1974; the lower halves were similarly treated in 1975. Chemical treatment consisted of 50 percent active ingredient (ai) karbutilate "brush balls" applied by helicopter at 4.5 kg ai/ha.

Due to the patchy nature of the brush and scarcity of herbaceous understory, not all shrubs burned on Mingus A. Top kill of shrubs was estimated at 65 percent on the upper half and 75 percent on the lower half. The top-killed shrubs sprouted quickly from their root crowns, and within a few years regained much of their prefire crown cover and ability to use water. No follow up control measures were applied on the burned watershed. Treatment effects on Mingus B were delayed because of low rainfall (56 percent of average in 1974 and 63 percent in 1975) and slow release and movement of karbutilate into the shrub root zone. Shrub mortality continues after 6 years. Overall brush reduction on the watershed is estimated at 50 percent.

Medium Precipitation Areas

Whitespar watersheds A and B are located near Prescott, Arizona, between 1,770 m and 2,135 m elevation. Precipitation averages 600 mm (23.6 inches) per year. Exposure is southeast, slopes are steep (25 percent to 65 percent), and the granite derived fine gravelly loam soils are 48 cm to over 100 cm deep. The mature chaparral cover, dominated by shrub live oak and mountain mahogany, is considered medium dense at 51 percent crown cover. Patches of Gambel oak (*Quercus gambelii*) dominate locally on cool northerly slopes, and alligator juniper trees are scattered throughout.

[4]The herbicides discussed in this report have been used experimentally; their use does not imply that they are recommended or registered for watershed use. The use of any herbicide for project or commercial purposes must conform with regulations of the Environmental Protection Agency and be registered for the intended use.

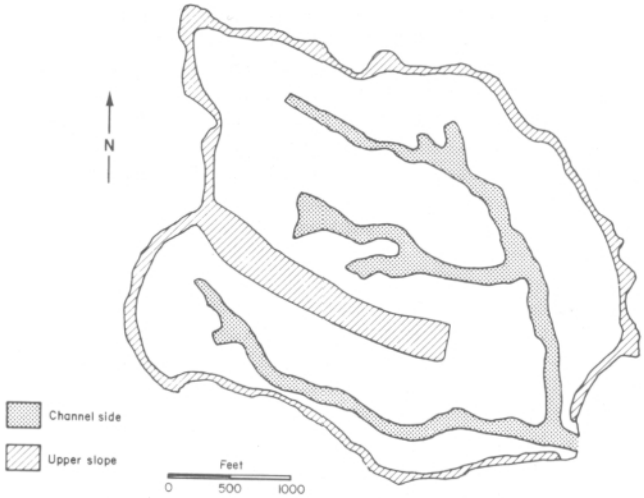


Figure 3--Whitespar watershed B on Prescott National Forest. Channel-side treatment was made in 1967, the upper slope treatment in 1973.

Chemical control of channel-side shrubs was the first of two treatments on Whitespar B (100 ha) (fig. 3). Channel bottoms and lower slopes were considered the most favorable sites to increase water yield because of greater soil moisture there, and therefore, a better opportunity to reduce transpiration. The second treatment, designed to simulate fuel break conditions, was on drier, more exposed ridge lines.

The channel-side treatment consisted of hand placement of pelleted fenuron (25 percent ai) at 26 kg ai/ha beneath the shrubs within 23 m either side of the stream channels in March 1967 on 15.4 ha (15 percent of the watershed). The treatment gave 80-90 percent control of the shrubs and follow up treatment has not been necessary. No grasses were seeded, since a fair population of native grasses and forbs were present; these increased adequately to protect the soil after shrubs were controlled. Cattle graze both watersheds.

The ridge line treatment was a helicopter application in 1973 of fenuron pellets (25 percent ai) at 14.9 kg ai/ha on a strip averaging 37 m wide inside the watershed boundary and a strip 80 m wide along a prominent interior ridge (fig. 3). The treated strips totalled 20 ha, or 20 percent of the watershed. Follow up hand treatment was necessary in 1976 because of uneven distribution of the chemical and poor shrub control from the aerial application. Overall shrub reduction was about 85 percent by 1980 (less than 10 percent shrub cover remaining).

High Precipitation Areas

The Three Bar watersheds (fig. 4) are characteristic of high precipitation, high-density chaparral. Elevation is 1,000 m to 1,600 m, exposure is northerly, and slopes are steep, some exceeding 60 percent. Soils are derived from coarse-grained, deeply weathered (6 m to 12 m) granite, and are capable of storing 500 mm or more of water (Ingebo 1969). Mean annual precipitation increases with elevation from 620 mm on watershed B to 750 mm on watersheds D and F. Shrub crown cover averaged 60-75 percent when gaging began in 1956. Dominants are shrub live oak and birchleaf mountain mahogany with sugar sumac (*Rhus ovata*), and Emory oak (*Quercus emoryi*) associated throughout.

Wildfire burned all watersheds in June 1959. Lovegrasses (*Eragrostis curvula*, *E. lehmanniana*, *E. chloromelas*), and yellow sweetclover (*Melilotus officinalis*) were seeded after the wildfire. Sprouting shrubs regained about one-third of their prefire crown cover in 3 years, and by the mid-1970's, after 11 years, recovery was 90 percent. Little herbaceous cover is present where shrubs were allowed to recover.

Watershed D (32.6 ha) was allowed to recover naturally after the fire to serve as the control; treatments to control regrowth were started in 1960 on watershed C (38.6 ha), in 1965 on watershed B (18.8 ha), and in 1969 on watershed F (27.7 ha).

Four annual spring applications of 2,4,5-T (1.8 kg ai/ha by helicopter) on watershed C beginning the year after the fire suppressed regrowth but killed only about half of the shrubs. Hand treatment of surviving shrubs with fenuron pellets at variable rates in 1964 and again in 1968 killed most of the remaining shrubs and reduced shrub cover to 8 percent. Three control burns (Pase and Knipe 1977) in 1971, 1974, and 1978, using grass

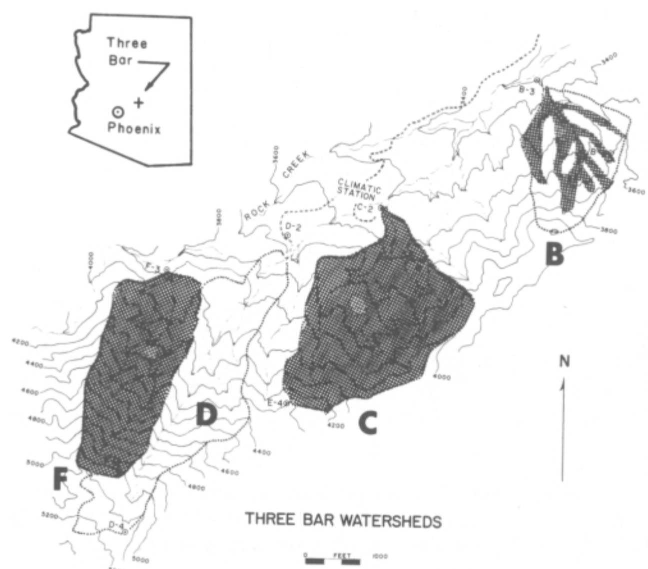


Figure 4--Three Bar experimental watersheds near Roosevelt Lake on Tonto National Forest.

to carry fire, kept shrub cover to less than 10 percent. Seeded lovegrasses and native grasses and forbs increased; their annual combined production averaged 1,345 kg/ha. Livestock have been excluded from the entire Three Bar area since 1947.

Watershed B was treated in two phases. Shrubs on northeast-facing slopes comprising 40 percent of the watershed were hand treated with either pelleted fenuron (20.5 kg ai/ha) or picloram (10.4 kg ai/ha) in 1965, 6 years after the wildfire. Follow up treatments on surviving shrubs in 1968 and 1978 kept shrub cover at about 8 percent. In phase 2, the remaining 60 percent of watershed B was hand treated in 1972 with 50 percent active karbutilate tablets at 7.5 kg ai/ha. The treatment was successful despite no rain for 4 months after treatment; no follow up treatment was required, since less than 10 percent shrub cover remained. Lovegrasses from the original postfire seeding and native grasses and forbs gradually increased on the treated areas, which provided adequate ground cover as the shrubs were controlled.

Watershed F was treated in 1969 with an aerial broadcast application of granular karbutilate at 22.4 kg ai/ha. Shrub crown cover was reduced from 55 percent to 4 percent the first year, and shrub kill increased to more than 95 percent (less than 3 percent shrub cover) after 2 years. Virtually all grasses and herbaceous plants were killed. In the second year after treatment a variety of forbs and grasses invaded the moist banks of the channel. In the third growing season forbs and grasses appeared on interior ridges, and by the fourth season a fair cover was present over all but the steep upper slopes, which were actively eroding. These steep slopes did not reach pretreatment stability for about 10 years.

RESULTS AND DISCUSSION

Changes in water yield are determined by the paired watershed method, in which annual water yields from the treatment watershed are regressed on those from the control watershed for the pretreatment and posttreatment periods. Any signifi-

Table 1--Water yield response to treatment of chaparral.

Watershed	Size	Portion treated	Shrub crown cover: Before[1] treatment	Shrub crown cover: After[2] treatment	Treat. period	No. of years	Precip.[3]	Expected yield[4]	Yield increase
	ha.	pct.					mm		
Natural Drainages									
A	5.4	100	20-25	0	55-71	17	485	34	5 ± 4[5]
	4.9	100	20-25	0	55-71	17	485	43	13 ± 5
Mingus									
A	38.9	100	47	14	76-80	5	480	2	10 ± 5
B	26.7	100	47	24	76-80	5	480	7	5 ± 5
Whitespar									
B Phase 1	99.8	15	51	<10	68-73	6	587	40	16 ± 5
B Phase 2	99.8	35	51	<10	74-80	7	589	47	13 ± 7
Three Bar									
C	38.6	100	73	<10	62-79	18	673	82	148 ± 84
B Phase 1	18.8	40	51	<10	66-72	7	564	9	30 ± 9
B Phase 2	18.8	100	52	<10	73-79	7	671	18	87 ± 54
F	27.7	100	55	<10	70-79	10	777	53	79 ± 34

[1]Prefire cover on Three Bar C and after 6, 13, and 10 years of postfire regrowth, respectively, on Three Bar B-1, B-2, and F.

[2]Shrub cover remaining after two or more years from first chemical application (see treatment descriptions). On Mingus A, unburned shrub cover was 14 pct. the first year, and resprouting shrubs increased the total cover each year thereafter.

[3]Mean precipitation for pretreatment and posttreatment periods combined.

[4]Expected yield is the amount that would be expected to occur without treatment.

[5]95 pct. confidence limits except Natural Drainage A and Mingus B, which are 90 pct.

cant change in the water yield relationship between watersheds after treatment is determined by covariance analysis and is interpreted as treatment effect. Acceptance or rejection of these changes is commonly made at the 95 percent confidence level.

Natural Drainages and Mingus Watersheds (Low Precipitation)

Increases in streamflow were significant at the 90 percent level on Natural Drainage A and Mingus B, and at the 95 percent level on all other treated watersheds (table 1). Average streamflow increases on Natural Drainages A and C for the 17-year posttreatment period were 5 mm (0.2 inch) and 13 mm (0.5 inch) per year, respectively (Ingebo and Hibbert 1974). Response varied from no increase in dry years to 26 mm (1 inch) increase in wet years (in fig. 5 Natural Drainages A and C are combined).

Average annual streamflow from Mingus A increased 10 mm (0.4 inch) for the 5-year period following the prescribed burns. Though small, the increase was nearly five times larger than the expected yield based on the mean yield of the control watershed for pretreatment and posttreatment periods combined (table 1). Precipitation was 22 percent above average for the 5 posttreatment years, due mainly to the fourth and fifth years being much above normal. At least part of the streamflow increase, particularly in the second treatment year, was attributed to an increase in overland flows from intense rains, due to reductions in infiltration and interception of rain caused by burning. We anticipate little if any increases in future years without retreatment.

The average increase on chemically treated Mingus B was 5 mm (0.2 inch) per year, most of which came in 1980, the fifth treatment year (fig. 5). Precipitation in 1980[5] was 768 mm, the most since gaging began in 1959, and 64 percent more than the 22-year mean. The lack of water yield increase from Mingus B during the first 4 posttreatment years is attributed to low rainfall and the slow breakdown of the brush balls. If brush injury and mortality continue to increase, it is anticipated that a water yield increase will be sustained, at least during wet years.

Whitespar Watersheds (Medium Precipitation)

Conversion of channel-side brush on Whitespar B increased annual yield an average 16 mm (0.6 inch) (table 1). If prorated to the area actually treated (15 percent of the watershed) the increase is 108 mm (4.2 inches). The second phase treatment along the ridgeline produced no increase in streamflow. Apparently, any water saved by shrub control on the upper slopes was lost to the intervening downslope vegetation as it moved through the regolith toward the channel.

The channel-side conversion created continuous flow for 5 years in the main channel, which had dried each year before treatment for as long as 8 or 9 months (Ingebo 1971). No follow up treatments were made on the few surviving shrubs after the original channel-side treatment.

Three Bar Watersheds (High Precipitation)

Streamflow increased substantially after brush conversion on all Three Bar watersheds. Increases were largest on watershed C, which averaged 148 mm (5.8 inches) per year more than expected without treatment for the 18-year posttreatment period (table 1). The conversion on watershed F increased streamflow by 79 mm (3.1 inches) per year for 10 years. Partial treatment (40 percent) on watershed B increased streamflow by 30 mm (1.2 inches) (75 mm if prorated to the area actually treated) for 7 years in phase 1, and full treatment increased flows by 87 mm (3.4 inches) in phase 2, also 7 years.

It should not be concluded from the results on Three Bar B that conversion of the entire watershed necessarily made it more water productive per unit area treated than conversion of 40 percent in phase 1. We anticipated that conversion of the entire watershed might increase yield less per unit area than conversion of the moist site areas in phase 1. However, precipitation was greater in the second phase, which created a higher yield potential as reflected by the expected yield in phase 2 being twice that of phase 1 (table 1). Had precipitation been similar in both periods, it is possible that the increase per unit area treated would have been less in phase 2 than in phase 1.

Three Bar C yielded less than control watershed D for each of the 3 prefire years (table 2). However, by the third year after the fire, with shrub sprouts being suppressed on C, there was a shift in the relationship between the two watersheds (Pase and Ingebo 1965). Watershed C produced twice as much as D (163 mm to 79 mm) in the third year when rainfall was near average, and 3.5 times as much in the fourth year with rainfall 67 percent of average. Streamflow on the control also increased relative to prefire conditions for several years after the wildfire, although increases in the third and later years were small (Hibbert 1971). The C/D water yield ratio for the 18-year treatment period, which included several very wet years, was 2.8; for the 12 intermediate years the C/D ratio was 3.5 (table 2).

A larger percent of precipitation was yielded in wet years than in dry years for both treated and control watersheds (streamflow increases exponentially with precipitation). The 3 wettest years, for example, produced 43 percent and 53

---

[5] Twelve months ending June 30, 1980. A July-June water year is used for all precipitation and streamflow data in this paper.

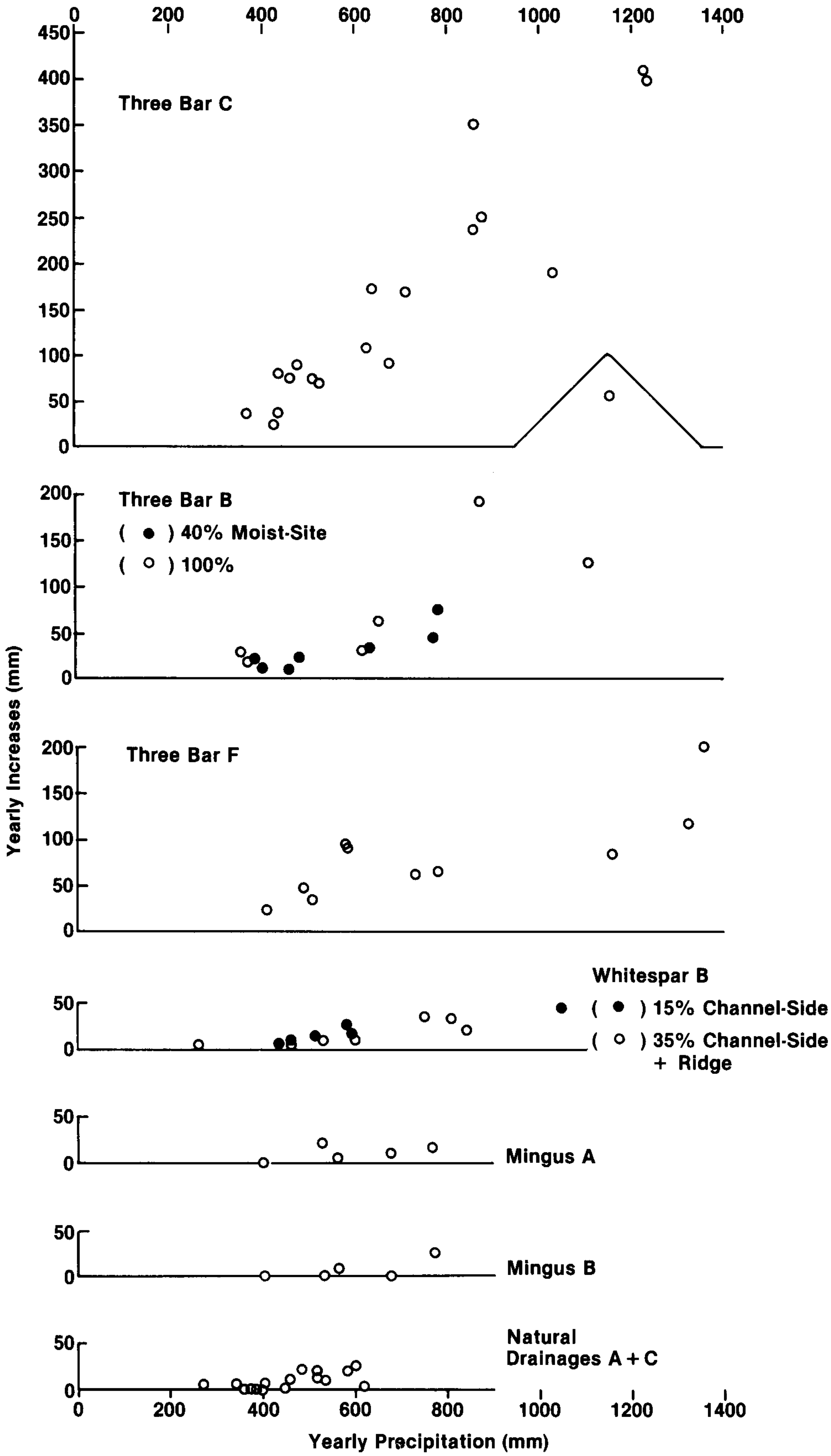


Figure 5--Yearly increases (difference between measured and predicted yield) plotted against yearly precipitation for posttreatment years.

Table 2--Comparison of annual precipitation and water yields on Three Bar watersheds C and D.

	Prefire 3 years	Post treat. 18 years	Wettest single year	Wettest 3 years	Inter-mediate 12 years	Driest 3 years	Driest single year
			Watershed C (treated)				
Mean precip. (mm)	554	693	1,240	1,168	645	414	371
Pct. of 24-yr. mean[1]	81	102	182	172	95	61	54
Mean yield (mm)	19	251	797	643	198	69	40
Pct. of 18-yr. mean[2]	--	100	18	43	53	5	0.3
Yield as pct. of precip.	3.4	36	64	55	31	16	11
			Watershed D (control)				
Mean precip. (mm)	620	765	1,334	1,283	711	465	411
Pct. of 24-yr. mean[1]	82	102	177	171	95	62	55
Mean yield (mm)	24	89	364	284	56	26	10
Pct. of 18-yr. mean[2]	--	100	23	53	42	5	0.6
Yield as pct. of precip.	3.8	12	27	22	7.9	5.7	2.4
C/D yield ratio	0.8	2.8	2.2	2.3	3.5	2.6	4.0

[1]Total period of gaging at Three Bar (1957-1980).

[2]First 2 postfire years were deleted from treatment period because of poor stormflow records and because fire-induced yield increases on the control were still high enough to partially obscure the effect of sprout control on watershed C. Streamflow not available for 1980.

percent of the total 18-year yields from the treated and control watersheds, respectively. This clearly indicates the importance of wet periods in determining and evaluating long term water yield averages.

The tendency for water yield to increase exponentially with precipitation both before and after treatment was apparent on most of the watersheds (fig. 5). However, neither Three Bar B nor F responded to conversion as strongly as did C. Streamflow increased nearly twice as much on C as on F, even though F gets more rain. Yearly increases on F were about the same as those on C in low to intermediate rainfall years, but were less in wet years (fig. 5).

Minor differences in treatment methods and cover reduction do not account for the large differences in response to conversion. There is the possibility of leakage into or out of one or more of the watersheds; watershed F yielded only 55 percent as much as control watershed D before treatment, and a fault extends across watershed F just above the stream gage and continues across the lower part of D and into C where it disappears. We have speculated on the possibility of water moving from F or D or both into C, which would help account for the yield differences between C and F. However, neither watershed C nor D showed any consistent shift in yield, based on precipitation, when F was treated, nor was there any indication before the wildfire that external water was entering watershed C, since it yielded less than D (F was not gaged until 1962).

Sharp increases in overland flow were observed after the wildfire on all the Three Bar catchments. In the summer before the fire, an intense rain (42 mm in 45 minutes) caused no streamflow on any of the watersheds. Six weeks after the wildfire, however, a very similar storm, (44 mm in 60 minutes), literally buried the stream gages under sediment and debris. Accurate measurement of stormflows from this and some of the later storms was not possible. However, it was obvious that rains of even moderate intensities were not soaking into the soil as before, and that overland flow and surface erosion were increased. Despite the spectacular flashiness of the summer stormflows, they contributed less than 20 percent of the early postfire streamflow. After the first summer, which was unusually wet, overland flows subsided gradually, and by 1964, peak flows and stormflows showed little sign of overland flow.

Streamflow on all the treated Three Bar watersheds became perennial at their outlets even though upstream channels were frequently dry. This was true even on watershed B after treatment of only 40 percent of the area. Flow was absent on B during the 3 prefire years, became intermittent shortly after the fire, and remained so until the 40 percent treatment in 1965.

Some of the watersheds responded more quickly to treatment than others. Increases in streamflow usually were detected within the first treatment year, sometimes within a few months of herbicide application. Streamflow responded on watershed F within a few weeks of first observed injury symptoms on the shrubs (Hibbert and others 1974).

Approximately 80 percent of total streamflow from control watershed D at Three Bar is from non storm or delayed flow. Treatment increases both storm and delayed flows, although it is uncertain which increases the most. We do know that about 85 percent of the increases are produced in the dormant season (November-April), which benefits the delivery of the extra water for downstream uses. Since many of the streams draining chaparral areas are dry during summer because of low inflows and heavy evapotranspiration losses along the watercourses, it follows that any small amount of water increases added in the summer might also be evaporated. However, since the increases are generated primarily in winter when streams are flowing already, further losses in transit to downstream storage should be small.

MANAGEMENT IMPLICATIONS

The experiments described in this paper were designed to get basic information on water yield relations in the chaparral, and on ways to increase streamflow. Some of the treatments would be unrealistic for management purposes, and are not recommended for large-scale application. To maximize water yield, shrubs should be eradicated as completely as practicable on the area actually treated, and the treated areas should be adjacent to or as close as possible to drainage ways to avoid loss of water savings to downslope vegetation.

The concept of creating brush-grass mosaics is being researched to integrate management objectives and optimize multi-resource outputs. Steep slopes and unstable soils must be avoided or given special attention to avoid excessive erosion. Likewise, domestic livestock, wildlife, and esthetic interests must be recognized and dealt with in designing treatments. Because of these constraints, water yield increases from future large-scale projects are likely to be less than those obtained from the experimental watersheds. Furthermore, since a disproportionate amount of the increased yield is produced in wet years, the extra water may be lost to the extent that downstream storage capacity is exceeded and water is spilled.

The extent to which these findings can be extrapolated to other areas is uncertain. The small increases obtained on Natural Drainages and Mingus watersheds were not unexpected because of low precipitation and relatively sparse shrub cover, which uses relatively less water, and therefore offers less potential for reducing evapotranspiration by conversion to grass. Based on these results, chaparral areas that receive less than 500 mm (20 inches) mean annual precipitation should be considered marginal for water yield improvement purposes. The potential appears good, however, for areas such as Three Bar, where average precipitation is greater than 500 mm, shrub cover is dense, and soils (regolith) are deep and permeable. But because of the large differences in treatment response at Three Bar, only partly explained by precipitation, extrapolation of these results to other areas involves some risk. Until reasons for the differences are better known, and can be quantified, large errors (± 2/3 of mean) (Hibbert and others 1974) must be expected in predicting response to treatment.

LITERATURE

Brown, David E.; Lowe, Charles H. Biotic communities of the Southwest. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Rep. RM-78. Map.

Carmichael, R. S.; Knipe, O. D.; Pase, C. P.; Brady, W. W. Arizona chaparral: Plant associations and ecology. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1978; Res. Pap. RM-202. 16 p.

Davis, Edwin A.; Pase, Charles P. Root system of shrub live oak: Implications for water yield in Arizona chaparral. J. Soil and Water Conserv. 32(4):174-180. 1977.

Hibbert, Alden R. Increases in streamflow after converting chaparral to grass. Water Resour. Res. 7:71-80. 1971.

Hibbert, Alden R.; Davis, Edwin A.; Scholl, David G. Chaparral conversion potential in Arizona. Part I. Water yield response and effects on other resources. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Pap. RM-126. 36 p.

Ingebo, Paul A. Effect of heavy late-fall precipitation on runoff from a chaparral watershed. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1969; Res. Note RM-132. 2 p.

Ingebo, Paul A. Suppression of channel-side chaparral cover increases streamflow. J. Soil Water Conserv. 26:79-81. 1971.

Ingebo, Paul A.; Hibbert, Alden R. Runoff and erosion after brush suppression on the Natural Drainage watersheds in central Arizona. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1974; Res. Note RM-275. 7 p.

Pase, C. P.; Ingebo, P. A. Burned chaparral to grass: Early effects on water and sediment yields from two granitic soil watersheds in Arizona. Arizona Watershed Symposium. [Sept. 1965:Tempe, Ariz.] Proc. 9:8-11. 1965.

Pase, C. P.; Knipe, O. D. Effect of winter burning on herbaceous cover on a converted chaparral watershed. J. Range Manage. 30(5):346-348. 1977.

Influence of Prescribed Burning on Nutrient Budgets of Mountain Fynbos Catchments in the S. W. Cape, Rep. of South Africa[1]

D. B. Van Wyk[2]

Abstract: The nutrient budgets of the Western Cape Mountain fynbos areas of the Republic of South Africa have been the subject of investigations since 1971. The average nutrient input (120 kg/ha/yr) exceeds the output (96 kg/ha/yr) by 29 percent. Because in this case the main source of nutrients in precipitation is the sea, heavy loads of Na and Cl are deposited into the fynbos areas. The other constituents of precipitation are K, Ca, Mg, Cl. Traces of HCO_3 and SO_4 were found, while no traces of N and P were detected. The constituents in streamflow were present in the same ratio as in precipitation. The influence of prescribed burning in different seasons on stream water quality was also investigated. Results indicate that nutrient release as a result of prescribed burning does not persist beyond the first winter after burning. The month in which burning takes place has an influence in this respect. It was found that the net release of nutrients takes place during the first two floods after the burn. There is no marked increase in sediment loads of the streams after burning.

The undisturbed mountain fynbos areas of the Western Cape characteristically produce sediment-free, high-quality water. Fire is a widely used tool in managing the vegetation here. Fire can have a beneficial effect by increasing the quantity of water flowing out of these catchment areas and also benefit the vegetation itself, but may have a negative effect on the mineral budgets and other facets of the fynbos ecosystems. Thus research was started in 1971 with the purpose of formulating suitable management prescriptions for the fynbos, which is inherently sensitive. Initially only the influence of prescribed burning on the chemical quality of the water was studied. Research was later expanded to include the study of mineral budgets in burnt, protected and afforested catchments.

Results show that in these systems bulk nutrient input appears to exceed output. Furthermore it is clear that veld management can have a marked effect on stream water quality as well as on the intricate balance that exists between precipitation deposition and internal mineral cycles within the catchment.

This paper reports the influence of prescribed burning at different rotations (4 to 13 years) and seasons (Spring, Early Summer and Autumn) on mineral budgets, water quality and sediment loads of streams in the Jonkershoek, Zachariashoek and Jakkalsrivier research areas in the Western Cape mountain fynbos areas.

THE STUDY AREA

The study areas are in the mountain catchments of the South Western tip of Africa, a zone of mediterranean-type climate. Some information about the relevant areas is listed in Table 1. The research areas are shown in Figure 1, and their position is approximately 19°E and 34°S.

The underlying strata present in these areas are of Table Mountain sandstone, shale and granite. The geology of the areas is discussed by Wilson (1964), Van der Zel (1974), Kruger (1974) and Wicht *et al*. (1969).

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems. An International Symposium, June 22-26, 1981, San Diego State University California.

[2]Hydrologist, Department of Water Affairs, Forestry and Environmental Conservation, Jonkershoek Forestry Research Station, Private Bag X5011, Stellenbosch, 7600. Republic of South Africa.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--The research areas and management practices applied

Area	Name	Geology	Mean annual precipit-ation (mm)	Mean annual runoff (mm)	Manage-ment	Rotation (years)	Season
A	Zachariashoek	Quartzites and shales of Table Mountain Group	1 238	581	Burning	6 & 12	Early Summer
B	Jonkershoek	Quartzites of Table Mountain Group and Cape Granite	1 618	723	Burning	Variable 4 - 13	Variable Winter
C	Jakkalsrivier	Quartzites and shales of Table Mountain Group	961	367	Burning	5 & 10	Spring Autumn

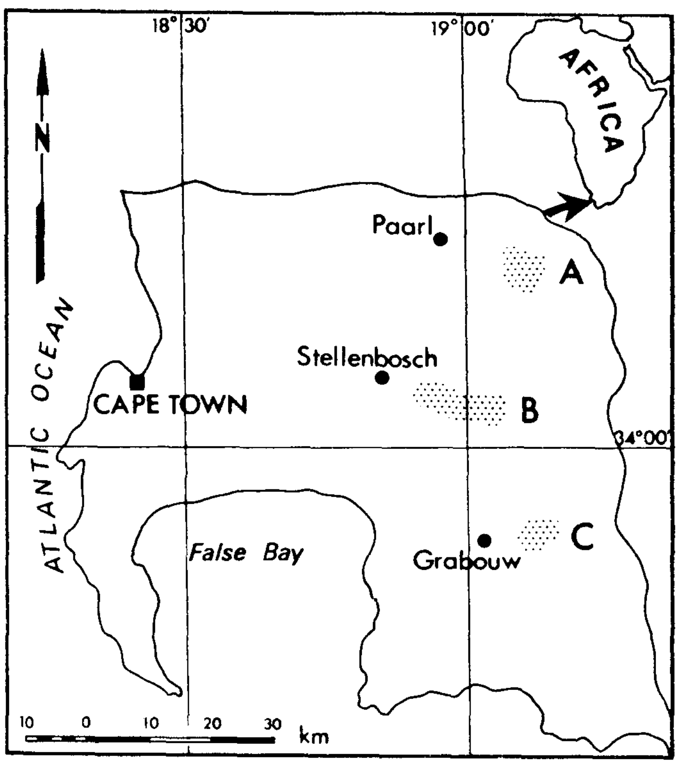


Figure 1--Location of the study area. A Zachariashoek, B Jonkershoek, and C Jakkalsrivier. (See Table 1).

CLIMATE AND HYDROLOGY

The climate of all the research areas is mediterranean. The summer seasons are dry, and the average temperature of the warmest months varies between 18°C and 22°C. Summer temperatures above 38°C are occasionally recorded. Cool to mild conditions prevail during winter.

The prevailing winds are north-westerly in the winter and south-easterly in the summer.

Over 90 percent of the annual rainfall occurs during the winter. The average rainfall in these areas ranges from 1 000 mm to 2 200 mm per year. The streams in all these catchments are perennial. Streamflow amounts to 40 to 60 percent of rainfall. See Table 1 for the mean annual precipitation and runoff.

VEGETATION

The natural vegetation of the research areas is discussed by Van Wilgen and Kruger (1981), Kruger (1974) and Wicht et al. (1969). Most of the area is covered with xerophytic, sclerophyllous scrub of a type characteristic of the mediterranean climate and which has ecological affinities with vegetation of other Mediterranean ecosystems. In the Republic of South Africa it is known as Fynbos.

EXPERIMENTAL METHODS

The experimental methods applied were adapted from the studies of Likens, Bormann, Johnson, Fisher and Pierce (1969).

Meteorological, rainfall and streamflow data are collected at all of the research areas on a routine basis (Wicht 1967). Manual water sampling of streams was carried out weekly from 1971 and precipitation samples were collected over the same period by means of a sterile apparatus that opens only when it rains (Van der Zel 1974). Dry input of the area was measured over a short period.

Table 2--The minimum detection levels and the nutrient concentrations in precipitation and streamwater of A Zachariashoek, B Jonkershoek and C Jakkalsrivier experimental catchments.

Ion	Concentrations mg/ℓ					
	Precipitation Area		Streamflow Area			Minimum detection level, mg/ℓ
	A	B	A	B	C	
Na	2,067	2,722	4,412	4,02	9,375	0,1
K	0,220	0,725	0,163	0,398	0,513	0,1
Ca	0,436	0,422	0,495	0,430	0,800	0,1
Mg	0,359	0,268	0,733	0,537	1,850	0,1
Cl	4,519	5,000	9,011	6,377	18,375	5,0
SO_4	<5,0	<5,0	<5,0	<5,0	6,25	5,0
HCO_3	<5,0	<5,0	<5,0	<5,0	<5,0	5,0
PO_4	<0,1	<0,1	<0,1	<0,1	<0,1	0,1
NO_3-N	<1,0	<1,0	<1,0	<1,0	<1,0	1,0
NO_2-N	<0,5	<0,5	<0,5	<0,5	<0,5	0,5

These measurements were obtained during weeks with no rain.

Apparatus for the sampling of floods was also developed at the Jonkershoek Forest Research Station. This sampler functions in stages on the rising and falling limbs of floods. The apparatus was used to sample the first floods after an experimental burn. Before the development of the sampler first floods after prescribed burns were sampled manually during the rising and the falling stages.

Conductance and pH of the samples is measured weekly, whilst a full chemical analysis of the water is done monthly by the C.S.I.R. (Council for Scientific Industrial Research). Samples are analysed for Na, K, Ca, Mg, Cl, SO_4, HCO_3, and P. The precision of the analyses is indicated in Table 2.

A factor (0,54) to convert conductance to total dissolved solids was calculated based on eight years' data for the Western Cape mountain streams.

The samples are vacuum filtered and sediment loads are determined.

PRECIPITATION CHEMISTRY

This was the first attempt at investigating precipitation chemistry in this region. The addition of nutrients by way of precipitation can certainly be of significance in areas of low natural fertility such as the fynbos mountain catchments.

The main input of nutrients into any catchment is through wet or dry deposition (Dethier, 1979). The location of the research areas in relation to the sea and industrial areas makes it probable that these two sources are significant for nutrient input in these fynbos areas.

The major chemical constituents of precipitation are K, Na, Ca, Mg and Cl. HCO_3 and SO_4 were undetectable in most samples, while no traces of P or N could be found during the study period. Data for inputs and outputs are summarised in Tables 2 and 3.

Bulk annual input of nutrients into Zachariashoek research area through precipitation varies from 66 kg/ha to 196 kg/ha; the eight-year average is 120 kg/ha/year (Table 4). Ion concentrations of precipitation range from 2 mg/ℓ to 60 mg/ℓ, and the relationship between rainstorm depth and ion concentration was negatively curvilinear, namely

Sampler RK: $Y = 20,4875 - 3,0153 \ln X$
Sampler RZ: $Y = 23,9000 - 3,8700 \ln X$

RK and RZ are precipitation samplers in the Zachariashoek research area, Y is ion concentration of precipitation (mg/ℓ) while X is the rainstorm depth (mm) that was sampled. In both cases r^2 was 0,24.

Precipitation dividers, developed at the Jonkershoek Forest Research Station, were installed and samples of precipitation at progressive stages during storms were collected. The results obtained did not show a trend as the rainstorms progressed.

Table 3--Average ion in- and output in the S. W. Cape mountain catchments by precipitation and stream discharge in Kg/Ha/Yr.

Average ION budgets/Kg/Ha/Yr		
Ion	Input	Output
Na	27,011	23,929
K	2,335	0,753
Ca	5,755	3,304
Mg	5,238	3,740
Cl	56,514	42,105
SO_4	TR	TR
HCO_3	TR	TR
P	TR	TR
N	TR	TR

In some cases there was a decrease in concentration, in other cases there was a rise and in some cases the concentrations were variable. Cole and Johnson (1977) found in a study near Washington U.S.A. that there was a variable increase in TDS over a 12 h rainstorm. This is comparable with the results obtained in this study.

Dry deposition in these areas is minimal and depends to a large extent on presence of fall-out from industrial areas, prevailing winds, traffic and cultivation. It constitutes 10,4 kg/ha/yr (8,4 percent of the bulk input) in the Zachariashoek area. In the case of Jonkershoek the dry input is probably more and in the case of Jakkalsrivier less - depending on the factors mentioned above. Brasell and Gilmour (1980) found that dry inputs can be regarded as minimal in Queensland, Australia. Low levels were also found in the U.S.A., but depended on the prevailing humidity (Cole & Johnson 1977).

Chemical analysis of dry deposition indicated that anthropogenic and continental aerosols were not the main dry input sources: low levels of Ca, Mg and SO_4 were found.

The ranges of concentrations of the constituents of precipitation in these areas appear in Table 2. These values show that the ionic concentrations in precipitation are lower than those in streams. The concentrations of SO_4 and HCO_3 are very low, and these ions cannot be regarded as regular constituents of precipitation input.

Low concentrations of nutrients are found during winter (2 mg/ℓ) and high values during summer (60 mg/ℓ). The high summer concentrations have a relatively minor effect on the total input of nutrients; more than 77 percent of the total yearly nutrient input is deposited during the period April to September (winter).

Table 4--The total average yearly nutrient budgets (Kg/Ha/Yr) of a mountain fynbos catchment at Zachariashoek in the Western Cape.

Total nutrient budgets			
	Kg/Ha/Yr		Average percent of output provided by input
Year	Average Input	Average Output	
72	73	55	133
73	98	65	151
74	114	110	104
75	121	98	123
76	173	119	145
77	174	169	103
78	90	61	147
Average	120	96	129

The average pH for precipitation in this area ranges from 4,7 to 5,0. This is higher than that of polluted rain from industrial discharge.

STREAMFLOW CHEMISTRY

Samples were taken from perennial streams in sixteen fynbos catchments in the three experimental areas. This sampling clearly indicates the range in quality of the streams in this region.

The concentration of solids in streams ranges from 10 - 60 mg/ℓ. There is a clear seasonal variation. During winter there is a drop in the concentration levels due to an increase in discharge. The reverse takes place during summer.

The main outflow of nutrients from these catchments comprises Na and Cl (see Table 3) with lower levels of K, Ca and Mg. No traces of P and N were found. As regards HCO_3 and SO_4 the results were not constant for the different research areas. Only traces of HCO_3 were observed at Zachariashoek and Jonkershoek (<5 mg/ℓ) while levels at Jakkalsrivier were constant at 6 mg/ℓ. The same trend was observed in the case of SO_4.

The budget in Table 4 shows a net gain of nutrients through precipitation to the Zachariashoek area by an annual average of 29 percent (24,5 kg/ha/yr). These results show that the areas are nutrient poor and that the loss of nutrients from the catchment is partly due to mineralization by ion exchange accelerated by heavy loads of ions in the precipitation.

Table 5-- First spates after prescribed burning. Average ion concentrations in the Zachariashoek (early summer burn) and Jakkalsrivier (autumn burn) catchments.

	Concentrations Mg/t				
	Early summer burn			Autumn burn	
	Output		Input	Output	
	Spate		Precipit -ation	Spate	
	Pro- tected	Burned		Pro- tected	Burned
Na	4,645	6,70	2,155	9,46	18,48
K	0,115	2,29	0,255	1,86	7,135
Ca	0,375	1,125	0,330	1,06	3,85
Mg	0,655	1,355	0,380	1,83	5,73
Cl	8,365	15,20	5,425	18,38	35,58
SO_4	5,000	10,60	2,500	5,83	27,57
HCO_3	1,225	3,690	1,000	2,958	6,687

The pH levels of the streams vary from 3,2 to 6,5, this variation correlates partly with substrate, the highest pH in the granites at Jonkershoek and the lowest value for the "black waters" of Jakkalsrivier.

BURNING AND STREAM CHEMISTRY

Experimental burns were applied to several catchments in September (spring) 1974 and 1979, November (summer) 1971 and 1977 and March (autumn) 1975 and 1980. The ion concentration values obtained during the first spate after these burns are presented in table 5, together with the results from the unburnt catchments. The two November burns were unfortunately followed by years of below average rainfall. This may have had a marked influence on the results obtained.

The total monthly outflow of nutrients rose by 1 kg/ha after an early summer burn at Zachariashoek. This effect lasted for only 10 months after the burn. The first two winter months after the burn produced the greater part of the post-burn nutrient outflow.

Six months after a spring burn at Jakkalsrivier the initial increase in nutrient levels in streamflow had returned to pre-burn levels. In these six months there were fourteen rainstorms with only four of more than 10 mm.

Twelve weeks after the autumn burn at Jakkalsrivier the total nutrient output returned to pre-burn levels.

In samples taken on a weekly basis, concentrations of Na and Cl showed a

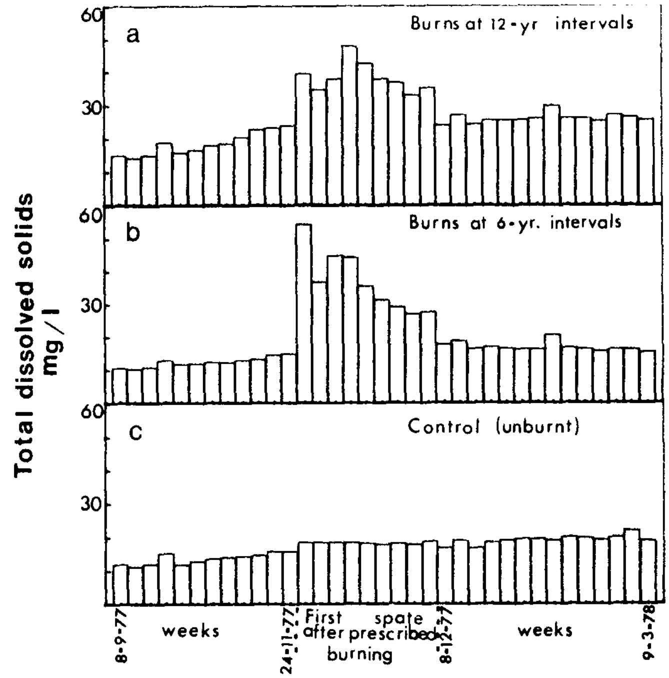


Figure 2--The influence of prescribed burning at different rotations at Zachariashoek on the total dissolved solid content of the first spate, on 30/11/77 and 1/12/77, after the burning.
(a) Zachariashoek catchment (b) Kasteelkloof catchment (c) Bakkerskloof catchment.

noticeable increase after burning but changes in the concentrations of Mg, Ca, and K could not be detected. However, there was an increase of SO_4 and HCO_3, which had been at very low levels before the burn.

Thus, Na and Cl comprised the bulk of the increase in total dissolved solids following fire.

Analysis of samples during the first four spates after an early summer burn shows an increase in total nutrient output during the first two spates only. Figure 2, a & b shows the influence of the burn during the first spate after fire. No increase in nutrients was found in the control catchment during this spate (see figure 2c). Furthermore a previous spring burn of two catchments at Jakkalsrivier had no influence on the chemical content of streamflow during a spate six months after the burn. The bulk outflow of nutrients occurred during a few spates after late spring rains. Only occasional rains were recorded in the summer. This is the normal rainfall pattern.

Analysis of the rainfall pattern shows that 13 rain storms occurred in the period

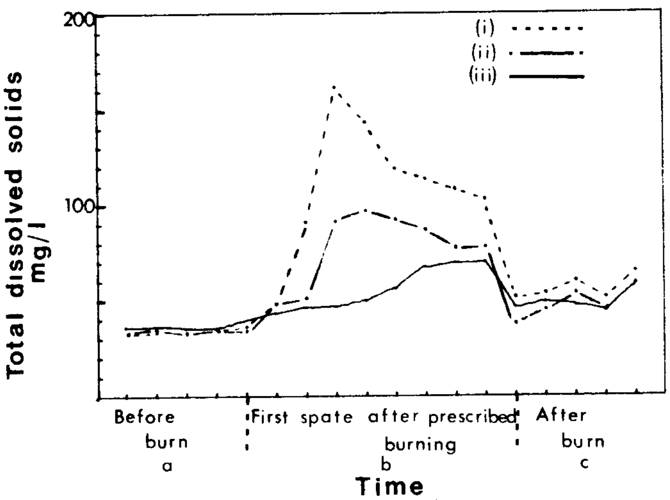


Figure 3--The response in total dissolved solids as they are influenced by source area at Jakkalsrivier. The trace mark represents the total dissolved solids in streamwater of a catchment that was (i) 100 percent burned (ii) 62 percent burned and (iii) 27 percent burned. Period (a) is a calibration period from 1978 to 1979 with irregular sampling; (b) sampling during spate over 24 hours based on stage; (c) irregular sampling after spate during 1980.

between the spring burn (October) and the autumn burn (March). Two were high intensity storms (27 - 35 mm) and the rest were of a minor nature. During these two storms the release of all nutrients which became available from the catchment after the burn probably took place.

Analysis for the ions Na, K, Ca, Mg, Cl, SO_4, HCO_3 also shows an increase in concentration during the first floods after the burns. The same trends were observed in all the burned catchments. It is interesting to note that SO_4 and HCO_3 concentrations which had been at more or less untraceable levels before, peaked during the flood. (See Table 5). In every case only traces of P and N in its various forms were found. Concentrations of all the measured ions declined on the recession of the spate. There was no increase in concentration of any of the ions in the control catchments during the spate.

The dilution effect of contribution of streamflow from protected catchments is shown by Figure 3. Samples taken from immediately below the burnt catchment showed an increase in nutrient outflow during the first spate after an autumn burn, while the sample point further downstream showed a delay in recording the increase of nutrients. The level of increase also drops markedly due to the influence of water inflow from the protected fynbos areas.

At Jakkalsrivier there was an increase in pH during the first spate after the autumn burning. The pH of the burnt catchments was 1,5 to 2,0 pH units higher than the pH of the control streams in the same area before burning took place. This was the case only in areas with black waters (humic stained) and where the normal pH is between 3,2 and 4,0. In the other catchments, where the pH is normally about 5,0, no response to fire was recorded.

EFFECTS OF FIRE ON SUSPENDED SEDIMENT

Results obtained by means of stage sampling for suspended sediment during spates show that the sediment loads from the fynbos-vegetated catchments at Zachariashoek are very low, the maximum average release of suspended sediment from a 350 ha fynbos catchment being 0,0291 kg/ha. This fynbos catchment yielded a total of 0,04 kg/ha of suspended sediment over the four spates that followed burning.

The sediment loss after prescribed burning in early summer at the Zachariashoek area was 0,20 kg/ha (287 ha catchment) and 0,97 kg/ha (324 ha catchment). The total suspended sediment release for the first three spates after prescribed burning was 224 kg and 748 kg from these burnt catchments. During the same period only 10 kg was released from the protected catchment, mentioned in the previous paragraph. If it is taken into account that sediment release occurred during three spates over a period of four months, and that the catchments cover an area of roughly 300 hectares, sediment loss may be regarded as minimal.

After an autumn burn at Jakkalsrivier the quantity of suspended sediment released was found to be even smaller. During the first spates after this burn, the protected catchments released less than 0,01 kg/ha, while the burned catchment released 0,04 kg/ha.

Loss of soil from fynbos catchments occurs in stages. The soil is brought down the slopes by soilcreep and is released from the catchment as bed load. This is the principal way in which soil is lost from most of the fynbos catchments of the Western Cape. Bedload release has been measured for the past ten years.

Results of bedload measurements from fynbos catchments show that the protected catchment releases more soil in this form than the burnt catchments. Soil slips also appeared in the protected catchments, but were not observed in the burnt catchments. Higher rainfall infiltration due to the higher vegetal cover may have an influence in the latter case. The results here show the weighted average yearly mass of bed-load from the regularly burned catchments was 6,26 kg/ha against 7,72 kg/ha from the control catchment with 10 years old fynbos.

Turbidity was not measured, field observation shows that it is very high during the rise of any spate, but lessens during the recession of the spate and the water soon becomes as clear as it had been before.

According to the results of measurement of suspended sediment from burnt and protected fynbos catchments obtained so far, it seems obvious that suspended sediment from the table mountain sandstone catchments is very low, and that burning does not have a significant effect on sediment loads.

Because sediment release is difficult to monitor, more data are required for the fynbos areas before a full understanding of sediment loss and the erosion of burnt and protected areas may be reached.

ACKNOWLEDGMENTS

My thanks to the sponsors of this symposium who gave me the opportunity to attend, the Council for Scientific Industrial Research (Water Unit) who did the analysis of the water samples. My thanks to the technical section of Jonkershoek FRS and in particular Mr. Barnard for his field work. Messrs F.J. Kruger, D.P. Bands and Mrs. Gouws for checking the final draft of the paper and Mrs. Basson for her excellent typing services. This work forms part of the conservation forestry research programme of the Directorate of Forestry and Environmental Conservation and is published with permission.

LITERATURE CITED

Brasell, H.M.; Gilmour, D.A. The cation composition of precipitation at four sites in far north Queensland. Australian J. of Ecology; 1980: 5, 397-405.

Cole, Dale W.; Johnson, D.W. Atmospheric sulphate additions and cation leaching in a Douglas fir Ecosystem. Water Resour. Res; 1977 April; 13(3): 313-317.

Dethier, David P. Atmospheric contributions to stream water chemistry in the North Cascade Range, Washington. Water Resour. Res.; 1979 April; 15(4): 787-794.

Fisher, D.W.; Gambell, A.W.; Likens, G.E.; Bormann, F.H. Atmospheric contributions to water quality of streams in the Hubbard Brook Experimental Forest, New Hampshire. Water Resour. Res. 1968 October; 4(5): 1115-1126.

Kruger, F.J. The physiography and plant communities of the Jakkalsrivier catchment. Unpublished M. Sc. thesis University of Stellenbosch; 1974.

Likens, G.E.;Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; Pierce, R.S. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecological Monographs; 1969 July; 40(1): 23-47.

Van der Zel, D.W. Catchment research at Zachariashoek. For. in South Africa 1974; 15: 23-30.

Van der Zel, D.W. 'n Veldbrandeksperiment op meervoudige opvanggebiede in Jakkalsrivier, Lebanon. Bosbou in Suid-Afrika 1969 Oktober, 10: 63-71.

Van Wilgen, B.W.; Kruger, F.J. Observations on the effects of fire in mountain fynbos at Zachariashoek, Paarl.J. S. Afr. Bot.; 1981; 47(2): 195-212.

Wicht, C.L. Forest Hydrological research in Southern African Republic; 1967; Intern. Symp. on Forest Hydrology. Penn. State Univ. Pennsylvania, U.S.A.

Wicht, C.L.; Meyburgh, J.C.; Boustead, P.G. Rainfall at the Jonkershoek forest hydrological research station. Annale University of Stellenbosch. 1969; 44A(1).

Wilson, P.T. Geological and geohydrological report on proposed experimental mountain catchments in the winter rainfall region. Unpublished report to the Inter Departmental Coordinating committee for hydrological research, 1964, January.

Effects of Vegetation Change on Shallow Landsliding: Santa Cruz Island, California[1]

Robert W. Brumbaugh, William H. Renwick, and Larry L. Loeher[2]

Abstract: Santa Cruz Island has been grazed by sheep for over 100 years. During this time large areas of coastal sage scrub and pine and oak woodland have been reduced to grass or barren ground and the resulting soil erosion has been severe. In 1978 an intense series of storms caused more extensive landsliding than has occurred in the last half century. Triggering mechanisms, slide morphology, and denudation rates are related to soil and vegetation characteristics. The most extensive landsliding is temporally associated with intense rainfall which occurred decades after vegetation conversion.

In many Mediterranean-type zones with rugged terrain, particularly southern California, mass movements include dry sliding, deep seated failures, and shallow soil slips. This paper will concentrate on the latter. Several studies have examined the relations of shallow landsliding to vegetation type in Mediterranean lands. Rice and others (1969) and Rice and Foggin (1971) have shown that conversion of chaparral vegetation to grasses resulted in a 180 to 640 percent increase in slip erosion (depending on storm size) in the San Gabriel Mountains, southern California. This is attributed to the decrease of root strength in the soil. On Santa Cruz Island, reduction in vegetal cover by grazing during the last 130 years has caused a considerable increase in erosion (Brumbaugh) 1980). It is yet unclear to what extent this increase is attributable to landsliding as opposed to fluvial erosion. In early 1978 a series of heavy rains caused very extensive shallow landsliding on the island, and this recent activity is the subject of the present study.

Santa Cruz Island lies 40 km south of Santa Barbara, a approximately 34°N, 119°45W (fig. 1). The 249-km^2 island has very rugged topography as a result of rapid stream downcuttinq, and slopes in excess of 40° are common. The diverse bedrock geology includes volcanic, plutonic, and diverse

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Department of Geography, California State University, Northridge, California; Department of Geography, Rutgers University, New Brunswick, New Jersey; and Department of Geography, University of California, Los Angeles, California.

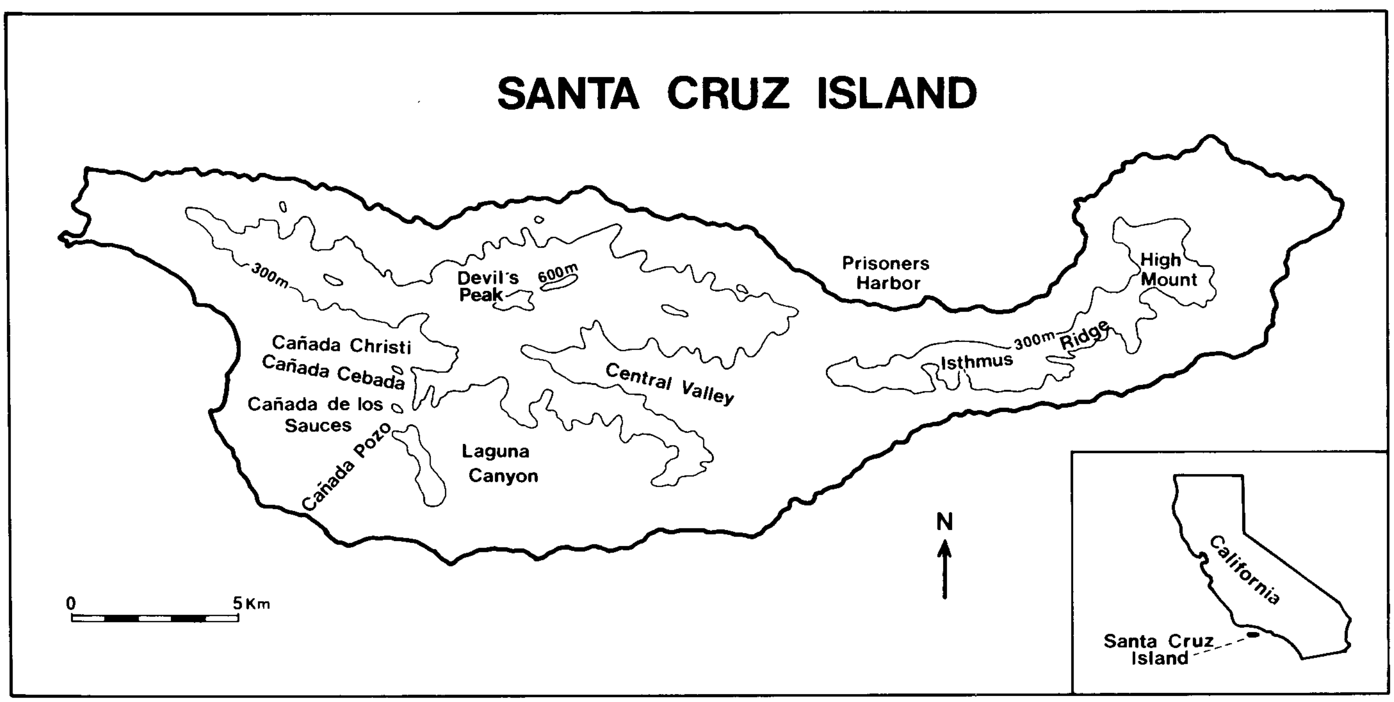


Figure 1--Map of Santa Cruz Island, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

sedimentary rocks (fig. 2). Soils developed on these rocks range from deep (1 to 1½ m) vertisols on some volcanic areas, to mollisols on some shales, and poorly developed entisols on all lithologies. Major vegetation zones include chaparral woodland (Quercus dumosa, Arctostaphylos spp.), pine woodland (Pinus muricata), coastal sage scrub (Artemisia californica), annual grasslands, and areas of essentially barren ground (fig. 3).

Grazing by feral sheep during the last 130 years has been the major cause of the substantial reduction of vegetation on Santa Cruz Island. Sheep were introduced to the island during the early 1850's (Brumbaugh 1980). By 1857, there were some 7000 or 8000 head of sheep on the island (Greenwell 1858), and by 1870, the sheep population had increased to at least 45,000 (U.S. Census of Agriculture 1870). Other estimates of sheep during the last half of the 19th century range between 60,000 and 100,000 head (Cromise 1868, Carman and others 1893, Towne and Wentworth 1945). Some control of the sheep during the last few decades has been attempted by fencing the open range and curtailing grazing over large areas of the island. Today, most of the feral sheep are confined to the more rugged and less accessible coastlands and mountains of the northeast and northwest portions of the island. A much smaller population with fluctuating numbers of sheep remains on the steepest slopes of the southern portion of the island.

Changes in vegetation since the 1850's (the onset of sheep grazing) are indicated by historical accounts and old photographs. Comparisons of U.S. Coast Survey accounts with present-day landscape indicates reduction of brush cover on various island locales (Brumbaugh 1980). Comparison of photographs taken in 1869 of the Central Valley with present-day photographs (Brumbaugh 1980) shows significant reduction of coastal sage scrub on south-facing slopes north of the Central Valley, in addition to depletion of several chaparral shrubs, especially chamise (Adenostema fasciculatum). Exposed root platforms on now-barren slopes also indicate widespread reduction of scrub woodland cover.

Shrubs and trees in areas still grazed by sheep appear to have experienced only gradual reduction over the last 50 years (comparison of 1929, 1940, 1964, and 1970 photographs in Brumbaugh 1980). Hobbs (1978, 1980) reports an absence of regeneration and an accelerated deterioration of Pinus muricata in sheep-grazed areas, and Leishman (1981) reports reduced health and vigor of chaparral shrubs in heavily grazed areas north of the Central Valley. Reduction of chaparral shrubs by grazing is species selective; for example, chamise is especially susceptible (Brumbaugh 1980, Minnich 1980).

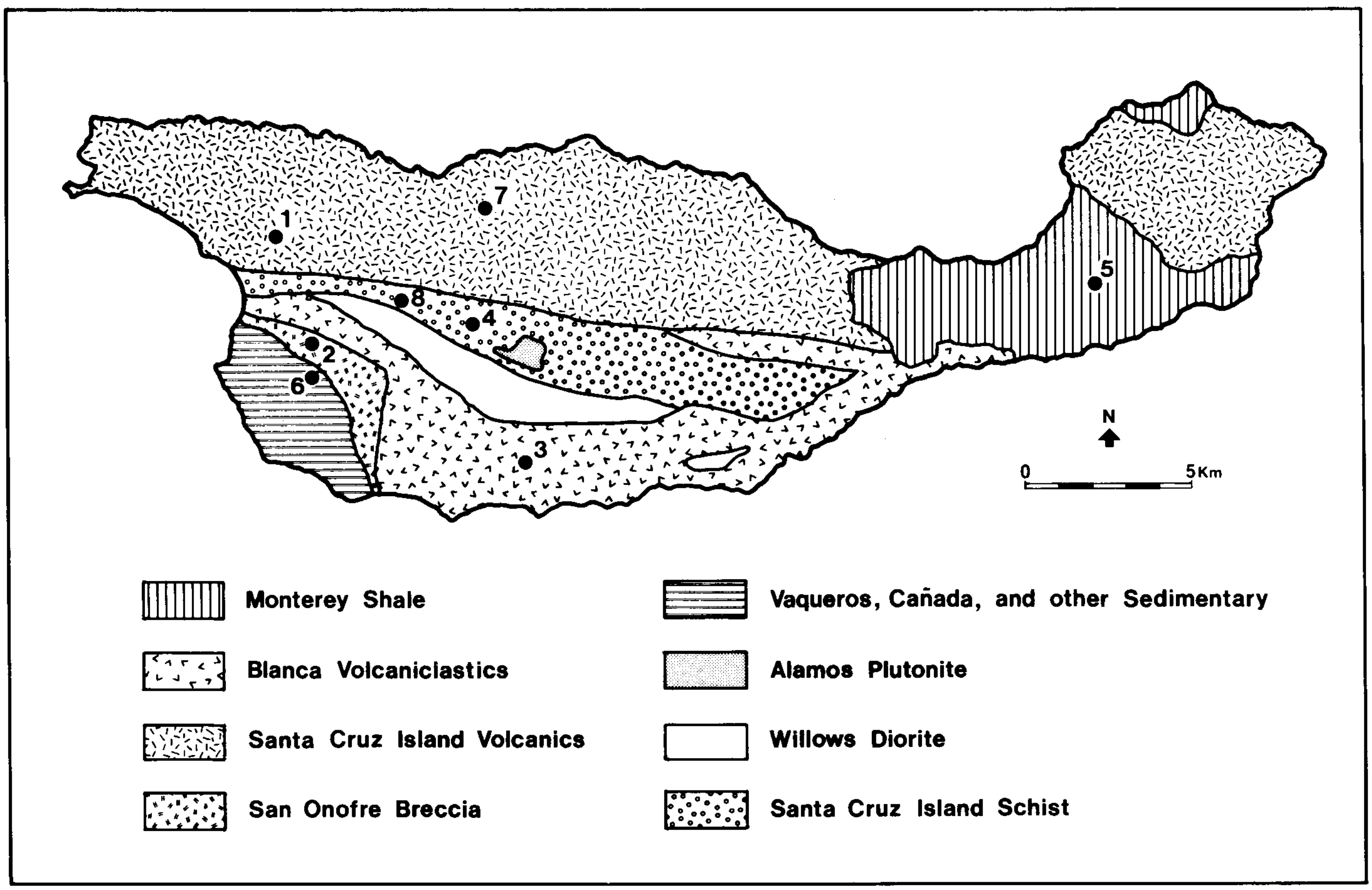


Figure 2--Generalized geologic map of Santa Cruz Island (simplified from Weaver and others 1969 and Howell and others 1976). Major rock units are listed in sequence from youngest to oldest.

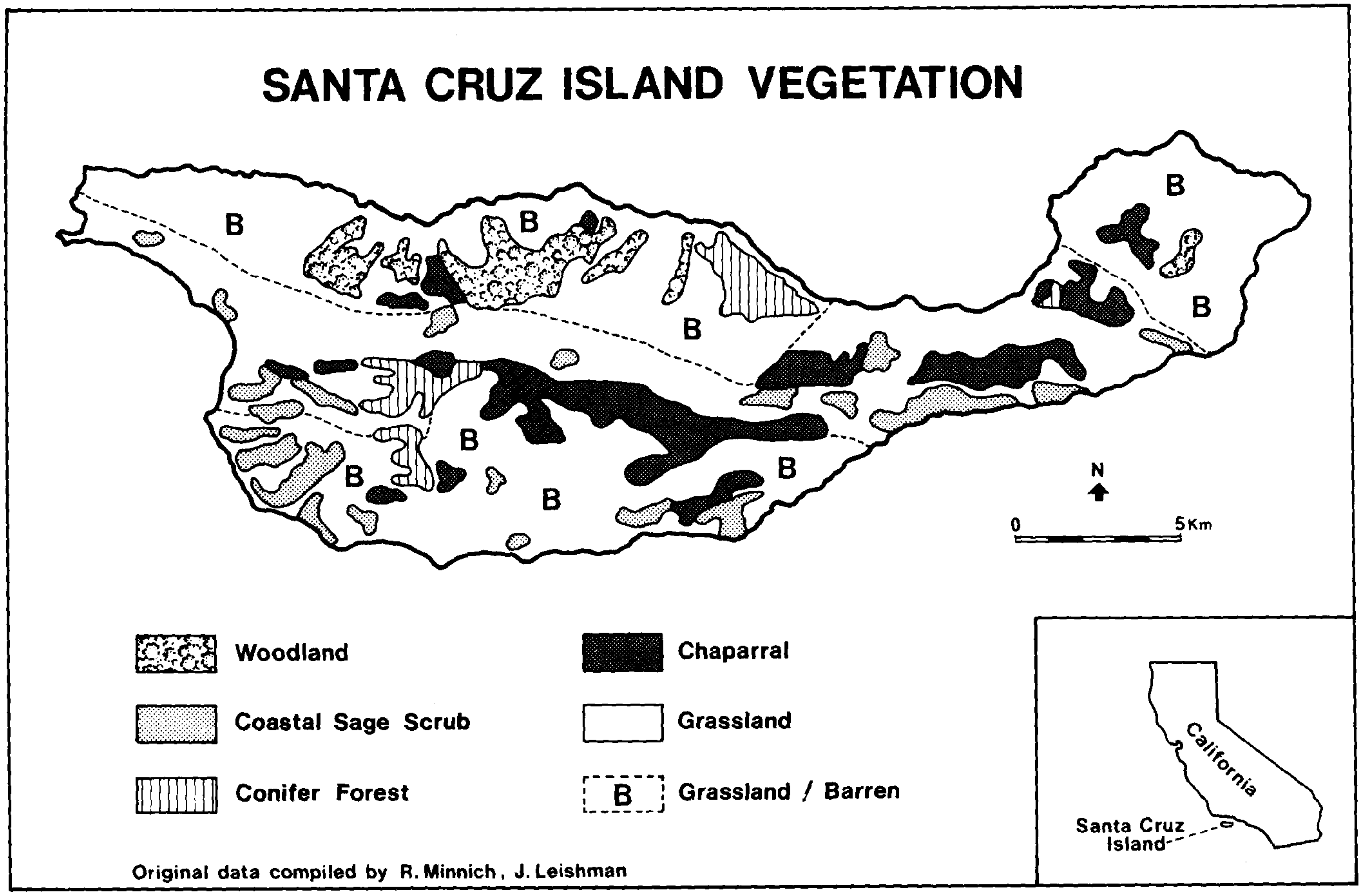


Figure 3--Generalized vegetation map of Santa Cruz Island, California.

Vegetation has recovered wherever sheep have been successfully excluded during the last 25 years. Regeneration of coastal sage is occurring on some portions of the island (Brumbaugh 1980, Minnich 1980), most notably, the steep southern slopes of the Isthmus and Canada Pozo, and Pinus muricata is regenerating in "sheep-free" areas (Brumbaugh 1980, Hobbs 1978,1980).

In addition, Brumbaugh (1980) reports that a small sheep exclosure located in the Central Valley experienced rapid vegetation recovery; post-sheep removal vegetation response included basal sprouting of toyon (Heteromeles arbutifolia) and scrub oak (Quercus dumosa) and return of native bunch grasses.

LANDSLIDING PRIOR TO 1978

Extensive aerial photographic coverage is available for the island. This includes black and white photos at a scale of approximately 1:20,000 flown in 1929, 1940, 1954, and 1964; color infrared at a scale of 1:20,000 flown in 1970 and 1980; and oblique color and color infrared photos flown by the authors in 1978.[3] The aerial photographs have been supplemented by the authors with extensive ground level photography. The quality of the above coverage ranges from fair to excellent. Resolution is poorest on the 1929 photos, allowing identification of features only as small 5 m. In most of the later photos, however, features 2 m in size are clearly distinguishable. Most of the shallow failures on the island are from 5 to 15 m in horizontal dimensions and are easily discernible on the photographs.

Daily precipitation has been measured on the island since the 1936-37 season (monthly data is available back to 1904-05), and the mean annual rainfall is about 500mm.[4] The daily data were

[3] 1929 photographs from the Fairchild Collection; 1940 photographs from the Soil Conservation Service, U.S.D.A.; 1954 and 1964 photographs from Mark Hurd; 1970 imagery from Orme and others (1971); and the 1980 imagery from the National Park Service.

[4] Data on file, Stanton Ranch, Santa Cruz Island, California.

Table 1--Extreme precipitation events (in mm) on Santa Cruz Island, 1937-1978.

Month/yr	maximum 1-day	maximum 2-day	maximum storm[1]	maximum 1-day + 30-day ante-cedent
2/37	99	208	218	362
3/38	163	163	252	412
1/41	164	204	248	530
3/58	86	139	123	297
2/62	161	221	394	253
1/69	61	115	230	364
3/78	140	161	258	507

[1]a storm is defined here as a period of time in which every day has here as measurable precipitation.

analyzed to determine which storms were likely to have caused extensive landsliding.

No single measure of precipitation accurately predicts landsliding. High soil moisture content and hence, high pore water pressures associated with landsliding are a function of both precipitation intensity and antecedent rainfall. Campbell (1975) found most slides occurring during intense periods of less than 6 hours duration. Although daily data mask these intensities there is a strong correlation between high hourly intensities and high daily totals. Daily totals and three other precipitation parameters for the seven heaviest rainfall years since 1937 are shown in table 1. The data indicate that 1941, 1978, and 1938 were the most severe. A high 1-day total occurred in 1962, but antecedent precipitation was low.

In view of the precipitation data there is surprisingly little evidence of any widespread shallow landsliding in any of the photos prior to 1978. Although quantitative estimates are difficult, the percent of land area in slides is at least an order of magnitude greater in the 1978 imagery than in any of the earlier years. Many slopes which show one or two scars in 1954 and 1964 have several tens of scars today. The most severe dap in photo coverage is that immediately after the 1941 storms, and it is quite possible that scars caused in that year had time to heal and were therefore not visible in the 1954 photos. Revegetation of scars may take up to a decade or more. Slips that occurred in 1978 are still quite visible in 1981, but scars shown in the 1954 photos are absent in 1970. The 1969 storms were intense and caused much landsliding on the mainland, but intensities were lower on the island and little landsliding is visible in the 1970 imagery.

SHALLOW LANDSLIDING IN 1978

Failures in 1978 were generally similar to those commonly described elsewhere (Campbell 1975, Rice and others 1969, Rice and Foggin 1971). Shapes vary considerably, from rounded and smoothly concave to highly irregular. Length/width ratios generally range from 1 to 5. Although there is some tendency for more irregularly shaped scars to be found in grasslands, there are many exceptions. Slides in woodlands and on barren areas are larger, having average surface areas of about 600 m^2 as opposed to an average of about 50 m^2 in grasslands. Individual slide volumes range from 3 to 3000 m^3. In most cases the debris flowed rapidly downslope and was delivered directly to stream channels.

The failure mechanism on areas of shale, volcaniclastic, and schist bedrock is presumed to be that described by Campbell (1975), in which infiltration in excess of deep percolation causes the formation of a perched water table in the soil, with resultant high pore water pressures and a reduction of shear strength. In areas of well developed vertisols on volcanic rocks, failure appears to occur as a result of water seepage from upslope or from permeable bedrock strata (fig. 4). The clay-rich A horizon confines soil water, and high pore water pressures result. Subsurface seepage may also contribute to failures in areas of permeable surface horizons. This would suggest that different precipitation parameters would be important in generating this type of failure, although there is no evidence that they occurred at a different time than the rest of the failures on the island.

Percent of surface area in shallow landslides was measured from oblique air photos and ground level photos at several locations on the island (table 2). There is a large range in landslide occurrence: from 0.002 to 3.5 percent of area on sampled areas of 14.5 to 455 hectares.

Much of this variability can be explained by spatial variation in precipitation intensity. Table 3 shows storm precipitation for locations in the central (Main Ranch, in the Central Valley), western (Christi, near the mouth of Canada Christi), and the eastern part (isthmus ridge) of the island.

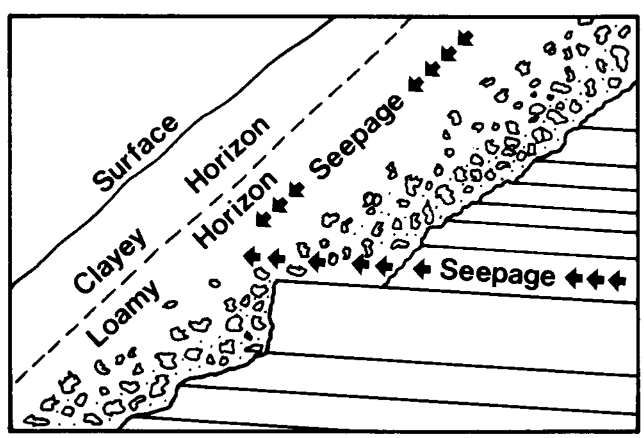


Figure 4--Diagram of subsurface water flow in vertisols resulting from bedrock configuration and convergent flow.

More shallow landslidinq occurred on the western portion of the island (northwest end, Canada de los Sauces, Canada Cebada, Canada Christi) than on the eastern portion (table 2). Correspondingly, greater 1-day rainfalls occurred in the central and western portions of the island than on the eastern portion of the island.

There is little evidence to demonstrate systematic variation in slide intensity with bedrock lithology. There are, however, significant variations in shallow sliding with soil and vegetation type. The most intense activity is associated with grassland areas underlain by vertisols (northwest portion and Canada de los Sauces). Measurement of percent area in failures suggests that grassland has higher slippage rates than coastal sage scrub, which in turn, has higher failure rates than oak or pine woodland (table 2). Chaparral species have deeper penetrating root systems than coastal sage, and coastal sage scrub slightly deeper than grassland mats (Hellmers and others 1955). However coastal sage scrub grows on slopes often characterized by shallow soils. The amount of shallow failures in coastal sage, therefore, may be as much dependent on soil character as on vegetation type. Although many fewer failures occur on woodlands than on grasslands, the failures are much larger in woodland areas. These failures are debris avalanches that clear off vegetation below the actual failure surface. Upon reaching the slope base, they mobilize channel-bed material resulting in debris torrents capable of completely disrupting the channel bottom and aggradinq the valley downstream. Thus, although less soil slip denudation may occur in the wooded areas than on grassland areas, watershed disruption is substantial -- disrupted surfaces downslope and along the adjacent channel, and often unwanted aggradation downvalley. Areas of little or no soil have few shallow failures; landslides are either absent or deep-seated.

MANAGEMENT IMPLICATIONS

The variation in failure rates in different vegetation types supports earlier work showing that shallow landsliding is more intense under grassland than under woodland vegetation, presumably due to the binding strength of woody roots. Although other studies have shown increases in landsliding following vegetation change, reduction of vegetation cover such as from woodland to grassland, has two contrasting effects on soil moisture which preclude simple recommendations. Evapotranspiration is reduced, which would tend to increase soil moisture, but at the same time, runoff is increased. Evapotranspiration is less significant during a storm, but will have important effects on antecedent moisture. On the other hand, devegetation generally causes a reduction in infiltration, which would tend to promote surface erosion at the expense of landsliding. Detailed site-specific hydrologic investigations are necessary to determine the relative importance of these two effects of vegetation cover change.

Table 2-- Shallow landslides, March 1978, on differing watershed types, Santa Cruz Island.

Location	Lithology/ soils	Vegetation	Area mapped (ha)	Number of slides	Average slide area(m^2)	Percent area in slides	Range of percent area in slides
Northwest end	volcanic/ vertisols	grassland	86.9	511	59	3.5	1.2 - 7.7
Canada de los Sauces	sedimentary: breccia, siltstone, sandstone	grassland	86.6	555	54	3.4	3.2 - 3.6
Isthmus	shale	grassland	[1]455	179	61	0.2	0.1 - 0.7
Canadas Sauces-Cebada-Alegria	sedimentary: breccia, siltstone, shale	coastal sage	14.5	13	42	0.4	0 - 1.2
East Central Valley	volcanic, volcaniclastic	coastal sage	21.1	3	63	0.1	0 - 0.5
Isthmus	shale	coastal sage	85	6	75	0.05	NA
Central Valley	schist	oak woodland	254	31	588	0.7	NA
Canada Christi	schist	pine forest	40.6	8	597	1.2	1.0 - 1.3
Isthmus	shale	woodland/ pine forest	71	1	15	0.002	NA

[1] sample includes large units of gently sloping surfaces.

Table 3--Variation in storm precipitation (in mm), March 1978 on Santa Cruz Island, California.[1]

	Main Ranch (62m elev)	Christi (33m elev)	Isthmus (460m
Storm precipitation (February 27-March5)	262	191	188
Pre-storm precipitation (30 day total)	315	223	326
One-day maximum	140	[2]145	69

[1]data courtesy of Dr. Carey Stanton, Santa Cruz Island Company.

[2]represents a 3-day total; however, it is probable that most precipitation fell within a 24-hour period.

The temporal patterns of landsliding suggest little direct association between vegetation removal and increased landsliding. Major vegetation changes occurred on the island in the late 19th and early 20th centuries, and accelerated erosion is very evident in the 1929 photographs. Vegetation has recovered locally in recent years, and yet the most severe landsliding in the last half century occurred in 1978. Several major storms occurred during this period, but apparently they were less intense than the 1978 storms. Precipitation characteristics are probably much more important than vegetation type in controlling landslide rates on Santa Cruz Island.

Acknowledgments: We thank Dr. Carey Stanton and Henry Duffield, Santa Cruz Island Company; Lyndall Laughrin, Santa Cruz island Reserve Field Station, University of California, Santa Barbara; and Moritz Bormann for their assistance in various portions of the research; and Robert Provin, Head Cartographer, Department of Geography, California State University, Northridge, California, for photographic reproductions.

LITERATURE CITED

Brumbaugh, Robert W. Recent geomorphic and vegetal dynamics on Santa Cruz Island, California. In Power, Dennis, ed. A multidisciplinary symposium on the California Islands. Santa Barbara, Calif.: Santa Barbara Museum of Natural History; 1980: 139-158.

Campbell, Russell H. Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California. U.S. Geological Survey Prof. Paper 851; 1975. 51 p.

Carman, E. A.; Heath, H. A.; Minto, J.. Special report on the history and present condition of the sheep industry of the U.S. Washington, D.C.: U.S. Government Printing Office; 1892.

Cromise, T.F. The natural wealth of California. San Francisco, Calif.: H.H. Bancroft and Co.; 1968.

Greenwell, W. E. Report of the Superintendent, U.S. Coast Survey; 1857; Washington, D.C.: U.S. Government Printing Office; 1858; Appendix 44; 392-395.

Hellmers, H.; Horton, J. S.; Juhren, G.; O'Keefe, J. Root systems of some chaparral plants of southern California. Ecology 36(4):667-678; 1955.

Hobbs, Elizabeth R. The effects of feral sheep grazing on Bishop Pine (Pinus muricata) forests, Santa Cruz Island, California. M.A. Thesis (unpublished); University of California, Los Angeles; 1978. 61 p.

______.Effects of grazing on the northern population of Pinus muricata on Santa Cruz Island, California. In Power, Dennis, ed. A multidisciplinary symposium on the California Islands. Santa Barbara, Calif.: Santa Barbara Museum of Natural History; 1980: 159-165.

Howell, D. G.; McLean, H.; Vedder, J. G. Cenozoic tectonism of Santa Cruz Island. In Howell, D.G., ed. Aspects of the geologic history of the California Borderland. Amer. Assoc. of Petroleum Geologists, Pacific Section: 1976; Misc. Publ. 24: 392-416.

Leishman, Norman J. Effects of feral animals on woody vegetation, Santa Cruz Island, California. M.A. Thesis (unpublished); University of California, Los Angeles; 1981. 71 p.

Minnich, Richard A. Vegetation of Santa Cruz and Santa Catalina Islands. In Power, Dennis, ed. A multidisciplinary symposium on the California Islands. Santa Barbara, Calif.: Santa Barbara Museum of Natural History; 1980: 123-137.

Orme, A. R.; Bowden, L. W.; Minnich, R. A. Remote sensing of disturbed insular vegetation from color infrared imagery. In Proceedings of the seventh international symposium on remote sensing of the environment. Univ. of Michigan, Ann Arbor, Mich.: 1971; 1235-1243.

Rice, R. M.; Corbett, E. S.; Bailey, R. G. Soil slips related to vegetation, topography, and soil in southern California. Water Resources Research 5:647-659; 1969.

Rice, R. M.; Foggin, G. T. Effect of high intensity storms on soil slippage on mountainous watersheds in southern California. Water Resources Research 7:1485-1496; 1971.

Towne, C. W.; Wentworth, E. Shepherds empire. Norman, Oklahoma: University of Oklahoma Press; 1945.

United States Bureau of Census, Census of Agriculture. Ninth census of the United States. Sacramento, Calif.: Calif. State Library: 1870; schedule of agricultural recapitulation, Santa Barbara County (microfilm); vol. 2.

Weaver, D. W.; Doerner, D. P.; Nolf, B., eds. Geology of the northern Channel Islands (California). Amer. Assoc. of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Sections: 1969; Special Publ. 200 p.

Erosion and Sedimentation as Part of the Natural System[1]

Robert B. Howard[2]

Abstract: Dividing exogenic processes into constituents enables one to distinguish between denudational and depositional environments. This distinction leads to the recognition that the chaparral assemblage occupies a zone which is predominantly denudational. A qualitative assessment of sane variables governing denudation rates is made. The factors associated with large sediment yields are all found in the chaparral watersheds of southern California.

Erosion and sedimentation are natural aspects of any environment regardless of geology or climate. The magnitude of erosion or sedimentation however differs from one environment to another. Various factors control the magnitude or rate of erosion in any given setting. To obtain a better understanding of contemporary erosion rates it is necessary to examine some of those geomorphic controls especially, in this paper, as they relate to the Mediterranean-type ecosystem. Concern with these present rates as well as attempts to estimate rates of these processes occurring in the geologically recent past fall within the province of geomorphology.

Geomorphology is that branch of the solid earth sciences concerned with the origin, development and morphology of the earth's myriad subaerial and submarine landforms and landscapes. There are two basic classes of processes responsible for earth surface morphology. These are the endogenic and exogenic processes. The endogenic forces derive their energy from the earth's internal heat. This group of processes is responsible for tectonism, igneous activity and metamorphism. Its global patterns and modes of operation are best understood in the light of the plate tectonic paradigm. The exogenic forces, on the other hand, are controlled largely by atmospheric agencies. These exogenic processes may be further subdivided into denudation and deposition.

EXOGENIC PROCESSES

Denudation involves both weathering as well as erosion. Weathering, the *in situ* mechanical disintegration or chemical decomposition of rocks, may be thought of as the fundamental exogenic geomorphic process. Without weathering there is no sediment production and thus nothing available to be entrained, transported and ultimately deposited. In the absence of this most fundamental exogenie process, there would be no denudational or depositional environments and thus landforms and landscapes would remain unchanged with time. Erosion involves the entrainment as well as transport of rock waste by running water, gravity or mass movement, waves and currents, glacier ice and wind.

Deposition of materials in transport occurs either because of a change in the environment or a change in the strength of the transporting agent. Deposition, commonly occurring in the course of denudation, may be either temporary or relatively permanent. Temporary deposition merely involves the geologically short-term storage of sediment while in transit. In the fluvial context this would be as floodplain, alluvial fan or other form of valley fill. Ultimately most of this valley fill will be re-eroded and eventually deposited at some relatively permanent site where lithogenesis can occur. As lithogenesis takes place, the sediments are slowly buried under increasing thicknesses of younger overburden and are thus transformed from their original loose, unconsolidated condition into sedimentary rocks.

EXOGENIC ENVIRONMENTS

From the foregoing, we may recognize two basic exogenic environments -- denudational and depositional. The denudational environments are those in which weathering and erosion dominate. In the fluvial context, these denudational environments tend to be found farthest upstream where slopes are steeper and relief tends to be greatest. In southern California the denudational environments coincide with the bedrock of the mountain fronts. This also tends to be the environment of the chaparral. These denudational environments may be either weathering or transport limited. In a weathering-limited environment, denudation depends on the rate of debris production by rock disintegration or decomposition. Where an environment is transport limited, denudation depends on the rate of accumulation of debris at slope bases and in stream channels, and by the frequency of events of sufficient magnitude to entrain and transport it. In most fluvial denudational systems, regardless of whether they are weathering or transport limited, there is a close association between the stream channel and its debris-contributing valley side slopes.

Environments in which deposition dominates tend to be found in the downstream direction where slopes are low and relief is small. In southern California, fluvial depositional environments are found along stream channels from their canyon mouths to the coast. Again, in southern California the depositional environment tends to be associated with the vegetation communities mapped

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Professor of Geomorphology, Department of Geography, California State University, Northridge.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

either as grassland or coastal sage. This is probably due to the rather high degree of ecological disturbance which occurs with each flood and subsequent depositional episode. In these depositional environments there tends to be a progressive divorcing of stream channels from their associated valley side slopes as one proceeds downstream.

Vegetation plays a very large role in fluvial environmental systems. Initially it acts as a biological barrier to erosion by intercepting precipitation and causing it to dissipate its kinetic energy on leaves and other aerial portions of the plant. Organic matter incorporated into the soil greatly influences soil structure and subsequently the hydraulic properties of the land surface. Vegetation's influence does not end with its effect on hydraulic properties of soils but continues through weathering and hence debris production. Vegetal-biochemical reactions termed pedochemical weathering aid in the formation of various alteration compounds as well as in the actual breakdown of bedrock.

CONTEMPORARY DENUDATION RATES

Contemporary denudation rates are based on measurements of sediment yielded from an entire drainage basin. This is usually accomplished by measuring the sediment (dissolved, suspended and bedload) departing the basin through its outlet. This total sediment yield provides an average basin-wide denudation value. Although a significant indicator of gross denudation, this type of measure does not provide information on actual source areas of sediment within the basin. Because sediment yields fluctuate widely (often by as much as a factor of five from year to year) calculations with the greatest validity are those made from considerable periods of record (Ahnert 1970). Holeman (1968) using a wide variety of sources projected sediment yield of the various continents. His study puts denudation into a global or spatial context. It also permits an initial understanding of some of those variables which exert controls on the rates of denudation. The results of Holeman's study show Asia and North America as the continents yielding the greatest average amounts of sediment to the oceans, North America yields an average of 245 tons/mi^2/yr as determined from humid streams of the eastern and southeastern United States. This results in a surface lowering of approximately 3.2cm/1,000yrs (1.25in/1,000yrs). Asian sediment yields, as determined from several streams draining highly mountainous monsoonal regions, approach 1530 tons/mi^2/yr for an average surface lowering of 20 cm/1,000yrs (7.87in/1,000yrs). Judson and Ritter (1964) examined regional denudational rates in the United States. Their study reveals that the Colorado river basin has the highest sediment yield with some 1255 tons/mi^2/yr or a surface lowering of 16.5cm/1,000yrs (6.5in/1,000yrs). The Pacific slope basins showed the second highest yields with values slightly more than half those of the Colorado (700 tons/mi^2/yr or 9cm/1,000yrs).

FACTORS CONTROLLING DENUDATION RATES

Coupling information from the aforementioned studies with studies by Ahnert (1970) on functional relationships between slope, relief and denudation and with that by Langbein and Schumm (1958) on the sediment yield-climate relationship, it is possible to delimit qualitatively those variables which exert a strong influence on denudation rates. Denudation rate is strongly dependent on scale, with smallest basins having the highest rates. This is probably a function of the steepness of slopes and, hence, greater relief of smaller basins of lower order (Ahnert 1970). Additionally, smaller basins would tend to be at higher elevations and, thus, receive more precipitation than neighboring, higher-order basins. Being primarily denudational these smaller basins would also be flushed by storm runoff more readily. Larger basins on the other hand tend to have lower sediment yields because an increasing percentage of the basin's area becomes depositional causing sediment storage to increase with basin size. With basin size held constant Langbein and Schumm (1958) demonstrated a relationship between denudation rate and effective annual precipitation. Maximum clastic denudation seems to occur at about 30.5cm/yr (12in/yr) or at the approximate boundary between desert and grassland. Reduced clastic denudation occurs at precipitation amounts above and below this 30.5cm/yr value because of increased vegetal coverage of the surface in wetter environments and reduced precipitation in the drier ones. At the high annual precipitation amounts typical of humid tropical regions denudation rates probably increase, however the denudation is probably chemical and not clastic. A final factor influencing denudation that should be mentioned here is revealed by Holeman's (1968) study which shows monsoon Asia with enormous sediment yields. Apparently strong seasonality in precipitation is associated with large sediment yields.

EVENT FREQUENCY, THRESHOLDS AND SEDIMENT YIELD

Before focusing on denudation and deposition in the chaparral system one last topic deserves to be mentioned. More and more frequently geomorphologists are being made aware of event frequency and thresholds in relation to sediment yield. In their classic study Wolman and Miller (1960) demonstrated that the greatest amount of work done on the landscape over the long run is accomplished by the frequently occurring moderate events. On this basis fluvial geomorphologists have concentrated on bankfull discharge as the most probable flood event and the flow to which the channel's geometry is adjusted. Statistically, this bankfull discharge can be expected to occur as the annual maximum every 1.58 years. On the other hand it can be expected to occur as a less than annual maximum every 0.9 year or 11 times in a 10-year period. In recent years, with the increasing publication of research on subhumid and dry region processes, the notion of the extreme event in these erosional systems is once again gaining credence (see especially Thornes 1976). While the general proposition put forth by Wolman and Miller concerning the magnitude and frequency of events is not in serious doubt for humid regions with perennial streams, the situation in arid, semiarid and subhumid environments appears to be different. Several arguments can be advanced to support the contention that in these drier environments total work on the landscape over the long run is biased toward the higher magnitude, lower frequency geomorphic events. First, detrital materials tend to be of larger size and greater volume in most dry regions and, thus, require higher critical stresses for their entrainment and transport. Moderate to low magnitude events, occurring however frequently, will generally be insufficient to reinitiate bedload movement, save for the smallest particles. Second, in most dry regions, alluvial surfaces consist of poorly sorted, highly permeable materials so extensive transmission losses can be expected when flows do occur. These excessive losses decrease the likelihood that any sediment transport will occur with low to moderate events. Third, detachment of soil particles from hillslopes followed by their entrainment is an intensity related phenomenon (Mutchler and Young, 1975). Fourth, mass movement in the form of soil slips, debris flows, slumps or landslides are triggered by high magnitude events (Campbell 1975; Rice and Foggin 1971; Scott and Williams 1978). If slope failure were related to more frequent, moderate events then they would present more of a problem than is the case at present. A last argument is based on the statistics of precipitation distribution. As the total annual precipitation decreases its variability increases (Goudie and Wilkinson 1977). A corollary to this statement is that as precipitation totals decrease then the likelihood of the total annual amount occurring as one or two storms increases. This argument implies that because the subhumid and drier regions experience low, highly variable amounts of precipitation then the idea of a single moderately frequent event to which the landscape or stream channels are adjusted is tenuous at best.

Coupled with rethinking of the magnitude and frequency concept there has been, especially in the last few years, recognition of the metastable condition of most landforms (Schumm 1973). From this recognition the notion of thresholds or potential morphological instability has been, and continues to be, developed (see especially Coates and Vitek 1980). There are two classes of thresholds, extrinsic and intrinsic. Extrinsic thresholds are external to the system. Examples are a storm induced flood event or an earthquake which triggers slope failure. Intrinsic thresholds, on the other hand, are internal to the system. An example of an intrinsic threshold might be the slow continuous weathering of slope materials until their shear strength is reduced to the minimal value for continued stability. The idea of thresholds means that slow changes in landforms or landscapes continue to occur through erosion or deposition. This slow change in morphology leads up to the threshold--that metastable condition or point of potential morphological instability. A subsequent event, not necessarily a major event either, can then occur and push the apparently stable morphological system over this particular threshold resulting in erosion, deposition and a sudden shift in form. A corollary to this threshold concept is that neighboring systems do not necessarily reach thresholds simultaneously. Thus, one area may be undergoing rapid change while adjacent areas are still approaching their metastable condition. This complex response of geomorphic systems can lead to considerable confusion in interpretation of a landscape's geomorphic history.

THE CHAPARRAL ENVIRONMENT AND SEDIMENT YIELDS

With these concepts in mind we can now attempt to characterize the geomorphic processes and responses of the chaparral environment. The physical environment of southern California's chaparral ecosystem exerts a strong control over rates and total amounts of denudation. The region is tectonically active with mountain masses being uplifted at rates between 3.96m/1,000yrs (13ft/1,000 yrs) in the Santa Monica mountains and 5.2m to 6.lm/1,000yrs (17ft to 20ft/1,000yrs) in the San Gabriel mountains (Gilluly, 1949). These tectonically active denudational environments (mountain masses) rise very abruptly from their associated depositional aprons of sediment (alluvial fans and alluvial plains). Because of tectonism the mountain masses possess very steep slopes, high relief and relatively small drainage basins especially along the mountain fronts. Lithologically the eastern Transverse ranges along with the Peninsular ranges are composed of crystalline igneous rocks largely of Mesozoic age coupled with some Prepaleozoic metamorphic rocks. Most of these rocks are highly altered because of age, emplace ment, weathering or faulting. The western Transverse ranges consist mainly of Cenozoic sedimentary rocks which have been uplifted and deformed into east-west trending folds and reverse faults by a predominant north-south compression. Climatically the chaparral environment displays a strongly seasonal precipitation pattern which is characteristic of the Mediterranean climate. This November to March rainy season quite obviously affects the distribution of runoff events. Superimposed onto this seasonal regime is the orographic influence on the spatial distribution of precipitation. The range of average precipitation is from 38cm (15in) near sea level to over 66cm (26in) at about 817m (2680ft). With this geological setting and climate, fairly high normal sediment yields should be expected from southern California's chaparral watersheds. This should be self-evident by comparing the nature of the physical environment with those variables which seem associated with high sediment yield, namely, seasonality of rainfall, small size of drainage basins, steep slopes and high relief, and precipitation amounts on the order of 38cm to 50.8cm (15in to 20in). Given these facts it is really quite surprising that the chaparral watersheds do not yield an even greater amount of sediment under normal conditions. This might be due to litter accumulations on the watershed's surface which promote infiltration and impede overland flow. Additionally, litter would absorb some of the raindrop impact and reduce the dislodging of soil particles. From time to time sediment yields increase dramatically due to the interplay between the factors of fire, highly variable annual precipitation totals and effects associated with approaching thresholds. The greatest sediment yields occur when all three of these factors combine as in wet years after a fire in an area where channels and slopes are near threshold conditions.

One cannot talk of the chaparral of southern California without mentioning fire. It appears that fire is a major environmental agent in shaping California's chaparral (Hanes 1977). Temporally, fire shows a distinct seasonality occurring in the late summer and early fall, just prior to the rainy season. Anywhere from four to six months of drought precede this fire season. The dryness can be further enhanced by the development of Santa Ana winds which occur most frequently during this time of the year (McCutchan 1977). The recurrence interval for fire is extremely variable but under natural conditions it ranges from 10 to 40 years (Muller et al. 1968). After fire, runoff and sediment yield increase well above normal. This is probably due in part to the development or enhancement of a hydrophobic layer below the soil's surface (DeBano 1966, 1971).

Mean annual precipitation in the Los Angeles basin as determined from the period 1960-1979 is 38cm and shows a strong winter maximum. For this mean precipitation value, the variability should exceed 30 percent (Goudie and Wilkinson 1977). The extremely variable precipitation and its potential effects are illustrated by the 12 year period 1968-69 to 1979-80. The water year 1968-69 was an extremely wet one with some 66cm (26in) of rainfall in the lowland areas of the Los Angeles basin. High daily totals imply that there were many high intensity episodes in the various storm events. During the drought year 1975-76 only about 20cm (bin) of rainfall was recorded in the basin. The wettest year in the previous 80 years occurred in the water year 1977-78 when approximately 80cm (31.5in) of rainfall were recorded in the lowlands. The daily totals of precipitation during the 1977-78 year were lower than for the 1968-69 year implying lower intensity storm events. Because major mass movements are related to large magnitude hydrologic events, dry years produce no debris flows, landslides and few soil slips. Tan (1980) has demonstrated that storm intensities in wet years influence the timing and types of mass movements. In very wet years with high intensity storms debris flows tend to be the dominant mass movement type. This was noted especially in January 1969 storms (Campbell 1975; Scott and Williams 1978). In the very wet year 1977-78, although higher total precipitation was recorded, the daily totals were less, implying lower storm intensities. Lower precipitation intensities allow for greater infiltration and subsequent percolation. This resulted in deep seated landslides occurring with delay periods of between 2 and 6 months after storms ended.

Thresholds may be slowly approached or attained even during the dry season. Studies have revealed that between one-third and almost one-half (45 percent) of the erosion in unburned chaparral watersheds occurs as dry ravel during the dry season (Krammes 1965; Rice 1974). Anderson et al. (1959) measured dry ravel yields of between 224kg/ha (200lbs/acre) to 4300kg/ha (3800lbs/acre) from small watersheds in the San Gabriel mountains. Subsequent studies by Krammes and Osborn (1969) have determined that between one-third and three-quarters of the wet season erosion was also occurring as dry ravel. This would mean that a maximum of from 63 to 86 percent of the total surface erosion in unburned watersheds is occurring as dry ravel. Some of this dry ravel material may accumulate behind stems and trunks or under litter. However, most of it finds its way into the steep low order stream channels where it builds up awaiting a storm of sufficient magnitude to transport it.

The greatest sediment yields from southern California chaparral watersheds occur when fire, a large magnitude event and an approaching threshold combine. The stage is generally set by events during the fire season. Fire consumes the aerial portions of most plants and, thus, the support for much material entrapped by vegetation is lost. Dry ravel may show as much as a 9-fold increase after fire (Krammes 1965). This increased volume of slope debris is added to the growing volume of fill existing in the stream channel. A very important effect of fire in the chaparral is the production or enhancement of a water-repellent layer caused by burning the litter. This water-repellent layer develops at depths of between 2 and 5 centimeters below the surface. The layer is most intense or best developed in soils with a large amount of sand because sandy soils have less specific surface to be coated with hydrophobic substances than a silty or clayey soil. Sandy soils also have higher permeabilities and thus greater penetration of the hydrophobic vapors occurs. This water-repellent layer reduces the effective moisture storage capacity of the chaparral regolith from a meter or so to less than a few centimeters.

During the rainy season the effects of water repellency are far-reaching. The immediate effect is to reduce moisture storage capacity. Subsequently, this reduced storage capacity influences infiltration rates, overland flow, raindrop impact, rill formation and debris flow initiation. Saturation of the upper few centimeters of the watershed's regolith results in positive pore water pressures and reduces the shear strength of the regolith. The reduction in moisture storage capacity forces overland flow to occur under precipitation amounts or intensities that would normally infiltrate completely. With most of a hillslope bare after fire, raindrop impact entrainment is increased. When coupled with saturation-induced overland flow, this maximizes surface erosion.

Rills tend to be a ubiquitous feature on rapidly eroding, burned, chaparral watersheds. Wells and Brown (in press) have proposed a mechanism for formation of these features which involves water repellency. Saturation of the upper few centimeters of soil above the hydrophobic layer results in the development of positive pore water pressure and significantly reduces the effective normal stress. A narrow linear failure occurs in the near surface wettable layer above the hydrophobic zone producing the rill. Fluvial erosion in the newly formed rill scours out the water repellent materials by developed turbulence. Once the hydrophobic layer has been scoured out of the rill's bottom infiltration may once again occur and the full thickness of the regolith is available for moisture storage. At this point flow in the rill may cease. In the formation of these rills a significant amount of sediment may be yielded to stream channels.

Debris flows also contribute very large amounts of sediment to stream channels. These flows frequently begin as soil slips, shallow surface failures that are often noticeable on the grassy hillslopes of southern California. Soil slip frequencies are maximized under post-fire conditions with high intensity storms (Campbell 1975). Even under moderate storms pore fluid pressures may attain significant positive values. Sediment yield potentials from soil slips can be considerable. Conservatively, soil slip scars may frequently cover 2 to 3 percent of a watershed's surface after a rainy season Each scar often has a surface area of 50 to 60mm^2(59 to 72yd^2) with average depths of material removed of about 40cm (15.7in). The volume of debris yielded from one of these small slips would be on the order of 20 to 24m^3 (26 to 31yd^3). In a 1 hectare (2.47acre) watershed with 2 to 3 percent of the surface scarred by soil slips having the above conservative dimensions the sediment yield would be on the order of 80 to 120 m^3 (104 to 156yd^3). Actual sediment yields from any watershed in any year would depend on surface conditions and storm magnitudes. Rice and Foggin (1971), for example, report brush area sediment yields in southern California of only 21.1m^3/ha for 1966, a year of moderate precipitation whose storm return period was about 9 years. In the wet year 1969 these brush area sediment yields increased to 298m^3/ha however this was for a storm season with a 32-year recurrence interval.

The hydrophobic layer also influences debris yields due to sheet erosion. For example, if 1mm (0.04in) is removed from the surface of a 1 ha basin, sediment yield will be some 10m^3 (13yd^3). From a 100ha (247acre) basin with a hydrophobic layer just 2cm (0.8in) below the surface there can be a potential loss of 18,800m^3 (24,400yd^3) of sediment. Scott (1971) reports that in January 1969 one small watershed on the south flank of the San Gabriel mountains near Glendora, California yielded the equivalent of approximately 60,000 m^3/ha (200,000yd^3/mi^2).

Dry ravel debris of considerable volume builds up in stream channels during the dry seasons between fires. Little erosion of this debris occurs during normal rainy seasons in the absence of fire. Post-fire increases in dry ravel are amplified during extremely wet years. Given a large magnitude flood event such as any of those that occurred in 1968-69, 1977-78, or 1979-80, slope debris is mobilized as soil slips are converted into debris flows. The large volume of sediment stored in the stream channels is also mobilized and flushed out and this reinforces the notion of the higher magnitude less frequent flood event being the principal fluvial geomorphic agent in dry and subhumid environments. The available research information would seem to imply that channel processes and sediment yields are time evolutionary. That is, several large storms of similar magnitudes will show decreasing sediment yields and channel scour because the first storm or two removes most of the available sediment and exposes the bedrock.

Rice (1974) and Rowe, et al. (1954) have discussed the pattern of sediment yield from chaparral watersheds after fires. Post-fire conditions usually last for about 8 to 10 years. In the first year after fire, sediment yields show anywhere from a 5-to 35-fold increase over normal. In subsequent years the reduction in sediment yields approaching normal becomes apparent. The second year after fire shows a 2-to 12-fold increase, third year increases over normal are reduced to, 0.7-to 7-fold. This increased sediment yield drops to zero after the 8-to 10-year recovery period. The percentage of total sediment increase also shows a decrease with time. In the first year about 55 percent of the total 8-to 10-year increase in sediment yield has occurred. This drops off to about 18 percent in the second year followed by 11 percent in the third year and 7 percent in the fourth. By the end of the first 4 years about 91 percent of the total sediment yield increase has occurred.

CONCLUSIONS

From the foregoing it can be seen that erosion and sedimentation are normal and must, therefore, receive consideration in any environment. In the chaparral environment of southern California with its tectonically active mountain masses, high relief, steep slopes and strongly seasonal precipitation large normal sediment yields are to be expected. Increased sediment yields of up to 30 times normal are also natural in this environment because of fire, approaching thresholds and the variable, seasonal precipitation.

Acknowledgements: I thank Wade Wells II, Pacific Southwest Forest and Range Experiment Station, and Robert Brumbaugh, Department of Geography, California State University, Northridge for their critical comments on the initial drafts of this review paper.

LITERATURE CITED

Ahnert, F., 1970, Functional relationship between denudation, relief, and uplift in large mid-latitude drainage basins: American Journal of Science, v. 268: 243-263.

Anderson, H.W., G.B. Coleman and P.J. Zinke, 1959, Summer slides and winter scour...dry wet erosion in southern California mountains: U.S. Department of Agriculture, U.S. Forest Serv. Tech. Paper PSW-36

Campbell, R.H., 1975, Soil slips, debris flows, and rain storms in the Santa Monica mountains and vicinity, southern California: U.S. Geological Survey Professional Paper 851.

Coates, D.R. and J.D. Vitek, 1980, Thresholds in Geomorphology: Winchester, Allen and Unwin.

DeBano, L.F., 1971, The effect of hydrophobic substances on water movement during infiltration: Soil Science Society of America, Proceedings, v. 35: 340-343.

DeBano, L.F., 1966, Formation of nonwettable soils ...involves heat transfer mechanism: U.S. Department of Agriculture, U.S. Forest Serv. Res. Note PSW-132.

DeBano, L.F., R.M. Rice and C.E. Conrad, 1979, Soil heating in chaparral fires: Effects on soil properties, plant nutrients, erosion, and runoff: U.S. Department of Agriculture, U.S. Forest Serv. Res. Paper PSW-145,

Gilluly, J., 1949, Distribution of mountain building in geologic time: Geological Society of America, Bulletin, v.60: 561-590.

Goudie, A. and J. Wilkinson, 1977, The Warm Desert Environment: Cambridge, Cambridge University Press.

Hanes, T.L., 1977, California chaparral, in M.G. Barbour and J. Major, eds. Terrestrial Vegetation of California: New York, Wiley Interscience: 417-469.

Holeman, J.N., 1968, The sediment yield of major rivers of the world: Water Resources Research, v. 4: 737-747.

Judson, S. and D.F. Ritter, 1964, Rates of regional denudation in the United States: Journal of Geophysical Research, v. 69: 3395-3401.

Krammes, J.S., 1965, Seasonal debris movement from steep mountain side slopes in southern California, in Federal Interagency Sediment Conference, Proceedings: Washington, D.C., U.S. Department of Agriculture Miscellaneous Publication 970: 85-88.

Krammes, J.S. and J. Osborn, 1969, Water-repellent soils and wetting agents as factors influencing erosion, in L.F. DeBano and J. Letey, eds. Symposium on Water Repellent Soils, Proceedings: Riverside, University of California: 177-187.

Langbein, W.B. and S.A. Schumm, 1958, Yield of sediment in relation to mean annual precipitation: American Geophysical Union, Transactions, v, 39: 1076-1084.

McCutchan, M.H., 1977, Climatic features as a fire determinant, in U.S. Forest Service, Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems: U.S. Department of Agriculture, U.S. Forest Service General Tech. Rep. W0-3.

Muller, C.H., R.P. Hanawalt and J.K. McPherson, 1968, Allelopathic control of herb growth in the fire cycle of California chaparral: Torrey Botany Club, Bulletin, v. 95: 225-231.

Mutchler, C.K. and R.A. Young, 1975, Soil detachment by raindrops, in Present and Prospective Techniques for Predicting Sediment Yields and Sources: U.S. Department of Agriculture, ARS-S-40: 113-117.

Rice, R.M., 1974, The hydrology of chaparral soils in Symposium On Living With The Chaparral, Proceedings: Riverside, California, Sierra Club: 27-34.

Rice, R.M. and G.T. Foggin, 1971, Effect of high intensity storms on soil slippage on mountainous watersheds in southern California: Water Resources Research, v. 7: 1485-1496.

Rowe, P.B., C.M. Countryman and H.C. Storey, 1954, Hydrologic analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds: U.S. Department of Agriculture, Pacific Southwest Forest and Range Experiment Station Report.

Schumm, S.A., 1973, Geomorphic thresholds and complex response of drainage systems, in M.E. Morisawa, ed. Fluvial Geomorphology: Winchester, Allen and Unwin.

Scott, K.M., 1971, Origin and sedimentology of1969 debris flows near Glendora, California: U.S. Geological Survey Professional Paper 750-C: 242-247.

Scott, K.M. and R.P. Williams, 1978, Erosion and sediment yields in the Transverse Ranges, southern California: U.S. Geological Survey Professional Paper 1030.

Tan, S.S., 1980, Slope failures in Orange County due to 1978 rain: California Geology, v. 33: 202-205.

Thorns, J., 1976, Semi-Arid Erosional Systems: London School of Economics, Geographical Papers Number 7.

Wells, W.G. and W.M. Brown, in press, Effects of fire on sedimentation processes, in Sediment Management for Southern California Mountains, Coastal Plains and Shoreline: Pasadena, California Institute of Technology, Environmental Quality Laboratory Report: Appendix D-4.

Wolman, N.G. and J.P. Miller, 1960, Magnitude and frequency of forces in geomorphic processes: Journal of Geology, v. 68: 54--74.

Erosion From Burned Watersheds in San Bernardino National Forest[1]

Gary Boyle[2]

Abstract: Following a brush fire in September of 1979, a residential area of San Bernardino was subjected to a series of flood events brought on by intense rains from subtropical storms. A majority of the debris from the small watershed above the residential area came from alluvium probably stored in the channel for hundreds of years. Erosion from the valley slopes was probably insignificant compared to channel scour. The interagency cooperation during burn rehabilitation and flood-fighting is discussed, as is the current status of the damaged homes and those homes still threatened by future flood events.

In September of 1979 a series of fires in the mountains above San Bernardino denuded about 3700 acres of valuable watershed. The Harrison Canyon watershed, within one of the burns, had not suffered a major fire since 1953. More than 90% of its area burned in the Shadow Branch 3 fire. The dominant vegetation was mature chamise with scattered pockets of scrub live oak. Mild Santa Aria conditions existed at the time of fire, resulting in an intensive burn.

The watershed drains into a debris basin operated and maintained by the San Bernardino County Flood Control District. The basin was constructed in the mid-1940's, and was neither designed nor intended to protect an urban area. The area below Harrison Canyon and the debris basin was developed in the early 1960's over the objections of the Flood Control District. Hampshire Avenue was to function as a flood channel carrying overflow from the basin to the East Twin Creek flood channel. Harrison Basin had never spilled in its 35 years of operation.

The development below the basin was typical urban residential, including an elementary school. More homes were located above the basin, adjacent to a gorge cut by the intermittent stream draining Harrison Canyon.

Following the fire, an interdisciplinary survey team reviewed the burned area. The team was an interagency effort with the Forest Service, California Department of Forestry, Soil Conservation Service, County Flood Control District, and the City of San Bernardino participating. Because of the location of the fire, a decision was made to seed the burn with coated Wimmera rye grass applied at a rate of 16 pounds per acre (8 pounds per acre of live seed). Seed was sowed by helicopter in early December.

Fall and early winter were very dry in Southern California, with less than one-half inch of rain. The first major storm was in mid-January when nearly 7.5 inches of rain fell over an eight-day period. Maximum one-day precipitation was 2.28 inches. Runoff filled the Harrison Canyon debris basin and sent debris down Hampshire Avenue. The street was filled, debris was deposited on lawns, and some vehicles were slightly damaged, but no homes were involved.

Before the debris basin could be cleaned out, a second intense storm struck, dropping three inches the first day and three and a half inches the second day. Since the debris basin was already filled, all of the runoff was deposited in Hampshire Avenue, damaging about 30 homes on Hampshire and Golden Avenues. Sediment was about eight feet deep in Hampshire Avenue. A massive cleanup effort was organized, using the resources of Federal, State, and local agencies, plus hundreds of volunteers.

As residents were cleaning their neighborhood and preparing to make repairs to their homes, a third storm struck in mid-February, depositing nearly 13 inches of rain over a nine-day period and again filling and overflowing the debris basin. A total of 32 homes along Hampshire and Golden Avenues were now involved in the debris flows. Another massive cleanup effort was mounted to clear the debris. Some of the homes were abandoned, and a sandbag wall was constructed parallel to Hampshire to protect the homes should another flood occur.

A fourth major storm in early March again filled the debris basin and damaged additional homes to bring the total number damaged to 41. The sandbag wall was completely buried. At this time, all homes were abandoned because of the recurring floods and the extensive structural damage suffered by many of them.

By the time the third storm struck, the burn rehab team had been reactivated to pursue courses of action within the burned watershed. Again, it was a multi-agency effort of the Forest Service, Soil Conservation Service, State of California, County of San Bernardino, City of San Bernardino, and the U.S. Army Corps of Engineers. Efforts

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Forest Hydrologist, U.S. Forest Service, San Bernardino National Forest, San Bernardino, California.

were concentrated on stopping erosion with gully plugs and sandbag wall using a soil-cement mixture to act as streambank protection. Another effort at seeding the watershed was made. All of the remedial treatments were recognized as stop-gap measures pending major structural improvements.

The gully plugs and sandbag wall were constructed using contributed and volunteer labor. The response of the community was overwhelming. Literally hundreds of volunteers showed up to help in the canyon and along Hampshire and Golden Avenues.

At the height of activity, 200 people, YACC, CCC, Inmate Crews, CETA and volunteers, were working in the canyon. Their equipment included seven cement mixers, one dozer, two jeeps, and one fire engine. BLM provided portable toilet facilities. Cement was delivered in bulk and stored in an underground facility built by the city. The cement was removed with a front-end loader, put into trailers, and hauled by jeep to the crews working in the canyon. Rebar was delivered to the city yards where it was cut to length, then delivered to the job site.

All in all, the wall cost about $500,000. Funds were provided by Federal, County, and City agencies. The State provided conservation camp crews and California Conservation Corps crews. No estimate was made of the value of the volunteer labor force.

No accurate records exist of the volume of sediment produced from Harrison Canyon, but estimates place the figure between 200,000 and 250,000 cubic yards, and all of this from a watershed of less than 400 acres (320,000 cubic yards per square mile).

During the burn rehabilitation survey in September, we had estimated a sediment yield of about 36,000 cubic yards from Harrison Canyon (65,000 cubic yards per square mile). The actual yield was about five times greater than anticipated.

Most of the sediment that came from the watershed was alluvium stored in the canyon bottom. There is now extensive rilling and gullying on the valley sides, but the incised channel has grown from six feet deep and ten feet wide to over 35 feet deep in places, and up to 125 feet wide. The alluvium is probably on the order of several hundred years old. It is poorly consolidated and readily collapsed during runoff events. In fact, it collapsed when there was no runoff.

The remedial treatments constructed in the canyon survived the remainder of the winter, but the anticipated major structural improvements failed to materialize. The Federal Emergency Management Agency purchased the homes on Hampshire Avenue on the condition the seller would deed them over to the city and the city would remove the homes and create a floodway. The city is in the process of having the homes removed now.

Most of the public's attention was focused on the homes along Hampshire Avenue, but the residents above the debris basin also suffered. The only road providing access on the west side of the canyon was washed out during the third event, while people on the east side of the canyon progressively lost their landscaping, support for their driveways, and finally their driveways. At least two, and probably more, homes are in danger of suffering structural damage as the gorge gradually widens. While the residents along Hampshire have at least been compensated for their losses, those above the debris basin are on their own.

The real lesson to be learned here is not that debris flows follow fire. The fire-flood sequence in chaparral has been recognized for years. The problem is the urban/wildland interface and ignorance of basic physical processes. By allowing people to develop floodplains, the government is implying it is safe, when in fact it is not. If there had been no homes below Harrison Canyon, damage would have been minimal. Some orange groves and a road might have been damaged or destroyed, and someone's income disrupted, but the human suffering and total dollar damage would have been insignificant compared to what transpired. Floods are only one part of the interface problem. That was brought home very forcefully last November when the Panorama fire destroyed 284 homes. Most of them were located in a typical urban setting, not scattered through the chaparral. That fire has stimulated renewed interest in the greenbelt concept. Whether that concept will be pursued and become an actuality remains to be seen.

Interestingly, one of the first things we faced following the Panorama fire was a proposal to develop an orange grove and construct homes immediately adjacent to National Forest lands. These homes would be subject to both fire and flood should they be built. In fact, the Sycamore fire of last November scorched some of the trees in the grove. The final decision on the fate of this new development has not yet been made.

Estimating Hydrologic Values for Planning Wildland Fire Protection[1]

Henry W. Anderson and Clinton B. Phillips[2]

Abstract: Expected effects of wildland fires on hydrologic values have been indexed by 11 hydrologic parameters of floods, sedimentation and water supply. Coefficients and watershed attributes from 10 multiple-regression models are used to distribute measured hydrologic parameters throughout each watershed. Other coefficients are used with present fire condition and fire frequency to estimate changes in the hydrologic parameters for four fire conditions: unburned, 1 percent average annual burn, after a 100 percent burn, and after a burn of 10,000 acres (3900 ha). Application is illustrated for north coastal, Sierra Nevada, and southern California watersheds.

Among the principal criteria for planning a system of wildland fire protection are measures of the values being protected. In addition to human occupancy and improvements, these values include timber, range, wildlife and wildlife habitat, recreation, and watershed or hydrologic values. The cost of protecting these values is related to the economic and social benefits expected from them, the net effects that wildfire would have upon them in the absence of protection, the changes in fire effects that can be achieved by various levels and practices of fire protection, and, of course, the people's ability and willingness to pay for protection (Phillips 1977).

The expected net effects of wildfire on hydrologic values in a watershed are proportional to (a) the hydrologic potential values in the watershed in the absence of fire, (b) the probability of fires occurring at different sizes and frequencies under various levels of protection in the area, and (c) the effects of those fires on the hydrologic potential values.

The authors have used the results of several previous studies to develop a procedure for measuring the expected net effects of wildfires on hydrologic values located in the area protected by the California Department of Forestry.

HYDROLOGIC OUTPUT PARAMETERS

The earlier studies found that hydrologic values may be indexed by measuring output parameters of floods, sedimentation, and water supply:

Floods: Annual maximum daily streamflow; 10-year maximum daily flow; and flood overflow rate.

Sedimentation: Deposition in reservoirs, channels, and overflow areas; suspended sediment discharge; and sedimentation from roads.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Consulting Hydrologist, Lafayette, California, Assistant Chief of Fire Protection, California Department of Forestry, Sacramento, California, respectively.

Water Supply: Mean annual streamflow; median annual minimum daily flow; 10-year annual minimum daily flow; average sediment concentration in streamflow; and turbid streamflow in days per year and its effects on water supply, fishability, and aquatic habitat and fish production.

WATERSHED ATTRIBUTES

Optimum management of the parameters of floods, sedimentation, and water supply with and among groups of watersheds requires evaluation of the contribution of the sources and causes of differences in those output parameters. The earlier hydrologic studies identified the attributes of individual watersheds that can be measured to explain differences in hydrologic output parameters between watersheds.

The use of measured outputs from many watersheds with diverse attributes makes it possible to evaluate the independent effect of an attribute on the hydrologic output parameters from watersheds. Different values of attributes produce different amounts of a hydrologic output parameter. Therefore different parts of watersheds with those differences in attributes may be reasoned to also contribute those relative differences in the amounts of the output parameters.

Watershed attributes and the distribution of attributes within watersheds were taken from aerial photographs and from maps of precipitation, topography, geologic rock types, landslide potential, and land use. They were taken also from the results of studies of the relation of specific attributes--such as rain/snow frequency, soil texture, and density of sediments--to mapped and photo-interpreted attributes.

Principal component and multiple regression analysis were the statistical tools used to test independence among the attributes to be evaluated and to evaluate the quantitative relation of each attribute (or variables expressing an attribute) to measured hydrologic output parameters. As many as 29 variables were used in a single evaluation. Several variables might be used for a single attribute. For example, 9 variables represented the geology attribute. As few as 23 and as many as 95 watersheds were used to make the evaluations in the different studies. The principal attributes and their variables used in evaluating watershed outputs or in distributing hydrologic output parameters to their sources within watersheds were:

Meteorological Attributes: Mean annual precipitation; rain/snow frequency; and storm and prestorm precipitation.

Soil-Geologic Attributes: Geological rock types; landslide potential; and soil texture.

Topographic Attributes: Area-elevation; slope of tributary streams; shape of watershed; and channel morphology.

Hydrologic Attributes: Daily streamflow; annual peak flow; sediment concentration; and periodic reservoir deposition.

Land-Use and Condition Attributes: Fire frequency; vegetation types; timber harvest; and roading.

Specific variables and units used in the analyses are given in Table 1.

The distribution of attributes in a watershed was estimated from measured hydrologic output parameters. The contribution of each area of the watershed to each hydrologic output parameter was estimated through the use of one or more of 10 multiple regression models developed in earlier studies. The models were applied also to watersheds for which no hydrologic output parameters had been measured. This application was made by relating the watershed to an adjacent watershed which had been studied and which had other known attributes similar to those of the unmeasured watershed.

FOREST FIRE ATTRIBUTES

Several attributes of forest fires are used in this procedure to index the effects of wildfires on hydrologic output parameters from watersheds. The attribute selected for a given watershed depends on the available data and how a particular hydrologic output parameter might be affected by wildfire. Thus, the procedure for northern California watersheds uses the total area of burns in the 10 years prior to a measurement in evaluating the effects of fire on suspended sediment discharge and on all streamflow parameters. That procedure also uses fire "effectiveness," depleted year by year for 26 years, for reservoir deposition. The procedure for southern California watersheds uses the effect of fire on cover density and the recovery of cover density to index the effects of fires on flood peaks and reservoir sedimentation (Table 1).

Table 1--Variables and fire effects used in analyses.

Symbol	b[1]	Description and unit
MAQ	9	Mean ann. streamflow (in. dep./yr)
DQ	13	Median max. ann. daily Q (cfs/m^2)
QTEN	22	Max. daily Q in 10 yrs. (cfs/mi^2)
QM	48	Median ann. min. daily Q (cfs/mi^2)
QM10	39	10-yr. min. daily Q (cfs/mi^2)
QP	10	Peak Q of storm or yr. (cfs/mi^2)
FL	38	Flood channel overflow (cfs/mi^2)
SS	171	Suspended sediment discharge (T/mi^2/yr.)
SC	149	Average suspended sediment conc. (mg/1)
TD		Turbid days with SC in a class (pct)
RD	49	Reservoir deposition, No. Calif. (m^3/h/yr.)
eD	17	Reservoir deposition, So. Calif. (AF/mi^2/ry)
q		Ann. peak streamflow (cfs/mi^2)
Q1		Isoline of MAQ (in./yr.)
DQ1		Isoline of DQ (cfs/mi^2)
Q10		Isoline of QTEN (cfs/mi^2)
QM1		Isoline of QM (cfs/mi^2)
QM101		Isoline of QM10 (cfs/mi)
MAP		Mean ann. precipitation (in./yr.)
P_{24}		Max. 24-hr. precipitation (in.)
aP		Antecedent precipitation during 21 days before a storm (inches)
RRA		Snow area, frequency of snow vs. rainstorms (pct.)
EL		Elevation (feet)
LAT		Latitude north (degrees)
AVLS		Landslide potential, per Radbruch & Crowther (class)
$\overline{AVLS}$		Landslide potential adjusted for Q1 (class)
C(t)		Vegetation cover density (pct.)
t		Time since area burned (years)
AVBR		Average ann. burned area (pct.)
UNBR		Unburned
10M		10,000 acre fire in watershed 2
Ach		Area of main channel (acres/mi)
k		Any constant

[1]"b" is the percentage increase of the hydrologic output parameter for each one percent of average annual burn; the "b" value for TD, q, and FP depend on individual watershed attributes.

The general model used to adjust each hydrologic parameter for different fire conditions is that the present measured value of the hydrologic parameter is multiplied by the regression coefficient for fire times the change in the parameter because of fire. The hydrologic output for present fire conditions is adjusted to 4 fire conditions or effects: (1) unburned condition; (2) changes induced by an average annual burn of one percent of the watershed; (3) changes induced by a 10,000-acre burn within the watershed (both the first year's effect after the fire and the average annual effect over 10 years following the fire); and (4) changes induced by a conflagration that includes the entire watershed (again, both the first year's effect after the fire and the average annual effect over 10 years following the fire).

Changes in the hydrologic output parameters may then be translated into potential economic and social effects. These effects are related to local and regional demands for water supply, utility of reservoirs, fish production and fishability, transportation systems, and to human occupancy, property, and land-use within the 2- to 100-year flood plains. These economic and/or social indexes then provide one basis for planning and evaluating alternative systems of wildland fire protection.

ECONOMIC MODEL

The general form of the economic equation is: The change in watershed value because of fire is equal to the normal state in a particular hydrologic output parameter times the change in that parameter because of fire, times the change in value (in dollars) per unit of that parameter. To determine the total change in watershed values because of fire, these dollar values are summed for all 11 hydrologic output parameters.

The general model represents our present knowledge. It is not complete. It does not include, for example, measures in the changes of soil productivity or of in-stream chemistry. There are simply no good or easy ways at present to measure those changes due to fire. Further research will lead to better models in the future.

PROCEDURE FOR MEASURING FIRE EFFECTS ON HYDROLOGIC OUTPUT PARAMETERS

Three steps are involved for each of the 11 hydrologic output parameters: (1) estimating whole-watershed outputs; (2) determining the distribution of partial watershed contributions; and (3) estimating the change in each hydrologic output parameter with fire.

These steps will be illustrated in detail for only one of the 11 parameters; details of calculations for other parameters of streamflow, flood flows, sedimentation, aid water quality are available upon request.[3]

Flood and sedimentation estimates for southern California watersheds will be described later.

Estimating Streamflow Parameters for Watersheds

Average annual streamflow, median daily maximum flow, 10-year maximum daily flow, median daily minimum flow, and 10-year minimum daily flow may be taken directly from published tabulations of the U.S. Geological Survey (1971). Flood overflow is taken as the 10-year maximum flow minus the median annual daily maximum flow.

Distributing Streamflow Parameters Within Watersheds

Mean annual streamflow (MAQ) by itself is an important hydrologic output parameter. It is also an important attribute for evaluating and explaining sedimentation, landslide potential, and water quality. As a hydrologic output parameter, mean annual streamflow explains the filling of reservoirs having holdover (more than one year) capacity. As an attribute of watersheds, mean annual streamflow is an important variable of the spatial variation of the meteorological potential. Therefore, the distribution of mean annual streamflow within a watershed is evaluated first.

To make this distribution, we use Equation (1) from Table 2 (Anderson 1975). A first approximation of k in the equation is calculated by taking the distribution of mean annual precipitation (MAP) from the state isohyetal map (U.S. Geological Survey 1969) together with the measured streamflow and the relation of streamflow to precipitation.

Table 2--Equations used in analysis.

(1) $MAQ = k + 0.442\ MAP + .004318\ MAP^2 - 0.128\ RRA$

(2) $RRA = 100\ \{1 - [EL - 250\ (LAT - 46)^2 / (LAT \times 10^6)]\}$

(3) $\Delta MAQ/\Delta AVBR = \text{antilog}\ (0.0378\ \Delta ABR)$

(4) $DQ = k + 0.627\ MAP + .00592\ MAP^2 + 0.91\ RRA$

(5) $QTEN = k + 1.325\ MAP + 0.013\ MAP + 0.078\ RRA$

(6) $\log QM = k + 0.774 \log MAP - .0081\ RRA + 0.620 \log EL$

(7) $\log QM10 = k + 0.5061 \log MAP\ \ .0061\ RRA + 0.4127 \log EL$

(8) $\underline{\log SS} = k + 0.335 \log Q1 + 0.214\ \underline{AVLS}$

(9) $AVLS = AVLS + 1.68 \log (Q1/MAQ)$

(10) $\log RD = k + 0.1397 \log MAP + .0255 \log MAP^2 - .0128\ SA$

(11) $SS = RD\ ((silt + clay - 32) \times 0.045)$

(12) $SC = 13.79\ (SS/Q1)$

(13) $C(t) = C_{Min} + C_{Max}\ (1 - e^{-kt})$

(14) $\log FP = 1.293 + 1.082 \log area + 1.870 \log P_{24} + 0.474 \log aP - 0.825 \log C$

(15) $\log eD = 1.041 + 0.866 \log FP - 1.236 \log C + 0.371 \log Ach$

Isolines of mean annual streamflow for selected values (Q1) are drawn parallel to MAP lines by substituting values of Q1 for MAQ in Equation (1) and using the computed value of k.

---

[3]Estimating hydrologic values for planning wildland fire protection. Henry W. Anderson and Clinton B. Phillips, Calif. Dept. of Forestry, 1416 Ninth St., Sacramento, California 95814. 40 p., illus. File Report, 1981.

Mean annual streamflow must be adjusted for different contributions of rain and snow storms (RRA) in those areas where both types of precipitation occur (Anderson 1975). The percent of rain-versus-snow storms is given in Anderson and Wallis (1963). It may be approximated by our Equation 2, using latitude (LAT) in degrees North and elevation (EL) in feet.

Measuring Fire Effects on Mean Annual Streamflow

The primary effect of fire on mean annual streamflow is on the availability of water for all uses. If MAQ is increased, there probably is an increased economic value. But if the increased MAQ occurs mostly in a relatively short period of time, and is accompanied by an increase in suspended sediment then the effect could be a negative economic value.

To evaluate the effects of mean annual streamflow, it is necessary to measure the average annual percent of an area burned (AVBR) associated with the particular mean annual streamflow. That measurement is obtained from historical fire records of the appropriate fire protection agencies. The change in mean annual streamflow because of the effects of fire (MAQAVBR) is given by Equation 3, Table 2 (Anderson 1975). Other changes in mean annual streamflow are given by the following formulas (terms are defined in Table 1):

For the unburned condition:

$$MAQUNBR \ \frac{MAQAVBR/antilog}{(0.0378 \times AVBR)}$$

For the 1 percent annual burn:

$$MAQ1pct. = MAQUNBR \times antilog\ (0.0378 \times 1) = MAQUNBR \times 1.09$$

For the 100 percent burn, 1 year after the fire (MAQ 100 pct.): No positive estimate of this parameter can be made because the effects of a fire are dependent on the soil moisture relations, precipitation, and recovery of vegetation. Study of the Tillamook Burn in Oregon (Anderson 1976(b) showed a 16-year increase of 11 percent in mean annual streamflow. Using this figure as an estimate, we get a first year increase in MAQ of 21 percent:

$$MAQ\ 100\ pct. = MAQUNBR\ 100 + (11 \times 2 - 1)\ /100 = MAQUNBR \times 1.21$$

For the 10,000-acre burn, 1 year after the fire (MAQ10MAC): We calculate the average effect over 10 years from the ratio of the 10,000 acres burned to the area of the whole watershed times the 21 percent obtained for MAQ100pct. Multiplying this effect by 2 gives the first-year effect.

$$MAQ10MAC = MAQUNBR\ (10000 \times 1.21) + (WPUA - 10000)/WPUA$$

Median maximum annual daily streamflow (DQ) is distributed on the basis of the distribution of MAP, using the relation of DQ to MAP and RRA in Equation 4, Table 2 (Anderson 1975) and the k value for that watershed.

Ten-year maximum daily streamflow (QTEN) is distributed on the basis of the distribution of MAP, using the relation of QTEN to MAP and RRA from the regression results of Anderson (1975) in Equation 5, Table 2, and the k value for that watershed.

The flood overflow (FL) contribution of watershed parts is taken as the difference between the Q10 isolines and the median daily flow isolines.

For watershed areas without measured streamflow, flow from a similar watershed area may be used to make estimates of Q10 and DQ. The 10-year flow is particularly sensitive to the contrast of basalt-versus-granite geologic rock types (Anderson 1975).

The annual (median) daily flow (QM), read from tabulations, may be distributed to get an estimate of the "relative contribution of watershed parts" by relation to the distribution of mean annual precipitation (MAP), rain-versus-snow frequency (RRA), and mean elevation in feet (EL), from Equation 6, Table 2 (Anderson 1975), and the k value for that watershed.

10-year minimum daily streamflow (QM10) is an indicator of drought and may have special interest in some areas. To the extent that forest fires might help to mitigate that drought problem by causing the release of additional water, fires might have a beneficial effect. The contribution of parts of watersheds to QM10 may be estimated from Equation 7, Table 2, and the k value for that watershed.

Distributing Other Streamflow Parameters Within Watersheds

The other selected streamflow parameters--maximum annual daily streamflow (DQ), 10-year maximum daily streamflow (QTEN), flood overflow (FL), minimum annual daily streamflow (QM), and 10-year minimum daily streamflow (QM10)--are distributed by methods similar to that used for MAQ, above, by applying Equations 4 to 7, Table 2.

Measuring Fire Effects on Other Streamflow Parameters

Fire effects on the other streamflow parameters are calculated by methods similar to that used for fire effects on MAQ, previously outlined, but using the appropriate value of "b", the one percent effect (see the footnote for Table 1). See footnote 3 on how to obtain further details.

Estimating Sedimentation Parameters for Watersheds

Suspended sediment discharge and deposition of sediment in reservoirs provide the quantitative base for evaluation of sedimentation. Suspended sediment parameters are estimated from published daily sediment concentration measurements, streamflow frequency, and the relation of sediment concentration to streamflow. This procedure gives directly (1) the average sediment concentration, (2) the product of sediment concentration and average annual streamflow which is suspended sediment discharge, and (3) the frequency both of percent of turbid days (TD) and percent of volumes of water by sediment concentration classes. These variables are related to water quality (Anderson 1979, Table 1). Reservoir depositions are taken directly from published measurements. Summaries have been published by the Soil Conservation Service (1965) and periodically by other agencies such as flood control districts, state and federal experiment stations, and by interagency river basin committees.

Distributing Suspended Sediment Parameters Within Watersheds

As a basis for sediment management, the sources of sediment parameters provide the best basis for allocating resources and providing fire protection. Measurements of sediment discharge (SS), sediment concentration (SC), and turbid days (TD) from a watershed may be distributed based on the distribution of mean annual streamflow (Q1), the landslide potential (AVLS) (Radbruch and Crowther 1973), and the relation of suspended sediment discharge to these two variables obtained from multiple regression analysis, Equations 8 and 9, Table 2 (Anderson 1979). Again a separate k value is computed for each watershed.

For a watershed for which no suspended sediment discharge has been measured previously, suspended sediment discharge and the distribution of SS classes may be estimated from a nearby "known" watershed. The measurements of the "known" watershed are adjusted to account for differences in the attributes of the "known" and "unknown" watersheds, using appropriate coefficients for road effects (Anderson 1975) and other variables from Anderson (1979).

If suspended sediment (SS) is the desired parameter, but only reservoir deposition (RD) has been measured in a watershed, SS may be approximated by using the estimated silt and clay content of the soil (Anderson 1954). Substituting silt and clay in Equation 11, Table 2, gives a correction factor for RD. Silt plus clay may be estimated for geologic rock types, elevation, and latitude from relations developed by Wallis and Willen (1963) or from soil surveys where soil series and types have been established.

Measuring Fire Effects on Sediment Parameters

The effects of fire on sediment discharge, sediment concentration, reservoir deposition, and turbid days have economic impacts in 3 areas: water quality, water use, and property damage. Adjustment of sediment parameters may be made in a manner similar to that for streamflow, using the "b" value from Table 1.

The effect of the 4 fire conditions on sediment-induced losses of water suitable for domestic or other uses or for aquatic habitat, if relatable to turbid days (TD) or turbid volumes (TV), may be estimated from the changes brought about by fire on suspended sediment concentration and streamflow frequency. The new streamflow and new sediment concentration are substituted in the frequency table (Anderson 1979, Table 1). That step gives the difference in the volumes of suitable water provided by the various fire conditions.

Distribution of Reservoir Deposition to Parts of Watershed

Rates of reservoir deposition contributed by parts of watersheds may be obtained by analogy to suspended sediment discharge, using Equations 10 and 11, Table 2. Fire effects on reservoir deposition may be estimated from the "b" value, the one percent burn effect, from Table 1.

WATERSHED VALUES AFFECTED BY FIRE IN SOUTHERN CALIFORNIA

The brushland watersheds of southern California and south coastal California require a special evaluation of watershed values affected by fire. In those areas a system of models can be used that is simpler than those used for northern California.

Several characteristics of the system make it possible to keep its calculation quite simple: (a) flood peaks (QP) and sedimentation (eD) from the watersheds are related to the vegetation cover density (C) on the watersheds; (b) the cover density for each vegetative and geologic type is related to the age classes (t) of the vegetation which in turn are related to forest fires; and (c) two rather simple precipitation parameters (P_{24} and aP) and past records of streamflow give a basis for correcting past frequencies and for estimating expected future flood events and, hence, flood and sedimentation damages under different fire protection programs.

The cover density (C) varies with time (t) from the fire as shown in Equation 13, Table 2, with the coefficients Min, Max, and k varying among 13 cover types and three geologic types (Anderson and Trobitz 1949).

On the basis of Equation 14, Table 2, a second model (Anderson 1949) relates reservoir deposition to the size of floods, cover density, and channel conditions (Equation 15, Table 2). For reservoir deposition in T/mi^2/yr., the constant is 4.342 instead of 1.041 (assuming 2,000 tons per acre-foot).

Fire Effects on Sediment Discharge and Flood Peaks

Fire effects on sediment discharge and flood peaks have been calculated for many southern California and south coastal California watersheds. Data for 41 watersheds are summarized in Anderson (1949). Data for other watersheds are given in USDA Flood Control Reports (1949-1952). The "b" values (Table 1) for one percent annual burn apply to Big Dalton watershed only.

DISCUSSION

Application of the above procedures has been illustrated for individual tributaries of the Russian River watershed (1700 mi^2, 4400 km^2) in the north coast, the Bear River watershed (150 mi^2, 389 km^2) in the Sierra Nevada, and the Big Dalton (4.4 mi^2, 11 km^2) watershed in southern California.[4] Maps showing the distribution of each streamflow and sediment parameter within the two northern California watersheds have been prepared; tables give measures of the hydrologic parameters for watershed tributaries and fire planning units for various burn conditions. With the Russian River watershed, for example, mean annual streamflow varied for 15 to 50 inches (380 to 1270 mm), mean annual suspended sediment discharge varied from 100 to 9400 tons/mi^2 (35 to 3300 tonnes/km^2), and average suspended concentration varied from 90 to 2600 mg/liter.

Further refinement in the maps may be made by application of the regression coefficients for differences in local slope, geologic fault areas, soil texture and erodibility, and land use.

We must ask, are the hydrologic effects of a succession of burns different than the effects of a single burn? Two studies have indicated cumulative effects or non-recovery following burns: the effects of "old fires" on sediment discharge from the 1938 flood in southern California (Anderson and Trobitz 1949) and the effects of high elevation brushfields resulting from repeated burning attributed to early sheepherders (Anderson 1974).

The adjustment of hydrologic outputs for expected fire frequency under various levels and practices of fire protection gives a basis for allocating protection funds for maximum economic and social benefits.

[4] Henry W. Anderson and Clinton B. Phillips. op. cit.

LITERATURE CITED

Anderson, Henry W. Flood frequency and sedimentation from forest watersheds. Trans. Amer. Geophys. Union 30(4); 576-584. 1949.

Anderson, Henry W. Suspended sediment discharge related to streamflow, topography, soil, and land use. Trans. Amer. Geophys. Union 35(2): 264-281. 1954.

Anderson, Henry W. The hydrologic potential of unit areas: a basis for managing water resources. Proc. Second World Congress on Water Resources, Int. Water Resource Ass., New Delhi, India, Dec. 12-17, 1975; IV: 61-69.

Anderson, Henry W. Reservoir Sedimentation Associated with catchment attributes, land slide potential, geologic faults, and soil characteristics. IN: Proc. Third Interagency Sedimentation Conf., Denver, Colo., March 22-25, 1970(a). Water Resour. Council: 35-46.

Anderson, Henry W. Fire effects on water supply, floods, and sedimentation. Conference on Fire Ecology of the Pacific Northwest, Portland, Oregon, Oct. 16-17, 1976(b), IN: Proc. Annual Tall Timbers Fire Ecology Conf. No. 15, 249-260.

Anderson, Henry W. Sources of sediment induced reductions in water quality appraised from catchment attributes and land use. Proc. Third World Congress on Water Resour., Mexico City, April 1979; 8:3603-3613, also IN: J. Hydrol. 51(1-4):347-358; 1981, May.

Anderson, Henry W.; Trobitz, Henry K. Influences of some watershed variables on a major flood. J. Forestry 47(5):347-356. 1949.

Anderson, Henry W.; Wallis, James R. Sediment sources, Pacific Coast basins in Oregon and California. Proc. Federal Interagency Sedimentation Conf. U.S. Dep. Agr. Misc. Publ. No. 970:22-30. 1963.

Phillips, Clinton B. Fire protection and fuel management on privately-owned wildlands in California. Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977: USDA Forest Serv. Gen. Tech. Rep. WO-3:348-353.

Radbruch, D.H.; Crowther, K.C. Map showing areas of estimated relative amounts of landslides in California. U.S. Geol. Survey, Misc. Invest. Map 1-747. 1973.

Wallis, James R.; Willen, Donald W. Variation in dispersion ratio, surface aggregation ratio, and texture of some California surface soils as related to soil-forming factors. Bull. Int. Ass. Sci. Hydrol., 8(4):48-58. 1963.

U.S. Geological Survey. Mean annual precipitation in the California region. Basic data compilation. 1 sheet. 1969.

U.S. Geological Survey. California streamflow characteristics (from records through 1968). U.S. Geol. Survey, Water Resources Div. Open File Rep., Menlo Park, Calif., Vol. 1 & 2:1-421. 1971.

U.S. Soil Conservation Service. Reservoir deposition in the United States. 300 pages. 1965.

Upland Research Needs in the Southern California Inland/Coastal Sediment System[1]

Brent D. Taylor[2]

Abstract: For the past several years Caltech in cooperation with several agencies has been studying the regional sediment system in coastal southern California. The first key element in this system are the upland catchments which deliver geological debris to low-lying inland areas and the shoreline. Through the Caltech study quantitative estimates have been obtained for upland sediment yields, and four important areas for further research have been identified.

One of the important dynamic processes in the natural environmental system in southern California is sediment movement. This movement, or system of movements, involves the continual relocation of surface geological materials -- erosion from upland catchments, delivery of this material to inland depositional areas (alluvial fans, valleys, coastal plains) and to the coast, though in some cases, even under natural conditions, the coastal deliveries are deposited in marsh or lagoon areas and many never reach the shoreline. Sand-sized material delivered to the shoreline is transported up and down coast by ocean waves and currents and thereby forms and nourishes beach areas. Eventually much of this sand is lost to offshore areas via submarine canyons (Chamberlain 1954), and by other processes. Finer silt and clay particles, which constitute the major part of the sediment load delivered to the ocean, do not deposit at the shoreline but are carried offshore and deposited outside of the surf zone.

During the past five years a research group at the Environmental Quality Laboratory at the California Institute of Technology, in conjunction with the U.S. Forest Service and other agencies, has been studying the coastal sediment system in southern California. Primary objectives in this study have been to quantitatively define 1) sediment movements under natural conditions, and 2) the effects of man-made inland and coastal structures on this system.

LITTORAL CELLS

Along a coastal section natural conditions often define a reach of coastline that is essentially independent of upcoast and downcoast conditions. The inland and coastal sources of beach nourishment are local, as are also the sand losses from the system.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems.

[2]Member of Professional Staff, Environmental Quality Laboratory, California Institute of Technology, Pasadena, Calif. 91125.

Inman and Brush (1974) have identified five such littoral cells in coastal southern California. The identification of these natural coastal sediment units provides a basis for studying the coastal sediment system in large enough scale to treat all upcoast (upstream) influences on local conditions.

In studying the sediment system in each littoral cell, and quantifying sediment budget factors, the first step in the CIT study has been to treat upland sedimentation processes and the flux of sediments yielded from geologically erosional areas, in each of the five littoral cells.

UPLAND SEDIMENTATION PROCESSES

The Caltech study has led to the development of detailed estimates of upland catchment sediment yields throughout the coastal drainages in southern California (Taylor 1981).

While these study results help considerably in quantitatively defining the coastal sediment system in this area, they do not treat some important questions pertaining to upland sedimentation processes. Through this study, however, there has been a sharpening of focus on needed follow-on research. This research can contribute substantially to regional management practices as well as basic understanding of upland sedimentation processes.

Field information and data indicate that throughout the coastal drainages in southern California, there are six dominant processes active in sediment erosion and transport. Three of the processes involve the independent movements of particles; and three are mass movement processes. Individual particle movements include dry 'ravel' (miscellaneous particle movement down slopes), and rainsplash and rill and channel hydraulic transport, which are wet processes.

Mass movements include soil creep, which is essentially a dry process, sediment flows under wet conditions, and landslides that can be initiated by both wet and dry conditions.

While all of these six processes appear to be active in the coastal drainages of southern California, the relative importance of each process must vary from one location to another. As an example, qualitative information indicates that soil creep is quite active in the Palos Verdes area but that sediment flows in this area are rare, Whereas in the San Gabriel mountains there is only scanty evidence of soil creep, but sediment flows are common.

In identifying the relative importance of individual processes a practical description would include:

1. Mass scale of process
2. Characteristic distance of movement
3. Time scale of process
4. Temporal and spatial frequency of occurrence.

A more complete description would also include:

5. Conditions of occurrence
6. Mechanics of movement.

The first four items are sufficient to quantify a particular process. The latter two items provide understanding of why and how the process takes place.

In Table 1, general estimates based on limited field data and observations in the southern California region are given regarding items 1,2, and 3 for each of the six sedimentation processes identified. With available data, it is not possible to accurately estimate item 4 and thereby estimate the relative importance of individual processes for the region. The first area of research to be identified, then, is the need for quantitative field studies that will define the relative importance of the six dominant sedimentation processes in affecting sediment yield.

Douglas L. Morton[3] of the U.S. Geological Survey has initiated studies of this kind in mapping recent mass movements in the western Transverse ranges. Radbruch and Crowther (1973), also, have prepared a map classifying local areas as to their relative susceptibility to surface mass movements. This map was prepared during a 3-month period with a very limited data base, and it was intended by its authors only as a first-order approximation, to differentiate between areas of <u>most</u> mass movement and <u>least</u> mass movement. While this map is neither quantitative nor detailed, it presents a useful first step.

In addition to these studies there need to be complementary studies of some of the basic mechanisms of the six sedimentation processes. Such studies would involve both laboratory and

[3]Personal communication.

Table 1--Characteristics of Dominant Sediment Erosion and Transport Processes in Southern California.

Sediment Movement Process	General Time Scales	General Mass Scales	General Distance of Movement
Ravel	seconds [1]0(100s)	Millionths of a Kilogram $0(10^{-6}kg)$	meters $0(10^{0}m)$
Rain splash	tenths of a second $0(10^{-1}s)$	Millionths of a Kilogram $0(10^{-6}kg)$	centimeters $0(10-^{2}m)$
Rill and Channel Transport	minutes $0(10^{2}s)$	Millionths of a Kilogram to Thousands of Kilograms $0(10^{-6}-10^{4}kg)$	kilometers $0(10^{3}m)$
Creep	years $0(10^{7}s)$	Hundreds of Thousands to Tens of Millions of Kilograms $0(10^{5}-10^{7}kg)$	centimeters per year $0(10^{-2}\ m/yr)$
Landslides	seconds $9(10^{0}s)$	Kilograms to Tens of Millions of Kilograms $0(10^{0}-10^{7}kg)$	tens of meters $0(10^{1}m)$
Sediment Flows	seconds $0(10^{2}s)$	Kilograms to Tens of Millions of Kilograms $0(10^{0}-10^{7}kg)$	hundreds of meters $0(10^{2}m)$

[1]0( ) means "on the order of . . .," i.e. approximate value within plus or minus a half power of ten of the indicated number.

field-type investigation. A primary research topic in this category is the mechanics of sediment flows. Sediment flows are common in coastal drainages in southern California, especially in the northern part of the study area. Sediment flows vary over a wide range in volumetric magnitude, frequently causing property damage and jeopardizing human safety, below burned catchments. The mechanics of these flows are not well understood, e.g. conditions that initiate movement; flow velocities as a function of material size, water content, and channel characteristics (slope, etc.); and amplification or diminution of flow volume along the path of movement. This is a second area of needed research.

Superimposed upon the set of six basic sedimentation processes, in southern California, are the effects of the regular occurrence of fire. In general, fire increases the short-term sediment yield in a catchment, but specific effects vary depending on local conditions.

Fire effects on sedimentation processes were first studied statistically in southern California by Rowe and others (1954). This study included sub-regional estimates of fire effects on catchment sediment yield. Since this study in the early 1950's, a lot more field data have been obtained. It would now be profitable to do a more detailed statistical analysis of fire effects data. Such a study could provide improved estimates of effects of fire on catchment sediment yield. Also, in specific areas there may be sufficient field data to begin to identify the relative effects of fire on one or more of the six regionally dominant sedimentation processes.

A fourth research question identified in the Caltech study deals with the routing of sediment in primary and secondary channel systems on upland catchments. Of particular interest is the quantitative relation between storm hydrology and the delivery of sediment from hillslopes to the channel system versus the movement of sediment in the channel system and its delivery to the mouth of the catchment.

Limited field observations suggest that during dry or moderate rainfall years, more material is delivered by the channel system to the mouth of the catchment, and thus there is channel aggradation and temporary storage. Conversely, during wet years and particularly during severe storm periods, there is significant channel scour, indicating that more material is delivered to the mouth of the catchment than is brought into the channel system from the hillslopes. This wet/dry channel cycling may be due in part to the loss of riparian vegetation and consequent streamlining of the channel during severe floods. On catchments where this channel unloading takes place during severe storm years, the volume of storm debris may be significantly increased depending on conditions during the intervening years since the last major event. Results from this study could assist in assessing annual flood potential on individual catchments.

SUMMARY AND CONCLUSIONS

In summary, the environmental system in coastal southern California involves the continual relocation of surface geologic materials. Under natural conditions erosion from upland catchments delivers an average of some 12 million m^3/year (6 million m^3 of fine material, 5 million m^3 of sand, and 0.8 million m^3 of gravel and boulders) to alluvial fans, inland valleys, plains and coastal areas. Sand-sized material delivered to the shoreline is moved up or downcoast at net rates generally between 100,000 and 1,000,000 m^3/year, in the five littoral cells. This longshore movement forms and nourishes beach areas. Eventually this sand is lost through natural processes, to offshore areas.

The first key element in this coastal system is the inland erosion and delivery of sediments from upland catchments. Through studies at Caltech over the past few years, wherein aggregate estimates of regional and sub-regional sediment yield have been obtained, four areas for further more-detailed research have been identified, as follows:

1. Field studies are needed to quantitatively identify the relative importance with regard to sediment yield of the six sedimentation processes common in this area.

2. Pioneering studies on fire effects by Rowe and others (1954) should be updated and improved upon with currently available data.

3. Laboratory and field studies should be undertaken to study the mechanics of sediment flows.

4. There should be a research investigation of wet/dry-year cycling of sediment storage in the primary and secondary channel systems on upland catchments.

Results obtained from the four areas of research identified could contribute substantially in improving upland management practices, as well as enlarging our understanding of regional sedimentation processes in coastal southern California.

LITERATURE CITED

Chamberlain, T.K. Mechanics of mass sediment transport in Scripps submarine canyon. La Jolla, California: Scripps Institution of Oceanography, University of California; Ph.D. Dissertation; 1960; 200 p.

Inman, D.L.; Brush, B.M. The coastal challenge. Science. 1973; 181; 20-32.

Radbruch, D.H.; Crowther, K.C. Map showing areas of estimated relative amounts of landslides in California. U.S. Geological Survey: Misc. Geologic Investigations Map I-747; 1973.

Rowe, R.B.; Countryman, C.M.; Storey, H.C. Hydrological analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds. U.S. Dept. of Agriculture; 1954; open file report.

Taylor, B.D. Upland sediment yields in coastal southern California. Submitted for publication to J. of Hydr. Div., American Society of Civil Engineers; 1981.

Fire-Loosened Sediment Menaces the City[1]

Arthur E. Bruington[2]

Abstract: Sediment management is an absolute requirement, but an expensive problem for the residents of the coastal strips between the mountains and the ocean in Southern California. The combination of earthquake fractured mountains, frequent freezing and thawing action in the wintertime, occasional torrential rainfall and explosive wildfires leads to a dangerous and destructive condition. Records of the Los Angeles County Flood Control District are used to cite data on high intensity rainfall and massive sediment movement together with examples of the effects on the communities lying near the mountains. The high costs of managing sediment are highlighted by a description of the sediment situation at San Gabriel Dam and Reservoir since its construction in the mid 1930's.

Sediment is a resource. It forms the soil upon which we live and within which we grow our food. Sediment is also a problem endured by people in some variety wherever they live.

In Southern California a special sediment problem arises as the result of the high ranges of mountains lying parallel to and relatively close to the ocean, creating a steep gradient for streamflow. The steep gradients, the earthquake fractured mountains, the recurring, massive wildfires in the chaparral-type mountain ground cover and the occasional occurrences of torrential rainfall work together to cause catastrophic movement of sediment out of the mountain valleys onto the coastal plain where people live. In Los Angeles County the San Gabriel Mountains average 27 miles from the ocean and the ridgeline elevation ranges from 2,000 feet to over 10,000 feet in elevation. The mountains are mostly granitics. The sediment is formed by wintertime freezing and thawing action acting on the fractures and shattering caused by earthquakes as well as the usual decomposition processes.

Rainfall in Southern California is relatively sparse, but occasionally warm storms from the Pacific Ocean at mid latitudes cause very intense rainfall. Typically, these storms consist of a series of disturbances moving fairly rapidly along a west-to-east path, sometimes carrying copious quantities of moisture. The final disturbance in the series is usually the most severe because it is associated with the high winds which cause the breakdown of the storm system, but also add intensity to the rainfall. Thus, the heaviest rainfall intensities usually occur on a saturated watershed, the best case for a high runoff condition.

On March 2, 1938, an average of 1.4 inches per hour of rainfall occurred for a period of 5 hours at Clear Creek, a mountain station located at 3,100 feet elevation. On April 5, 1926, at a mountain station of about 4,400 feet elevation, a rain gauge registered 1 inch in 1 minute. At a nearby location in January 1943, 26 inches of rain fell in 24 hours. In 1969, there were 2 major rain storms 1 month apart, the first in January caused 45 inches of rain over a period of 9 days at Hi Hill, a mountain station near Mt. Wilson. In February, 21 more inches of rainfall occurred in 3 days. Each of the storms was flood producing. In February 1978 at a rainfall station located in northern San Fernando Valley at an elevation of 3,500 feet, a fairly typical flood producing rainfall pattern occurred. By 3:00 p.m. on February 9 precedent rainfall for the season had been 29.2 inches and over the last 22 hours, 5.3 inches. During the following 7 hour period 2.2 inches of rain occurred. From 10:00 p.m. until 1:05 a.m. another 2.0 inches of rain occurred, an intensity of more than 0.6 inches per hour, significant in any situation. Between 1:05 a.m. and 1:30 a.m. a deluge of 1.4 inches occurred, of which 0.4 inches fell in 5 minutes (equivalent to 4.8 inches per hour). This was the shortest interval registered by the rain gauge. These rainfall intensities occurred during the passage of a very intense cold front. Later I will relate these latter rainfall records to downstream sediment movement.

In Southern California production of sediment occurs more rapidly than runoff can carry it away. As a result alluvial valleys have been formed at the foot of the mountains. In their natural condition all of the valley streams are in an aggrading condition. Aggrading streams change course. When the velocity of the stream slows down, the heavier sediment particles settle out and raise the streambed. This causes the stream to become higher than the surrounding ground so the stream breaks out to another course having a naturally steeper gradient. Changes caused by sediment deposition generally occur very slowly, but, during, a few hours of a major storm event, major movement and deposition can cause severe damage and/or greatly change the land configuration.

Let's look at some of the historical occurrences. During the 1880's there were a number of major floods in Southern California. These caused damage to roads and railroads and water

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

systems, but there had been relatively little development along rivers so the hazard to people and property was relatively small. During the following period until 1914 no major storms occurred. Many people moved into the area. Development encroached into the flood plain of the Los Angeles River and other natural water-courses. A major flood occurred in 1914 with loss of life and considerable property damage. The community response in Los Angeles County resulted in the formation of the Los Angeles County Flood Control District in 1915.

The first attempts by the District were to define stream courses and to confine streamflows to those stream courses. While that approach was successful for small storms it could not succeed in controlling major flood flows carrying large amounts of sediment. Efforts were then centered on providing regional flood control protection with reservoirs and major channel improvements. This was followed beginning in the 1950's with various approaches to the management of the production, movement and deposition of sediment. Managing the sediment capable of being produced by the San Gabriel Mountains is important to the safety of the residents of the District, but frankly it is like trying to hold back the storm tides of the ocean.

Let's look at what has happened in the largest mountainous watershed in Los Angeles County. San Gabriel Dam was constructed during the 1930's to form a flood control reservoir. The dam is located about 5 miles upstream of the mouth of the mountain canyon. The reservoir has a tributary, uncontrolled mountain watershed of 160 square miles. The dam began blocking streamflow and disrupting the natural downstream movement of sediment in the summer of 1936. The original reservoir capacity at spillway elevation was 53,000 acre feet. From 1936 to the summer of 1980 the reservoir had collected sediment in the amount of 26,000 acre feet or 43 million cubic yards. From time to time sediment was moved through the dam by the process of sluicing. Sluicing consisted of using streamflow to dig sediment out of the reservoir bed and carry it through the dam in a low-level tunnel. Sluicing could occur only when there had been a large snowpack developed in the tributary area and when it was feasible to empty the reservoir before the runoff from the melting snowpack had receded below an efficient carrying capacity. During those 45 years, sediment was removed by the process of sluicing in the approximate amount of 10 million cubic yards. The cost of this process was 10 cents per cubic yard adjusted to 1981 prices.

Two sediment removal contracts were awarded by the Flood Control District. Sediment was removed by mechanical means and disposed in an upstream canyon about 1 mile away. The configuration of the disposal area was designed to assure that runoff would not bring the sediment back to the reservoir. The first of these contracts was awarded in 1968. It involved the removal of about 14 million cubic yards at 70 cents per cubic yard. Typical of the problems with occasional intense rainfall and large sediment movement, the contractor lost a great deal of equipment in the reservoir when it was buried by sediment during the floods of winter 1969. Later he was able to complete his contract. A second contract was awarded in 1978 following floods and additional sediment deposition that occurred the previous winter. The second contract was for 5 million cubic yards at $2.00 per cubic yard. Thus, after 45 years of operation of San Gabriel Reservoir and the expenditure of approximately $20 million for sediment removal the reservoir capacity remains impaired by sediment to the extent of 14 million cubic yards, 16 percent of the original capacity. Through the District, the residents are battling, but sediment is still winning.

Now let's look at the effect of fires in the watershed. When high temperatures, extremely dry air and strong winds combine, the high fuel content of the chaparral cover can explode into uncontrollable wildfires that may extend over thousands of acres before control is gained. Then the stage is set for catastrophic sediment movement. Records have been obtained in more than 37 controlled watersheds in Los Angeles County for periods greater than 25 years. This data demonstrates that up to a 40 fold increase in sediment production can occur during the first storm season following a watershed fire if high intensity rainfall occurs. Under normal conditions a period of brush regrowth of 10 years is needed to return to a baseline sediment production situation. Where less than an entire watershed is burned, outflow of sediment is often reduced to the extent that natural storage of sediment occurs within the watershed. Where the entire watershed is burned, severe storms have resulted in the movement of soil, rocks and boulders equivalent in volume to the removal of the top 2 or 3 inches of soil covering an entire watershed. Controlled burning of small areas, as proposed for brush management, reduces the probability of catastrophic events, but sediment production will be increased in direct proportion to the size of the burned watershed area and according to the coincidence of the occurrence of major storms. Thus, the obvious conclusion is that controlled burning should be done only in those years in which heavy rainfall will not occur in the following storm season.

Having now made my mark on posterity with that profound statement let me continue with another contribution to folklore. It has been observed in the Los Angeles County situation that the highest rainfall intensities in a given storm system always occur upon the most recently burned watershed. No scientific explanation has been developed for this phenomenon although possible, but unlikely, explanations include increased availability of raindrop nuclei from ash particles or differences in heat reflection from the burned area.

Following are some examples of major sediment events. In the New Year's Day flood of 1934 there were large but unmeasured sediment flows onto the partially developed alluvial fan area of La Crescenta. The streams carried and deposited boulders of up to 20 feet in their largest dimension.

During the March 2, 1938 flood all 10 mountain reservoirs owned by the Flood Control District were rendered inoperable by sediment plugging of their outlet works. Sediment inflow into West Ravine Debris Basin amounted to 120,000 cubic yards per square mile on a 0.25 square mile watershed which had been burned in 1933. Most major highway and railroad routes out of Southern California were blocked by sediment deposits, flooding or flood washouts.

During the major storms of January and February 1969, sediment inflow to Hook East Debris Basin amounted to 223,000 cubic yards per square mile on a 0.30 square mile watershed, which had burned in the Fall of 1968. This fire had covered a very large area of the frontal slopes of the San Gabriel Mountains lying upstream of the City of Glendora. Numerous canyons within the City carried heavy sediment flows and created problems for residents within and below the canyons. In one nearby canyon, stream-deposited sediment covered a one-story house up to the eaves of the roof. A 7 foot by 6 foot concrete box storm drain below Hook Canyon was blocked by a boulder of about the same dimension at a location about 1/2 mile downstream of the storm drain inlet. The portion of the storm drain upstream of the boulder was filled completely with sediment. It was cleared with a piece of mining equipment designed for working in a small cross-sectional area.

On February 10, 1978, sediment inflow to Zachau Debris Basin in the Sunland area was estimated to be at least 100,000 cubic yards per square mile on a 0.35-square-mile watershed which had burned in the Fall of 1975. Sediment overflowed the structure and spread over an area of about 1/2 square mile of densely populated area downstream. Streets were blocked, houses filled with sediment, and considerable damage was done to landscaping, parking lots and other outdoor facilities. A sediment-blocked storm drain in Shields Canyon in La Crescenta caused sediment-laden storm flow from the mountain canyon with a 2-year-old burn to be diverted onto a residential street. Several homes were severely damaged before the flow found its way back into the defined watercourse. Sediment and flood flows from a 2-square-mile mountain canyon contributed to the destruction of many buildings in a small mountain community killing 11 people. These events occurred as a result of the intense rainfall described earlier in the paper.

Well then, what is the outlook? In my opinion there is little likelihood of totally controlling sediment production or movement. Sediment management will continue to be directed at protecting people and lowering costs. Avoiding catastrophic events will lower the risk to people. It is likely that costs will continue to be high. However, for people to live and work safely in the communities at the base of the San Gabriel Mountains, sediment management is an absolute necessity.

Vegetative Management Aspects of Flood Control and Water Projects[1]

Scott E. Franklin[2]

Abstract: The Department of Water Resources has initiated a program of prescribed burning in watersheds above State Water Project reservoirs and adjacent watersheds. The Department sees its role as a catalyst and guide to accelerate the work of the California Department of Forestry, the U. S. Forest Service, and the Bureau of Land Management. The California Water Commission supports vegetative management as an integral part of existing and future flood control and water conservation projects. Vegetative management in the watersheds above flood control reservoirs could be a part of Governor Brown's resources investment program to break the fire/flood cycle which has occurred historically.

In June, 1980, the California Water Commission held a workshop in Sacramento on vegetative management in watersheds. Testimony was received from the U. S. Forest Service (USFS), the National Park Service (NPS), the Bureau of Land Management (BLM), the California State Office of Planning and Research, the University of California - Davis (UCD), the California Departments of Water Resources (DWR), Forestry (CDF), Fish and Game (DFG), and Food and Agriculture (DFA), the California Air Resources Board (ARB), and Santa Barbara County.

At that meeting the Northern California Grindstone Project of the Forest Service was discussed. We learned that this experimental brush conversion project was begun in the 1950's to convert selected brush areas to grass by prescribed burning to improve range and wildlife habitat. By 1972, 2,000 acres had been converted. In 1973, the Forest Service and Fish and Game agreed to develop and demonstrate techniques for coordinating wildlife habitat needs with fuel modification programs. Under this agreement, 12,000 acres of brush were burned. The benefits included increased water yield, fuel reduction, and decreased likelihood of catastrophic wildfire.

Estimates of the increased water yield were made by UCD researchers using data from this brush conversion project. This data showed an increased yield of about 5 inches following brush conversion in the experimental watersheds near Hopland (Mendocino County) and Lincoln (Placer County). This amount declined to zero over a period of several years unless suppression of brush growth continued. Since the increase does not entirely coincide with the pattern of water use, brush conversion would be most beneficial in watersheds above reservoirs. Brush removal on steep or unstable slopes, however, could cause sediment problems that would counter the benefits of increased runoff.

The cost of prescribed burning given in the 1979 Mendocino National Forest report, using the "Heli-torch" and jellied gas, is approximately $5 per acre. Using hand crews, costs averaged $10 to $30 per acre, depending on accessibility of needs of ignition. Subsequent maintenance with prescribed burning is claimed to cost less than $1 per acre. Using these figures and the yield of 0.45 acre foot per year, the cost of increasing runoff by brush conversion averages between $3 and $7 per acre foot per year over a ten-year period.

Significant Environmental Effects and Mitigation Measures

An initial increase in erosion from rainfall and runoff, with consequent increase in turbidity and sediment loads, generally occurs following prescribed burning. However, this adverse effect can be reduced by careful attention to several factors. The Forest Service at the Mendocino National Forest has observed all areas to return to normal within 3-6 years following certain procedures.

To mitigate the initial increase in erosion, sedimentation, and runoff turbidity resulting from prescribed burning, several steps should be taken. First, it will be recognized that some soils are so erosive and some geologic formations are so unstable that prescribed burning would cause erosion and sedimentation damage; these are therefore, unsuited for prescribed burning. Where such risks can be avoided, a management plan to minimize fire and geologic risks should be developed. Potential fire damages for alternative plans would be evaluated to select the best management plan. Second, the possibility of both water erosion and landslides which increase greatly with increasing slope must be evaluated. For each soil type, a limiting slope will be established above which burning will be avoided wherever possible.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Chairperson, California Water Commission, Sacramento, California 95814.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Third, timing burns to reduce the possibility of heavy rainfall on burned areas before the soils stabilize and grass is established will be done to the extent possible. Fortunately, light spring or early summer burns are also desirable for other reasons, particularly since they accomplish an excellent brush kill.

Vegetative Management by State Water Project

Following the June 1980 workshop, the Commission passed a motion asking DWR to prepare a report on the potential for prescribed burning at major Department reservoirs and adjacent watersheds. The report was to provide a program proposal for a multi-agency project to conduct prescribed burns. We asked that the report:

1. Identify DWR lands and adjacent watersheds where prescribed burning may be beneficial,
2. Provide preliminary estimates of water yield
3. Identify local, State, and Federal entities which may participate in the program.

Ronald B. Robie, Director, DWR, forwarded a report to the Commission on August 1, 1980, which included the following information:

The Department made preliminary estimates of additional runoff which indicated a potential 300,000 acre feet per year at existing and possible future State Water Project facilities. There is an additional potential of about 600,000 acre feet at other existing storage reservoirs within the Central Valley drainage basin. Increased runoff potential is not necessarily directly convertible to increased safe dependable water supply (yield gross), although in some instances it may be. The report pointed out that more work is needed to refine the estimates and determine the true lasting impacts on project water supplies.

Because the entire Central Valley drains to the Delta, it is possible that vegetative management on land outside the watersheds of SWP reservoirs could also produce additional water supplies for the Delta to help meet the Delta outflow requirements. DWR subsequently retained a consultant during 1980-81 to aid the Department in determining how vegetative management could best provide an increased water supply and to better estimate the amount of runoff that might be realized. DWR sees its role on brush conversion as a catalyst to guide and possibly accelerate the work of the California Department of Forestry, the U. S. Forest Service, and the Bureau of Land Management.

Forestry has historically had an ongoing program which includes authorization to burn State lands and to conduct cooperative burning of private lands. Stimulated by the recent passage of Senate Bill 1704, Forestry developed a goal of burning 120,000 acres of brush every year for the next twenty years. Water Resources will work with Forestry and the Board of Forestry by providing input on water supply benefits and priorities.

The Forest Service is developing management plans for each national forest which will be available during the next three years. Water Resources is working with them to assure proper consideration of vegetative management, including brush control, in the plans. The Forest Service will conduct burning on its lands. The State's involvement could include advising the Forest Service of the State's priorities and helping to establish monitoring programs to measure increased runoff.

Water Resources believes the most effective way to Attain potential water supply benefits from brush conversion is to initiate a State program to influence and support efforts of CDF, USFS, and BLM. In FY 1980-81, DWR initiated a program in cooperation with CDF, DFG, USFS, using State Water Project funds. The Department has initiated a pilot area study in the Feather River watershed above Oroville Reservoir, where it increased runoff of about 25,000 to 100,000 acre feet per year. The potential water salvage will be identified more closely through careful evaluation of vegetation types, erosion hazard, land ownership, access problems, and other factors.

Chapter 525, Statutes of 1980 (SB 1704 - Keene) authorized Forestry to conduct prescribed burning in cooperation with landowners and other agencies. The Department anticipates that prescribed burning will be conducted in the Feather River watershed as part of this program.

Vegetative Management at Hansen Dam, Los Angeles County

On October 24, 1980, the Commission held a public meeting to review the public interest and necessity to investigate the desirability of removing sediment from Hansen Dam in Los Angeles County. Hansen Dam is an earth-fill structure, 97 feet high and 10,475 feet long, on the Tujunga Wash about miles upstream of its junction with Los Angeles County. The dam can impound 29,700 acre feet of flood water. Facilities for recreation, which were developed by the City of Los Angeles, consist of a 125-acre lake with boat launching ramps and a swimming beach, picnic areas, riding and hiking trails, golf course, and baseball field. The primary purpose of the dam is flood control. The Corps of Engineers cooperates with the City of Los Angeles to operate the public park and recreation facilities in the reservoir area.

Due to the devastating fire in the upstream watershed that occurred in 1975, and three subsequent back-to-back, extremely wet winters, the dam is loaded with debris in the form of sand and vegetable matter, and in the near future could seriously jeopardize its flood control capability, which could cause loss of water conservation and recreation activities.

The Department of Water and Power (LADWP) of the City of Los Angeles could lose approximately 10,000 to 15,000 acre feet of potential ground water recharge annually if the present situation continues. This amount of water has a projected worth, in 1984 dollars, of almost two million dollars (replacement cost from the Metropolitan Water District). The City Council of the City of Los Angeles has approved a resolution which seeks sponsorship of federal legislation to add recreation and water conservation to the authorized purposes of Hansen Dam. The resolution would authorize a prompt cost estimate and feasibility study to clean out the silt, sand, and gravel. Assemblyman Richard Katz introduced Assembly Joint Resolution 14 to support such a study. The Commission asked that AJR 14 be amended to include vegetative management in the upper stream watershed. The Commission feels that with vegetative management in tributary areas, the inflow of silt and sediment to the reservoir can be more closely managed.

Governor's Vegetative Management Program

In December 1980, Governor Edmund G. Brown Jr., held a press conference in Los Angeles to announce his proposed $4 million Renewable Resources Investment Program in California to break the fire/flood cycle that has plagued Southern California and an immediate grant program to clean and replant the fire-damaged areas in the Panorama fire in San Bernardino National Forest. He also announced the creation of a task force on chaparral fire and flood risk management. The task force will make recommendations supporting use of prescribed burning and related techniques for controlling large volumes of brush in rural and urban areas.

The investment program for chaparral management takes the entire environmental system and the fire/flood cycle into consideration. A program of controlled burning and revegetation will not only help prevent forest fires and mudslides, but will benefit wildlife, recreational values, and water supplies. It will reduce air pollution, erosion, and the cost of firefighting, and the damages resulting from fires and floods.

The new program will be based on controlled burning of overgrown fire-hazardous areas in winter months when fires can be easily controlled. The program will use helicopter-helitorch devices to burn precisely defined areas. The controlled burning will reduce dangerous fuel supplies and old chaparral stands and will provide fire breaks to help in the control of wildfires.

Hydrology of Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Wade G. Wells II[2]

Presentations in two sessions have addressed three major hydrologic problems of Mediterranean-type ecosystems: flooding and sedimentation, water yield, and water quality. Because fire is common to all Mediterranean-type ecosystems and profoundly affects their hydrologic systems, Its effect on each of these problems was also addressed. This summary highlights the important points discussed, identifies some obvious gaps in our understanding, and suggests some major research and management needs.

FLOODS, EROSION, AND SEDIMENTATION

Every speaker dealt with the problem of flooding and sedimentation, and in three-fourths of the presentations it was the main topic. It is undoubtedly the major hydrologic concern in California's chaparral, and although less important in other Mediterranean areas, it is nevertheless recognized as significant.

An obvious reason for the problem is the Mediterranean climate itself. Howard (these Proceedings) has pointed out that erosion rates tend to increase with both the seasonality of rainfall and the tendency toward relatively large, infrequent storms, two key characteristics of a Mediterranean climate. Further, depending on temperature, highest erosion rates occur in those regions having between 300 and 750 mm of annual rainfall (Schumm 1977), and this is true for most of the stations in the world's Mediterranean areas (McCutchan 1977). In parts of California and Chile, the size and intensity of storms are increased by the presence of high mountains near the ocean.

It is interesting that Brock and DeBano (these Proceedings) did not find a significant increase in erosion rates with increases in slope. Other studies[3] (Anderson and Trobitz 1949) similarly found no strong correlations between slope and sediment production. Superficially, these results may seem to contradict common sense, but the concept of thresholds and equilibrium helps to explain it. Because erosion in arid regions tends to be episodic, not continuous (Schumm 1977; Howard, these Proceedings), slopes tend to reflect a state of equilibrium with their environment, and erosion occurs only after some type of disturbance (storm, fire, earthquake, etc.). This equilibrium is maintained over a range of conditions, and the limits of these conditions are thresholds. When a disturbance causes one or more thresholds to be exceeded, the slope erodes in order to establish a new equilibrium.

Carson and Kirkby (1972) have used the term "angle of maximum slope" to describe a common threshold. Essentially, it is the maximum angle at which the soil on a slope can resist failure under gravity. It is based on concepts of soil mechanics, and in its strictest sense can only be applied to slopes of uniform, unconsolidated material. As a concept, however, it clarifies the effect of thresholds on very steep slopes. As a slope approaches this angle (threshold), it becomes more and more unstable until its stability depends almost entirely on a specific set of local conditions (such as root biomass or moisture). Its angle of maximum slope, in the strict sense, is actually exceeded. The term, "oversteepened," is often used to describe this metastable condition. When a disturbance occurs, large increases in erosion are necessary to achieve a new equilibrium, and the result is an episode of high sediment production. Rice (1974) has proposed that a fundamental change in the dominant erosion processes occurs as slopes become steeper, and mass-wasting replaces fluvial processes. He further suggests that this threshold is somewhere around 50 to 60 percent, which tends to agree with my observations. In California's San Gabriel Mountains, where oversteepening is common, large erosion episodes are also common, and the extremely high rates of sediment yield reported by Bruington (these Proceedings) should be considered quite normal.

In a recently completed study, Taylor (1981 and these Proceedings) has identified six major inland sedimentation processes in coastal southern California. Rainsplash and channel transport are ubiquitous processes which dominate in the absence of the other four. Creep, landsliding, dry ravel, and sediment flows reflect local conditions and are relatively site specific. Dry ravel and landslides are characteristic of oversteepened

---

[1]Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Hydrologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

[3]Pers. commun., Brent D. Taylor, Environmental Quality Laboratory, California Institute of Technology, Pasadena, Calif., 1978.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

environments and tend to dominate in southern California's mountains and offshore islands. Rice (1974) estimates that these two processes account for over 85 percent of the erosion in southern California's chaparral zone. Brumbaugh and others (these Proceedings) report high incidence of soil slippage and landsliding on heavily overgrazed Santa Cruz Island. Sediment flows are also common, and their occurrence is often related to fire (Wells 1981).

Anderson and others (1959) have pointed out the yearly dry-wet cycle of erosion in California. Channels fill during the dry season, mainly by dry ravel, then scour in the wet season when the rains produce channel flow. Krammes (1965) found that channel filling actually occurs throughout the year. This fill-scour sequence, operating in cycles longer than 1 year, could be important in determining the amount of sediment produced by large flood events with return periods of several years. Vanoni and others, and Wells[4] have suggested that the low rates of sediment production by the storms of 1980 in southern California were caused by a lack of sediment supply in stream channels, a result of intense channel scour by similar storms in 1978. With only 2 years between these major storm events, there was not sufficient time for a large supply of sediment to accumulate in the channels. A longer time between such events would allow more sediment to be delivered from the hill slopes to the channel, and thus more would be available for transport when the next event occurred.

Fire

Fire is common to all Mediterranean ecosystems and probably figures more prominently in their management strategies than any other single factor. This is certainly true of its effect on flooding and sediment yield. The so-called fire-flood sequence (U.S. Dep. Agric., Forest Serv. 1954) is well documented in California's chaparral, and has been observed in other Mediterranean ecosystems as well. Brown (1972) and Burgess and others (1981) have described its occurrence in Australia, and Van Wyk (these Proceedings) reported an increase of suspended sediments in runoff water for 10 months after prescribed burning of South Africa's fynbos.

The effect of fire on flooding and sediment production in California is dramatic. Rowe and others (1954) have estimated that sediment yields in the first year after fire can be as much as 35 times normal. Peak flows can be four times normal for a 1-year event, and 34 times normal for an event with a 0.1-year return period. Wells (1981) reported that the sediment yield from 0.008-ha plots on a 50 percent slope in California chaparral increased by over two orders of magnitude in the first year after burning. Boyle (these Proceedings) presented a dramatic case study in which a series of postfire flows caused a residential development to be converted into a floodway.

The immediate cause of these extremely high flows is order-of-magnitude increases in both sediment bulking ratios and total runoff. Normal rates of postfire overland flow are 10 to 15 times the prefire rates, and increases of as much as 40 times the prefire rates have been measured (Rice 1974). Davis (1977) reported that sediment bulking ratios in the San Gabriel Mountains increase from 40 to 60 times in the first year after fire. In unburned catchments, sediment makes up from 1 to 2.5 percent of the total flow, and, for a given basin, these values remain quite constant for all discharges. After fire, sediment makes up from 30 to 60 percent of the total flow. Indeed, many postfire flood events are sediment flows rather than water. When the increases in runoff are combined algebraically with the increase in bulking ratio, the results are very near those values reported by Rowe and others (1954).

The underlying reasons for these increases in runoff and bulking ratio are not fully understood and are the subject of many current studies. The most obvious fire effect is removal of vegetation and litter from an area; removal of litter has been shown to increase sediment production (Brock and DeBano, these Proceedings). This removal exposes the soil surface to the undiminished impact of falling raindrops, which has been shown to be the major source of energy for "sheet" erosion during storms (Mutchler and Young 1975). Young and Wiersma (1973) found that raindrop energy accounted for over 90 percent of all the movement of sediment into rills from interrill areas and for about 10 percent of the total sediment transport off a site. Dunn and others (these Proceedings) have found that a unique postfire community of heat-shock fungi imparts some ability to recently burned soils to resist detachment by raindrop impact. The full range of this fungal-soil interaction is currently under study.

Two other important postfire erosion processes are dry ravel and rill formation. Dry ravel has been shown to increase substantially after fire (Krammes 1960), and changes induced in the particle-size distribution of soils by heating in a fire may play a part in this increase (Duriscoe and Wells, these Proceedings). After the first

[4]Vanoni, V. A.; Born, R. H.; Nouri, H. M. Erosion and deposition at a sand and gravel mining operation in San Juan Creek, Orange County, California. Paper presented at symposium on storms, floods and debris flows in southern California and Arizona 1978 and 1980. Committee on Natural Disasters, National Research Council. September 17-18, 1980, Pasadena, California.

Wells, W. G. II. The storms of 1978 and 1980 and their effect on sediment movement in the eastern San Gabriel front. Paper presented at symposium on storms, floods and debris flows in southern California and Arizona 1978 and 1980. Committee on Natural Disasters, National Research Council. September 17-18, 1980, Pasadena, California.

winter storms, the most striking erosional features on freshly burned slopes are the numerous rills. There is considerable qualitative evidence to suggest that water-repellent soil and extensive rill formation on burned slopes are closely linked (Wells 1981), and fire in chaparral is known to produce a layer of water-repellent soil a few centimeters beneath the soil surface (DeBano 1981).

The fire effect does not last long. Rowe and others (1954) estimated that whole basins return to normal in 8 to 10 years. Brown (1972) found that 4 to 5 years was sufficient for recovery in Australia. Plot studies indicated that hill slopes in California chaparral recover in 3 years (Wells 1981). Van Wyk (these Proceedings) reported that only 10 months are required in South Africa's fynbos.

Management Implications

The cost of sediment management can be very high even without the effect of fires. Bruington (these Proceedings) reported that sediment control on one reservoir in the San Gabriel Mountains has cost almost $1/2 million per year for 45 years. The costs of postfire flooding in Harrison Canyon (Boyle, these Proceedings) are equally impressive. In land use planning, we must fully understand the magnitude of the forces we are dealing with and the time periods over which they operate. Only then will we be successful in managing their effects.

WATER YIELD

Another problem shared by most Mediterranean areas is a relative scarcity of water. Most of the drainages in these areas are ephemeral washes, and there are few perennial streams. The ever-increasing demands for water are forcing us to look for ways to increase usable runoff in these areas. Franklin (these Proceedings) has reported that this is one of the major land management goals of the State of California.

The two major approaches to increasing water yield in the western United States have been vegetation manipulation (usually type conversion) and periodic prescribed burning. Water harvesting--the use of prepared catchments to collect rainfall--is quite common in Australia and Israel but has found limited use in the United States except in parts of Hawaii (Myers 1975). Hibbert and others (these Proceedings) have looked into both vegetation manipulation and prescribed fire as ways to increase runoff in Arizona chaparral. Their results seem to indicate that the response to vegetation manipulation is better than that to prescribed burning.

Attempts to increase water yield have been made in southern California, and increases have been noted after both fire and type conversion (Colman 1953, Crouse 1961). However, accelerated erosion in the wake of these efforts has been a major problem (Orme and Bailey 1970, Rice 1974), and the costs frequently outweigh the benefits. One of the problems with using fire is the increase in bulking ratios found by Davis (1977). It is difficult to recover usable water from flows which are 30 to 60 percent sediment, and disposal of the sediment is also a problem.

It must be expected that any attempt to increase water yield will probably incur a cost in terms of increased sediment yield. The relative magnitude of this cost will diminish, however, as the demand for water continues to grow. It seems certain, therefore, that ways to minimize this trade-off will be an important subject for future hydrologic research. Increased water production is already a major management goal.

WATER QUALITY

Water quality received the least attention of the three major problems addressed in this session. Perhaps this is related to the problem of water scarcity. When water is scarce, we don't worry as much about its quality. As we are able to increase water yield and as our management becomes more intensive, water quality must receive more attention. Only three aspects of water quality will be discussed here: nutrients in streams, suspended sediments (turbidity), and thermal pollution. Problems such as industrial pollution, and the effects of road construction and fire control, are too complex to be adequately addressed. Again, fire has important effects.

Thermal pollution changes the rates of both chemical and biological activity in natural streams, and thus influences the chemical makeup of the water delivered. It also has a direct effect on the streams' suitability as a fish habitat. Streamside vegetation is an important component of most Mediterranean ecosystems and is extremely important in maintaining stream temperature. Any degradation of such vegetation by fire, recreational use of the area, or clearing results in much higher mean temperatures with large diurnal fluctuations. Heating by fire itself does not seem to have a significant effect (Norris and others 1978).

Elevated levels of nutrients in runoff water following fire have been reported, but none are so high that they actually become pollution problems. Tiedemann and others (1979) reported that several workers in the United States have found increases in NO_3-N, NH_4-N, and organic-N, as well as in major cations (Ca, Mg, Na, and K). Van Wyk (these Proceedings) found major increases in Na and Cl and minor changes in SO_4 and HCO_3 after fire in the fynbos of South Africa. Riggan and Lopez[5]

[5]Riggan, P. R.; Lopez, E. L. Nitrogen cycling in the chaparral ecosystem. Paper presented at Western Society of Naturalists meeting; December 27-29, 1979, Pomona, California.

reported elevated NO_3-N levels in runoff from chaparral sites that have been converted to grass. They also found high NO_3-N levels in storm runoff (relative to base flow levels) in the San Gabriel Mountains. Dry deposition from the smog of nearby Los Angeles[6] and NO_3-N in rainfall (Liljestrand and Morgan 1978) may account for part of this.

Suspended sediment is often the most significant type of pollution. Increases in suspended sediment following fire have been reported from Australia as well as the United States (Brown 1972, Tiedemann and others 1979). Turbidity is not just a fire effect; almost any disturbance to the ecosystem can result in turbidity in nearby streams. Anderson and others (1976) reported eightfold increases from logging operations in northern California. Because cations are adsorbed by suspended clay particles, turbidity can be an important factor in nutrient loss.

HYDROLOGIC MODELING

As our knowledge of the environment advances, the need for a systems approach to it becomes more apparent, leading to the use of models that can rapidly generate information needed for informed management decisions. Two models have been discussed in these sessions. Anderson and Phillips (these Proceedings) presented a method for using existing data to evaluate the effects of fire on different hydrologic parameters. Rice and others (these Proceedings) presented a model which predicts changes in hill slope stability under different fuel management strategies. The former is designed primarily to assist managers, while the latter has both research and management applications.

Modeling, though an important tool in our discipline, must be carefully used. Many hydrologic models outstrip the data base in sophistication, so that highly refined models are often used to process very crude data. As a result, the answers reflect the model rather than the data. The real need in hydrology is for more data suitable for use in the models.

CONCLUSIONS

The Mediterranean-type regions of the world are attractive places to live and will continue to grow in population, with accompanying growth in the need for more intensive land management. This need, in turn, demands that we understand the natural processes operating on these lands better than we ever have before. These discussions suggest that some of the more pressing needs are these:

- A better understanding of fire's effects on sedimentation and flooding. We do not yet understand the fire-flood sequence well enough to deal effectively with its associated problems. High postfire erosion rates result from a major change in the erosion processes operating on a watershed. This change causes all sedimentation processes to reflect both the frequency and intensity of fires.

- A more detailed study of steepland erosion processes, particularly mass-wasting. Methods for dealing with erosion on agricultural lands have often proved inadequate in mountainous terrain. If we understand steepland erosion processes, we can deal with them more realistically.

- A quantitative assessment of delivery of sediment to channels, storage of sediment in channels, and transport of sediment through channels. A series of sediment budget studies covering different environmental conditions (postfire, fuelbreaks, undisturbed, etc.) is needed.

- A greater effort to increase water yield without incurring unacceptable penalties in sedimentation and pollution. Combinations of techniques designed for specific sites should produce the best results.

- More studies of nutrient loss from disturbed watersheds and the process by which it occurs. Also needed are studies of the chemistry of natural streams and the degree of variability in their chemical makeup.

- A stronger and more widespread effort to collect baseline data to support efforts in hydrologic modeling. This requires the establishment and maintenance of more data collection sites, particularly for sedimentation data.

For my final comment, I must mention the potential of prescribed fire in sediment management. Fire affects almost every part of the ecosystem, and its selective application can produce many benefits. Its use as a possible means of increasing water yield has already been mentioned, and it shows real promise as a preemptive tool for reducing the potential size of wildfires. It may also be useful, in a similar way, as a sediment management tool. Erosion in mountainous terrain cannot be stopped--nor should it be. Its consequences, flooding and sediment production, have to be managed. The long-term sediment yield rates in the San Gabriel Mountains are 10 to 20 tonnes/hectare (5 to 10 tons/acre) annually. An estimated 70 percent of all sediment production in California's chaparral is triggered by fire (Rice 1974); the fire-flood sequence has already been mentioned. Burning catchments, periodically, in small patches produces a mosaic of different-aged vegetation, lessening the chance that a major fire will burn an entire catchment at one time. Channels can usually contain the postfire flows from these smaller prescribed burns, and the mosaic, by reducing the chance of burning an entire catchment, also reduces the chance of a catastrophic postfire flood.

[6]Pers. commun., h. M. Liljestrand, Department of Civil Engineering, University of Texas, Austin, Tex., 1979.

LITERATURE CITED

Anderson, H. W.; Trobitz, H. K. Influence of some watershed variables on a major flood. J. For. 47:347-356; 1949.

Anderson, H. W.; Colman, G. B.; Zinke, P. J. Summer slides and winter scour. Tech. Paper 36. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1959. 12 p.

Anderson, H. W.; Hoover, M. D.; Rinehart, K. G. Forests and water: effects of forest management on floods, sedimentation and water supply. Gen. Tech. Rep. PSW-18. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1976. 115 p.

Brown, J. A. H. Hydrologic effects of a brushfire in a catchment in southern New South Wales. J. Hydrol. 15:77-96; 1972.

Burgess, J. S.; Rieger, W. A.; Olive, L. J. Sediment yield change following logging and fire effects in dry sclerophyll forest in southern New South Wales. In: Erosion and sediment transport in Pacific Rim steeplands. International Association of Hydrological Sciences Publ. 132; Christchurch, New Zealand; 1981; 375-385.

Carson, M. A.; Kirkby, M. J. Hillslope form and process. London: Cambridge Univ. Press; 1972. 475 p.

Colman, E. A. Fire and water in southern California's mountains. Misc. Paper 3. Berkeley, CA: California Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1953. 8 p.

Crouse, R. P. First-year effects of land treatment on dry season streamflow after a fire in southern California. Res. Note 191. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1961. 5 p.

Davis, J. D. Southern California reservoir sedimentation. Paper presented at American Society Civil Engineers fall meeting and exhibit, San Francisco, CA., 1977.

DeBano, Leonard F. Water repellent soils: a state of the art. Gen. Tech. Rep. PSW-46. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1981. 21 p.

Krammes, J. S. Erosion from mountain side slopes after fire in southern California. Res. Note 171. Berkeley, CA: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1960. 8 p.

Krammes, J. S. Seasonal debris movement from steep mountain side slopes in southern California. Proceedings of the second Federal interagency sedimentation conference; 1963 January 28-February 1; Jackson, MS. Misc. Publ. 970. Forest Service, U.S. Department of Agriculture; 1965; 85-89.

Liljestrand, H. M.; Morgan, J. J. Chemical composition of acid precipitation in Pasadena, California. Environ. Sci. and Tech. 12:1271-1273; 1978.

McCutchan, M. H. Climatic features as a fire determinant. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, 1977 August 1-5, Palo Alto, CA. Gen. Tech. Rep. WO-3. Washington, DC: Forest Service, U.S. Department of Agriculture; 1977; 1-11.

Mutchler, C. K.; Young, R. A. Soil detachment by raindrops. Present and prospective technology for predicting sediment yields and sources. Agric. Res. Serv. ARS-S-40. Washington, DC: U.S. Department of Agriculture; 1975; 113-117.

Myers, L. E. Water harvesting--2000 B.C. to 1974 A.D. Proceedings of water harvesting symposium; 1974 March 26-28; Phoenix, AZ. Agric. Res. Serv. ARS-W-22. Washington, DC: U.S. Department of Agriculture; 1975; 1-7.

Norris, L. A.; Hawkes, C. L.; Webb, W. L.; Moore, D. G.; Bollen, W. B.; Holcomb, E. A report of research on the behavior and impact of chemical fire retardants in forest streams. Corvallis, OR: Pacific Northwest Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1978. 152 p. w/app.

Orme, A. R.; Bailey, R. G. The effect of vegetation conversion and flood discharge on stream channel geometry: a case of southern California watersheds. Proc. Am. Assoc. Geog. 2:101-106; 1970.

Rice, R. M. The hydrology of chaparral watersheds. Proceedings of the symposium on living with the chaparral; 1973 March 30-31; Riverside, CA. Sierra Club; 1974; 27-33.

Rowe, P. B.; Countryman, C. M.; Storey, H. C. Hydrological analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds. Berkeley, CA: California Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture, 1954.

U. S. Department of Agriculture, Forest Service. Fire-flood sequence on the San Dimas Experimental Forest. Tech Paper 6. Berkeley, CA: California Forest and Range Exp. Stn., Forest Service, U.S. Department of Agriculture; 1954. 22 p.

Schumm, S. A. The fluvial system. New York: John Wiley and Sons; 1977. 338 p.

Taylor, B. D. Inland sediment movements by natural processes. EQL Rep. 17B. Pasadena, CA: Calif. Inst. Tech.; 1981. 107 p.

Tiedemann, A. R.; Conrad, C. E.; Dieterich, J. H.; Hornbeck, J. W.; Megehan, W. F.; Vierick, L. A.; Wade, D. D. Effects of fire on water. Gen. Tech. Rep. WO-10. Washington, DC: Forest Service, U.S. Department of Agriculture; 1979. 28 p.

Wells, W. G. II. Some effects of brushfires on erosion processes in coastal southern California. In: Erosion and sediment transport in Pacific Rim steeplands. International Association of Hydrological Sciences Publ. 132; Christchurch, New Zealand; 1981; 305-342.

Young, R. A.; Wiersma, J. L. The role of rainfall impact in soil detachment and transport. Water Resour. Res. 9:1629-1636; 1973.

Fire

Fire

Distribution of Lightning- and Man-Caused Wildfires in California[1]

Jon E. Keeley[2]

Abstract: During the 1970 decade on lands under fire jurisdiction by the California Division of Forestry (CDF) and the United States Forest Service (USFS) there were over 100,000 wildfires, 16.2 percent of which were lightning-caused and these accounted for 13.1 percent of all area burned. On USFS land, August is the peak month for lightning fires whereas July is the peak for man-caused fires. On average, lightning fires occur at higher elevations than man-caused fires and this is reflected in differences in the types of vegetation providing fuel for ignition. The number of lightning fires is positively correlated with distance from the coast and latitude whereas the number of man-caused fires is negatively correlated with these two parameters. Correlations between other parameters are presented and the question of "natural" burning patterns is discussed.

Wildfires are a major influence on the structure and function of most mediterranean–type ecosystems (Mooney 1977). This is certainly true for the brushland and forest communities of California. Many plant species in these communities have adaptations such as basal burls, refractory seeds or serotinous cones which are generally interpreted as evolutionary responses to a long association with fire. In light of this, desirable management of such fire-prone systems requires an understanding not only of the present characteristics of the fire regime but some understanding of the prehistorical (natural) fire regimes. The purpose of this paper is to provide a picture of the present burning pattern in California and attempt to evaluate the relationship between this pattern and that produced under "natural" conditions. With respect to fire regime, the term "natural" has various interpretations (Keeley 1980). In this paper I will he using the term in reference to the fire regime unaltered by contemporary or aboriginal man.

The question "what was the natural fire regime in California wildlands" can be approached several ways. Forested ecosystems provide a limited view of presettlement fire frequency through fire scars on long-lived fire-resistant trees (e.g., Kilgore and Taylor 1979). Byrne and others (1977) have approached this question by using sediment cores which contain charcoal deposits and then developing models for interpreting these deposits in terms of the presettlement fire regime. A third approach has been to examine the recent distribution and frequency of lightning fires and extrapolate these findings to estimates of presettlement fire frequency (e.g., Keeley 1977, Parsons in press). At best, each of these methods provides a limited view of the natural fire regime.

In the present study I have assembled statistics on the distribution of wildfires in California. These data give a clear picture of present burning patterns in the state. Additionally, by distinguishing lightning-caused and man-caused wildfires a framework is provided for evaluating prehistorical burning patterns.

METHODS

Fire statistics spanning the 1970 decade for California lands under the jurisdiction of the California Division of Forestry (CDF) and the United States Forest Service (USFS) form the basis for this analysis. The terms "CDF land" and "USFS land" will be used to indicate lands under the jurisdiction of those agencies, although not-necessarily owned by them. Data on the number of fires and hectares burned per year by cause was available from both the CDF and the USFS. Detailed data on cause, month, elevation, acreage and fuel type of ignition for every fire during the 1970 decade was available only from the USFS. Since the area was not reported for fires less than a quarter acre (.10 Ha.) these "spot fires" were arbitrarily assigned a value of .1 acre (.04 Ha). In the early part of the decade several realignments were made by the CDF and USFS. These were taken into account and statistics are presented for forests as they appeared 1979.

These data were computerized and analyzed with the UCLA Biomedical Statistical Programs (BMDP 1977 series). Since CDF ranger units and USFS forest districts differ in size, all data was standardized and expressed on a per million hectare basis.

The distribution of fires was evaluated along a gradient from the coast to the interior and along a latitudinal gradient. For this purpose each ranger unit or forest district was assigned a position along these two gradients which approximated the center of the unit or district.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean Type Ecosystems; June 22-26, 1981, San Diego, California.

[2]Assistant Professor of Biology, Occidental College, Los Angeles, California 90041.

Table 1--Average number of, and area burned by lightning-caused and man-caused wildfires on CDF and USFS land in California during the 1970 decade.

	No/Million Lightning	Ha/Yr Man	Ha/Million Lightning	Ha/Yr Man
CDF	31	541	416	3,347
USFS	129	134	189	669

RESULTS

The combined California Division of Forestry (CDF) and United States Forest Service (USES) land covered by this survey was over 22.8 million hectares. During the 1970 decade there were 76,169 fires on CDF land and 25,084 on USFS lands. The distribution of these fires by cause is shown in table 1. There were twice as many fires and four times more area burned on CDF land than USFS land. On CDF land only 5 percent of the fires were caused by lightning and these fires accounted for 11 percent of the area burned. Lightning accounted for 49 percent of the fires on USFS land but these fires burned only 22 percent of the total area consumed. In general lightning fires were more common on USFS land than on CDF land. However, on average, a lightning fire on CDF land burned 10X more area than one on USFS land.

As one might expect, the distribution of fires was not uniform across the state. A breakdown, by CDF ranger unit and USFS forest district, of wildfires is presented in tables 2 and 3. The arrangement of units or districts is more or less from south to north and coast to interior (see fig. 1 for locations). On CDF land (table 2) the average number of lightning fires varied from a low of 4/million ha/yr in the southern part of the state to a high of 134/million ha/yr in the northern part of the state. A similar pattern was observed on USFS land (table 3) with lightning fire frequency varying from 20/million ha/yr in the southern part of the state to 393/million ha/yr in the northern part of the state. Man-caused fires showed a latitudinal trend opposite to this with more fires in the southern end of the state and fewer in the northern end. These patterns are evident in correlations presented in table 4. With all ranger units and forest districts considered there was a highly significant positive correlation between lightning fire frequency and latitude and a significant negative correlation between man-caused wildfires and latitude. A similar pattern was observed with respect to distance from the coast; a highly significant positive correlation with lightning-caused fires and a highly significant negative correlation with man-caused fires. The same pattern was observed with respect to area burned, however the correlations were not significant for lightning-caused fires.

Table 2--Breakdown by ranger unit for average number of, and area burned by, lightning-caused and man-caused wildfires on CDF land during the 1970 decade.

Ranger Unit	No/Million Lightning	Ha/Yr Man
1. San Diego	31	914
2. Orange	4	4,286
3. Riverside	27	1,735
4. San Bernardino	34	934
5. San Luis Obispo	6	325
6. San Benito-Monterey	7	307
7. San Mateo-Santa Cruz	7	1,698
8. Santa Clara	5	402
9. Sonoma	7	868
10. Lake-Napa	17	490
11. Mendocino	40	316
12. Shasta-Trinity	73	539
13. Humboldt-Del Norte	42	289
14. Tulare	11	172
15. Fresno-Kings	8	103
16. Madera-Mariposa	36	266
17. Inyo-Mono	6	62
18. Tuolumne-Calaveras	28	713
19. Amador-Eldorado	23	922
20. Nevada-Yuba Placer	15	217
21. Butte	43	748
22. Tehama-Glenn	18	201
23. Siskiyou	133	253
24. Lassen-Modoc	134	104

Table 2--(Continue)

Ranger Unit	Ha/Million Lightning	Ha/Yr Man
1. San Diego	190	2,803
2. Orange	3	12,080
3. Riverside	1,553	31,742
4. San Bernardino	138	1,086
5. San Luis Obispo	29	4,384
6. San Benito-Monterey	13	5,344
7. San Mateo-Santa Cruz	1	4,185
8. Santa Clara	940	6,859
9. Sonoma	5	6,162
10. Lake-Napa	33	12,618
11. Mendocino	55	3,448
12. Shasta-Trinity	6,019	2,401
13. Humboldt-Del Norte	285	4,547
14. Tulare	186	3,646
15. Fresno-Kings	197	9,182
16. Madera-Mariposa	1,253	3,837
17. Inyo-Mono	31	991
18. Tuolumne-Calaveras	197	9,183
19. Amador-Eldorado	111	13,050
20. Nevada-Yuba Placer	13	7,287
21. Butte	143	4,455
22. Tehama-Glenn	211	20,313
23. Siskiyou	329	1,814
24. Lassen-Modoc	10,731	546

Table 3-- Breakdown by forest district for average number of, and area burned by, lightning-caused and man-caused wildfires on USFS land in California during the 1970 decade.

Forest District	No/Million Lightning	Ha/Yr Man
1. Cleveland	54	433
2. Angeles	68	372
3. San Bernardino	118	380
4. Los Padres	20	97
5. Mendocino	67	53
6. Six Rivers	32	80
7. Klamath	164	58
8. Shasta-Trinity	263	242
9. Sequoia	116	56
10. Inyo	84	74
11. Sierra	183	138
12. Eldorado	148	172
13. Stanislaus	163	136
14. Lake Tahoe Basin	191	1,147
15. Tahoe	157	154
16. Plumas	393	297
17. Lassen	165	79
18. Modoc	126	21

Table 3--(Continue)

Forest District	Ha/Million Lightning	Ha/Yr Man
1. Cleveland	36	12,101
2. Angeles	1,256	20,190
3. San Bernardino	184	3,919
4. Los Padres	2,237	1,734
5. Mendocino	24	1,619
6. Six Rivers	4	36
7. Klamath	597	171
8. Shasta-Trinity	47	1,709
9. Sequoia	98	1,559
10. Inyo	25	115
11. Sierra	44	1,879
12. Eldorado	24	593
13. Stanislaus	130	558
14. Lake Tahoe Basin	19	122
15. Tahoe	101	99
16. Plumas	209	530
17. Lassen	200	52
18. Modoc	1,699	396

The year-to-year variability in number of fires in a particular CDF ranger unit or USFS forest district was evaluated by comparing the coefficient of variation (CV percent = (SD ÷ $\overline{X}$) X 100). On most units and districts CV = 20-30 percent and never >50 for man-caused fires. Number of lightning-caused fires on USFS land was more variable with 2/3 of the districts having CV >50 percent (range 33-96 percent). On CDF land, number of lightning-caused fires ranged from 45-177 percent with nearly half of the units having CV >100 percent.

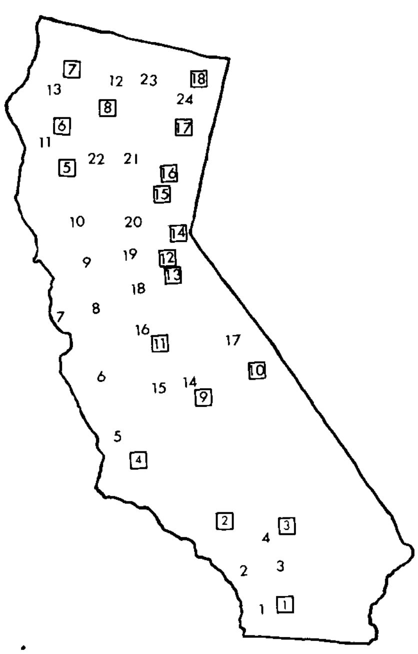


Figure 1--Distribution of CDF ranger units (unenclosed numbers) and USFS forest districts (enclosed numbers) listed in tables 2 and 3 respectively.

Variation in area burned per year was much more variable. Lightning-caused fires had CV >200 percent for half of the CDF units and USFS districts. Man-caused fires were equally variable on USFS districts but less on CDF units; only one unit had CV >200 percent.

Detailed Analysis of Fires (USFS Lands Only)

Month

Lightning-caused fires were most frequent (32 percent) in August whereas man-caused fires were most frequent (21 percent) in July. Lightning-caused fires were more heavily concentrated during the summer with 73 percent occurring in June, July and August whereas only 56 percent of the man-caused fires occurred in these months.

Based on the ten year averages for the 18 USFS forest districts, the correlation of percent of fires occurring in each month from June to September, with various other parameters, was analyzed. For lightning-caused fires, distance from the coast was positively related to the percent of fires occurring in July (r = +.52*) and negatively related to the percent in September (r = -.76 **). Latitude was positively related to percent

Table 4--Correlation of distance from the coast and latitude with average number of, and area burned by lightning-caused and man-caused wildfires for all CDF ranger units and USFS forest districts in California (N = 42).

	Latitude	Distance From Coast
Lightning		
No/Million Ha/Yr	r = + .37**	r = + .49**
Ha/Million Ha/Yr	r = + .20NS	r = + 14NS
Man		
No/Million Ha/Yr	r = -.39**	r = -.34*
Ha/Million Ha/Yr	r = -.39**	r = -.34*
NS = P >0.05	* = P <0.05	** = P <0.01

in June (r = +.50*), mean elevation was positively correlated with percent of fires in July (r +.61 **) and negatively correlated with percent in September (r = -.62**). The number of lightning-caused fires (per million ha per yr) was positively related to the percent occurring in June (r = +.65**).

For man-caused fires there was a positive correlation (r = +.54*) between distance from the coast and percent of fires in September. Latitude was positively related (r = +.47*) to the percent in August. As with lightning-caused fires, the average number of man-caused fires was positively related (r - +.55*) to the percent of fires occurring in June. The average area burned by man-caused fires was negatively correlated (r = -.58**) with the percent of fires occurring in August.

Elevation

The elevational distributed of lightning-caused and man-caused wildfires on USFS land are shown in figure 2. Lightning fires typically occurred at higher elevation than man-caused fires, and the latter were more broadly distributed over the elevational gradient.

A breakdown by forest is shown in table 5. The average elevation of lightning fires on a forest (not shown) was positively related to the average elevation of man-caused fires (r =+.78**). Average elevation was also positively correlated with distance from the coast for both lightning-caused (r = +.69**) and man-caused (r = + .80**) fires.

Correlation analysis between area burned per fire and elevation of that fire showed no sign-

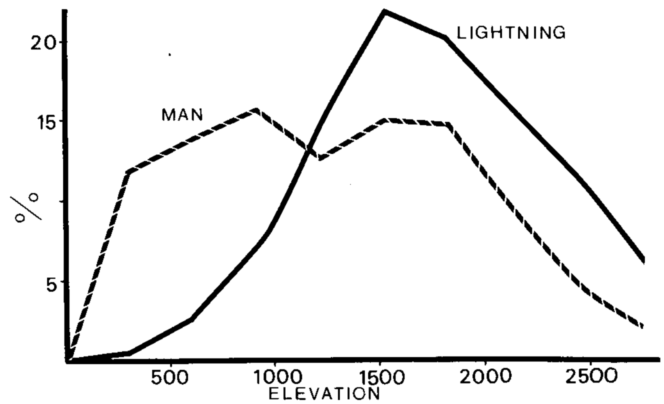


Figure 2--Elevational distribution (meters) of lightning-caused and man-caused wildfires on all USFS lands in California during the 1970 decade.

ificant relationship when analyzed across the state. Analysis within particular forests showed two forests with weak but highly significant negative correlations between size and elevation for lightning fires: San Bernardino r = -.14** (N = 548) and Sierra r = -.15** (N = 1,032).

Area Burned

Size of individual fires was exceedingly variable. On USFS land 97.6 percent of lightning-caused fires and 92.3 percent of man-caused fires were "spot-fires" (<.1 ha.). The remaining fires ranged as high as 17,800 ha for lightning-caused to 47,400 ha for man-caused fires. For the 12,228 lightning-caused fires CV = 5103 percent and for 12,796 man-caused fires CV = 3816 percent.

The percent of fires on a forest district as spot fires was positively related to distance from the coast and latitude for both lightning-caused (r = +.63**, r = +.50*) and man-caused (r = +,58**, r = +.65*) fires. For man-caused fires the size of the largest fire during the decade was negatively correlated (r = -.56*) with latitude.

Fuel Type of Ignition

Table 6 shows the distribution by fuel type for wildfires on USFS lands. The majority of lightning-caused wildfires occurred in timber vegetation, including hardwoods as well as coniferous communities. Grasslands which included meadows and scattered woodlands was the fuel type for only 7% of the lightning-caused fires whereas 27% of the man-caused fires occurred in grasslands.

The percent of lightning-caused fires igniting in chaparral was negatively correlated with distance from the coast (r = -.46*) and latitude (r = -.66**). The percent igniting in timbered vegetations was positively related to distance from the coast (r = +.56*) latitude (r = +.62

Table 5--Distribution, by elevation, of lightning-caused and man-caused wildfires on California lands under USFS jurisdiction during in the 1970 decade.

Forest	Percent by Elevation Lightning		
	<1067m (3500')	-	>1676m (5500')
1.Cleveland	18	60	22
2.Angeles	7	44	49
3.San Bernardino	4	23	73
4.Los Padres	20	41	39
5.Mendocino	19	59	22
6.Six Rivers	47	51	2
7.Klamath	20	54	16
8.Shasta-Trinity	32	54	14
9.Sequoia	3	11	86
10.Inyo	0	1	99
11.Sierra	5	21	74
12.Eldorado	6	28	66
13.Stanislaus	32	54	14
14.Lake Tahoe Basin	1	0	99
15.Tahoe	3	21	77
16.Plumas	5	44	51
17.Lassen	6	41	57
18.Modoc	0	75	25

Table 5--(Continued)

Forest	Percent by Elevation Man		
	<1067m- (3500')	-	>1676m (5500')
1. Cleveland	72	18	10
2. Angeles	72	15	14
3. San Bernardino	27	31	42
4. Los Padres	82	10	8
5. Mendocino	53	37	10
6. Six Rivers	87	12	1
7. Klamath	50	39	11
8. Shasta-Trinity	72	23	5
9. Sequoia	37	33	30
10. Inyo	24	43	33
11. Sierra	42	29	29
12. Eldorado	9	30	61
13. Stanislaus	24	36	40
14. Lake Tahoe Basin	0	0	100
15. Tahoe	11	25	64
16. Plumas	32	59	10
17. Lassen	14	69	17
18. Modoc	1	74	25

The average area burned each year by lightning-caused fires was negatively correlated (r =-.53*) with the percent igniting in timbered vegetations.

For man-caused fires the percent igniting in grasslands was negatively correlated (r = -.71**) with distance from the coast. The percent igniting in chaparral was negatively correlated (r = -.69**) with latitude. The percent igniting in timbered vegetation was positively correlated with both distance from the coast (r = +.71**) and latitude (r = +.64**). Additionally, the percent igniting in chaparral was positively correlated with both the number of fires per million ha per year (r = +.63**) and the area burned per million ha per year (r = +.77**), As with lightning-caused fires the percent igniting in timbered vegetation was negatively correlated (r = -.72**) with area burned per million ha per year.

DISCUSSION

One way of summarizing the data which illustrates the potential burning pattern for wildfires is to calculate the recurrence interval to be expected (calculated by dividing the total area in the ranger unit or forest district by the average acreage burned per year). Although some regions within a unit or district are likely to burn more frequently than others, the numbers is a rough estimate of the number of years required to burn the entire area under jurisdiction by a unit or district.

Tables 7 and 8 show these recurrence intervals for CDF and USFS lands. It is not clear how much confidence can be placed in these estimates, though the USFS data for the Cleveland and Angeles Forests suggests there may be a great deal of value in them. The 21 and 27 year interval for these largely chaparral covered forests matches quite well with the commonly accepted notion that chaparral presently burns on a 20-30 year cycle.

The recurrence interval for lightning-caused fires is of little value in terms of absolute numbers but may be useful for comparing regions. For example Modoc County in the northeastern part of the state has one of the lowest recurrence intervals based on both CDF data (table 7) and USFS data (table 8).

Table 6--Distribution, by fuel type of ignition of lightning-caused and man-caused wildfires on California lands under USFS jurisdiction during the 1970 decade.

	Percent	
	Lightning	Man
Grassland	7	27
Sage	3	2
Chaparral	19	22
Timber	50	39
Non-vegetation	<1	10

Table 7--Calculated recurrence interval for lightning-caused wildfires alone and all wildfires on CDF land. Recurrence interval in years = total area/average area burned per year.

Ranger Unit	Year	
	Lightning Fires Alone	All Fires
1. San Diego	3,117	197
2. Orange	37,857	9
3. Riverside	281	13
4. San Bernardino	3,280	369
5. San Luis Obispo	26,842	174
6. San Benito-Monterey	70,078	369
7. San Mateo-Santa Cruz	170,909	167
8. Santa Clara	772	45
9. Sonoma	79,184	63
10. Lake-Napa	19,541	51
11. Mendocino	15,163	239
12. Shasta-Trinity	103	73
13. Humboldt-Del Norte	2,695	159
14. Tulare	3,585	174
15. Fresno-Kings	2,899	132
16. Madera-Mariposa	483	119
17. Inyo-Mono	11,748	355
18. Tuolumne-Calaveras	2,477	52
19. Amador-Eldorado	3,267	27
20. Nevada-Yuba-Placer	27,132	'48
21. Butte	2,786	86
22. Tehama-Glenn	3,113	32
23. Siskiyou	1,081	166
24. Lassen-Modoc	55	53

Relating lightning fire frequency to the natural fire frequency for a region such as California is very difficult. Man extinguishes most lightning fires before they spread very far and man ignites many fires which consume a great deal of potential fuel. At the same time there is no a priori reason to assume that present burning patterns reflect natural patterns. Man accounts for most of the acreage burned in California wildlands and these fires differ greatly from lightning-caused-fires in their temporal and spatial distribution.

Several considerations suggest that the present burning potential is greater than under prehistorical conditions, at least for some regions. Man-caused fires occur at lower elevations than lightning-caused fires where fuel conditions are more conducive to fire spread. Also, though the data from this study does not reflect this, the weather conditions during man-caused fires are more conducive to fire spread than during lightning-caused fires. Lightning caused fires consistently are associated with thunderstorms and thus precipitation (Snow and Kotok 1923). Undoubtedly, many of these fires would not spread very far even if they were not suppressed.

One observation I believe is reflective

Table 8--Recurrence interval for USFS land calculated as in table 7 except two estimates were made for southern California forests, one based on a 10 year average for the area burned and an-other on a 25 year average (additional data from Keeley 1977).

	Year	
	Lightning Fire Alone	All Fires
1. Cleveland	5,679 (1,743)	17 (21)
2. Angeles	223 (554)	13 (27)
3. San Bernardino	2,529 (3,828)	113 (106)
4. Los Padres	356 (854)	201 (189)
5. Mendocino	17,975	265
6. Six Rivers	169,730	15,700
7. Klamath	1,406	1,093
8. Shasta-Trinity	9,807	261
9. Sequoia	12,230	725
10. Inyo	31,260	5,501
11. Sierra	12,725	294
12. Eldorado	13,532	516
13. Stanislaus	3,080	583
14. Lake Tahoe Basin	3,560	482
15. Tahoe	4,803	2,434
16. Plumas	1,533	434
17. Lassen	2,690	2,133
18. Modoc	452	366

of this, is a pattern of increasing numbers of reported lightning-caused wildfires over the past 50 years. This was earlier reported for the Cleveland National Forest in Southern California (Keeley 1977). It is perhaps best illustrated by data from Yosemite National Park. Fire records show that for the 20 yr period beginning in 1931 there were 17.2 (SD = 11.2) lightning-caused fires /yr whereas for the 20 yr period ending in 1979 there were 58.8 (SD = 29.9) lightning-caused wildfires ($P < 0.01$ by the Mann Whitney U Test). I interpret this to mean that 50 yrs ago many lightning fires were allowed, knowingly or unknowingly, to burn themselves out and would do so today if given a chance. Undoubtedly, much improved detection available today accounts for this phenomenon. What it suggests is that many of the lightning fires which are suppressed as spot fires probably would not have developed any further if left alone. Thus, the number of lightning fires during pre-fire suppression times, which would have produced sizeable fires, is a small subset of the total number recorded in the data for the 1970 decade.

One conclusion from this study does agree with another study concerned with estimating natural fire frequencies. Byrne et. al.[3] have suggested

[3]Bryne, R. Michaelsen, J.; Soutar, A. Fossil charcoal from varved sediments in the Santa Barbara Channel: An index of wildfire frequencies in the Los Padres National Forest (735 A.D. to 1520 A.D.). Unpublished Ms.

based on charcoal deposits off the coast of Santa Barbara, that whereas fires occurred on average once every 65 yrs along the coast they were approximately twice as frequent further inland. Their conclusion is reinforced by our finding of a highly significant positive correlation between number of lightning-caused fires and distance from the coast.

Other estimates of prehistorical fire frequencies are suggested from studies of fire-scars in long-lived trees, particularly in Sierrean coniferous forests. These estimates however are greatly affected by aboriginal burning. Data from Kilgore and Taylor (1979; as discussed in Keeley 1980) show clearly the tremendous influence of aboriginal burning. It appears that aboriginal burning may have increased the "natural" fire frequency several-fold and to have had a substantial impact on forest structures since the often cited white-fir invasion of mixed conifer forests is clearly traceable to the suspension of aboriginal burning and easily 20 years prior to active fire suppression in that region. That lightning fires alone were inadequate to produce the fire frequencies observed from fire-scar data was also suggested from observations made by Reynolds (1959).

SUMMARY

The data presented in this paper gives an overview of present burning patterns in California. A framework is provided for evaluating the relationship between present and pass fire regimes. The natural fire regime for California may have consisted of fewer fires at lower elevations than presently observed. If this were the case then, due to fuel accumulation, these fires would have been of much greater intensity than is commonly observed today. Any future studies which use this approach to evaluate prehistorical burning patterns will need to go beyond simply assembling statistics. A modeling approach which incorporates lightning fire distribution with fire behaviour characteristics, topographical, weather and fuel conditions could be successful.

Acknowledgements: I thank Pam Suda (USFS Pacific Southwest Fire and Aviation Management Unit) and the Fire Management Officers at all USFS District Offices for help in compiling data.

LITERATURE CITED:

Byrne, R., Michaelsen, J.; Soutar, A. Fossil charcoal as a measure of wildfire frequency in southern California: A preliminary analysis. Proc. of the Symp. on the Environmental Consequencies of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service General Technical Report WO-3; 1977;361-367.

Keeley, J.E. Fire-dependent reproductive strategies in Arctostaphylos and Ceanothus. Proc. of the Symp. on the Environmental Consequencies of Fire and Fuel Management in Mediterranean Ecosystems, USDA Forest Service General Technical Report WO-3: 1977; 391-396.

Keeley, J.E. Reproductive cycles and fire regimes. Proc. of the Conference Fire Regimes and Ecosystems Properties. U.S. Forest Service Genl. Tech. Report WO-26: 1980.

Kilgore, B.M.; Taylor, D. Fire history of a sequoia-mixed conifer forest. Ecology 60:129-142, 1979.

Mooney, H.A. ed. Convergent in Chile and California Mediterranean Climate Ecosystems. Dowden, Hutchinson & Ross, Inc. Stroudsberg Penn: 1977.

Parsons, D.J. The historical role of fire in the foothill communities of Sequoia National Park. Madrona in press.

Reynolds, R.D. Effects of natural fires and aboriginal burning upon the forests of the central Sierra Nevada. M.S. thesis, Univ. California, Berkeley; 1959.

Snow, S.B., Kotok, E.I. The occurrence of lightning storms in relations to forest fires in California. Monthly Weather Review 51: 175-182; 1923.

Fire History of the Santa Monica Mountains[1]

Klaus W-H Radtke, Arthur M. Arndt, and Ronald H. Wakimoto[2]

Abstract: The Santa Monica Mountain Range in Los Angeles County is the only major mountain range in the United States of America that divides a large city. Wildland fire history of the area was investigated to help in the decision making process for fire and vegetation management. Specifically the fire records for fires over 40.5 ha (100 acres) were analyzed for the fire exclusion period 1919-1980. Selected fires were used to demonstrate the predictive effect of land use, climate, vegetation, topography, fuel loading and fire suppression activities on fire patterns and fire behavior.

DESCRIPTION OF THE AREA

The Santa Monica Mountain range parallels the Pacific Coast of southern California in Ventura and Los Angeles Counties at 34°05'N latitude. It stretches for a distance of about 70 km from Ventura County into the heart of the City of Los Angeles to the east (Figure 1) and thus provides an ideal recreational setting for over 10 million people in this region. At its western extent it measures 15 km in width, narrowing to about 4 km at its eastern boundary. The southern boundary is the Pacific Ocean; the eastern boundary consists of the cities of Santa Monica and Beverly Hills and the West Hollywood section of the City of Los Angeles, The northern boundary is the Ventura Freeway (Highway 101). The mountains encompass approximately 97,000 ha or 240,000 acres (USDI, 1980).

The topography of the mountains is characterized by rugged terrain in its western and central section. In the west, Sherwood Peak rises to 1175 m within 10 km of the coast and in its central section, Saddle Peak rises to 885 m within 4 km of the coast. Almost half the mountain range has slopes exceeding 35 percent. The coastal slopes are characterized by steep hillsides that descend suddenly into many narrow north-south running canyons.

The area has a Mediterranean climate characterized by warm, dry summers and cool winters with approximately 80 percent of the precipitation falling from October through March. The 90-year mean annual precipitation ranges from 380 mm to 400 mm at the coastline to approximately 625 mm at the crest, and back down to 400 mm at the inland boundary along the Ventura Freeway (Los Angeles County Flood Control, 1976). Climatic averages are of limited value as the rainfall is often concentrated into a few heavy winter storms with intervening periods of high temperatures. Thus the fire season may extend into January during drought years.

The natural airflow for most of the year creates night and morning downward flows of air from the seaward side of the mountains over the Santa Monica Bay. In the afternoon this flow is carried inland by the seabreeze (USEPA(1977). During the summer the Catalina eddy penetrates the mountain canyons to a considerable distance with cool, moist marine air. The summer fog line extends up to the coastal ridges and to a considerable distance into the canyons. FLUim1 late September through December and occasionally even into January and February the area is characterized by strong (north to northeasterly foehn winds, locally known as Santa Ana winds. These winds are born as high pressure areas in high desert, great basins of Utah and surrounding areas. As they descend to lower elevations they become hot, dry (and gusty and may create erratic wind patterns when meeting the local mountain winds.

Major vegetation types found in the Santa Monica Mountains include a) coastal sage scrub(which is found below 300 m along the drier coastal slopes and as a band surrounding the higher mountains; b) oak woodland on some northern slopes with deep soils and areas relatively protected f.0 fire; c) riparian woodland along stream channels in areas where moisture is found at or near the surface throughout the year; d) grasslands of primarily introduced grasses on finer textured clay soils that may be saturated during the rainy season; and e) the woody, evergreen chaparral which is the most common vegetation type.

The early fire history of California as well as the Santa Mbnica Mountains is obscure. Sampson (.1944), after surveying historic documents dating back to the 15th Century, concluded that in areas away from the coast, burning by Indians had little influence on chaparral distribution. Drucker (1937) stated that when the Spaniards arrived, they found a hunting and gathering society of Indians who probably used fire only sparingly to increase hunting success. Once a fire started it was not controlled but was allowed to run its course. Other authors maintain that Indians practiced primarily spring burning to maintain grasslands (Lewis, 1973). Such fires would be of limited extent. Brown (1978) cited Dana as reporting extensive fires in the coastal ranges of southern California in the 1830's.

Burning by Indians and settlers often endangered settlements as well as livestock ranges. In 1793 Governor Jose de Arilleja issued California's

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Wildland Resource Scientist, Head Deputy Forester respectively, Los Angeles County Fire Department, Los Angeles, California; Assistant Professor of Wildland Fire Management, University of California, Berkeley.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

first fire control law prohibiting any kind of burning that may be detrimental to someone else (Lee and Bonnicksen, 1978). With California statehood in 1850, fire control became the responsibility of the individual landowners. Deliberately set fires increased as they served as a cost-effective way of opening up chaparral for access, development, grazing, ranching and mining. However, it is unlikely that this period greatly affected the fire history of the Santa Monica Mountains until 1900.

The period 1900 to 1918 was characterized by many large fires that burned the area on an average of at least two times (Santa Monica Evening Outlook 1900-1918). In 1919, the Forestry Department was established as fire suppression agency for the unincorporated areas of Los Angeles County and began maintaining records of all fires. Figure 1 illustrates these records as frequency of fires over 40.5 ha (100 acres) for the fire exclusion period 1919-1980 and shows that the highest fire frequency was historically located in the coastal zone. The coastal zone from about Las Flores Canyon to beyond the Ventura County line was burned 3-5 times giving an average burn frequency of from 12.4 to 20.7 years. Smaller areas not identified on the map burned up to 7 times. Mountainous areas inland of the ridge line, for the most part, burned only once. The 3-fire frequency corridor shown in the Las Virgenes-Mulholland block was created by fires that got an upslope running start along the Ventura Freeway on north slope range land consisting of flash fuel annual grasses and coastal sage. These fires occurred during strong Santa Ana wind conditions in 1958, 1970 and 1980.

FIRE FACTORS

An evaluation of the factors that determine fire patterns in the Santa Monica Mountains is necessary to understand the recorded fire history, speculate back from it to natural fire history and predict future fire patterns. The four most important factors that influenced the fire history in the Santa Monica Mountains are land use, vegetation, fire topography and climate (fire winds). They will be reviewed in this order.

Land Use

Almost every fire in recorded history was accidentally or deliberately set by man. In the Santa Monica Mountains, lightning fires are an almost unknown ignition source since they start primarily in the wet season and are out of phase with the foehn winds. Before 1900 most fires were started by local ranchers and homesteaders during weather conditions that prevented the development of large-scale fires. However, after 1900 the increasing population base at the southeastern end of the mountain range and the hunting season, which coincided with the fire season, served as ignition sources of carelessly set fires. Some of these fires burned uncontrolled for several weeks and caused extensive damage to ranchers while creating a better hunting season through brush regrowth. The establishment of an organized fire fighting force in 1919 put an end to such fires. Since then most fire starts have occurred along access routes leading into or through the mountains.

Vegetation

Many of the coastal slopes are covered by coastal sage. This plant community is characterized by

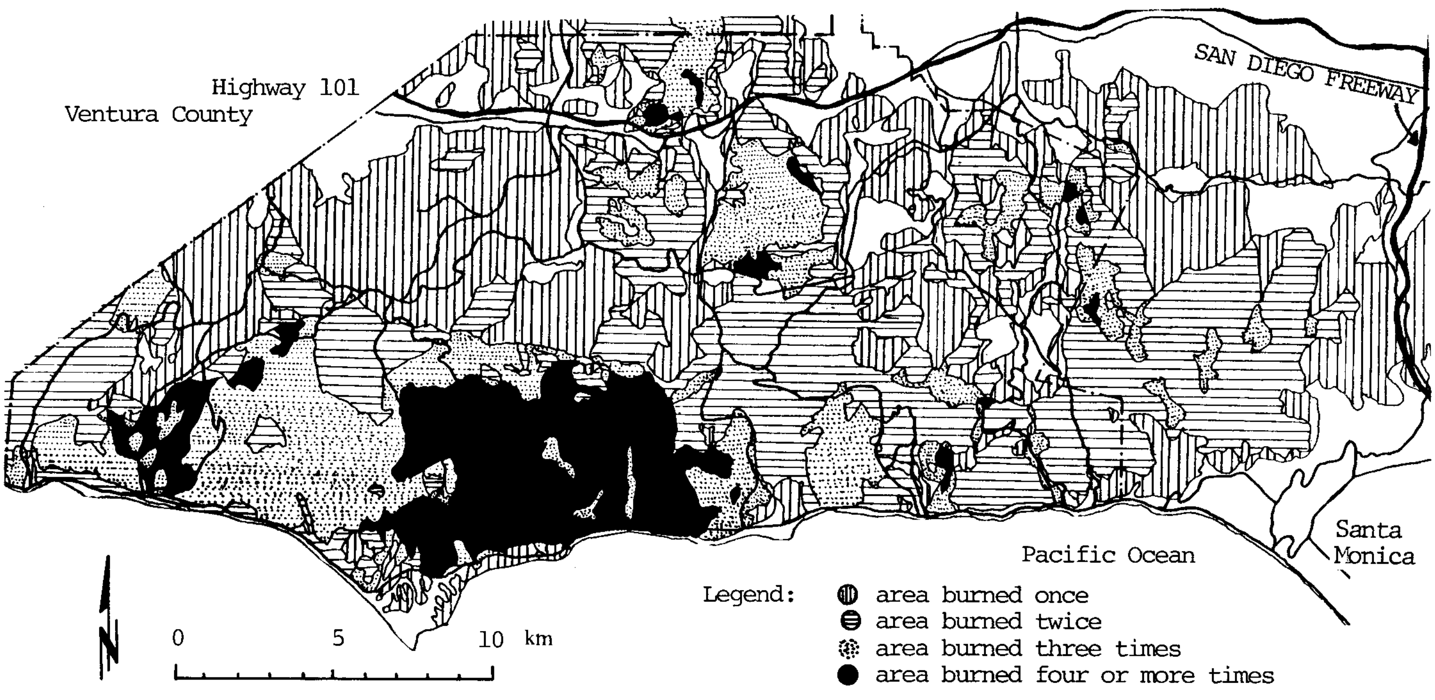


Figure 1--Fire frequency for fires over 40.5 ha for 1919-1980 (Ventura County to San Diego Freeway)

drought deciduous, short-lived shrubs that readily carry a fire within 7-10 years after a previous burn. Chaparral is found in a belt above the coastal sage slopes and becomes highly flammable on south slopes within 15-20 years. This is due to the preponderance of highly flammable chamise (Adenostoma fasciculatum), floristic components of coastal sage, and the lad fuel moisture of these plants. The flammability of chaparral is high until the third to fifth season after a fire because the short-lived herbaceous postfire flora carries the fire (Rothermel and Philpot, 1973). Chaparral is quite fire-resistant from 5-15 or 20 years or until the dead to live fuel ratio increases such that hot fires can again be supported. North slope chaparral consists of a mixture of more mesic species. Except in periods of extreme drought or dry foehn winds, this community does not become highly flammable unless the shorter-lived perennial species, such as Ceanothus, die, increasing the proportion of dead fuel. This generally does not occur for at least 20-25 years. Thus coastal chaparral can be considered relatively fire-resistant for the first 5-15 years or more whereas coastal sage may be highly flammable after 7-10 years.

The flammability of individual sites depends on a variety of site specific factors. However, during intense fire conditions fuel moisture is lowered because of low relative humidity, drying of fuels by the wind and, once a fire has started, the preheating of vegetation ahead of the fire. Thus the more flammable coastal sage can reduce the greater fire resistance of south slope chamise chaparral by carrying flames upslope into the chaparral. Similarly south slope chaparral can reduce the fire resistance of north slope communities.

Fire Topography

The coastal mountains extend east to west with all major canyons running north and south. Weide (1968) stated that in the eastern part of the Santa Monica Mountains, the canyons run south to southwesterly or parallel with the fire winds so that fires will be channeled up the canyon, spread out as they meet the ridges, contract again as they are funneled downhill through the canyons and may fan out in either direction as they reach the beaches. Weide also stated that this close linearity of fire winds and canyons is not present in the western section. Here the fires are more controlled by the direction of the wind and are thus more irregular in shape. However, a closer analysis shows that these generalities need to be further refined. First, the central and western portions of the range have much steeper canyons than the eastern portion so that fires are difficult to control. Canyons all reach from the ocean inland whereas in the eastern portion, from Pacific Palisades and beyond, fire spread is blocked by the city. Furthermore, major canyons in the western section run primarily northeast to southwest and in the central section north to south. These directions parallel the fire winds.

Wind Patterns (Climate)

Wind and fuel moisture are the two most important elements affecting fire behavior. Wind primarily controls the direction and spread of fire. It also affects fire behavior by reducing fuel moisture, increasing the oxygen supply needs for combustion, preheating the fuels, and bending the flames closer to the unburned fuels ahead of the fire. In intense wildland fires, the upper airflow may have a different direction from the surface winds and may influence fire behavior by not only carrying fire brands ahead of the fire but also into new directions (Greenwood, 1962).

In the Santa Monica Mountains large-scale fire patterns may seem erratic but they are predictable. Airflow is guided by topography into the north-south facing canyons so that onshore winds are channeled up canyon as well as upslope and the foehn or Santa Ana winds down canyon. This is especially noticeable during strong northerly Santa Ana winds. The sharp ridge lines produce significant turbulence and wind eddies on the lee side. Eddies that are associated with the rims of steep canyons may rotate and result in moderate to strong upslope winds that are opposite to the direction of the winds blowing over the rim. In general, when strong winds blow through steep canyons, wind eddies can become localized in bends in the canyons or the mouth of tributary canyons. The compressed air in mountain passes also results in horizontal and vertical eddies that fan the fire out as it descends downslope on the leeward side.

During the Santa Ana season the local daytime wind pattern is characterized by moderately strong onshore breezes along the coast and gentle to weak upslope and up canyon winds in the adjacent mountain areas. The nighttime cooling produces downslope and offshore winds that are of lesser magnitude than the daytime winds (Schroeder and Buck, 1970). This air circulation is predominant at the coastal side of the mountains, especially at lower elevations. Strong Santa Ana winds eliminate the local wind patterns so that little difference in day and night patterns exist in the initial stages. As the Santa Ana wind weakens, it shows diurnal patterns. During the daytime a light onshore seabreeze is often observable along the coast and light upslope winds along the coastal slopes. Such weak Santa Ana winds are held aloft along the coastal slopes so that the turbulence and strong up and dawn drafts found on the lee side when strong winds blew perpendicular to mountain ranges are not found. Furthermore, the air in the seabreeze may be returning Santa Ana wind which is not as moist as the marine air. After sunset, surface winds reverse and became offshore downslope winds. Increasing air stability may then allow the weaker lee turbulence aloft to produce the familiar mountain airwaves that hit the surface of leeward slopes and produce strong downslope winds. As the Santa Ana winds weaken further, normal seasonal and diurnal wind patterns return.

Strong Santa Ana surface winds that push the fire in a southwestern direction up the inland mountain slopes often change their direction to south and east as the winds are funneled into the coastal canyons. Thus the fire is fanned east up the canyon walls at the sane time it continues up and down canyon in a southwesterly direction across the canyons. This is especially noticeable in steep terrain and areas of heavy fuel loading.

ANALYSIS OF FIRE PATTERNS

When an organized fire department was established in 1919 for the unincorporated areas of Los Angeles County, fuel loading in the Santa Monica Mountains was at a low level. Large-scale fires had burned the mountain range several times between 1900 and 1919. Principally among the many fires were the 1903 Rindge Fire, the 1909 Malibu Fire, the 1910 Las Flores-Temescal Fires, the 1911 Santa Monica-Ventura Fires, and the 1913 Topanga-Escondido Fires. The 1911 fire was the largest. It burned the mountain range for several weeks and extended from Santa Monica into Ventura County.

The most complete fire records since 1919 are available for an area of 54,000 ha extending from Ventura County to San Diego Freeway to the east. Further discussions will pertain to this area. When fires over 40.5 ha are analyzed for the active fire suppression period 1919-1980 their cyclic periodicity is readily noticed. Figure 2 shows the total area burned per decade as well as the cumulative area burned, and illustrates that the overall burn cycle averages 20 years. As the fuel loading of the inland chaparral increased, more and more of its vegetation was incorporated into the burn cycle. This resulted in the steadily increasing peaks of hectares burned as listed in table 1.

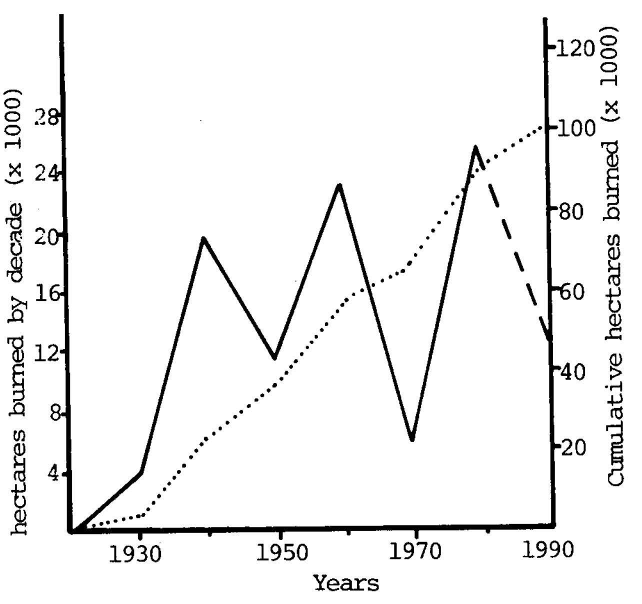


Figure 2--10 year periods and cumulative area burned by fires over 40 ha (1919-1980)

Table 1 - Fire Size By Decade (in ha)

Time Period	Size of Fire			Area Burned (in ha)
	40-200	200-400	400+	
1920-29	8	1	2	4,000
1930-39	3	0	5	20,000
1940-49	6	0	4	12,000
1950-59	8	2	6	23,500
1960-69	1	1	3	5,800
1970-79	4	0	6	26,500
1980	1	0	1	1,122
	31	4	27	92,922

Table 1 shows that 8 of the 11 fires (73 percent) for the decade 1920-29 ranged in size from 40 to less than 200 ha. Figures for 1930-39, 1950-59 and 1970-79 are 60, 50 and 40 percent respectively. Thus, as fuel loading increased, the number of small fires decreased and large fires increased. With the present land use pattern and level of fire protection, it is predicted that the area burned per year for the period 1980-89 will average 800 to 1,200 ha; a yearly reduction of at least 1,400 ha burned per year over the previous decade.

Next, the fires were analyzed for the time of year of burning. Figure 3 shows that the total area burned prior to August was insignificant, that it was relatively low in August (2,500 ha), but that it increased sharply thereafter. It tripled in September and again more than doubled in October (29,000 ha) before finally declining for the rest of the year. Table 2 shows that of the 25 fires under 200 ha, 20 or 80 percent were encountered prior to October. Twenty-three fires or 88 percent of all fires over 400 ha were encountered after September. Fires prior to August started almost exclusively in annual grassland or degraded sage.

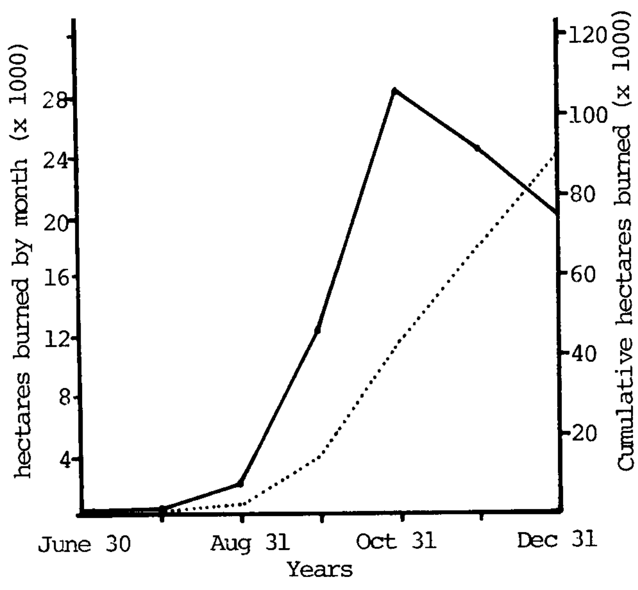


Figure 3--Monthly and cumulative area burned by fires over 40 ha (1919-1980)

Table 2 - Fire Size By Time of Year (in ha)[1]

Time Period	Size of Fire			Area Burned (in ha)
	40-200	200-400	400+	
Feb-June	2	0	0	10
July	8	0	0	66
August	4	1	1	2,41
September	6	0	2	12,78
October	0	2	7	29,06
November	4	0	11	24,84
December	1	0	5	20,68
	25	3	26	90,55

[1]The month of year of some of the earlier fires is not known. These have been omitted.

Individual fires seemingly show great differences in burning pattern. Some are confined to the inland regions and never reach the coast. Others are confined to the central region and never reach the coast, sate burn along the coast, others burn across the whole mountain range. A history of fire behavior of selected fires follows in an effort to support the picture of the composite fire history discussed so far. The fires discussed are shown in figure 4.

Fires in Initially Strong Northwest Wind Conditions

The 1944 Woodland Hills Fire started near the Ventura Freeway and, fanned by northwest winds, spread in a southeastern direction for about 9 km. Mulholland Highway was an effective fire barrier on its southern flank and limited the size of the fire. Large-scale fires during northwestern wind conditions have historically been effectively controlled with aggressive backfiring, hose lines and tractor work. The present use of helicopters, though not as effective as aggressive backfiring against a frontal fire, nevertheless limits these fires in size with the slightest break in fire weather.

Fires in Santa Ana and Onshore Wind Patterns

During the 1935 Latigo (Malibu) Fire light northeasterly winds allowed the local updraft mountain winds to spread the flames upslope and toward the ridge line where they were picked up by the light Santa Ana breeze and pushed toward the west. Hot spots still burning in the canyons

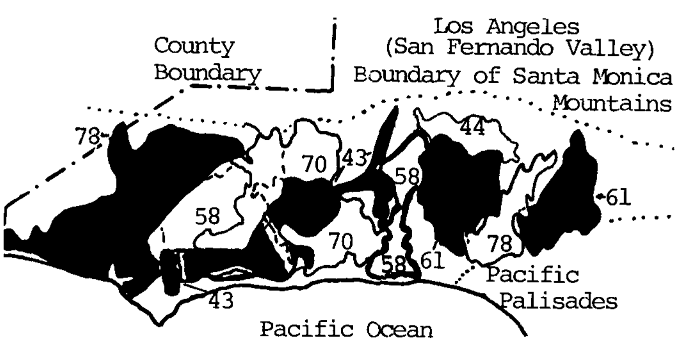


Figure 4--Fires that swept the mountain range from north to south

would lay down at night but would be whipped into flames early in the morning, making another run for the ocean. Onshore winds and local surface winds would push the fire again uphill and easterly upslope. Aggressive backfiring on a 27 km wide front finally contained the north and eastward spread of the fire. Thus Santa Ana winds coupled with local winds are responsible for spreading flames in both directions.

Santa Ana Fires from Coastal Ridges to the Coast

The 1956 Newton Fire started in the upper Newton Canyon watershed at the coastal ridge and raced to the beach while fanning out east and west. Changing wind patterns make the coastal mountain slopes vulnerable to east as well as westward fire spread, but quick aerial response and ground access make it now possible to limit the eastward spread of a coastal ridge fire.

Santa Ana Winds Fires Spreading from Highway 101 or Mulholland Highway to the Coast

Fires starting along the inland boundaries of the mountain range will normally became large if they are pushed by strong Santa Ana winds. Such fires were unknown from 1919-1935, were uncommon until 1957, but have since then occurred at least once every decade. Examples of such fires are the 1943 Woodland Hills Fire, the 1956 Sherwood Fire, the 1958 Liberty Fire, 1961 Topanga and Bel Air Fires, the 1970 Wright Fire, and finally the 1978 Kanan-Dune and Mandeville Fires. The 1978 twin fires burning through stands of chaparral in excess of 50 years old show the reliance on the north to northeasterly winds to set fire boundaries despite an army of men and a fleet of modern fire fighting equipment. Today, fire fighting personnel is geared to saving life and property during catastrophic fires. There is really no means of controlling such fires until the wind dies down or the fire runs out of fuel.

FIRE BOUNDARIES, FIRE FIGHTING TECHNIQUES

As the wind dies dawn, fire barriers such as firebreaks, roads and even previous burns as old as 20-30 years can become important fire boundaries. For example, the southwestern extent of the 1978 Kanan-Dume Fire was checked and prevented from crossing into Ventura County by the 1-year old Carlisle burn. Flames in the 1-year burn were supported by dead stands of aerially seeded annual ryegrass (Lolium multiflorum) and dead herbaceous annuals, but the law intensity flames were stopped on Decker Road despite winds gusting in excess of 60 km/hour. The westerly flank of the 1958 Liberty Fire was prevented from reaching the beach but not before it had crossed Latigo Canyon Road and burned several km into a 2-year burn. The southwestern extension of the 1970 Wright burn was also checked by a 3-year old burn. The 1978 Mandeville burn wedged between the 1961 Topanga and Bel Air Fires and made a run in chaparral stands in excess of 40 and 63 years. It was prevented from reaching the beach when it ran out of fuel in urban developments and the strongly gusting Santa Ana wind subsided.

The 1935 Latigo Fire is of interest in that the northern extent of the fire was slowed down when burning through a 10-year old burn. An indication that the chaparral was not highly flammable is shown by the large unburned stands along the northern boundaries of both the 1925 and 1935 burns.

The shapes of both the 1958 Warner Fire (Hourglass) and the 1943 Woodland Hills Fire indicate the successful use of aggressive backfiring and/or pinching off the flanks of fires by taking advantage of strategic fire barriers, such as firebreaks, roads and previous burns. The 1943 fire stretched like a worm from Woodland Hills to Point Dume, an aerial distance of approximately 23 km. It showed that southwesterly spreading fires, even when pushed only occasionally by Santa Ana winds, are hard to control. Prior to the use of helicopters, constant flareups when the winds picked up converted many seemingly controlled fires into uncontrolled fire disasters. The value of a helicopter thus lies in extinguishing fires through aerial water drops as soon as the wind dies down and extinguishing many spot fires before they can become major new fires.

CONCLUSION

This study showed that the coastal slopes of the Santa Monica Mountains had a higher fire frequency both in the prefire suppression period 1900-1918 as well as in the fire suppression period 1919-1980. During this latter period, the higher fire frequency was found predominantly in the coastal sage vegetation. Fire suppression was more successful in the inland chaparral regions. This resulted in a steady fuel buildup and a shift from small to large disastrous fires. The area investigated showed a cyclic periodicity in area burned of about 20 years. Coastal sage vegetation is able to carry large-scale fires within 10 years after a burn, south slope chaparral within 15 years, and north slope chaparral within 20 years.

Most large-scale fires occur during the Santa Ana fire wind conditions from mid-September through December. The probability of large-scale fires is also enhanced by the linearity of the fire winds and the canyons. When taking into account fuel type, topography and other site specific factors, it is therefore possible to predict the occurrence of large-scale fires and use fire management techniques inclusive of fire exclusion and prescribed burning more effectively to reduce high fire risks.

ACKNOWLEDGMENTS

We thank the Los Angeles County Forester and Fire Warden (Fire Department) for contributing data. This study was supported under the cooperative agreement on Chaparral Ecology and Related Ecosystems Studies between the County of Los Angeles and the U.S. Forest Service, PSW Forest and Range Exp. Stn., Berkeley.

LITERATURE CITED

Brown, G. D. Historical Mt. Gleason. County of Los Angeles Department of Forester and Fire Warden; 1978. 38 p.

Drucker, P. Culture Element Distribution; Southern California. University of California, Anthropological Records; 1937. 1:1-52.

Greenwood, Harold W. Bel Air, Brentwood and Santa Ynez Fires. Worst Fire in the History of Los Angeles. Los Angeles Fire Dept.;l962.

Lee, R. G.; Bonnicksen, T. M. Brushland Watershed Fire Management Policy in So. California. Calif. Water Resource Center, U.S; 1978. 71 p.

Lewis, H. T. Patterns of Indian Burning in California: Ecology and Ethnohistory. Ballena Press. Anthropological Monograph, Pomona #1;1973. 130 p.

Los Angeles County Flood Control District. Hydrological Report (Los Angeles County);l974-75, 1976. 319 p.

Los Angeles Times. Articles on December 4, 1903 Fire. Los Angeles, California; Dec. 5, 1903.

Rothermel, R. C.; Philpot, C. W. Predicting Changes in Chaparral Flammability. J. For. 71 (10); 1973. 640-643 p.

Sampson, A. W. Plant Succession on Burned Chaparral Lands in Northern California. University of California, College of Agric., Agric. Exp. Stn. Bul. 685; 1944. 144 p.

Santa Monica (Evening) Outlook. Fires in the Santa Monica Mountains; Dec. 5,6,7, 1903; Oct. 17-21, 1904; Sept. 15,16, Oct. 25, Nov. 3, 1909; Sept. 10, 1910; Nov. 11-28, 1911; Aug. 13, 26, Sept. 13, Oct. 21, 1913.

Schroeder, M. J.; Buck, C. C. Fire Weather . . . A Guide for Application of Meteorological Information to Forest Fire Control Operations. USDA-Forest Service Handbook 360; 1970. 27 p.

U.S. Department of the Interior, National Parks Service. Draft EIS and General Management Plan. Santa Monica Mountains National Recreation Area in Los Angeles and Ventura Counties, California. U.S. Government Printing Office, Washington, D.C.; 1980. 191 p.

U.S. Environmental Protection Agency. Final EIS/EIR Las Virgenes-Triunfo Malibu-Topanga. U.S. EPA, San Francisco, California.

Weide, D. L. The Geography of Fire in the Santa Monica Mountains. Unpublished Master's Thesis. Department of Geography, California State College, Los Angeles; 1968. 178 p.

Grazing, Fire, and the Management of Vegetation on Santa Catalina Island, California[1]

Richard A. Minnich[2]

Abstract: 19th century ground photos and aerial photographs reveal that chaparral and coastal sage scrub on Santa Catalina Island resembled modern stands on mainland coastal areas ca. 150 years ago, but were converted into an open herbaceous savanna due to overgrazing by feral goats, pigs, and other exotic fauna. This transformation has limited fires due to continuous removal of fuels. Browsing has also modified the floristic composition of brushlands. Removal of feral herbivores will result in rapid vegetal recovery and increasing fire danger.

Santa Catalina Island, located 70 km south of Los Angeles, California has experienced a limited history of fires during the 20th century. This is due primarily to continuous grazing and denudation of chaparral, coastal sage scrub and herbaceous fuels over the past 150 years by feral goats, pigs, and other exotic fauna. This trend is an extraordinary anomaly in southern California's mediterranean climate where fire is an annual possibility in most wildlands. Unfortunately, the present "solution" to the fire problem is accompanied by a multitude of other problems. These include island wide erosion, slope failure, destruction of indigenous wildlife, and decline or even extinction of numerous plant species, some of which are or were island endemics (Thorne 1967). Because of the devastation of the island, The Center for Natural Areas[3], under contract with the Los Angeles County Department of Parks and Recreation, has prepared a Natural Resources Management Plan (CNA 1980) on which this study is based. One recommendation of the report is the removal of feral herbivores, especially goats and pigs. Such a plan if implemented will result in increasing fire danger due to the accumulation of fuels in recovering vegetation.

This study documents a vegetation history of Santa Catalina Island by investigating the nature of pregrazing vegetation on 19th century ground photographs; present vegetation as mapped from 1976 color infrared aerial photography; long-term vegetation change as seen from retakes of old photographs, and comparative analysis of 1944 and 1976 comprehensive vertical aerial photography. From these data I speculate on past vegetation change, future fire potential, and management of brushland fuels if feral animals are removed.

GRAZING HISTORY

Grazing became important on Santa Catalina Island soon after attainment of statehood (1850). Commercial sheep and cattle grazing continued on Santa Catalina until the early 1950's when most of the domestic stock was removed.[4] The goat is thought to have been introduced to Santa Catalina during the late years of Mexican occupation (1820-1840, Coblentz 1976). Goats slowly became feral and were left to multiply at will in the absence of indigenous predatory animals. Present populations, numbering about 5000, are most abundant in three areas: the Silver-Grand Canyon drainage system, Gilbralter Rock on the north coast, and on the West End. These were excluded by fencing from interior drainages east of the isthmus in the 1950's. Goats prefer most herbaceous plants. Most chaparral and coastal sage species except for Rhus integrifolia, Malosma laurina, and Salvia spp. are browsed during the summer and fall when herbaceous cover is desiccated (Coblentz 1980). Pigs were introduced from Santa Rosa Island in the 1930's. They most commonly occur in deep soiled areas with dense chaparral cover and which are free of goats (Coblentz 1980). Although the pig is a grazer and browser, its greatest impact on vegetation results from its fruit—eating habits, the thoroughness of which inhibits the reproduction of many woody species.

FIRE HISTORY

Although Santa Catalina Island may be more exposed to maritime influences than mountain ranges on the southern California mainland, it is still subject to summer drought, desiccation of vegetation, and high fire potential. In spite of these conditions, only a few fires, mostly less than 10 hectares, have occurred in

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Professor of Geography, University of California, Riverside, Calif.

[3]South Gardiner, Maine

[4]Personal communication from A. Douglas Probst, Santa Catalina Island Conservarey September, 1979.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

recorded times. This trend contrasts sharply with the fire history of the mainland where thousands of hectares are burned each year, and the accumulative fire frequency over several million hectares of coastal sage scrub and chaparral averages once every 30 to 40 years (Hanes 1977; Minnich 1978). The most compelling evidence for the fire potential on the Channel Islands comes from the summer of 1979 when 7,000 ha were burned on nearby San Clemente Island. All but 1500 goats had been removed from San Clemente during the middle 1970's.

PRESENT VEGETATION

A vegetation map of the island was interpreted from 1:22,000 color infrared photography taken by overflight in February, 1976. The map was digitized according to physiognomic class. Polygons were then correlated with other digitized data including elevation, slope, aspect, soil depth, and erosion (Table 1).

General Vegetation Features

The vegetation resembles most overgrazed landscapes of the world (see Mooney and Conrad 1977). Indigenous woody cover is predominantly a small tree savanna with continuous herbaceous understory, strikingly reminiscent of the oak woodlands found in coastal central California (Minnich 1980). The prevailing plant communities include annual grassland, coastal sage scrub, chaparral, and woodlands (see Barbour and Major, 1977).

European grasses form the major portion of the total plant cover. They thrive best in deep loamy soils on alluvium, marine terraces, or gentle surfaces, but may even prevail on steep rocky slopes. Density and cover varies significantly depending on grazing patterns but occurs in gradients having little correlation with fencing, owing perhaps to the territorial behavior of goats (Coblentz 1976).

Coastal sage scrub is relatively uncommon (20 percent of island cover) compared with its abundance in the coastal mountains of mainland southern California (Mooney, 1977). This community occurs on steep south and east facing slopes with little or no soil. Contiguous stands reminiscent of the mainland (0.5-1.5 m tall; greater than 70 percent cover) are widespread in the vicinity of Avalon. In more heavily grazed areas coastal sage scrub becomes increasingly degraded, fragmented, and admixed with *Opuntia littoralis*. Field observations indicate that *Artemisia californica* and *Eriogonum giganteum* thrive best in areas protected from goats. *Salvia apiana* and *S. mellifera* are dominant elsewhere.

Evergreen sclerophyllous scrub or chaparral rarely forms extensive stands except on north facing slopes and in canyons. Only one third form contiguous cover. The remainder exist in parklands of mostly tall shrubs with sharp browse lines, underlain by annual grassland, coastal sage scrub or *Opuntia*. Although chaparral tends to cover steep slopes, it is associated with deeper soils, less erosion, and more rapid soil permeability than other communities

Table 1--Summary of Vegetation of Santa Catalina Island (total hectares and percent of total island area for each variable)

Vegetation Type	Total	Elevation (ml)			Slope Class (degrees)					Slope Aspect			
	Area	0-183	184-366	>366	0-10	10.1-30	20.1-30	31.1-40	>40	NN,N	NE,E	SE,E	SW,W
Grassland	11912	54	63	72	71	69	61	56	54	63	53	59	73
Coastal Sage Scrub	3383	20	19	12	10	14	21	21	18	6	23	32	14
Chaparral	2756	15	16	10	8	12	15	20	13	27	21	2	6
Urban, Cult, Bare	1183	11	2	6	11	5	3	3	15	4	3	7	7

Vegetation Type	Depth to Bedrock (m)			Erosion		Slope		Permeability		
	0-0.6	0.6-1.0	>1.0	None-Moderate	Severe	Failure	Flooding	No Soil	Slow	Rapid
Grassland	58	67	48	59	65	43	43	48	66	58
Coastal Sage Scrub	21	11	7	16	20	7	8	23	15	16
Chaparral	13	17	11	20	8	5	14	9	15	17
Urban, Cult, Bare	8	5	34	5	17	45	35	19	4	9

(Table 1). This trend is inconsistent with mainland vegetation where chaparral tends to occupy the steepest and rockiest slope (Wells, 1962). This difference may reflect a long term feedback from overgrazing inasmuch as present deep rooted chaparral stands that have survived continuous browse pressure are responsible for the maintenance of deep soils.

The floristic and age composition of chaparral varies with slope exposure. Rhus integrifolia and Malosma laurina, tend to form open stands on south facing slopes. Juveniles are often seen side by side with old individuals within a single stand. On north facing slopes, chaparral is dominated primarily by Quercus dumosa and Rhus integrifolia. Individuals are typically old, robust, shrubs 5-10 m tall with d.b.h. of 30-50 cm. Stands are open to contiguous, exhibit browse lines 1 to 2 m above the ground, and contain considerable herbaceous understory. In the least disturbed areas adjacent to Avalon Quercus dumosa and Heteromeles arbutifolia are admixed with Cercocarpus betuloides blancheae, Ceanothus arboreus, and C. megacarpus insularis, with embedded patches of Adenostoma fasciculatum. These are mostly contiguous, have minimal browse damage and contain sufficient fuels to induce the Los Angeles County Fire Department to construct fuel breaks. A. fasciculatum and Ceanothus chaparral are surprisingly unimportant on the island, in view of their abundance in mainland California (Hanes 1977). Mesic north facing slopes, canyon, and bottomlands support broadleaf evergreen forests (Prunus ilicifolia lyonii, Quercus chrysolepis, Q. tomentella, and Lyonthamnus floribundes floribundes). The areal extent of this physiognomic type appears to be independent of grazing pressure because many of the best stands occur in areas with heaviest goat populations.

VEGETATION HISTORY

In view of such enduring disturbance, one cannot assume that the present island vegetation represents prehistoric conditions. Woody vegetation was probably much more extensive before the introduction of domestic stock, and perhaps once strongly resembled present day brushlands on mainland southern California rather than as open, "arborescent" woodlands seen now (Minnich 1980). The nature of such transformation to the present pattern is not simple to evaluate. It involves not only the mechanical effects of browse, resultant denudation of woody cover, and disruption of reproductive processes, but also the modification of the natural fire regime due to the continuing harvest of woody and herbaceous fuels. Unfortunately, the aboriginal state of island vegetation is undescribed and vegetation change can be analyzed only from aerial photographic data taken in the present century and a few old ground photographs taken during an otherwise dim past.

Pre-Grazing Vegetation

Although goats were introduced perhaps no earlier than the 1840's and sheep a decade later, most old photographs dating to the 1880's show severe overgrazing and even more widespread vegetation damage than is seen at present (Minnich 1980). Grass cover is clipped or stripped, Opuntia is widespread, coastal sage scrub is nearly absent, and browse-lined chaparral shrubs are widely scattered. A few very early photos may give a glimpse of the nature of pregrazing vegetation. A photo of Mt. Black Jack taken cir. 1885, for example, shows a continuous stand of Adenostoma fasciculatum, with embedded Quercus dumosa, Rhus integrifolia, and Malosma laurina (Minnich 1980). Photographs of the same site in 1900 and 1980 show that Adenostoma had disappeared, leaving a savanna of browsed shrubs, mostly Q. dumosa. Perhaps the most significant photos of pregrazing vegetation on the Channel Islands were taken in the Central Valley of Santa Cruz Island in 1869, only 14 years after the introduction of sheep (Brumbaugh 1980). These photos show south facing slopes covered with continuous low chaparral, dominated by Adenostoma fasciculatum, Ceanothus megacarpus insularis, and coastal sage scrub. Together these resemble present-day stands in the mainland Santa Monica or Santa Inez Mountains. Browse lines are absent and evidence of past fires is reflected in the uniform physiognomy of several stands. Today these areas are covered with grass and scattered oversized shrubs of Quercus dumosa and Cercocarpus betuloides. Coastal sage scrub disappeared altogether.

1944-1976 Vegetation Changes

Comprehensive black and white aerial photography of Santa Catalina Island (scale 1:24,000) flown in 1944 was compared with 1976 color infrared with a Bausch and Lomb Zoom Transfer Scope in order to evaluate shrub dynamics. The photography was sampled at 213 locations approximately two hectares square in area, uniformly distributed over the island. The scale of both imageries was adjusted so that the same plants could be matched. The following was recorded: (1) the number of shrubs in 1944; (2) the number of fatalities since 1944; (3) reproduction since 1944; and (4) the number of plants in 1976. The data presented in Table 2 shows a pattern of increasing shrub cover over wide areas of the island since 1944. Recovery is not so much due to increased reproduction; it is the remarkable lack of mortality since 1944.

Mortality

If 1944-76 mortality rates were extended indefinitely there would be complete removal of 1944 individuals in 523 years for oak chaparral on northern exposures and 928 years for Rhus-

Table 2--Aerial Sample of Combined Shrub Frequency by Area and Slope Exposure for 1944 and 1976

Area	Goat[1] Pressure	Slope Exposure	No. Samples	1944 Plants	1944-76[2] Mortality	Local[3] Mortality Turnover Rate (years)	1944-76[4] Repro-ducton	Repro.[5] Doubling Rate (years)	1976[6] plants	pct.[7] change since 1944
Avalon	-	S	15	960	5	6144	362	85	1317	137
		N	7	365	3	3893	208	63	570	156
Whites Landing	-,o	S	7	405	7	1851	109	119	507	125
		N	10	395	24	525	83	152	454	115
East Channel Slope	o,+	S	6	183	21	468	27	217	189	103
		N	8	392	23	545	30	418	399	102
West Channel Slope	-,o,+	S	6	166	8	664	77	69	235	142
		N	16	569	40	455	10	1820	539	95
West Pacific Slope	o,+	S	6	270	15	872	41	211	296	110
		N	4	106	4	848	6	565	108	102
L. Springs Cottonwood	-,o	S	12	393	18	1048	114	110	489	124
		N	17	779	15	1662	33	755	797	102
Sweetwater-Bullrush	-,o	S	21	967	24	1289	214	145	1157	120
		N	21	855	33	829	94	291	916	107
Salta Verde	-,o	S	7	559	4	4472	70	256	625	112
		N								
Grand-Silver	+	S	11	360	45	256	26	443	341	95
		N	11	409	95	138	13	1007	327	80
Island		S	96	4263	147	928	1040	131	5146	121
		N	95	3870	237	523	477	260	4110	106

1. - = light; o = moderate; + = heavy
2. No. fatalities of plants observed in 1944
3. $\frac{\text{No. plants in sample}}{\text{No. fatalities}} \times 32$ years
4. No. plants observed on 1976 photographs not evident in 1944
5. $\frac{\text{No. plants in sample}}{\text{No. reproduction}} \times 32$ years
6. 1944 plants + reproduction - mortality
7. $\frac{\text{1976 plants}}{\text{1944 plants}}$

Malosma on southern exposures. Post-1944 mortality ranges as high as 20 to 30 percent in scrub oak chaparral in core grazing areas, which is equivalent to a turnover rates of 225-250 years. The implied longevity of chaparral is high, in comparison with the short period of time between defoliating fire events in mainland chaparral. Many chaparral species, however, sprout as many as 20 to 30 times at a fire frequency of ca. 30 years. In this sense they may be equally as long lived as the shrubs on Santa Catalina.

Fatalities usually occurred individually. Vegetation stripping on a mass scale was observed in a few localities with heavy goat pressure. Stripping appears to arise from two processes. In some cases, shrubs too dense for easy goat access are eventually opened up sufficiently to allow rapid browse and denudation. Otherwise, vegetal removal appears to stem from slope failure during heavy winter rains. The resilience of surviving shrubs is clearly due to their existence above the browse line. Smaller plants have little chance. Therefore, it could be argued that present low mortality rates derive from the fact that only the sturdiest plants remain after decades of grazing pressure. The opening up of brush cover reduces competition for water and nutrients. Nutrient cycling and soil enrichment is made more efficient by the browsing of plant material that would otherwise slowly decompose in an arid environment. While Miller (1980) has attributed the dominance of Quercus dumosa to high soil nitrate, which is no doubt increased by feral herbivore activity, our data contradicts this in that most oaks predate feral grazing. Their dominance is due primarily to their endurance against browsing.

Reproduction

Aerial photographs reveal increases in shrub frequency of 10-30 percent of 1944 levels over much of the island. At 1944-1976 reproductive rates shrub frequencies would double in approximately 130 years on southern exposures and 260 years on northern exposures. Rates vary greatly over the island and correlate inversely with grazing pressure. Reproduction is minimal in goat infested areas. Heaviest reproduction (140-160 percent of 1944 levels) has occurred in the Avalon area and adjoining slopes where urbanization has reduced goat and pig activities. The story elsewhere on the island is mixed. Reproduction tends to be good on south-facing slopes and poor on north facing slopes. New growth on south faces are mostly Rhus integrifolia and Malosma laurina, both undesired by goats and pigs. This seems to confirm Miller's (1980) observation that R. integrifolia abundance is increased by grazing and low fire frequencies. Reproduction in Quercus dumosa stands on north slopes appears to be completely stifled by pig rooting and browsing. Most young plants in this community are Rhus integrifolia and Heteromeles arbutifolia. Adenostoma fasciculatum, Ceanothus megacarpus, and C. arboreus seedlings and saplings are few and far between. This is not surprising since these species are nearly depleted from the island, incapable of long-distance seed dispersal and reproduce best after fire (Wells, 1969; Hanes, 1977).

Long-term brushland recovery is best recorded in Avalon Canyon where slopes have been photographed continuously since the 1880's. An overgrazed landscape of sparse grass, Opuntia, and open, pruned chaparral developed rapidly into coastal sage scrub by 1900, after the resort town was established. Thereafter, chaparral dominated by animal dispersed species, notably Heteromeles arbutifolia and Rhus integrifolia, has invaded at a slower pace, becoming conspicuous on photographs after about 1940.

DEVELOPMENT OF A MANAGEMENT PROGRAM

The potential for wildfire on Santa Catalina Island is small compared to that on the mainland. Nevertheless, under appropriate conditions fire can be supported by the present vegetation over most of the island. European annual grassland burns readily during summer drought as it is 100 percent dead fuel. Browsing pressure reduces the continuity of cover and the possibility of large herbaceous conflagrations. Such would certainly become an immediate problem if feral animals were removed. The tree-like physiognomy and open nature of chaparral enhances the possibility of their escaping ground fires carried by grass or coastal sage scrub. An exception is the vegetation around Avalon. The chaparral is rapidly taking on the physiognomy of mainland stands. Most are contiguous, lack browse lines, and are capable of carrying a Santa Ana wind driven brush fire with intensities comparable to those in coastal mountains of southern California. Ironically, an intense fire would be a death knell to woody vegetation under the present grazing regime. Most brushlands survive now because shrubs reach above the browse line. After fire, seedlings and resprouts would be grazed to destruction. Thus fire can be seriously considered as a management tool only after feral herbivores are removed from the island. Presumably chaparral would redevelop horizontal and vertical continuity similar to mainland stands with the cessation of grazing. Exclosure studies on Santa Cruz Island have demonstrated this trend (Brumbaugh 1980).

The accumulation of fuels attendant with the removal of feral animals will necessitate planning of a vegetation management scheme that prevents or controls severe wildfire while still encouraging further development of woody cover to ameliorate watershed problems. This will require the development of a comprehensive management plan to control wildland fires. There are two basic concepts of fuel management in controlling wildland fire. Greene (1977) has termed these fuel break and block and prescribed mosaic burning.

Fuel Break and Block

Land managers are uncomfortable with the widespread continuous nature of mature chaparral because they are unable to place safely manpower and equipment. Fire fighting agencies constructed a system of fuel breaks which represent lines of type conversion from brush to herbaceous cover, 30-100 m wide. Fuel breaks divide the chaparral into blocks, provide a safety zone for fire fighters, as well as resist the spread of fire from one block to another. The problem with the fuel break and block plan is that the vegetation within the blocks is not managed. Chaparral is allowed to become old, decadent, high in dead fuel content, and highly flammable until the inevitable fire comes. Fire suppression selects for uncontrollable fires in the worst weather because fires in good weather are put out. Therefore, fires easily skip across fuel breaks and end up burning especially large areas which are later subject to erosion and flooding until new growth redevelops. The failure of this approach on the mainland serves as a warning not to implement it on the island as long-term policy (Philpot 1974).

Prescribed Mosaic Burning

As alternative management strategy is to use fire as a tool for managing brushlands. In the long run, the intent of prescribed mosaic burning is to develop a patchwork of different aged stands roughly 200 to 700 ha in size. Such a mosaic was described in southern California in the late 1800's when fires still ran free and may presently be seen in the chaparral of northwest Baja California where fire suppression has never been instituted. The mosaic is the basis of fire control since younger, less flammable growth checks the progress of fires burning in older growth (Philpot 1974). I recommend the implementation of prescribed mosaic burning in the vicinity of Avalon as soon as feral animals are removed. In ensuing decades a fire mosaic should be established over the rest of the island. In the meantime traditional fire suppression practices should be continued until woody vegetation recovers sufficiently to protect the watershed. While it is recognized that the vegetation will not duplicate its pregrazing density or flora, it is anticipated that a healthy shrub community can be reestablished in the regime of periodic fire.

CONCLUSION

It appears that feral grazing over the last 150 years has removed much woody cover on Santa Catalina Island while selecting in particular against the smaller, less durable *Adenostoma fasciculatum* and *Ceanothus megacarpus insularis* and most coastal sage scrub species. *Salvia* spp. have survived to dominant status over small areas of the island due primarily to their impalatability. Chaparral has been more and more confined to north-facing slopes. It is now time to recognize the damage feral animal grazing has done to Santa Catalina Island. The removal of these animals, however, could result in growing fire danger and the potential for further watershed deterioration. Effective reestablishment of brushland vegetation will require a management strategy linking traditional fire suppression and prescribed mosaic burning.

LITERATURE CITED

Barbour, M.; Major, J. eds. Terrestrial Vegetation of California. New York: John Wiley and Sons; 1977. 1002 p.

Brumbaugh, R. W. Recent geomorphic and vegetal dynamics on Santa Cruz Island, California. In: Power, D. M. ed. The California Islands: Proceedings of a Multidisciplinary Symposium. Santa Barbara Museum of Natural History; Santa Barbara, California, 1980; 139-158.

Center for Natural Areas. Santa Catalina Island Natural Resource Management Plan to the Los Angeles County Dep. of Parks and Recreation. South Gardiner, Maine. 122 p.

Coblentz, B. E. Wild Goats of Santa Catalina. Natural History 85:70-77; 1976.

Coblentz, B. E. Feral Herbivores. Natural Resource Management Plan prepared for Los Angeles County Department of Parks and Recreation. Center for National Areas. South Gardiner, Maine. 1980.

Green, L. R. Fuel breaks and other fuel modification for wildland fire control. U.S. Dep. Agric., Handb. 499; 1977. 79 p.

Hanes, T. L. Chaparral. In: Barbour, M. G.; Major, J. eds. Terrestrial Vegetation of California. New York: John Wiley and Sons; 1977: 417-470.

Miller, P. C. Report on Santa Catalina Island and a preliminary outline of a chaparral grazer model. Natural Resources Management Plan prepared for Los Angeles County Department of Parks and Recreation. Center for Natural Areas; South Gardiner, Maine. 1980.

Minnich, R. A. The Geography of Fire and Conifer Forest in The Eastern Transverse Ranges, California. Ph.D. Dissertation. University of California, Los Angeles. 1978. 395 p.

Minnich, R. A. The Vegetation of Santa Cruz and Santa Catalina Islands. In: Power, D. M. ed. The California Islands: Proceedings of a Multidisciplinary Symposium. Santa Barbara Museum of Natural History. Santa Barbara, California; 1980: 123-138

Mooney, H. A. Southern Coastal Scrub. In: Barbour, M. G.; Major, J. eds. Terrestrial Vegetation of California. New York: John Wiley and Sons; 1977: 471-490

Philpot, C. W. The changing role of fire on chaparral lands. In: Rosenthal, M. ed. Symposium on Living with the Chaparral. San Francisco, California: Sierra Club; 1974: 131-150.

Thorne, R. F. A Flora of Santa Catalina Island, California. Aliso 6:1-77; 1967.

Wells, P. V. Vegetation in Relation to Geological Substratum and Fire in the San Luis Obispo Quadrangle, California. Ecol. Monogr. 32:79-102; 1962.

Wells, P. V. The relation between mode of reproduction and extent of speciation in woody genera of the California chaparral. Evol. 23:264-267; 1969.

Effects of Past and Present Fire on the Vegetation of the French Mediterranean Region[1]

Louis Trabaud[2]

Abstract: Fire has shaped the French Mediterranean vegetation for a long time. Man used and abused fire for reclaiming agricultural lands. Today, fire is mainly lit by carelessness. Most plants of the mediterranean vegetation have acquired strategies to withstand and survive fire. After wildfire, vegetation turns back quickly towards its initial stage. By using prescribed burnings according to different frequencies and seasons the structure of a Quercus coccifera garrigue was changed, but not the floristic composition.

Since 1960 wildfires have burned an average of 36,000 hectares a year of natural vegetation in southern France. Some years the area burned greatly exceeds this average (e.g. 52,800 hectares in 1976). The most important trends for the last two decades are a steady increase in number of fires, but a relative constancy in the total area burned (Trabaud 1980).

The most numerous and most harmful wildfires occur in the Mediterranean zone, an area which stretches from the eastern Pyrenees to the southern Alps, including Corsica. This area is characterized by its geographical position near the Mediterranean sea and by its climate with hot dry summer and mild rainy winters. The long dry summer season, with warm temperatures and low relative humidity, is particularly favourable to fire. Besides, the mediterranean vegetation type is highly flammable and combustible due to the preponderance of species with a high content of resins or essential oils. In addition, the rugged topography of the area increases the ease of fire spread. The presence of millions of people (both residents and tourists) in this region can also contribute to create an "explosive" fire situation under certain conditions.

It is apparent that fire is an important past and present ecological force which has played and continues to play a significant role in fashioning, positioning, and developing numerous mediterranean plant communities. Used for a long time by man to reclaim virgin lands or to maintain already burned plots, fire associated with other human activities has had a significant impact on shaping the current landscape of the French Mediterranean region.

FIRE HISTORY ELEMENTS

Fire during Prehistory

Man had probably begun to frequent the French Mediterranean region half a million years ago. At that time he had little impact on the native vegetation as he was primarily fed by hunting animals and gathering fruits and edible roots.

As soon as man possessed fire (about 300,000 years B.C.; Perles 1975, 1977) he had many reasons for burning. These have remained essentially the same until the present time. In fact, man has probably voluntarily used fire for hundreds of thousands of years. Without knowing how to create fire, man carefully preserved natural fire whenever possible. Hough (1926) said that the oldest known torch dates from about 100,000 years ago in France. It was not until later (40,000 to 50,000 years B.C.) that prehistoric man learned to create and control fire.

First the hunter and the herdsman must have noted that the animals they fed upon were attracted by burned zones, where vegetation appeared greener and softer. Hence, it appears that man has set fire, accidentally through lack of care, but also intentionally, for a great number of purposes. It seems that fire has been used to increase food choice, to facilitate the gathering of edible plants, and to attract and hunt game. Testimonies are available to show that Paleolithic man used this technique in Greece (Liacos 1974), Israel (Naveh 1974), Spain and France (Perles 1977). With the domestication of animals, which took place in the French Mediterranean region about 7,000 years B.C. (Bailloud 1975), man needed rangelands. He burned the forest to be able to see more clearly and protect his domestic animals against their natural predators.

During the Neolithic (about 5,000 years B.C.), men of this area were primarily field growers and sedentary herdsmen (Pannoux and Pannoux 1957, Dugrand 1964). They occupied fields after partial burning of the forest, supplementing their resources by picking fruit. Beaulieu (1969) interpreted evidence of fire in the pollen diagram of the Font-Salesse peat-bog (Monts de 1'Espinouse) as being from this period, and concluded that it must be ascribed to human intervention. Those farming peoples, or their immediate predecessors, could have engaged in nomadic agriculture, a sort of shifting cultivation such as is still used in some

1-Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

2-Departement d'Ecologie Générale - Centre d'Etudes Phytosociologiques et Ecologiques B.P. 5051 - 34033 - Montpellier Cedex - FRANCE

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

areas of Africa and Asia where fire is set before or after tree-felling, followed by reclamation and cultivation. Cultivation shifted as soon as production decreased as a result of the soil becoming poorer. The village might also be moved to remain near the arable lands.

The successors of the paleolithic hunter-gatherer, the mediterranean shepherds, used and still today are using fire to open the dense thickets of maquis and garrigue to increase the area of rangelands for their herds (goats, sheep and cattle). Thus, Niederlender and others (1966) ascribe the modification of the vegetation of calcareous regions of southern France to man, who set fires repeatedly during the Neolithic.

Fire during historical times

During the historical period (which runs from the first Greek factories, 750 years B.C., up to the beginning of the 20th century), that country today occupied by the garrigue underwent a series of changes. Periods of population increase produced new waves of land reclamation, and simultaneous increase in the number and size of herds. There followed both an expansion of cultivated lands at the expense of rangelands and of rangelands at the expense of forests. On the other hand, during periodic disasters, due to wars, invasions, epidemic diseases and economic crises, cultivated lands were abandoned, returning to post-cultural or pre-forested stages (Dugrand 1964).

Most fires ignited by man were set for agricultural or pastoral purposes. Due both to poor yields and the need to feed growing numbers of people, man had to increasingly reclaim new cultivated lands. Fire was associated with the "essartage" or "ecobuage". In the first case, trees were first felled, then burned and the land was sown. In the case of "ecobuage" the technique was more complex. The ground was "fleeced" with adapted tools and according to precise methods; afterwards, the clods were dried up, then burned. The ashes were used as fertilizer.

These agricultural practices were in use throughout the French Mediterranean region at least from the Middle Ages through the end of the 19th century (Ribbe 1865, Kuhnholtz-Lordat 1938, 1958, Sigaut 1975). Ecobuage was mainly employed in Languedoc and Roussillon where, during the 18th century, authorities intervened to limit cultivation on burned lands. It was between 1820 and 1830 that the largest areas were burned by ecobuage in southern France (Sigaut 1975). Essartage was still used in 1870 in crystalline Provence (Les Maures, 1'Esterel) and in the Montagne Noire. In Provence the forests of maritime pine (*Pinus pinaster* Soland) were burned. The burned pines were then cut and sold at Marseille and the cleared lands cultivated (Kuhnholtz-Lordat 1958). In Corsica that technique was still in use in 1930 to create arable fields (Sigaut 1975).

Fire has also been used as a technique for com-try around Montpellier was regularly burned to promote proliferation of the kermes oak (*Quercus coccifera* L.) cochineal bettle (*Kermococcus vermilio*) in order to obtain from it a red dye for dyeing wool (Delmas 1958).

Fire has also been effectively used as a war weapon for destroying crops. The country to be subdued was ravaged and the inhabitants famished and demoralized by setting afire forests and fields. In 970 A.D., the people, around Nice set fire to the forest to hinder the ambushes of the Saracens (Kuhnholtz-Lordat 1938). In the Middle Ages, the "Grandes Compagnies" and bands of ruffians pillaged and set fire to fields and woods (Fourquin 1975). During the 16th century, great areas of forest were burned as the armies of the constable of France Charles de Bourbon, of Charles V, and of Emmanuel de Savoie passed through. The forests of Mont des Maures were burned during the battles between the armies of Charles V and those of Francois I (Seigue 1972). It was the same during the rebellion of the Camisards in the Cevennes (Le Roy Ladurie 1976).

In later periods (towards the middle of the 19th century, Sigaut 1975), with the emergence of new technologies, fire has been less and less used to reclaim lands. Only shepherds continued to set fire, primarily through tradition to open rangelands on abandoned fields that had become increasingly invaded by shrubby vegetation. Fire was required to promote the growth of new shoots of palatable species. As Le Roy Ladurie (1976) states, burning off pasturelands in Languedoc was the only way used during the 17th century to improve feed for animals. Animal husbandry was regulated by "transhumance" (travelling into the mountains to graze in summer and coming back down to the plains in winter ; transhumance was documented 1,000 years B.C., Bailloud 1975). Shepherds burned every four or five years either in February or March, before the growth of herbaceous species, or at the beginning of autumn before the flocks come down from transhumance.

Fire today

While the causes of burning have shifted over the years the French Mediterranean region has continued to be fired. It is difficult to know the importance of the lightning fires in the past because we have no precise records, but today in southern France only 1 percent of the wildfires are caused by lightning.

At present, flocks of sheep, although less numerous, continue to graze the garrigue rangelands. But the origin of fire is no longer the exclusive liability of shepherds. The town dwellers, eager for calm and clean air and wishing to "come back to nature", are building homes in increasing numbers in the country. Large numbers of people who now travel through southern France are tourists or holiday-makers. They create a new danger. As a consequence of current ways of life (homes in the woods, barbecues, hikers) fire risks are increasing. Besides, people living or travelling through these zones which are susceptible to fire are often ignorant of the chance they take or the imprudence they create for other people.

Today the areas burned by wildfires change according to the vagaries of meteorological conditions. In the area called "the red belt" in Provence and Corsica (Southeastern France) each piece of natural vegetation would be burned, on an average, once every 25 years (Seigue 1972). This fact clearly shows the problem of vegetation fire in southern France, but also the importance of fire as an ecological force shaping the landscape and the plant communities. This emphasizes the necessity to obtain a scientific knowledge of the effects of fire.

ECOLOGICAL EFFECTS OF FOREST FIRES

In France, to date, only a few authors have studied the role of fire as a factor in succession (Braun-Blanquet 1936, Laurent 1937, Kuhnholtz-Lordat 1938, 1958 , Kornas 1958, and Barry 1960). Generally these authors describe stages corresponding to vegetation types ; they give some information about succession following fire, and compare the different stages to each other only in a synchronic way. Precise diachronic observations are very rare on the actual succession of plant communities after fire. There are also few available data about the ecological consequences of fire.

Effects of fire on mediterranean plants

Plants react to fire in very different ways. They possess numerous fire-related adaptations. Nobody has studied in a precise manner the problem of the relative resistance of species to fire, probably because of the numerous factors which are acting.

For any given species there is a range of fire-resistance possibilities which vary according to fire intensity. These possibilities may vary with growing season and maturity. For example, observations show that winter or spring fires do not harm the subsequent development of sprouts of Quercus ilex L. (holly oak) or Q. coccifera L. (kermes scrub oak ; Trabaud 1970, 1974, 1980), while fires in summer or autumn, which are more intense, decrease sprouting ability.

The plants of sclerophyllous communities in the mediterranean region are adapted to survive after the passage of fires, particularly light fires, where the plant cover quickly builds up again (Le Houerou 1974, Naveh 1974, Trabaud 1974, 1980). Among the fire adaptations observed are plants with little or no bark, but which can survive owing to subterranean organs (bulbs, rhizomes, and tubers), geophytes such as Asphodelus cerasifer Gay (Trabaud 1974) and Ophrys sp.p (Naveh 1974, 1975), and grasses such as Brachypodium ramosum (L.) R. et S. (Trabaud 1974). The latter species shows a noteworthy indifference towards burning dates and fire frequency. Some species possess strong vegetative subterranean systems, like Quercus coccifera (Trabaud 1974, 1980). Other kinds of vegetation shaped by fire include tall maquis dominated by Q. ilex, and Ericaceae including Arbustus unedo L., Erica arborea and E. scoparia L. All these species produce vigorous stump sprouts; consequently they dominate the burned forests or maquis (Le Houerou 1974, Naveh 1974, 1975).

Some trees, such as Quercus suber L. (cork oak), have relatively thick bark permitting them to resist fire. According to Le Houerou (1974) cork oak forests would be a stage in fire succession of the Q. faginea Lamk. forests in North Africa, Portugal and Spain, where the latter oak has been eliminated by burning. In France, cork oak would be only a vicariant of holly oak on warmer and moister siliceous soils. When fire is neither very frequent nor very intense, open forests of Q. suber maintain themselves. However, despite the role of bark thickness, many species with thin bark, such as Q. ilex, withstand fire very well. This species sprouts abundantly from stumps, but when fires are not too intense it can produce sprouts from epicormic buds.

Some species do not withstand fire directly but, owing to their ability to disseminate numerous seeds, they can survive fire and also colonize large areas. Such species include Cistus sp.p. (Trabaud 1970). Le Houérou (1974) quotes 12 species of mediterranean Cistus considered as typical active pyrophytes propagating only by seed. Another example is that of coniferous species, which are among the most flammable ecosystems in the region. Pinus halepensis Mill. (Aleppo pine) and P. pinaster Soland. (maritime pine) constitute huge forests in the Mediterranean region. They can regenerate only by seed, disseminated by cones which often burst during fires (Le Houérou 1974, Trabaud 1970, 1980). Generally after fire the pine forests are colonized by a large number of pine seedlings which produce a new pine forest, with no change in the floristic composition. Since seeds of these two Pines germinate on mineral soil in sunny places, where competition is weakest and where mineral nutrients are abundant, the pine forests may perpetuate themselves indefinitely.

Ecological effects of fire on plant communities of Southern France

After fire the vegetation of the garrigue returns quickly towards its initial state (Trabaud 1974, 1977, 1980, Trabaud and Lepart 1980). Most often the species which are present 12 years after fire are the first ones to appear immediately following fire and become more and more numerous through the years. To study this, 47 observation plots were established in areas burned by wildfires in Bas-Languedoc. These were located in 8 types of plant communities representative of the area. One year after fire 70 percent of the study plots

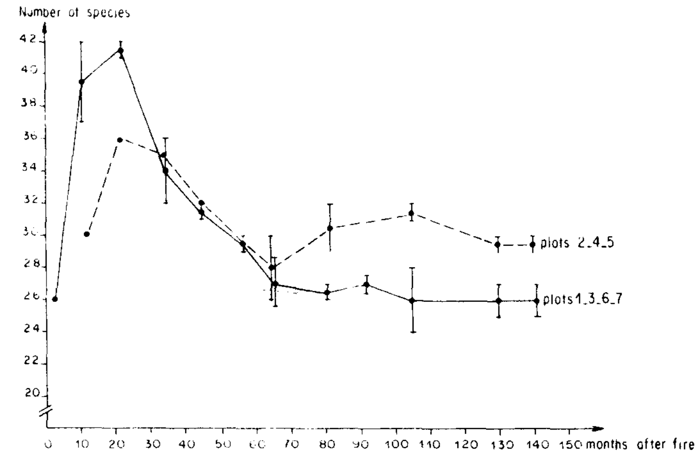


Figure 1 -- Floristic richness of dense Quercus ilex coppices.

possessed more than 75 percent of the species which are present 10 or 12 years later. Two years after fire, this percentage was over 80 percent; and in five years it reached 100 percent. The reversion towards a metastable state, at least for the time considered, was quickly accomplished.

This study of the development of floristic richness following fire shows that the different communities follow a highly general model (fig. 1). During the first months after fire there were relatively few species. Floristic richness reaches a maximum between the first and the third year after fire, and finally tends to stabilize after the fifth year.

The generally higher number of species during the first three years can be attributed to the fire-induced opening of vegetation cover, the disappearance of litter, and to the richness in nutrients of the upper soil. These conditions favour the establishment of exogenous species which will later disappear as plant cover closes up.

The index of species fugacity is similar to the model of floristic richness (fig. 2). A "fugacious" species is defined as one that does not survive

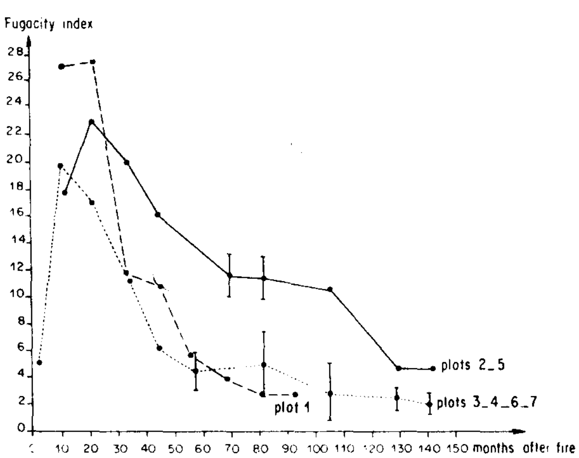


Figure 2 -- Development of the fugacity index: dense Quercus ilex coppices

the period of observation (Trabaud and Lepart 1980). The fugacity of any species is measured by the number of observations in which it is missing. The fugacity index can be considered as a measure of floristic stability: if the index is high, the community has not reached a stable state, if it equals zero the community is floristically stable. Fugacity is low immediately after fire and reaches its maximal value during the first and second year, when floristic richness is also at its maximum. Therefore the richness of the intermediate stages results from shortlived species which are progressively eliminated during vegetation recovery. Most often these species are therophytes which do not belong to the communities.

Actually, after fire, there is no real succession in the sense of substitution of species or communities, but only a progressive return towards a stage similar to the one before fire. Most often the species of the "terminal" community (defined by the latest dated observation) appear long before the alien species. Floristic composition of present communities is changed very little by fire. The return towards a metastable state occurs quickly and the floristic diversity of the landscape does not seem to be affected. At least for the length of time of this study and for the plant communities in Bas-Languedoc there is no convergence towards similar vegetation types. Each community keeps its own characteristics.

This result is also confirmed by the structural development of the communities. The passage of fire has not only an effect upon floristic composition but it modifies the plant arrangement and phytomass. After fire and through succeeding years, stand strata get more and more complex and vegetation tends to grow up from the lower layer to the upper layers with a progressive multiplicity of strata similar to those of origin (fig. 3): the higher strata appear later in succession. These trends were quantified by recording the number of hits on plants at various layers by a needle dropped along a transect line. During the 12 years of observation only Quercus ilex coppices reach the fifth layer (from 2 to 4 m). Pinus halepensis stands, though belonging to forest communities generally do not grow beyond the third layer (1 m). This difference is due to the kind of survival strategy used by the dominant species of each community to regenerate after fire. Q. ilex sprouts vigorously from stumps and rapidly grows reaching heights 'of 2 m in 70 months, while P. halepensis can only regenerate by seed and thus shows a slower growth following fire (80 cm in 80 months).

Changes in Q. coccifera garrigue with different prescribed fire regimes

The study of the development of post-wildfire vegetation showed that plant communities quickly recover, and that after about 10 years they are not much different from those which existed before the fire. To analyze more precisely and to better understand the effects of fire on plants and vegetation, it is necessary to set up experimentation with prescribed fires. Only an experimentation on vegetation stands identified and studied before burning will give reliable results which can be compared with observations from plots burned by wildfires.

Such experimentation was set up in a Quercus coccifera garrigue 10 km north of Montpellier. The objective was to analyze:

1) the development of vegetation with regards to the initial pre-fire state to determine the fire resistance of species;

2) the impact on vegetation of different frequencies of repeated burns (a burn every six years, a burn every three years, and a burn every two years);

3) the effects on vegetation of the time (season) of burning, to determine how seasonal conditions, which affect the phenological behavior of species, relate to fire effects.

The presentation of the experimental techniques and partial results were published previously by Trabaud (1974, 1977, 1980). Thus only a brief summary of effects on floristic composition and changes in vegetation structure will be discussed in the present paper.

The combination of burning frequency and burning season gives six treatments:

6 P - vegetation burned every six years in spring
3 P - vegetation burned every three years in spring
2 P - vegetation burned every two years in spring
6 A - vegetation burned every six years in autumn
3 A - vegetation burned every three years in autumn
2 A - vegetation burned every two years in autumn

The unburnt vegetation was considered as a control (T). All of these treatments have five replicates. As for the study of the development of vegetation structure after wildfire, the importance of vegetation is given by the number of hits on plants of defined layers by a needle.

The floristic composition of the Quercus coccifera garrigue is on the whole very stable. After burning it is identical to that which existed at the beginning of the experiment. The dominant and characteristic species are present at all times. The advent or the disappearance of some of them produces only a small floristic change. This relative stability is due to the fact that most of species present in the plots before burning regenerate predominantly by vegetative means (sprouts), while the "invading" species appear only the first year after burning as individuals coming from seeds. They are rapidly eliminated in later years. The influence of season of burning is much more important than burning frequency; with autumn burnings many alien short-lived species appear increasing

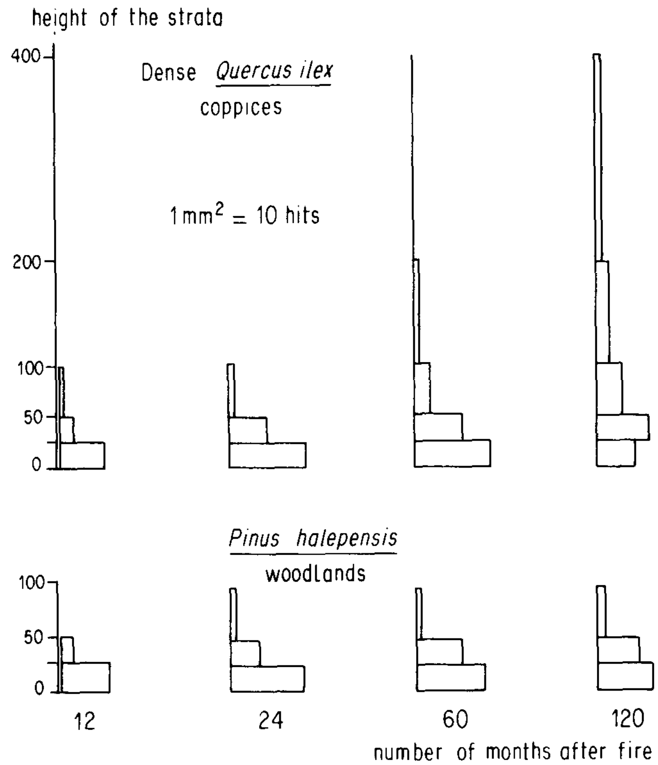


Figure 3 - Development through time of the number of hits according to the height of strata of the communities burned by wildfires.

the floristic richness for a short time whereas other species of the original community disappear.

Frequently repeated fires alter the structure of the vegetation. Immediately after each burning there was a decrease in the number of hits (disappearence of above ground vegetation), then a progressive increase, following autumn burns this increase is slower. When burning is only every six years, the vegetation of the Quercus coccifera garrigue reaches a level similar to that of the unburnt garrigue within five year after prescribed fire. On the other hand, burnings regularly set every two years produce a decrease in the total number of hits. This repetition of burns leads to a disappearance of the upper layers (above 50 cm) but it favours an increase in the amount of vegetation in the lower layers (< 25 cm).

The decrease in the number of hits is mainly due to the woody plants which have fewer long sprouts bearing fewer leaves. But the number of hits from herbaceous plants is not diminished by successive fires; rather it is increased and particularly so with autumn burnings. The influence of fire on the increment of herbaceous plant phytomass has been recognized for a long time (Ahlgren and Ahlgren 1960, Daubenmire 1968, Vogl 1974).

In the unburnt vegetation, the proportion of the number of hits on woody plants as compared with herbaceous plants does not vary through the years (fig. 4). This is also true for vegetation burned in the spring. In the vegetation regularly burned

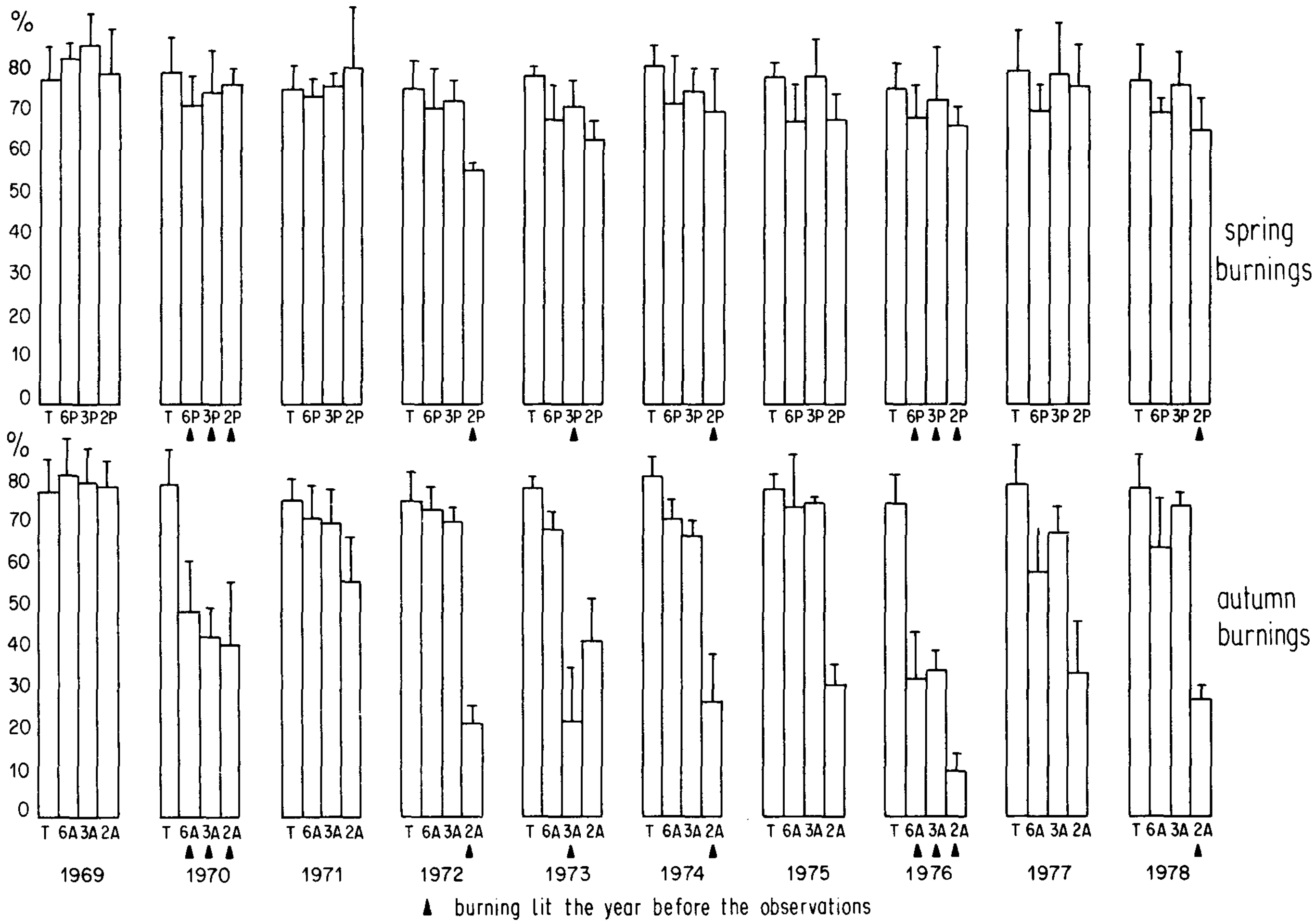


Figure 4 -- Changes in the ratio of hits of woody plants to the total vegetation number of hits.

every two years in autumn, this proportion goes down from about 4/5 in 1969, before prescribed burns, to 1/3 in 1975 and again in 1978, or lesser.

These results are confirmed by a brief study of above-ground phytomass as a function of the different treatments. In may 1979, for each treatment seven 1 m2 samples were collected from each different plot. Then vegetation was hand-sorted, separating woody from herbaceous plants, dried, and finally weighed. Total above ground phytomass of the unburnt vegetation weighed, on an average, 30 t.ha^{-1} (table 1), or a production of 1 t.ha^{-1} yr^{-1} of dry matter since the last wildfire. This value is similar to that reported already by Long and others (1967) twelve years earlier.

Burning frequency has an effect on the amount of vegetation produced. Four years after a second burn (1979; 6P, 6A) total phytomass only represent one third of that of the unburnt vegetation. But herbaceous plants do constitute a greater proportion than in the unburnt vegetation (respectively 12.9 percent for treatment 6P; 18.7 percent for 6A, and 3.2 percent for T). For the other treatments, comparison becomes more difficult because of differences of elapsed times from the latest burns and the sampling date.

As regards the effect of season of burning, the total mass of vegetation burned in spring is always greater than that burned in autumn. In spring-burned vegetation the above-ground mass of woody plants is always greater than that of vegetation burned in autumn. On the contrary, the mass of herbaceous plants of autumn-burned vegetation is higher than that of spring-burned vegetation. About two years after the fifth burn the herbaceous phytomass of the vegetation burned every two years in autumn (2 A) is greater than that of the unburnt vegetation (T).

CONCLUSIONS

The results presented here show that the development of vegetation after fire follows the "initial floristic composition" model described by Egler (1954): all the pre-fire species are present immediately after fire, even if later on, the relative abundance of individuals changes. Thus there is no succession of floristic relays, or different communities succeeding on the same sites as is characteristic of secondary succession.

The presence of invading therophytes which often characterize young communities (Bournerias 1959,

Table 1 -- Mean above-ground phytomass (g per m2 of dry matter) of the Quercus coccifera garrigue according to the different prescribed fire regimes (May 1979). (Extreme values are presented in parentheses).

	Fire Regimes						
Phytomass (g m^{-2})	T	6 P	6 A	3 P	3 A	2 P	2 A
Woody plants	2.944.9	983.4	754.8	135.0	19.1	440.5	157.5
	(4000.0 1450.0)	(1124.0 610.0)	1060.0 175.0)	(218.8 68.6)	(38.0 8.2)	(733.9 226.6)	(336.0 28.9)
Herbaceous plants	97.0	145.5	173.7	23.1	24.0	33.0	117.5
	(285.0 1.5)	(278.4 24.3)	(441.5 27.9)	(70.0 0.7)	(78.0 5.7)	(78.1 8.0)	(223.7 30.7)
Total plants	3041.9	1128.9	928.6	158.1	43.1	473.5	275.0
	(4170.0 1475.5)	(1317.3 888.4)	(1160.4 422.3)	(235.5 93.6)	(105.6 13.9)	(749.2 234.6)	(417.5 162.9)
Age of community	28 years after latest wildfire	48 months after 2nd prescribed fire	44 months after 2nd prescribed fire	12 months after 4th prescribed fire	8 months after 4th prescribed fire	24 months after 5th prescribed fire	20 months after 5th prescribed fire

Bazzaz 1968) is practically non-existent except for communities where herbaceous plants are dominant. In fact, mediterranean vegetation does present a recovery by "direct" endogenous process, i.e. the species which existed before fire reoccupy the burned ground, as opposed to an "indirect" or exogenous recovery characterized by a succession of stages as Bournerias (1959), Drury and Nisbet (1973) and Guillerm (1978) have described for old fields. The plants which persist are those which appear immediately after fire and which existed before fire. This is due to the strategies used by the plants to regenerate: mainly by vegetative survival, or by residual seeds buried in the soil or coming from nearby unburnt communities.

If fires are lit more frequently than the normal cycle (i.e. about every five or six years at least for such communities as the Quercus coccifera garrigues of Bas-Languedoc), the tendency towards a return to the initial stage is slowed and phytomass gradually decreases. This reduction is due to a decrease in the phytomass of woody plants. Their stems which are located above the ground are constantly burned and do not have enough time to sprout again before the next fire. However, in spite of the burning frequencies, there is little change in the flora of the Quercus coccifera garrigue. The impact of fire only leads to a change in vegetation structure as the upper layers of woody plants disappear and the amount of herbaceous species increases. Thus, the use of prescribed burning would be a possibility to transform these shrubby rangelands as was sometimes done by shepherds many years ago.

The plants of the French Mediterranean region are well adapted to withstand fire. The present vegetation of Bas-Languedoc results from many years of evolution during which plants have acquired mechanisms to overcome the effects of fire as well as climatic (especially summer drought) factors. This evolutionary impact has been manifested by positive and negative feedback responses that enable direct fire tolerance or permit its avoidance, followed by vegetative and reproductive regeneration.

Acknowledgments: I particularly thank Dr. Lepart who performed the indices of fugacity and discussed thoroughly the French manuscript. I thank also Dr. G. Long for fruitful discussions and comments of the French manuscript. I am grateful to the technicians for their work during the burnings. I greatly appreciated the help from Dr. D. Parsons for reading and correcting the English text.

LITERATURE CITED

Ahlgren, I.F.; Ahlgren, C.E. Ecological effects of forest fires. Bot. Rev. 1960;26:483-533.

Bailloud, D. Avant l'histoire. in Histoire de la France rurale, Ed. Seuil, Paris ; 1975;1:119-189.

Barry, J.P. Contribution à l'étude de la végétation de la région de Nimes. Année Biologique, 1960; 36:311-550.

Bazzaz, F.A. Succession on abandoned fields in the Shawnee Hills, Southern, Illinois. Ecology, 1968; 49:924-936

Beaulieu, J.L. de. Analyse pollinique dans les Monts de l'Espinouse (Hérault). Pollen et Spores. 1969; 11:83-96

Bournerias, M. Le peuplement végétal des espaces nus (Essais expérimentaux sur la génèse de divers groupements pionniers). Mem. Bull. Soc. Bot. Fr. 1959 ;300 p.

Braun-Blanquet, J. La forêt d'Yeuse Languedocienne (Quercion ilicis) Monographie phytosociologique. Mem. Soc. Etud. Sci. Nat. Nimes. 1936 ;5:147 p.

Daubenmire, R. Ecology of fire in grasslands. Advances in Ecol. Res., 5, Academic Press, New York 1968 ;209-226.

Delmas, M. La diversité de la vie animale dans la garrigue. Ann. Soc. Hort. Hist. Nat. Hérault, n° spécial la garrigue, 1958; 59-70.
Drury, W.H., Nisbet, I.C.T. Succession. J. Arnold Arbor. Harv. Univ., 1973; 54:331-368.
Dugrand, R. La garrigue montpellieraine. P.U.F., Paris, 1964; 292 pp.
Egler, F.E. Vegetation science concepts. I. Initial floristic composition, a factor in old field vegetation development. Vegetatio, 1964; 4:414-417.
Fourquin, G. Le premier Moyen Age. Le temps de la croissance. in Histoire de la France rurale, Ed. Seuil, Paris, 1975;1: 297-550.
Guillerm, J.L. Sur les états de transition dans les phytocénoses post-culturales. Thèse Etat, Univ. Sci. Techn. Lang., Montpellier, 1978; 127 pp.
Hough, W. Fire as an agent in human culture. U.S. Natl. Mus. Bull., 1926; 139, 270 p.
Kornas, J. Succession regressive de la végétation de garrigue sur calcaires compacts dans la montagne de la Gardiole près de Montpellier. Acta. Soc. Bot. Poloniae, 1958; 27:563-596.
Kuhnholtz-tordat, G. La terre incendiée. Essai d'agronomie comparée. Ed. La Maison Carrée, Himes, 1938; 361 pp.
Kuhnholtz-Lordat, G. L'écran vert. Mem. Mus. Natl. Hist. Nat. 1958; B, 9:276 pp.
Laurent, L. A propos des incendies de forêts en Basse Provence. Le Chêne, 1937; 44:139-148.
Le Houerou, H.N. Fire and vegetation in the mediterranean basin. Proc. Annu. Tall. Timbers Fire Ecol. Conf., 1974; 13:23/-277.
Le Roy Ladurie, E. De la crise ultime à la vraie croissance. in Histoire de la France rurale, Ed. Seuil. Paris 1976; 2:359-611.
Liacos, L. Present studies and history of burning in Greece. Proc. Annu. Tall. Timbers Fire Ecol. Conf., 1974; 13:65-95.
Long, G., Fa, F., Thiault, M., Trabaud, L. Essais de détermination expérimentale de la productivité d'une garrigue de Quercus coccifera, CEPE-CNRS, 1967. Doc. n° 39, 28 p.
Naveh, Z. The ecology of fire in Israel. Proc. Annu. Tall. Timbers Fire Ecol. Conf., 1974; 13:131-170.
Naveh, Z. The evolutionary significance of fire in the Mediterranean region. Vegetatio, 1975; 29:199-208.
Niederlender, A., Lacam, R., Arnal, J. Le gisement néolithique de Roucadour (Themines, Lot) Suppl. Gallia Prehistoria, 1966; 3, 226 pp.
Pannoux, P., Pannoux, C. Monographie préhistorique de la région des Matelles (Hérault). Compte-rendu 15° session Congrès Préhist. Fr., 1957; 781-814.
Perles, C. L'homme préhistorique et le feu. La Recherche, 1975; 60:829-839.
Perles, C. Préhistoire du feu. Masson, Paris, 1977; 180 pp.
Ribbe, C. de. Des incendies de forêts dans la région des Maures et de l'Estérel. Rev. Agr. Forest. Provence, 1865; 201-213.
Seigue, A. Les incendies de la forêt méditerranéenne. Historique, Essai prospectif. Bull. Tech. Inform., 1972 ; 268:415-423.
Sigaut, F. L'agriculture et le feu. Mouton et Cie Paris, 197 ; 320 pp.
Trabaud, L. Quelques valeurs et observations sur la phytodynamique des surfaces incendiées dans le Bas-Languedoc. Natur. Monspel., 1970; 21:231-242
Trabaud, L. Experimental study of the effects of prescribed burning on a Quercus coccifera L. garrigue. Proc. Annu. Tall. Timbers Fire Ecol. Conf., 1974; 13:97-129.
Trabaud, L. Comparison between the effects of prescribed fires and wildfires on the global quantitative development of the kermes scruboak (Quercus coccifera L.) garrigues. Proc. Symp. Environm. Consequences of Fire and Fuel Manage. in Medit. Ecosystems. USDA Forest. Serv. Gen. Techn. Rep. WO-3, 1977; 271-282.
Trabaud, L. Impact biologique et écologique des feux de végétation sur l'organisation, la structure et l'évolution de la végétation des zones de garrigues du Bas-Languedoc. Thèse Etat. Univ. Sci. Tech. Lang. Montpellier, 1980; 291 p.
Trabaud, L., Lepart, J., Diversity and stability in garrigue ecosystems after fire. Vegetatio, 1980;43:49-57.
Vogl, R.J. Effects of fire on grasslands. in Fire and ecosystems. Academic Press. New York, 1974; 139-194.

Fire Effects and Fuel Management in Mediterranean Ecosystems in Spain[1]

Ricardo Vélez[2]

Abstract: Forest fuels in the Mediterranean ecosystems of Spain are characterized by generalized pyrophytism and large accumulations of woody shrub vegetation. The Forest Service prepared in 1978 a fuel management plan and a program of surveys including: A study on the vegetation's evolution in forests after fires; the experimental use of prescribed burning and grazing to reduce forest fuel accumulations; a study of the evolution of fuel accumulations in areas treated in 1976 and 1977 in Southern Spain; and a study of economics of slash chipping.

The 1977 forest fire season was considered a successful one in Spain. The number of fires did not reach 50 percent of the average for the 3 previous years and the total area burned was less than 40 percent of that burned in each of the previous years (table 1). In contrast, 1978 presented an extremely prolonged fire season. Over 150,000 ha of forest and nearly 300,000 ha of brushland and pastureland were burned by 8,324 fires (table 1). These contrasting years reemphasized the fire danger in the Mediterranean ecosystems of Spain. They revealed the necessity for a fire prevention program which considers the factors determining the magnitude of the fire hazard (Vélez 1980a).

In 1976 and 1977 the Forestry Service (ICONA) was able to carry out pruning and clearing on over 120,000 ha of reforestation areas. This was achieved with special funds provided to reduce unemployment amongst agricultural workers. Moreover, in 1977 Spanish foresters had two opportunities to compare techniques with experts from other countries and thus to reflect on their fire prevention policy. These were the Technical Consultation (FAO/UNESCO) on Forest Fires in the Mediterranean Region, held in France (ICONA 1978a), and the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, held in Palo Alto, California (Mooney and Conrad 1977). The concern over the need to protect Spanish forests, together with exposure to the ideas and practices of other countries led to an active program of fuel management and research. In this paper I review the progress and development of the early years of this program.

DEVELOPMENT OF A FUEL MANAGEMENT ACTION AND RESEARCH PROGRAM

A fuel management plan for all danger areas as well as a program of research on the effects of fire and preventive silviculture techniques has been developed (ICONA 1978b). The goal is to enable forest treatment methods to be perfected through an improved knowledge of fire's role in Mediterranean ecosystems.

Fuel Management In The Forests

The fuel management plan developed for Spain can be summarized as follows: Fire prevention (Vélez 1977) has the basic purpose of controlling the fuel load in strategically important places, either by reducing or removing it. The technique used most commonly is that of fuel breaks, areas from 60 to 100 m wide which divide the forest into 300 to 1,000 ha stands and on which natural vegetation is modified to reduce biomass and flammability. To the extent possible, fuel breaks should link up with agricultural crops, recreational areas, campsites and natural barriers, so as to form a system dividing the forest into compartments, making it easier to stop fires from spreading.

Preventive work projects are designed to reduce fire danger. They must specify the work to be done, techniques used, the area to be treated and the area to be protected. The work to be included in such projects is varied. It must be remembered, however, that unlike extensive forest treatments directed towards improving production, the intent of fuel management is to establish fire barriers. This means intense action in small areas, strategically located to prevent ignition and contain the fire from spreading. The work includes pruning, thinning and clearing in auxiliary strips along roads, and removing slash. It may involve construction of roads and lanes, accompanied by the relevant auxiliary strips, as well as the preparation and maintenance of areas with a humid microclimate, such as watercourses and gullies. This may include the restoration, on a small scale, of mesic vegetation. Reduction of brushland by hand or mechanical clearing or by controlled fire, and the opening up of spaces, including the improvement of natural pasture for use by cattle and wildlife are also involved. Fuel management also includes the removal of slash by burning or chipping. Classifying an area as protected does not by itself assure that it is fire proof. It does mean it is less likely for a fire to start, and should a fire be started, damage should be kept to a minimum.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Doctor Ingeniero de Montes, ICONA - Forest Fire Section, Madrid Spain.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Table 1--History of forest fires in Spain, 1961-1980.

Year	No. fires	Burned area (ha)			Losses (millions pesetas)		
		Forested	Un-Forested	TOTAL	Commercial	Environ-mental	TOTAL
1961	1,680	34,506	12,195	46,701	928	575	1,503
1962	2,022	23,911	31,571	55,482	598	507	1,105
1963	1,302	13,279	9,400	22,679	311	312	623
1964	1,645	17,671	13,727	31,398	372	546	918
1965	1,686	21,777	16,241	38,018	412	599	1,011
1966	1,443	24,644	24,710	49,354	446	700	1,146
1967	2,229	33,930	42,645	76,575	575	858	1,433
1968	2,109	20,547	36,081	56,628	549	695	1,244
1969	1,494	19,296	34,423	53,719	484	656	1,140
1970	3,203	34,330	52,994	87,324	764	1,176	1,940
1971	1,714	13,194	21,751	34,945	334	657	991
1972	2,148	18,048	39,235	57,283	559	1,016	1,575
1973	3,765	40,559	54,698	95,257	1,118	1,574	2,692
1974	3,980	58,789	81,422	140,211	1,992	7,709	9,701
1975	4,242	111,091	76,223	187,314	4,121	13,855	17,976
1976	4,596	79,853	82,447	162,330	3,974	12,575	16,549
1977	2,148	26,454	41,086	67,541	981	3,393	4,374
1978	8,324	159,264	275,603	434,867	9,205	17,639	26,844
1979	7,167	119,579	152,139	271,718	6,790	16,819	23,609
1980	7,000	101,086	156,638	257,724	6,000	12,000	18,000

In the last two years fuel management work has accomplished the following:

Action:	1979	1980
Fuel Break Preparation	31,050 ha	17,356 ha
Fire Break Maintenance	--	2,661 ha
Road Building	375 km	140 km
Area Protected	500,000 ha	200,000 ha

Research on Fire Effects and Prevention Techniques

The research program on fire effects and preventive silviculture comprises these projects:

A. A study of forest succession following fire. Its aims are to study the effect of summer fires on forest soils, to analyze the effect of fire on regeneration, and to establish the grounds for future prescribed burning. Work on this project commenced in 1978, with data being collected from burned areas in the provinces of Gerona, Tarragona, Valencia, Madrid, Avila and Pontevedra.

B. Experimental use of prescribed burning to reduce forest fuel accumulations. Work on this project began in Galicia (NW Spain) in 1978 and has progressed from initial burning of plots less than 1 ha in size to burns of over 200 ha in pine plantations. Objectives include perfecting prescribed burning techniques as a means of controlling brushland and for forest fire prevention, and understanding the atmospheric and vegetation features most suited to prescribed burning.

C. Experimental use of grazing to reduce fuel accumulations. Work on this project began in Galicia in eucalyptus plantations. The idea was to use goats to remove *Ulex* and *Erica* brush. The goal is to determine the possibilities of using grazing to reduce fuel accumulations in areas covered with brush and in pine, eucalyptus and hardwood forests.

D. Study of fuel accumulation in Andalusia (South of Spain). The aims of this project are to determine the rate of brush regeneration, including the time at which it reaches a level at which brush removal is needed, determining the effectiveness of different methods of destroying brush, and comparing success in reducing fuel buildup by mechanical or manual clearing, and prescribed burning. These studies are being carried out in pruned and cleared forest areas where debris has been burned in piles, in unforested areas where fire and grazing have maintained the herbaceous vegetation, and in pruned and cleared forests where the branches have either been left on the ground for weathering or have been burned.

PRELIMINARY RESULTS

Fire Effects

Plant Survival

Surface fires that consume brush and herbaceous vegetation without reaching tree tops make up 70 percent of all fires in Spain (ICONA 1968-1979). The fire generally consumes the herbaceous vegetation and destroys most of the above ground brush, with only the thickest lignified stems left standing. These fires usually burn the soil, reducing litter to cinders and forming a layer of ash of variable thickness. Tree damage is a function of fire intensity and the amount of fuel accumulated on the ground. In general, the bark is burned on the outside but this does not necessarily signify cambium damage. The thermal effect on leaves seems more important. If the fire is rapid and the trees have been pruned, only the lower levels of foliage will be burned and the upper branches will survive. If the fire is slow burning and the hot air envelopes the crown, survival is unlikely. Isolated trees frequently survive fires in pine groves. Unfortunately, it is difficult to collect this type of information since to simplify forestry operations, surviving trees are usually felled wherever fires have occurred.

Data is being collected on tree survival in pine groves after fires. In Lanjaron (Granada), where there were fires in successive years (1973, 1974), all the pine trees died in areas which burned during the daytime. On the other hand, on areas which burned at night, the fire became less intense as the wind dropped and humidity increased, and only litter was burnt. A stand of Pinus sylvestris with diameters of 5 to 10 cm and branches from the base of the trunk survived the fire as only the lower branches dried up. In Musques (Vizcaya) incendiary fire in an unpruned stand of P. radiata, with diameters of 10-15 cm, burned at night, with high atmospheric humidity. The fire slowly consumed the Ulex brush, leaving the pine grove clean, as if it had been a prescribed fire.

In evaluating the effects of fire on broad-leaved species we must distinguish between the typically summer-drought Mediterranean (Quercus ilex, Q. suber, etc.) and the more mesic species (Q. robur, Castanea sativa, Fagus sylvatica, Betula sp., Populus sp. etc.). The former usually grow in sites similar to pine forests, forming either open "dehesas" (the typical case of Q. ilex) or closed formations as in Q. suber. In the "dehesas" fire is the creeping, rapid type, burning the dry grass, often allowing the oaks to survive. In closed formations there is usually a large amount of brush and branches so that the fire easily gets to the tree tops, defoliating the trees.

Statistics indicate that on a scale from 1 to 10 the flammability of hygrophytic broad-leaved species equals 1 while that of conifers equals 10 (Vélez 1980a). Thus the former are considered as species which "do not burn". Indeed, on a yearly basis formations of hygrophytic broad-leaved species suffer little from fire, both in numbers of fires and area burned. But, what happens when fire does occur? Without exception, the above ground part of oaks (Quercus robur), chestnuts (Castanea sativa), and beech (Fagus sylvatica) die. Their tender leaves cannot withstand the heat and the bark is not sufficiently thick to insulate the cambium. However, it is noted that these trees generally form a fire barrier. The plants that are in front have perished, but the forest has been saved. The reason is that these species exist only in areas with abundant moisture. The fire is stopped because it spends its heat evaporating water, and in the end there is more water than heat. Naturally, if the fires were to occur often enough these stands could be eliminated. But, more commonly, they serve as an effective fire barrier.

Plant Regeneration

Observations made in recent years indicate that, contrary to public opinion, fire does not sterilize an area but instead stimulates the sprouting of vegetation after the first rainfall. These sprouts usually consist of a larger number of species than that present before the fire. Subsequently, the variety of species diminishes or at least is masked as some predominate over others[3]. The case of spurge flax (Daphne gnidium) is typical in that it appears on all kinds of burned ground with enormous vitality (it grows up to 50 cm in a year) but becomes much less obvious in later years. Woody brush also regenerates strongly, sometimes sprouting from a stump (Erica, Calluna, Ulex, Genista, Quercus coccifera, Juniperus, Chamaerops, etc.), and sometimes from seeds (Cistus).

Pines seem to regenerate from seed easily after fire as long as the stand was sufficiently old to have fertile cones. In the Ayora-Enguera fire (July 17-21, 1979 which burned 22,796 ha of pine forest in Valencia (the most extensive fire recorded in Spain to date) regeneration of Pinus pinaster and P. halepensis was abundant one year later. The autumn following the fire was quite favorable with frequent, non-torrential rainfall, so that seeds had germinated when spring arrived. They rooted well with that seasons rain and most were able to survive the summer. Pine trees 20 cm high were found in November, 1980, together with others which had just germinated. All the burned area had been logged, as the burned timber could be commercially exploited. Over a 4,000 ha area of Pinus pinaster was burned in 1976, near the Ayora-Enguera fire. Total regeneration of the pines was observed, reaching over 50 cm in height after 4 years. Regeneration is at present being aided by manually cleaning out around each tree.

In a drier area of Valencia, (Serra, Portaceli fire, 1978), a lag of approximately one year in regeneration has been observed. In addition, little if any regeneration occurs on the driest,

[3]1980 Internal Report by Ruiz del Castillo on the study on fire effects in vegetation, Inst. Nac. Investigaciones Agrarias, Madrid.

stoniest sites, which have a steep slope. The influence of exposure is not clear but sunny slopes seem to be less favorable than shaded ones. Regeneration appears to be greatest where the most ash has accumulated. This might be because of the high carbon content which retains a greater amount of water, and thus favours seed germination. In areas where former charcoal furnaces were located regeneration is noticeably better, both in terms of the number of trees and the height reached in one year.

For certain species, used for reforestation, like Pinus radiata, fire seems almost necessary for regeneration, since the cones require heat to open. In some reforested areas, mainly P. pinaster and P. halepensis, little regeneration occurs. It is not clear whether or how this might be related to site quality.

Among the broad-leaved species, Quercus ilex and Q. suber regenerate by crown sprouting. Chestnuts are weakened as they may suffer wounds in their roots when the fire goes deep into the surrounding thick litter. Poplars sprout readily and even withstand repeated, low intensity fires. Birches disseminate their seeds better after fire. In any event, not much information is available on these species since they are seldom burned.

Introduced eucalyptus trees are able to withstand fire. Even when the above ground part is killed, they sprout readily, often growing more than 2 m the next year. They also disseminate seed readily after fire. In Galicia E. globulus is extending its area due to the large number of fires occurring in that region (Dalda 1978a).

In light of these preliminary observations, generalized pyrophitism of the Mediterranean forest vegetation seems to be confirmed. In truth, the story of our forest formations would be incomplete if the role of fire was not included. Fire is not and never has been a rare event in these forests. It is now, apparently, more frequent than a few years ago and has more intense effects. However, it has always been there. The vegetation can tell us whether fire burned recently in an area. Chestnut and beech are clear signs that there have been no fires for a prolonged period. A pine grove or Cistus shrub are, on the other hand, probable indications of a relatively recent fire (Martín Bolaños 1949). The very name of the forest sometimes gives an indication of fire history. Magnificent pine stands are known as "El quemado" (the burnt one) in many places.

Controlled Fires

Experimental fires were burned on test plots in unforested areas and eucalyptus plantations with dry matter accumulation over 2 kg/m^2 in the former and 1 kg/m^2 in the latter (Vega 1978). The slope varied between 10 and 15 percent. In some cases brush height came to 3 m. Burning was carried out several days after rain in the spring. The majority of the fires were started with no brush preparation. Only on one eucalyptus plot was the brush cut first and left on the ground. In the first fire fuel reduction ranged from 55 percent in the unforested areas to 50 percent in the eucalyptus groves. In the latter, all trees over 10 cm in diameter survived without damage. The influence of fire intensity on the trees was also studied. The second burning, one year later, produced less fuel reduction, but the effects on the trees were similar. It was not found that the increased cost of cutting the brush significantly increased fuel reduction. Birch and oak (Q. robur), with diameters less than 10 cm, were common on the plots. Practically all survived or sprouted after the fires. The same happened to the few pines that were associated with the eucalyptus grove.

Fires were used on a greater scale in 1980 on pruned Pinus pinaster and P. radiata plantations with diameters of 10 to 40 cm and where brush cover was from 1 to 4 m high. In one case, the flash fuel was a thick layer of pine needles. Burning was carried out in March and April, several days after rain. The burned areas varied between 3 and 170 ha in size.

The following are presented as tentative conclusions. Additional studies will extend these findings and check future effects:

a) Six months after fire the forest is easy to travel through and little fuel is on the ground. This makes it difficult for fire to start as well as facilitates the suppression thereof.
b) It does not appear that P. pinaster or P. radiata with diameters over 10 cm suffered appreciable damage.
c) Burning should be carried out so that brush is consumed as completely as possible. If the brush is thick, it may be advisable to first fire under high moisture conditions and then remove the rest with a second burning.
d) Trees should be pruned to a height above 2 m. The low branches dry and drop a large number of pine needles. If there is a large accumulation of needles they should be raked away from the base before burning.
e) Burning should be carried out with the support of roads or fuel breaks at the top and bottom. Butane lighters or diesel torches are good ignition tools. Stirring up the pine needles with rakes aids fire spread.
f) An average of 1 ha can be burned per day in mountainous terrain. This is notably cheaper than clearing by manual methods.
g) The possibility of keeping the burned land clear by introducing horses, cattle or goats should be considered.
h) A survey should be started on the effects of burning on tree growth since these are basically plantations for timber production.
i) Apart from surveys on the effects of fire prevention, it would be of interest to study the effects of fire on the natural regenera-

tion of pines. It is probable that the lack of regeneration in many stands is due to the absence of fire.

Use Of Grazing

The first grazing experiments were carried out in eucalyptus plantations (*E. globulus*) in Galicia. Goats were the primary animal used although some horses and cows were included. The plantations consisted of mature trees with diameters over 10 cm. The understory is mainly *Ulex*, *Erica* and *Calluna*.

The vegetation removal capacity of goats is such that at certain times of the year natural pasture does not suffice and their intake has to be supplemented with concentrated feed. Animal densities needed to keep the forest clean without erosion are estimated at one goat per 1 to 1.5 ha or one horse for each 4 ha (Rigueiro 1979). Impacts on the flora are being studied since the animals eat selectively, leaving the least appetizing species alone. For example, removal of leguminous species may influence nitrogen fixation. The influence of fertilization from manure must also be considered.

It is interesting to connect this work with that of using controlled fire, bearing in mind results from Santander where efforts are being made to rationalize the traditional practice of burning meadows and brush in order to "renew the pasture" (Montserrat 1978). The intention is to avoid extensive controlled burning which makes the vegetation uniform, creating a continuous fire danger. It has been recommended that mosaics of small areas (maximum 200 m^2) he burned by shepherds and grazed over the following years.

Fuel Management

It must he recognized that the budget for fuel management has also had the aim of reducing unemployment. This forced manual methods to be employed wherever feasible. The common approach has been pruning and clearing with hand tools, followed by piling of brush and branches for burning. In areas with young trees and sparse canopy cover it is estimated that further clearing will be required every 2 to 3 years. If the trees are older and give more shade brush regeneration is less important. Some species, like *Pinus sylvestris*, inhibit brush growth in mature stands. In any event, sufficient information is not yet available to establish clearing rotation periods.

This system involves very high costs. To reduce costs in areas with poor access it was decided to deposit slash on the ground and leave it for humification. In dry areas, this process is slow and the danger arising from the fuel is much greater than before, although it is true that the branches prevent development of new brush. The conclusion is that the slash should generally be removed as soon as possible. The burying of slash calls for the use of machinery which is not easy in forested stands. Combining the manual fuel removal system with other techniques appears more promising.

In the province of Jaen fire breaks are combined with roads and open spaces in burning brushland. Wildlife comes down to eat the sprouting brush, thus keeping biomass low. Burning may be needed every five years in such situations.

Another possibility is to find a commercial use for slash in order to make removing it from the forest profitable. This has been studied for *Pinus sylvestris* forests (Puig 1980). It requires a chipper drawn by a tractor and a second tractor to drag away the slash and pile it in strips along the forest road. The potential profits are variable since the conditions in the forest and slash to be chipped are heterogeneous. Products derived include chips for particle board (pine) and chips for fuel briquettes (oak, pine or brush). This use is limited by the chip market which is low at this time, and by the fact that there is only one briquette factory in Spain. In any event, it is an interesting alternative to the burning of piles.

RECOMMENDATIONS

Observations on fire effects indicate that to protect the forests (Vélez 1980b) it is necessary to: a) recognize that fire is a natural ecological process that is only harmful in excess or when it conflicts with man-created values: b) recognize that genetic diversity produces morphologically diverse ecosystems which in turn are the most apt to be perpetuated by fire; and c) recognize that fire must be managed as a recurring process. In short, forest fire protection and management requires the bringing together of a variety of principles and types of knowledge. This must consider the advisability of mixing species, introducing hygrophytic species and alternating forest and grazing lands (Gonzalez Vazquez 1950).

In some places fire can be controlled with hygrophytic species. They should be respected where found and introduced where ecologically desirable in order to create "fire resistant places." Generally, the areas available for forest restoration are degraded, dry and stony, and are hardly suitable for hygrophytic species. But there will always be watercourses nearby and often scattered broad-leaved species of trees. Respect for them and promotion thereof must prevail. The practice of planting birch trees in water courses and at the side of forest roads is being practiced in Galicia. Birch does not resist fire but it does retain moisture and contributes to retarding the fire's advance (Dalda 1978b). Poplars, willows (*Salix*) and ash (*Fraxinus*) are common wherever there is moisture and may also be used. We must not hesitate to promote mixed stands which in addition to being more natural, defend themselves better from fire.

In areas with high fire danger it is not advisable, for instance, to replace cork oaks (Quercus suber) since their thick bark makes them fire resistant, as well as being able to sprout back after burning. On the other hand, there is some evidence that the eucalyptus plantations in Galicia are turning out to be more and more attractive in view of the recent wave of incendiary fires. They suffer little from fire, vigorously sprouting from the stump. In any event, defense against fire cannot be based primarily on replacing species with other less combustible ones. Indeed, pyrophytism, so generalized in the Mediterranean area, reveals that natural fire defense includes the mechanisms that stimulate reproduction after fire.

Forest fuel management should be directed primarily towards the idea of reducing flammability. This should be based on the creation of breaks which transform the forest into a mosaic of species and biomass, conifers mixing with broad-leaved species, mixed ages, spaces being opened up between forest areas, etc. The even aged single species stand, ideal for exploitation, is only ecologically possible in limited areas of this country due to its high susceptibility to fire.

Thus, the traditional concept of fire breaks, which are costly to preserve, should be replaced by the idea of fuel breaks as defined above (Vélez 1977). Likewise, low cost practices like controlled fires, and techniques which produce an economic yield like grazing and slash chipping, must be brought into forest fire preventive treatment.

The development of these programs must bear in mind criticism (Folch 1977) against the removal of fuel from forests for ecological reasons. Experience up to now shows that those areas where fuel has been reduced are less liable to suffer from wildfires. In addition, if fire occurs, the intensity is noticeably decreased, facilitating suppression. Nevertheless, it is necessary for the "ecology + economy" binomial to be carefully analyzed in order to obtain valid results based on scientific findings.

Literature Cited

Dalda González, J. Los efectos del fuego en la vegetación forestal de Galicia. Madrid: ICONA; Naturalia Hispanica; 1978a. 53 p.

Dalda González, J. Conveniencia y utilidad del abedul para diversificar la cubierta forestal del noroeste ibérico. Madrid: ICONA; Técnicas españolas de lucha contra incendios forestales; 1978b; 65-68.

Folch Guillén, R. Sobre ecologismo y ecología aplicada. Barcelona: Ketres, Ed.; 1977. 309 p.

González Vázquez, E. La riqueza forestal española. Madrid: Dossat, Ed.; 1950. 63 p.

ICONA. Técnicas españolas de lucha contra incendios forestales. Madrid. 1978a. 91 p.

ICONA. Programa de estudios sobre ordenación y control del combustible forestal para prevención de incendios. Madrid: Bol. Est. Cent. Ecología (14). 1978b; 93-97.

ICONA. Los indencios forestales en España durante 1968-1979. Reports published yearly from 1968 to 1979. Madrid. 1968-1979. 75 p. each.

Montserrat Recoder, P. El incendio de pastizales y sus peligros. Madrid. Rev. Pastos (8), 1978; 31-36.

Martín Bolaños, M. Jaras y jarales. Madrid: Instituto Forestal de Investigaciones y Experiencias; 1949. 228 p.

Mooney H. A. and Conrad, C. E. (Eds). Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems: USDA Forest Service Gen. Tech. Report WO-3; 1977. 498 p.

Puig Sales, R. Aprovechamiento de residuos forestales. Soria: Seminario sobre recuperación de recursos de los residuos; 1980. 73 p.

Rigueiro Rodríguez, A. Control de la vegetación mediante pastoreo. Madrid: Rev. Agricultura; 1979; 871-873.

Vega Hidalgo, J. A. Utilización del fuego controlado en las comunidades vegetales de Galicia. Madrid: Bol. Est. Cent. Ecología, (14). 1978; 3-19.

Vélez Muñoz, R. Prevención de incendios mediante ordenaci6n del combustible forestal. Madrid: Bol. Est. Cent. Ecología (12). 1977; 41-52.

Vélez Muñoz, R. Criterios para la elaboracien de mapas de peligro de incendios forestales. Madrid. ICONA. Report. 1980a. 22 p.

Vélez Muñoz, R. Fire prevention alternatives in reforestation. Madrid: FAO/ECE/ILO Seminar on afforestation and reforestation machines and techniques. 1980b. 13 p.

Prescribed Burning in the California Mediterranean Ecosystem[1]

Lisle R. Green[2]

Abstract: Prescribed burning is feasible for reducing conflagration costs. Prescription elements to consider before the burn are dead-to-live-fuel ratio, fuel volume, live fuel moisture, chemical content, terrain, and season. Just before and during the burn, 3-day weather forecasts, windspeed and direction, dead fuel moisture, relative humidity, and air temperature are important. A chaparral stand with 30 to 40 percent dead fuel might be burned during the winter with 60 to 75 percent live fuel moisture, 8 to 12 km/h (5 to 8 mi/h) of wind, 6 to 10 percent dead fuel moisture, 23 to 32 percent relative humidity, and air temperature of 10° to 22° C.

Wildfires that burn over thousands of acres of mature chaparral occur primarily when winds are gusting 30 to 80 mi/h (50 to 130 km/h), relative humidity and dead fuel moisture are around 5 percent, and air temperatures are near 100° F (38° C). Such fires are disastrous for soils, vegetation, wildlife, structures, and sometimes human life. The widespread use of prescribed burning is frequently suggested as the only practical way to reduce the intensity and extent of wildfire acreage burned, and the resultant damage.

Prescribed burning is the scientific application of fire to wildland fuels under conditions of weather, fuel moisture, soil moisture, and other factors that allow the fire to be confined to a predetermined area, while at the same time accomplishing certain planned objectives (Ford-Robertson 1971). For Mediterranean ecosystem burning, these objectives usually include wildfire hazard reduction and wildlife habitat improvement, but may include others. For example, the National Park Service uses prescribed fire as a tool to reintroduce fire as a force in naturally functioning ecosystems (Parsons 1977). If the desired prescribed burning objective is clearly expressed, a burning prescription to accomplish the objective can be written.

Many fuel, weather, and topographic factors affect fire behavior and must be considered in planning for prescribed burning. Time of day and season are important as they interact with the other factors. Several of the primary determinants of fire behavior can be considered well ahead of the burn date. These "prefire" determinants will be considered as a group in this paper. Other factors that must be considered or determined immediately before and during the burn will then be discussed. These factors all come together in the prescription. Writing the prescription is the task that has been the greatest worry to prescribed burning planners and bosses, most of whom feel more comfortable with suppression procedures. The guidelines presented here should help.

Although this paper is based primarily on experience in California, the principles dealt with are the same elsewhere. Once objectives are well defined, the guidelines provided can be used in any Mediterranean ecosystem. This paper summarizes a recent report, "Burning by Prescription in Chaparral" (Green 1981) which provides a more detailed discussion of prescribed burning, including topics not covered here, and a more complete review of the literature.

PRESCRIPTION ELEMENTS TO CONSIDER BEFORE THE BURN DATE

Fuel Volume

Fuel volume, or loading, is expressed as pounds or tons of fuel on an area of land. The term commonly covers total biomass, but no fire burns all biomass, except perhaps in grassland. The part of the biomass actually consumable by the fire is the available, or burnable, fuel.

Total biomass in annual grassland is typically 1/3 to 1 ton/acre (0.7 to 2.2 t/ha) and when dry, essentially all will burn. Soft chaparral (Paysen and others 1980), sagebrush (*Artemisia*), or light chamise (*Adenostoma fasciculatum* H. & A.) biomass varies from 3 to 10 tons/acre (7 to 22 t/ha), and 70 to 85 percent is consumed by a hot fire. Biomass of dense chaparral dominated by chamise is typically around 15 to 25 tons/acre (33 to 56 t/ha), about two-thirds of which burns. Only about 50 percent of brush dominated by large shrubs--those 6 ft (1.8 m) or more in height with basal stems 2 to 5 inches (5 to 13 cm) diameter--is consumed. Such brush has a biomass of 30 to 45 tons/acre (67 to 100 t/ha). Remaining, following any prescribed burn, are the branches larger than 1/4 to 1/2 inch (0.6 to 1.3 cm) (fig. 1). Even in hot wildfire, green branches are seldom burned to diameters greater than 1/2 inch

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Range Scientist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Figure 1--During a hot chaparral fire, all dead fuel is consumed, but most green branches larger than 1/4 inch diameter remain. Unburned green fuel may amount to half or more of the chaparral biomass on north exposures.

(1.3 cm). Actual quantities of burnable fuel are becoming more important as greater restrictions are placed on the quantities of burn residues that can be added to the atmosphere during a prescribed burn.

In southern California, knowledgeable foresters established that 2 tons of fuel per acre (4.5 t/ha), dry weight, was the maximum that should be allowed on fuelbreaks (Pacific Southwest Forest and Range Exp. Stn. 1963), because the heat from that fuel volume could usually be tolerated by firefighters. Nearly all chaparral fuelbeds contain 8 tons/acre (18 t/ha) or more of available fuel and can be expected to burn as moderate- to high-intensity[3] fires, if they burn at all. An objective of prescribed burning for hazard reduction may thus be to reduce the burnable fuel down to acceptable levels of around 2 tons/acre (4.5 t/ha), sometimes in a series of prescribed burns.

The Dead-to-Live-Fuel Ratio

Fire behavior in brushfields is determined to a great extent by the amount of dead twigs and branches present in the brush canopies, and by the amount of cured herbaceous residue in the understory. If the mature brush has been removed by fire or equipment during the previous several years, or if the mature brush is sparse, a stand of annual grasses and forbs may have developed and their residue often determines the fire behavior. Brush stands in which annual grass and forbs intermingle with soft chaparral species, such as bush buckwheat (*Eriogonum fasciculatum* Benth.), sage (*Salvia* spp.), and California (coastal) sagebrush (*Artemisia californica* Less.), occur frequently at low elevations or intermingle with chaparral communities on south slopes; these, like grassland, have a high dead-to-live ratio and can burn fiercely at almost any age.

Stands of chamise on south slopes accumulate dead fuel faster than do chaparral communities on northerly or easterly exposures, especially if chamise is associated with soft chaparral species (fig. 2). Such south slope brush can be burned by prescription at an earlier age--perhaps at 15 to 20 years--than the chaparral of northerly exposures.

Stands of chaparral dominated by such species as scrub oak (*Quercus dumosa* Nutt.), ceanothus, chamise, manzanita (*Arctostaphylos* spp.), toyon (*Heteromeles arbutifolia* M. Roem.), and mountain mahogany (*Cercocarpus betuloides* Nutt.) are more resistant to fire than the various chaparral/grass-forb associations, especially on northerly exposures. About 5 to 8 years following clearing of such brush, the new canopy closes and forbs and grasses are then quite effectively suppressed (Bentley and others 1966). The chaparral stand will likely contain no more than 10 percent dead fuel--skeletons left from previous fires and the remains of deerweed (*Lotus scoparius* [Nutt.] Ottley) or other semishrubby vegetation. With only 10 to 20 percent of dry fuel, a chaparral

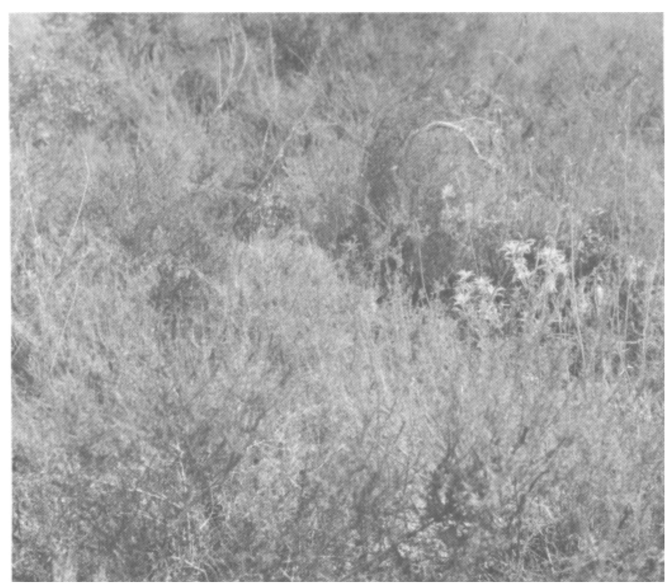


Figure 2--Soft chaparral frequently has a high dead-to-live ratio and burns at a younger age than chaparral. Dominant species in this picture are white sage, California sagebrush, and chamise.

[3]Fire intensity is the rate of energy or heat release per unit of time and length of fire front.

stand is quite resistant to prescribed fire, and burning attempts in such stands are nearly always futile.

As the proportion of dead fuel in a brushfield reaches 25 to 35 percent, the stand is susceptible to prescribed burning. This proportion may be reached when the chaparral on southerly exposures is around 20 to 25 years old. Chaparral on northerly or easterly exposures is probably older before it accumulates enough dead fuel to be burned successfully. Chaparral 40 to 80 years old is seldom more than 40 to 50 percent dead. Soft chaparral stands may be two-thirds dead, if the abundant litter is considered, a fact which explains in part why there are many more wildfires in the soft chaparral type than in the chaparral, and why the soft chaparral communities can be burned by prescription at an earlier age.

The proportion of dead fuel in chaparral communities can be estimated roughly from the age of the brush, can be estimated in the field, or can be cut on plots and weighed. The latter method is extremely time consuming and is usually a research activity. Mature chaparral tends to have roughly 1 percent of dead twigs, branches, or plants for each year since the brush canopies closed. Thus, 20-year-old chaparral is likely to be 10 to 15 percent dead, while 40- or 50-year-old chaparral may be estimated to be 35 or 40 percent dead. This is a very rough rule of thumb, but it can be of considerable value to fuel managers.

Since the proportion of dead fuel is so important in prescribed burning, it should be checked by field observation. Dead material is generally obscured from above by the green canopy, so an observer must get under the canopy cover at several locations within a proposed burn. The proportion of main branches that are dead should be counted on several plants, then the small dead twigs attached to live branches evaluated. Keeping in mind that most of the weight is in the larger branches, an observer can approximate the proportion of dead fuel.

Live Fuel Moisture

Live or green fuel moisture is the moisture content of living twigs to 1/8 inch (3 mm) diameter and attached leaves, expressed as a percentage of dry weight, unless some other size class is specified. This definition was agreed on by California agencies concerned with wildland fire, and has been in use for two decades.

The live fuel moisture has been recognized as important in prescribed burning (or wildfire danger) by some fuels management workers, but ignored by others. Fuel moisture content of living fuel is usually so high that the fuel will not burn unless dried by an outside heat source. Heat released from dry fuel as it burns must dry out the live twigs so that they will burn and add energy to the fire if the burn is to be successful. Most forest fuels, when ovendry, have a heat value near 8500 Btu/pound (3860/kg). If the fuel moisture content is 80 percent, the effective heat value is cut in half to about 4200 Btu (1930/kg) (Countryman 1977). The greater the live fuel moisture percentage, the more dead fuel must burn to drive off the water.

Live chaparral fuel moistures are typically high during the spring, 130 to 200 percent; they decline through the summer and reach a minimum of 50 to 80 percent in September or October. With several inches of rain during the fall, there is some recovery of live fuel moisture. Otherwise, it may remain low until spring.

If green fuel moisture is greater than 85 percent, prescribed burning is seldom successful unless there is a very high proportion of dead fuel or unless the brush is crushed or sprayed to reduce the moisture content. Green fuel moistures less than 60 percent in old brush stands indicate hazardous conditions and burning should be avoided or special precautions taken. A green fuel moisture range of 60 to 75 percent is usually about right for burning standing mature chaparral.

Procedures for measuring green fuel moisture have been published (Countryman and Dean 1979), and general trends of green chaparral fuel moisture throughout California are published each 2 weeks by the Southwest Region, U.S. Forest Service, during the spring, summer, and fall. Green fuel moisture of chamise or other abundant species to be burned should be determined 3 or 4 weeks before a projected prescribed burn date, and again 1 or 2 weeks before the burn. This allows for adjustment of other prescription elements if the green fuel moisture is high or low.

Chemical Content

The chemical content of shrubs is generally ignored during prescribed burning, but perhaps should not be. One class of chemicals--the ether extractives--make up a substantial part of the dry weight of many flammable species, from about 8 percent of pine needles (Rothermel 1976) to 15 to 18 percent of California sagebrush and the shrubby *Salvias* (Montgomery 1976) (fig. 3). The extractive content is highest during the fall and lowest during the spring (Philpot 1969). Extractives are readily volatilized by heat and frequently burn fiercely several feet above the shrubs.

If an area to be burned contains considerable soft chaparral, and the chaparral species bigberry manzanita (*Arctostaphylos glauca* Lindl.) and chamise, it can be expected to burn hotter than an area dominated by such chaparral species as toyon, laural sumac (*Rhus laurina* Nutt.), ceanothus, scrub oak, and mountain mahogany--just because of the high chemical content.

Figure 3--Oils, fats, terpenes, and other chemicals are volatilized from flammable brush by heat from fire, and these products then contribute to the intensity of the fire. Soft chaparral contains more of these products than most chaparral species.

A second class of chemicals, the mineral elements, have an opposite effect from the ether extractives and tend to make vegetation less flammable (Philpot 1970, Shafizadeh 1968). Phosphorus has been more effective than other elements for reduction of flaming combustion.

Seasonal Considerations

The season for prescribed burning can be anytime that burning can be accomplished within the prescribed limits of weather, fuel, and manpower, and when burn objectives can be accomplished. Late summer and early fall contain the fewest burn days because of weather extremes and extremely dry fuel.

The early winter months--October, November, and December--contain days suitable for burning in California. Days are short, nights are cool, and there has been little recovery in the moisture content of green brush. This is a good time for hot burns with maximum consumption of brush. Midwinter also presents some good burn opportunities. Soon after rainstorms, 1-hour timelag fuels, those less than 1/4 inch (6 mm) diameter, can be burned, and after several dry days, small brush fuels. Excessive quantities of available fuel can be burned in stages during this season.

Growth starts in the spring during periods when there is available soil moisture, and daytime temperatures are above 40° F (5° C) (Bentley and Talbot 1951). Moisture content of shrubs increases rapidly during the spring, and the risk of escape is less than at any other time of year. This is an excellent time to burn crushed brush, brush piles, old stands of south slope vegetation, or other concentrations of dead woody fuel. It is not the best time for good consumption of green brush during broadcast burning.

Terrain Considerations

Prescribed burning in chaparral is always in or near rough topography that affects burning decisions in many ways.

Slope has an effect on fire similar to windspeed, and the steeper the slope, the greater the uphill rate of fire spread. During daytime hours, air movement is normally upslope and this reinforces the slope effect, thus ensuring rapid spread of fire up to the ridgetop. Because this is so, prescribed burns are generally ignited on the highest ridges that form burn boundaries, and a fireline is burned into the wind and downslope from the ridgetop. Prescribed burn bosses must also be aware of downcanyon air movement that begins shortly after sunset, or sometimes earlier on shaded north or east exposures.

Gusty, turbulent windflows occur at canyon intersections or where canyons change direction. Eddies are created where wind crosses a ridgetop, and windspeeds are higher through saddles than at adjacent higher elevations along the ridge.

The most severe fire microclimates are on southerly or southwesterly exposures, and fire danger increases from northern to southern exposures. Chamise, a flammable species, frequently dominates on southerly exposures and may be burned at times without firelines if less flammable species with higher fuel moistures grow on adjoining northern exposures.

PRESCRIPTION ELEMENTS TO CONSIDER AT BURN TIME

Fire intensity and rate of spread are directly affected by several factors which must be determined shortly before the fire is to be ignited, and during the prescribed burn. These include windspeed, dead fuel moisture, relative humidity, and air temperature. If these are within the prescription range, ignition and firing can proceed. If one or more is not within range, unless some trade-off can be made with another prescription element, the burn must be postponed.

Windspeed and Direction

Prediction of windspeed and direction is our greatest problem in local weather forecasting, especially in mountainous terrain. Wind, more than any other factor, is responsible for erratic fire behavior, for prescribed burn escapes, and for large wildfires. Some wind, except on steep slopes, however, is needed to move fire through chaparral during prescribed burns.

Windspeed is measured by the U.S. Weather Service and by Fire Danger Rating stations at a standard 20 ft (6.1 m) above open ground or vegetation. However, wind velocity measurements taken on prescribed burns usually approximate the "midflame" windspeed zone for chaparral. Winds at midflame height are usually about half the velocities at 20 ft (6.1 m) for fuels such as grass and brush. Windspeed as given in this paper should be considered to be midflame windspeed.

The maximum safe windspeed for prescribed burning in chaparral is generally considered to be 10 mi/h (16 km/h). Gusting above this windspeed will occur, and if these gusts reach 15 to 20 mi/h (24 to 32 km/h) during the burn, control problems will surely arise. Windspeeds of 4 to 8 mi/h (6.4 to 12.8 km/h) are about right for prescribed burning in chaparral.

In other vegetation types, higher windspeeds have been recommended. Winds of 8 to 15 mi/h (12.8 to 24 km/h) nave been suggested for level terrain in Texas where grass carried the fire into and through brush (Wright and Bunting 1976) and in juniper (Martin 1978; Pase and Granfelt 1977; Northwest Region, Forest Serv. 1973).

Wind direction and changes in wind direction may be as important as windspeed to the prescribed burn operation. Usually, a prevailing wind pattern can be identified before the burn, and firelines and ignition patterns are planned with this, and the terrain, in mind. Winds tend to change direction and vary in velocity as the airstream flows around and over ridges and through saddles, and otherwise adapts to the topography. Near the ocean, sea breezes may disrupt the wind pattern, or create their own pattern. During warm daylight hours, the wind movement is typically upslope. At night, after air near the ground has cooled, it flows downslope. Santa Ana winds can override this pattern (Schroeder and Buck 1970).

Dead Fuel Moisture

The moisture content is the most important factor determining whether or not fuels will ignite and burn. A fuel moisture content of about 25 percent of the dry weight of the fuel is the approximate value above which fuels will not burn (Rothermel 1972). The precise value depends on the type of fuel, the fuel loading and arrangement, size of firebrand, windspeed, and perhaps other factors. Fuels generally do not burn vigorously if the fuel moisture content is above 15 percent, unless fanned by strong winds or on steep slope.

As the moisture content of wildland fuels decreases below 15 percent, the flammability increases rapidly. The fire spread rate is estimated to double as moisture content drops from 15 to 10 percent, and to triple when it drops from 10 to 5 percent (U.S. Dep. Agric., Forest Serv. 1975). Thus, fuel moisture content changes below 10 percent can markedly affect fire behavior, and the prescribed burn boss should be very aware of this. Fuel moisture contents of 5 percent or less encourage spotting and excessive spread rates. Moisture contents of 6 to 10 percent are frequently good for prescribed burning, but if the proportion of dead fuel is greater than 40 percent or if burning is done under tree canopies, higher fuel moisture contents--10 to 15 percent--are needed to keep the intensity and spread rate within bounds.

The moisture content of dead fuels 1/4 to 1 inch (0.6 to 2.5 cm) diameter can be determined accurately by laboratory techniques (Countryman and Dean 1979), but is frequently estimated in the field through the use of "fuel moisture sticks." These are 1/2 inch (1.27 cm) ponderosa pine dowels mounted on two hardwood pins and weighing 100 grams, moisture free. Any weight in excess of this is an estimation of the moisture content in percent.

Relative Humidity

Moisture in the atmosphere--the humidity--is important in prescribed burning because of its effect on moisture content of fine dead fuels. Relative humidity is the amount of moisture in the air at a given temperature and air pressure compared to the amount that it would hold if saturated. A low relative humidity, 10 or 20 percent, indicates a great capacity for the atmosphere to take up moisture and dry out fuels. Dry fuels will absorb moisture when the percent relative humidity is high, until they reach about 20 percent moisture. At that level, fuels are difficult to ignite and burn.

Relative humidity can be quickly and accurately measured by a sling psychrometer. However, a word of caution: The psychrometer should be fanned or twirled until there is no further decrease in the wet bulb temperature reading before it and the dry bulb readings are recorded. A common error is reading it too soon.

Atmospheric pressure has enough effect on relative humidity readings that charts or slide rules designed for low elevations should not be used at higher elevations. Errors of several percent in relative humidity readings can easily result. Charts are available for various elevations that assure accurate relative humidity measurements.

Experience has shown that to burn standing, untreated chaparral 25 to 40 or more years old, and with about one-third of the fuel dead, relative humidities of 25 to 35 percent are about right. If the relative humidity is above 40 percent, and particularly if it has recently been higher, fire will not spread without strong wind or steep slope. If chaparral is 40 to 60 percent dead, as after spraying, relative humidities of 35 to 60 percent will be needed to keep the fire intensity within bounds. If the proportion of dead fuel is only 20 percent, relative humidities of 15 to 18 percent, and winds near the upper prescription limits, will be needed.

Air Temperature

Air temperature has little direct effect on fire, but considerable indirect effect. When air temperature rises, relative humidity decreases, evaporation proceeds more rapidly, fine fuels become drier, and less heat energy is required to cause a loss in fuel moisture. Air movement due to convection and spotting becomes more of a problem, particularly as air temperature rises above 80° F (26° C).

High air temperatures contribute to crown scorch, and are desirable if the objective is to kill trees. For cleaning up the forest floor with minimum damage to crowns, 55° to 70° F (13° to 21° C) is about right.

Time of Day

The safest time of day for prescribed burning is generally from midday to midafternoon, providing prescription requirements are met. As burning is extended into late afternoon, temperatures tend to decrease and relative humidity to increase, and control problems are less.

Table 1--Prescription elements for burning chaparral.

Factors affecting fire intensity	Fire intensity		
	Low	Medium	High
Prefire consideration			
Total biomass, tons/acre	3 to 10	11 to 30	31 to 45
Available fuel, tons/acre	3 to 6	6 to 10	10+
Dead fuel, pct. of available	20 to 30	31 to 40	41+
Live fuel moisture, percent	90 to 76	75 to 60	59 to 45
Chemical content	Low	Medium	High
Season	Spring	Winter and early spring	Summer, fall, early winter
Slope, percent	0 to 19	20 to 40	41 to 70
Aspect	N, NE	E, SE, NW, W	S, SW
Burn date consideration			
Windspeed, mi/h	0 to 4	5 to 8	9 to 12
Dead fuel (fuel stick) moisture percent when chaparral is:			
20 to 30 percent dead	12 to 9	8 to 6	5 to 3
31 to 45 percent dead	18 to 12	11 to 7	6 to 5
46 to 65 percent dead	20 to 15	14 to 9	8 to 6
66 to 100 percent dead	30 to 19	18 to 11	10 to 8
Desired relative humidity percent when fuel is:			
20 to 30 percent dead	35 to 26	25 to 18	17 to 15
31 to 45 percent dead	45 to 36	35 to 24	23 to 18
46 to 65 percent dead	60 to 41	40 to 31	30 to 25
66 to 100 percent dead	75 to 41	40 to 36	35 to 20
Desired air temperature, °F	20 to 59	60 to 80	81 to 95
Time of day	Early morning	Late morning or late afternoon	Midday to midafternoon

Sometimes, prescribed burns are conducted as early in the morning as fuels will burn so as to complete the burn or to burn out a safe line before the heat of the day. Such burns are facilitated by low nighttime relative humidities (Philpot 1965). In some localities near the coast, the movement of maritime air determines the time of day for burning.

THE PRESCRIPTION

Information in the previous discussions can be summarized and made more convenient for use by listing the recommendations in a table. This has been done for chaparral in table 1, and for burning under oak or pine tree canopies in table 2.

Before a burning prescription can be developed, the piece of brushland under consideration must be evaluated to determine the prescribed burning prospects. If most elements for prefire consideration fall in the medium intensity range (table 1), the area is probably right for burning. An approximate date can be selected and local weather monitored as the date approaches. If most elements are in the low intensity range, consideration should be given to (1) delaying the burn for a few years, (2) applying desiccants or crushing treatments to dry out the brush, or (3) compensating by burning when windspeed, dead fuel moisture, relative humidity, and air temperature are in the high intensity range during the late fall or winter.

If the elements for prefire consideration are mostly in the high intensity range of table 1, some cautions are in order. If the total biomass and available fuel fall under "high" intensity, if the dead fuel comprises 40 to 60 percent of all that will burn, and if the burn is on a steep southerly exposure, consideration should be given to burning during late winter or early spring when the green fuel moisture has risen and when the extractable chemicals are not at a peak. Also, burning when dead fuel moisture is greater than 10 percent, when relative humidity less than 30 percent is not expected, when maximum air temperatures will not be higher than 60° or 70° F (15° to 21° C), and when windspeeds are 0 to 5 mi/h (0 to 8 km/h) will contribute to safe burning.

Brush grows among oak trees at all elevations, and among coniferous trees at the higher elevations. If the canopies are open, as mature pine trees may be, there will be brush and tree reproduction under the crowns, and perhaps stair-stepped into them. If tree branches are dense and brush the ground, as oak branches frequently do, brush under the canopies may be low in volume and mostly dead, but brush from outside will surround the trees and finger into the canopies.

In the mixed-conifer forest, prescribed burning can be accomplished readily when there is a good needle fall, where there is bearclover (*Chamaebatia foliolosa* Benth.), or in openings where herbaceous plants form a continuous cover. Flame heights can usually be kept to 3 ft (1 m) or less, and out of tree canopies.

Burning under and around oak canopies without damaging crowns is usually difficult (Green 1980). Hand pruning of lower branches may be needed. Bulldozers can sometimes be used to push brush away from trees, or a dozer can crush brush for burning during late winter or spring. The actual burning must be done with a low-intensity fire (table 2).

Table 2--Prescription elements for burning under pine or oak tree canopies.

	Fire intensity		
Factors affecting fire intensity	Low	Medium	High
Fuel that will burn, tons/acre	1 to 2	3 to 5	6+
Proportion of fuel that is dead, pct.	15 to 25	25 to 30	31+
Dead fuel moisture, percent	18 to 12	11 to 7	6 to 5
Live fuel moisture	85 to 76	75 to 60	59 to 50
Relative humidity, percent	60 to 41	40 to 31	30 to 25
Windspeed, mi/h	0 to 2	3 to 4	5 to 10
Air temperature	20 to 39	40 to 70	71 to 85
Time of day	Morning	Late morning or late afternoon	Midday to midafternoon
Fuel arrangement	Crushed or cut	Beneath tree canopies	Brush extends up into tree canopy

LITERATURE CITED

Bentley, Jay R.; Green, Lisle R.; Evanko, A. B. Principles and techniques in converting chaparral to stable grassland in California. Proceedings of the X International Grassland Congress; 1966; Helsinki, Finland: X Int. Grassi. Congr. Sec. 4, Paper 14; 1966; 55-59.

Bentley, J. R.; Talbot M. W. Efficient use of annual plants on cattle ranges in the California foothills. Washington, D.C.: U.S. Dep. Agric.: 1951; Circ. 870. 52 p.

Countryman, Clive M. Heat and wildland fire--part 1. The nature of heat. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.; 1977. 11 p.

Countryman, Clive M.; Dean, William A. Measuring moisture content in living chaparral: a field user's manual. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1979; Gen. Tech. Rep. PSW-36. 27 p.

Ford-Robertson, F. C. (ed.). Terminology of forest science, technology practice and products. Washington, D.C.: Soc. Amer. For.: 1971; Multilingual Forestry Terminology Ser. 1. 349 p.

Green, Lisle R. Prescribed burning in California oak management. Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of California oaks, June 26-28, 1979, Claremont, California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. PSW-44; 1980; 136-142.

Green, Lisle R. Burning by prescription in chaparral. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981; Gen. Tech. Rep. PSW-51. 36 p.

Martin, Robert E. Fire manipulation and effects in western juniper (*Juniperus occidentalis* Hook.). Proceedings of the Western juniper ecology and management workshop, January 1977, Bend, Oregon. Portland, Oreg.: Pacific Northwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. PNW-74; 1978; 121-136.

Montgomery, Kenneth Reid. Ether extractives and flammability of Mediterranean-type shrubs. Pomona, Calif.: Calif. State Polytechnic Univ.; 1976. 38 p. Dissertation.

Northwest Region, Forest Service. Crooked River national grasslands begins prescribed burning program. Fuel Manage. Notes 1(7): 1-2. 1973.

Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture. Guidelines for fuel-breaks in southern California. Fuel-Break Rep. 9. Berkeley, Calif.; 1963; 25 p.

Parsons, David J. Preservation in fire-type ecosystems. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. USDA Forest Serv. Gen. Tech. Rep. WO-3; 1977; 172-182.

Pase, Charles P.; Granfelt, Carl Eric, tech. coords. Use of fire on Arizona rangelands. Fort Collins, Colo.: Rocky Mountain Forest and Range Exp. Stn.; Arizona Interagency Range Committee: 1977; Publ. 4. 15 p.

Paysen, Timothy E.; Derby, Jeanine A.; Black, Hugh, Jr.; Bleich, Vernon C.; Mincks, John W. A vegetation classification system applied to southern California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Tech. Rep. PSW-45. 33 p.

Philpot, Charles W. Diurnal fluctuation in moisture content of ponderosa pine and whiteleaf manzanita leaves. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1965; Res. Note PSW-67. 7 p.

Philpot, C. W. Seasonal changes in heat content and ether extractive content of chamise. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1969; Res. Paper INT-61. 10 p.

Philpot, C. W. Influence of mineral content on the pyrolysis of plant materials. For. Sci. 16(4):461-471; 1970 April.

Rothermel, Richard C. A mathematical model for predicting fire spread in wildland fuels. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1972; Res. Paper INT-115. 40 p.

Rothermel, R. C. Forest fires and the chemistry of forest fuels. In: Thermal uses and properties of carbohydrates and lignins. New York, San Francisco: Academic Press; 1976: 245-259.

Schroeder, Mark J.; Buck, Charles C. Fire weather--a guide for application of meteorological information to forest fire control operations. Washington, D.C.: U.S. Dep. Agric.: 1970; Agric. Handb. 360. 229 p.

Shafizadeh, F. Pyrolysis and combustion of cellulosic materials. Adv. Carbohyd. Chem. 23:419-474; 1968.

U.S. Department of Agriculture, Forest Service. Fireline handbook. Washington, D.C.; 1975.

Wright, Henry A.; Bunting, Stephen C. Prescribed burning in the Rio Grande plains. Noxious brush and weed control. In: Research highlights, Vol. 7. Lubbock, Texas: Texas Technol. Univ.; 1976: 42.

Fire Management and Vegetation Effects in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

David J. Parsons[2]

In order to develop and implement an effective fire management program in fire-prone environments it is necessary to understand both the fire history of the area and the effects of fire on the local biotic communities. It is also necessary to clearly identify the objectives of the program. Once such information is available it is possible to implement a fire management program that accomplishes the desired objectives. This may include the use of prescribed burning and/or natural ignitions, together with any of a variety of physical or biological manipulations.

The papers in this session present examples of both the types of input needed in the development of fire management programs for mediterranean climate ecosystems as well as selected examples of the implementation of such programs. While they by no means represent a complete analysis of the situation they do constitute a representative cross-section. The papers by Keeley and by Radtke, Arndt and Wakimoto deal with the question of fire history on a large and small scale, respectively. Both papers focus on the importance of the local vegetation in determining fire frequency and burning pattern. The paper by Minnich deals with the additional problem of the effect intense grazing has had on altering both the present vegetation and recent fire history. Trabaud adds an international perspective with his analysis of the history of man's use of fire and its effects on the vegetation in the mediterranean region of France. Vélez carries this approach a step further by detailing the development of multi-faceted fuel management programs in the mediterranean ecosystems of Spain. Finally, Green describes in detail the guidelines needed to implement a prescribed burning program in southern California chaparral.

The first problem which must be faced in the development of a fire management program is the identification of management objectives for the area. In mediterranean climate ecosystems this is especially important in that the dominant vegetation types are commonly recognized as highly flammable and having evolved with periodic fire (Mooney and Conrad 1977). Examples of the types of management objectives that must be distinguished between include fuel hazard reduction (Biswell 1977, Green 1977), preservation of naturally functioning ecosystems (Parsons 1977, 1980), promotion of conditions favorable to wildlife (Hendricks 1968, Lillywhite 1977), increasing water yield (Hill and Rice 1963) and the elimination or maintenance of specific vegetation types or plant species (Kayll 1974). These objectives are often mutually exclusive. Which one is chosen will influence both the type of program to be adopted and the details of how it is implemented.

In developing a fire management program it is essential to understand the ecological role of fire in the area of concern. This includes an understanding of the effects of fire (including different intensities, seasonalities, and frequencies of burning) on survival, reproduction and succession of the local vegetation. It also includes an understanding of present and past fire history.

Keeley's paper "Distribution of lightning and man-caused fires in California" looks, on a regional level, at recent burning patterns and compares' them to that occurring under "natural" conditions. Keeley analyzes the distribution of lightning and man-caused fires during the 1970 decade in relation to latitude, distance from the coast, time of year, elevation, acreage and fuel type. This represents the most complete effort to date to summarize data on the present fire regime in California. Keeley recognizes, however, the difficulties in extrapolating data on present lightning fire frequency to represent "natural" conditions (he defines "natural" as being "prehistorical"). This is due to the fact that man now extinguishes many fires before they get very large, as well as setting other fires; thus altering considerably the fuel conditions potentially available to burn in lightning fires. This problem could be somewhat alleviated for at least some vegetation types by defining "natural" as referring to "presettlement" conditions (as has been done by the U.S. National Park Service who includes aboriginals as part of the natural scene), Keeley's approach is only exacerbated in those areas with longer periods of human occupation and consequent vegetation modification (Naveh and Dan 1973). In such conditions, or whenever long term fire history records are needed, fossil charcoal or pollen analysis may be the best hope for documenting ancestral fire history (Swain 1973, Byrne et al. 1977).

Radtke, Arndt and Wakimoto's paper "Fire history of the Santa Monica Mountains" deals with the problem of documenting fire history for a relatively localized area. In addition to surveying historical accounts and more recent fire records, the authors focus on those factors influencing fire history and behavior. A careful analysis of local patterns of vegetation, topography, climate and land use in relation to ignition sources, together with case studies of specific fires provide a good understanding of the conditions under which different types of fires occur. This approach is of considerable value in understanding

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Scientist, Sequoia and Kings Canyon National Parks, Three Rivers, California.

local fire behavior and predicting future burning patterns. It is of more limited value in elucidating historical or prehistorical fire frequencies or patterns. Unfortunately it is difficult to use standard fire history techniques for shrub and herb communities (Parsons 1981).

When land management practices greatly alter the vegetation of an area the historical role of fire can change significantly. Minnich deals with this problem in his paper "Grazing, fire, and the management of vegetation on Santa Catalina Island, California." In this case grazing by feral animals has denuded the vegetation to such an extent that fires will generally not carry except in ungrazed grasslands. The problem thus becomes one of what would happen to the vegetation and fire potential should the feral goats and pigs be removed. Should this proposal be carried out, Minnich recommends a management program of using prescribed burning to develop a mosaic of community types and age classes. This should reduce the potential of destructive wildfires while returning to a more natural vegetative mosaic. It would also serve the desired function of protecting the watershed. Similar problems are faced in many heavily grazed Mediterranean climate ecosystems (Naveh and Dan 1973).

Trabaud's paper "Effects of past and present fire on the vegetation of the French Mediterranean region" adds an international perspective to the study of fire history and effects. Trabaud reviews the history of man's use of fire in southern France and how it led to the degradation of much of the area's landscape. He discusses in some detail the adaptations of various French mediterranean species to fire as well as post-fire succession in the *Quercus coccifera* garrigue following different frequencies and seasons of burning. This type of detailed information on the effects of varying fire regimes on species composition, cover and biomass is essential to being able to predict the effects of a fire management program. The methodology presented (see also Trabaud 1977) provides a useful model for fire effects studies anywhere.

Vélez's paper "Fire effects and fuel management in Mediterranean ecosystems in Spain" focuses on the development and implementation of a multifaceted fuel management plan. Based on the objective of protecting the forests from destructive wildfires, the program focuses on means of fuel reduction. These include physically removing or chipping slash fuels, building fuel breaks, type conversion, grazing, encouraging hygrophytic species and using controlled fire. Much of the intent is to develop and maintain mosaics of species, age classes, biomass and flammability that will serve as fuel breaks. The program recognizes fire as an important evolutionary factor. It also recognizes that an understanding of flammability and fire adaptations of the important species is essential to developing an effective fire protection program. Research is being carried out in conjunction with the management program on the effects of fire on soils, vegetation succession and regeneration and refinement of prescribed burning techniques to achieve desired results. The paper also investigates possible economic uses of slash chips for particle board and briquettes for fuel. Such economic spinoffs may be of increasing value in future years.

The development and refinement of burning prescriptions (temperature, humidity, wind, fuel characteristics, fire types etc.) to achieve specific management objectives requires considerable experience and experimentation. Green's paper "Prescribed burning in the California mediterranean ecosystems" summarizes many years of data collected for prescribed burns in southern California chaparral and mixed-conifer forests. He presents recommended prescription ranges for low, medium and high intensity fires for such elements as fuel volume, dead-to-live fuel ratio, live and dead fuel moisture, chemical content, time of year, topography, wind, relative humidity, and air temperature. While the data presented are for southern California the general approach is valid for any fire management program. The specific values must be refined for the management objectives and vegetation of the area of concern. Green's paper should be of considerable value as a model to be followed in developing prescriptions for other areas.

The papers presented in this section represent selected examples of the types of information required to develop a fire management program. They do not, nor are they intended to cover all aspects of fire history or vegetation effects studies either available or required for any fire-prone area. Regardless of objectives, such a program requires an understanding of past and present fire regimes (frequency, periodicity, ignition source, seasonality, intensity etc.) as well as the effects of fire on the local vegetation. Such an understanding requires detailed research which must be closely tied to the areas management program.

LITERATURE CITED

Biswell, H. H. Prescribed fire as a management tool. In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977; 151-161.

Bryne, R., Michaelsen, J. and Soutar, A. Fossil charcoal as a measure of wildfire frequency in southern California: a preliminary analysis. In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977; 361-367.

Green. L. R. Fuelbreaks and other fuel modification for wildland fire control. U.S. Dept. Agric., Agric. Handb. 499; 1977; 79 p.

Hendricks, J. H. Control burning for deer management in chaparral in California. Proc. Tall Timbers Fire Ecology Conf.; 1968; 8:219-233.

Hill, L. W., Rice, R. M. Converting brush to grass increases water yield in southern California. J. Range Manage.; 1963; 16(6):300-305.
Kayll, A. J. Use of fire in land management. In Kozlowski, T. T. and C. E. Ahlgren (Eds.). Fire and Ecosystems. Academic Press, New York; 1974; 483-511.
Lillywhite, H. B. Animal responses to fire and fuel management in chaparral. In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977; 368-373.
Mooney, H. A. and Conrad, C. E. (Tech. Coords.). Proceedings Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977; 498 p.
Naveh, Z. and Dan, J. The human degradation of Mediterranean landscapes. In DiCastri, F. and H. Mooney (Eds.). Mediterranean Type Ecosystems: Origin and Structure. Springer. Heidelberg, Germany; 1973; 379-390.
Parsons, D. J. Preservation in fire-type ecosystems. In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977; 172-182.
Parsons, D. J. The role of fire management in maintaining natural ecosystems. In Proc. Conference Fire Regimes and Ecosystem Properties. USDA Forest Service Gen. Tech. Report WO-26; 1980.
Parsons, D. J. The historical role of fire in the foothill communities of Sequoia National Park. Madroño; 1981; 28(3):(in press).
Swain, A. M. A history of fire and vegetation in northern Minnesota as recorded in lake sediments. Quat. Res.; 1973; 3:383-396.
Trabaud, L. Comparison between the effect of prescribed fires and wild fires on the global quantitative evolution of the Kermes scrub oak (*Quercus coccifera* L.) garrigues. In Proc. Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA Forest Service Gen. Tech. Report WO-3; 1977. 271-282.

The Use of Fire in Silviculture[1]

Pierre Delabraze and Jean Ch. Valette[2]

Abstract: In the French mediterranean area the use of fire, practiced in the past by the farmers, is now being reactivated by the forest managers. It relies on the flammabilities of the most important species and on the combustibilities of the main vegetal associations. The first prescribed burns demonstrate the sensitivity of forest trees and the role of dead material and wind. The results of these tests lead also to a better evaluation of fire risk and to organization of the clearings.

During the last century, the maintenance of chestnut plantations to make harvest easier, of pinelands to reduce fire risk and damage, and of pastureland to get rid of ungrazed grass, was carried out by means of small winter prescribed burns. This method was nearly completely given up as a consequence of the exodus from rural areas. In forests under the authority of the state and the departments, prescribed burning was not accepted as a forestry technique. Currently the use and even the introduction of fire in forest areas have been banned for fear of fire outbreaks. Owners are given impairments from October 15 to April 1.

The decrease in fire danger (outbreaks and especially spread) is related to the clearing of underbrush. The four techniques: clearing by hand or machine, use of weed-killers, use as pasturelands, and prescribed burning are scientifically compared in order to present a set of efficient and often complementary methods to the managers.

To deal with prescribed burnings, the Mediterranean Sylviculture Center of the I.N.R.A., Forest Research Department, has developed research in order of urgency established after consultation with the forest managers. Dealing first with forecasting of fire danger, the research has led to study of the silvicultural possibilities of fire along these lines:

– flammability of the main species of forest trees, in order to determine the risks of fire outbreak and to understand their development

– combustibility of the main forest associations, to define the risks of fire spread

– combustibility of the forest litter responsible for both the outbreak and spread of fires

- use of data gathered through these investigations, in order to perfect the prescribed burning methods.

FLAMMABILITY OF FOREST SPECIES

Principle of Measurement

The flammability of a vegetal sample is calculated according to the time necessary for appearance of flame when the sample is subjected to a fierce heat radiation.

Apparatus and Method

Experimental Apparatus

A radiator sends out a flux of about 7 watts per square centimeter and 3 microns wavelength. The pilot flame allows the ignition of the air-gas mixture resulting from the thermic decomposition of the sample, but it does not play any part in this decomposition.

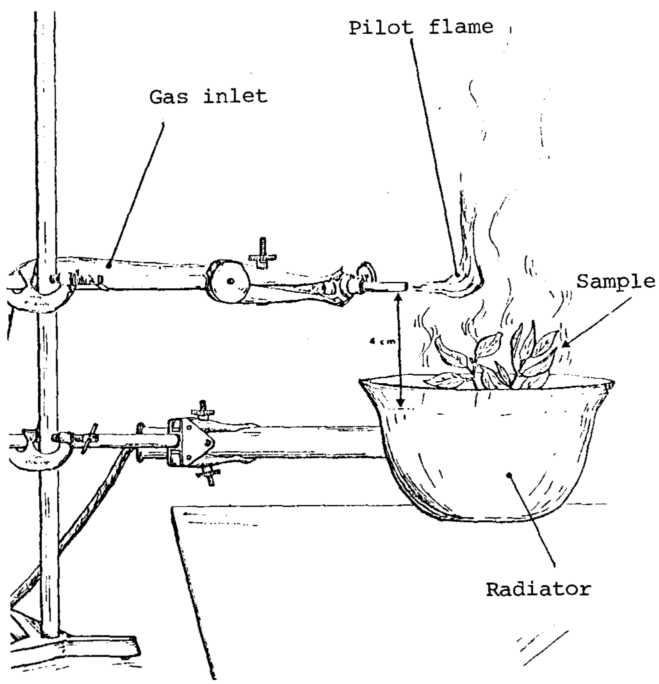


Figure 1--Flammability measurement apparatus.

[1]Presented at the symposium on Dynamics and Management of Mediterranean-type Ecosystems June 22-26, 1981, San Diego, California.

[2]I.N.R.A. Station de Sylviculture Mediterraneenne Avenue A. Vivaldi - 84000 AVIGNON.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The Fuel (table 1)

Only the flammability of the fine elements of the main forest species is measured, as these elements cause the fires.

Experimental Checklist and Significant Data

For each studied species, the monthly periodicity of testing is reduced to 10 days when the fire danger increases, generally in the summer time.

Picked according to very precise criteria on homogeneity, the 200 or 300 grams of green matter required for a specific test are put into tight bags under partial vacuum and then placed in a cooling-box; thus the water-loss is reduced to a minimum during transport. A specific test is composed of 100 basic tests made in three running series. Each 1-gram sample is put on the heating disk. The time between the moment when the sample is set in place to the appearance of the first flame is recorded. The test is positive if the time is less than 60 seconds.

Then for each specific test these values are calculated:

– the percentage of positive tests

– the mean flammation time, averaging the flammation times of the positive tests, expressed in seconds

– the mean moisture content, averaging the moisture contents of the four samplings, expressed as a percent of the ovendry weight (24 hours at 60°C).

The close relation between the percentage of positive tests and the mean flammation time have made a scale of flammation possible. (table 2)

Results

Species can be classified at regular intervals according to their flammability. Table 1 makes clear that the flammability is:

– grossly linked to plant physiologic activity; very low or close to null at the time of bud burst, it increases with the time of new tissue lignification and reaches a maximum at the time of summer dormancy

– temporarily influenced by rainfall or the air moisture content; specific reactions take shape--the pluviometry, and more precisely the amount of water stored in the soil, bring about wide variations in flammability.

Use of the Results

Knowledge of the specific flammabilities leads to:

- defining the fire outbreak risks and above all their sudden aggravation and their territorial distribution

- making seasonal maps of fire danger, from the forest associations maps, which should give a sufficiently accurate account of the flora composition of the various stories.

Table 1--Specific flammabilities during the fire danger period

Studied species	Flammability		
	July	August	September
Calcareous Provence			
Tree story			
Pinus halepensis	4 4 4	4 4 4	4 4 4
Quercus ilex	4 4 4	5 4 4	4 4 4
Quercus pubescens	5 5 5	5 5 5	5 5 5
Shrub story			
Quercus coccifera	0 2 3	4 3 4	4 4 3
Phillyrea angustifolia	1 4 4	5 5 5	5 4 4
Rosmarinus officinalis	2 3 4	5 5 5	3 3 3
Cistus albidus	2 3 3	5 4 2	2 3 2
Thymus vulgaris	4 3 5	5 5 4	4 4 5
Herbaceous story			
Brachypodium ramosum	- 4 5	5 5 5	5 5 5
Crystalline Provence			
Tree story			
Pinus pinaster	3 3 3	1 2 2	3 3 3
Quercus suber	4 5 4	5 4 5	5 5 4
Shrub story			
Erica arborea	2 4 4	4 4 4	4 4 3
Erica scoparia	4 4 4	4 4 4	4 4 4
Arbutus unedo	0 1 3	2 2 3	1 1 1
Cistus monspelliensis	2 3 3	3 3 2	2 1 0
Calluna vulgaris	3 4 3	4 4 3	3 2 3

Table 2--Flammability marks levels as a function of the percent of positive tests and the mean flammation time

Mean flammation (time seconds)	Percent of positive tests					
	98 to 100	95 to 97	90 to 94	85 to 89	80 to 84	80
less than 12.5	5	4	3	2	1	1
from 12.5 to 17.5	4	3	2	1	1	0
from 17.5 to 22.5	3	2	1	1	0	0
from 22.5 to 27.5	2	1	1	0	0	0
from 27.5 to 32.5	1	1	0	0	0	0
more than 32.5	1	0	0	0	0	0

The forester in charge of forests threatened by fires is given the decision elements to rank his intervention:

- on areas of species which are highly flammable or dangerous owing to sensitive surrounding plantations

– on bushy and low-branching plants such as Pinus halepensis, with its dead lower verticils, covered with dry needles, which come nearly in contact with the high calorific potential associations of Ulex parviflorus, Quercus coccifera, and Brachypodium ramosum

– last but not least, when he uses prescribed burning.

COMBUSTIBILITY OF FOREST ASSOCIATIONS

Principle

First restricted to the low bush associations, the study of combustibility is based on a re-planting of the various vegetal stories, from the litter to the bush, on a combustibility measurement apparatus, and consists in recording the data of the combustion.

Apparatus and Method

The Combustibility Measurement Apparatus (figures 2 and 3).

The litter and collected vegetation are laid on identical surfaces on eight trucks, each 1 square meter by 25 centimeters. The moving walls act as the surrounding vegetation by protecting the fire from external agents (wind) and by reflecting the heat; a top screen simulates the tree canopy. The variable thread blade fan allows creation of wind at speeds ranging from 5 to 40 meters per second.

Fuel

The study deals with these main forest associations:

Calcareous Provence	Crystalline Provence
Quercus coccifera	Arbutus unedo
Ulex parviflorus	Erica raborea
Rosmarinus officinalis	Cistus monspelliensis
Quercus ilex	Calluna vulgaris

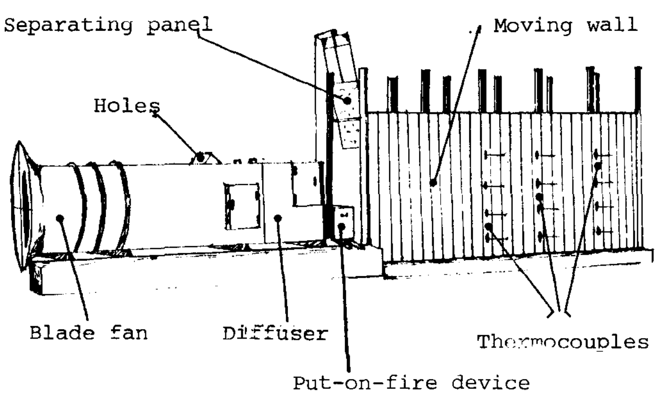


Figure 2--Combustibility measurement apparatus (outside).

Test Phases and Data Collected

The vegetation and litter are both gathered from homogeneous and representative associations on eight aligned and continuous plots, each 1 square meter. Before each sampling a sketch of the plant layout on the soil is drawn, along with a description of the phenologic stages and of respective measurements and weight. The crop and all the following processes are preceded by measurements of the air temperature and moisture content and of the wind speed and bearing. Transport is carried out under cover. The plants are planted out on the apparatus according to the sketches. A detailed checklist states the fire ignition conditions. During the burning, the fire rate of spread and the flame front characteristics are recorded. At the end of the test, the unburnt plants are measured and weighed.

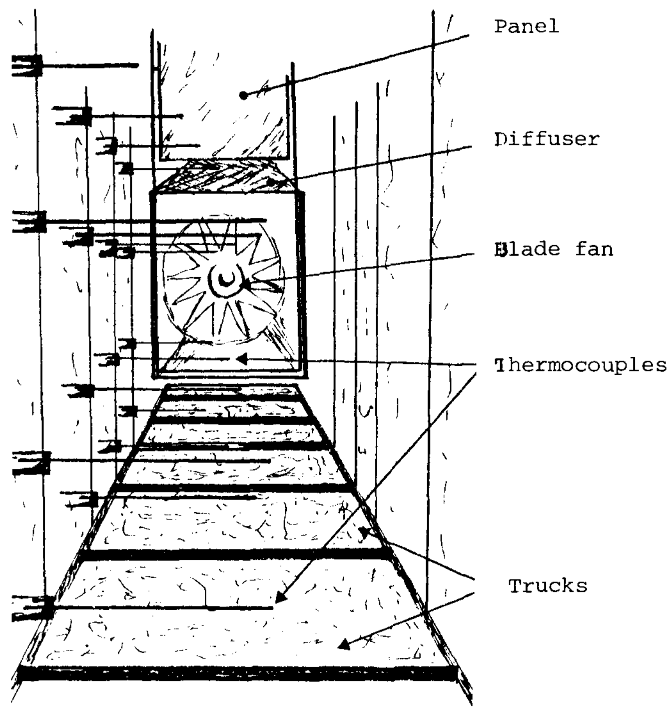


Figure 3-- Combustibility measurement apparatus (inside).

Results (table 3)

The litter plays a determining part because of the surface dead fuel. Fire has great difficulty in spreading when the litter is missing, even if the living fuel is at its lowest moisture content. Only the surface of dead fuel burns when it is bulky; when it is abundant and light it encourages the fire spread. The fire rate of spread is negatively linked with the litter moisture content--hence the propitious consequences of a light rainfall.

The herbaceous story transmits the fire from the litter to the shrubby story. Its phenologic stage and its abundance affect fire spread more by its high flammability than by the released energy. The graminaceae that dry out in summer are the more dangerous; some of these turn green again after the first storms of late summer.

The rain brings about a quick change in combustibility. It increases the moisture content of the litter and leads to a new start of the vegetative activity. In summer, 50 percent of the tests in which fire covers the 8 meters of the apparatus are in samples taken more than 10 days after the last rain; on the other hand, 85 percent of the tests whose combustion stops within the first meters of the apparatus have been on samples taken less than 10 days after a rain.

Wind speed and rate of fire spread are positively linked to one another. The increase of the flame length and the width of the flaming area the flaming front incline on the combustible explain it.

Fire spread is linked with the plant structure: for the same biomass, an effective low bulk density increases combustibility owing to the large heat-absorbing surface and to the possible ventilation inside the fuel.

Use of the Results

The combustion of the low story vegetation is correctly modelled on the apparatus:

– the flame front specific energies are calculated according to Byram's formula from the vanished combustible mass, its moisture content, fire rate of spread, and knowledge of the heat release

– the energy radiated by the flame front is inferred from study of its development and of the measured temperatures (adaptation of the Stephan-Blotzmann formula)

– also, the biomasses and the laws of their development are drawn from these tests.

DEAD MATERIAL COMBUSTIBILITY

Principle of Investigation

Currently, dead fuel combustibility is only studied on leaves or needles picked on trees, desiccated, and then laid out by hand in regular layers.

Apparatus and Method

Experimental Apparatus (figure 4)

Table 3--Combustibilities of the main forest associations

Forest Associations	Combustibility
Calcareous Provence	
Quercus coccifera	Good in summer, poor in autumn
Ulex parviflorus	Excellent in summer, existent in winter
Rosmarinus officinalis	Poor
Quercus ilex	Similar to Q. coccifera
Crystalline Provence	
Arbutus unedo	Poor
Erica arbora	Excellent in summer,
Cistus monspelliensis	Excellent in case of summer drought
Calluna vulgaris	Good in summer

A fuel bed (86 x 58 x 6 centimeters) rests on scales (15.00 $\pm$ 1.5 grams). Eight thermocouples (Nc-Na), one above the other, and a fluxmeter are connected to recorders. A photographic apparatus records the combustion.

Studied Species

Material is harvested in autumn from branches of Pinus nigra Arn. ssp laricio, Pinus pinaster Soland, Pinus halepensis Mill, Cedrus atlantica Manetti.

Fuel

It has these characteristics:

– surface/volume ratio of the leaf or the needle, expressed as

$$= \frac{2}{e} \text{ or } = \frac{2\,(+2)}{e}$$

where e = thickness of leaf or needle

– initial mass

– moisture content, expressed as a percent of ovendry weight

– dry material initial mass

– bulk density, , in grams per centimeter

Results

Dried needles of Pinus nigra laricio

$= 4.7\ mm^{-1}$ $= 1.8\ 10^{-2}\ g.cm^{-1}$

All the combustion data of the tests made in horizontal position are positively related to the initial ovendry mass from a threshold of steady rate of spread on 3.6 t/ha. The most accurate fittings are linear and the correlation coefficients are superior to 0.9.

When the fire moves upwards, from a 20° slope, the fire spread laws are totally altered. The fire spreads up the slope very fast, burning only the upper layer of the dead fuel.

The tests made with fires moving downwards give results which can be compared with those made on a flat position, yet the slopes of the regression lines are lower.

Dried needles of <u>Pinus</u> <u>pinaster</u>

= 2.7 mm^{-1} = 2.10^{-2} $g.cm^{-3}$

The characteristics of the combustion of this dead fuel are akin to those obtained with needles of <u>Pinus</u> <u>nigra</u> <u>laricio</u>. The slopes of the regression lines are not significantly different whereas the ordinates at the origin are slightly superior.

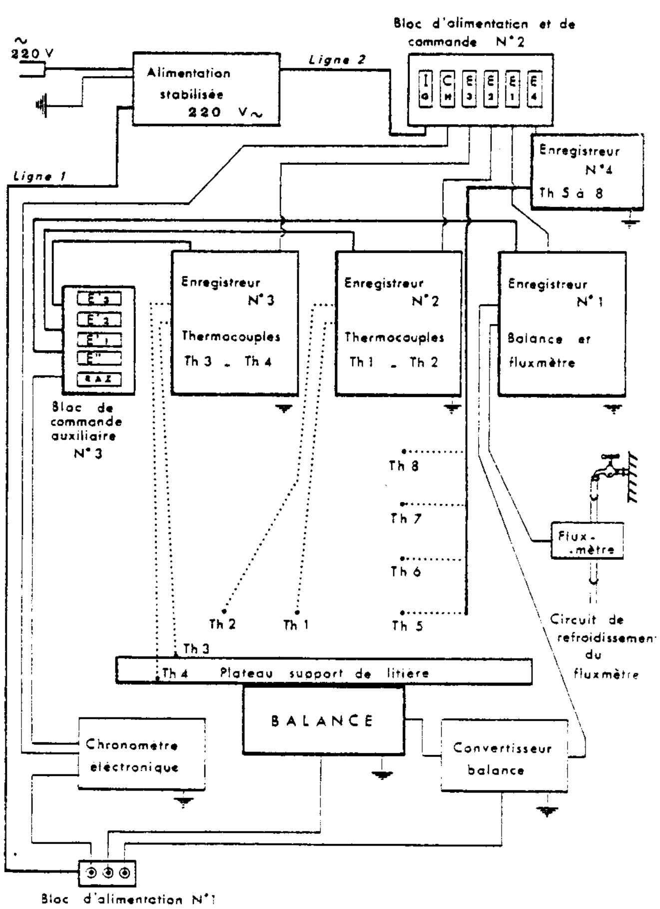


Figure 4--Diagram of the apparatus for measuring the dead material combustibility.

Dried needles of <u>Pinus</u> <u>halepensis</u>

= 6 mm^{-1} = 3.3 $.10^{-2}$ $g.cm^{-3}$

The fire rate of spread threshold is close to 1.8 t/ha. All the data are related to the initial ovendry mass, yet the slopes of the regression lines are significantly lower than those of the two aforementioned pine trees.

Dried needles of <u>Cedrus</u> <u>atlantica</u>

= 33.10^{-2} $g.cm^{-3}$

Achieving a continuous carpet requires the equivalent of 5 t/ha. Even for the highest values the fire does not spread.

HIGH CALORIFIC VALUES, ASH AND MINERAL CONTENTS

The data allow an accurate estimation of the energy released during the combustion.

<u>The High Calorific Value</u>

Determining this allows us to calculate the potential energy of forest combustibles and the maximum heat release. Measured every month according to the classical calorimetry method, the H.C.V. are comparatively lower during growing time than after lignifying time. The H.C.V. of <u>Erica</u> <u>arborea</u> is higher than the values given for most of the tree species (table 4). The H.C.V. of mediterranean species are generally superior to those of more northern species. As for the building material, no link between the H.C.V. and the specific flammabilities has been clearly shown.

<u>Ash and Mineral Contents</u>

Determined every month by decomposition at 450°C in a muffle furnace, the ash contents are low during growing time and higher after lignifying time. The ash content of the <u>Arbutus</u> <u>unedo</u> leaves is double that of the ash content of the <u>Erica</u> <u>arborea</u> leaves, whose Ca content is very similar to the Ca content of the <u>Ulex</u> <u>parviflorus</u> shoots (table 4).

The study did not show any clear link between these contents and the characteristics of combustion.

THE PRESCRIBED BURNINGS IN FRENCH MEDITERRANEAN AREA

Widely used in the past, the prescribed burning method is nowadays only used by a few shepherds in Corsica and some peasants in the Maures and Cevennes Mountains.

Table 4--Specific high calorific values, ash and mineral contents

Fuel	H.C.V. (kJ.g^{-1})	Contents				
		Ash	P	K	Mg	Ca
		(percent ovendry weight)				
Leaves of *Erica arborea*	24.0	2.42	0.07	0.49	0.23	0.30
Needles of *Pinus halepensis*	22.2	3.20	0.11	0.50	0.15	0.63
Shoots of *Ulex parviflorus*	20.9	2.34	0.08	0.62	0.13	0.37
Leaves of *Arbutus unedo*	21.0	4.15	0.10	0.61	0.27	0.99
Leaves of *Quercus ilex*	20.3	4.05	0.09	0.50	0.15	0.96
Leaves of *Quercus coccifera*	20.0	4.20	0.07	0.53	0.14	1.22

Aims

The tests on prescribed burnings are intended to define the rules of use according to the climatic, relief, and soil conditions and to improve knowledge of the reaction of forest tree species to the various types of prescribed burning.

Plotting Out and Method

Each test area is delimited by a surrounding cleaned area, gridded with posts to make marking and measurement easier to determine.

– importance, nature, and qualities of the dead fuel and of the various vegetation stories

– measurements of the trees where thermosensitive plates are set

– microclimatic conditions

– fire ignition conditions, flame front spread, development of flames on trees, and reactions of the various species

– aspect of the ground and conditions prevailing there after the test.

Later, the restoration and new setting up of vegetation will be observed with interest (table 5).

The prescribed burns are generally made against the wind or at counterslope.

Table 5--Scale for obvious fire damages

Obvious damages	Scale
No damage	0
Over 2/3 of the initial leaf mass are green	1
From 1/3 to 2/3 of the initial leaf mass are green	2
Less than 1/3 of the initial leaf mass is green	3
Some green leaves	4
No green leaves	5

Results (table 6)

These tests being on the whole quite recent, the results are only provisory.

From the first investigations, the following points can be noted:

– large damages to the tree story in tests 3, 8 and 9, which were made at the bottom of the slope on account of an adverse wind

– satisfactory aspect of tests 4 and 7, ignited at counterslope, and of tests 1, 2 and 6, which were made against the wind: the low stories are well burnt back and trees are spared

– the high combustibility of *Quercus ilex* and of *Pinus halepensis* foliage and the relative endurance of needles of *Pinus pinaster*.

Prescribed burning can only be correctly carried out

– if the wind direction is well established and if its speed is low and steady

– if the dead fuel or herbaceous layer is continuous enough to guarantee a steady rate of fire spread

– if the fuel on the ground is dry enough

– if the low verticils of trees are more than 2 to 4 meters above the low story.

Conclusions

These first tests show that planted firebreaks or trimmed bushes of *Quercus pubescens* covering a graminaceous grassland can be maintained, that there are maintenance problems in planted firebreaks where there are no resinaceous species, owing to a scarce litter, and that there are limits to the use of prescribed burning in forested areas as soon as the mattoral (maqui and garrigue) are fully grown.

PUBLICATIONS OF THE CENTER ON THESES SUBJECTS

Caramelle Ph., Clement A., 1978 - Inflammabilite et combustibilite de la vegetation mediter- raneenne. Flammability and combustibility of the mediterranean vegetation. (3rd year thesis E.N.I.T.E.F., July 1978, 158 p.)

Delaveaud, P., 1981 - Le feu, outil sylvicole. Utilisation pratique des donnees de combusti- bilite. The fire as a sylvicultural technique; practical use of combustibility data. (3rd year thesis E.N.I.T.E.F., July 1981, to be published.)

Doat, J.; Valette, J. Ch., 1981 - Le pouvoir calorifique superieur d'especes forestieres mediterraneennes. High calorific value of mediterranean forest species. Ann. Sci. For., to be published.

Valette, J. Ch.; Clement, A.; Delabraze, P., 1979 - Inflammabilite d'especes mediter- raneennes. Flammability of some mediterranean species. (Research note 79-3, Mediterranean Sylviculture Center, 39 p.)

Valette, J. Ch,; Vannier, G., 1981 - Inflamma- bilite estivale des principales especes forestieres de Provence calcaire. Summer flammability of the main forest species of calcareous Provence. To be published.

Table 6 --First tests of prescribed burnings

Number of test	1	2	3	4	5	6	7	8	9
Place of test	Var	Permian mark	Maures Crystalline Provence			Ht Var	Alpilles Calcareous Provence		
Type of Plantation	mixed forest		mixed forest		Planted Fire breaks				
Tree storey Before the fire	*Pinus pinaster* and *Pinus halepensis* 5 to 10 m.high Pruned to 2.5 m. Dormant		*Pinus pinaster* and *Quercus ilex* 3 to 10 m. high unpruned Dormant		*Quercus Suber* 3 to 5 m. Pruned Dormant	*Quercus Pubescens* 4 to 5 m. Pruned Dormant	*Pinus halepensis* 4 to 8 m. *Quercus ilex* 2 to 4 m. Pruned to 2 m. Dormant		
Immediately after the fire	Low verticils turning yellow		Destruction of trees Ø 7 and less	low verticils turning yellow	no damage	no damage	Verticils turning yellow		
Six months later	turning green again death rate 2.5 to 3 m.	death rate 2.5 to 5 m.	Partial turning green	" " " "			turning green again		
Upper shrub storey Before the fire	Missing		*Erica arborea* and *arbutus unedo, calycotoma spinosa* Numerous 2 to 4 m.	1 to 2m.	Sparse	Missing			
Immediately after the fire			Destruction total	Partial					
Six months later			Some shooting	partial turning green					
Lower shrub storey Before the fire	Missing		*Genista pilosa*		Missing	Missing	*Quercus coccifera*		
Immediately after the fire			total destruction				total loss of leaves		
Six months later			no turning green				growing shoots		
Herbaceous storey	dry graminaceous carpet		sparse graminaceous		Missing	thick carpet	thick carpet of brachypode		
Immediately after the fire	totally destroyed		total disparition			totally destroyed	Totally destroyed		
Six months later	total turning green		some signs of turning green			total turning green	total turning green		
Dead fuel Before the fire	abundant,made of dried needles graminaceae				Missing	dried leaves	Dried needles and graminaceae		
Immediately after the fire	totally destroyed					burnt to 75 %	burnt to 75 %		
Six months later	Building up by dried needles fall Partial		Partial	low		no reconstruction	Partial building up with dried needles		
Prescribed Burning Type	Successive lines	Simultaneous lines	moving upwards	moving downwards	moving downwards	against wind	moving downwards	moving upwards	Successive Lines
Plot relief	Flat	Flat	5° slope	5° slope	10° slope	Flat	5° slope	10° slope	10° slope
Fire Rate of Spread (m/h)	45	200	37	17	—	60	12	60	60
Conclusion	Highly Satisfactory	Satisfactory	Un Satisfactory	Satisfactory	—	Highly Satisfactory	Highly Satisfactory	Not So Satisfactory	Not So Satisfactory

Predicting Fire Behavior in U.S. Mediterranean Ecosystems[1]

Frank A. Albini and Earl B. Anderson[2]

Abstract: Quantification and methods of prediction of wildland fire behavior are discussed briefly and factors of particular relevance to the prediction of fire behavior in Mediterranean ecosystems are reviewed. A computer-based system which uses relevant fuel information and current weather data to predict fire behavior is in operation in southern California. Some of the difficulties encountered in attempts to isolate model and data deficiencies are described.

Recurrent wildland fires are common to those areas of the world that enjoy Mediterranean climate (McCutchan 1977). Because these areas are relatively populous, they present a particular challenge to the wildland manager who would use fire as a tool in ecosystem management or who seeks to minimize the undesirable consequences of wildland fires. The challenge of fire management in Mediterranean ecosystems is made more stringent by the flammability of the native vegetation and the frequent occurrence of long periods of severe burning conditions (Philpot 1977). These factors combine to intensify the need for and value of the ability to predict the behavior of wildland fires. Timeliness of such predictions is of paramount importance; indeed, the character of a system designed to satisfy the needs for fire behavior prediction and fire control dispatching assistance in southern California was dictated by the time constraints under which it must perform (Van Gelder 1978).

Quantifying Fire Behavior

Wildland fire behavior can be described quantitatively by measures of the rate of fire growth, its energy release, the distance over which it can be expected to spawn new fires (to "spot") remote from its present site, and the likelihood that it will consume or propagate in the crowns of the overstory forest if it burns in such. Free-burning fires tend to maintain geometrical similarity under constant fuel and burning conditions,[3] so projections of perimeter and area can be based on the forward rate of spread. The energy released per unit area burned is proportional to the quantity of fuel per unit area (fuel loading). The product of spread rate and the energy release per unit area gives the fireline intensity--or Byram's intensity--as the energy release per unit time per unit length of fire edge (Byram 1959). Another measure of intensity is the heat release per unit burning area per unit time, called "reaction intensity" by Rothermel (1972). The potential spotting distance is probably proportional to flame height (Albini 1979, 1981a) and thus to fireline intensity[4] (Nelson 1980; Albini 1981b). In this paper we shall not address the burning of tree crowns.

These considerations suggest that fire behavior can be described using three quantities: forward rate of spread, fuel loading (or heat release per unit area), and reaction intensity. Fireline intensity is the product of spread rate and heat release per unit area, and is roughly proportional to flame height and potential spotting distance. Flame length is roughly proportional to the square root of the fireline intensity (Byram 1959; Nelson 1980; Albini 1981b). Reaction intensity can be used to gauge the vigor of burning for prescribed fire planning.

Methods of Predicting Fire Behavior

Fire behavior can be predicted by any of three methods, each with unique merits and shortcomings:

1. One may draw upon personal experience in similar situations. This method is always instantly available and is the first and last resort of every experienced field firefighter. But although experience is the best teacher, it is also the slowest and most expensive. And the transfer of this capability from one individual to another is both difficult and error-prone. While firsthand experience is actively to be sought and experienced judgment ever to be respected, this means of prediction cannot be the sole resource for today's fire manager because it is a perishable and poorly shared commodity.

2. Experience may be captured for use by others through inferential (or statistical) models. Fire

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, Calif.

[2]Mechanical Engineer, Intermountain Forest and Range Experiment Station, Missoula, Mont., and Operations Research Analyst, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif., respectively, both with Forest Service, U.S. Department of Agriculture.

[3]Personal communication from Hal E. Anderson, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Missoula, Mont., January 1981.

[4]Nelson gives a formula for flame height under wind influence that can be interpreted as proportional to fireline intensity or its square root.

behavior in similar situations can then be calculated by the inexperienced through observation of indicator variables such as windspeed, temperature, humidity, fuel type, etc. This technique is in principle cheap and simple to apply, and it represents a compact means of sharing experience. The unique deficiency of this approach stems from the great number of variables that influence fire behavior and the fact that chance observations must form a large part of the data set. This is so because extrapolation beyond the range of the data base supporting an inferential model is not valid and may lead to large errors. So, if severe fire behavior is to be predicted, it must be measured and correlated to its causative variables, in whatever combinations opportunity provides. The fact that one may not control any substantial number of these variables makes it unlikely that such models of broad applicability will ever come to be. Where such models exist and span important ranges of fire behavior, they should be exploited. But at present the realm of our combined experience, as captured in quantitative form, does not offer us the option of assembling the models needed to span the wide range of fire behavior experienced in Mediterranean ecosystems.

3. A third alternative for predicting fire behavior is the assembly and use of a mathematical model that rests mainly on well-established laws of physics. Several such models have been proposed. While none of them are sufficiently general to handle the entire spectrum of wildland fire behavior, Rothermel's semi-empirical model (1972) has been mechanized (Albini 1976) and widely applied. It describes the behavior of fires in a variety of wildland surface fuels with gratifying consistency (Andrews 1980). The strength of this approach lies in the flexibility and growth capability and especially in the opportunity it affords to make use of controlled test data to improve important empirical components of the model (Wilson 1981). Such virtues, however, are of little value to the practical user if he must make lengthy computations. The complexity of the model renders it inscrutable and thus suspect; its demand for input data makes it tedious to apply; some data are unfamiliar but the model is sensitive to them, leaving the user unsure of the validity of the results.

Automating Fire Behavior Prediction

If the user of fire behavior predictions need not supply input data yet is supplied with prompt results, the difficulties just described can be largely circumvented and the mathematical model used as an aid to strategic and tactical fire control decisionmaking. Automation of calculations and maintenance of a machine-readable data base are needed to achieve this. Automated fire behavior prediction as part of the southern California FIRESCOPE system will be described in general terms below.

We shall show the sensitivity of fire behavior predictions to some fuel and environmental inputs in order to outline the minimal requirements that the automated data base must meet. We shall restrict attention to fuel communities typical of Mediterranean climate wildlands. We shall describe how the FIRESCOPE fire behavior data base is derived and maintained. Examples of system performance will be given and we shall describe efforts to test the reliability of the fire behavior predictions that are now possible.

FACTORS AFFECTING FIRE BEHAVIOR

Factors that affect the behavior of a wildland fire can be classified broadly as either environmental or fuel properties. Fuel properties can be described as intrinsic (i.e., the physical properties of the fuel matter) or extrinsic (i.e., the amount, arrangement, and physical condition of the fuel). While the model is indeed sensitive to intrinsic fuel properties and seasonal variation of them is likely (Philpot 1969), the range over which these properties vary is small enough that they may be considered to be constant for present purposes. So the principal variable factors affecting fire behavior in Mediterranean ecosystem wildlands are environmental and extrinsic fuel properties.

Extrinsic Fuel Properties

Fuel quantity is described in terms of dry weight per unit plantform area, or fuel. loading. For annual grasses and perennial shrubs, fuel loading is in approximate proportion to the height of the vegetation for any particular site. So fuel loading may vary seasonally and with stand age, but the compactness (or "packing ratio") of the fuelbed often may be considered to be a characteristic of the fuel species (or mix of species) and the number of plants per unit area. The relative behavior of wildland fires in such fuel complexes, as affected solely by fuel loadings, is shown in figure 1.

Rate of spread, reaction intensity, and flame length are proportional to fuel loading (for constant packing ratio), while fireline intensity varies quadratically with loading, all other things being invariant. This sensitivity is typical of the standing fuel complexes with which we are concerned here, but is not universally true for wildland fuels. Forest litter and harvest debris, for example, exhibit such strong dependence of packing ratio upon loading that the generalization of figure 1 does not apply to them. And forest understory growth, desert shrub stands, and bunch grasses lack the uniformity necessary to apply this simple rule even approximately.

The Mediterranean climate exempts wildland vegetation from hailstorms, snowpack, and ice buildup, so dead foliage and small stems may persist on standing shrubs for many years and dead grasses or forbs may not lodge for several seasons. So the relative abundance of live and dead fuel components

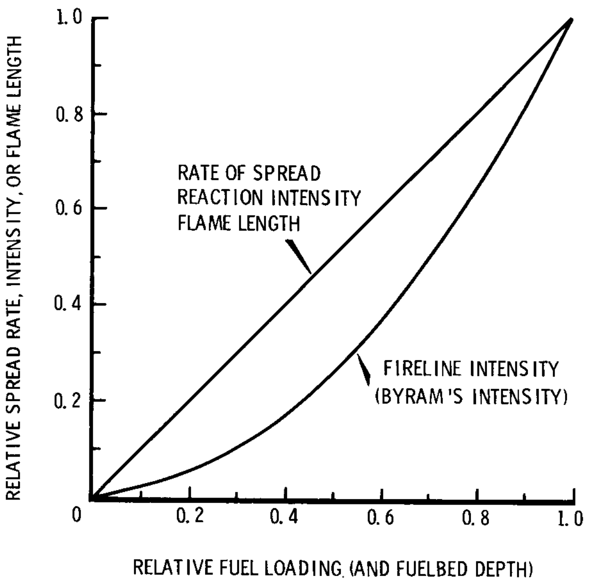


Figure 1--The effect of fuel loading on behavior of fire (fuelbed depth is assumed to be proportional to fuel loading).

may vary with stand age and season (Rothermel and Philpot 1973). Any given region in a Mediterranean climate zone may include sites with greatly different live-dead fuel loading proportions.

Sensitivity of predicted fire behavior to fraction of fine fuel loading that is live is shown in figures 2 and 3. The hypothetical fuel complex used to derive these curves consisted of particles identical in every respect except that the dead particles were kept at 4 percent moisture content and the live particles at 50, 100, or 150 percent. The surface/volume ratio of the particles was assumed to be 2000 ft^{-1} (66 cm^{-1}). It was further assumed that the "moisture of extinction" (Rothermel 1972) of the dead fuel was constant at 20 percent. That is, if the dead fuel moisture were raised to 20 percent it would not support a spreading fire. This parameter is thought to be a property of the fuelbed as an entity, not an intrinsic property of the fuel material.

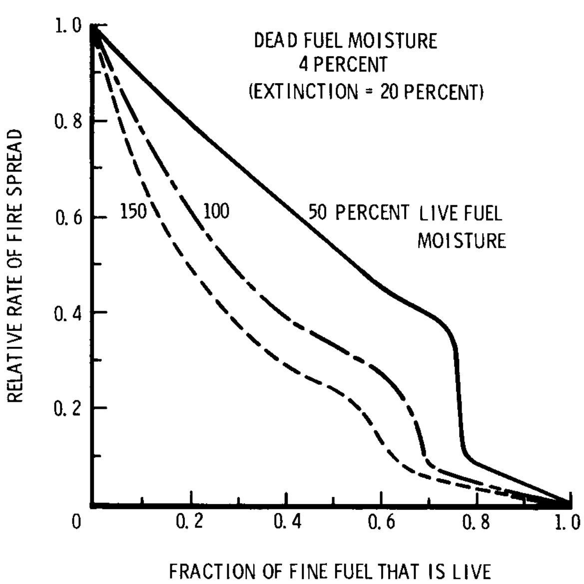


Figure 2--The effect of live-dead proportions on rate of spread of fire.

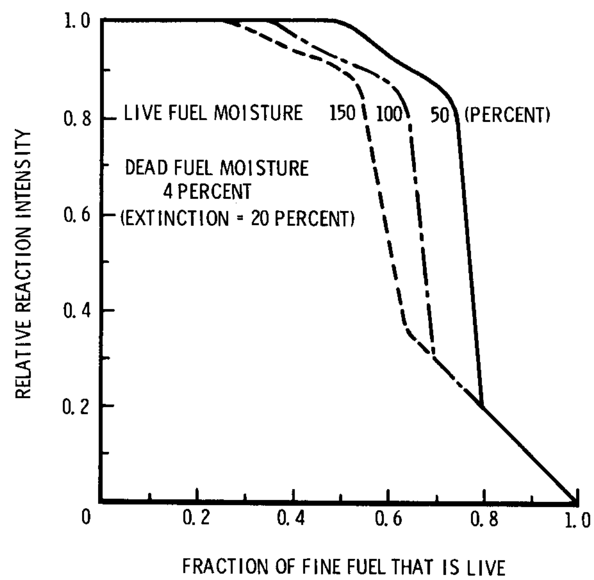


Figure 3--The effect of live-dead proportions on reaction intensity of fire.

Figure 2 shows that rate of spread (and so fireline intensity) decreases with increasing live fuel fraction, with a sharp decline at some large live fuel fraction. The model predicts that, at this critical live-dead loading ratio, the live fuel no longer contributes to the release of energy in the fire front. This feature is exhibited much more strikingly in figure 3, which shows the variation of reaction intensity with live fuel fraction. Although this transition point prediction is probably the most weakly-supported relationship in the fire behavior model, it fortuitously gives results that are in good agreement with field experience in southern California chaparral.[5]

---

[5]"There are several factors which affect fire behavior that can be evaluated prior to the burn date. The most important of these is the proportion of fuel that is dead.... If less than 20 percent of the brushfield is dead fuel, burning efforts are nearly always futile. If about one third of the fuel is dead, and other factors are favorable, we should have a good burn. If half or more is dead, conservatism in the use of other burning variables is necessary, or another Marble Cone wildfire situation would exist." - Lisle R. Green, Chaparral Research and Development Program (Riverside Fire Laboratory), Chaps Newsletter, December 1980, p. 1.

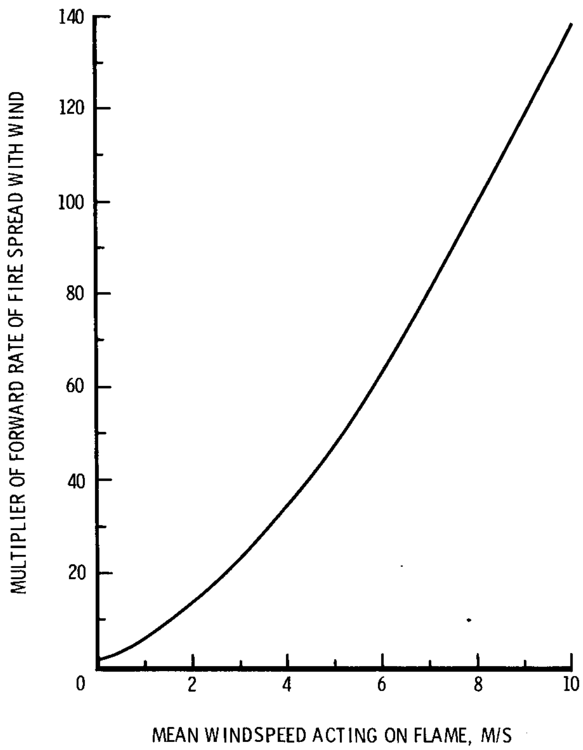


Figure 4--The effect of wind on rate of spread.

Environmental Factors

Wind, terrain slope, and fuel moisture content are the environmental variables that must be specified to the fire behavior model. Terrain slope must be archived to a spatial resolution consistent with the anticipated use of the model, but can be considered for present purposes to be a site-dependent constant. Windspeed, wind direction, and fuel moisture are subject to great temporal variability. These volatile and important factors impose stringent demands on the process for maintenance of a timely data base for fire behavior prediction.

Mediterranean climate zones are prone to occasional winds of great force during their long, dry burning seasons, as well as nearly daily land and sea breezes (McCutchan 1977). The great sensitivity to windspeed of spread rate--and hence fireline intensity--is illustrated in figure 4. Rate of spread increases by more than 2 orders of magnitude as the windspeed acting on the flame goes from zero to 10 m/s. It is apparent that a modest error in windspeed can give rise to a serious misprediction of fire behavior.

To construct figure 4, a fuelbed of particles with surface/volume ratio of 2000 ft^{-1} (66 cm^{-1}) was assumed, with an "optimum" packing ratio that maximizes the wind-insensitive reaction intensity. This is not a "conservative" assumption, because southern California chaparral fuels often exhibit packing ratios (Rothermel and Philpot 1973) which increase their windspeed sensitivity beyond that displayed in figure 4. For a packing ratio equal to half the "optimum" value, the spread rate ratio of figure 4 would increase by about 30 percent.

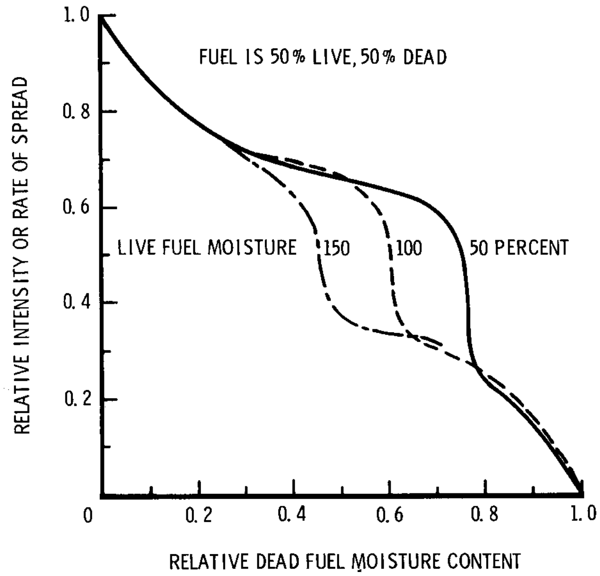


Figure 5--The effect of fuel moisture content on rate of spread and fire intensity.

The long, dry summer season of Mediterranean climates favors drought-resistant shrub species that exhibit live foliar moisture contents in the neighborhood of 50 percent toward the end of the dry season. But the flush of new foliar growth in early spring can raise the mean live foliar moisture to 150 percent or more. This is in stark contrast to the relatively slight seasonal variation of live foliar moisture common to understory vegetation of more moist temperate climates (Hough and Albini 1978) and conifer foliage in even cold climates (Philpot and Mutch 1971; Van Wagner 1977). In addition to this seasonal variation expected in live fuel moisture, fine dead fuel can exhibit large and rapid changes in moisture content, in response to the wide swings in humidity that occur (usually twice daily) in coastal areas.

Sensitivity of spread rate and reaction intensity to fuel moisture are nearly identical, as shown in figure 5 for a hypothetical fuelbed made up of equal parts live and dead particles of 2000 ft^{-1} (66 cm^{-1}) surface/volume ratio. Dead fuel moisture content is represented in figure 5 by its value relative to the "moisture of extinction" mentioned earlier. The precipitous drop in intensity corresponds, as before, to the loss of a heat release contribution by the live fuel components.

The factors discussed above represent the most important data variables that must be maintained if prompt prediction of fire behavior is to be attempted for fuel communities typical of Mediterranean climate wildlands. Each factor imposes a different spatial and temporal resolution requirement on the data gathering and maintenance elements of the FIRESCOPE system, as it must on any similar system.

THE FIRESCOPE SYSTEM

Ultimately, the FIRESCOPE predictive fire behavior modeling system will incorporate 3 levels of sophistication. The simplest model is called southern California FIREMOD and is used by dispatchers and fire managers to predict first-hour, free-burning fire behavior characteristics (i.e., rate of spread, fireline intensity, and potential size in acres) based upon inputs such as fuel type (mixed brush, chamise, or grass), fuel age, fine fuel moisture, slope, and windspeed. A second level of suppression-oriented operational modeling couples fire behavior characteristics with fire suppression information and results in a "probability of successful containment and control" prediction given a designated suppression resource dispatch to a fire site. Each of these two levels assume elliptical fire shapes to provide estimates of area burned within specific time intervals. The most sophisticated level of modeling is for large "campaign" fires and will provide expected fire perimeter locations over a long fire period, taking into account suppression actions and using information such as airborne infrared data to update or reinitialize the computation process.

In the ultimate system, these models will operate from a common computerized data base having terrain and fuel characteristics (age and type) stored and retrievable through an appropriate coordinate system. Inputs with seasonal and/or diurnal variations would be calculated as needed, using information supplied from a remote automated weather station network. Completion of the ultimate FIRESCOPE system is not expected for several years since considerable effort is still required to establish the data bases, integrate the models, and evaluate the system operationally.

Prototype Evaluation

During the past several fire seasons, prototype models of the first 2 levels were made available and evaluated in southern California. Evaluation of the prototypes included examination of the input-output data formats, assessment of data requirements, and estimates of the utility of the predictions. The prototype structure, though limited in fidelity, provided some indication of the problems which would require solution prior to implementation of the final operational system. Unfortunately, field evaluation of the prototypes was not as simple or clean as imagined earlier by the system developers.

Field use of FIREMOD began with establishment of an Operations Coordination Center (OCC) in Riverside, Calif., for use by southern California fire agencies involved in the FIRESCOPE program. When a fire would occur within the jurisdiction of a given agency, the dispatch office of that agency would call in the necessary input information to the OCC which in turn would access the computer and calculate a fire behavior prediction for the requesting agency. Followup was limited to subsequent discussions between the OCC and the fire agencies that commented on the utility of the predicted fire behavior information in relation to what actually occurred in the field. With the initial prototype FIREMOD, discussions with the field indicated that the predicted fire behavior was accurate enough to be useful about 50 percent of the time.

A more controlled evaluation was conducted with the midlevel system. An experimental model, called the Experimental Initial Attack Evaluation Program, was developed by the Mission Research Corporation (Sanderlin and Sunderson 1976), and modified into a midlevel prototype by the USDA Forest Service. This was later renamed the Initial Attack Assessment (IAA) Program. During the 1978 fire season the San Bernardino National Forest, USDA Forest Service, and the San Bernardino Ranger Unit, State of California, Department of Forestry, participated with the FIRESCOPE Program Office, Riverside, Calif., in an operational evaluation of the IAA. The procedure involved identifying fuel type, fuel age, and slope from maps available in the agency dispatch office using coordinates or landmark identification from the person reporting the incident to locate the fire site. Weather data, including windspeed, wind direction, temperature, and relative humidity, was that available from the weather station closest to the incident. These input data were available to the dispatcher, with verification of the fuel and slope characteristics possible only after arrival of the first firefighting resources.

Evaluation Results

Results from the early operational evaluation of the prototype models was disappointing because of many major differences between the predicted fire behavior and that observed at the fire site. A consistent and disturbing occurrence was the great difference in fire behavior predicted by FIREMOD and IAA. At this juncture, it appeared that a thorough reassessment of the prototype models, and how they were being used, was needed. Initial effort involved an orderly debugging of the computer programs followed by many runs of each model using "made-up" fire data to isolate inconsistencies and differences in the logic of the prototype models. After completion of these steps, some minor differences in output values remained because the formats of input field-level data and later conversions to common internal parameters varied between the models.

The simpler of the models, FIREMOD, was converted to account for the fact that in Mediterranean-type ecosystems under 10 years of age, the fuel usually consists of a grass/brush mixture (Rothermel and Philpot 1973). A simplifying assumption was made that for mixed fuel up to 2 years of age, a grass model would be used. For fuel ages from 3 to 10 years, linear combinations of the rates of spread, intensities, and flame lengths computed via the 2 different fuel models are used to represent the grass/brush mixture.

After adjustment of FIREMOD, fire incident data were rerun and comparisons of the model output with behavior values reported from the fires are shown in table 1. Reasons for the variations in most cases were traced to (a) lack of knowledge of the actual fuel carrying the fire (i.e., in some cases,

Table 1--Some comparisons of acres burned predictions vs. actual fire size.

Fire data	Fire date (1978)	Actual size (acres)	Predicted size[1] (acres)
		(1 acre = 0.4 Ha)	
Fuel: brush	9/21	2	4
Slope: 0-5 pct.	9/27	12	7
Age: 5-10 yr.	10/1	1	1
	10/13	7	30
Fuel: brush	9/23	220	100
Slope: 10-30 pct.	10/3	3	3
Age: 5-10 yr.	10/11	10	33
	10/12	90	400
	10/22	5	150
Fuel: grass	8/14	1	1
Slope: 0-5 pct.	8/22	1	4
Age: annual	8/23	4	32
	9/14	12	3
	9/28	5	1
	10/3	4	7.5
	10/24	2	2

[1]Calculated at time of control. Assumes a free-burning fire until time of control.

the fuel was identified as brush, but later discussions revealed the actual fire was carried by grass understory); (b) weather data were taken from stations distant from the fire area; and (c) topographical variations (e.g., the general area has a 30 to 40 percent slope while the actual fire was burning in a rather small local flat area), etc., (d) suppression actions not modeled; (e) natural barriers inhibiting fire growth.

It became obvious that further evaluation to establish the accuracy of the models through field evaluation would require more detailed knowledge of the actual fire conditions than was normally available in the dispatch offices of the evaluating units Our evaluation of IAA is being delayed until a more sophisticated data base and weather station reporting network is available. In the interim, the updated FIREMOD was used to assess fire potential in southern California during the 1980 fire season. Although written records of success ratio or accuracy were not kept, comments from users indicated that with accurate inputs (such as those transmitted to the OCC when first-in firefighting resources reached the fire) the model provided a reasonable assessment of fire potential 70 to 80 percent of the time.

Model Integrity vs. Input Data Accuracy

Attempts to evaluate the theoretical fire behavior models described above through operational or field-level experiment resulted in unclear definitions of the reasons for output inconsistencies. It is impossible, for the most part, to isolate the cause of output variations to either the accuracy or resolution of the input data, applicability of the model to the real world, or (in some cases) to errors which may have crept into the program during the implementation process. Even in the simplest model, FIREMOD, complex relationships between input data readily available to field personnel and internal model parameters exist (table 2). This makes it extremely difficult to evaluate which input variable is suspect when deviations are noted between predicted and actual fire behavior characteristics. Further "fine tuning" of models used in the FIRESCOPE system would require a controlled evaluation program using trained observers at actual fires throughout the fire season. Also needed is a validated, computerized fuels data base coupled to a weather reporting network that would provide on-site windspeed and fuel moisture (or temperature, relative humidity, and previous rainfall) to a higher degree of resolution than is currently available. The minimum resolution needed is presently unknown.

CONCLUSIONS

The input demands of the fire behavior model used in the FIRESCOPE system impose 3 time scales for data maintenance:

1. Stand age must be maintained for each shrub field site in the domain of the system in order to infer fuel quantity from growth models. Stand composition, condition, and other site-specific factors must also be verified periodically.

2. Seasonal trends must be tracked and perhaps deviations from a long-term norm should be accommodated.

Table 2--Inference of fire behavior input variables for southern California FIREMOD prediction program.

Input variable	How variable is determined
Fuel loading	Fuel type and stand age, keyed to map. (Height of stand is age-dependent also.)
Live/dead ratio	Inferred from stand age.
Fine dead fuel moisture content	Entered by operator (usually assumed to be fixed by current data from the nearest weather station).
Live fuel moisture content	Calendar date used in standard seasonal profile.
Windspeed	Nearest weather station last available reading.
Terrain slope	Keyed to map location of fire, read from topographic relief map.

3. Temperature and humidity (which determine dead fuel moisture) and windspeed and direction must be updated at least frequently enough to accommodate diurnal variation, and more frequently when significant changes are anticipated.

The spatial resolution required of the data base depends upon the uniformity of fuel type, stand age, and condition, the amount and regularity of terrain relief, and the operational needs which the fire behavior model output is expected to fill.

Testing the reliability or accuracy of fire behavior predictions is subject to great uncertainty, not the least of which is that associated with validating the data base and the inferences drawn therefrom. Specifically, our operational experience in southern California indicates that:

1. Accurate assessment of the southern California fire behavior models will require controlled on-site evaluation by trained observers during actual fires.

2. Actual operational use of the fire behavior models must await completion of an accurate stored computerized data base accessible to the dispatcher through input of fire location coordinates.

Weather information will require considerable improvement in resolution through use of a sophisticated weather station network and computerized wind models to interpolate conditions to fire site locations.

LITERATURE CITED

Albini, Frank A. Computer-based models of wildland fire behavior: a users' manual. Ogden, Utah: Intermt. For. and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1976. 68 p.

Albini, Frank A. Spot fire distance from burning trees--a predictive model. Ogden, Utah: Intermt. For. and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1979; Res. Paper INT-56, 73 p.

Albini, Frank A. Spot fire distance from isolated sources--extensions of a predictive model. Ogden, Utah: Intermt. For, and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981a; Res. Note INT-309. 9 p.

Albini, Frank A. A model for the windblown flame from a line fire. Comb. and Flame (to be published). 1981b.

Andrews, Patricia L. Testing the fire behavior model. In: Robert E. Martin and others, eds. Proc. sixth conf. on fire and forest meteorology. Wash., D.C.: Soc. Am. For.; 1980; 70-77.

Byram, G. M. Combustion of forest fuels. In: Kenneth P. Davis, ed. Forest fire control and use. New York: McGraw-Hill Book Co.; 1959; p. 90.

Hough, W. A.; Albini, F. A. Predicting fire behavior in palmetto-gallberry fuel complexes. Asheville, North Carolina: Southeastern For. Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1978; Res. Paper SE-174. 44 p.

McCutchan, Morris H. Climatic features as a fire determinant. In: Proc. of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. Wash., D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. WO-3; 1977:1-11.

Nelson, Ralph M., Jr. Flame characteristics for fires in southern fuels. Asheville, North Carolina: Southeastern For. Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Res. Paper SE-205, 14 p.

Philpot, C. W. Seasonal changes in heat content and ether extractive content of chamise. Ogden, Utah: Intermt. For, and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1969; Res. Paper INT-61. 10 p.

Philpot, C. W.; Mutch, R. W. The seasonal trends in moisture content, ether extractives, and energy of ponderosa pine and Douglas-fir needles. Ogden, Utah: Intermt. For. and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1971; Res. Paper INT-102. 21 p.

Philpot, C. W. Vegetative features as determinants of fire frequency and intensity. In: Proc. of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. Wash., D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. WO-3; 1977:12-16.

Rothermel, Richard C. A mathematical model for predicting fire spread in wildland fuels. Ogden, Utah: Intermt. For. and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1972: Res. Paper INT-115. 40 p.

Rothermel, R. C.; Philpot, Charles W. Predicting changes in chaparral flammability. J. For. 11:640-643; 1973.

Sanderlin, J. C.; Sunderson, J. M. Users' guide, experimental and initial attack evaluation model. Santa Barbara, Calif.: Mission Research Corp. Rep. No. 7611-1-376; 1976.

Van Gelder, Randall J. FIREMANS--a fire management system simulation model for operational fire planning support. In: Proc. workshop/ symposium on simulation techniques in forest operational planning and control. Wageningen, The Netherlands. 1978:188-194.

Van Wagner, C. E. Conditions for the start and spread of crown fire. Can. J. For. Res. 7:23-34; 1977.

Wilson, Ralph A. A reexamination of fire spread in free-burning porous fuel beds. Ogden, Utah: Intermt. For, and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981 (to be published).

Research and Development for Improved Fire Prevention and Suppression in Rural Victoria[1]

James R. Barber[2]

Abstract: Victoria's wildfire problem results from a combination of extreme fire weather, highly flammable vegetation and people--on farms, in towns and around cities which often abut bushland or forest. The CFA administers an extensive volunteer fire service and supervises fire prevention activity in the community. It conducts applied research for improved fire prevention and develops vehicular design, communication and training to improve suppression capability.

This paper gives a broad brush presentation of the rural fire problem in Victoria, Australia, and some research and development being undertaken to reduce it.

Victoria (fig. 1), is the second most compact of the Australian States (22.8 mha--2.94 percent of the total) with a relatively high population (3,645,276--26.8 percent of the total). Its annual grassland fire danger period commences in December and extends through to April, although early rains of the Autumn "break" may decrease this period.

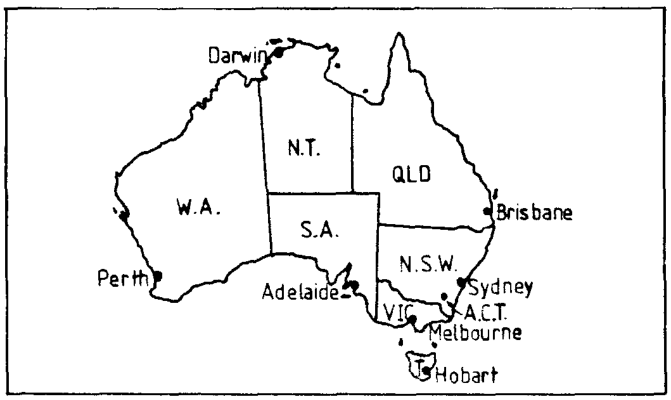


Figure 1--Australian States and Territories

The significance of wildfires in Victoria is established by the factual data of its fire history --the frequency and magnitude of fires, human fatalities, stock and property losses in a recurring sequence annually and in major proportions periodically. Some major fire occurrences:
1939 January. Most disastrous bushfires ever swept over three-quarters of the State. Deaths 71. Hundreds of homes, many towns, devastated.
1944 January 14. Three large fires in Western District joined after the south west change, 440,000 ha burnt. Damage $3m (1944). Heavy loss of life--15 people died within 25 km of one rural settlement (Foley 1947).
1969 January 8. A day of severe meteorological conditions though tempered by grasslands not being fully cured in many areas. 17 holiday makers lost their lives on one highway, total deaths 21. 1977 February 12. 11 large fires, majority in Western District. 5 lives lost. Other losses table 1--from CFA Records.

Table 1--Summary of Losses in Eleven Major Fires February 12, 1977.

Fire No.	Area Burnt (ha)	Capital Assets Destroyed: Sheep	Cattle	Bales Hay (000)	Houses	Other Bldgs	Fenc -ing (km)
1	1100	200	2	13	1	6	74
2	7300	11000	104	60	0	13	222
3	19410	42200	1291	301	13	159	910
4	3500	1700	113	1.4	5	3	105
5	22400	60000	748	356	38	100+	981
6	4500	3400	25	11.1	12	22	188
7	35300	72500	1067	417	19	n.a.	1434
8	1200	200	15	14.7	3	n.a.	68
9	1600	2000	0	21.8	0	n.a.	68
10	2600	1600	0	3	1	3	50
11	1700	40	0	0.3	1	4	43
Total	100610	194840	3365	1199	93	310+	4143
Estimated unit value ($000)		.012	.075	.001	[1]30.3	[2]10.0	1.25
Total value ($m)		2.34	0.25	1.20	2.79	3.10	5.18
Total estimated damage--$14.86 million							

[1]includes some allowance for contents
[2]includes some allowance for farm machinery

There are, however, many intangibles which must be considered in assessing total losses in rural fires, e.g., damage to pastures, disruption to breeding lines, loss of breeding potential in sheep.

FREQUENCY and DISTRIBUTION of fires are signifi-cant particularly in suppression strategy. Daily fire occurrences reported to the CFA during an average annual fire danger period are illustrated in figure 2. On January 8, 1969, CFA recorded 253 fires across the State whilst on February 12, 1977 60 fires (11 of major proportions) occurred. Mul-tiple fire occurrences strain resources and lines of communication and may require massive deployment of fire vehicles and volunteer crews.

Causes of wildfires are numerous. A major cause is associated with the use of fire--burning off excess vegetation and rubbish and the fire escapes (25-30 percent of total rural fires). Children with matches and overhead power lines clashing on days of high winds are also major contributors.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean--type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Chief Officer, Country Fire Authority, Victoria, Australia.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

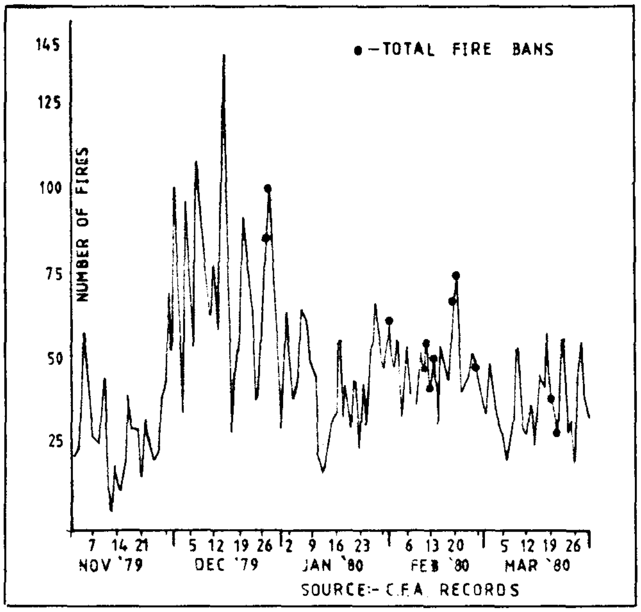


Figure 2--Number of fires reported to CFA Headquarters during months of high fire danger 1979-80.

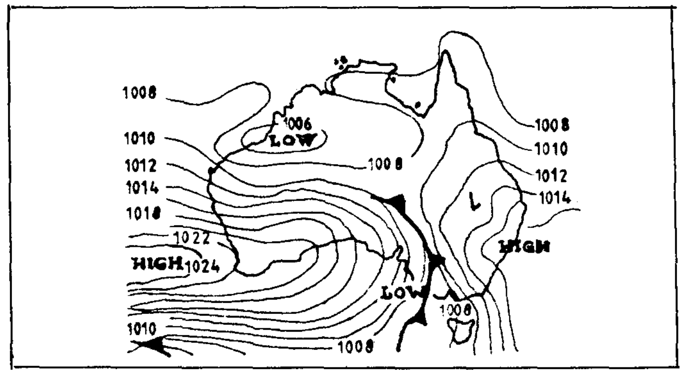


Figure 3--Synoptic Situation, Noon, December 22, 1980. High fire danger in Victoria. Hot northerly airstream over the State--wind NW, 25 km/h, 40 km/h. Highest Temperature 42°C; other places 40°C, 41°C. R.H. 10--13 per cent. Cold front entering Western Victoria--wind SW 25km/h, Gusts 50 km/h.

FACTORS CONTRIBUTING TO THE FIRE PROBLEM

Wind is generally the most important daily weather element governing the outbreak and spread of fires in Victoria. In the fire danger period with grassland vegetation fully cured, high temperatures (30°-40°C) and low humidities (20-10 percent) strong winds from most directions will result in a high incidence of fires with rapid rates of spread. Time since last good rain is a further factor. Strong dry gusty north to north west winds are the most dangerous. These winds, associated with the west to east passage of anticyclones south of latitude 20° followed by troughs of depression, are extremely hot and dry, bringing in air from the dry interior of the continent. Foley (1947).

As the cold front passes across the State the north winds back west to south west, creating turbulent conditions and causing breakaways from the eastern flanks of going fires. Cooler and more humid conditions, frequently with showers, follow and decrease the fire danger. Normally such extreme fire danger lasts less than 48 hours. However, a stationary anti-cyclone or "blocking high" may be located over the New South Wales coast causing fire weather in Victoria to persist for several days.

When extreme conditions are forecast the CFA Chief Officer, after consultation with the Forests Commission, may declare a total fire ban. Such Declarations prohibit the lighting of any fire whatsoever for the period of the ban. Figure 3 represents a total fire ban situation.

The mediterranean-type climate in southern Australia favours grassland vegetation having an annual life cycle as shown by Parrott (1964, Fig. 4.

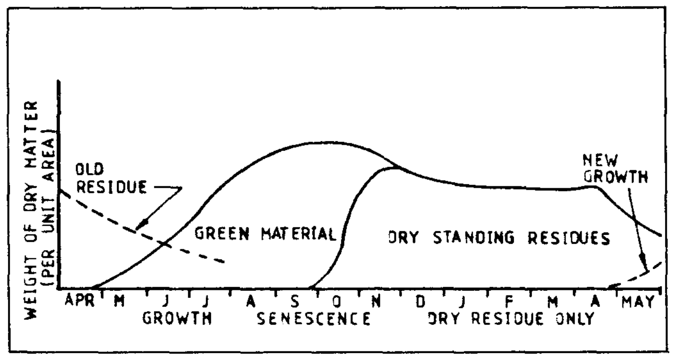


Figure 4--A generalised diagram of the life cycle of an annual sward at Adelaide S.A.--Parrott (1964).

Native grasses and pasture association of ryegrasses (*Lolium* spp) and clovers (*Trifolium* spp) are dominant in the improved pastures covering most pastoral areas, whilst *Phalaris* tuberosa also grows strongly. In non-irrigated areas average height (ungrazed) of ryegrass may be 40--44 cm, whilst clovers may reach 12--14 cm, with a representative average pasture density of 14.0 tonnes/ha (field weight). Grazed pasture would be less, depending on stocking rate. In most northern and some southern areas in Victoria, cereal crops are also grown, viz., wheat, oats, barley.

The decreasing moisture content of pastures and cereals during senescence (curing) is a significant factor in an approaching fire danger period as is fuel quantity with its influence on fire intensity. Luke and McArthur (1978).

In Victoria the relative intensity of farming practices, the population expansion in the outer urban/rural interface, proliferation of 2; 4-and 20-ha hobby farms and recreational activity create a high fire loss potential whilst the more closely settled areas experience increasing fire occurrences.

COUNTRY FIRE AUTHORITY ORGANISATION

The devastating fires of 1939 and 1944 caused significant changes in the attitudes of people and government to fire in Victoria. The CFA was established by Act of Parliament in 1944 based on recommendations from a Royal Commission, Stretton (1939). Since its inception the CFA has embodied research and development in fire prevention and suppression in the rural sector of Victoria.

An operational chain of command from individual rural and urban fire brigades to the Chief Officer, together with appropriate administrative sections, was established (fig. 5). Volunteer officers are in charge of most brigades and all groups, whilst permanent officers are in charge of regions and zones. 21 urban brigades are staffed by permanent officers (including 12 also with permanent firemen) to support the volunteers in large urban/industrial centres. Current strength:
215 urban brigades-- 6241 registered volunteers
1067 rural brigades--100820 registered volunteers
with 319 permanent operational personnel, 169 in various services and 60 in administration.

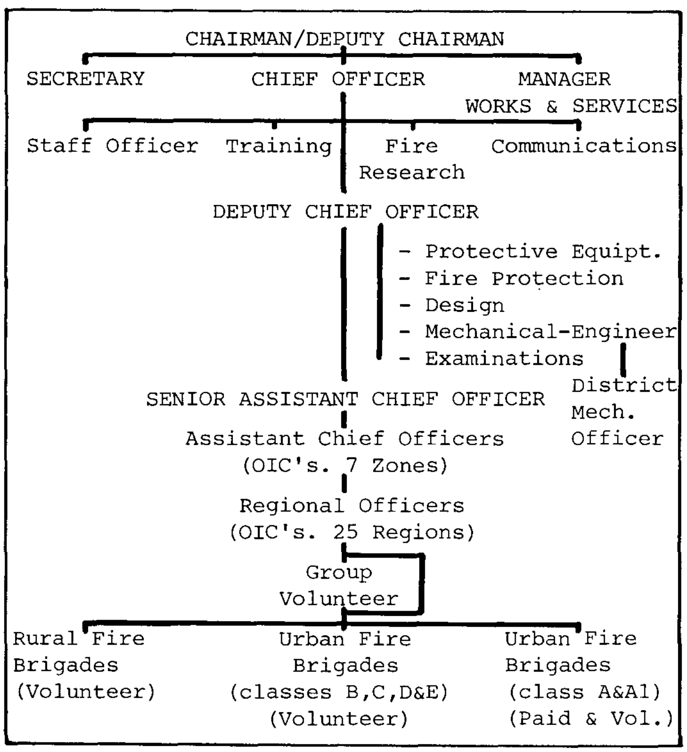


Figure 5--CFA Organisation

The CFA has established operational principles as guidelines for carrying out the AIM of the Authority, viz., the PREVENTION AND SUPPRESSION OF FIRES, with maximum efficiency. These are

MAINTENANCE OF THE AIM--a continuing function;
FORESIGHT--preplan for operations and support
SPEED--react to fires and give support with greatest possible speed (with safety)
FLEXIBILITY-- ability to react to new or unforeseen situations, requires holding a reserve;
SECURITY--for firemen, equipment and fire area;
ADMINISTRATION--backup support for operations;
MORALE--motivate brigades to increase efficiency;
MOBILITY--groups of radio equipped vehicles moving and deployed as a controlled force;
CONCENTRATION--have the right force at the right place and time--never "too little too late";
ECONOMY--use forces necessary for the operation but over ensure rather than under ensure;
CO-OPERATION--an automatic reflex for fire service;
COMMUNICATION --the flow of information--leaders require information for decision making.

The application of these principles is an essential feature of command in any successful fire fight and officers should learn to think in these terms.

RESEARCH IN FIRE PREVENTION

The philosophy of the CFA toward research is
. it is an important component of the Authority's duty under the Country Fire Authority Act 1958;
. rural research should be a primary objective;
. applied research should be carried out for direct benefit to the volunteer firefighter, the fire prevention planner and the general public.

Joint research arrangements with "outside" bodies avoids duplication of effort and combines expertise and facilities for mutual benefit.

The dissemination of research findings is an important function of the Research Unit. Training notes and articles are prepared for in-service use or incorporated in the Authority's fire prevention literature. Research papers are published.

Research Projects

(1) Fire Behavioural Studies: e.g., Maldon Fire, Central Victoria, December 26, 1980.

Cause--heated bearing from harvesting machine. Fuel--wheat crop, native grasses, clover (*Trifolium* spp), ryegrass (*Lolium* spp), pasture, light eucalypt woodland. Undulating topography with some steep hills and rock outcrops. Area dissected by creeks and eroded gullies made access difficult. Fire Behaviour--rapid fire spread up to 15 km/hr. One spot fire occurred ahead of main fire. Sudden westerly wind change without customary lull caused breakaways on eastern flank when gale force winds spread fire in long fingers from the main perimeter. Township endangered. Rapid deployment of a large number of firefighting vehicles--105 CFA and many private units--provided concentrated attack. Weather--30-40 km/hr winds from N-NW experienced during early stages of the fire, then wind change SW-S, T 40°, RH 16 percent.

Lessons learnt/confirmed--anticipating wind change and moving equipment to meet threat on eastern flank important. Green firebreaks on northern rural interface protects houses. Width of perimeter to be secured was considerably greater than that necessary for normal wind conditions. Burning trees near fire edge should receive particular attention.

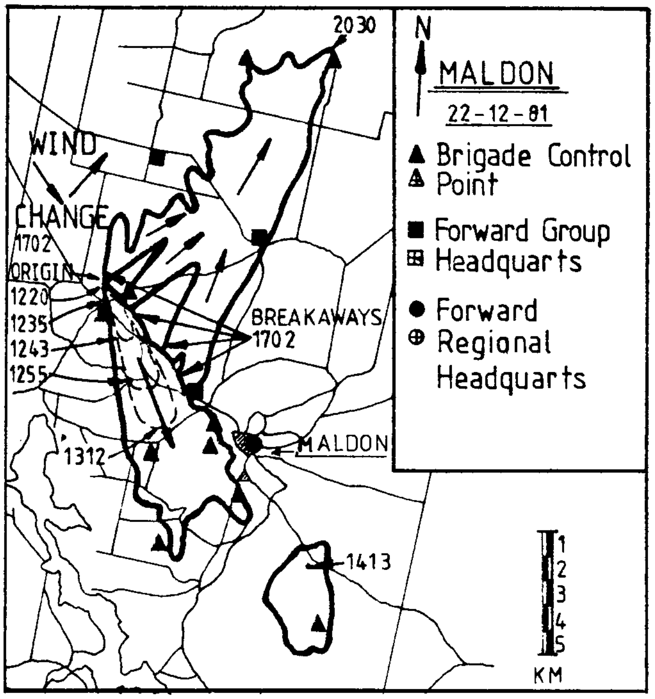


Figure 6--The Maldon Vic. Fire December 12, 1981

(ii) Grassland Curing Project--effective procedures for obtaining field data to monitor the approaching fire danger period and to aid fire behavioural studies have been determined. Barber and Pratt (1980). The programme requires repetitive field sampling (18--21 days or less if possible), Statewide, October to February and laboratory measurements of fuel moisture content (FMC), soil moisture content (SMC) and fuel quantity (tonnes/ha). Both FMC and SMC are plotted (as percentage of oven dry weight) against time. (fig. 7).

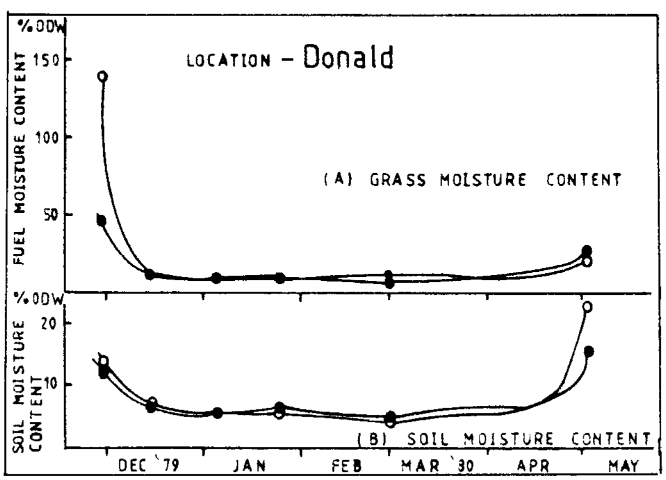


Figure 7--Variation in FMC & SMC, Donald, Vic. 1979/80 (Two locations).

(iii) Remote Sensing in Fire Prevention--the application of Landsat multi-temporal, multi-spatial technology to monitor vegetation as a possible alternative to the previously described labour intensive and time consuming procedure is being studied. The project is part joint research by CFA, Monash University and IBM (Australia) Limited using the ERMAN II package. Other digital and analogue analysis methods will be studied to ascertain the most practical within constraints of economy and time. Classification character maps of training fields are studied in conjunction with ground data and aerial photography (vertical [70 mm] and oblique [35 mm]) at the time of each acquisition to test classifier accuracy. Regard is paid to vegetation strata; species dominance; plant height, density and moisture content; soil moisture and reflectance measurements in the simulated MSS bands 4--7. The relationships of total biomass and plant moisture content to reflectance in visible and near IR wavelengths are currently being studied.

(iv) Fire Hazard Mapping--described by Morris and Barber (1980). The method is applicable in municipalities planning new residential or other development and involves preparation of a medium scale map (1:50,000), a detailed report and area specific recommendations on future land use. Areas of high fire hazard are where fires are most likely to occur and where such fires would create danger for both residents and firefighters.

The potential fire hazard may be assessed by rating the following ten criteria (with built in weighting factor) from 1 to 5, for increasing hazard, when applied to each discrete homogeneous area in the municipality:

1 FREQUENCY OF FIRE SEASON
2 LENGTH OF FIRE SEASON
3 SLOPE--ASPECT
4 SLOPE--STEEPNESS
5 VEGETATION--GROUND COVER
6 VEGETATION--AVERAGE ANNUAL DRIEST STATE
7 FIRE HISTORY
8 AMOUNT OF EXISTING DEVELOPMENT/USE
9 EGRESS FROM AREA
10 FIRE SERVICES AVAILABLE

The ten hazard scores are added to give a total fire hazard rating which then determines the hazard category for each area. The map is marked up accordingly.

Recommendations and guidelines relating to land use and development control for the protection of life and property are included in the report, e.g.,
(a) Applications for subdivision and development in very high hazard areas should be discouraged and in some cases prohibited. Where development is permitted it should be preceded by a comprehensive fire protection plan incorporating strategic fire breaks and buffer zones, fire access tracks and water supplies, property layout and building design.
(b) Any development which is likely to involve large numbers of people (e.g., school camps), should not be permitted in areas of very high and high hazard. Special care should be taken in locating such development.

(v) Design and Siting Guidelines--describes "built in" fire protection for rural properties, large and small (Morris and Barber 1980). Such fire protection measures should be incorporated in new developments and progressively in modification of existing properties (fig. 8).

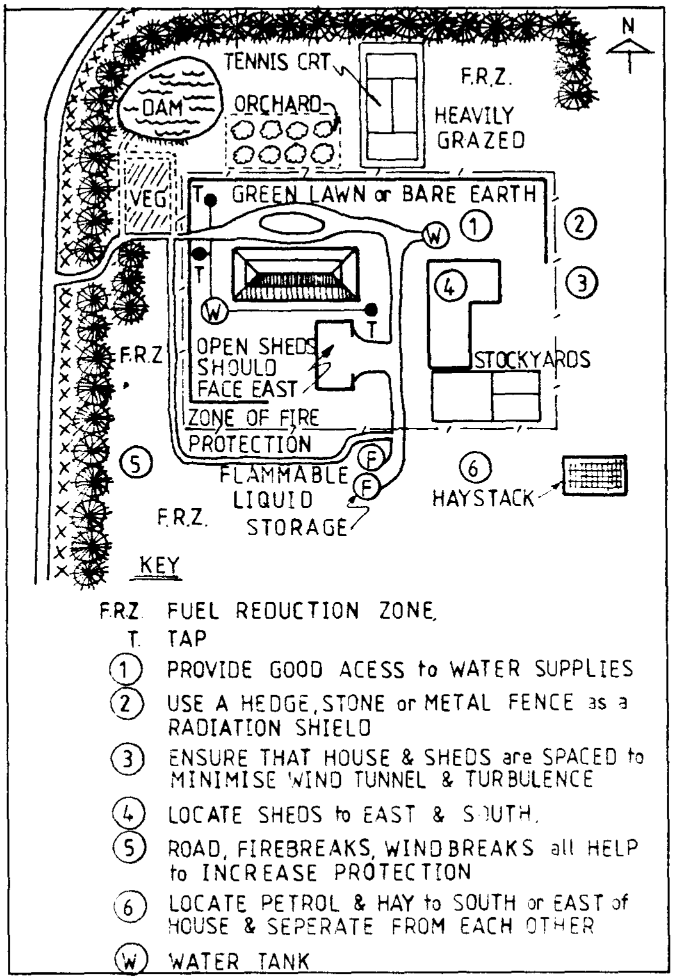


Figure 8--Layout of well-protected property.

The location and siting of dwellings should have regard to the direction of prevailing fire danger weather, slope and aspect, proximity to bushland, the manner of setting the house on a slope, static water supplies and fire access tracks. Existing features, e.g., roads and streams, are ready-made fire breaks and should be used to advantage.

(vi) Electric Fences--a fire hazard? Circumstances in which electric fences may ignite grassland fuels were tested (McCutchan and Pratt 1980). Flashover across the surface of green leaves between a live conductor and earthed metal, with very dry finely divided plant material in close proximity, is the most likely mechanism to cause a fire. A series output resistor will minimize the chance of ignition. Fires caused by electric fences are statistically improbable but are still possible.

(vii) Firebreaks and Buffer Zones--The CFA promotes the planning and construction of linear fire prevention measures and aids to fire suppression. Also Legislation provides for advisory committees in municipalities and regions for fire prevention planning.

The CFA appreciates that firebreak and buffer zone construction methods may modify the environment. Therefore planners should be aware of methods that may degrade those attributes important to successful land management, and appreciated by residents and visitors, and at the same time achieve maximum firebreak effectiveness.

In the high fire-hazard Dandenong Ranges area east of Melbourne, the Victorian Government has acquired private property which is set aside from residential development and managed as a fire buffer zone by the Forests Commission.

DEVELOPMENT OF SUPPRESSION CAPABILITY

Primary factors for improved suppression capability are an efficient fleet of vehicles, adequate communications and highly trained brigade personnel

The CFA has built up a large fleet of fully equipped fire fighting vehicles distributed to brigades as support for local equipment:

Aerial Appliances		5
Urban Pumpers	1600--3000 1pm	236
Rural Tankers	1000--4000 (4x4&4x2)	1097
Trailer Units	Pumps	84
	Tankers	190
	Hose Trailers	104

Such wide distribution allows brigades to attack a fire with speed and concentration. In rural brigades the CFA units may be the only equipment immediately available for turnout, farm vehicles being engaged in bulk grain or hay cartage.

Flexibility, simplicity and reliability of operation are important design criteria for vehicles operated by firemen in high-stress situations. One new CFA design is shown in figure 9, with specifications as indicated.

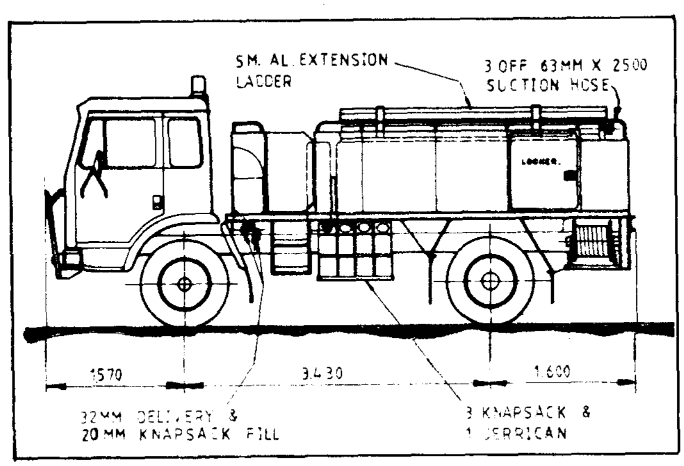


Figure 9--CFA Rural Tanker, New Design.

Cab/Chassis--International ACCO 610A 4 x 4
Engine--V345 8-cylinder petrol (150 hp)
Water Tank--3,000-litre capacity fibreglass
Pump--2 stage, 370 litres/minute @ 700 KPa powered by 15-hp Briggs and Stratton engine.
This unit will replace many other vehicles.

Two important communication facilities are telephone alerting system for volunteer fire brigades where fire stations are unattended and two-way radio communications between fire vehicles, a mobile command vehicle and their headquarters.

Three separate Fire Reporting Services have been designed and implemented. These services are comprehensive and reliable intercepting and signaling systems which utilize the existing private telephone services installed in volunteer residences. The systems allow the volunteer to answer the fire call, speak to the caller and if necessary activate the fire siren. They also provide a conference facility to allow the volunteer officers to confer with others prior to answering the call.

FRS. Installations--Type 1 cities and towns	173
--Type 2 small rural communities	360
--Type 3 sparsely populated districts	318

Two-way radio was introduced into fire brigades after World War II. Much equipment was ex-Service privately purchased. Brigades formed radio networks to ensure their mobility and rural fire fighting became a group operation. Since then more efficient equipments have been installed and maintained by the CFA. High frequency (2-4mhz) SSB networks provide Statewide communications for Zone and Regional officers whilst VHF 163mhz is used intraregion. The advent of VHF has required remotely sited base stations on hill tops with control by land line or radio link. Some solar-powered remote installations have been designed and constructed.

Equipments in operation include:

	Base Stations	Mobiles
CFA owned	458	1,532
Group & Brigade owned	261	2,185

With the development of increasingly sophisticated equipment and deployment of vehicles and crews Statewide to major fires, training of large numbers of volunteers became necessary. The CFA established a Training Wing on a 140 ha site 60 km north west of Melbourne with facilities for 50 live-in and 150 daytime students. CFA philosophy is that the Training Wing trains volunteer and permanent officers who in turn conduct training in their home regions for group and brigade personnel. Subjects include fire suppression strategy and tactics, communications, use and care of specialised equipments, e.g., breathing apparatus, and methods of extinguishing specialised fires, e.g., L.P. gas and flammable liquids. The Training Wing operates 7 days per week for 44 weeks each year. Training in 1980 included

	Numbers of Courses	Numbers of Students
Volunteers Schools	79	2,552
Permanent Staff Schools	39	271
Outside Groups Schools	38	697

Advanced training is underway with the introduction in 1980 of the National Command Course sponsored by the Australian Assembly of Fire Authorities for senior officers of fire services from all Australian States.

SUMMARY

Wild fires in rural Victoria are largely the result of vegetation becoming highly flammable at the time of seasonal high fire danger weather. People are directly or indirectly the cause of the majority of the fires whilst in the event of a fire occurring, people, their stock and property are at considerable risk and often suffer severe losses.

The Country Fire Authority was established to mitigate such losses and has set up an effective Statewide organisation with principles of operations clearly defined. Rural orientated research has commenced to improve understanding of fire behaviour and fire prevention methods whilst development in suppression capability is proceeding through improved vehicular design, communications and training.

LITERATURE CITED

Barber J.R.; Pratt B.T. The Flammability of Grasslands; Operations Supplement No.93, The Fireman June 18, 1980, Vol.34 No.12; ed. 11 Chester Street, Oakleigh, Vic. Aust.

Foley J.C. A Study of Meteorological Conditions Associated with Bush and Grass Fires and Fire Protection Strategy in Australia; Bulletin No.38 Bureau of Meteorology, Aust. 1947, P.96

Foley J.C. ibid. P.53

Luke R.H.; McArthur A.G. Bushfires in Australia; Australian Govt. Publishing Service, Canberra, 1978, P.78

McCutchan J.; Pratt B.T. Electric Fences--A Fire Hazard; Operations Supplement No.89, The Fireman, February 20, 1980, Vol.34 No.8.

Morris Wendy; Barber J.R. Fire Hazard Mapping; Operations Supplement No.96, The Fireman, September 17, 1980, Vol.35 No.3.

Morris Wendy; Barber J.R. Design and Siting Guidelines : Bushfire Protection for Rural Houses; Operations Supplements Nos. 98 & 99, The Fireman, Vol.35 Nos.5, 6.

Parrott R.T. The Growth, Senescence and Ignibility of Annual Pastures. Thesis, Waite Agricultural Research Institute, University of Adelaide, S.A., Aust. 1964, P.5.

Stretton L.E.B. Report of the Royal Commission to Inquire into the Causes of and Measures Taken to Prevent the Bush Fires of January 1939 .... A/Government Printer, Melbourne, Aust. 6912/39-1939, P.20.

Fire Management in Southern California[1]

Michael J. Rogers[2]

Abstract: Fire has always played a major role in Southern California. Fire suppression forces have a good record controlling brush fires under normal weather conditions. Present suppression strategies become ineffective on wind driven fires under "Santa Ana" weather conditions. Prescribed burning has emerged as a viable tool for developing age class mosaics. Age class mosaics should become the key building block of a totally integrated fire management program. This kind of program will significantly reduce suppression costs, wildfire damage, related flood damage and sediment reduction while providing optimum benefits to wildlife, water, timber, range and recreation.

Wildland wildfires have had a major environmental influence in Southern California for two million years or more (Axelrod 1958). Analysis of charcoal layers in lake and ocean bottoms has provided evidence of periodic wildfires (Bryne and others 1977). Examination of fire scars on older conifers also provides additional data on high intensity fire frequency prior to the establishment of official, written records (Arno and Sneck 1977).

The early day missionaries, who began the first non native American settlements, started a migration to Southern California that continues even today. Father Junipero Serra and his Franciscan followers founded numerous missions which became the cornerstone of community development in Southern California. Large Spanish Land Grant ranches soon surrounded each mission. These early day settlers may have used fires as a means of clearing the vegetation from the fertile valley floors and alluvial plains (Komarek 1969) that stretched from the mountain slopes to the shores of the Pacific Ocean. The deep alluvial soils in the valleys below the coastal mountains produced good feed for cattle, good wells, numerous crops, vineyards, avocado and citrus groves.

As the population grew, additional ranches and farms sprang up on the more marginal terrain. Eventually ranches and farms occupied all the valley lands from the shores of the Pacific Ocean to the rugged slopes of the Coast Range. Occasionally droughts created hard times for the ranchers. Wildfires in the valleys and the foothills often accompanied these droughts.

Dana, in his book "Twenty Years Before The Mast", states that in 1836 he encountered a great forest fire all along the Southern California Coast Range during his journey northward to Santa Barbara. Periodically, newspapers carried accounts of raging forest fires in the coast range mountains of Southern California. Specific newspaper accounts of Southern California wildfire activity occurred in 1869, 1872 and 1878. During these early years residents expressed little direct concern over these wildfires.

Cattlemen intentionally set many fires in the valleys and foothill areas as late as the 1870's and 1880's. Finally, in 1884, a series of severe winter storms hit Southern California. The new Southern Pacific Railroad suffered heavy damage as a result of the flooding. Following this episode, intentional burning of vegetation ceased. Periodically, however, large wildfires would break out, usually in the fall. These wildfires eventually reached the mountains where they burned themselves out after running into old burns (Barret 1935).

In 1896, Southern California experienced a severe drought accompanied by high summer temperatures and strong winds. The numerous wildfires that occurred and the flood damage that followed resulted in a loud outcry of local protest. As a result, the Federal Government initiated plans to establish fire fighting organizations for all of the newly created forest reserves in Arizona, New Mexico and California.

In spite of these efforts, wildfires continued to occur. To combat the threat of large wildfires the Forest Service attempted to contain each fire at the smallest size possible. In the early 1930's the Forest Service protection policy called for immediate attack and suppression of absolutely all fires that occurred.[3] Under this policy mature chaparral would eventually form a thick continuous cover over the soil. Sooner or later a wildfire would break out under extreme weather conditions and all of the steep mountain watersheds would burn. Serious flood and debris problems usually followed on the heels of these wildfires. After repairing the storm damage

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Fire Management Officer, Angeles National Forest, Forest Service, U.S. Department of Agriculture, Pasadena, California 91101.

[3]Personal communication from Chief F.A. Silcox to Regional Foresters, Forest Service, U.S. Department of Agriculture, 1935.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Forest Service personnel would then start all over again, protecting the new brush until it became old and decadent and would again burn under high intensity wildfire conditions. This unsuccessful policy of complete fire exclusion continued until 1978.

In addition to implementing a policy of complete wildfire prevention and suppression, the Forest Service took several positive steps in an effort to disarm the explosive potential of the steep brush covered mountain slopes. As fire fighters began to use mechanized equipment to control wildfires, the Southern California Forest Managers began implementing a system of preattack planning. This planning system inventoried all those ridges where mechanized equipment could be worked effectively. The fire fighter now had a way to preplan the placement of bulldozers and other equipment before a wildfire occurred. Unfortunately, wild fires would usually overrun these ridges before the equipment could construct the firebreaks. After repeated failures the Forest Service began requesting and receiving additional funds to preconstruct many of these improvements, especially firebreaks. Wildfires burning under extreme adverse weather conditions quickly overran the preconstructed firebreaks. Heavy winter rains and intense summer thunder showers also caused unacceptable erosion on these firebreaks.

Eventually, firebreaks gave way to the wider fuelbreaks. Fuelbreaks support low growing and low volume vegetation which helps to reduce erosion while providing a safe place for fire fighters to make a stand. We learned that even with wide fuelbreak systems supported by roads, heliports and strategically located water systems, under extreme adverse weather conditions (low humidities, low live fuel moistures and strong winds) fire fighters could not effectively isolate a wildfire within the established fuelbreak system. (Pinecrest, Sage, Monte, Crown Valley, Placerita Fires 1979; Mountain Trail 1978; Middle Fire 1977; Mill, Village Fires 1975). However, the fuelbreak system did become highly useful for containing wildfires once the adverse wind conditions subsided.

Fuelbreaks will continue to play a key role in reducing the number of acres burned under most high intensity wildfire conditions except under strong Santa Ana wind conditions. However, even under the less extreme weather conditions, fuelbreaks alone will not eliminate the soil damage resulting from the high intensity wildfires that burn between the fuelbreak system (Mountain Trail Fire 1978; Pine Crest Fire 1979; and Stable Fire 1980).

Suppression expenditures and related resource damages represent just the tip of the iceberg in terms of wildfire-flood related costs and losses. As an example, the 1975 Mill Fire cost $1.5 MM to suppress and it resulted in some $200,000 in resource damages. The floods and debris which followed this high intensity wildfire in February 1978 caused an additional estimated $75MM in property losses and damages. The majority of the flood and debris damage that occurred throughout Los Angeles County in 1978 could be traced back to recent high intensity wildfires.

In spite of all our best prevention, detection, suppression, preattack, firebreak and fuelbreak strategies and the money spent to implement these strategies, we still seem unable to reduce the number of high intensity wildfires that burn under extreme weather conditions and the damages associated with these wildfires. The number of wildfire starts continues to grow each year with 60 wildfires in 1970 to 131 wildfires in 1979.[4] For the past thirty years wildfires have burned an average of 18,500 acres on the Angeles National Forest: 1950-1959 16,917 acres; 1960-1969 21,395 acres; 1970-1979 18,511 acres. Most of these large acreage losses have occurred between September and December under high velocity Northeast Santa Ana winds. These wind driven wildfires continue to be the single greatest cause of soil damage and personal property loss in Southern California. Some typical examples of personal property loss follow in Table 1. Unfortunately statistics are not available for the number of structures actually saved under conflagration conditions.

Table 1--Dwellings Lost in Conflagration Wildfires, 1970-1980.

Fire Name	Date	Jurisdiction At Point Of Origin	Homes Destroyed
Boulder	9/70	Cleveland National Forest	383
Mill	11/75	Angeles National Forest	15
Sycamore	7/77	Los Padres National Forest	216
Mandeville Canyon	10/78	Los Angeles City	20
Kanan	10/78	Los Angeles County	230
Stable	11/80	Los Angeles County	57
Thunder	11/80	Angeles National Forest	26
Panorama	11/80	San Bernardino National Forest	284

Each wildfire precludes managements option for controlling the timing of quality water yields, creating optimum wildlife habitat conditions, reducing losses of forest soils, providing additional area for grazing, establishing tree plantations and healthy chaparral stands for future dispersed recreation opportunities and for allowing greater use of those portions of forests now restricted by annual fire closures.

---

[4]Data on file, USDA Forest Service, Angeles National Forest, Pasadena, California

The long, warm, dry summers and mild winters that originally made the Spanish feel at home still continue to draw 200,000 Americans to Southern California each year. Single family residences, apartments and condominiums have long since replaced the ranches, orchards and vineyards established by early day settlers. The unending demand for additional housing and privacy has become so intense that residential developments now compete for the only remaining land base, the steep brush covered privately owned hillsides. Residents of these areas have little understanding or appreciation for the hazards involved with living in the urban wildland interface. Fire Management problems continue to become increasingly complex.

Can anything be done to charge or correct what appears to be a growing and totally hopeless situation? Yes, a number of things can be done, however, there are no simple or individual solutions to this complex problem. From the stand point of vegetation management, the fuels that lie between the fuelbreaks must be conscientiously managed and not just protected. Prior to 1975 none of our management strategies suggested managing the carpet of chaparral fuels that lay between the fuelbreaks. Fire modeling (Albini 1976) and personal observations suggest that by managing the age of the fuels the manager can favorably influence fire intensity. The older the fuel, the greater the dead to live fuel ratio and the greater the resulting intensity once ignition occurs (Green 1980).

The data in Table 2 illustrates this point very graphically[5].

Table 2--Brush Fuel Model with Slope at 50 percent, 10 Hour Fuel Stick of 2.0, Wind Speed of 20 Miles Per Hour, on September 4.

Age (Years)	Flame Length (In Feet)	Intensity BTU/Sec/Ft	Size(Acres in 1st Hour)
10	6.36	316	142
20	5.89	267	7
30	19.26	3,518	102
40	30.09	9,284	280
50	33.65	11,838	384

With wind, slope and fuel moisture held constant and age of the vegetation the only variable, one can readily see that fire intensity, resistance to control, and acres burned in the first hour begins to increase rapidly beyond twenty years of age. The rapid increase in the dead to live fuel ratio beyond twenty years of age causes these increases. Most of the chaparral species have produced viable seed by their fifteenth year. This data suggests then that somewhere between 15 and 20 years of age, chamise-chaparral vegetation should be converted back to the age of zero, or burned under a prescription that will remove a large percentage of the smaller sized dead fuels. Prescribed burning can be carried out under a carefully coordinated plan which will result in a mosaic of different age classes.

Age class management enables the land manager to have a good deal of control over wildfire intensity and related resource and off site damages. Wildfire suppression should be more effective in the younger, thriftier chaparral fuels. In addition the land manager can now begin to realistically plan for other resource opportunities such as increased grazing, an increase in wildlife habitat diversity, and an increase in quality water yields.

Because of the steep slopes and fragile soils, it appears that very few alternative methods of large scale vegetative management other than prescribed burning could be successfully implemented in the Angeles National Forest. The Southern California National Forests have used prescribed burning with a high degree of success as a vegetative management tool since 1977.

Based on our experience on the Angeles with both wildfires and prescribed fire I offer the following observations and opinions:

FIRE INTENSITY EFFECTS

The flood damage that follows wildfires can be directly related to two factors: (1) wildfire intensity and (2) storm intensity. Wildfire intensity increases with the age of the fuels. The combination of older fuels burning under a September-December hot dry Northeast wind conditions creates some of the highest wildfire intensities possible. Not only does an intense fir burning in late summer after a long drying period consume all of the organic matter in the soil, it can destroy the soil structure and create a "water repellent" soil condition. The more intense the fire the greater the change that this "water repellent" soil condition will develop. However, if abundant rain falls, surface water will start flowing down the steep slopes and as these flows gain velocity soil particles become detached and transported. Surface rilling and slumping starts to occur. Major channels scour out down to solid parent material. Tons of debris begin to flow off the slopes and out of the forests into residential areas that border the foothills. All of the main channels in the fire area will carry major debris flows which on the Angeles will usually be contained in debris basins. These debris basins must be cleaned out periodically, at a present day cost of $8.00/cubic yard. During periods of heavy rainfall clean out activities must occur on a daily basis just to keep up with the new debris flowing into the structures. If the daily clean out did not occur hundreds of homes below these structures would be destroyed by flowing debris.

Very extensive "water repellent" soil conditions occurred during the 1975 Angeles National Forest Mill Fire, in 56-year-old-fuels. Fortunately

[5]Van Gelder, Randall, J. Unpublished Firecasting Operators Guide on file at the Fire Lab, Riverside, California.

only light winter storms occurred during the next two winters. Extensive "water repellent" soils also occurred on the 1977 Middle Fire which burned in 75-year-old-fuels. Heavy winter storms in 1978 produced major debris flows from these two burns which resulted in extensive flood damage and loss of life[6].

This pattern of severe flooding did not occur however on another wildfire known as the Mountain Trail Fire. The Mountain Trail Fire started on October 23, 1978 under strong Santa Ana wind conditions and burned all of the watershed north of the City of Sierra Madre. In 1978/1979 Southern California experienced another wet winter with expectations for heavy flood damage in the City of Sierra Madre. However, the city did not experience any heavy flooding or debris damage. A review of the fire history records indicated that the Mountain Trail Fire area had not burned since the 1961 Sierra Fire which also occurred under strong Santa Ana wind conditions. During the winter following the Sierra Fire the town of Sierra Madre suffered heavy flooding resulting in extensive damage to numerous homes. Deep rilling, gullying, and slumping had occurred on the mountain slopes sending tons of debris into the city below. Prior to the Sierra Fire, this area had not completely burned since 1911. The Sierra Fire, therefore, burned in 50-year-old-fuel. By contrast, the Mountain Trail Fire burned in 17-year-old-fuel, a relatively thrifty fuel. Although all of the stream channels on the-Mountain Trail Fire produced record amounts of debris, most of this material had accumulated in the ravine and canyon bottoms as dry creep long before the 1978 Mountain Trail Fire. The burning of the thriftier fuels, even under extreme weather conditions, did not result in the extensive "water repellent" soil condition that has developed on other high intensity fall wildfires.

During the winters of 1977/78 and 78/79 Ranger District personnel conducted numerous prescribed burns throughout the Angeles National Forest. Many of these burns took place prior to heavy torrential winter rains, the same rains that caused extensive flood damage on areas burned over in the Mill and Middle Fires. We did not observe any rilling or extensive soil movement on these prescribed burn areas. The low intensity prescribed fires, some of them in 60-year-old-fuels, did not create the "water repellent" soil condition that develops when high intensity wildfires burn under extreme weather conditions in older fuel beds. In fact, within two weeks 90 percent of the prescribed burn areas had a cover of grass or herbaceous plants.

In addition to carefully prescribed fuel and weather conditions at the time these burns took place, the soils at all burn sites had high moisture contents due to the long and above normal winter-spring rainy season. By contrast, our damaging wildfires occur in the fall, in older fuel beds, after all the forest fuels have dried out and the living vegetation has become dormant.

In April 1980, during a period of 80 mph Northeast winds, some hot material rekindled and escaped outside the burned area perimeter. The resulting wildfire burned in 60-year-old-fuels. Before the winds finally died down the Monroe Fire had consumed 3,000 acres. However, this wildfire occurred in the spring during a time of very high soil moisture. As with all of our prescribed burns new vegetation started to appear within two weeks. By June the burn contained a new carpet of vegetation. Research personnel examined the soils and concurred that little if any "water repellent" soil conditions had developed.

The Mountain Trail Fire and the Monroe Fire demonstrate two important concepts.

1. We can influence wildfire intensity by conscientiously managing chaparral fuels in a mosaic of various age classes. The 1978 Mountain Trail Fire showed that less soil damage occurs when younger, thriftier fuels burn then when older fuels burn, even under extreme wildfire conditions.

2. The 1980 Monroe Fire suggests that intense winter/spring fires in the old fuels do not seriously destroy soil structure as do high intensity wildfires in the fall. The high soil moisture content present during Spring Fires appears to play a key role in preventing the creation of "water repellent" soils. We have all observed that vegetative recovery on fall burns occurs very slowly, while on spring burns the reverse situation occurs.

PRESCRIBED BURNING AS A MANAGEMENT TOOL

Prescribed burning has several distinct advantages over wildfire in that it offers the manager the opportunity to control the size and shape of the burn. Under wildfire conditions no such control exists. If the manager observes the prescribed burn producing higher soil temperatures then desired, the firing pattern can be adjusted accordingly. Again under wildfire conditions no such opportunity exists.

With prescribed burning the manager can select the timing and the conditions required to produce an end product consistent with pre established objectives. Again, under wildfire conditions this opportunity does not exist.

As we continue to gain experience with prescribed burning, we must develop the capability of burning several thousand acres each day. This concept seemed impossible to even think about several years ago. However, the helitorch now provides us with the capability needed to burn large areas each day. With all of the various constraints we work under such as (1) no burn days because of poor air quality, (2) no burn day because the burn falls out of the prescription

---

[6]Los Angeles Times feature on a study conducted by California Institute of Technology, Pasadena, California on the Relationship of Wildfire Intensity to Soil Damage; March 5, 1978.

on either the low end (humidity and fuel stick too high, no wind, fire won't burn) or the high end (humidity and fuel stick too low, wind too strong, any fire could be too intense), (3) no burn days because a very complex high risk burn will be ignited on an adjoining district and back up forces from neighboring units must be reserved in the case of an escape, (4) insufficient humidity recovery at night which constrains the manager from initiating new prescribed burns until "mop up" of previous burns can be accomplished. This all means that once each critical factor falls into prescription, good soil moisture exists, good humidity recovery occurs in late afternoon and stays through the night, air quality conditions permit prescribed fires and the weather forecast looks favorable for continuation of similar conditions for the next 48 hours or more the manager must move rapidly to accomplish as many acres as possible. For example the goal of 18,000-19,000 acres each year on the Angeles may conceivably take place on 8 to 10 key days where all factors favor planned ignition. These 8 to 10 burn days may be scattered throughout the winter, spring and early summer, between November and early July. Fortunately, the risks will lessen as we eliminate more and more of our 30-year-old and older fuels.

Hopefully costs can be cut by accomplishing more and more burning without using expensive preconstructed fire lines. We have successfully used humidity recovery on several burns including the Horse Ridge Fuel break in April 1978, and the Drinkwater Fuel Reduction Project in May 1978. In both these cases the humidities rose to the point at about 3:00 pm where we could no longer ignite the fuels. Sustained high humidities through the night nearly extinguished all fire on both projects. Prescribed burn managers monitered the relative humidities using on site hygrothermographs.

PREVENTING PRESCRIBED FIRE ESCAPES

As previously mentioned the Winter-Spring of 1980 proved to be a totally different kind of year. Humidity recovery above 60 percent rarely occurred for sustained periods. Northeast winds periodically surfaced throughout the winter-spring burning period. On April 11, 1980 a Northeast wind with unpredicted velocities of 80 mph surfaced over the Angeles National Forest. Two prescribed burns initiated originally on April 7 eventually escaped. Both wildfires headed towards heavily populated areas. The Dagger Burn consumed 705 acres and the Monroe Burn consumed approximately 3,000 acres. Fortunately the winds died down before either of these two fires reached the wildland urban interface.

Some cautions and considerations for use of prescribed fire in a Mediterranean-type Ecosystem:

1. Under strong wind conditions, the vegetation in a Mediterranean-type Ecosystem will burn at any time of the year. The probability for an intense fast running fire increases dramatically as the fuels exceed 20 years of age. Our most dangerous winds, the strong Northeast winds, can occur during any month of the year. The data in Table 3 comes from a 10 year study (1951-1960) of Santa Ana wind frequency on the Angeles National Forest (Schroeder and others 1964).

Table 3--Santa Ana Wind Frequency by Month for the Angeles National Forest.

Month	Avg. No. Santa Ana Events Each Year	Average Duration (In days)	Avg. No. Santa Ana Days Per Month
January	0.7	1.7	1.2
February	1.0	1.9	1.9
March	1.7	2.5	4.3
April	0.8	1.8	1.5
May	0.7	1.4	1.0
June	0.4	4.5	1.8
July	0.2	2.5	.5
August	0.0	0.0	0.0
September	1.1	4.4	4.8
October	1.9	4.5	8.6
November	2.6	5.0	12.8
December	1.8	3.7	6.6

The probability of high velocity Northeast winds must always be considered when planning to burn. The combination of strong Northeast winds, wildfire and the floods that follow destroy more structures in the wildland urban interface than any other combination of causes.

2. Managers must resist pressures to take risks that they find unacceptable. We have began to build a good solid fuel management program. Admittedly, we have made some mistakes and we have grown from these mistakes. We received criticism that our rate of progress is not fast enough. Today we stand at the crossroads: we can develop a good solid prescribed burning program and continue to enhance our creditability as professional land managers or we can wind up losing this opportunity by becoming overly ambitious and taking some foolish chances.

3. In Southern California, it would be unusual to find good prescription conditions must past July. Therefore, it will remain necessary to attack all those wildfires occurring during the summer and fall with a rapid and aggressive suppression effort. Some people advocate letting wildfires go during the summer wildfire season. They claim these wildfires would develop a natural age class mosaic. Perhaps this concept might have worked prior to the intrusion of residential development into the privately owned wildlands of California. Today, however, to let a wildfire run loose to the point it could endanger or destroy private property if winds developed would be totally irresponsible. If we allowed this to happen the public would be justified in asking if there is a difference between prescribed fire and wildfire. A prescribed fire must always be fully under control and designed in such a way

that it meets a predetermined objective using a predetermined set of constraints. A wildfire knows no such bounds. No opportunity exists to control the size, shape, intensity or timing of a wildfire. In addition, based on our experience the soil damage from a summer wildfire would not be acceptable.

4. There will never be one single answer to all of our wildland management problems. Although age class management will reduce fire intensity, under strong wind conditions, any fuel age class will burn. Additionally, in strong winds, air-tankers and helitankers that usually can be more effective in lighter fuels often can not get off the ground because of the extreme air turbulence. During the Stable and Thunder Fires, 5, 10 and 30 year-old-fuels all burned with equal rates of spread. Aircraft could not be used until the Northeast winds finally subsided. We can, however, expect less soil damage under the younger age class fuels because of the lower intensities, which means less flood damage under these conditions. Homes in the path of a wildfire in any fuel type will be destroyed unless communities insist on fire safe building practices, such as fire safe roofs, closed eaves, properly placed attic vents, small windows, and proper landscaping in wildfire prone areas.

SUMMARY

Any successful wildland protection program must be built on an integrated approach consisting of:

1. A plan and financing for a vegetative management program that will reduce the intensity and the number of large wildfires while producing timber, recreation, range, wildlife, water and other benefits.

2. A continuation of a strong wildfire prevention effort. This prevention effort should also emphasize public education so that hazards of wildfire in a Mediterranean ecosystem are well understood.

3. A strong ground and air initial attack suppression organization with cooperator back up in the event a project wildfire occurs.

4. Homeowners living in Southern California's brushlands must have the benefit of living in fire safe homes built in areas that can be effectively defended from wildfire by both the homeowner and the fire services. Greenbelt or buffer concepts, fire safe building codes and low growing fire resistant vegetation should be fully integrated to provide this protection. New structures should be effectively separated from brush stands.

I believe that we can reduce fire and flood related losses considerably while enhancing other resource values by implementing a totally integrated protection strategy like the one I have described.

LITERATURE CITED

Axelrod, D.I. Evolution of Madro-Teritiary geoflora. Bot. Rev 24:433-509, 1958.

Albini, Frank A. Estimating Wildfire Behavior and Effects. Ogden, Utah.: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1976: Gen. Tech. Rep. INT-42. 92 p. illus.

Arno, Stephen F.; Sneck, Kathy M. A method for determining fire history in coniferous forests of the mountain west. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1977; Gen. Tech. Rep.INT-42. 28 p.

Barret. L.A. A record of forest and field fires from the days of the early explorers to the creation of the Forest Reserves. File at the Pacific Southwest Forest and Range Exp. Stn. Library.; Forest Serv.; U.S. Dep. of Agric.; 1935, 171 p.

Byrne, Roger; Michaelson, Joel; Soutar, Andrew. Fossil charcoal as a measure of wildfire frequency in Southern California. A preliminary analysis. Proceedings of the Symposium of Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems; 1977 August 1-5; Palo Alto, Calif.; 361-366.

Green, Lisle R. Burning by Prescription in Chaparral in California; A Summary of What We Know. Berkeley, California; Pacific Southwest Forest and Range Exp. Stn.; Forest Serv., U.S. Dep. Agric.; 1980 Gen. Tech. Rep. PSE-51. 36 p.

Komarek, E. V. Sr. Fire and Man in the Southwest. Proceedings of the Symposium on Fire Ecology and the Control and Use of Fire in Wildland Management. 1969 April; Tucson, Arizona, 17 p.

Schroeder, M.J. and others. Symoptic Weather Types Associated with Critical Fire Weather. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn.; Forest Serv., U.S. Dep. Agric. 1964: 264-268.

Operational Use of Prescribed Fire in Southern California Chaparral[1]

Ron Dougherty and Philip J. Riggan[2]

Abstract: The use of prescribed fire in the chaparral could reduce the incidence and impacts of severe wildfires and enhance watershed resources. This paper describes the operational planning needed for a successful prescribed fire and discusses the recent experience with this technique on the Cleveland National Forest.

Fire is a dominant natural feature in Mediterranean-type ecosystems throughout the world. With their characteristic summer droughts and highly flammable vegetation, these ecosystems are frequently coursed by catastrophic wildfires.

Nowhere is the threat to human life and property more acute than in the complex association of wildland chaparral and developed urban areas in southern California. Here, in November 1980, over 320 homes were destroyed and 36,000 ha of chaparral watershed were burned by major wildfires raging under the influence of foehn-type Santa Ana winds. These were not uncommon events; in modern times, homes are destroyed and thousands of hectares are burned every year by wildfire. Loss of life and property can be even greater in the flooding and debris production that often follows major chaparral fires.

Fire suppression and prevention programs have reduced the frequency and size of wildfires, but this approach alone has not prevented catastrophic wildfires, and natural fire regimes may have been altered, with profound effects upon this fire-adapted ecosystem. In response to these problems, efforts are being made to use fire under prescribed conditions to manage chaparral fuels and provide positive resource benefits.

A program designed to develop and demonstrate the use of prescribed fire and other management techniques in the chaparral has been underway since 1977 on the Laguna-Morena Demonstration Area in San Diego County. This paper discusses the rationale for prescribed burning in the chaparral and associated ecosystems, presents an overview of the operational planning needed for a successful prescribed fire, and discusses our recent experience with this technique.

PRESCRIBED FIRE OBJECTIVES

Fire Hazard Reduction

The use of prescribed fire in chaparral has potential for reducing the occurrence, size, and impact of large wildfires. Mosaics of different-aged chaparral stands can be produced and maintained by periodic burning under low to moderate fire intensity conditions. These mosaics break up large areas of heavy fuel accumulation and maintain a substantial area of chaparral in a young, productive state. The occurrence and adverse effects of large wildfires should be reduced since fire propagation and resistance to control are considerably less in well-stocked young stands with their low dead fuel volumes (Rothermel and Philpot 1973, Philpot 1974).

Areas of young chaparral have been useful in the suppression of large wildfires burning under extreme conditions. In 1979, the 1900-ha Monte Fire in the Angeles National Forest was contained on the south and west when driven by moderate Santa Ana winds into areas burned 4 years previously by the Mill and Pacoima Fires. Fire activity in the young age classes was greatly reduced, with only uneven fire spread through grass and light fuels on the north-facing slopes.[3] The southward advance of the 1980 Turner Fire in and adjacent to the Trabuco District, Cleveland National Forest, was halted under 30 to 50 km/h winds when it reached an age-class boundary of the 1975 Tenaja Fire.[4] The 1980 Thunder Fire in the Mt. Baldy District, Angeles National Forest, burned southward along San Antonio Canyon under the influence of strong Santa Ana winds. Long distance spotting into 27-year-old chaparral on the east side of the canyon propagated the fire and required sustained fire suppression action. Spotting into chaparral burned during the 1975 Village Fire on the west side of the canyon produced only poorly propagating fires that presented little resistance to control.[5] While even young stands of chaparral may propagate fire under the most extreme conditions, both the resistance to

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Fire Management Officer, Eldorado National Forest, Placerville, Calif.; Soil Scientist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

[3]Personal communication from C. Gripp, Angeles National Forest, Flintridge, Calif.

[4]Personal communication from M. Stout, Cleveland National Forest, Santa Ana, Calif.

[5]Personal communication from W. Hite, Angeles National Forest, Glendora, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

control and potential for mid- and long-range spotting are greatly reduced.

These benefits are particularly valuable at the wildland-urban interface where a mosaic of natural and planted vegetation often presents extreme fire hazards. Embers from large chaparral wildfires, such as the highly destructive Stable and Panorama Fires of 1980, can be carried a considerable distance into the developed community by long-range spotting. Carefully applied prescribed burning and age-class management in heavy chaparral adjacent to the interface could substantially reduce this problem. Less is known about the value of prescribed burning where the fuels are coastal sage scrub.

Prescribed fire can also be applied for the protection of high-value riparian and woodland resources. In stands of California live oak (Quercus agrifolia Nee), substantial mortality in younger age classes can occur during severe wildfires, and larger trees can suffer damage to the cambium and lower stem that makes them more susceptible to disease and insects (Plumb 1980). California black oak (Quercus kelloggii Newb.) is more susceptible and can be largely topkilled during wildfire. Understory prescribed burning can be successfully applied in stands of these species to reduce fuel accumulations (Green 1980) and provide protection against severe wildfires. Understory burning may also encourage seedling regeneration in areas of heavy litter accumulation, aid in the control of forest pathogens (Parmeter 1977), and mineralize nutrients in the forest floor litter.

Serious fire hazard problems also exist in many of the coniferous forest areas of southern California. Before 1905, ponderosa (Pinus ponderosa Laws.) and Jeffrey (Pinus jeffreyi Grev. and Balf.) pine stands in the San Bernardino Mountains were coursed by low intensity fires at a frequency averaging 10 to 12 years (McBride and Laven 1976). The mature overstory was not readily damaged by these fires, yet fuel accumulations are now large enough to virtually assure destruction of the mature stand. Prescribed fire can be used successfully to reduce these accumulations, but care must be taken to minimize tree damage and control the fire.

Enhancement and Management of Watershed Resources

The application of prescribed fire may provide a variety of watershed and wildlife benefits. Foremost among these is a reduction in the impacts of severe wildfires. In recent years, wildfires have frequently burned under the most extreme conditions due to suppression of low and moderate intensity wildfires, a high incidence of human-related ignitions during severe fire weather, and a possible buildup of fuels because of active fire suppression. Fire frequencies also may have increased in some areas of coastal sage at the urban interface.

A large-scale age-class management program could be designed to substantially reduce the adverse impacts of high intensity wildfire. Prescribed fires can be conducted under weather and fuel conditions chosen to minimize fire intensity and planned to encompass specific terrain of limited area. Cooler fire temperatures reduce nutrient loss (Dunn and DeBano 1977), soil water repellency (DeBano 1981) and erosion (Wells, in press), and seed destruction. Prescribed fires frequently burn only 40 to 70 percent of the vegetation within the fire perimeter, thus creating both a diversity of habitat and more nutrient-rich browse that are favorable for wildlife (Lillywhite 1977, Bissel and others 1955). The area burned within major watersheds can also be controlled, and this helps to reduce downstream flooding potential. A planned sediment management program using prescribed fire on important watersheds could be designed to minimize and regulate debris production.

The intensity and effects of a prescribed fire in chaparral may necessarily be greater than those associated with prescribed burning in coniferous forests or other woodlands. In conifer forests, light ground fires with flame lengths less than 1/2 m could be used to achieve good fuel reduction. Flame lengths greater than 2 m could well be excessive, causing undue damage to tree crowns and boles, and the forest floor. In the chaparral however, flame lengths greater than 2 to 3 m may be necessary to propagate the fire and attain desired fuel reduction. The amount of soil heating can be acceptable since the duration of heating is short and the alternative is burning under wildfire conditions with possibly extreme fire effects. Flame lengths in themselves are not here a cause for concern, as they are in forest understory burning where canopy damage must be avoided.

PLANNING THE PRESCRIBED FIRE

Site Selection

The selection of sites for prescribed burning on the National forests is an interdisciplinary process involving professionals from fire, resource, wildlife, and planning disciplines. Priorities are determined by the land and resource management objectives specified in the National forest management plan. A prescribed fire may have one or more major resource objectives related to fire hazard reduction, range improvement, sediment and flood management, or wildlife habitat improvement. These objectives are important in determining the size, layout, season, intensity, and frequency of burning in the prescribed fire operation. They will also determine the proportion of the area to be burned within the planned perimeter. For these reasons, a clear statement of resource objectives is necessary for planning and evaluating the prescribed fire.

For example, if fire hazard reduction is the primary goal, the resource objectives might have the following form:

> Within a 5-km radius of residential communities and for Santa Ana conditions with windspeeds of 60 km/h, (a) reduce long-range spotting to distances less than 200 m and (b) maintain 50 percent of the chaparral with fuels that will propagate fire at a rate of spread less than 0.4 m/sec.

The fire planner can use existing models (for example, see Helfman and others 1975) to evaluate the effects of different patterns of prescribed burning on wildfire behavior in specific areas of terrain and chaparral. In this way, different burning options for the management area can be compared so as to determine if the resource objectives are realistic. When the primary goals are forest protection, flood and debris control, or wildlife habitat improvement, similarly specific resource objectives can be stated.

Environmental Analysis

An essential step in planning the prescribed fire is the environmental analysis. This analysis weighs the possible benefits and impacts of the management action and outlines mitigating measures that may be required. It serves as a compendium of information on the vegetation, wildlife, sensitive or threatened and endangered species, soils, and archaeological or cultural resources of the project area.

Project Layout and Preparation

The size and extent of the prescribed fire are determined jointly by the fire management officer and the appropriate resource officers. The planned fire perimeter is designed for ease of containment within the framework of the burning objectives and requirements of the environmental analysis. Often, the burn can be easily enlarged or reduced to improve the operation while still achieving the planned objectives.

Whenever possible, existing barriers to fire propagation should be used as control points. Not only are existing roads and fuelbreaks useful, but natural barriers such as ridge lines, riparian areas, and age-class boundaries in the chaparral can be used effectively for containment. Prescribed fires are often conducted under conditions that are just severe enough to propagate the fire. Changes in humidity or topography may have a strong influence on the rate of spread and can be used to contain the fire. The construction of artificial control lines should be minimized due to their high cost and possible soil disturbance. Understory burning in riparian areas, such as California live oak woodlands, can provide an effective control line for broadcast burning chaparral. If California black oak or mixed pine forests are present in adjacent areas, they should be understory burned under low intensity conditions before the planned chaparral burn. If high accumulations of fuel are present around isolated groups of trees within the planned chaparral fire perimeter, hand or mechanical clearing in their vicinity may be required to assure their survival.

The burning prescription should be designed to meet the specific resource objectives for the planned fire. Guidelines for developing a prescription are available (Green 1981); they require a knowledge of the local fuels, terrain, and weather behavior. Conditions required to propagate fire and achieve reasonable objectives in one stand may be extreme in another. Fuels information, including total biomass and especially the dead fuel loading and live fuel moistures, should be gathered from a range of locations representing the different aspects, vegetation types, and terrain present within the fire area. Some interpretation of the available prescription guidelines may be necessary since the important variables influencing fire behavior will strongly interact. For example, an area with relatively low dead fuel volumes may require a prescription with relatively low relative humidity and moderate windspeeds in order to achieve burning objectives. It is important that the forest officer in charge of the prescribed fire be familiar with fire behavior in the local fuels and have the experience to determine realistic objectives and prescriptions.

A knowledge of regional and local weather conditions is imperative for a successful prescribed fire. Foremost is a knowledge of the probability of dangerous fire weather during or after the burn. High pressure systems that create strong Santa Ana winds may develop rapidly, so it is important to have reliable weather forecasts before, during, and after the fire. Local weather conditions should also be monitored for a minimum of 1 week before the burn, and the trends in humidity and wind for the day should be estimated. If you are "in prescription" at 1000 h, you must have a reasonable idea whether or not you will still be in prescription at 1400 h.

When local fuels and expected weather conditions are known, fire behavior may be partly controlled by the nature of the planned ignition pattern (Martin and Dell 1978). In heavy fuels with a high proportion of dead material, backing fires may be required to control the rate and progress of burning and to contain the fire. In lighter fuels, head fires or multiple ignitions may be required to achieve an acceptable fuel reduction or fire coverage. Areas of flashy fuels or higher dead material accumulations may be used to build heat and propagate fire into upslope areas of less flammable vegetation.

The placement and requirements for fire suppression crews should be determined by a potential escape analysis from which clear action plans can be developed to control problem areas in the fire. The burning operation for large fires can also be broken into stages, each of which should be brought to a degree of completion before crews proceed to the next.

The burning objectives should provide an assessment of the fire behavior required, including proportion of the area to be burned, fraction of the litter layer to be consumed and allowable flame height (in forest stands), rates of spread, and amount of standing vegetation consumed. These factors should be subjectively assessed as the burning operation proceeds. A more complete evaluation should be conducted following the prescribed fire to determine (1) whether resource objectives were fulfilled, (2) if any adverse fire effects occurred and how they should be minimized in future operations, and (3) if improvements are needed in ignition patterns and holding operations.

CASE HISTORIES

Operational prescribed fires conducted recently on the Descanso District of the Cleveland National Forest have demonstrated that large prescribed fires can be conducted safely in a variety of chaparral and woodland communities. Four of these, the Noble Canyon, Kitchen Creek, Troy Canyon, and Mt. Laguna-Flathead Flats projects, illustrate the use of prescribed fire under a variety of conditions. Site characteristics and burning conditions of these fires are shown in tables 1 and 2.

Noble Canyon

The first large prescribed fire in southern California was the 400-ha Noble Canyon Fire conducted June 13-14, 1978, at the beginning of the summer drought. The primary objective of this fire was the 100 percent reduction of the dead fuels and fine live fuels in 50 to 70 percent of the heavy chaparral on the site.

The Noble Canyon project presented a complex situation (fig. 1). The site included a variety of terrain and vegetation, including steep hill slopes covered by 60-year-old chaparral, California live oak woodlands along the riparian zones, and California black oak-Jeffrey pine woodland along the upper project boundary.

Preburn treatments included hand and mechanical line construction, understory burning in the oak communities, and a few preparatory burns (fig. 1). Existing or recleared roads were used as control lines along 7 km of the project boundaries. Handlines were also constructed through the chaparral over a distance of. 1.8 km. The mixed oak-pine woodland was understory burned when the annual grasses there were still green. Dead leaves and needle litter carried this fire with little reduction in live understory fuels.

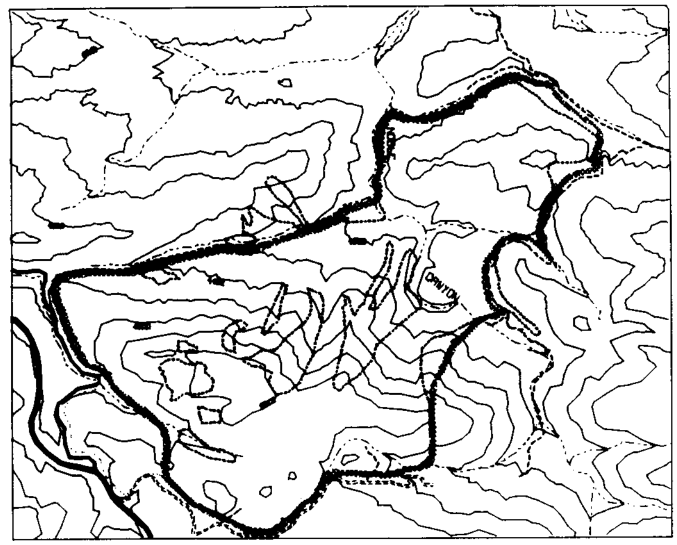


Figure 1--Topography and layout of the 400-ha Noble Canyon prescribed fire. The planned fire perimeter is indicated by cross-hatching, and the actual burn boundaries are shown by the dotted line. Unburned islands occurred on the main hill slope, and two out-of-bounds fire runs occurred at the west perimeter. The fire perimeter could have been easily extended to the paved road at the lower right and to the riparian area at the upper right.

Weather observations prior to the fire revealed that the normal southwesterly airflow pattern, humidity recovery, and the marine influence occurred by 1800 h, and the desert influence and low humidities (20 to 25 percent) returned at approximately 0200 h.

The prescribed fire was ignited by two crews using hand-held drip torches. They began by burning the upper project perimeter with a backing fire. Then they moved down the flanks and across the lower boundary, burning the lower reaches and most of the hill slopes with a head fire. Flame lengths on the hill slopes averaged 3 to 4 m with a maximum of 8 m.

Two small burns were ignited outside the project perimeter by spotting across areas of untreated riparian woodland. When these occurred, burning crews were held in place on the main fire while holding crews concentrated on control of the out-of-bounds fires. These were contained at a total size of 1.5 to 2 ha. No holding problems were encountered where the woodland understory had been previously prescribed burned.

With the onset of marine influence at about 1800 h, the relative humidity rose above 35 to 40 percent and fire could not be sustained in the standing chaparral. Recovery of higher relative humidity and lower air temperatures proved effective in suppressing fire activity.

Table 1--Site characteristics of four prescribed fire projects

Project and date	Objectives	Vegetation	Size	Slope	Elevation	Aspect	Chaparral stand age (approx.)
			ha	Percent	m		
Noble Canyon 6/13-14/78	Fuelbreak construction and fuel reduction	Mixed oak-pine woodland upper elevation	400	35 to 75 on hill slopes	1130 to 1600	All, slopes predominantly SW	60
		Mixed chaparral on hill slopes--Af., Cg, Qd					
		Qag woodland in major drainages					
Kitchen Creek 11/14-15/79	Fire effects research	Qd-dominated mixed chaparral--Qd, Cg, Af, Ag, Cl	2	60+	1340 to 1580	East	35
Troy Canyon 4/9, 14/80	Wildlife habitat and fuel reduction	Qag woodland with mixed chaparral on hill slopes--Cb, Af, Qd	120	40 to 50 on hill slopes	1280 to 1520	N-S trending canyon	35
Laguna Mountain 2/12 through 5/29/80	Reduce activity fuels, fuelbreak construction	P. jeffreyi--Q. kelloggii woodland, P. coulteri with Ag understory	140	0 to 35	1720 to 1800	Predominantly W-SW	70

[1]Af--Adenostoma fasciculatum, Ag—Arctostaphylos glandulosa, Cb—Cercocarpus betuloides, Cg—Ceanothus greggii, Cl--Ceanothus leucodermis, Qag--Quercus agrifolia, Qd--Quercus dumosa.

Table 2--Burning conditions for four prescribed fires

Project	Air temperature	Relative humidity	Windspeed and direction	Fuel stick	Live fuel moisture	Fraction of chaparral dead
	°C	Percent	km/h	Percent	Percent	Percent
Noble Canyon	15 to 26	28 to 50	5 to 21 NW, morning; SW, afternoon	4.5	75 (Af)	30
Kitchen Creek	12 to 15	21 to 27	Wind run--4.8 gusts to 24; NE	4.5	78 (Qd)	<20
Test fires:						
5/21/79	27	25	<8; NE-SE		130 (Qd)	
7/25/79	30	25 to 30	<13; NE-SE	5.25	100 (Qd)	
8/15/79	24	38 to 42	<6; NE-SE		88 (Qd)	
Troy Canyon	13 to 22	21 to 33	10 to 16 NW	9	80 (Af)	<25
Laguna Mountain	9 to 19	50 to 72 in P. coulteri-A. glandulosa stands	0 to 19 SE-SW	10 to 15+	80 to 110 (Ag)	60 to 70 in P. coulteri-A. glandulosa stands

[1]See footnote 1, table 1, for key to abbreviations.

From the experience gained in this project, it was apparent that the operation could have been improved in two areas. First, the construction of handlines could have been avoided on both the south and northeast perimeters. The fire could have been easily extended on the south to the existing county highway and an abandoned road (fig. 1) without creating traffic control problems. On the northeast, the perimeter could have been extended by firing along the canyon bottom north to the Noble Canyon Road. The existing handline on the northeast proved to be a poor location for firing since the backing fires ignited there progressed only poorly down or along the hill slope and the prevailing wind tended to carry firebrands across the line. Firing from an extended line in the canyon bottom would have been upslope and in the lee side of the hill. Second, the understory of the live oak woodlands could have been burned without the construction of handlines. Burning under relative humidities greater than 35 percent and with higher chaparral live fuel moistures during the early spring would have effectively contained the fire at the woodland perimeter.

The Noble Canyon project successfully demonstrated prescribed burning in old chaparral and rugged terrain. Fire intensities were moderate and there were no serious adverse effects. It provided valuable experience in the planning and execution of a large prescribed fire, and demonstrated the need for complete pretreatment operations, and the effectiveness of late afternoon humidity recovery in controlling fire spread.

Kitchen Creek Research Prescribed Fires

A series of prescribed fires conducted jointly by the Chaparral Research and Development Program of the Pacific Southwest Forest and Range Experiment Station and the Descanso District, Cleveland National Forest, was begun in the summer of 1979. This project was designed to provide replicated fires in mixed chaparral in which fire effects and biological recovery processes could be studied. It was located on east-facing hill slopes above Kitchen Creek on southern Laguna Mountain. The chaparral, last burned in a wildfire in 1944, consisted primarily of scrub oak, chamise, and two species of *Ceanothus*--*C*. *greggii* and *C*. *leucodermis* Greene. Standing biomass in stands of scrub oak was 18.5 MT/ha.

Our research needs required strip fires on a uniform slope and aspect, with the strips running perpendicular to the contours so that any sediment movement would be restricted to the strip. Handlines were cut on an intermediate ridge at the top of the slope, and some preparation burning was conducted on the flank of a hanging valley beyond this ridge. In the event of a major escape, containment could be made at the top of the main ridge where there is an age-class boundary with chaparral burned during 1970. Areas 30 m wide were hand cleared on the north and south project boundaries to provide both lateral fire containment and harvested areas for research purposes. Control lines 2 m wide were also cleared on the strip boundaries, and the dried brush was burned under high humidity conditions.

Burning trials conducted throughout the late spring and summer provided an opportunity to observe fire behavior as live fuel moisture in new growth was reduced from 130 to 78 percent under continuously dry weather conditions. These fires showed generally low flame heights and poor rates of spread despite relatively hot and dry weather (table 2), and indicated that relatively hot prescription conditions and mass ignition would be required to achieve the desired fire coverage and fuel reduction.

Three successful prescribed fires were conducted November 14-15, 1979 under relatively severe weather using a helitorch for ignition (table 2) (fig. 2). Strips measuring approximately 30 by 200 m were burned at the north end and center of the project on the first day. These fires were well behaved, showed slow runs with little lateral spread, and partially (60 to 70 percent) burned each strip after several passes of the helitorch.

Wind direction was from the northeast so the southern or leeward edge of each strip was ignited first, with successive passes of the helitorch moving further toward the windward edge. This ignition pattern gave the best possible visibility and minimized the chance of burning areas outside of the intended strip. Several passes of the helitorch were required to build heat and obtain good fire coverage.

Weather conditions during the second day remained similar to those of the first. However,

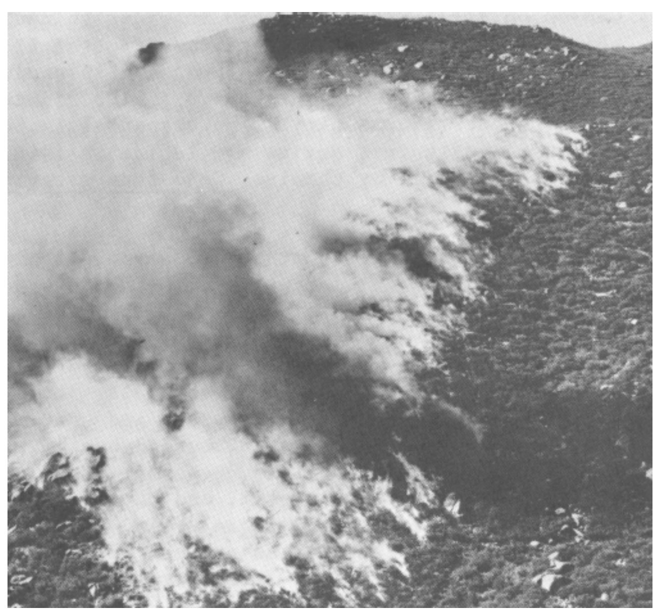


Figure 2--Strip burning with a helitorch in mixed chaparral at Kitchen Creek.

several of the brush piles from the adjacent hand-cleared area were inadvertently ignited by firebrands. Windspeed also increased to 7.5 km/h (gusts to 32 km/h), and fire spread into standing brush outside of the project boundary. During the burning operation, the Laguna Hot Shot crew was strategically located for fire control at the upper end of the project, and the helicopter used for ignition had a water bucket available at the helibase used for the operation. When fire spread beyond the project boundary, burning was suspended and these crews suppressed the out-of-bounds fire. Fire runs outside the project boundary moved slowly upslope and posed no control problems.

Our experiences at Kitchen Creek have demonstrated the importance of site fuel properties. Even though it is fully mature, the mixed chaparral at this site has species with characteristically low dead fuel accumulations and flammability. Windspeeds, humidity, and fuel moisture that might produce severe burning conditions in other chaparral community types are required to propagate fire in these stands. This prescribed fire was successful because we were able to conduct a series of burning trials under successively more severe conditions and refine our prescription. Fire runs did leave the intended project boundary due to spotting and increased windspeed, but we were fully prepared to deal with these. We also knew from past experience in this fuel type that such problems would not produce a large escaped fire. This project also demonstrated that a fire can often propagate in a stand only if a sufficient amount of heat is initially generated by use of natural fine fuels or special ignition techniques such as the helitorch.

Troy Canyon

A prescribed fire was conducted along Troy Canyon on April 9 and 14, 1980 in order to reduce the fine fuels in the understory and forest floor of a California live oak woodland, and to produce a mosaic of different age classes in the adjacent mixed chaparral community. The chaparral in this area was last burned during a wildfire in 1944, and was dominated by chamise, Ceanothus greggii, and scrub oak.

From past experience at Noble Canyon, Kitchen Creek, and elsewhere in this area, it was expected that prescription conditions with low humidity and moderate (12 to 20 km/h) winds would produce well-behaved fire runs. Humidity recovery late in the day was also expected to drastically reduce fire activity, especially on north- and east-facing slopes. This area was bounded on the east by areas of low-flammability chaparral and a moist, grass fuelbreak system, and on the west by a highway. These control areas would effectively contain any fire leaving the project area. For these reasons, no control lines were constructed.

The light fuels and forest floor under the oaks were ignited by hand-held drip torches. Approximately 6 km of understory burning was conducted over 2 days using a crew of six persons for ignition and needed suppression activities. Burning was conducted with a relative humidity ranging from 20 to 33 percent and 12 to 20 km/h winds out of the northwest. Live fuel moistures were generally at the lowest point of the year. Flower buds in the Ceanothus greggii were beginning to burst; otherwise, there was little new growth or rise in the dormant season fuel moistures apparent.

Good fire behavior and results were achieved. Fire did carry into some oak trees, but it burned in the canopy for less than 10 seconds and little damage was produced. A general pruning of the lower canopies was achieved. A partial reduction of the oak forest floor occurred (fig. 3), but a large input of fresh oak litter from scorched leaves was later observed. A second burn in 1 to 3 years may be desirable to further reduce litter accumulations in the oak woodland.

The understory fires were carried by the wind up the west-facing hill slopes and stopped at the ridge line with little carryover onto the adjacent east-facing slope. The latter slopes were shaded and apparently had higher live fuel moistures. Burning conditions would propagate fire uphill with the wind, but would not allow it to carry down the opposite slope. These chaparral fires achieved good fuels reduction and produced the desired mosaic pattern. Overall, about 30 to 50 percent of the chaparral along the canyon reach was burned. Burning was suspended when weather forecasts indicated developing Santa Ana wind conditions, and patrols were assigned to monitor the burned area for possible outbreaks.

This project successfully used vegetation and fuel differences on different aspects and late afternoon humidity recovery to effectively contain the prescribed fire. A substantial area of oak woodland and adjacent chaparral was burned in

Figure 3--Understory burning and fuels in a California live oak woodland at Troy Canyon.

rough terrain with only a small fire crew and no established control lines.

Laguna Mountain Understory Burns

The conifer–oak woodland found on Laguna Mountain is one of the most important areas for recreation and wildlife habitat in San Diego County. Large areas have no known fire history and support heavy accumulations of forest floor litter and downed woody fuels. The Laguna Mountain area is subject to less than one ignition from lightning each year,[6] but illegal campfires are a problem. Wildfires in this area would be expected to destroy the pine–oak overstory, and result in dense manzanita thickets on some aspects. A second wildfire burning in the regenerated manzanita and young pine could eliminate the pine from the site.

A series of prescribed fires was initiated in the area north of the Mount Laguna Air Force Station in February 1980 in order to reduce the accumulations of forest floor and manzanita fuels in the woodland and encourage regeneration of the forest species. Stand composition varies from an association of. Jeffrey pine and California black oak with some Ceanothus palmeri Trel. in the understory on more mesic slopes to open stands of Coulter pine (Pinus coulteri D. Don) with an Arctostaphylos glandulosa Eastw. understory on the drier west–facing aspects (fig. 4). The manzanita stand is about 2 m high with a biomass of 19 MT/ha. The underlying forest floor averages 8 to 10 cm in depth, and pine needle accumulations in the manzanita contribute to the stand's flammability.

The 185–ha project was subdivided into nine units ranging from 5 to 40 ha in size. Existing roads and trails were used to delineate units where possible, and hand clearing was used to complete the control lines. The most difficult prescribed burning problem in this project was in the areas of. Coulter pine and manzanita; caution was needed to avoid damaging the canopies of the overstory trees.

Firing with hand–held drip torches began with a backing fire ignited along the top of the ridge on the leeward side of a block. Good fire propagation and minimal tree damage in Coulter pine stands were obtained when the relative humidity was above 70 percent. Below this value the fire became too intense, and hose lays and handtool work were necessary to control flame lengths and prevent damage to the tree crowns. Some crown scorch did occur, but less than 5 percent of the trees were badly damaged or killed. Good reduction of fine fuels was achieved in the manzanita and forest floor, but heavy accumulations of the larger size class dead material remain. A second

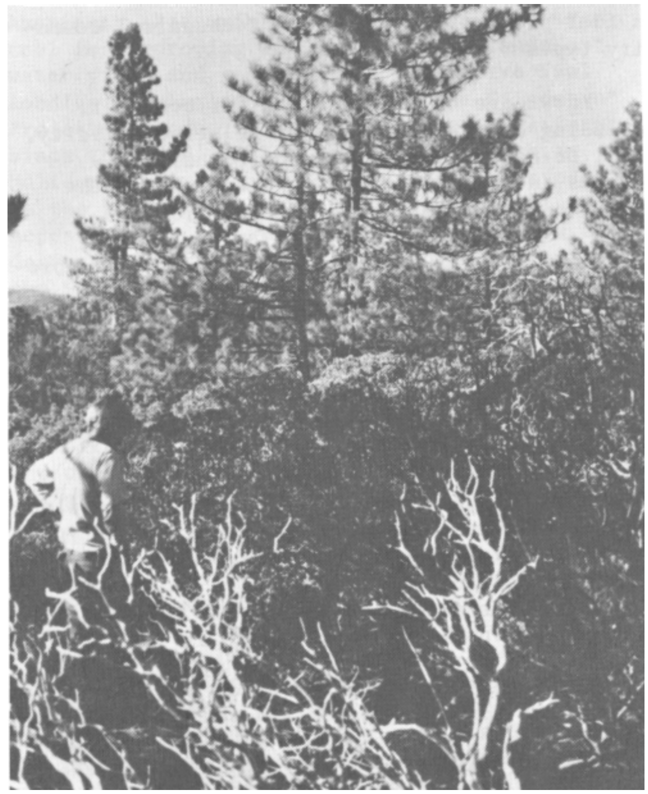


Figure 4--Coulter pine with manzanita understory fuels on Laguna Mountain.

or third fire is needed to further reduce forest floor and standing dead material accumulations, especially after scorched needles fall and provide new ground fuel to carry the fire. The manzanita is also rapidly resprouting, and subsequent fires could reduce its density and growth rates.

High humidity and low windspeeds are required to successfully burn mixed conifer–chaparral stands with heavy fuel loadings, vet good fuel reduction can be obtained in these areas with minimal overstory tree damage. Repeated burns may be necessary to achieve desired fuel reductions and wildfire protection for these valuable areas.

CONCLUSIONS

Prescribed fire is an important chaparral management technique that may be used to meet resource objectives including fire hazard reduction, wildlife habitat improvement, sediment management, and the reduction of adverse wildfire effects. It may be used successfully in a variety of chaparral fuel types and weather conditions. Successful prescribed fires require:

° Management by an experienced fire management officer

° Knowledge of stand fuel characteristics, particularly the proportion of fine dead fuels, total fuel loading, live fuel moisture, and the changes

[6] Personal communication from D. Studebaker, Cleveland National Forest, Alpine, Calif.

in fuel properties in different chaparral community types

° Knowledge of expected weather behavior, including diurnal patterns of relative humidity, onset of desert influence conditions, daily changes in wind direction, and especially the likelihood of severe burning conditions

° Knowledge of differences in fuels and microclimate with terrain, including north- and south-facing slopes or trends with elevation

° Consideration of transient (nonsteady state) fire behavior, including the use of special ignition techniques and light fuels to control fire spread and activity

° Careful planning of fire control lines along natural features such as ridge lines, fuel-type boundaries (for example, conifer-oak woodland or riparian woodland with chaparral), and chaparral age-class boundaries; or the use of weather and fuel conditions to contain the fire

The Laguna-Morena Demonstration has been a focal point for development and refinement of prescribed burning techniques in the chaparral. Careful application of prescribed fire and the knowledge acquired here has the potential for substantial resource benefits in chaparral throughout California.

LITERATURE CITED

Bissel, h. D.; Harris, B.; Strong, H.; James, F. The digestibility of certain natural and artificial foods eaten by deer in California. Calif. Fish and Game 41(1):57-78; 1955.

DeBano, L. F. Water repellent soils: a state-of-the-art. Can. Tech. Rep. PSW-46. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 21 p.

Dunn, P. H.; DeBano, L. F. Fire's effect on biological and chemical properties of chaparral soils. In: Mooney, h. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Gen. Tech. Rep. W0-3. Washington, DC: Forest Service, U.S. Department of Agriculture; 1977; 75-84.

Green, Lisle R. Prescribed burning in California oak management. Plumb, Timothy R., tech. coord. Proceedings of the symposium on the ecology, management, and utilization of. California oaks, June 26-28, 1979, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 136-142.

Green, Lisle R. Burning by prescription in chaparral. Gen. Tech. Rep. PSW-51. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 36 p.

Helfman, R. S.; Deeming, J. E.; Straub, R. J.; Furman, R. W. User's guide to AFFIRMS: time-share computerized processing for fire danger ratings. Gen. Tech. Rep. RM-15. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1975. 107 p.

Lillywhite, H. B. Animal responses to fire and fuel management in chaparral. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Gen. Tech. Rep. W0-3. Washington, DC: Forest Service, U.S. Department of. Agriculture; 1977; 368-373.

Martin, Robert E.; Dell, John D. Planning for prescribed burning in the inland Northwest. Gen. Tech. Rep. PNW-76. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1978. 67 p.

McBride, J. R.; Laven, R. D. Scars as an indicator of fire frequency in the San Bernardino Mountains, California. J. For. 74(7):439-442; 1976.

Parmeter, J. R., Jr. Effects of fire on pathogens. In: Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, August 1-5, 1977, Palo Alto, California. Gen. Tech. Rep. W0-3. Washington, DC: Forest Service, U.S. Department of Agriculture; 1977.

Philpot, C. W. New fire control strategy developed for chaparral. Fire Manage. 35:3-7; 1974.

Plumb, Timothy R. Response of oaks to fire. Proceedings of the symposium on the ecology, management, and utilization of. California oaks, June 26-28, 1979, Claremont, California. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1980; 202-215.

Rothermel, R. C.; Philpot, C. W. Predicting changes in chaparral flammability. J. For. 71:640-643; 1973.

Wells, W. Fire effects on sedimentation processes. In: Brooks, N. H., ed. Sediment management for southern California Mountains, coastal plain, and shoreline. Lab. Rep. 17D. Pasadena, CA: Calif. Inst. Tech., Environ. Qual.; [in press].

Use of the Helitorch in Prescribed Burning on the Mendocino National Forest[1]

Denny Bungarz[2]

Abstract: Prescribed fire has been used as a tool for improving wildlife habitat range and water yield and reducing the vegetative fuel loading in chamise chaparral on the Grindstone Project, Mendocino National Forest, California, since the 1950's. In 1979 the helitorch, a helicopter-borne ignition device, was introduced to the project, which increased the amount of acres burned, allowed burning on more days, and decreased costs. Policies and procedures for the use of this new tool were developed for both prescribed burning and as a backfiring tool on wildland fires.

Since the early 1940's prescribed fire has been used as a management tool on the Grindstone Project on the Mendocino National Forest in Northern California. The Grindstone Project is a chamise-chaparral area of 165 square miles managed for wildlife, watershed, range, and fire management objectives.

The Grindstone Project evolved out of a serious need to manage, or at least control, the thick, massive stands of brush that created catastrophic fire conditions. The disastrous "Rattlesnake Fire" of 1953, which claimed 13 lives, focused attention on the intensity of the problem.

The project site was chosen for several reasons. The vegetation, climate, topography, and soil conditions resemble other areas along the interior valley slopes of California. An equally important consideration was whether the area could be managed in a way that not only met the needs of forest and range resources, but would reduce wildfires as well. The Grindstone Project originated in the Grindstone and Rattlesnake drainages on the east slope of the California Coast Range Mountains in northern Glenn and southern Tehama counties.

Years of research, experimentation, administration, and application of brushland management techniques in the area have improved wildlife habitat and grazing for cattle, increased water yields, and reduced the threat of serious fire situations.

In addition to the Forest Service, other cooperators are involved in carrying out the original objectives of the program. The objectives that have been spelled out for the Grindstone Project have set the stage and served as guidelines for all those with an interest in and/or decision making responsibility for similar projects.

COOPERATION OF OTHERS

Back in the 1950's and 1960's, the United States Forest Service managed and disposed of the heavy brush. In the 1970's, the California Department of Fish and Game, and the Glenn County Fish and Game Commission joined forces with the Forest Service to identify the most suitable uses and the benefits that could be derived from the land and its resources.

In 1973, a new, expanded cooperative program focused on rebuilding past accomplishments and reemphasizing wildlife, grazing, watershed, fire management, and recreation needs. At that time, the Grindstone Project became a coordinated effort between the California Department of Fish and Game, the County of Glenn, local ranchers, and the Mendocino National Forest.

Today, this joint venture has expanded beyond Grindstone Canyon. It now includes the California Department of Forestry, Bureau of Land Management, Soil Conservation Service, other counties and many private landowners. Everyone with an interest or responsibility in the program works together to reach common objectives.

TREATMENT METHODS

Fire has always played a vital role in the Grindstone Project. By 1973, some 2,500 acres of brush had been converted to grass, at a cost of 85 dollars per acre. Controlled burning of small patches of brush, called "sprout burning", has enhanced wildlife, range, and watershed conditions. Through "sprout burning," old brushfields have become open stands of young brush, grass, and forbs.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Fire Management Officer, Mendocino National Forest, U.S. Forest Service, Willows, California 95988

The handheld drip torch served as the primary fire starter, and the construction of fire lines enabled control. Through experimentation a less expensive technique for controlled burning of brush was adopted. This technique, known as "prescribed burning," uses weather factors—wind, temperature, humidity—to determine the size of the burn. This has eliminated the need for costly fire lines. Prescribed burning to reach resource objectives is done under careful supervision and only when specific weather conditions prevail. By the mid-70's, burning brush, without converting to grass, cost between 10 and 30 dollars per acre.

The Grindstone Project could actually be called a "pilot area." The advances in fire technology learned and practiced here can be applied in Southern California, as well as other parts of the country. The Mediterranean-type climate and heavy brushfields also make the Grindstone a test area for other parts of the world where conditions are similar.

HELITORCH IN PRESCRIBED FIRE

The helitorch, a newly introduced fire starting device suspended under a helicopter was brought to the Grindstone Project in March 1979. This was the first use of this airborne tool for burning chaparral brush.

The helitorch consists of an aluminum frame, 55-gallon barrel, pump, and ignition device. The fuel used is a mixture of regular gas and fuel thickener, which forms "gelgas." The pilot activates the pump and ignition device which spreads the "gelgas" on the ground in golf ball size drops and ignites the brush.

The helitorch was tested on the Grindstone Project to determine whether it could improve the efficiency of existing burning methods. Under rigid test conditions, the helitorch proved it not only had a place in prescribed burning, but had the capability of being used in controlling wildfire as well. This testing on the Mendocino National Forest led to the development of policies and procedures for use of the helitorch in prescribed burning and wildland fires.

The cost and effectiveness of the helitorch greatly exceeds that of handheld torch burning methods. In March 1980, 1,700 acres of brush were burned in one day. Normally, fire crews using the conventional method would require an entire season to treat that much brush. Not only is prescribed burning less costly with a helitorch, 5 to 7 dollars per acre - it is more efficient and not as risky as brush burning by hand. The helitorch can ignite brush when conditions are wetter than normal, and this tool also permits the use of prescribed fires in areas previously declared unsafe or inaccessible.

MAJOR OBJECTIVES - BENEFITS AND ACCOMPLISHMENTS

1. To improve habitat conditions and increase wildlife populations.

Big and small game have prospered. For example, it is estimated that the Alder Springs Deer Herd population increased by 300 percent between 1973 and 1979.

2. To increase the grazing capacity of the range.

Through burning, old fields of brush are converted into open stands of brush and grass. More than 1,500 pounds of forage are produced on-site annually. One cow can feed on two burned-over acres for a month.

3. To increase the quantity of water.

Prescribed burning increases run-off by 100,000 gallons per acre per year. Part of the increase comes as run-off in the winter; part as an extended flow into the dry summer. The results are increased year-round springs, more water being stored off-site in reservoirs for longer water flow periods.

4. To reduce the threat of catastrophic wildfire.

After brush has been treated, wildfire can be controlled quicker and easier, with increased safety afforded to the firefighters.

5. To involve, communicate with, and develop an understanding among interest groups and cooperators.

Working relationships, efficiency, knowledge, and decision-making capabilities among these groups have improved.

6. To provide a demonstration area where people can be trained in the use of prescribed fire in brush lands, in burning without control lines, and in helitorch techniques, and where cost-effectiveness of these techniques can be tested.

Hundreds of people have been trained on the Grindstone Project. The cost-effectiveness of the various techniques used here has been monitored. The application and economic evaluation of these new skills is now being tested elsewhere.

7. To enhance recreation enjoyment.

Hunting and fishing opportunities increase with improved habitat and watershed conditions. Equally important is improved access and esthetic qualities of the landscape.

8. To achieve a favorable cost-benefit ratio for the project.

Analysis completed for a five-year study period (1974-1979) concluded that resource management benefits derived from the Grindstone Project totaled 638,082 dollars. This equated to a 7.85 dollar return for each 1 dollar invested.

HELITORCH IN WILDLAND FIRE SUPPRESSION

The Pacific Southwest Region of the Forest Service selected a committee of land managers and fire management personnel to develop a testing and evaluation procedure for use of the helitorch during the 1979 wildfire season in California.

The Committee recommended that two Forest Service helicopter modules be equipped and trained to operate with the helitorch for the 1979 fire season.

Helicopter crews on the Mendocino National Forest and the Cleveland National Forest were chosen as the first two crews due to their experience with the torch during the spring prescribed burning season and their location in the state (one north, one south).

The Committee developed testing and evaluation procedures requiring a trained Firing Boss with helitorch experience and a Fire Behavior Officer on each fire at which the torch was to be used. A helitorch firing plan and fire weather readings had to be prepared before the torch could be deployed.

The Committee also required that the Helitorch Firing Boss have positive control of the helitorch on firing runs by means of an exclusive radio frequency and visual contact during each run. This resulted in a second helicopter being used as the observation platform for the Helitorch Firing Boss. Safety regulations would not allow the firing boss to ride in the helicopter carrying the helitorch.

The helitorch was first used on a wildfire on the Nacimiento Fire on the Los Padres National Forest on September 4, 1979. It was subsequently used on six more wildfires in California during the 1979 fire season.

Summary

Following is a summary of the helitorch use:

Nacimiento Fire - Los Padres National Forest, September 4, 1979

Burned 100-150-acre island of chamise across a steep canyon from the fire line. Successful burn. Many firemen were able to observe.

Pinecrest Fire - Angeles National Forest, September 14, 1979

Used to burn out areas inaccessible or unsafe to do by hand methods, 40-60 acres. Burned ground fuels, did not burn canopy. Burn considered a success.

Pinecrest Fire - Angeles National Forest, September 15, 1979

Burned islands of brush under Mt. Wilson after fire made its initial run.

Sage (Monte) Fire - Angeles National Forest, September 16, 1979

Used helitorch to assist backfiring around Mt. Gleason Complex. Ignited 100 acres of chamise to draw fire away from buildings. Very successful. Changed wind direction and increased wind from 10 to 20 miles per hour. Observed by a number of City, County and California Department of Forestry Firemen. Also fired about 1/2 mile on preconstructed firebreak. Very successful operation.

Sage Fire - Angeles National Forest, September 17-18, 1979

Assisted in firing handline. Fire jumped line, used helicopter for water dropping and medivac.

Santa Ana Fire - San Bernardino National Forest, September 19-21, 1979

Assisted in hand line fire out operation. Moderate success due to Recon Helicopter unavailability. Burned out four miles of fire line in nine-year old brush. Used 600 gallons of jellied gas. Incident Commander said helitorch reduced manning that fire line by one full shift.

Otay Fire - California Department of Forestry, San Diego County, September 21, 1979

Helitorch used on about 500 acres of burnout. California Department of Forestry Firing Boss said results were very good.

It was apparent during the testing and evaluation period that the helitorch gives the wildland fireman more ability to ignite backfires or to burnout where it is impossible or unacceptably unsafe to fire by conventional methods. It also provides a much more rapid method of ignition which allows the fireman to take advantage of favorable weather conditions (i.e. wind direction and speed, humidity, etc.).

In prescribed burning with limited permissive burn days, the helitorch makes it possible to burn more area per burn day, and to burn in a more favorable prescription.

After a successful testing evaluation period the Regional Helitorch Committee met and recommended that the helitorch be declared an operational tool for use in prescribed burning and wildfire in California with a minimum of restrictions and conditions. The Committee also recommended that nine helicopter modules be equipped and trained to operate the torch during the 1980 wildland fire season. These recommendations were accepted and made policy by the Regional Forester on December 21, 1979.

Further information on the use of the helitorch in prescribed burning and wildfire can be obtained by contacting DENNY BUNGARZ, Fire Management Officer, Mendocino National Forest, 420 East Laurel Street, Willows, California 95988, phone (916) 934-3316.

Mechanical Treatment Impacts to Cultural Resources in Central Arizona: The Marden Brush Crusher[1]

J. Scott Wood[2]

Abstract: Forest Service management practices have the potential for impacting cultural resources in a variety of ways, ranging from complete removal to alteration of the environmental context of prehistoric or historic proper ties. Much of this impact is derived indirectly from activities designed not so much to manage the land surface (the location and contextual matrix of cultural properties) but the vegetation on that surface. This study examines one such activity--brush crushing--and its effects on archeological site integrity. Although much remains to be done, it demonstrates that mechanical manipulation of vegetation has the potential for serious disruption of cultural resources.

Cultural resources are usually defined as the locations and contents of prehistoric and historic archeological sites, historic buildings and settlements, and areas which were the scene of important historic incidents, such as battlefields or exploration routes. This definition is legally adequate for management purposes, but does not take into account the value of these properties. First of all, they represent the history and cultural heritage of the nation-an important value in and of itself. However, the primary importance of cultural resources is that they are the physical remains of former times. They represent the interaction of humans with natural and cultural environments. By necessity, then, they contain representations of the relationships within and between cultural/technological systems and environmental systems. In other words, cultural resources can provide us with information on the development of human social, economic, political, and technological adaptations to changes in demography and natural environment. They can also provide us with information on environmental conditions at various times in the past and on the extent to which environmental changes and present conditions may have been affected by human activity. They do this by virtue of their being composed of cultural and natural materials which can be shown to be associated in both space and time. Thus, besides documenting the development of cultural systems, they also document the development of environmental systems, both of which can be useful as baseline or comparative data for the management and use of those same environments today. That is, they could if land managers and other resource specialists would begin to take cultural resources management and archeological research seriously.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Forest Archeologist, USDA Forest Service, Tonto National Forest, Phoenix, AZ 85038.

Present-day management of cultural resources on the National Forests of the United States is not directed toward the recovery and use of these kinds of data, despite the long-demonstrated similarity (at least in the Southwest) between prehistoric land use patterns-some of which succeeded and many of which failed-and historic and modern American land use patterns. Instead, the job of cultural resources management in the U.S. Forest Service is to integrate cultural resources protection from damage and loss with the more production-oriented management activities of the Forests and their users. This job consists primarily of identifying the cultural resources of a Forest and then working out ways to avoid damaging or destroying them while attempting to manage other resources.

Direct impacts to the land surface, and thus to the cultural resources on and below that surface, are easy to see and understand. Any form of construction or resource exploitation which involves the removal, relocation, or compaction of soils, sediments, or mineral materials, or which require the modification of existing topography, has the potential to damage, destroy, or remove cultural properties and/or their artifactual content. Even the relocation of features and/or artifacts can significantly alter an archeological site, since it is from the spatial arrangement of artifacts and other cultural and non-cultural materials in surface and subsurface topographic contexts that behavioral and environmental patterns are identified. These patterns constitute the primary informational content of any prehistoric or historic archeological site. Since the goal of cultural resources management on Federal lands is ostensibly to protect and preserve this information, protection from impacts should be directed at preserving the integrity of behavioral contexts. Damage to individual artifacts is one type of impact to the data-producing value of a site, and, as such, it merits study and prevention (c.f. Gallagher 1978). However, it appears to be less of a factor in data loss than dislocation, as the patterns of behavior involved in making an artifact are much simpler and less informative about human organization and adaptation than are the behaviors which resulted in the eventual location of that artifact and its associations with other natural and cultural materials. It has been demonstrated by several experiments (DeBloois, Green, and Wylie 1974, Gallagher 1978) that tractor travel over an archeological site is extremely destructive to surface artifact spatial relationships and locations; markedly more so than to artifact integrity. Thus, surface disturbances such as road building, log skidding, scarification, fence building, machinery operations, pipeline trenching, posthole digging, stock tank construction, parking lots, recreation areas, etc. are all activities or facilities which could damage or destroy the contents and context of any cultural property they encountered. Less obvious potential impacts can also result from activities not specifically designed to modify the land surface, but rather to modify the vegetative cover of that surface. Examples of such practices include chaining, juniper pushing, crushing or "roller chopping" as it is sometimes known, burning, and the use of herbicides in order to either change the composition of the vegetation or to eliminate or reduce cover to lessen fuel accumulation risks for fire management.

Several of these activities would seem to present fairly straightforward dangers to cultural properties. The violent uprooting of trees by chaining will necessarily damage any cultural features that might have trees growing on or near them. Others are less apparent or are indirect; both burning and herbicide use, by removing cover, may initiate erosion that could damage cultural properties. In addition, burning will destroy most standing historic structures, many of which are built primarily out of wood, and it may, under certain circumstances, affect the ability of some heat-sensitive cultural materials to be dated. Because of the lack of information about the effects of these vegetation manipulation practices, current Forest Service management policies, at least in the Southwest, generally assume that they will either damage cultural resources or that their indirect effects are not substantially more of a threat than natural processes. Thus, it is possible that some damages are being overlooked while other activities which may do no damage are being restricted. To provide efficient management of all resources, it would be best to know just what kinds of impacts can be expected from any particular kind of activity. It was in this context that the Prescott National Forest in Arizona requested a study of the impacts to be expected from their extensive and continuing program of chaparral conversion by mechanical treatment-specifically, the use of the Marden Brush Crusher.

Little systematic observation of mechanical treatment impacts to cultural resources has been made to date, other than for several of the more obvious ones-chaining (DeBloois, Green, and Wylie 1974) and scarification (Gallagher 1978). No study had been made for treatments specific to the chaparral vegetation type prior to this one. The purpose of this study, therefore, was to develop and describe a procedure by which any mechanical impact to surface or subsurface features and artifacts could be defined, and at the same time to identify the impacts of brush crushing on cultural properties. Specifically, three types of cultural property were selected to be observed for effect: surface artifact scatter, surface (low relief) architectural features, and subsurface artifactual materials. This study was made in the simplest manner possible, by means of "before and after" observational tests.

The area utilized for this study was a 60 acre parcel of Prescott National Forest land, located on the Walnut Creek Ranger District of that Forest near its Camp Wood Administrative Site. This area had been selected for conversion from a chaparral to a grass type vegetation and was surveyed for cultural resources clearance in 1978 (Wood 1978). The archeological survey also served to identify properties suitable for a test of the impacts to be expected from the mechanical treatment proposed for the parcel. The remainder of this paper will describe the results of the impact study carried out by myself and Harlow Yaeger of the Prescott National Forest in 1979 (Wood and Yaeger 1978, Wood 1979).

Vegetation in the study area was primarily turbinella oak and manzanita chaparral with a discontinuous overstory of alligator juniper, Emory oak, and an occasional pinyon, broken by stringers of ponderosa pine in the basins and drainages. The chaparral understory, locally quite dense, also contained some mountain mahogany, Fendler ceanothus, datil yucca, silktassel, beargrass, prickly pear and mammilaria cactus, and occasional patches of ring muhly and grama grasses. Substrate in this hilly area was primarily decomposed granite, ranging from rocky residual clay sediments to more homogenous loamy colluvium. Bedrock outcrops of granite were common.

The conversion project which took place in the study area involved the use of a Marden Brush Crusher, a non-motorized device consisting of two slightly offset tandem rollers fitted with hardened alloy "paddlewheel" blades. It is generally pulled as a trailer by a large bulldozer-type tractor. The twelve blades on each roller are of two different widths, providing an uneven gait, and the offset between rollers provides for additional churning of the surface and a variation in blade angles at contact. The combination of these features and a gross weight of 44,000 pounds (20,000 kg) results in the rapid removal of chaparral-type plants. However, this device can operate only in relatively low-slope areas without a substantial tree canopy, and where the ground surface is free of exposed bedrock or talus. Rocky surfaces tend to dull and break the blades. Thus, its normal operation will often leave a pattern of irregular patches of crushed and uncrushed stands of brush, reflecting variation in topography and substrate.

IMPLEMENTATION AND DESIGN

Surface artifacts and architectural features on cultural properties in central Arizona have a long history of disturbance and modification by various land use practices, including grazing, farming (in some areas, for nearly 2000 years), logging, mining, recreation, vehicle travel, and pot hunting (the deliberate vandalism, destruction, and looting of archeological sites). Added to this is an even longer history of natural impacts such as weathering, erosion, soil movement, and alluviation all of which serve to alter the physical characteristics and/or locations of cultural materials. Sites located on hills or on shallow soils are especially subject to this form of alteration of behavioral contexts (McGuire 1977). Nevertheless, a Marden blade applies a considerable amount of force, and so must be expected to have at least the potential for having at least as much of an effect on the structural integrity of artifacts and features as any of the "recognized" impacts.

In response to the problems and values discussed here, this study was designed to test what appeared to be the two most critical potential impacts expected from the use of the brush-crusher: surface artifact and architectural displacement and subsurface artifact breakage and displacement, taken as an indicator of all subsurface impacts.

Surface artifact damage was also recorded in the form of breakage, used as a simple means to represent all the various potential types of physical alteration which could be regarded as damage to the informational content of a site.

At this stage in the development of impact studies, it was felt best to emphasize the observation and assessment of dislocation impacts to the presence, absence, and distribution of cultural materials and architectural features, since these factors relate directly to a site's behavioral/informational integrity. A study of this type, while it may not be suitable for quantified predictions, will nevertheless allow generalizations to be made concerning the type of impacts to he expected in surface-disturbing chaparral management activities. Thus, the test program was designed to observe three specific aspects of potential impact. The first two involved recording the displacement, breakage, addition, and loss of (1) surface artifacts and (2) structural components (wall stones) located within designated one meter square test plots. The third aspect of the program was to investigate subsurface impacts. To do this, a series of simple artificial test situations were constructed in the study area by burying sets of large and small ceramic flower pots to simulate subsurface artifactual remains. Specific burial locations were selected according to considerations of soil texture and vegetative cover, as were the test squares. Each burial contained two sets of pots at different depths. These depths were determined on the basis of excavation data from similar environments nearby. In order to control for the effect of time on surface artifact distribution, all the surface plots and burials were laid out two months before the crushing operation was scheduled to begin.

The location selected as a control was a single room rock-outlined pit house habitation site. It was selected because it contained a well-defined architectural feature, surface artifact scatter, and showed a strong dichotomy between areas with and without brush cover and having rocky and fine textured soils. These criteria were used for all test selections in the study. The only impacts expected here were time, rainfall, and the curiosity of other Forest personnel.

The location selected for the architectural tests was a fairly well-defined architectural feature with artifact scatter and little brush cover. The area selected to test impacts to surface artifact scatter contained a fairly dense concentration of surface artifactual material situated near the architectural test locus. It showed a strong dichotomy between brush cover and bare ground within a minimal area as well as a wide variety of artifact types.

In order to test impacts to subsurface materials and features, a series of control and test burials was laid out at various points; the control site and in a separate testing locus some distance away. The burial tests and controls were all placed according to the same criteria as the surface plots-brush cover and bare ground--with additional variations in depth and soil texture.

THE CRUSHING OPERATION

The Marden device used in this study was pulled by a D7H Caterpillar tractor. The strategy utilized was more or less representative of standard Marden crushing operations. It involved a series of concentric, overlapping paths being followed throughout the treatment area. Those areas too steep for safe operation (above 20 percent slope) were avoided, as were areas where the vegetative cover was primarily trees or that were too rocky for the somewhat brittle blades on the crusher. The end product of this strategy was a natural-looking mosaic of pine-oak stringers, brushy hillsides and outcrops, and crushed flats which should eventually be grassed over.

The crushing of test plots and burials was more or less a sample out of a normal crushing operation. Owing to unfortunately restrictive time and budget limitations (so what else is new?) the test loci could not be crushed entirely in the overlapping pattern usually followed. Instead, carefully choreographed paths were laid out through them so that the crusher made a single pass over each test plot and burial. Because of this, the results of these tests must be seen as representing only the minimum level of impact that might result from use of the Marden device.

RESULTS AND COMPARISONS

Fifty-two surface artifacts were originally identified in the four surface test squares. Almost 90 percent of these were impacted in some way. Sixty-two percent of these impacts involved the loss of artifactual materials from the observable surface inventory. Next in importance were the displacement of original material and the addition of new material brought up from below the surface. Breakage was the least frequent impact. The patterns of change at the control site were exactly the opposite. Natural causes produced primarily breakage of artifacts in place-simple deterioration, with minor relocation by runoff and periodic additions to surface inventories from subsurface materials. Below surface, no displacement of materials was observed nor were there any changes in the structure. As expected, these observations indicate that the natural transformation of cultural features and materials into what are known as archeological sites is a slow process which preserves much of the original integrity of the property. The pattern of change produced by Marden impact is characterized by a sudden loss of a large amount of the surface artifact inventory with little replacement from the subsurface population. This, combined with breakage and displacement, means a sudden change in 90 percent of the surface artifact inventory and nearly half of the near-surface buried material. In addition, disruption of surface architectural remains runs from 40 to 100 percent, depending on the amount of exposure. In the case of a very shallow site with little or no post-occupation deposition, this would constitute a near-total disruption of the visible portion of that site. The recognition of any site's character-shallow or deep-would be seriously impaired if suddenly over half of the visible artifacts were to disappear. And whatever its direct effects are on a site, the Marden device invariably opens and softens soil surfaces, making them susceptible to erosion and to subsequent further artifact displacement by mixing from grazing, vehicular travel, and even walking.

Factors in Assessing Impacts

Damage from the Marden device as observed here was dependent on four factors: 1) contact with the blades; 2) soil texture; 3) depth; and 4) artifact size. Contact with a blade invariably produced both surface and subsurface artifact damage or displacement. Rocky soils or soils with expansive clays produced the highest percentage of subsurface damage, while fine soils produced the most damage (by displacement) in surface inventories. However, it must be noted that the presence of residual clays and large numbers of rocks in a surface soil is usually a result of natural, in place development rather than cultural deposition, though this is not always the case. While it was expected that certain amounts of cover would act to provide a protective cushion over cultural surfaces and fill, the results of the tests indicate little or no difference due to cover. It can be said, then, that cover has no effect and is therefore not a factor in the amount of impact. The third factor, depth, proved highly useful, as damage was higher in shallow burials than in deep, and highest on the surface itself-25 percent of deep burials were impacted, 75 percent of shallow burials, and 86 percent of the surface inventory. Clearly, impact increases as depth decreases. Finally, there was the factor of artifact size. The ratio of large to small buried pots broken (by expansive clay) at the control locus was 3 to 1; at the test burial locus, it was 5 to 1. As well, only the larger surface artifacts were ever physically damaged. This too indicates a strong pattern-larger artifacts have a higher susceptibility to damage. In some cases this was apparently due to larger area of potential blade or rock contact, while in others it may have been due to the larger artifact's having had less structural integrity or resistance to stress than a smaller one of the same materials. Unfortunately, these observations must remain tentative and inconclusive, as much more variability was encountered than expected in soil, surface, and brush composition. Still, it can reasonably be said that under the variety of conditions tested, nearly 90 percent of the cultural surface and 50 percent of the subsurface inventories were damaged by crushing.

SUMMARY AND CONCLUSIONS

Three direct impacts of brush crushing to cultural properties were identified from this study: 1) disruption of the spatial relationships of surface and subsurface artifacts; 2) disruption of structural elements in surface and subsurface architectural features; and 3) physical damage to surface and subsurface artifactual materials. The disturbance of artifact distributions is seen as the most critical of these, since disrupting or destroying the spatial context of these remains severely limits any attempt to characterize and identify not only specific behaviors at sites but sites themselves and regional and the regional and chronological patterning of occupations and developments. Indirect impacts to these properties may also arise from erosion and, in some cases, from increased site visibility, which tends to invite vandalism. This being the case, it must be recognized that the use of a Marden Brush-Crusher in areas containing cultural resources cannot be allowed without some measure of protection being given to those resources.

Acknowledgements: This paper represents a summary of the original report (Wood 1979) which has been published in the USDA Forest Service Southwestern Region's Cultural Resources Reports series (No. 27). Beyond recognizing the support provided by the Prescott and Tonto National Forests, I would like to thank my crew, Raven MacReynolds and Jim Mackin of the Prescott National Forest and, especially, Harlow Yaeger, formerly with the Prescott National Forest, without whose knowledge and expertise this project could not have been carried out. I would also like to acknowledge the editorial assistance of my wife, Patti Fenner, a range conservationist with the Tonto National Forest, who aided greatly in adapting the paper to this forum.

LITERATURE CITED

DeBloois, Evan I.; Green, D.F.; Wylie, H.G. A test of the impact of pinyon-juniper chaining on archeological sites. Ogden, Utah: Intermountain Region, Forest Serv., U.S. Dep. Agric.: Archeological Reports; 1974.

Gallagher, Joseph G. Scarification and cultural resources: an experiment to evaluate serotinous lodgepole pine forest regeneration techniques. Plains Anthropologist 23-82, Pt. 1: 289-299; 1978.

McGuire, Randall H. Prehistoric subsistence at the Kiewit site, northwestern Arizona. Tucson, Ariz.: The Kiva 43(1):49-82; 1977.

Wood, J. Scott. An archeological survey of a brush control crushing area near Camp Wood administrative site, Walnut Creek Ranger District, Prescott National Forest. Prescott, Ariz.; Prescott N.F. Cult. Res. Inventory Report (Manuscript); 1978.

Wood, J. Scott. Chaparral conversion and cultural resources on the Prescott National Forest: an experimental study of the impacts of surface mechanical treatment by Marden Brush-Crusher. Albuquerque, New Mexico: Southwestern Region, Forest Serv., U.S. Dep. Agric. Cultural Resources Reports 27; 1979.

Wood, J. Scott; Yaeger, Harlow. Research design for an experimental test of the impacts on archeological sites of chaparral conversion by Marden Brush-Crusher, Camp Wood, Walnut Creek Ranger District, Prescott National Forest. Prescott, Ariz.; Prescott N.F. Cult. Res. Inventory Report (Manuscript); 1978.

Fire Behavior and Management in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Serena C. Hunter and Charles W. Philpot[2]

Our speakers have based their presentations on practical fire management problems and solutions in Mediterranean ecosystems. Managers in these areas must be concerned about public safety, costs, offsite damages, short-term weather changes, unique resources, and a host of other problems when designing fire management programs. Successful fire management in these ecosystems requires an understanding of both fire behavior and ecological processes and their effects upon one another. Knowledge of these factors is important for both fire use operations and fire suppression. Managers must constantly be on the lookout for tools that can help them understand, predict, and control fire behavior and fire effects. These tools can aid them in planning and carrying out successful fire management programs.

FIRE BEHAVIOR PREDICTION

One promising tool discussed during this session is a fire behavior prediction system. Albini and Anderson described the development and implementation of fuel and fire behavior models for chaparral. The models are part of a system now in operation in southern California that is designed to quantify and predict wildland fire behavior. It takes into account the same fuel factors (loading and live/dead ratio) and environmental factors (wind, slope, and fuel moisture content) that the other speakers have emphasized as being important in fire behavior.

The system is still in the process of being tested and debugged to improve its predictive ability. The complexity of the system makes it difficult to determine whether less than satisfactory predictions are caused by inherent deficiencies in the model or by inaccurate descriptions of fuel, terrain, and weather conditions at the fire site. If the latter is the case, then its success will depend on improved monitoring of fuel and weather conditions during fire season. Improved mapping of terrain may also be necessary. It is also likely that more training will be required so that fire managers fighting fire or using fire will be able to fully utilize the capabilities of fire behavior predictive models.

PRESCRIBED BURNING

Prescribed fire is beginning to receive a more appropriate emphasis in Mediterranean ecosystems in the United States and Europe. Prescribed fire has been an integral part of Mediterranean ecosystem management in Australia for years. Although some of our speakers pointed out problems associated with prescribed burning, all were enthusiastic about its potential.

Denny Bungarz presented a number of multifunctional land management reasons for using prescribed fire and showed us how they have been demonstrated by the Grindstone Project on the Mendocino National Forest. Benefits include improved wildlife habitat, increased grazing and water yield, enhanced recreational opportunities, and reduced threat of wildfire. And best of all, these benefits are not mutually exclusive. Fire has increased the Grindstone area's potential for multiple use. The keys to the success of the Grindstone Project have been the long-term commitment and cooperation of the groups and agencies involved and the willingness to try new methods of dealing with the chaparral.

Both Mike Rogers and Pierre Delabraze point out that percent dead material is probably the most important vegetative characteristic in determining how intensely a prescribed fire or a wildfire in chaparral will burn. It is on this premise that the concept of age-class management of fuels, described and endorsed by Mike, is based. By maintaining more young stands and by preventing older stands from extending over large continuous areas, the threat of large, high-intensity fires can be reduced. Prescribed fire is the most promising tool for safely reducing fuels and achieving a desirable age-class distribution.

As Mike pointed out, one of the problems with using prescribed fire to achieve and maintain a desirable age-class distribution in southern California is that there are very few days during the year when a burn can be both safe and successful. Because of the rough terrain and dense brush involved, not nearly enough vegetation can be treated each year using conventional ignition methods. The helitorch that we saw in Denny's slide-tape promises to be at least a partial solution to this problem.

With the helitorch, there is the potential for safely burning hundreds of acres on a single day for as little as $5 to $7 per acre. As we learn to use the helitorch in various fuel types and weather conditions, we should move cautiously, taking the time to get the bugs out. And, undoubtedly, as we find solutions to one problem,

[1]Prepared for the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Forester and Assistant Director, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

other problems will pop up. However, there is a great deal of optimism that at last we have a tool that will make age-class management of fuels in southern California's chaparral truly feasible.

INTERNATIONAL FIRE MANAGEMENT PROBLEMS

Dr. Barber has shared with us some of the problems of fire management in rural Victoria, Australia, and the way that the Country Fire Authority deals with them. When reading Dr. Barber's paper before the Symposium, we could not help making comparisons between the fire situation "down under" and the situation here in southern California. The area within the jurisdiction of Victoria's Country Fire Authority is roughly equivalent to one-third of the State of California--approximately 57,000 square miles. However, whereas southern California's population is greater than 10 million, Victoria's total population is only 3,650,000 with less than one-third of these people living in the rural areas protected by the Country Fire Authority.

Dr. Barber's description of weather and climatic influences on fire sounded very familiar. Like us, the Victorians experience dry summers and wet winters. Hot, dry inland winds, comparable to our Santa Ana's, are the most important weather factor influencing the outbreak and spread of fire. Most large fires in southern Australia, as in southern California, occur on a few days of extreme fire danger. On those days, it is impossible, in either country, to control all fires or to prevent disastrous losses.

The ways in which Victorians and southern Californians are organized to combat the wildfire problem also make an interesting contrast. Country Fire Authority volunteers are eagerly enlisted and trained; they number over 100,000 and outnumber permanent personnel by almost 200 to 1. Southern California's firefighting forces are made up entirely of government-paid personnel. Both the U.S. Forest Service and the California Department of Forestry have policies prohibiting the use of volunteer firefighters.

Interestingly enough, Victoria's Country Fire Authority receives only one-third of its funding from government sources. The other two-thirds come from insurance companies. Whether or not these insurance companies are required to contribute to the Country Fire Authority or do so in support of their own best interest is not clear. Although community volunteer fire departments in the United States undoubtedly receive some of their financial support from private insurance companies, most firefighting forces are strictly government funded. The twin questions arise: "Is government doing all it should be doing to combat the fire problems in Victoria?" and "Should the private sector be more involved in dealing with the fire problem in the United States?"

Many of the fire problems faced in France's Mediterranean region are also comparable to those faced by managers in California and Australia.[3] The north wind that causes severe fire problems in France is known as the mistrel. Like our Santa Ana's, these are high-pressure gradient winds carrying very little moisture. During the wet season, heavy rainfall combined with the loss of vegetation from fire produces heavy property damage along the coast in Marseilles. This is a problem with which Californians are all too familiar.

Southern France has large expanses of brush-covered hills that in many ways are very similar to those found in southern California. Until the last few centuries, however, the vegetation on many of these sites consisted of great stands of commercial oak and pine. These stands were eliminated by repeated harvesting and indiscriminate wildfire, and were replaced by brush. Although there is evidence that some forest sites in southern California have been converted to brush for these same reasons, the area involved is not nearly so extensive. The French are currently reforesting large areas with conifers.

Early in the 1800's, fire was used to clear the forests of France. But conditions for burning were not controlled, and the results were sometimes disastrous. Subsequently, laws prohibiting the use of prescribed burning were passed. French foresters are now in the process of learning to predict and control fire behavior in various vegetation types so that prescribed burning can again be used safely there. Pierre Delabraze detailed some of those efforts for us.

IMPACTS OF FIRE MANAGEMENT PROGRAMS

Land managers around the world must be concerned with the social, economic, and environmental impacts of their fire management programs. That is why new tools and techniques such as prescribed fire, biomass harvesting, and the helitorch must be so thoroughly tested before they are made operational.

All impacts--not just effects on personal life and property, but also effects on socially valued goods such as cultural resources, wildlife, and long-term site productivity--must be given weight in fire management decisions. For example, Scott Wood's study suggests that equipment used in site preparation, biomass harvesting, or brush crushing can do irreparable damage to archeological resources. What about fire--is it just as damaging? How do the effects of wildfire compare to the effects of prescribed fire where cultural

[3]Chaparral Vegetation Management Program International Study Group. Fire and fuel management in the Mediterranean ecosystems of Spain and France. 1979. (Unpublished report).

resources are concerned? How do we identify and protect areas of archeological value? Are there ways of protecting these cultural resources without greatly disrupting our fire management activities? Answers to these questions and others regarding impacts and potential impacts of management activities could help to make our fire management programs more sound.

CONCLUSION

The opinions presented by the speakers in this session are their own and do not necessarily represent the policies of their countries or organizations. The same is true of this summary paper. We have taken the liberty of using and interpreting as we saw fit the information presented during the session. We hope that no misinterpretations have occurred.

To summarize, we have reviewed the factors that affect fire behavior in Mediterranean-type ecosystems. Using our knowledge of these factors, we are beginning to be able to predict wildfire behavior with timesaving computer models. Our increasing understanding of fire behavior is also giving us the confidence we need to use prescribed burning safely and successfully to achieve fuel reduction. We are getting closer to our goal of age-class management on chaparral lands. But, as we move toward this goal, we must be on the lookout for social and environmental problems, such as damage to cultural resources, that implementation of our goal might aggravate.

Planning

Planning

The Challenge of Vegetation Management at the Local Level[1]

Thomas Oberbauer and Michael Evans[2]

Abstract: Several Mediterranean ecosystem vegetation types in Southern California have been significantly reduced in extent and viability in recent years. These reductions have occurred because of conversion to agriculture, residential uses and support facilities, and habitat management by public agencies. Measures to control loss of sensitive vegetation on privately owned land are limited. Resource Conservation Areas (RCAs) identified in the County General Plan are one planning tool to distinguish areas of outstanding resource value. San Diego County has applied several techniques to conserve such scarce resources, including large or clustered lot zoning or open-space easements.

Planning for vegetation management at the local level can be as complex a process as at the State or Federal level. Most Mediterranean vegetation occurs as a mosaic of vegetation communities arranged in an intricate manner over a variety of topographic features, soil types and climatic patterns. In many Mediterranean climate areas, developments for agriculture, suburbanization and industrial uses have substantially intruded into areas with native shrub ecosystems. This has resulted in substantial losses of certain vegetation and wildlife habitat types and has increased wildfire control problems considerably.

A variety of tools and techniques can be utilized to help insure that some resources in Mediterranean ecosystems can be preserved in a naturally viable state. In the following, we examine examples of sensitive Mediterranean ecosystems from the San Diego County region, and describe some of the tools and techniques that may be used in protecting these ecosystems at the local and regional governmental level.

VEGETATION TYPES

Climate conditions in San Diego County, California, range from relatively dry coastal areas with warm dry summers and cool winters to moist mountain areas with cold winters and warm summers. During the late summer and early fall, hot dry wind conditions occasionally occur; these conditions are a major factor influencing the occurrence of fire. Soil factors, precipitation, temperature patterns and climatic evolution have resulted in a diversity of vegetation communities classified as Mediterranean-like. However, a number of these vegetation community types have been significantly reduced in extent and quality within recent historic times. Thus, some of these communities have become increasingly sensitive to human-caused disturbance.

Examples of sensitive Mediterranean vegetation communities in San Diego County include Coastal mixed chaparral or maritime chaparral (Axelrod 1978), the Diegan subunit of Coastal sage scrub (Griffin 1978), Southern oak woodland, Riparian woodland/gallery forest, Vernal pools (Barbour and Major 1977), vegetation adapted to unique soils (eg., derived from gabbro and metavolcanic rocks), and other Mediterranean ecotypes that serve as habitats for wildlife sensitive to disturbance or of limited distribution.

Coastal mixed chaparral or maritime chaparral is a woody shrub community found in cool coastal areas which contains a large number of endemic species of plants. Coastal mixed chaparral may never have been widespread but it has been further reduced by development so that today it exists on about 2000 acres along the coast of San Diego County.[3] Coastal sage scrub is a drought-deciduous shrub community that has been heavily impacted by development with as much as seventy percent of its former areal extent obliterated.[3] It previously occurred in summer-warm valleys near the coast and interior. Vernal pools are a specialized Mediterranean vegetation type in which plants are adapted to winter inundation and summer desiccation. Shrub vegetation, gabbro and metavolcanic soils are often habitats of very limited distribution found in the foothills of San Diego County. Gabbro and metavolcanic habitats, as well as vernal pools, contain a large number of restricted endemic species of plants.

Sensitive Mediterranean habitats which support specialized wildlife include Riparian

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Environmental Management Specialists, County of San Diego, 5201 Ruffin Road, San Diego, California 92123

[3]Oberbauer, in prep.

and Oak woodlands as well as some micro-habitats of more widespread community types. For example, the Gray vireo (Vireo vicinor) appears to be limited to mature stands of montane chaparral in the southwest United States.

FACTORS INFLUENCING VEGETATION

The vegetation communities in San Diego County considered sensitive are spread throughout all portions of the region. This distribution pattern undoubtedly occurs in other Mediterranean climate areas throughout the world. Unfortunately, in areas with pressures for development, this pattern makes it extremely difficult to protect these resources with large viable habitat areas.

The recent loss of vegetation communities in the San Diego region has resulted from destructive human uses, including over-grazing, sand mining and flood control, improper fuel management and inundation from dam building. However, agriculture and residential development have been the primary causes of the destruction of vegetation communities in the San Diego region. Clearing for avocado planting has destroyed nearly 35,000 acres of chaparral in northwest and central San Diego County in recent years[4]. At the present time, agricultural production on marginal soil and steep slopes continues to cause the loss of substantial amounts of chaparral and sage scrub each year. These areas would otherwise probably be unbuildable for residential uses because of the steep slopes. Potential future crops, such as Jojoba (Simmondsia chinensis) or eucalyptus for firewood, have the potential to substantially destroy even more Mediterranean vegetation.

Land subdivisions for residential and commercial/industrial development is a major cause of the loss of Mediterranean ecosystems, particularly near the coast and in the coastal foothills of Southern California. In these areas, habitat loss has been 94% of the vernal pool habitat, 70% of Coastal sage scrub, and 60% of Coastal mixed chaparral[3].

Economics and traditional building practices have entailed carving the land to fit the use, necessitating mass grading, sometimes with cut or fill banks over 100 ft in height. This results in direct loss of vegetation for grading and indirect associated impacts including siltation, erosion, off-road vehicle impacts, increased wildfire frequency, introduction of cats and dogs, indiscriminate trash dumping, etc.

Besides "urbanization", with dense types of development, another significant factor in the loss of Mediterranean ecosystems in the San Diego region is rural residential development (at a density of less than one dwelling unit per acre). "Rural development" results in widely scattered residential uses interspersed in chaparral or sage-scrub or live oak woodland communities. This pattern of development also disperses the increased potential of wildfire starts into the surrounding shrub vegetation. The widely spaced nature of these residential uses makes them substantially more difficult to protect by fire-fighting agencies when fires do erupt. This pattern of development has resulted in the need to reduce the wildfire potential over very large areas of scrub communities, to reduce fire damage to a few scattered, although monetarily valuable, residential improvements.

Large-scale vegetation management plans have been proposed for numerous locations in the Mediterranean shrub communities of Southern California, in an effort to reduce the potential life and property losses associated in rural areas with large wildfires. These plans usually include, as a major factor, a reduction of the volume of flammable vegetative material (plants or fuel) and to compartmentalize the vegetation into generally controllable cells of modified vegetation. Techniques of modification range from hand and mechanical cutting, heavy grazing by goats, and more recently, controlled burning. These types of vegetation modification usually result in altered habitats favoring wildlife species adapted to transitional habitats. These techniques are also used for locally increasing populations of game species. However, enhancing habitats for one species usually means some detrimental effect on other species adapted to the original habitat. Inasmuch as the original habitat may be depleted already, these detrimental effects may he quite serious.

The frequency with which natural fires occurred in the past has not definitely been established for the majority of vegetation types and geographic regions. Furthermore, the effect of fuel or habitat management techniques on sensitive plant and animal species is poorly known. Because of underfunding and the short time available for management implementation, there is little or no chance to accurately assess either the exact resources present before management controls are applied, or the effects on sensitive species after the vegetation management. It is likely that there will be a continued loss of habitats until more is known of species requirements.

---

[3]Oberbauer, in prep.

[4]San Diego County Department of Agriculture, pers. comm.

From the preceding discussion, it should be evident that some Mediterranean ecosystems have been seriously damaged by human influences, especially agricultural and "urban" development. In San Diego County, there have been attempts to apply various methods to help control these losses. In the remainder of this paper, we will discuss tools available to local planners to control the losses of sensitive Mediterranean ecosystems. Using San Diego County as an example, we will examine the application of these tools through the planning process and some of the problems and solutions we have encountered.

SOURCES OF INFORMATION AND PLANNING TOOLS

Data sources available for local planning include the basic tools generally needed for resource planning: Aerial photographs, topography and soil maps, as well as reports from governmental, academic, and conservation institutions which deal with regional resource identification. Frequently, unpublished information may be available, but it is often difficult to access, interpret and evaluate. In addition, local planning staff may not have the resource data background to understand some technical reports. In general the ideal resource planner should have experience in resource evaluation as well as traditional planning concepts.

Local planners have a number of planning tools to control and manage land uses. The key tool for land use control in California, as well as several other states, is the requirement for local jurisdictions to adopt a General Plan which guides land use decisions. Such plans, containing several elements (land use, conservation, open space, transportation, etc.) establish long range goals, objectives and policies. These goals and policies guide land use decisions such as zoning and discretionary projects and set density limits, lot size and permitted uses. The adopted land use map, which identifies and controls land uses, is the main focus of the General Plan. Content and effectiveness of the General Plan depend on the expertise of staff, degree and kind of citizen involvement, and political complexion of the decision-makers.

The Environmental Impact Report can also be a useful planning tool. The EIR process prescribes a standardized format whereby the potential environmental impact of any anticipated action can be evaluated and whereby other agencies and the public can provide information and opinion regarding these future decisions and impacts. EIRs are particularly effective when used to forecast potential environmental consequences of various planning strategies in a large scale planning effort. However, the value of environmental impact reporting can be felt at all levels of planning and implementation, from the macro-scale (program planning) through the micro-scale (implementation) levels.

One of the most important problems with any EIR process is that of eliminating bias. Frequently the agency planning to carry out an action is the same agency preparing environmental analysis on the project. Although the implementing party may best be able to understand the project and its objectives, their enthusiasm for the project may make it difficult to be completely objective in predicting the potential environmental effects if a policy direction has already been determined. If potential environmental consequences are evaluated from the very beginning of the decision process in a step-wise manner, problems of bias can be minimized. Environmental impacts can be further focused as the project itself is defined, all the way to the implementation stage. Thus, the environmental review process becomes an integrated environmental planning process.

Model Plans

San Diego County, California is perhaps typical of many western American situations. For land use planning purposes, the 4,200-square mile county is divided into community planning areas based on geographic and historic relations ranging from a few dozen to several hundred square miles.

Since the late 1960's these community planning areas have been systematically planned in an evolving process as described below:

Phase I: Collecting all known data useful for planning, including previously prepared planning reports, environmental impact reports, aerial photographs, other natural and cultural resource reports and records, climatic and hydrology data, traffic, and air pollution reports.

After an initial data survey, formal meetings with area residents may reveal other data sources and direct plan formulation. This procedure helps focus on resources and potential problems, and existing policy framework, as it applies to the planning area.

Phase II: Resource identification leads to production of a constraints map by evaluating resources and rating them for land use limitations. This typically is done by mapping constraints on transparent overlays on a map of the project area. This permits visual integration of various constraining factors.

Phase III: Preliminary and alternative land uses and residential densities are chosen based on community input and resource constraints.

Phase IV: These alternative plans are shared with citizen's advisory committees, who recommend other changes, which are incorporated into alternatives for the environmental studies or reports. At this time the draft Environmental Impact Report for the plan is written and sent out for public review. Data used for resource evaluation is the basis for the EIR. During the public review period, comments and additional information received are incorporated into the Environmental Impact Report.

Phase V: This report, and other social and economic factors, are weighed by elected decision-makers in adopting a plan or combination of plans at public hearings.

Phase VI: Upon adoption of the General Plan land use map and policies, detailed zoning controls consistent with the plan are adopted in public hearings. The environmental document prepared for the General Plan remains a useful source for individual project environmental analysis. All future land decisions must follow the goals, policies and land use map of the General Plan.

The environmental planner or resource manager tries to develop land use plans which impact least on the most sensitive and most limited resources, and require the least amount of site preparation and resource destruction for ultimate development. Little research has been done concerning the effects of various designs and strategies of suburban and rural development on native Communities, but theoretical works such as those of Diamond (1975) on island biogeography and the design of natural reserves appear to have useful ideas. Generally, special concern should be given to resources regionally in short supply. The patterns and intensity of uses in relation to the resources to be conserved may greatly control impacts and thus conservation effectiveness. Managing limited or potentially endangered species on the habitat level is preferable to later managing them as a single species or even individuals.

THE SAN DIEGO COUNTY EXPERIENCE

The County of San Diego has developed a process to identify and apply land use controls to conserve certain limited or sensitive vegetation communities and wildlife habitats on privately owned lands within its jurisdiction. Such resources are identified as Resource Conservation Areas (RCAs) on the General Plan, the principal land use control available. Resource Conservation Areas outline geographic areas that contain outstanding examples of rare and endangered species habitats as well as generally exemplary wildlife habitats. Such areas are mapped from aerial photographs and maps of collection sites of rare species are field verified. Criteria for identification of RCAs involve the presence of viable populations of rare and endangered species, areas of particularly significant wildlife habitats, of viable examples of vegetation types of extremely limited distribution, such as those discussed earlier in this paper. RCAs are adopted by the Board of Supervisors as part of the Conservation Element, a mandatory element of the General Plan controlling land use. Adoption as RCAs simply identifies the presence of these resources to decision-makers, land owners, planning staff, and other citizens. Control to actually protect or conserve resources so identified requires subsequent action by the decision-makers, including additional changes to the land use element of the General Plan, further implementation through rezoning, or project approval or denial. RCAs play an important role in the environmental review process by providing early identification of critical resources which may require special mitigating design. This enables all parties concerned, including property owners, project designers, agency staff, citizens, and decisionmakers to review prospective land use changes in the light of the sensitivity of the identified resources. At the same time, the Resource Conservation Area concept can also be used as a focal point to educate the citizens and decision-makers of the value of their sensitive resources. This is extremely important because the greatest successes for environmental controls generally take place in areas where special efforts have been made to educate the local property owners and citizens.

Further controls may be applied to areas within RCAs, including special land use (General Plan) designations, special zoning regulations, large lot sizes or requirements for clustering houses outside of sensitive areas. The County has devised a special overlay zone regulation called the Sensitive Resource Regulator, to protect vegetation types or habitats sensitive to human impacts. This zone restricts removal or addition of vegetation over areas larger that 1000 square feet for any purpose without an administrative permit subject to environmental review. The County of San Diego has thus far applied the Sensitive Resource Regulator Zone to a few areas with unique vegetation types and habitats of rare and endangered plants. Mitigation of impacts of proposed land use projects in such areas may take the form of Open Space Easements dedicated to the County, these easements prohibit the removal of vegetation or the placement of structures. Such easements merely restrict destructive uses but do not allow entry of the property by the public. The property owner still retains fee ownership.

Purchase of fee title is another option for protecting endangered biological resources. Private conservation foundations such as The Nature Conservancy have expressed interest in purchasing land with vernal pools, Engelmann oak woodland, Coastal mixed chaparral, or other isolated rare vegetation types. However, because of the large amount of endangered resources and the high cost of land in Southern California, the actual amount of land which could be purchased would be very small. Therefore, protection of sensitive resources on privately owned land is especially valuable. The use of Resource Conservation Area (in the General Plan) designations is one way land use controls can be used to limit the loss of resources, while still allowing the owner a reasonable use of the land. However, the successful use of these tools depends on the information available, how it is used, and on successfully educating the citizenry and decision-makers about the importance of these resources. Managing such resources on private land must carefully weigh private property rights and the public benefits of conservation.

Therefore, there is a greater burden on the manager of public lands to conserve these limited resources. On public lands, impacting uses are much more easily controlled and there is an opportunity to carefully evaluate the impact of various management techniques. Detailed ecosystem-wide analysis of the impacts of controlled burns and other management techniques prior to their widespread application can be carried out. Since public land managers are acting as stewards for the people of the State and nation, they have a responsibility not to cause gross and irreversible impacts to any major part of the ecosystem, particularly those resources limited in areal extent and of high sensitivity. Given the recent trends in destruction of Mediterranean ecosystems in private ownership in California, it is conceivable that public lands will be the last remaining stronghold for these ecosystems in any semblance of a natural condition.

In summary, certain areas of Mediterranean ecosystems such as southern California have suffered extensive loss of sensitive resources. The continued loss of these resources can be controlled to a degree through the use of planning tools. However, these controls can only be effective if the political climate favors resource protection. Education of the public is the only way to effect the political climate toward the concept of resource protection.

LITERATURE CITED

Axelrod, D.I. The origin of coastal sage scrub vegetation in alta and baja California. Amer. J. Bot. 65(10):1117-1131; 1978

Barbour, M.J. and J. Major. eds. Terrestrial vegetation of California. New York: John Wiley and Sons; 1977.

Diamond, J.M. The island dilemma: lessons of modern biogeographic studies for the design of natural reserves. Biol. Cons. 7:129-146. 1975.

Griffin, J.R. Maritime chaparral and endemic shrubs of the Monterey Bay Region, California Madrono 25(2):65-81:1978.

Land Management Decision Model: Planning the Future of Fire-Dependent Ecosystems[1]

O. L. Daniels and R. W. Mutch[2]

Abstract: Integrating diverse biological, physical, social, and economic factors in determining land allocation decisions and scheduling future resource activities is the challenge facing land managers today. Criteria were established to resolve key issues and concerns in the selection of an action program on the Lolo National Forest. The early integration of fire information into this planning process is a significant change in direction for the Forest Service. The end result is the actual scheduling of fire suppression, fuel management, and prescribed fire programs to achieve resource management objectives.

LAND MANAGER INVOLVEMENT IN FIRE MANAGEMENT

Those responsible for managing vegetation and people's use and occupancy of complex fire-related ecosystems face specific and special challenges. The vegetation is dynamic and can be physically manipulated to produce different outputs. Economic values are high. Social and political factors are often entrenched and unrelated to ecologic realities. A multitude of physical and biological science specialties contribute knowledge on which decisions are based. Considering all these factors, the best of modern management techniques are needed. Because fire management--the blending of traditional fire control activities with fire ecology principles and land management planning requirements--has an important role to play in attaining this goal, we need to thoroughly understand the manager's involvement. There are few current examples available to aid in this process. The Lolo National Forest planning effort is one such model.

DeBruin (1976) asserted that "fire management is change: it is a change in concept, a change in policy, and a change in action:" His concluding thought to the conferees was that "the goal of this entire effort is to manage change, to enjoy change, because we believe from the changes we are making will come a better land."

What are some of the present-day problems in implementing the changing direction? Philpot (1976) cited these reasons why only a small percentage of existing knowledge is being effectively applied by land managers:

1. Lack of personal commitment or acceptance of fire's role in land management.

2. Lack of expertise and technical knowledge.

3. The fire ecology knowledge is not in usable form.

4. Lack of administrative understanding and strong leadership.

5. Absence of fire ecology considerations in the basic land management planning process.

The crux of the problem rests largely in the lack of personal commitment. Philpot advocated an expanded role for fire management professionals, coupled with training in fire ecology for <u>all land managers</u>.

Kilgore (1976) also included commitment among five broad goals necessary to effective long-range fire management programs:

1. Better understanding of fire as a process.

2. Better understanding of fire as a tool.

3. Greater commitment by managers to use on the land the best of what we already know.

4. A well-trained cadre of prescribed-burners.

5. Greater public understanding of and involvement in developing and approving our management practices.

A wealth of technical information on Mediterranean ecosystems has been presented at the Palo Alto (1977) and San Diego symposia. Unfortunately, however, a substantial gulf often exists between knowledge and the practical application of that knowledge to solve land management problems. We have reviewed some of the reasons that contribute to this application timelag. The remainder of this paper will outline several steps that we have found useful in applying the latest fire ecology information to the management of fire-dependent ecosystems in western Montana.

THE RIGHT INFORMATION AT THE RIGHT RESOLUTION

Land management planning efforts often fail to prescribe comprehensive fire management actions (presuppression, suppression, and prescribed fire) that support resource objectives. Examples

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Forest Supervisor and Fire Staff Officer, respectively, Lolo National Forest, Forest Service, U.S. Department of Agriculture, Missoula, Mont.

of the resulting problems include the loss of range forage and wildlife habitat due to the encroachment of other species, suppression damage from heavy equipment, suppression costs exceeding values protected, loss of plant and animal diversity, unnatural fuel accumulations, fire rehabilitation programs that disregard the natural regeneration capacity of native species and society's failure to recognize the true severity of the urban/wildland fire situation.

One remedy to these problems is to assist land managers in better integrating fire considerations into land management planning and resource management decisions through "front-end analysis." This remedy hypothesizes that a skill and knowledge deficiency is the primary reason why resource management decisions are not appropriately supported by a spectrum of fire management actions. Some might debate that environmental and motivational deficiencies are also contributing causes. But there is evidence to suggest that the training hypothesis is worth testing.

What ecosystem-related knowledge is necessary to permit managers to more closely simulate the "model" condition? The manager needs to know something about the area's natural history, the impacts of human activities, ecosystem changes over time that influence land management decisions (fire effects), and today's fire situation (fuel and fire behavior interpretations).

Fire management actions will support resource management objectives when land managers have such knowledge of fire relationships and the skill to use this knowledge during the planning process. The result of this "front-end" analysis will be the development of presuppression, suppression, and fire use criteria and actions that actively further management direction. A recent fire ecology reference document (Davis and others 1980) provided necessary information that managers needed to specify appropriate direction for resource decisions; and the format of this reference document should be of interest to others.

The habitat type groups used in this reference are helpful descriptors that can be used to connect fire/ecosystem relationships to the planning process and to implement fire management prescriptions. The habitat type groups are recognizable parts of ecosystems that are ecologically distinct in terms of topographic features, soils, vegetation, fuels, and fire behavior potential. The groups can be classified and mapped; thus, they can serve as a ready index for many kinds of information.

Not only does the ecosystem stratification account for the important intra-unit attributes, but also portrays interactions among units. The patterning of habitat type groups in space (each with inherent biological, physical, and climatic features) guides a logical process in formulating management decisions.

PLANNING PROCESS ON THE LOLO NATIONAL FOREST: THE DECISION MODEL

The planning process used to allocate land to different resource purposes and schedule resource management activities on the Lolo National Forest complied with requirements of the National Forest Management Act of 1976. The Forest Plan (1980) established integrated land management direction and time frames for implementation; direction for implementing, monitoring, and evaluating projects, activities, programs, and budgets; and criteria for amending and revising the plan.

One novel aspect of this new planning process is that 52 public issues and management concerns identified on the Lolo National Forest provided the focus for all subsequent planning. (Former land management planning methods relied on almost encyclopedic amounts of inventory data and information, whether it was needed or not.) A public issue is a resource management subject or question of widespread public interest identified through public participation. A management concern is a problem requiring resolution or a condition constraining management practices as identified by the interdisciplinary team. Public issues and management concerns were resolved through one or more of the following processes: quantitative analysis using a mathematical model; forest policies; forest management standards and guidelines; and prescriptions establishing specific management practices for management areas.

This issue-driven and systematic planning process insures that fire-related information is integrated with other data at the very onset of planning. These steps are being followed on the Lolo National Forest to integrate fire considerations into the Forest-wide management plan:

1. Identify the issues and management concerns.

The fire management issues and management concern: on the Lolo National Forest revolved around basic questions about how much fire can be used to achieve resource objectives within air quality standards, how compatible fire use and suppression programs are with the role of fire in various ecosystems, and how cost effective the fire suppression program is upon implementation.

2. Develop planning criteria (e.g., for data base, analysis of management situation, alternative formulation, estimating effects of alternatives, evaluation and selection of alternatives).

3. Develop, Process, and interpret fire data base. Assess implications of historical fire cycles; evaluate fire behavior potential recognizing several levels of resolution (experience and judgment, National Fire Danger Rating models, nomographs, photo series, on-the-ground fuel inventories); determine fire management implications and opportunities.

4. Integrate fire information into the land stratification framework (e.g., ecological land units, habitat types, major ecosystems, etc.). An example of this step is presented in a paper titled "Fire Ecology of the Lolo National Forest Habitat Types" by Davis, Clayton, and Fischer (1980). This integration is used in the analysis of the management situation.

5. Formulate land management alternatives and develop fire management direction.

6. Evaluate fire and economic effects of alternatives.

7. Select a management alternative and its fire management direction. The guidance is in the form of broad direction for various resource activities including wildlife, timber, esthetics, and wilderness.

8. Prepare operational fire management plans. This is really the bottom line to the whole planning process: action programs on the ground that support land management objectives.

9. Feedback. Monitor and continually refine the process.

10. Amendment and revision.

The "front-end" integration of fire information into the planning process is a significant change in direction for the Forest Service. On the Lolo National Forest we are making a positive effort to manage the change, to enjoy the change, and to assure more thoughtful management decisions because of the change. We certainly don't have all the answers on how to most effectively implement change. But we do have the commitment, the climate, and the interdisciplinary concept to learn as we go.

In addition to manager commitment, technical ecosystem data, and a systematic planning process, two additional components are essential in implementing changes in resource management programs. Those two components involve building a receptive organization and developing public understanding.

DEVELOPING AN ORGANIZATION

Once a resource manager is committed to the total fire management job, a responsive organization must be built. The organization needs to provide the expertise and manpower to do the suppression, land management planning, inventory, and fire management activities; and supply the necessary information concerning the ecosystems involved. It is important to organize in a manner that will keep presuppression and suppression costs within bounds so that funds are available to implement the rest of the program.

Some of the organizational steps leading to successful accomplishment include:

- Assembling the right team with the right frame of mind. Acquire the proper mix of generalists and specialists with a firm grasp of ecosystem dynamics. Hire missing skills if necessary. Recognize that a new concept is often implemented because of an individual's commitment, not the organization's commitment. When an individual transfers, the new concept often transfers with him; strive to replace key people with like people.

- Develop a productive climate for change. Set the example of receptivity to change. Encourage an interdisciplinary approach on problems. Insist that fire personnel interact with other specialists early in the planning process. Provide for challenging training. Establish priorities and reasonable schedules to assure a high-quality, professional effort.

- Seek opportunities to implement change on the ground . . . and demonstrate a capability to apply current state-of-the-art procedures.

- Match fire management strategies to land management objectives.

- Take calculated risks. Risk taking is a part of the job if we are doing right things. Don't shut a program down when the going gets tough. Be alert to invalid attacks and take immediate action to counter them with facts. Expect a professional and thorough planning job and critical review -- and support subordinates in a risk situation. Be prepared to establish and defend a shift in funding emphasis.

- Establish effective inform and involve programs. Reach public and Government agency groups.

- Kilgore cautions to avoid any bandwagon approach to the use of fire: "while there is some element of risk in reasonable fire management, we will lose both credibility with, and support of, knowledgeable fire control experts as well as support of the public if we do not use the best possible professional skills and judgment in our use of fire in the forest."

- Maintain an aggressive fire suppression capability. We will be able to proceed only as fast as our ability to contain fire when and where we want it.

INFORM AND INVOLVE EFFORT

Concurrent with planning and organizing for a comprehensive fire management program, it is necessary to develop a satisfactory public and political environment for change. All people need to understand and accept the role of fire in ecosystems. This requires a factual and objective portrayal of fire history regimes and the effects of fire on plant and animal communities. Armed with the pertinent facts, the various publics then need to have ample opportunities to comment on different fire management strategies to achieve land management objectives.

Public support should be nurtured early in program development so that later "surprises" are minimized. Even the best conceived efforts are doomed to negative confrontations every time the public is surprised with unexpected fire results. But if the public well understands the role fire plays in maintaining the viability of many ecosystems, they will be in a much better position to accept such tradeoffs as reduced air quality resulting from prescribed fire.

These facets of the inform and involve job are key to effective program accomplishment:

- Full commitment of facts and knowledge to the important issues.

- The internal audiences (our own people) are as important as the external audiences. Don't forget to build understanding with the maintenance person in the motor pool and the receptionist on the front desk . . . they make numerous daily contacts, too.

- We need to involve the public in the decision-making process, as well as informing them. But let's involve an informed public.

- The inform and involve effort is everyone's job. It cannot simply be delegated to Public Information Officers.

- Appreciate the importance of sincere one-on-one communications with many people.

- Go beyond a "key people" list of contacts. Get into the schools and service groups; reach the person-in-the-street.

- Be imaginative and innovative in approaches. Make good use of audio-visual aids. Avoid the stereotyped "public meeting" atmosphere.

- Remember that the name of the game is communication: a two-way exchange of information and ideas. Be a good listener.

- Recognize critical audiences and approach them with an honest desire to build understanding.

- Identify air quality concerns as a crucial resource management issue and approach it in a professional and competent manner. We have smokeless tobacco but not smokeless fires. Prepare the public to appreciate some smoke as an inevitable byproduct of prescribed fire programs.

CURRENT FIRE MANAGY ENT PROGRAM

Historically, fire has been a frequent visitor to ecosystems on the 2,000,000 acres of the Lolo National Forest. Data compiled for the period 1955 to 1974 indicate an average of 180 fires per year. About two-thirds of these fires are lightning-caused and one-third are man-caused.

The presence of fire cycles has been well documented for western Montana in recent years. These cyclic fires played a variety of roles that included (1) seedbed preparation, (2) recycling of nutrients, (3) setting back plant succession, (4) providing conditions favorable for wildlife, (5) providing a mosaic of age classes and vegetation types, (6) reduction of numbers of trees susceptible to attack by insects and disease, and (7) reduction of fire hazard.

Several categories of fire management actions have been established on the Lolo National Forest in response to property values, economics, and resource objectives. The first is the wildland/homes fire management situation where life and property values are so high that we want to achieve immediate control of fires. Many more people are building homes in wildland areas where fires are common. An interagency fire prevention and suppression program is being developed that will enable people to live more compatibly within wildland ecosystems that periodically burn. In the modified dispatch fire management situation, initial attack dispatch procedures were modified to improve the cost effectiveness of suppression actions during low fire danger periods.

Unplanned fires started by humans and lightning are permitted to burn under approved prescriptions to fulfill wildlife and wilderness objectives. These fire management areas pose little threat of fires burning outside the boundaries and causing resource and property damage. Over 310,000 acres on the Lolo National Forest have been allocated to observation fire management areas in the current program. These fires are monitored daily to insure they remain in prescription.

The use of prescribed fire is expanding to meet resource objectives: reducing the fire hazard after logging, exposing mineral soil for seedbeds, regulating insects and diseases, changing the composition of species in plant communities, improving the yield and quality of forage, improving wildlife habitat, maintaining aesthetic quality and appearance of campgrounds and historical areas, and perpetuating natural ecosystems in wilderness. Increasing public concerns over air quality require the development of smoke management strategies that minimize unwanted effects by shifting some burning programs to spring and summer months to avoid fall air stagnation problems, using more logging residues for other purposes such as firewood so that a smaller quantity of material requires burning, and improving our forecasting capability to insure adequate smoke dispersal.

SUMMARY

Several important facets of any fire management program must be understood by everyone. First, there are risks involved --primarily the risk of fire escaping. Also, fire management programs will cost money -- money for the inventories, planning, and fire monitoring activities.

Smoke in the atmosphere will be another inevitable by-product.

Faced with the risk factor, costs, smoke, and possible public controversy, the question might be asked, "Why do it at all?" Because the benefits are substantial. Integrating fire considerations into the land management planning process should be cost effective in the long run, improve ecosystem productivity, help prevent conflagrations, and provide tangible results to society.

A fire management program that is fully integrated into the total land management program of a National Forest has definable elements. Because this integration effort is a change from the past, there are few guidelines to follow. The people on the Lolo National Forest have developed the elements of their program as follows:

1. Develop and maintain commitment of the top management team to basic concepts.

2. Maintain aggressive fire suppression capability.

3. Develop an organization to provide expertise and manpower to carry out the program.

4. Develop and use processes of planning that integrate fire considerations into ongoing activities.

5. Develop fire knowledge base to the unit.

6. Develop and maintain public and political acceptance of these programs.

7. Implement the program by getting fire into the ecosystems in a way that meets objectives.

The key factor in the entire program is the land manager and management team -- their commitment and drive. They need to understand the concepts, have a vision of where they are going, and have the courage to take the risks involved.

Daniels (1976), expanded upon the idea of commitment in some detail:

"A manager should be willing to commit his personal time to the program, otherwise it will not succeed. Fire management brings together all the elements of complex land management: public emotions, professional emotions, economics, environmental impacts, a high risk of heavy capital expenditure. All these things mean that the manager should be deeply involved in the decision making. He is the one who must balance the complexities and reach a meaningful decision. Considering the newness of the concepts, I believe it is a nondelegable responsibility."

The reward in better land management and professional satisfaction makes the effort well worthwhile.

Literature Cited

Daniels, Orville L. Fire management takes commitment. Proceedings of the Tall Timbers fire ecology conference and Intermountain Fire Research Council; 1974 October 8-10; Missoula, Mont.: Tallahassee, Fla.; Tall Timbers Research Sta.; 1976; 163-165.

Davis, Kathleen M., Bruce D. Clayton, and William C. Fisher. Fire ecology of Lolo National Forest habitat types. Ogden, Utah: Intermountain Forest and Range Exp. Sta., Forest Serv., U.S. Dept. Agric.: 1980; Gen. Tech. Rep. INT-79. 77 p.

DeBruin, Henry W. From fire control to fire management, a major policy change in the Forest Service. Proceedings of the Tall Timbers fire ecology conference and Intermountain Fire Research Council; 1974 October 8-10; Missoula, Mont.: Tallahassee, Fla.; Tall Timbers Research Sta.; 1976: 11-17.

Forest Serv., U.S. Dept. Agric. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems; 1977 August 1-5; Palo Alto, Calif.: Washington, D.C.; Forest Serv., U.S. Dept. Agric.; Gen. Tech. Rep. W0-3. 498 p.

Forest Serv., U.S. Dept. Agric. The proposed Lolo National Forest plan. Missoula, Mont.: 144 p.

Kilgore, Bruce M. From fire control to fire management: an ecological basis for policies. Transactions of the 41st North American Wildlife and Natural Resources Conf.; Wildlife Management Institute; Washington, D.C.: 477-493.

Philpot, Charles W. 1976. Are land managers applying our current knowledge of fire ecology? Proceedings of the Tall Timbers fire ecology conference and Intermountain Fire Research Council; 1974 October 8-10; Missoula, Mont.: Tallahassee, Fla.: Tall Timbers Research Sta.; 1976: 430-433.

Planning for a Large-Scale Chaparral Management Program in California[1]

Leonard A. Newell[2]

Abstract: Senate Bill 1704 (Keene) is a key piece of state legislation that allows the California Department of Forestry to cost-share in prescribed burning on private land. Top management in CDF and other organizations have been involved with framing the legislation, developing realistic budgets and staffing key positions. Middle management, with extensive public involvement, produced the program environmental impact report and regulations. Public involvement resulted in significant changes. Funding is uncertain. The program is now legally ready for operations in the field.

The wildfire problem in California's Mediterranean Climate region is one of the most severe in the world. Recent findings of a Governor's Task Force say that the trend is worsening, due among other things to more population in rural and mountainous areas, unwise construction and the continued accumulation of highly flammable wildland fuels (California Governor's Office, 1981).

Writing of the disastrous 1970 California fire season, Countryman (1974) concluded similarly that "climate, fuels, topography and people create" the fire problem.

This paper focuses on the fuels element of these factors, and particularly on the use of prescribed fire to reduce these fuels on a large scale, with emphasis on the chaparral and other shrub formations on private land in California.

Prescribed fire is effective in reducing fire hazards in the chaparral because fires in this type are carried by accumulations of dead vegetation which are age-related: the younger the stand, the less dead wood there is to carry fire (Philpot, 1977) (Green, 1981). Thus, burning off the accumulation of dead material under prescribed conditions reduces the hazard of intense wildfires for many years.

The California Department of Forestry (CDF) is charged with the fire protection responsibility for approximately 50 percent of the shrub formation lands in California (Calif. Dep. of Forestry, 1981), most of which are privately owned. There has been an active permit burning system since 1945, whereby landowners have conducted prescribed burns on their property at their own initiative, risk and expense. However, there has been no way for the CDF to actively target areas for fuel reduction. In addition, prescribed burning on private land has declined in the state since the mid-1950's (Phillips, 1977)[3].

For these reasons, top management in the CDF and other agencies nurtured a lengthy process of lawmaking that resulted, on July 16, 190, in Governor Brown signing Senate Bill 1704[4] into law.

Sponsored by Senator Barry Keene of Mendocino, this pioneering legislation removed major obstacles to effective management of these private lands. The law becomes effective on July 1, 1981. Its basic provisions are these:

1. The Director of the CDF "may enter into a contract for prescribed burning with the owner or any other person who has legal control of any property which is included in any wildland for any of the following purposes, or any combination thereof:"

   (a) Prevention of high-intensity wildland fires...
   (b) Watershed management
   (c) Range improvement
   (d) Vegetation management
   (e) Forest improvement
   (f) Wildlife habitat improvement

2. The state may assume a proportionate share of the costs, in terms of personnel and equipment, of site preparation and prescribed burning, to 90 percent of the total cost.

3. The CDF will provide a third-party liability policy of insurance which provides coverage against loss resulting from a wildland fire sustained by any person or public agency, including the federal government.

Federal lands are specifically excluded from receiving cost-sharing funds from the state, but otherwise cooperation is encouraged by the law.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Manager, Vegetation Management Program, California Dep. Forestry, the Resources Agency, Sacramento, California.

[3]Exceptions are the Counties of Santa Barbara, San Benito, Kern and Shasta, which have active range improvement associations.

[4]Public Resources Code Section 4104, 4462,4464, 4475, 4476, 4491, 4493, 4494, 4475.5 and 4478. Health and Safety Code 13009.

With the authority of SB 1704, CDF can actively assist in the management of private shrub-formation lands, without infringing on landowner rights. Further, federal agencies such as the U.S. Forest Service, Bureau of Land Management and National Park Service, and the State Department of Parks and Recreation, can now plan and execute prescribed burns in concert with intermingled private lands.

The advantages of having all landowners/ managers in an area able to participate in a prescribed burn are obvious: projects can be designed using logical boundaries such as roads and vegetation changes, which aid control and lower costs; the chances for an "escape" are reduced, and economies of scale can be realized by all participants.

In summary, SB 1704 provides the legal authority to fill the critical gap that had tended to discourage private landowners from participating in an overall pattern of shrubland management with their federal and other neighbors. This paper discusses how various management levels, organizations and interest groups participated in the framing of the law, and how they have influenced planning to the present time. The paper concludes with a brief discussion of program funding.

THE ENABLING AUTHORITY AND PROGRAM: TOP MANAGEMENT ROLES

The job of developing and implementing this or any legislation falls to elected representatives in the California Legislature, and to top management in state agencies and departments. The roles of the state executives can be divided into the following categories:

1. Sensing the needs
2. Finding and working with interested Assemblymen and/or Senators
3. Building a consensus of support from involved constituencies
4. Drafting the legislation with the help of those most affected by it
5. Developing realistic budgets and seeking viable funding avenues
6. Staffing the new program's key positions
7. Monitoring and directing middle management

In the case of SB 1704, as in many other bills, items 1-5 were done concurrently. Ideas from one role area impact development in others, so there is a continuous feedback and correction, or successive iteration process that, when skillfully managed, results in a solid consensus on legislative language and broad funding support.

The process of developing this broadly supported enabling authority for a major new-emphasis program takes at least two years. In the case of SB 1704, it took 3 years of concentrated attention by top management to get us where we are today. The law takes effect in a few days.

An effort of this magnitude is too much for any one government entity to accomplish alone. It will continue to require the support of many organizations and individuals to make it happen. Fortunately, many agencies in California have recently signed an agreement to participate in Coordinated Resource Management Planning (CAMP)[5]. This agreement provides a framework for coordinating various agency roles over many land jurisdictions and ownerships. Table 1 summarizes involvement to date.

One of the conclusions that may be drawn from a perusal of Table 1 is that there exists a general perception of need to manage California's shrub-formation ecosystems by the use of prescribed fire. A proposal must have intrinsic value to elicit participation and support over so wide a spectrum of interests.

Before moving on to middle management roles, a few comments are in order on funding and staffing, as seen from top management perspectives. One key decision made about funding the Chaparral Management Program (as the operational entity to implement SB 1704 is called) was to do so out of the state's new Energy Resources Fund (ERF). This fund uses tidelands oil revenues to provide natural resources investment capital in the state.[6] This fund is the state's venture capital for promising new initiatives. The presumption is that new programs which demonstrate favorable benefit/cost ratios and public support will survive to be funded by the state's General Fund. As conceived, ERF is an extraordinarily astute way of channeling revenues from depletable resources into long-term renewable resources. Unfortunately and ominously, the ERF fund is currently being eyed by a budget-short legislature and others. Proposals for funding everything from railroads to schools are beginning to emerge. As of this writing, the Chaparral Management Program will have total financing of about $3,100,000 in state Fiscal Year 1981-82, which begins July 1, 1981.

---

[5]Memorandum of Understanding for Coordinated Resource Management Planning in California; in process of being signed, May 1981.

[6]Public Resources Code 26400-26407, Statutes of 1980.

Table 1[1]--Summary of Cooperating Entities in the Chaparral Management Program[2]

State	Federal
+Off. of the Governor +The Calif. Res. Agency *Calif. Bd. of For. *Calif. Dep. of For.[3] (primary leadership) *Univ. of Calif. Coop. Ext. Serv. *Dep. of Fish & Game[3] *Dep. of Water Res. +Dep. of Parks & Rec. +Dep. of Conservation +Air Resources Bd. +Dep. of Food & Agri.	+USDA, Forest Serv.[3] +USDA, Soil Conserv. Service[3] +USDI, Bur. of Land Management[3] +USDI, Nat. Park Serv. USDI, Bur. of Indian Affairs USDI, Fish & Wildlife Service USDA, Agri. Stabiliz. & Conserv. Serv.[3]
Local	**Private[4]**
+Res. Conservation Districts[3] +Soil & Water Cons. Districts Air Pollution Control Districts Local Water and/or Flood Cons. Dists.	+Calif. Cattlemen's Association The Nature Conserv. Sierra Club The Audubon Society Range Improvement Associations, Counties: Kern, Santa Barbara, San Benito, Shasta

[1]Symbol meaning:
*Initiating or other key roles
+Major supportive roles and/or parallel programs on public lands
No symbol indicates formal involvement in one or more phases of work.

[2]Source: Final Environmental Impact Report, Calif. Dep. of Forestry, 1981.

[3]Has signed agreement to participate in Coordinated Resource Management Planning

[4]This list is merely a sampling of private involvement. A complete list would take more

A second key decision concerning funding involved the integration of the Chaparral Management Program with the Fire Suppression Program, by means of integrated use and funding of a CDF-run helicopter fleet. Analysis showed that, by obtaining surplus military medium-turbine helicopters and operating them with contract pilots, CDF could achieve these things:

a. Have year-around use of helicopters, of

b. much greater lift and crew capacity than provided by the light-turbine ships previously contracted for, at

c. only slightly more expense per year than the light-turbine cost for the 107 day fire season alone, and

d. ensure the availability of the aircraft for helitorch work, when needed.

What this means is that very large economies can be achieved, i.e. fire suppression capability will be greatly enhanced, while helitorch operations will cost the state very little at the margin. This plan has been vigorously attacked by the helicopter industry, but at this writing, funding for the plan is apparently going to be approved by the Legislature.

Staffing of the key middle-management position; at the Sacramento level was done directly by CDF top management. Program staff were carefully selected from CDF ranks while a search for a program manager was conducted within CDF and elsewhere. Selection of the author for this position was done in October of 1980, from the ranks of the USDA, Forest Service. An Intergovernmental Personnel Act[7] agreement is the instrument by which this two-year assignment is authorized.

PROGRAM DEVELOPMENT, PLANNING AND POLICY: MIDDLE MANAGEMENT ROLES

As used in this paper, the term "middle management" refers specifically to the tiers of an organization that are just below the decision-making, or "line officer", level.

The nature of middle management's role is to make recommendations, based on sound technical analysis, budget constraints, and organizational and political realities. When these recommendations are such that top management can ratify them with only minor changes, middle management has succeeded and the program develops smoothly. A major prerequisite for this success is frank and frequent communication between the levels, so that false starts, wrong assumptions and other errors that waste critical time are minimized.

The program development phase may be conceived of as the second side of a triangle which represents a fully operational program.

The third side, Operations, may be thought of as the "feedback side" to the Enabling Authority: the success on the ground that determines continued acceptance and funding in the future; the support of landowners and the public that translates into legislative support.

[7]5 U.S. C. 3371-3376, 1970.

A program with these three legs in place is a very stable one. The CDF and cooperators (Table 1) have nearly completed the program development phase, and field operations will begin within the next few months.

The broad middle management tasks of developing the Chaparral Management Program are

1. Development of Regulations and a Program Environmental Impact Report
2. Budget development, presentation and defense
3. Training
4. Detailed Program Planning

All of these must be done with the active involvement of interested groups and individuals.

Because the first of these broad tasks has just been completed, because it is the area of planning most directly benefited by a symposium such as this one, and because it illustrates well the way in which various interest groups get involved, we should look closely at it.

Development of regulations is required by Section 4475.5(b) of the Public Resources Code. Protection of the environment by the state, while the state is engaged in activities that significantly affect the environment, is required by the California Environmental Quality Act of 1970.[8] Thus, regulations must incorporate provisions for protection of the environment.

A decision was made by CDF top management to meet the requirements for environmental protection in part by preparation of a program environmental impact report (EIR). The purposes of the report are probably familiar to most of you. Briefly, they are:

1. describe affected ecosystems;
2. present a discussion of how the proposed action will affect these systems;
3. highlight any adverse impacts that are foreseen;
4. prescribe specific mitigation measures to bring the adverse impacts within acceptable limits;
5. discuss a range of alternatives that might achieve similar goals, and explain why the proposed action is preferred over them.

The process of environmental impact report preparation and adoption is a legal and formal one. Interested groups and the general public have chances to provide suggestions, comments and objections through two formal avenues: written comments on the Draft EIR and Regulations, and oral comments at formal meetings of the State Board of Forestry. In the case of the Chaparral Management Program, nearly 100 percent of the formal public response was in the form of written comments.

We received 46 letters. Under the California Environmental Quality Act, all such letters must be answered in detail. Further, the letters and replies must be published as part of the final EIR when it is presented for adoption.

These letters and replies provide a most interesting record of how various interest groups within the state view the program, and of how their views shaped the final document. In democratic government, the process of public involvement is much more than a token listening to comments. In the case of the Chaparral Management Program, the process definitely shaped the final result. Some examples here will be helpful to illustrate this. We will look at these 3 issues in detail:

1. private property rights vs. state control and CEQA
2. issues involving land management objectives
3. burning in the winter and spring season

The discussion will cite letters from the published Final EIR and Comments, by letter number, as references for the points illustrated.

Private property rights vs. state control is an issue of ongoing importance, and has been since the earliest days of the conservation movement in the United States (Pinchot, 1947). The SB 1704 program cannot work without the support of landowners, nor can it be legally implemented without safeguards to the environment. To assure the latter, a written management plan is needed. The Board of Forestry's Range Management Advisory Committee, which is made up largely of ranchers and range managers, had recognized the need for ongoing management, not just the use of fire.[9] Yet both the California Cattlemen's Association (#328) and rancher Richard Wilson (#11, #19) expressed suspicion of long-term plans. Mr. Wilson was particularly concerned about questions of access and interagency roles. Professor Omi (#33) reinforced the need for good plans as a way to determine priorities. Our reply to the Cattlemen's Association on this point (#28 reply) sums up the balance we tried to achieve: "The landowner's stewardship attitude is expressed by his/her management plan, and is a prerequisite for serious consideration in cost sharing." As a further reinforcement to the need for landowner commitment to ongoing management, the Final EIR makes specific that the landowner is the leader

[8]Public Resources Code 21000 et. seq.

[9]Official Minutes, Range Management Advisory Committee, March 5, 1981. On file at the office of the Board of Forestry, 1416 9th Street, Sacramento, California 95814

of the interdisciplinary (I.D.) team for the project on his/her land.

A second concern involving landowner rights vs. state control centered upon the existing permit burning program. Under this program, the CDF is a passive partner who permits fires to be started, but who does not assume responsibility for the fires or any liability that may arise. Initiative is in the hands of individual ranchers and range improvement associations, who bear their own expenses, provide their own insurance, and otherwise retain control. These people have a strong sense of private initiative and individual accomplishment. Many are suspicious of government. Their letters (#19, 28, 29, 34) urged that the option of the existing permit system be left open to landowners without further restrictions. As a result of this expression of concern, the CDF will offer both options to landowners: the current permit system as it has operated since 1945, and the 1704 program with its requirement of plans, environmental checklist procedures and contracts.

A third concern in this area centered on the problem of monitoring project results. Landowner interests (#11, 19, 28) were chary of long-term arrangements, in part due to past experience of what they perceived as high-handedness by government officials. Yet 4 other reviewers (#15, 22, 25 and 39) think strongly that monitoring is essential. Two of these (#15 and 29) recommended that all prescribed burns be monitored in detail. We currently plan for detailed evaluations on a 10 percent sample basis, statewide, stratified by size and predicted impact or importance of predicted change.

Issues involving land management objectives were a second cluster of issues. The author noticed that various reviewers, depending on their particular interest, appeared to favor 3 broad goals and 3 broad approaches to chaparral management. A brief discussion of them will aid understanding of the objectives problem. Goals tend to center upon:

a. reduction of conflagration fires
b. optimization of soil and water productivity for man's use (over the long run)
c. protection and improvement of intrinsic floral and faunal values

The three broad approaches have been termed theories X, Y and Z by the author. Table 2 gives a summary of these.

Faced with these many options, the program solution is that what constitutes desired species will be determined by the landowner, according to land management objectives. Rare and endangered species, and other environmental values addressed in the program EIR, will be protected by regulation. In other words, the landowner decides, but must stay within the limits of the EIR. It seems necessary to add that the Theory Z approach, particularly in the area of energy development, has major technological problems and environmental unknowns. Any large-scale proposal for harvesting chaparral as biomass will require a separate EIR.

Season of the year for burning was a third major issue that developed in reviewer comments. There are a number of reasons for wanting to burn in the cool season, and the draft EIR indicated that considerable winter and spring burning was being considered. Four letters (#25, 26, 29 and 32) were strongly against extensive burning during this time, and/or advocated summer and fall burning. Three other letters (#13, 16 and 22) gave cautionary advice against winter and spring burning, while 1 letter (#7) advocated winter and spring burning. In analyzing these comments, the program staff developed Table 3.

Table 2--Summary of Approaches to Chaparral Management

Theory & Letter #	Summary Statement	Examples
X 18, 28, 34, 35, 36	Convert the vegetation to something else	1. Volunteer grass and forbs, with a limited shrub canopy[1] 2. Establish plants adapted to the climate, selected for low flammability 3. Drill-seeding of grasses and/or forbs 4. Irrigated avocados, citrus, etc.
Y 21, 22, 25, 26, 27, 32, 38, 45	Manage for the intrinsic floral and faunal values of the shrub formations	1. rotational burning on a 20, 30 or more year basis, which would simulate pre-white-settler conditions 2. development of age class and vegetation type mosaics 3. improve habitat for rare/endangered plant and animal species, or for other desired native species [1]
Z 30	Manage for commodity production	1. use existing old-growth for product-ion of energy 2. increase water yields

[1]An example of where Theories X and Y may overlap

Table 3--Pros and Cons of Winter and Spring Burning

PRO	CON
1. Safer from standpoint of controlling fires in extensive areas of heavy brush	1. Moist seeds of grasses, forbs and shrubs do not survive surface soil temperatures as well as dry seed (#16, 25, 26, 32), hence plant species diversity will be reduced
2. Can easily schedule crews to do burns when fire season emergencies are not a factor	2. Seeds that do survive will probably not germinate and/or establish viable plants, due to the approach of the dry season, predators and other factors (25, 26)
3. Better smoke management weather (fewer inversions, higher mixing levels)	
4. Control lines can be minimal, as diurnal humidity recovery gives a good safety margin	3. Burrowing mammals are more easily killed in the moist season (#26)
	4. Will favor chamise over the other plants (#26)

The species diversity arguments are powerful, and, while not totally supported by data, indicate that caution is necessary. The EIR mitigations for winter and spring burning, in view of these arguments, are (1) burn no more of the project area than is necessary for safety, and (2) burn the rest of the area in summer or fall to allow propagation of herbaceous plants. Of course, if the objective on an area is to convert to grass by drill seeding in the fall, season of burn is moot, since seed and moisture would be available.

This discussion of how reviewer concerns helped to shape the final document is intended to illustrate both how public agencies must respond to public concerns in a dynamic, democratic environment, and how this process can strengthen the document. The Board of Forestry adopted the Regulations and the Program EIR on June 2, 1981, in Eureka.[10]

Finally, a few words about funding are in order. After the disastrous fires in San Bernardino, Riverside, Los Angeles and elsewhere during latter November, 1980, Governor Brown supported a chaparral management program of slightly over $4,000,000 as did Senator Keene and others. After the disastrous $2 billion shortfall prediction by state fiscal analysts for the General Fund in fiscal year '81-'82, the Legislature removed $945,000 from this program.[11] Worse, many more renewable resource investment projects intended for funding with tidelands oil revenues (The Resources Agency, 1981), have been cut, as of this writing, by one or the other House of the Legislature, to cover projected deficits in the General Fund.

It is cruelly ironic that the burdens of both a massive tax cut (for real effects of Proposition 13 are just now being felt) and continuing inflation have fallen on the very investments in natural resources that are needed to solve the problem in the long run. This and other worthwhile efforts may suffer even worse next year, and are perhaps indicative of what lies ahead in the Federal experiment with tax and program cutting. We who believe in the wisdom of natural resource conservation and management must not allow this to happen.

[10]Office of the State Board of Forestry, op. cit.
[11]Proceedings of the California Legislature June 4, 1981.

LITERATURE CITED

Calif. Dept. of Forestry. Final Environmental Impact Report for the Chaparral Management Program, including Comments Received on the Draft Environmental Impact Report. Sacramento: 1981: 453 p.

Calif. Governor's Office. Recommendations on Reducing the Risk of Wildland Fires and Flooding in California: Report of the Governor's Task Force on Chaparral Fire and Flood Risk Management. Sacramento: 1981: 46 p.

Calif. Resources Agency. Investing for Prosperity Sacramento: 1981: 51 p.

Countryman, Clive M. Can Southern California Wildland Conflagrations be Stopped? Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Sta., Forest Serv., U.S. Dep. Agric.: 1974; Gen. Tech. Report PSW-7. 11 p.

Green, Lisle R. Burning in Chaparral - A Summary of What We Know. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Sta., Forest Serv., U.S. Dep. Agric. (In Printing March, 1981).

Phillips, Clinton B. Fire Protection and Fuel Management on Privately-owned Wildlands in California in Mooney, Harold A. and C. Eugene Conrad (Eds.): Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1977: 348-353.

Philpot, Charles W. Vegetative Features as Determinants of Fire Frequency and Intensity in Mooney. Harold A. and C. Eugene Contrad (Eds.): Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1977: 12-16

Pinchot, Gifford M. Breaking New Ground. Seattle, Wash.: University of Washington Press: 1947: 522 p.

Natural Resources Planning and Management in the National Park Service — Pinnacles National Monument[1]

Kathleen M. Davis[2]

Abstract: Preservation of ecological processes rather than scenic objects is the goal of natural resources management. This entails allowing natural events, i.e., fire, insects, flooding, etc., to operate to the fullest extent possible within park boundaries. Ecosystem management for a park is guided by a natural resources management plan that discusses opportunities and problems for working with natural resources. Pinnacles National Monument illustrates an ecosystem management program where prescribed fire is employed to restore native chaparral and oak/pine woodland communities.

Current natural resources planning and management in the National Park Service are the outcome of historical management and policy development. The earliest parks were managed with an indiscriminate multiple use concept where incompatible activities were allowed, such as grazing, mining, logging, and clearing. Establishment of Yellowstone National Park in 1872 marked the beginning of protecting natural ecosystems because public land was withdrawn from settlement, occupancy, sale, and development. This reflected a change of American attitudes to increasing awareness of exhaustible resources and beauty in nature.

In 1916, the National Park Service was created with a mandate to conserve natural resources while providing for enjoyment of the public in a manner that would leave ecosystems unimpaired for future generations. The Service now recognizes the importance of protecting ecological processes and strives for sound management through planning and policies.

PLANNING PROCESS

Natural resources management planning is embodied in the overall planning process of the Park Service. Figure 1 schematically diagrams the process that follows establishment of an area and shows the various levels and types of plans. Public review and input occur on most levels.

Each area has specific enabling legislation describing it and stating purposes for establishment. Intent of enabling legislation determines management and designation of the area, e.g., park, monument, historic site, etc. Areas are added usually in response to public action and nomination.

The first step following legislation is a statement for management that gives a current summary of the state of the park, guides short and long-term management, and helps decision makers determine type and extent of planning required to meet management objectives (U.S. Dept. Int., National Park Service 1978b). These objectives are a list of desired conditions; for example, maintain native ecosystems in natural zones or provide facilities for visitor use. They are a framework for conserving park resources and accommodating environmentally compatible public uses. Until the general management plan is approved, the statement for management guides day-to-day operations.

The general management plan is a parkwide plan for meeting broad objectives identified in the statement for management. This plan contains short- and long-range strategies for natural and cultural resources, interpretation and visitor use, visitor protection, development (facilities), and maintenance and operations. It identifies concerns and opportunities and the subsequent programs to manage a park as an integrated system.

Specific plans are components of the general management plan as illustrated in the figure. They give detailed discussion of management concerns and describe methods to implement programs. While specific plans are not always prepared concurrently with the general management plan, they are consistent with park management objectives that already have been identified. In a small park, the general management plan may embody all specific plans in one document. However, they are usually separate documents for large parks and any park where administration requires greater detail.

Contents of specific plans depend on the type of park. For example, Statue of Liberty National Monument has plans for visitor use, interpretation, and protection as well as development; a plan for natural resources would be inappropriate.

NATURAL RESOURCES MANAGEMENT

Planning

As shown in the figure, there are various specific plans. Since the topic here is natural resources, the remainder of this paper will focus on the planning and management for natural communities. Fire management in Pinnacles National Monument, a mediterranean environment, is given as an example.

Ecosystems are described and management is guided by a natural resources management plan that identifies problems and opportunities for working with wildlife, vegetation, air, soil, water, etc. It establishes principal strategies that will be continued, phased out, modified, or initiated for

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Plant/Fire Ecologist, Western Regional Office, National Park Service, U.S. Department of Interior, San Francisco, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

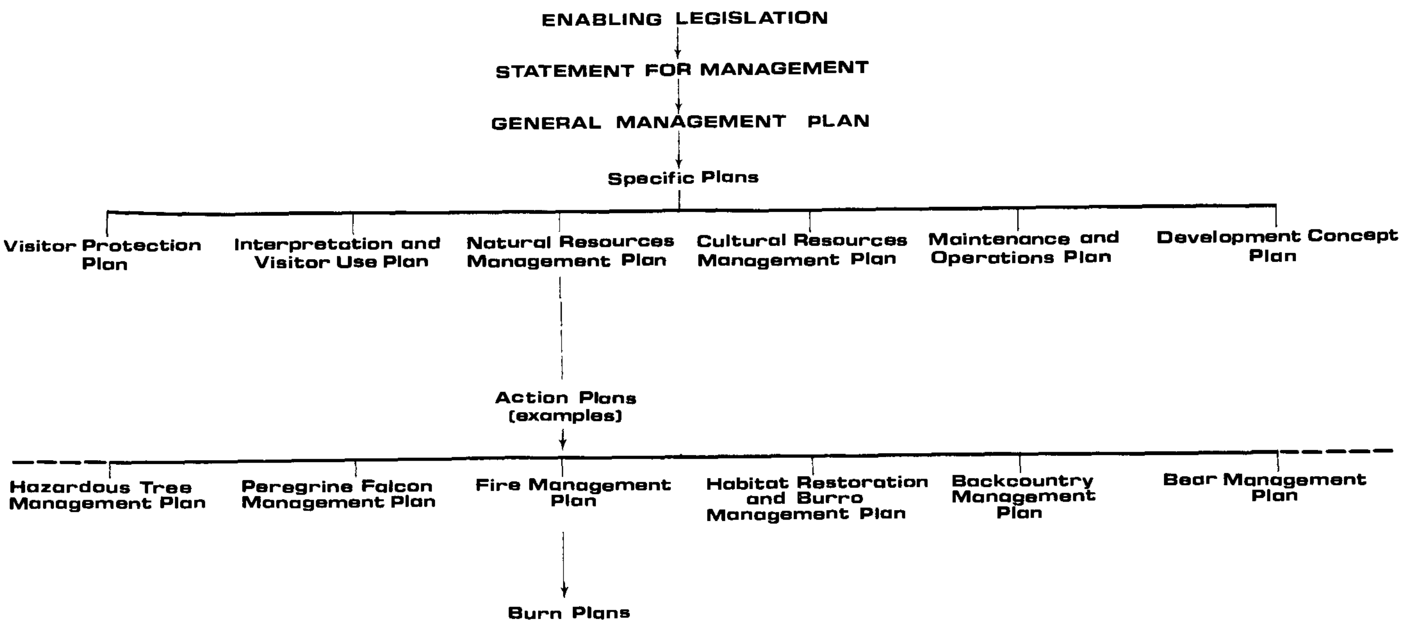


Figure 1--Schematic diagram of the National Park Service planning procedure for natural resources management showing examples of action plans.

the purpose of perpetuating natural resources processes (U.S. Dept. Int., National Park Service 1978a). In the addendum of each plan are project statements, which are proposals for money, personnel, research, or services to deal with such concerns as fire history investigation, exotic species removal, pest control, or fire management.

Action plans originate from a natural resources management plan and are either embodied in the plan or, if complex or lengthy, prepared as separate documents. Action plans focus on particular problems or opportunities for management of such things as native wildlife and vegetation habitat, exotic species, fire, reintroduction of native species, hazardous tree removal, insect and diseases, site rehabilitation, and endangered species. They are working documents used by park staff to achieve a particular condition of natural resources in parks.

Policy

In addition to the mandate of the 1916 National Park Service Act, several legislative actions, executive orders, and mission and policy statements have shaped current management practices. The enabling legislation of each park strongly influences ecosystems management, and for this reason sometimes certain practices must be allowed that do not seem to fit the "idea" of a national park, i.e., hunting, logging, skiing, mining, and maintaining exotic species.

It has only been the last two decades that serious attention has been given to total resources management. When the National Park Service was created, emphasis was placed on protecting objects, e.g., trees, mountains, or volcanoes, as a means to preserve environments. While this philosophy suits some areas such as Gettysburg National Military Park, it is wrong for natural areas such as Lassen Volcanic National Park. Since 1916 the goal of natural resources management has evolved to protecting and promoting ecological processes rather than objects. This change of philosophy is expressed in current management policies (U.S. Dept. Int., National Park Service 1978a):

> "Management of...natural features and values is concerned with ecological processes and resources. The concept of perpetuation of a total natural environment or ecosystem, as compared with the protection of individual features or species, is a distinguishing aspect of the Service's management of natural land."

The current servicewide policy for natural resources management was strongly influenced by recommendations of the Advisory Board on Wildlife Management in National Parks, more commonly known as the blue ribbon "Leopold Committee." It stated that maintenance of suitable habitat is the key to sustaining healthy animal populations and that protection of animals is no substitute for providing habitat requirements (Leopold and others 1963).

Habitat is not a stable entity that can be preserved; instead it is the product of various ecological components that create constant change and diversity. In short, the National Park Service was doing a disservice to wildlife and total ecosystems by trying to control natural events such as fire, insect and disease outbreaks, predation, and flooding.

The Leopold Committee recommended a major policy change for the Park Service: to recognize the enormous complexity of ecological communities and diversity of management procedures required to preserve them. Preservation of objects would not keep ecosystems intact; only preservation and protection of ecological processes would.

The Leopold Committee further recommended identifying ecosystems existing at the time technological man appeared and implemented activities that interrupted natural processes. Native people (Indians, Hawaiians, Eskimos) are considered part of the environment because they subsisted directly on resources. As much as possible, efforts should be made to restore biotic associations of that era and then allow ecological processes to operate with the least possible human interference. National parks should represent a vignette of primitive America.

Restoring primitive ecological communities cannot be done easily or completely because prior to inclusion into the Park Service, most areas went through periods of indiscriminate uses of resources even to the point of extinction of some plants and animals. Also, some later activities by the National Park Service contributed to accelerated alteration of ecosystems, i.e., predator control, fire suppression, insecticide use, etc. Yet, if the goal cannot be fully achieved, it can be approached using the utmost skill, judgment, and ecological sensitivity.

FIRE MANAGEMENT IN NATIONAL PARKS

Automatic suppression of all fires regardless of cause has had a long history in the Park Service; consequently, a dramatic effect on ecosystem. It began as standard procedure with Yellowstone in 1872 and continued as policy for other areas entering the system. Suppression was justified by strong conviction that fire caused nutrient and soil loss, destruction of plant and animal life, forage reduction, and ugly landscapes. Misunderstandings of the natural role of fire and interrelationship of ecological components also added to prejudice against fire.

Prescribed fire was specifically mentioned by the Leopold Committee as an essential tool to manage fire-adapted biotic associations. The report gave examples of significantly altered ecosystems resulting from fire exclusion by pointing out changes and decline in fire-adapted plant and animal communities. In 1968 the Park Service made policy the revolutionary proposal of the committee to return fire to parks.

Since 1968, policy has been revised and expanded to accommodate growth of fire management in the Service. Following are excerpts from current policy (U.S. Dept. Int., National Park Service 1978a):

> "The presence or absence of natural fires within a given ecosystem is recognized as a potent factor stimulating, retarding or eliminating various components of the ecosystem. Most natural fires are lightning-caused and are recognized as natural phenomena which must be permitted to continue to influence the ecosystem if truly natural systems are to be perpetuated.
>
> "Natural zones should represent the full spectrum of the parks' dynamic natural vegetative patterns. Sharply defined zones or blocks of vegetation limited to certain species locked in over time are not natural and only rarely justified.
>
> "Prescribed natural fire is the preferred means to achieve the prescriptions in natural zones...prescribed burning may be used as a substitute for prescribed natural fire in natural zones only where the latter cannot meet park objectives. In natural zones, the objective for prescribed burning is to stimulate to the fullest extent the influence of natural fire on the ecosystem.
>
> "All fires not classed as management fires are "wildfires" and will be suppressed... (in a manner) causing the least resource damage, commensurate with effective control."

Returning fire to its ecological role must be based on clearly defined management objectives discussed in the natural resources management plan. Depending on the situation in a park, prescribed natural fire and/or prescribed burning may be used. Fire suppression always remains in the program. These aspects of Park Service fire management are discussed further:

--Prescribed natural fires result mainly from lightning and volcanic eruptions, and they are permitted to burn during predetermined prescriptions and within established boundaries. This is the preferred method for carrying out a fire program, and there are two situations where it is used. First, it is a continuation program after prescribed burning has reduced hazardous fuels that resulted from years of suppression. Second, it can be used initially where pretreatment is not needed because suppression has not created heavy fuel loads.

--Prescribed burning is intentional ignition of vegetation and litter by park staff done to simulate the natural role of fire or reduce fire hazard. Following years of fire exclusion, several burns over a period of time may be necessary to achieve a more natural state of fuels and vegetation. Preferably, a natural fire program would follow prescribed burning, but some parks may need to continue a prescribed burning program indefinitely because of boundary considerations or limited natural ignitions within administrative boundaries. The National Park Service has no policy against prescribed burning in designated wilderness.

--Unwanted fires, or wildfire, will be suppressed regardless of origin. This occurs when fire threatens cultural resources, human life, and property; exceeds prescription; threatens to cross a boundary; or otherwise does not meet management objectives. While the Service's policy is to suppress human-caused fires, a few exceptions have been given on a park-by-park basis for certain situations when a fire meets management goals, when suppression impacts would be long lasting, and when suppression is not cost effective for public dollars. Sometimes common sense is an equalizer.

Fire exclusion is a serious form of environmental tinkering recognized years ago by some individuals in the Service. A research burning program began in Everglades National Park, Florida, in 1951. In 1968, research burns were used in Sequoia and Kings Canyon National Parks, California, that led to the first natural fire program in the Service. Since the start of total fire management within these parks, several others have or are developing programs. A goal for natural resources management is to return fire to all natural areas in parks where administratively possible.

PINNACLES NATIONAL MONUMENT--AN EXAMPLE

Environment

Pinnacles National Monument is in the central coast range of California about 130 miles (209 kilometers) south of San Francisco. Established as a forest reserve in 1906, it became a National Monument in 1908 first administered by the Forest Service then transferred to the National Park Service in 1923. The enabling legislation established it for protection of unique volcanic rock formations, but later Pinnacles was enlarged to 16,233 acres (6558 hectares) to include surrounding chaparral and oak woodland communities and native wildlife habitat. In 1975, most of the monument was designated wilderness by Congress.

Climate is a mediterranean type with dry, hot summers and cool, moist winters. Rainfall averages 16 inches (41 centimeters) occurring mainly in winter months. Topography is rugged and steep with ridges, peaks, and deep canyons created by volcanic activity and erosive forces. Soils are mostly sandy loams and very erosive. Generally, they have little development with low nutrient and water-holding ability.

Vegetation is composed of chaparral and oak/pine woodland communities. Major species are chamise, manzanitas, buckbrush, holly leaf cherry, digger pine, blue oak, and coast live oak. About 80 percent of the cover is chaparral, 7 percent oak/pine woodland, and 13 percent riparian or xeric (Webb 1971).

A variety of wildlife species occur. Most notable are blacktail deer, bobcat, raccoon, grey fox, coyote, rattlesnake, gopher snake, prairie falcon, turkey vulture, raven, and golden eagle. In the past this was part of the range for California condor. Diverse habitat requirements, especially food and cover, have been lacking for wildlife primarily due to homogeneous, over mature plant communities resulting primarily from fire suppression.

Fire History

Pinnacles has a classic fire environment where climate, topography, and vegetation create a situation for cyclic fires. A fire history report recently completed for the monument and surrounding Gabilan and Diablo Ranges gives a better understanding of past fires and their effects (Greenlee and Moldenke 1981). By studying current lightning patterns, the authors proposed that prehistoric lightning fires started mainly in oak or pine trees at higher elevations during early summer and fall. Hold over fires in trees probably were not unusual. Fire spread was extensive in grass and shrub fuels, and crowning was uncommon. A good portion of the area was probably oak/pine woodland with scattered large brushfields.

With the arrival of Indians about 11,000 years ago, burning in fall, and perhaps spring, became customary. Fire was used for various purposes including harvesting of plant foods, hunting, and burning houses to kill ticks and fleas. The overall effect on vegetation communities is suspected to be a maintenance of oak/pine woodlands and possibly reduction of shrubfields. The location of archeological sites in Pinnacles strongly supports this deduction of vegetative condition because sites have been found in dense chaparral. It is inconceivable that Indians would have lived surrounded by hazardous fuels while conducting their own use of fire. There were also lightning-caused fires during this era, so all evidence strongly suggests a more open vegetative condition than now exists.

Spanish and Mexican settlement from late 1700's to 1848 drastically removed Indians as an ignition source by bringing them into missions and ranches. Heavy use of grazing lands by increasing herds of cattle, sheep, and horses degraded natural grasslands and woodlands through erosion, compaction, and introduction of exotic plants. While most impact was in valleys, stock did move into mountainous areas. The result of settlement activities was that grasslands and woodlands decreased while shrubfields increased. Fire probably became less frequent and more intense as chaparral fuels accumulated.

After 1848, Anglo settlers dominated the region. They cut oak and pine for housing, fuel, and forage as well as clearing agriculture land. Drought, fire, and clearing reduced tree cover, and chaparral extended into former grasslands and woodlands on hills as farming superseded ranching and excluded cattle. Today remnants of large oaks are found in shrubfields providing evidence that oaks occurred throughout the monument. By late 1800's severe fires were occurring in chaparral and reducing the tree component.

The twentieth century brought fire-fighting organizations. Suppression lengthened the burning cycle, so fuels accumulated to abnormal loadings. While fire-fighting became quicker and more efficient, fire severity in homogeneous fuels increased. Records of fires since 1877 show that most fires have entered Pinnacles from the north, and that widespread fires in 1877 and 1900 covered much of the monument. Since 1927 most of the monument has burned, and some areas have burned two or three times. The most recent large fire was in 1931, but since then most have been small, more frequent, and difficult to control. Fire frequency prior to settlement would have varied with fuel types, and it is difficult to give average frequencies for the monument because of the lack of fire-scarred trees. Current evidence suggests a frequency of about 20 years throughout the monument.

Fire Management

The statement for management covers fire in the management objective to preserve and protect natural resources by perpetuating coastal biotic communities by reintroducing natural processes suppressed by man. The general management plan recognizes fire as an integral element and further states that suppression created over-mature botanical communities declining in plant and animal variety as well as stability. It states prescribed burning is necessary to reestablish natural succession of ecosystems. The natural resources management plan describes the interrelationship of fire in Pinnacles' ecosystems and the effects of total suppression. It calls for a fire history study, a fire effects study, and a fire management plan to include prescribed burning while improving protection from unwanted fires.

A wildfire in 1974 that entered from adjacent lands was the start of a new fire management plan. In keeping with Park Service policy, bulldozers were not allowed to construct fireline in the monument unless an emergency existed. Consequently, the fire was allowed to burn a larger area while natural barriers and hand lines were used for containment. Circumstances associated with this fire and the potential threat to park visitors, staff, and facilities focused attention on the immediate need to treat hazardous fuels as well as return fire to the ecosystem.

In 1975 Dr. Harold Biswell was contacted to write a fire management plan that would enable the staff to reduce heavy fuels and restore fire in a manner to recreate as much as possible the ecosystem that would have existed now had natural fires always burned in the monument. Prescribed burning was selected because of the heavy, continous fuels, experimental nature of the beginning program, desire to choose when and where fire is used, and infrequent lightning fires. Biswell (1976) proposed a 20-to 30-year rotation for burning 600 to 800 acres (240 to 320 hectares) yearly to create a mosaic for ecological diversity and safety from wildfire. Three firing techniques were recommended:

--Upslope strip burning in chaparral in winter and early spring;

--Broadcast burning in chaparral and oak/pine woodland after grasses are cured, which usually is May;

--Broadcast burning in chaparral and oak/pine woodland soon after initial fall rains, usually in late October or November.

Program Implementation

Parcels of 50 acres (20 hectares) or less are burned around developed sites, i.e., monument headquarters, ranger station, housing, and picnic grounds. In wilderness, larger parcels of 100 to 200 acres (40 to 80 hectares) are treated. An area is considered treated when management objectives are met: increasing safety from wildfire and reestablishing natural succession associated with fire.

Fire behavior is predicted using weather data and National Fire Danger Rating System (NFDRS) components and indices based on information from monument headquarters weather station. Specific details are gathered from a remote station placed on proposed burn sites. Live fuel moisture is monitored daily or weekly since live crowns of chaparral strongly influence fire behavior. Chamise and buckbrush live fuel moistures are measured near headquarters and on selected burn sites.

Prior to ignition, burn plans are written for approval by the superintendent. They are working plans that provide tactical details on dates, locations, objectives, organization, logistics, topography, weather, fuels, firing and holding operations, communications, safety, and maps. An air quality clearance and burning permit are obtained from county representatives before ignition.

Fireline construction is minimal since natural barriers are used, especially vegetation and fuel moisture changes, ridgelines, gullies, shade, and bare areas. Each fire is staffed by 2 or more people applying fire and observing behavior. Park fire crews contain and cold trail when necessary.

Program Results

From general conditions provided in Biswell's plan, a prescription is being continually refined. Model B of the National Fire Danger Rating System is used (table 1). To date prescribed burning has been done primarily in southfacing chaparral stands and oak/pine woodlands, but more attention is being given to moist northfacing slopes since fuel breaks have been created. Most burning is done in the optimum range, but for moist sites it is necessary to take calculated risk on the dry side of the minimum and maximum range.

Table 1--Fire prescription for Pinnacles National Monument (NFDRS Model B).

	Ranges	
	Min.-Max.	Optimum
Temperature (F)	40-94	65-84
Relative humidity (pct)	8-100	25-35
Windspeed (mph)	0-35	<10
10-hour time lag moisture (pct)	4-14	7-9
Live fuel moisture (pct)	42-180	80-120
Spread component	0-16	6-12
Energy release component	0-45	25-44
Burning index	0-58	35-50

Three firing techniques have evolved for Pinnacles (Clark 1981):

--Upslope strip burning in chaparral--Fire is set at the base of a thick stand of brush and induced to run upslope. As flames become self-sustaining, the burner ignites vegetation while walking downhill so fire behavior is controlled by indrafts of the main fire. This technique creates rapid, but short-lived mass fire that dies at fuel breaks. Upslope fires occur at the hottest, driest period of the day usually in spring and fall.

--Broadcast burning on ridges and slopes--Grass is the main carrier of fire. Burners begin early in the day along ridges then move downslope and along contours until one burner ties in with another. This method resembles a strip headfire pattern. Backing fires under pine and oak are desired, and every opportunity is taken to drop below a shrubfield in order for intense fire to burn the stand.

--Pile burning--On occasion this method is used for special projects such as access routes before upslope strip burning, perimeter control, mop up, and localized hazard reduction. Piles are also cut for fuel triggers to generate heat for upslope strip burning.

From 1977 through 1980 a total of 1,001 acres (405 hectares) and 204 piles have been burned at an average cost of $11.59 per acre ($28.63 per hectare) (Clark 1981). Average costs have decreased as the program becomes more routine and park staff more efficient. While $11.59 may seem expensive when compared to costs of about $5.00 per acre when using a helitorch, it must be remembered that the goal is to burn small area mosaics in a limited acreage per year. Fireline construction is minimal, heavy equipment is not used, and fuels are not pretreated by crushing or spraying.

Prescribed burns have been carried out cooperatively with neighbors. One burn was a joint effort with an adjacent rancher, Department of Interior Bureau of Land Management, and California Department of Forestry. More cooperative burns are planned as a means to achieve management objectives and reduce costs.

Visitation to Pinnacles National Monument is heaviest on weekends; therefore, prescribed burning is conducted on weekdays. Interpretive displays in the visitor centers and contact with park staff inform the public about the fire program. Use of fire has wide support from the visiting public and neighbors.

SUMMARY

To summarize, it is appropriate to talk about commitment and action. Natural resources management planning and policies are vehicles for ecological stewardship of land. However, they are ineffectual unless carried out by people with commitment to natural resources programs.

Success of the Pinnacles National Monument prescribed fire program is due to commitment of people. Superintendent Rod Broyles knew fire belonged for ecological reasons as well as for safety. He acquired funding after a wildfire to hire a qualified person to start a prescribed fire program. Forestry technician Dean Clark combined his experience of fire ecology, behavior, and suppression to develop a "back-to-basics" program that incorporates knowledge of local area residents. Park staff work strenuously to prepare for a burn and carry it out. Consultants, volunteers, and other Park Service employees also contribute to make this fire program serve nature and management.

Taking action in a prescribed fire program is a determined step, especially considering potential risks. But there are greater risks living in hazardous fuels and trying to prevent natural processes. Too often, management postpones taking action to wait for all the information, but rarely can all the information be gathered without taking action. Pinnacles is an example where management used what it knew to start a program then grew with the program. Monument staff began prescribed burning with guidelines from the fire plan and the knowledge that fire belongs in the monument. As they develop skills using fire, they are learning about ecological effects and practicing suppression techniques. They are becoming experienced managers of fire and natural resources.

Fire history information continues to be incorporated as prescriptions are refined and historic biotic communities restored. Further study of fire effects is proposed to gain more understanding of ecological relationship, Several interesting responses have been noticed since the program began in 1977. Seven new plant species recorded for Pinnacles have been found on recently burned areas, the seed having been stored in the soil. One, the fire poppy, illustrates an obvious association with fire. Four species of manzanitas occur that do not regenerate by root sprouts, thus depend on fire to crack hard seed coats and perpetuate the species. Strong response of native perennial grasses after fire where chaparral formerly dominated and remnants of oaks in brushfields support the belief that oak/pine woodlands historically covered more of the monument. A species of wasp was discovered that burrows a few inches underground and requires fire to break dormancy. It is through burning, studying observations, and incorporating results that we progress. As we burn, we learn.

LITERATURE CITED

Biswell, H.H. 1976. A management plan for restoring fire in chaparral at the Pinnacles National Monument. Final report, contract PX8450-6-0378. U.S. Department of Interior, National Park Service, San Francisco, Calif. 32p.

Clark, D. 1981. Test burning at Pinnacles National Monument, 1977-1980. Unpublished report.

Greenlee, J.M. and A. Moldenke. 1981. History of wildland fires in Pinnacles National Monument, California. Final report. U.S. Department of Interior, National Park Service. San Francisco, Calif.

Leopold, A.S., S.A. Cain, C.M. Cottam, I.N. Gabrielson, and T.L. Kimball. 1963. Wildlife management in the National Parks.

U.S. Department of Interior, National Park Service. 1978a. Management policies. 170p.

U.S. Department of Interior, National Park Service. 1978b. Planning Process Guideline NPS-2.

Webb, R.C. 1971. A guide to the plants of the Pinnacles. Southwest Parks and Monuments Assn. 76p.

Planning Issues for the Management of Mediterranean-Type Vegetation in Australia[1]

A. Malcolm Gill[2]

Abstract: Southeastern and southwestern Australia have quasi- and classical-Mediterranean climates respectively. Vegetation varies widely from forests to woodlands to shrublands. Attitudes to landscape have been important in allocating land use in these areas with a general contrast between what is "practical" and what is "picturesque". The allocation of land to nature conservation has risen dramatically since the 1960's and scientific survey has helped this process. Management of these reserves requires suitable frameworks of management and attention to the hazards posed by fires and exotics. Increased input of manpower and finance would be desirable.

The classic Mediterranean climate features warm to hot dry summers and mild to cool wet winters. In Australia, this description excludes the northern half of the country because of its summer-rainfall emphasis and it excludes the interior because of its low-and erratic rainfall of less than 250 cm yr^{-1}. Areas included by the definition are the southwestern corner of Western Australia, the southeastern parts of South Australia and small parts of western Victoria.

The remainder of well-watered southern Australia may be designated as "quasi-Mediterranean". Here, summer rainfall may be greater than in classic-Mediterranean areas but because of high evaporation and the greater uncertainty of summer rainfalls, these areas may be regarded as having, in effect, a modified Mediterranean climate.

By including both classic and quasi-Mediterranean regions of Australia, I have defined, for most part, the areas of most reliable annual rainfall (Leeper, 1970), the major agricultural regions of Australia (e.g. winter cereals - Forster, 1970), the climate giving most human comfort (Hallsworth, 1976) and supporting the greatest population, the major hardwood timber areas of the continent, and the zone colonized by Mediterranean annuals (Donald, 1970). Also, these regions, with their summer fire occurrence, experience some of the fiercest forest fires in the world.

The natural vegetation of both the classic and quasi-Mediterranean regions is very varied and includes forest, shrublands and woodlands. This heritage has been treated in the many ways open to people with tool kits ranging from fires to axes, saws, ploughs and bulldozers.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981 San Diego, California.

[2]CSIRO Division of Plant Industry, P.O. Box 1600, Canberra City, A.C.T. 2601, Australia.

Two particular issues will be expanded below and both relate to vegetation management planning. The first is the allocation of land to particular uses, a problem that has challenged man since the beginning of european settlement. The second is the management of land once it has been reserved: in our case, this topic will be confined to non-agricultural land.

ALLOCATION OF LAND USES

Productive Uses or Non-productive Uses?

The earliest european settlers of Australia found themselves in a landscape that was to them weird, grotesque and monotonous (Elliott, 1967). Their initial purpose was to feed and house themselves. Utility of the landscape was of prime concern; amenity was regarded as unimportant.

There has been tension between these two views of landscape - amenity and utility - for most of the european history of Australia, and it is still a major issue (Lowenthal, 1976). Just what is meant by "amenity" and "utility" may have changed from time to time but their expression in the reservation of natural landscapes or allocation to the production of food and fiber, respectively, has not changed. Some people have contrasted the "picturesque" or "philosophical" with the "practical". The "practical" view involves economic values directly; the "philosophic" view involves aesthetic and spiritual values. More recently "conservation" has been seen as the wise use of land for particular purposes, whether these purposes be for agriculture, forestry or nature conservation (Downes, 1975). Such nomenclature plays down polarization and may assist in rational land-use planning.

Because Australia has been so economically dependent on agriculture, setting land apart for this purpose has been very prominent in the region under discussion. As technology advanced, pasturing on native grasses gave way to cropping and improved pasture. A Mediterranean annual, *Trifolium subterranean*, became a key element in pasture improvement while additions of superphosphate enhanced the fertility of some of the

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

most infertile soils in the world.

At first little need was seen for the preservation of natural areas because there seemed to be so much land in this condition already. As land development became widespread, however, this position changed (Australian Academy of Science, 1965). Foresters, in particular, became worried and "many controversies occurred between the Lands Departments, anxious to provide more land for settlement, and the Forestry Departments wishing to preserve forests" (Wadham, Wilson and Wood, 1957).

Land set aside for ecological reserves has traditionally been land of little value for agriculture or forestry and could therefore be reserved without economic loss (Slatyer, 1975). New discoveries have changed land of no previous value to agriculture to profitable pasturage, however, and have thereby required a change in attitude to land if it was to be set aside for naturalness. Alienation of large areas of Western Australia for agricultural and pastoral purposes from the 1950's was paralleled by the first major expansion of reserves there (Ride, 1975). Reserves in South Australia expanded particularly in the late 1960's and 70's (Harris, 1974), reflecting the position in Australia as a whole. Australia's conservation reserves increased in area from about 8.5 million ha. in 1967 (Mosley, 1968) to nearly 29 million in 1979 (Aust. Ranger Bull. 1, 3).

Natural areas have been reserved as forestry operations have intensified. The initiation of export woodchip industries in both southeastern and southwestern Australia led to considerable debate over land use and new reserves for nature conservation were proclaimed in the concession areas (Ride, 1975; Senate Standing Committee on Science and the Environment, 1977).

The land-use debate continues in various forms with the "productive" versus "non-productive" uses of land underlying most issues. While the traditional arenas for debate remain - unalienated lands of governments - new arenas are the reserves themselves (Recher, 1976) where conflict arises over use for recreation (productive?) versus use for nature conservation (non-productive?).

Most reserves in the past have been allocated to nature conservation in an *ad hoc* manner (Mosley, 1968). As more land is allocated to urban or agricultural use the number of options on future land use decline. Deciding which land should remain in its natural state (and thereby retaining most options for future "use"), which land uses should take place side by side, and which combinations of land use should occur on the same area of land is difficult and remains a continuous challenge to planners.

Scientific Contributions to Decisions on Land-Use Allocation

Science has affected the allocation of uses to land in many ways. Notable have been the successes of the agricultural scientists in discovering nutrient deficiencies in plants and animals and introducing productive plant species for pastures and crops, but my emphasis here will be on the contributions of science to the issues of shape, size and location of reserves for effective nature conservation. Concern over recreational impacts is set aside here but note that the arguments used by Hallsworth (1976) in predicting recreational demand for beaches could be adapted to that for reserves.

Many areas have been assigned as reserves in the past with little knowledge of their value for nature conservation. Only recently have serious attempts been made to ascertain how effectively various plant alliances and rare and endangered species have been conserved (Specht *et al*., 1974). Stimulated by the "Specht Report", refinements and adjustments are being made to lists of plants at risk (Hartley and Leigh, 1979) and cases are being made for reservation of particular plant alliances at present poorly conserved (e.g. Senate Standing Committee on Science and the Environment, 1977). We may regard these activities as the habitat approach to planning for nature conservation.

For animals there has been no survey yet completed comparable to that of Specht *et al*. (1974). The assumption is that if the plants - as part of the animal habitat - are conserved, the requirements of animals can be met at the same time. A prerequisite of course is that the sizes and shapes of the reserves are adequate.

Questions of size and shape for reserves received much attention with the development of the equilibrium theory of island biogeography (MacArthur and Wilson, 1967). Reserves for conservation were seen to be, or become, "islands" isolated for each other by "seas" of agriculture, intensive forestry or urbanization.

The basic ideas of island biogeographic theory are that as area increases so do the number of species (maximum area equals maximum number of species); that there are movements of species between areas (representing local extinctions and immigrations); and that an equilibrium number of species will be maintained on an island although the particular species present may alter with time. As "islands" become smaller and more "isolated" from each other it may be expected that local extinctions would increase and immigrations decline. Fewer species would be conserved.

For nature conservation the conclusions which may be reached from this are that reserves should be as large as possible and that not all species can be reserved in perpetuity (Slatyer, 1975). Many have used the equilibrium theory of island biogeography as the basis for scientific discussion on reserve shape, size and location but, recently, after a thorough review of the theory, Gilbert (1980) concluded that "the equilibrium theory remains insufficiently validated to permit its widespread application to many problems of biogeography, ecology and nature conservation".

Gilbert's paper is an important one in terms of the development of ecological theory and its application to practical situations. I quote:- "There is no evidence that any extinctions in reserves have been due directly to any decrease in area.... "; "The apparent lack of conformity of the model when any taxon other than that of birds is considered points to a major flaw in its derivation...." Clearly, anomalies in the equilibrium-theory approach need to be cleared up before it can be used without prejudice.

One of the deficiencies of the theory is that is does not accommodate habitat variety. It is a commonplace observation, however, that the plant and animal diversity within a region is likely to be greatest where habitat diversity is greatest. Such "horizontal" diversity may be enhanced by "vertical" diversity; e.g. greater diversity of birds may be expected where "foliage height diversity" is greatest (Recher, 1969).

Some geographic regions have a much more diverse flora than others. Southwestern Western Australia, for example, has remarkable plant species richness and high endemism especially in its heathlands (George _et_ _al_., 1979). If this area were annexed completely for nature conservation (an impossibility of course) it would quite possibly contain a greater proportion of the total flora of the nation than a similar area of any other region in Australia. By choosing specific areas because of their richness it is theoretically possible to find the total flora and fauna in much less than the total area of the continent.

If a natural _ecosystem_ is to be preserved it will include its full complement of animals as well as plants. The design of reserves will need to take account of migrations overland as well as insuring that areas are sufficiently large to maintain genetic diversity.

Genetic diversity is a function of population size in animals and "theoretical evidence suggests that the minimal population size for retention of a substantial degree of genetic variation . . . is of the order of thousands" (see Slatyer, 1975). Sizes appropriate for the conservation of thousands of large animals for a thousand generations may be extreme but necessary if plant-animal interactions are to be conserved as well as the animals themselves. Unlike genetic diversity in animals, genetic diversity of plants may be stored as seeds in soils.

The habitat approach, the island-biogeographic approach and the genetic approach are all potentially useful in assigning land for purposes of nature conservation. However, the past dictates the terms within which land allocations for specific purposes can now take place. Many plant species at risk are not conveniently located in areas where large conservation reserves can be created. The road verges of rural Mediterranean lands in Western Australia, South Australia and Victoria provide examples. Specialist theory is not needed here for species conservation but appropriate legislation and enforcement are essential. Effective allocation of lands for all our needs depends on integration of the information and expertise of science, law, history, sociology and economics.

MANAGEMENT OF "NATURAL" LANDSCAPES, ESPECIALLY CONSERVATION RESERVES

Because of problems that have arisen from recreation, fire, and exotic species the need for management has became well recognized. Manpower and money, management systems, and hazard assessment are considered as the major issues of management in the region in question.

Manpower and Money

A Committee of Enquiry into the National Estate (1974) noted that field staff employed to operate Australia's conservation reserves in 1973 numbered 661 of whom 103 were graduates of tertiary institutions (this includes diplomats): at that time the nature-conservation estate was about 17×10^6 hectares, i.e. approximately 25,000 hectares per person employed! The International Union for the Conservation of Nature and Natural Resources (IUCN) recommended 10,000 hectares per person working full time at management and supervision (Burbidge and Evans, 1976).

"Conservation reserves" include not only the preservation of natural ecosystems in their charter, Other uses may include passive and active recreation, water catchment and storage, protection of aboriginal relics, wilderness, and even mining in some areas. Below, I emphasize the management of conservation reserves for nature conservation only.

Management Systems

Proposals for management systems - if they are to be practical - should take into account the present lack of personnel and finance but also look to the future when needs may be better met. The same applies to management of research: management of conservation reserves should be based on knowledge but our understanding of natural systems is poor.

Research into the function of natural ecosystems in Australia has usually been _ad_ _hoc_ or moulded and directed by an outstanding management problem: Shea (this volume) provides an example of the latter. More often the problem is not well defined and the need is for an overall understanding of the ecosystem. Overseas models of attempts to do just this have been the large and expensive programs of the International Biological Program of the USA, the less intensive Hubbard Brook study, the strategic workshop style of Holling (1978) and the selected biome approach of the South Africans. Each has involved focus on a particular ecosystem and area and each has been typified by periods of short-term intensive involvement and inter-disciplinary co-operation.

The challenge to planners in Australia - who have limited finance and many areas of diverse ecosystems to consider - is to produce a low-cost system which allows a quick assessment of current knowledge and an appreciation of deficiencies in that knowledge. If it could also be used for risk assessment, record keeping and monitoring, its value would be greatly enhanced. Such a system would be explicit, not consisting only of files and publications and integrated in the mind of only one person, but readily available in an up-to-date synthesis. Integrated planning astute management and a modest injection of finance could produce such a system for Australian needs based on the pioneering research of Kessell (1976).

Kessell's method has been to make an inventory of the landscape (which can include vegetation, floristics, fauna, streams, roads, slopes, aspects, elevations, rock types, fuel loads etc.) on a grid system at a suitable scale (depending on scale of variation, finance available, state of existing data base etc). Biological characteristics are linked to the physical through an ordering procedure. Process can be introduced by including the time element and appropriate attributes of plants for example (Cattelino et al., 1979). Real-time fire information can he obtained when appropriate data are included in the system. Without the computer, of course, such a system is impossible. At present, there is no computer system operating at a management level in this way in Australia although appropriate systems are being developed.

The systems devised by Kessell have great potential but require administrative, managerial and research hack up. They can warn the manager of data which is based on limited information and thereby alert him to research topics to be allocated among students, professional researchers and competent amateurs. They can be developed to guide decisions on fires and could be improved by a consideration of hazards.

Monitoring is a challenge rarely faced yet monitoring is the way in which the effectiveness of management could be assessed. Two types of monitoring can be distinguished. The first can be called "non-target monitoring" and is that used for no particular purpose but provides a valuable record of condition and change : e.g. photographs from satellites and planes. The value of ground photography may be seen in research at Koonamoore in South Australia (e.g. Noble, 1977) and at Kosciusko National Park in N.S.W. (Wimbush and Costin, 1979). The second type may be called "target monitoring" i.e. where monitoring is for more specific purposes e.g. the monitoring of population sizes of rare and endangered species.

Management - including aspects of inventory, monitoring, operations and research - can take place at many different scales and appreciation of this is most important. Flexibility in management systems may be needed to account for this. This is true also of the understanding of the natural ecosystem in which scientific management should be based.

Hazard Assessment

Under this general heading I identify three issues pertinent to vegetation-management planning in Mediterranean-type vegetation. They concern the problems of boundaries, and of fires and exotics, and are considered in terms of hazard because each problem is associated with risks to the achievement of the aims of management. Insufficient attention has been given to these problems and quantitative assessments of risk are needed to rationalize the planning process (e.g. Gill, 1977).

Boundaries mark differences in land-use and define limits of responsibility for particular areas. Thus, smoke management, fire management, fertilizer application, spraying of herbicides and insecticides etc. need to be contained within the system for which they are designed. Land-use planners can minimize any adverse effects of non-complementary land uses being adjacent to each other by allocating land around conservation reserves as buffers.

Urbanization is a particular problem. Many reserves are near to or enclosed by cities and towns. This often leads to problems with fire: the natural fire regime is upset by the fragmentation of the landscape in the first place; and altered by increased and unwanted ignitions from people in the second; thirdly, "natural" fire in the reserve may pose a threat to the surrounds so prescription burning is introduced to protect property and people beyond the boundary. Thus, a buffer area within the reserve is being managed, not for any internal purpose, but to protect values outside the reserve. The effective area of the reserve for nature conservation may be greatly reduced while the more appropriate solution to the problem may have been to have the conservation reserve bounded by a buffer area, not by houses.

Natural ecosystems in this region have evolved under particular combinations of fire types, frequencies, seasons of occurrence and intensities (each combination being a particular "fire regime"). Recognizing this assists the manager in planning because then it is realized that the events following any one fire are also related to the effects of previous fires. Man has altered fire regimes by affecting rate of ignition and extents of fires so we can no longer assume that a "natural" regime can be maintained in a small reserve.

Most fires today are caused by people although lightning is an important factor. With ignitions being more frequent the manager is faced with a dilemma. He knows he can reduce fuel on his area by prescription burning and thus reduce any impact of fires on people and property but it is possible to burn too frequently and thereby adversely affect the resource. Establishing reserves only in remote areas has been precluded by history in many cases, so short-term plans need to consider strategic burning.

Maintaining fires, whether natural or man-ignited, within areas of management responsibility poses particular problems in this region. Fires may be ignited during thunderstorms in dry weather after a long drought or be lit by arsonists during similar conditions. The result fire of enormous intensity - up to 60,000 Kw m^{-1} (Luke and McArthur, 1978) - and impossible to control directly. Such fires send fire-brands ahead of themselves causing further ignitions. Under such circumstances the usual fire breaks become insignificant. The spread of fires by the spot-fire mechanism and the severity of Australian forest fires have been a strong influence in determining the fire-management systems operating today. They are the background against which many decisions are taken. They stimulated the introduction of prescription burning to reduce fire "hazard".

Fire "hazard" has too often been considered as a variable unrelated in any specific way to people, buildings or the achievement of stated objectives. For people and buildings, hazard will vary with distance as well as fuel loads and weather conditions. For nature-conservation values it could be defined, for example, according to the vulnerability of species, soils or water quality. It also would need to he defined in relation to the keeping of fire within the reserve. The challenge remains as to how hazards can be defined and modified especially in relation to high intensity fires. Large-area prescription burning has been the common answer to the problem of high intensity fire since the 1960's with fires being lit, often aerially, under mild conditions at times of year when severe fires are most unlikely.

Fire may prepare the way for weeds, and feral animals as may other events. Whatever the cause, exotics are becoming more common in some areas. The alpine region of Kosciusko National Park, though by no means an "island" in the sense of being surrounded by an exotic landscape, has had an increase in exotic plant species from 6 in 1951 to 27 in 1979: the natural flora there is about 200 species (Costin *et al*., 1979).

Some areas have inherited exotics because of land use prior to their being established as conservation reserves. One such is Cleland Conservation Park in South Australia (South Australian National Park and Wildlife Service, 1979). Of this area approximately 75% is considered to be "weed infested" and several feral vertebrates are common.

Kings Park in Perth, W.A., is an example of a situation where frequent fires and firebreaks have aided the spread of exotics particularly in or near firebreaks or where the soil has been disturbed (Baird, 1977).

CONCLUDING REMARKS

The attitudes and perceptions of people have been important forces in determining land use. These have changed with time. A shift in balance to "amenity" was indicated in the 1960's. The extent of clearing, the intensification of forest management, perhaps the rise of aerially-ignited management fires and certainly the general rise in awareness of the environment by the general public assisted this process. Scientific survey and debate over the sizes, shapes and numbers of reserves also contributed. Land-use planning is needed to optimize the choice of land for nature conservation in a society where pressures for the use of land for urbanization, recreation and the intensive production of food and fibre are increasing.

In lands set aside for nature conservation the planning challenge is to develop frameworks for management within the context of available manpower, money and technology. Inventory, monitoring, record-keeping, risk assessment and research should all be considered in the system of management.

ACKNOWLEDGMENTS

I thank Mr. A. Fox and Drs. J.H. Leigh, R. Story and G. Yapp for their comments on the draft manuscript.

LITERATURE CITED

Australian Academy of Science. "National Parks and Nature Reserves in Western Australia". Aust. Acad. Sci., Canberra, and the National Pks Brd of W. Aust.; 1965; 266 p.

Baird, A.M. Regeneration after fire in King's Park, Perth, Western Australia. J. Roy. Soc. W. Aust. 60:1-22; 1977.

Burbidge, A.A., and Evans, T. The management of nature reserves in Western Australia. W. Aust. Dept. Fish. Wildl.; 1976; Rep. 23.
Cattelino, P.J., Noble, I.R., Slatyer, R.O. and Kessell, S.R. Predicting the multiple pathways of plant succession. Environ. Manag.: 3:41-50; 1979.
Committee of Enquiry into the National Estate. Report of the National Estate. Canberra: Aust. Govt. Publ. Serv.; 1974.
Costin, A.B., Gray, M., Totterdell, C.J. and Wimbush, D.J. "Kosciusko Alpine Flora". Sydney: Collins. 1979. 408 p.
Donald, C.M. The pastures of southern Australia. In: Leeper, G.W. (ed.) "The Australian Environment" 4th edit. (rev.). Melbourne: CSIRO and Melb. Univ. Press; 1970: 68-82.
Downes, R.G. Conservation in the context of land use. In: Fenner, F. (ed.). "A National System of Ecological Reserves in Australia". Canberra: Aust. Acad. Sci., 1975: 53-63.
Elliott, B.R. "The Landscape of Australian Poetry". Melbourne. 1967.
Forster, H.C. Field crops. In: Leeper, G.W. (ed.) "The Australian Environment" 4th edit. (rev.) Melbourne: CSIRO and Melb. Univ. Press; 1970: 94-119.
George, A.S., Hopkins, A.J.M. and Marchant, N.G. The heathlands of Western Australia. In: Specht, R.L. (ed.). "Ecosystems of the World 9A. Heathlands and Related Shrublands", Amsterdam: Elsevier; 1979: 211-30.
Gilbert, F.S. The equilibrium theory of island biogeography: fact or fiction? J. Biogeog. 7:209-35; 1980.
Gill, A.M. Management of fire-prone vegetation for plant species conservation in Australia. Search. 8:20-5; 1977.
Hallsworth, E.G. Making the most of Australia. J. Aust. Inst. Agric. Sci, 42: 167-74; 1976.
Harris, C.R. The National Parks and Reserves of South Australia. M.A. Thesis, Dept. Geog. Univ. Adelaide. 1974.
Hartley, W. and Leigh, J.H. Plants at risk in Australia. Aust. Nat. Pks. Wildl. Serv. Occ. Pap. No. 3, 1979; 80 p.
Holling, C.S. "Adaptive Environmental Assessment and Management". New York: Wiley Interscience; 1978. 377p.
Kessell, S.R. Wildland inventories and fire modeling by gradient analysis in Glacier National Park. Proc. Ann. Tall Timbers Fire Ecol. Conf, 14:115-62; 1976.
Leeper, G.W. Climates. In: Leeper, G.W. (ed). "The Australian Environment" 4th ed. (rev.) Melbourne: CSIRO and Melb. Univ. Press; 1970: 12-20.
Lowenthal, D. Perceiving the Australian environment: a summary and commentary. In: "Man and Landscape in Australia. Towards an Ecological Vision". Australian National Commission for UNESCO. 1976.
Luke, R.H. and McArthur, A.G. "Bushfires in Australia". Canberra: Aust. Gov. Publ. Serv., 1978.
MacArthur, R.J. and Wilson, E.D. "The Theory of Island Biogeography". Princeton: Princeton University Press: 1967. 203 p.
Mosley, J.G. National Parks and equivalent reserves in Australia. Guide to legislation, administration and areas. Aust. Conserv. Found. Spec. Pub. 2; 1968; 43 p.
Noble, I.R. Long term biomass dynamics in an arid chenopod community at Koonamore, South Australia. Aust. J. Bot. 25:639-53; 1977.
Recher, H. Bird species diversity and habitat diversity in Australia and North America. Amer. Natur. 103:75-80; 1969.
Recher, H. An ecologists view. The failure of our national parks system. Aust. National Hist. 18-398-403; 1976.
Ride, W.D.L. Towards an integrated system: a study of selection and acquisition of national parks and nature reserves in Western Australia. In: Fenner, F. (ed.). "A National System of Ecological Reserves in Australia". Canberra: Aust. Acad. Sci.; 1975; 64-85.
Senate Standing Committee on Science and the Environment. "Woodchips and the Environment". Canberra: Aust. Gov. Publ. Serv.; 1977.
Slatyer, R.O. Ecological reserves: size, structure and management. In: Fenner, F. (ed) "A National System of Ecological Reserves in Australia." Canberra: Aust. Acad. Sci.; 1975; 32-38.
South Australian National Parks and Wildlife Service. "Cleland Conservation Park, Mount Lofty Ranges, South Australia. Draft Management Plan". Adelaide: South Australia, Dept. Environ., 1979. 277 p.
Specht, R.L., Roe, E.M. and Boughton, V.H. Conservation of major plant communities in Australia and Papua New Guinea. Aust. J. Bot. Suppl. Ser. 1974; No.7, 667 p.
Wadham, S., Wilson, R.K. and Wood, J. "Land Utilization in Australia" 3rd edition. Melbourne: Melb. Univ. Press: 1957.
Wimbush, D.J. and Costin, A.B. Trends in vegetation at Kosciusko I-III. Aust. J. Bat. 27:741-871; 1979.

Vegetation Management Planning on the San Bernardino National Forest[1]

Gay Almquist and Jeanine Derby[2]

Abstract: Long-range resource plans are being developed for National Forests under legislated environmental planning regulations. Vegetation is the common denominator of the resource activities for which the Forest Service is responsible. Through the management of vegetation, water yield, sediment yield, erosion rates, wildlife populations, species diversity, wildfire potential, biomass production, plant vigor, and overall changes in ecosystem dynamics are all affected. An interdisciplinary approach and public involvement are both vital to the process.

Planning Background

Natural resource planning is not new to the Forest Service. It has been practiced in varying degrees since the early 1900's. However, much of the past planning has been directed toward specific activities such as timber harvesting, wildlife management, and recreation. Management planning was accomplished in later years through such vehicles as Ranger District Multiple Use Plans. These plans usually provided for broad zoning of National Forest lands as the basis for future decisions and management activities. They also included coordinating requirements considered necessary to ensure compatibility of resource uses. These plans were limited in scope, in that only general resource management goals were identified, and then only from a single Ranger. District, rather than from a Forest perspective.

In 1969, the National Environmental Policy Act (NEPA) was passed. It set the framework for the formal planning processes the Forest Service follows today. The major changes from the multiple use and individual resource planning of the past, as dictated by NEPA, were that plans were to be done in more detail, and were to apply to geographic areas containing similar social and physical characteristics. Plans were to be developed incorporating strong interdisciplinary interaction, and the public was to play a more active role in providing input and review for the documents.

Within a few years of the passage of NEPA, two other pieces of legislation were enacted which have had a tremendous influence on the scope and intensity of resource planning within the Forest Service. These are the Forest and Rangeland Renewable Resources Act of 1974 (RPA), and the National Forest Management Act of 1976 (NFMA).

RPA requires an assessment of renewable resources on a nationwide basis, and makes projections of present and future demands for these resources. This assessment is updated every ten years. RPA projections provide the output targets that are used by the Forest Service as National goals for production of goods and services.

NFMA takes the process one step further by establishing statutory direction for the Forest Service to respond to National demands by developing very comprehensive land and resource management plans. These plans will integrate resource management direction for all activities for the next fifty years into a single document. They will also specify the capability and suitability of the land to produce goods and services, the amount of land allocated to uses such as recreation, wildlife habitat, and biomass production, and the schedule of outputs from these activities over time. Driven by local public issues and management concerns to be resolved, the Forest land management plans will specify management practices to be used, such as labor-intensive brush control or prescribed fire; predict the environmental consequences of specific management practices; and specify monitoring and evaluation steps to be implemented.

Identification of Resource Management Goals and Objectives

One of the most significant changes Forest planning presents is that for the first time, National Forests will be developing long-range resource plans that not only deal with the integration and interaction of all the resources simultaneously, but specify a schedule of activities and resulting outputs over time. Developing definitive resource management goals, which are applicable to the individual National Forest, is one of the earliest tasks associated with any forest planning process. Without this initial step, there would be no basis for establishing individual resource objectives, determining what data should be collected, or knowing what end result to anticipate.

To help develop resource management goals, legislated environmental planning regulations (NEPA and NFMA) require the identification of

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Land Management Planning Officer and Forest Botanist, respectively, U.S. Forest Service, San Bernardino National Forest, San Bernardino, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

internal management concerns and public issues. During the initial phase of the Forest planning effort, through public involvement, the San Bernardino National Forest identified fourteen major issues and concerns which represent a wide range of activities. The type and intensity of management in chaparral and related vegetation was identified as one of the overriding concerns on the Forest by both management and the public. The challenge of managing chaparral lands to achieve an integrated resource program will be a key issue in the Forest Plan. The following are a few of the types of issues that will be addressed:

– The San Bernardino is one of the four primary southern California Forests that provide recreation opportunities to the more than 13 million people of the area. The demand is increasing to open more public land to recreation uses. Many of the proposed uses are compatible with other land uses, but others are not. What kinds and amounts of recreation opportunities should be emphasized, taking into consideration all other resource uses and impacts? What kind of vegetation manipulation will most enhance these experiences?

– The San Bernardino National Forest provides municipal water to 12 individual water agencies and numerous irrigation districts, both within and outside the Forest boundary. Under existing management conditions, the Forest produces over 250,000 acre feet of water annually. Water quality and quantity are directly affected by the manipulation of vegetation, and one of the questions to be answered is to what extent management practices should maintain or enhance water production from National Forest lands.

– How can the integration of resource management objectives with fire protection objectives be more effectively implemented? Added to this concern is the fact that the San Bernardino National Forest is one of the most fire-prone forests in the entire National Forest system. Protection of the land from wildfire is a complex task because of the rugged topography and vast expanses of highly flammable chaparral fuels, the Mediterranean-type climate, Santa Ana winds, and increasing urban intrusion. The rapidly developing interface between existing urban development and the National Forest chaparral slopes presents the dual problem of protecting Forest lands from man-caused fires, and homes from wildland fires. The feasibility and effectiveness of establishing greenbelts or their equivalents as buffer zones between developments and chaparral areas is being studied as a part of the land management plan.

– Land use coordination has become a vital issue because of the pressures of development in the private sector and the growing demand for the use of public lands. The San Bernardino is the only National Forest in the nation with a year-round permanent population of over 40,000 people within its boundaries. On weekends and during other high-use periods, this figure can rise to over 100,000 residents.

- Some additional concerns to be dealt with are increasing range opportunities, enhancement of wildlife habitat, protecting or enhancing visual quality, and what kind of transportation network is needed to support Forest activities.

Issues will be addressed in the Forest Plan under one of three categories: management of vegetation; allocation of support facilities and structures; or specially administered lands such as wilderness areas, cultural or historical areas, and biological areas. Of the major issues identified, more than half will be addressed by translating policies, standards, guidelines and management direction into acres of vegetation on the ground to be manipulated over time.

Vegetation is the common denominator of the majority of the resource activities for which the Forest Service is responsible. Through management or manipulation of vegetation, water yield is increased or decreased, sediment yield and erosion rates are affected, wildlife populations and species diversity may be enhanced, wildfire potential is changed, biomass production and plant vigor are influenced, and overall ecosystem dynamics are changed. Not only are these activities controlled to a great extent by the periodicity of removal, but they are also affected by the spatial patterns resulting from vegetation treatment and the methods by which the treatment is carried out--prescribed burning, mechanical removal, herbicides, and so forth. Since each resource activity benefits to a greater or lesser degree from various and sometimes conflicting approaches to vegetation management, the challenge to the resource manager is to determine the goals and definitive objectives for which the land will be managed over time, to recognize the complex interrelationships among those objectives, and to develop a sound rationale for management that is ecologically, economically, socially, and politically acceptable.

Although this description depicts the San Bernardino National Forest, the basic scenario, in varying degrees, represents similar conditions all over the world, wherever there are vast areas of chaparral-type vegetation, a Mediterranean climate, high resource values to be managed and protected, and the increasing pressure of urban development. Management of the vegetation is one of our major working tools. The diverse vegetation systems of southern California offer some of the greatest challenges to management in the Nation, if both the intent and the letter of the law as set forth in the National Forest Management Act are to be met. The remainder of this paper will outline one possible approach to the application of the land management planning process, as outlined in NFMA regulations, to a Mediterranean ecosystem, specifically, the chaparral and related vegetation on the San Bernardino National Forest.

Vegetation Management Planning

Vegetation management, as we are defining it on the San Bernardino National Forest, includes actively applying some practice to the ground, such as doing something to the vegetation, and also deliberately excluding activity, thus allowing some growth-related or development-related processes to occur. Implicit in this definition is the requirement that the persons responsible for land management understand the dynamics of the systems they manage. It requires an understanding of the relationships between the physical and biological components of the systems being managed. It requires that managers be able to predict with confidence the effects of doing or not doing some specified activity or sets of activities.

There are basic questions a Forest Plan must address regarding vegetation management. Assuming that products include commodities such as wood products and water, and also non-commodities such as wildlife habitat, recreation, and visual experiences, what can be produced from the land? Where can it be produced, and on what schedule? What is the cost of producing these things, and what is the value of the things being produced? What are the measurable short-term, long-term, on-site, and off-site effects of producing goods and services on National Forest lands?

The focus of this paper is on techniques for predicting the capability of the land to produce goods and services. The question of whether specified areas within the land base are suitable for a specific use will not be addressed here. Suitability is a function of many social and political issues or constraints and must be determined outside of the physical-biological realm.

The scientific community has produced some significant results in several areas of vegetation and ecosystems research. However, we are all aware of the many gaps in existing information, especially for southern California. Taking a positive approach, there are a number of tools available to facilitate planning. The vegetation of southern California is now described in a systematic and hierarchical manner (Paysen, et al, 1981) which is compatible with the National Land Classification System[3] and is patterned after the UNESCO system of vegetation classification (UNESCO, 1973). Some literature is available which allows interpretation of the reproductive strategies and developmental processes of various plant communities (Keeley and Zedler, 1978, and others). Some information is available which will allow planners to predict relationships between the physical and biological elements of the systems (Bailey and Rice, 1969; Rice and Foggin, 1971). The Forest Service has also developed some in-house tools to facilitate predictions about the relationships between various characteristics of the vegetation systems being managed and the outputs being produced.[4]

With that basic framework, Forest planners and other team members can begin to examine management activities in a manner which will allow them to predict outputs, analyze effects, and display the relevant cause-and-effect relationships between outputs and effects. Perhaps most important, predictions can be tested and examined through follow-up monitoring.

Although the Forest Service conducts many different activities on the ground to meet a variety of vegetation management objectives, all of those activities can be grouped into one of four basic vegetation management categories. The first category is removing vegetation. Activities in this category include removing entire plants or parts of plants, resulting in a temporary change in vegetation structure or species composition. Generally, this treatment induces a different successional phase in the stand of vegetation being treated.

The second category is changing the vegetation type in order to produce a relatively permanent change in physiognomy, such as converting trees to grass, or shrubs to trees. Vegetation manipulation activities which would be implemented imply some level of management over time to maintain the vegetation in the desired state. Greenbelts comprised of orchards, irrigated pastures, recreation areas, or managed woodlots are examples that might be included in this category.

Third is protection from insect or disease epidemic. This category includes all activities associated with treating and protecting vegetation on a large scale, where there may be a potential for significant effects on system dynamics.

The fourth category is revegetation; the enhancement of existing vegetation through replanting on a large scale, or reintroducing species into historic range. It could include the introduction of non-native species, for example, introducing annual grass seed on a burn.

[3] Driscoll, Richard S., John W. Russell and Mary C. Meier, Recommended National land classification system for renewable resource assessments. Unpublished report on file at the Rocky Mountain Forest and Range Experiment Stations, Ft. Collins, Colorado.

[4] Recreation Opportunity Spectrum, U.S. Forest Service. Wildlife Habitat Relationships, R-5, U.S. Forest Service.

Early in the process, a decision must be made about how the vegetation Series, or stands of dominant vegetation which are present on the Forest will be grouped for predicting land capability and for analysis. This is a separate exercise from mapping. Ideally, the decision is reached through a carefully considered interdisciplinary process. Each resource specialist must determine the logical grouping of vegetation that allows some amount of confidence in predicting the effects of a set of activities, and also allows the prediction of the outputs produced in goods or services. A leveling session must follow permitting the various resource specialists to bargain and to agree upon the common aggregation of plant communities that they can finally and unanimously live with. The task is much easier for the conifer zones on the Forest, where established management practices and observable results are documented. Vegetation types which have been managed for a number of years provide an opportunity to experience the effects of management. When working in the frontier of vegetation management such as with chaparral and oaks or other hardwoods of the Mediterranean ecosystems, we do not have the luxury of past experience. We must use all the professionalism available, in other agencies as well as our own, in developing a common basis for writing management prescriptions.

Management prescriptions will be applied to aggregates of vegetation Series in order to predict outputs and set priorities for land allocation. Ideally, the criteria used to aggregate the vegetation should be based upon biological principles. Criteria might include the structural characteristics of the vegetation--both characteristics of individual plants as well as community structure. They might also include the physiological characteristics of dominant overstory plants, and life cycle characteristics, including reproductive strategies of dominant plants.

Physical characteristics such as percent slope, landform, and climate zone will be applied in order to ultimately sort the various groups of vegetation into manageable units for analysis purposes. The physical land characteristics will have an effect on the productivity potential of a vegetation group and will also affect the method which can be used to treat the vegetation. However, in most cases, it is not possible to predict a direct relationship between the physical characteristics of the land and the dominant overstory species that exist on the ground.

After vegetation has been grouped by Series into categories of similar biological response and the significant physical features of the landscape have been applied as a further sorting process, the most difficult task awaits. Ultimately, all disciplines must arrive at a common understanding of, and agree upon, the various successional stages or changes in overall plant community structure which produce significant changes in outputs, effects, or costs. This agreement among disciplines on the relationships between changes in resource production and changes in vegetation structure or successional phase is essential. This step is key to developing management prescriptions, which are the basis for the plan analysis. At the same time, standards that will guide or constrain the activities are developed. The constraints will be carried through and applied to actual on-the-ground management.

EXAMPLE

A hypothetical example of a management treatment or prescription which might be applied to Chamise Chaparral on the south side of the San Bernardino Mountains follows:

Management Direction

Within all chamise chaparral land units of 500 acres (202.5 ha) or more, the vegetation will be managed in a mosaic of age classes on a 20-year rotation cycle and will be treated at 5-year intervals.

Standards and guidelines applied with this practice might include

1. No more than 2000 total acres (810 ha) of land shall be treated during any one year within the Santa Ana River drainage.

2. No more than 10% increase in sediment will be tolerated within the watershed through-out the treatment cycle.

3. Prescribed fire will be the preferred treatment method on slopes >50%.

4. Every initial treatment shall include cultural and historical inventories and sensitive plant inventories.

5. At least 10% of the chamise chaparral vegetation shall be retained in a mature phase (>50 years old) at all times.

6. The pattern of treated acres should be spatially arranged in 35-50 acre (14-20 ha) patches with at least 200' (61 meters) of untreated ground between the patches whenever possible.

7. Treated acres abutting the urban interface will be accomplished in a manner compatible with any proposed greenbelt projects.

For every 10 acres (4 ha) treated within the chamise chaparral, the treated land might produce 50 acres (20 ha) of wildlife habitat improved for early successional indicator species, 0.5 acre feet (616 cubic m) of water yield, 20 visitor days per year for recreationists, 10 acres of cultural resource inventory completed, and one animal unit month of range. Again, these are hypothetical numbers for the purpose of illustration. The point is that because all disciplines have participated in developing the rationale for writing the prescription, each can predict some outputs which are tied to a treatment schedule on a specific land type, and develop the standards and guidelines which will maintain the activity within acceptable impact levels. The intense interaction that takes place among disciplines to achieve this stage in planning produces a confidence level which will carry through for the rest of the process. Time and energy spent in developing feasible management prescriptions is rewarded through a commitment to the reliability of the resulting plan and an eagerness to implement it. Production models can be tested incorporating ground truth into the future plan revisions.

Summary

Probably every person involved in this stage of land management planning is somewhat idealistic. They are hoping to achieve greater perfection than is possible, given the present level of experience in managing these lands and the time frame in which to produce a plan.

Each participant also recognizes that as social or political emphases change, the plan may need to change; that it must be flexible enough to accommodate unplanned events such as fire, flood or earthquake. Given these unknowns, what is the value of investing so much time and energy in a Forest Plan? The real value will be realized when assumptions and predicted relationships relative to vegetation system dynamics have been documented and tested. The set of planning criteria being developed will suggest links between actual management practices being applied to the ground and measurable elements or characteristics of the systems being managed. The set of criteria and relationships can be tested through research and monitoring over time. The plan will be an attempt to define the now missing links between management practices, measurable characteristics of the systems being managed, and the goods and services which can be produced. Even though management priorities may change or the demand for various kinds of outputs may change, the basic principles upon which land capability is based will not change.

The Forest Plan itself will be validated only if and when we can show that the sum of individual projects applied to the ground and implemented on a specified schedule, within established constraints, will produce the predicted outputs and effects.

Literature Cited

Bailey, Robert G. and Raymond M. Rice. 1969. Soil Slippage: An Indicator of Slope Instability on Chaparral Watersheds of Southern California. Professional Geographer 21(3): 172-177.

Forest and Rangeland Renewable Resources Planning Act - 1974.

Keeley, Jon E. and Paul H. Zedler. 1978. Reproduction of Chaparral Shrubs After Fire: A Comparison of Sprouting and Seeding Strategies. American Midlands Naturalist 99:142-161.

National Environmental Policy Act. 1969. Code of Federal Regulations, 40 parts 1500-1508.

National Forest Management Act. 1976. Code of Federal Regulation, 36, Part 219.

Paysen, Timothy E., Jeanine A. Derby, Hugh Black, Jr., Vernon C. Bleich and John W. Mincks 1981. A Vegetation Classification System Applied to Southern California. U.S.D.A. Forest Service General Technical Report PSW-45, 33p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Ca.

Rice, R.M. and G.T. Foggin III. 1971. Effect of High Intensity Storms on Soil Slippage on Mountainous Watersheds in Southern California. Water Resources Research 7(6):1485-1496.

UNESCO 1973. International Classification and Mapping of Vegetation. United National Education, Science, and Cultural Organization, Ecol. and Conserv. Serv. 6, Paris. 93 p.

National Environmental Policy Act - 1969. Code of Federal Regulations, 40 parts 1500-1508.

Vegetation Management Planning in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

Cecile Rosenthal[2]

The six papers on vegetation management planning raise important and controversial issues for all levels of government. These issues fall into four categories:

1. Absence of basic policy direction.
2. Impact of private property rights.
3. Need to consider fire in private land use planning.
4. Lack of informed participants.

ABSENCE OF BASIC POLICY DIRECTION

Only the National Park Service (whose policy to preserve natural systems is set by legislation) is relatively free from controversy over land use allocations. In other agencies, however, decisions on allocations must be made before planning can begin for vegetation management. It is essential that planners and the public resolve basic questions such as

1. Should some shrublands be managed for direct commodity production such as energy, fuelwood, increased water supply and grazing?
2. Should some shrublands be managed for indirect (and hard to quantify) commodities such as recreation, watershed, wilderness, wildlife and aesthetics?
3. Are some shrublands suitable for permanent conversion to, and management as, other vegetation types that can be economically maintained without environmentally adverse consequences?

Although it is possible to get several benefits from land under multiple use, it is not possible to benefit from conflicting uses that require different management techniques. Eventually choices must be made, such as

1. Should a fire be allowed to burn or should it be put out?
2. Should the fuel be allowed to build up, or should it be reduced by prescribed fire or other techniques?

Not all uses will thrive on the same decision.

It is my belief that these basic land use decisions have not been made for most Mediterranean shrublands. Shrublands have been neglected because of a perceived lack of economic value. Planners and the public need to look at the economic benefits from shrublands (such as water, recreation, wildlife and erosion control) and the costs of mismanagement (such as fire losses, floods, sedimentation, and slope instability). Planners must provide the public and the decision makers with a discussion of the options, the costs, and the benefits of various management directions within Mediterranean shrublands. These management options have been considered in the allocation of timberlands and grasslands, and the shrublands must now get similar attention if disasters of fire, flood and erosion are to be avoided.

IMPACT OF PRIVATE PROPERTY RIGHTS

There are obvious conflicts between urbanization adjacent to public lands--a widespread problem which Gill's paper pointed out on the basis of the Australian experience. Urbanization is especially difficult when fire is a threat or a major management tool. Problems of liability were not mentioned in the papers, but concern over legal action is a constraint on management that cannot be ignored.

The use of fire can be controversial between adjacent private landowners if one objects to the use of fire, while another favors it as a management tool. Urban growth in rangeland aggravates this problem with neighbors not wanting the smoke nuisance or the escape risk. The paper by Newell reviewed California's approach to using prescribed fire and discussed the emotional and practical problems of using prescribed fire when a landowner must allow agency access and get state approval. Under the California approach, an uncooperative landowner, who refuses to participate, but who owns a key piece of land, can thwart the public purposes of fuel reduction in the state's program.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, Calif.

[2]Member, State Board of Forestry

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The California program will test the feasibility of fuel management on private property where permission of the owner must be obtained. Furthermore, if fuel buildup cannot be controlled on private land, the public cost for fire suppression will continue to rise, damages to both public and private lands will continue.

The Oberbauer and Evans paper based on the experience of San Diego County implies that our private land use regulatory system may not be capable of preventing ecosystem degradation on private lands. If true, and I believe it is, then the entire preservation burden falls on the public land manager who is also under pressure to produce more commodities.

NEED TO CONSIDER FIRE IN PRIVATE LAND USE PLANNING

Public expenditures required to support building in and adjacent to shrublands include

1. Fire prevention, management and suppression.

2. Flood and debris control.

3. Assistance to those rebuilding after fire, flood, or mudslide.

These costs are increasing because of fuel buildup and the resultant larger fires that escape containment; growing intensity of development in and near shrublands that often preclude use of backfires and fuel reduction; and general inflation. The public costs must be evaluated and balanced against the benefits to and the rights of shrubland landowners. As a minimum, planning on private land must consider fire safety in terms of building materials, location of development, access, water availability, fire protection services, density, buffer zones, and fuel management. It is a challenge that planners and decision makers must meet unless we are to accept increasing fire damage in Mediterranean climates.

LACK OF INFORMED PARTICIPANTS

Good planning depends on an informed public and enlightened decision makers. Since Mediterranean shrublands involve fire, and fire involves risk, society must be knowledgeable in order to make the proper choices. In the absence of decisions, fuel continues to build up. Delay is often an inadvertent decision for a big fire. The "inform and involve" effort advocated in the paper by Daniels and Mutch can help, but all agencies involved in Mediterranean ecosystem management must be more effective in explaining to the public what options and risks exist.

These papers show the commitment of public agencies to plan and manage vegetation in Mediterranean ecosystems. The papers also suggest that social and political systems are lagging behind ecological knowledge and managerial skills. The true challenge will be implementing management plans in the real world of property rights, pressure groups and the political process.

Review

Review

Review Comments[1]

Charles W. Philpot[2]

The quote I least agreed with was by one of the Monday morning keynote speakers. He was talking about management of Mediterranean systems. He said that the science of their management was virtually unknown. I really think what he meant to say was that many management proposals for Mediterranean systems have no scientific basis.

Point two that I'd like to mention deals with the concern expressed all during the week about the lack of social, political, and economic subjects in this symposium. That was pretty much by design, because this was meant to be a technical session, although it is not a classical symposium in some senses. We tried to make up for that lack, that we all agree is important, by having some planning papers this morning dealing with two issues. One is the planning process itself, whether operational activity, program planning, or whatever. That's how most of this technical information is applied, if it is applied. And the second thing, was to make it clear that there are social, political, and economic considerations that in many cases far outweigh the technical information we tried to transfer this week. I still believe, however, you can have all the political support, economic support, etc., and if you're doing things that are technically wrong you are not going to make it in the long run. But in any case, we were aware of that problem and we tried to make up for that this morning with the land use management planning session. I personally feel that the speakers did a very good job on that issue.

The third thing I would like to talk about was mentioned by Malcolm Gill and several others who have been to the last two symposiums. I was also at the 1973 symposium on Living with Chaparral, which was sponsored by the Sierra Club, California Department of Forestry, and the U.S. Forest Service. At that symposium, prescribed burning was not mentioned by anybody. Now some of us tried to mention it by using "sneaky" words, but generally that was a no-no at that meeting. That wasn't too many years ago.

In 1977, what Malcolm said was entirely true, prescribed burning was mentioned by some speakers, and occasionally in the audience, but you could tell it was a highly controversial subject and one on which we had a long way to go to gain support, even in research agencies.

It's interesting to note that in 1981 at this symposium, there were almost no papers that did not mention prescribed burning either just to say that we were considering doing it or that the paper itself was about prescribed burning. I consider that quite a change in just 8 or 9 years. In fact, amazing in many respects because I didn't think it would ever happen. But I tend to be a cynic.

The other two things I noticed are that in 1977 we had a very hard time getting people to present papers on soil nutrients in Mediterranean systems and wildlife in Mediterranean systems. In this symposium, we had an overabundance of nutrient papers. We had to turn a lot of nutrient papers down. We still, although we had adequate papers on wildlife, do not have adequate research in Mediterranean systems on nongame species. That's another area we have to address. Maybe at the next symposium we'll have a lot of papers about nongame species. You can get all the papers you want on deer and moo cows!

My fourth point, and Bob Callaham did mention it also, is that it's very difficult to transfer information to managers at an International Symposium, because historically they are designed to transfer information among scientists and not to practitioners. Therefore, you have to deal with two things. One is the format of the symposium and the participants, and the second is the format of the presentations. It's very difficult to get researchers to write papers and talk about their research in terms of management needs or management implications, or even to make statements at the end about what this means to management. We did have some good examples of researchers that did this: Tim Paysen, Lisle Green, Paul Zinke, and Sid Shea. I'm not just singling them out, but their papers are examples of the kinds of papers that we can present that clearly explain management implications.

I'd also like to say that in my opinion the practitioner papers at the symposium which are normally not included in international symposiums are, for the most part, outstanding. I think it would have been a good move on our part to have a workshop format for some of the afternoon sessions and have some afternoons totally free. We argue about this every time we put a symposium together. Someday some of us will win on that point.

Bob Callaham also mentioned that we're going to try and rewrite the proceedings into a short 50 or 60 page synthesis document for managers. I think we can do that. At this point, the proceedings would be about 700 pages, which would be a little tough to handle in the field.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Assistant Director, Continuing Research for Southern California and Hawaii, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

The next point I'd like to make is the point that many of us have tried to make for several years. It has to do with the difference between prescribed burning, prescribed fires, and wildfire. There isn't any difference between prescribed fire and wildfire in the fire behavior and fire effects sense. Prescribed burning and wildfire are political terms, policy terms, and legal terms. They're not fire behavior terms or fire effects terms. The reason I point this out is that there's a lot of fire effects information available that has come off wildfires and people tend to ignore it because it came off wildfires. It can be a very serious problem. There is no difference. Fires that spread the same way, have the same intensity, and burn the same terrain and the same fuel types--they're the same fire, prescribed or not. This leads to another problem we have, especially in research. We still have a lot of research going on in fire effects, where the fire itself is not documented. People are presenting information to managers from high intensity fires, low intensity fires, and medium intensity fires and managers have difficulty using it, because somebody assigns high intensity to a fire in one watershed and a mile away the same fire behavior may be somebody else's low intensity fire. A lot of fire effects information, in fact about 95 percent of it nationwide, is almost useless from a standpoint of implementation because it cannot be related to fire behavior characteristics which is how managers are writing prescriptions. They don't know how to predict effects because they don't know what the researcher meant when he said "low intensity." So I hope we can get that in better shape in the next few years.

Another problem or concern I have with prescribed burning, especially in Mediterranean ecosystems, is there are people talking, at least I perceive that they are talking, about massive, broad–scale approaches to prescribed burning. I think they need to look at some of the work Tim Paysen has done and some of the comments Jeanine Derby made this morning indicating that there is quite a mosaic of conditions and sites out there. There are very different fire needs and very short spatial changes. We have the ability now to write prescriptions and talk about fire effects on a much more refined scale than just taking a flying drip torch out, touching off 20,000 acres every afternoon because we want to manage fuels, type convert, or whatever. If you're going to talk about vegetation management, I think you ought to get serious about it and get a little bit back from those kinds of approaches.

One more thing and it's just a suggestion for the future. I started adding up the number of acres of prescribed fire officially planned for southern California for chaparral management (including the Los Padres National Forest). I came up with something like 150,000 to 200,000 acres a year. We don't have the resources on a forest or a district, or a California Department of Forestry region, or a County to go into that kind of a prescribed burning program in southern California, because of limitations of people, money, air space, and windows--prescription windows. I think the prescribed burning people and the fire people and the practitioners in this room, and other places, need to get together and give prescribed burning the same emphasis they're giving suppression through things like FIRESCOPE and the Operations Coordination Center.

There are tools, organizations, contracts, agreements, and all kinds of things available for coordination and sharing of resources. These ought to be converted and modified so they could be used for prescribed burning. One place in the world where this approach is very successful is Western Australia, where prescribed burning is planned about 2 years ahead. The windows are allocated down to the forest level, resources are allocated down to the forest level, and everybody isn't going out on the same day and burning 18,000 acres of their ground. It may look like that sometimes in the movies, but that's not how they do it. We have that same problem in southern California. I just can't imagine the prescribed burning that we need, and are planning, and are committed to now, going on much longer at the district or small organizational level.

Review Comments[1]

Richard Vogl[2]

A few concerns have arisen during this symposium. One of these relates to the transfer of research findings to management practices. Under normal circumstances in science, one study is of little significance until the study is duplicated and similar findings are obtained, particularly by various investigators at different locations. By this process of reproducibility, some hypotheses become principles and some ideas will be eventually stated as facts. These facts and principles must then be evaluated by experienced researchers in the context of the ecosystem and verified by seasoned resource managers in the light of man's needs before they are incorporated into management.

I think we should be cautious about the significance of the findings of one study and of formulating and executing management practices as a result of it. Although chaparral ecosystems have suffered from lack of management or mismanagement, and managers are now anxious to correct this, they must patiently wait for research findings to withstand the test of time before basing management actions on them. This, of course, does not mean that any study is worthless or unnecessary, but rather that it is an important and essential building block of science.

Meanwhile, there are numerous management practices that can be put into execution immediately without waiting for the many details to be resolved by science. This can be accomplished by employing management practices that work within the natural framework of the system, -- management that works with nature. Resource management practices, for example, that duplicate natural processes inherent to a given region are the most likely to succeed and be compatible. Sound management must also use common sense and put things into perspective. Such management would be a big step forward because until now we have largely ignored nature and have attempted to defy the natural laws of chaparral ecosystems.

We must also be aware of California's history of a "brush fighter's" mentality and that such feelings toward "brush" still exist and might again prevail. For years the U. S. Forest Service and California Division of Forestry, along with private landowners, waged war on chaparral. One-twentieth of California is occupied by this "worthless brush" that has defied destruction by livestock, burning, cutting, spraying, bulldozing, and conversion. We have eradicated California's native grasslands, have worn the California deserts bare, and are presently eliminating our forests with saws, smog, second-homes, and unnatural fires. Even the indestructible tropical forests of the world are now being irreversibly destroyed at the rate of 50 acres per minute. There must be those who believe that the eradication of chaparral, present in the backyard of progressive California, must also be near at hand.

Such negative attitudes toward chaparral are expressed less commonly today. In recent years there has been talk among even the hard-core brush fighters of "learning to live" with chaparral. One does not know if this is an admission of defeat or the acquisition of ecological wisdom. Current considerations of the large-scale harvesting of chaparral for use as fuel for energy may be a way that the latent brush fighters may be able to renew their costly war on brush.

The brush fight will continue to arise in various forms unless we make efforts to fully understand chaparral ecosystems. Ecologists maintain that the native plant growth that has become established in a given region is the best adapted vegetation. In other words, nature knows best, and there is little or nothing man can do to improve upon it. This means that the existing vegetation such as chaparral does the best job of controlling erosion, stabilizing the area, maintaining the watershed, surviving climatic extremes, providing biological diversity, and supporting wildlife without the help of man, or without cost. If we replace or alter the native growth we will find that it is not only unsatisfactory in various ecological ways (triggering never-ending degradation overruns and tailspins), but is also an eternal commitment of time, money, and energy (items in critical shortage in the U.S.A.). Without these continued expenditures, a degraded and continually deteriorating system that may not return to the original vegetation will result. If we think that chaparral presents problems and appears worthless, we have not thought ahead to the degraded alternatives that would replace chaparral if we succeeded in eliminating it. When man wars against nature, man wars against himself!

It seems that "practical" men have ruled our world through time and this is one of the reasons that it is presently in such a mess. Perhaps the only meaningful use of chaparral will be to humble those men -- the conquerors -- who are ever trying to change and "improve" the face of the earth -- who believe that chaparral is one of nature's mistakes. Maybe chaparral will help us to learn to live with nature, coexisting with the natural resources present in an area. Perhaps the only worthwhile use we will ever get from chaparral is studying it, and in that way understanding it, thereby helping us to understand ourselves. Even though we come from a long line of ecosystem destroyers, and it's in our genes, I think we can still change our ways, and begin to live with the premise that nature knows best.

Review Comments[1]

R. L. Specht[2]

MEDITERRANEAN ECOSYSTEMS

The mediterranean regions of the world are characterised by an annual climatic sequence in which a hot dry summer season alternates with a cooler wet period. Mediterranean regions, showing this climatic oscillation, extend from the semi-arid to the humid zone.

A wide range of plant communities may be observed throughout mediterranean regions, ranging from semi-arid grasslands and shrublands to woodlands, open-forests and even tall open-forests (containing the tallest trees in the world).

The nature of the ground stratum depends on the nutrient level of the soil - a grassy/ herbaceous ground stratum is characteristic of rich soils, while a sclerophyllous (heathy) ground stratum flourishes on soils very low in plant nutrients.

It is this wide range of ecosystems which must be considered in a discussion on the interaction of research and management in mediterranean-type ecosystems.

CONSERVATION OF MEDITERRANEAN ECOSYSTEMS

Any landscape is likely to be subjected to a number of competing methods of land-use, developed to satisfy the needs of man. Among the various land-use alternatives may be cited:- urban and industrial development; water supply; waste disposal; transport; mining; agriculture and horticulture; forestry; tourism and recreation. The conservation of ecosystems and of associated biota must be regarded as sharing an equal place with the many other conflicting land-uses. Unfortunately for the land-use planner, natural ecosystems are often unique to the area; in weighing alternatives, it may be impossible for the planner to dismiss conservation reserves as a land-use strategy which can be achieved elsewhere.

> The first priority in landscape planning should be to acquire a comprehensive and adequate system of conservation reserves. These reserves should be of sufficient size and diversity to ensure adequate conservation (for both perpetuation and evolution) of the range of mediterranean ecosystems and their component biota.

It is often assumed that conservation reserves must be protected from natural perturbations such as fire, overgrazing by herbivores, insect plagues, etc. which have influenced ecosystems for countless years in the past. Such decisions may lead to relatively homogeneous, overmature communities, often with reduced species diversity. Heterogeneity of age classes and diversity of landscape appear to be essential requirements for long-range conservation and for evolution of biota and ecosystems. Management is necessary to attain these objectives.

As well, environmental impacts imposed on the conservation reserve both from people within the reserve and from adjacent land-use strategies may need careful management techniques to conserve the ecosystem intact.

MULTIPLE LAND USE

However, only a small percentage, say 5 to 10 percent, of the landscape will be declared as conservation reserves. Much of the landscape will be converted to man's immediate needs - urban and industrial development with associated land uses such as reservoirs, grazing, agriculture, forestry, and mining to supply water, food, timber and minerals. In many mediterranean landscapes, the topography may be unsuitable for complete conversion of the original ecosystem. Multiple land use may be attempted in these less accessible areas; conservation may be one of the aims of management of these areas but it is probable that, in the long-run, only the most resilient of the species will survive. The objective of management in these areas is then, not conservation, but the maintenance of ecological stability, possibly with a continual supply of extractable products. The ecological stability present in the original ecosystem may include a supply of fresh water (with balanced nutrient-levels), a stable soil surface, a minimum of fires. Fires become an increasing problem when urban development impinges on these semi-natural mediterranean landscapes.

What are the extractable products which may be gained from semi-natural mediterranean ecosystems? Water; fodder for grazing and browsing of domestic animals; fuel and timber; native and feral mammals and birds (hunting and food); herbs, cut and dried flowers; some fruits and bulbs; honey; possibly peat, clay and rock.

It would appear possible to maximize the supply of one or more of these extractable products by manipulation of the ecosystem. Nevertheless a number of attempts to achieve

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Botany, University of Queensland, St. Lucia, Queensland 4067, Australia.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

these objectives has led to instability. For example, conversion of the deep-rooted, crown-root sprouting, evergreen chaparral vegetation to a shallow-rooted seasonal grassland has:-

(1) Improved water flow, but with release of nitrate ions stored in soil (Sodium ions are released from solodic soils in mediterranean Australia).

(2) Increased seasonal herbage for grazing animals, but with:-

- increased soil erosion during flood periods at the end of the dry summer season
- invasion of mediterranean weeds and pathogens
- increased fire hazard from both lightning strikes and man (grass fires, often causing loss of life and property in mediterranean Australia, may occur every year whereas brush fires are relatively infrequent).

The conversion of brushland to grassland may be an extreme example of the instability induced in an ecosystem by manipulation. It is cited to emphasize the sensitivity of many mediterranean ecosystems to perturbation.

ECOSYSTEM RESEARCH

In order to provide a sound basis for management decisions, it is necessary to continue, to strengthen, or to establish a number of integrated projects for analysis of the structural dynamics and functioning of representative mediterranean ecosystems especially in response to the effect of various environmental impacts, for example, fire, erosion, grazing, selective removal of plant or animal species (by harvesting or hunting), nutrient removal by harvesting or grazing, invasive weeds, vermin, pathogens, atmospheric pollution, nutrient and other chemical contamination, salination - all of which can be simulated by controlled experimentation. Each integrated project, investigating one or more major environmental impact, should be planned from an holistic (not fragmented) systems approach. It is desirable to supplement the large projects, which necessarily have to be limited in number, with a series of supplementary projects intended to solve special problems, as well as supplying additional information for comparison and synthesis.

The aim of the integrated project is to define the basic ecological rules operating within the ecosystem - rules which are applicable to all mediterranean ecosystems - and to synthesise these rules into a relatively simple working model which will enable the effect of an environmental impact to be predicted.

It must be stressed that even a simple model, as outlined in this author's paper on the General Characteristics of Mediterranean-type Ecosystems in the first session of this Symposium, appears to provide a basis for national and international predictions of the results of management practices on mediterranean ecosystems.

The essential point is to establish the basic ecological rules as they operate seasonally, annually, and cyclically (over the life cycle) in the ecosystem. In the past, ecosystem research, which tackled the problems associated with sharp environmental discontinuities or with ecosystem change along environmental gradients, has established many basic rules and is likely to be a productive area of research in the future. Once basic ecological rules have been established, the best management policy can be determined in the light of the various environmental impacts likely to be experienced in conservation reserves or semi-natural ecosystems (where multiple land use is practised). The ultimate aim should be long-term stability of the ecosystems, associated with sustainable yield, albeit at a level below the maximum possible (on a short-term basis).

Nevertheless, it must never be forgotten that extremely rare events (such as volcanic eruptions, land-slips, cyclonic storms, floods etc.) are virtually impossible to predict and may disrupt even the most soundly based management program.

RECONSTRUCTION OF DEGRADED MEDITERRANEAN ECOSYSTEMS

Throughout mediterranean regions, there are many areas where these objectives of sustainable yield and long-term stability have not been realised. Long-term stability has been forfeited, often unintentionally, for a relatively short period of maximum yield. As alternate land-use may not be possible, efforts should be made to restore these degraded areas to their former status of long-term stability (with or without sustainable yield). Such reconstruction efforts should be based on the basic ecological rules derived from research projects such as outlined above, rather than the empirical trial-and-error methods which are often applied. At this stage of our knowledge, it would be unwise to claim that reconstruction of original ecosystems (containing all conservation objectives) is possible. However, long-term stability (with or without sustainable yield) seems a valid aim.

FUTURE RESEARCH AND MANAGEMENT

Research in mediterranean ecosystems should aim at understanding the basic ecological rules operating within the system and how resilient these ecosystems (and their component species) are to environmental stress. Simple working models will enable the effect of an environmental impact to be predicted. Such ecosystem research, basic to management problems, will be the major theme of the Fourth International Conference on Mediterranean-type Ecosystems to be held in Perth, Western Australia, August 1984.

Review Comments[1]

Harold J. Biswell[2]

Since 1947, I have been a strong advocate of prescribed burning in California's Mediterranean-type ecosystems, primarily to reduce fire hazards and the severity of wildfires. Also, through prescribed burning the high cost of suppressing fires can be reduced. I am also a strong advocate of fire prevention and suppression. All of the three aspects of fire management -- prevention, suppression, and prescribed burning -- are extremely important. They should go together and be treated about equally. In past years much attention and expense have gone into fire prevention and suppression, but very little into prescribed burning. This has been a mistake. About equal attention and expense should go into each of the three aspects. When Prescribed burning is pursued vigorously and carefully, fire prevention and suppression become easier and less expensive.

The general public is being involved more and more in decisions regarding resource management plans and research. Many of those people are becoming concerned about the difficulties encountered in controlling wildfires, and the damage they cause, the expenses involved. Probably this concern will increase; we will be forced to do more prescribed burning to reduce fire hazards.

I must emphasize that the foremost problem in managing California Mediterranean-type ecosystems is that of severe wildfires. I am not sure that the symposium emphasized this enough. In southern California where the soils are highly erodable on steep topography, wildfires in chaparral that burn entire watersheds can create extremely severe flooding and soil erosion problems. Furthermore, the problem of wildfires is not diminishing. On the contrary, it becomes more critical each year as fuels continue to build up, particularly in the interfaces between country and town where there are more houses to be destroyed or damaged.

Living as I do on the edge of Berkeley and Tilden Regional Park, exactly where a wildfire on September 17, 1923, burned 625 houses and other structures in two hours, and seeing the fuels over this area as they exist today, I am very aware and scared about the risk and danger of another but more severe wildfire in the same area, burning under conditions of low humidity and winds of 60 miles or so per hour. Certainly it is not too soon for research to study the social problems involved and for management to start reducing fire hazards in the Park and surrounding areas to abate the probability of another wildfire disaster.

One or two basics: Lightning strikes are natural and so are the fires they start. Recognition and acceptance of this fact is important to an understanding of fire ecology. Fires have always burned over our dry landscapes and inevitably they will continue to do so. Attempted fire exclusion has introduced a new dimension into our wildland ecosystems. What are we forcing upon our natural environment and what are the environmental impacts and consequences? The end product is usually a severe wildfire burning in heavy tinder fuels. In fire exclusion activities one is working pretty much against nature; in doing so, the natural balance is being upset. Now we need to use fire wisely and begin working more in harmony with, and not so much against nature. Both research and management should be centered around this philosophy.

The symposium did not include enough on Mediterranean-type forest ecosystems. It will be found someday that prescribed fires can be man's most useful tool in timber management. Why do research and management continually ignore the use of fire in California's forest-land ecosystems?

On the whole, the symposium was very good. We need more conferences of this sort.

Question from the audience: Dr. Biswell, how long have we been effectively stopping wildfires in this country, now compared with 25 and 50 years ago?

Answer from Biswell: Perhaps I can answer this best by referring to forested areas. Some 50 years ago fuels in natural forests were at a low level; they had been kept down by naturally recurring low intensity fires set by lightning and Indians. At that time fire suppression was easy and effective. Twenty-five years ago fuels had increased considerably from logging operations. Thickets of young trees began to grow in with the logging debris, and suppression became less effective. At present, many forests are tinder boxes, full of debris and ladder fuels. Even with all kinds of equipment and manpower for suppressing fires, those burning under conditions of low humidity and strong winds are nearly impossible to control until the weather changes or until the fires run into less flammable fuels, or run out of fuels altogether.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Forestry and Fire Ecology, Emeritus, University of California, Berkeley, CA 94720.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Review Comments[1]

E. R. Fuentes[2]

I would like to make two opening observations:

(1) I will speak as a biologist and as a concerned citizen of a developing country where evergreen shrublands (chaparral/matorral) are an important resource. (2) Although the responsibility for these comments is mine, they were discussed with the other Chilean participants in this meeting and are thus part of a consensus among us.

Whereas there are many striking similarities between the various Mediterranean ecosystems around the world, there are very important differences in sociocultural aspects. Thus, whereas the biology satisfies a convergence criterion in many cases, the history of management, the history of science, and the aims and resources of the people inhabiting those areas do not converge. People in the various Mediterranean areas seem to impact different requirements on their ecosystems. In part, these differences are due to the fact that the use of the Mediterranean-type ecosystems shrublands, from man's point of view, is not independent from the use of other ecosystems. Thus, for example, the California chaparral is a heavily subsidized system in which the possible uses are only in response to needs of city dwellers: water management, fires, and recreation. The income and resources required by people inhabiting the area of the California chaparral come from sources other than the chaparral ecosystems. This situation is most likely to be different just across the Mexican international border. There, although the biology would probably be very similar to the one we see here, the system is much less subsidized and people have to live out of what the Mediterranean ecosystems can supply them. There, uses are not as much associated with requirements of city dwellers as to people actually living in the shrublands. The situation with California Indians might have been similar to that in developing countries.

In fact, observing across the various Mediterranean-type ecosystems, there is a whole spectrum of these kinds of situations in which California and perhaps South Africa are at one extreme and North Africa, Mexico, and Chile are closer to the other.

In central Chile, for example, the matorral occurs along a 1000-mile-wide altitudinal vegetation belt on the longitudinally extended Andes and on the Coastal Ranges. The central valley between these mountain ranges is occupied by a savanna, and the marine terraces along the coast were occupied by a mixture of evergreen and drought-deciduous shrublands. Further north, drought-deciduous plants dominate. Towards the south, the predominant elements are evergreen forests.

Chilean evergreen shrub lands are thus part of wider management units in which the various altitudinal and to a lesser degree latitudinal vegetation belts offer different resources and impose different constraints. Along the wider valleys where there is irrigation, fruits and other crops are grown. On the dry, flat areas, the main problem now is grazing. Fires seem not to have been part of the natural situation in Chile.

Historical grazing management units seem to have been strips of land that would allow animals to graze at low elevations during the winter and early spring, and the high altitude grasses during the summer and early fall. Today, this is still largely the case, although a more sedentary situation also holds. In both cases, however, management questions could be roughly dichotomized into problems in the dry, flat areas and those on the slopes.

On the flatter areas, continuing research is dealing with substituting the existing shrub cover with more palatable species (i.e., Atriplex spp.). This arrangement should provide grasses during one part of the year with the shrubs buffering the animal's requirement when the grasses are dry. Animal science, management of plant cover, animal loads, and optimization are key phrases. A poster was presented during these meetings which explains the research efforts and results in more detail.

By contrast on the slopes, potential erosion is high enough so that only animal numbers can be managed. Removal of the shrub cover could cause severe soil losses and is no longer recommended. In fact, during the 19th and early 20th centuries, the removal of shrubs was done and severe erosion followed. Here, along the steeper slopes which is where the poorest people live, the key phrases for us are ecosystems resilience, management of goats, and fuel extraction for domestic purposes.

Earlier in this meeting, J. Simonetti and I presented some results concerning the possible devastating consequences of the introduction of goats into Chilean shrublands. We even posed the question that eventually goats may so devastate the vegetation that they may have to be replaced as a source of income.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego. California.

[2]Professor of Biological Sciences, Pontificia Universidad Catolica de Chile. Casilla 114-D, Santiago, Chile.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

However, since there are people living in and out of the Chilean shrublands, biological considerations have to be compromised with studies of human desires and needs. Therefore, as it is likely to be the case in other Mediterranean ecosystem regions, biological research in the Chilean matorral must include collaboration from scientists in nonbiological disciplines. Thanks to the efforts of the Man and the Biosphere (MAB) Program, this collaboration is occurring.

I do not need to refer here to the problems that arise when this kind of effort must be implemented. I believe, though, that symposia such as the one this week will help increase the understanding between people working in various disciplines. Meetings should include not only biological and physical scientists and managers but also social scientists.

In this meeting, as well as in a previous one held in Chile about 10 months ago, I found that there is a "gap" between managers and scientists. This should decrease in the future and instead of being a drawback, it should be a reason for more meetings of this sort--international and diverse. Particularly, as a biologist from a developing country, I think there is need for true integration among disciplines in which the biology of human use is studied and later set into a wider perspective in collaboration with researchers from other disciplines. Within this context, the differences between Mediterranean ecosystems and the aims and uses people make of them could actually become a source of fruitful comparisons and inspiration for us all.

Review Comments[1]

Vernon C. Bleich[2]

When I was first asked to participate in a panel discussion, I was hesitant to do so. After careful consideration, I consented because it presented me with the rare opportunity to voice my views on a subject, and to speak those views to an audience which might be influenced by them. The panel members were provided with brief guidelines on which their discussions were to be based. Five major points were included, but I have elected to emphasize certain ones, and mention others only in passing. It should be pointed out that these views are those of a scientist who is employed as a manager, and they may therefore be particularly pertinent as they relate to interactions between research and management disciplines.

During this discussion, I will limit my remarks to three main points: (1) the quality of presentations; (2) the observed interactions (and lack thereof) between persons affiliated with various disciplines; and (3) the relevancy of what was presented here to application in the "real world," and the future common path that researchers and managers must take.

QUALITY OF PRESENTATIONS

> Much effort is required for a man to learn the truth--but it is twice as difficult for him to make it known to his fellow man.
>
> Plato

During this Symposium, I attended some of the finest presentations I have ever heard; conversely, many others had been rather poorly prepared. Symposia are designed to provide an open communication of ideas by the speaker and a ready response by the audience. Poorly prepared presentations virtually preclude this possibility, and one of the most important aspects of a symposium, the opportunity for discussion and instant feedback, is lessened substantially.

Throughout the week, many authors made outstanding presentations. Clearly, these individuals were not only competent in their areas of expertise, but they were familiar with their subject material and used excellent graphics to accompany their presentations. In contrast, others had not even taken the time to review a set of slides to make sure that they were arranged properly. Still others used material of such poor quality that its value as a visual aid was at best questionable. The importance of presenting high quality graphical material cannot be overemphasized (Hooper, 1974).

All of us put untold months, if not years, worth of effort into most traditional publications we prepare. The opportunity for immediate feedback from colleagues does not occur with traditional publications as it does with presentations at symposia. If that important opportunity is to be fully realized, we must all make the effort to stimulate responses, and adequate preparation is the primary avenue by which that will occur.

INTERDISCIPLINARY INTERACTION

> Now the Sirens have a still more fatal weapon than their song, namely their silence... Someone might possibly have escaped from their singing; but from their silence, certainly never.
>
> Franz Kafka, Parables

Throughout this Symposium, observed interaction between disciplines was not as evident as I'd hoped it would be. This, I'm sure, is partly human nature, but also is partially a result of mutual avoidance reactions which seem to persist. At future symposia, it is necessary that this apparent barrier to interaction degenerate.

With the current Administration, there likely will be a decline in Government funding for much research that previously had been supported by the National Science Foundation and other such agencies. As a result, I anticipate greater interaction between university affiliates and personnel employed in management positions. Managers must be willing and able to communicate their needs to researchers, and researchers must be willing to provide managers with the information they require. I suspect that at future symposia of this type there will be more interaction; if not, these words have been wasted.

THE FUTURE

> Men ought to know that in the theatre of life it is only for gods and

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Associate Wildlife Biologist, California Department of Fish and Game, Hemet, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

angels to be spectators.

Francis Bacon, New Atlantis

Throughout this Symposium we were exposed to a variety of papers which dealt with many subjects, all related in one way or another to management or research in Mediterranean-type ecosystems. Some of these papers dealt with very esoteric research topics- topics that have relatively little, if any, management implication. Others did an admirable job of integrating with management implications that which superficially appeared to be esoteric.

Our colleagues from foreign countries appear to be at the forefront of conducting management-oriented research. Ed Fuentes presented an excellent example of applied research in Chilean matorral, as did Leonidas Liacos in Greek maquis. Although some Americans presented the results of management-oriented research, it is evident that this type of work is a much higher priority among our foreign colleagues.

An infinite number of opportunities exist for us to broaden the scope of research efforts, but managers must be willing to communicate their needs to those capable of supplying the answers, and those capable of supplying the answers also must be willing to do so.

One thing that became more evident as the Symposium progressed is that all of the participants are partners, and we must be willing to work together toward a concept of ecosystem management. Our Australian colleagues, as evidenced by Syd Shea's excellent presentation, have adopted that approach, but much out of necessity as he related. We Americans have some distance to go toward meeting that objective.

Sometime ago, Frank Egler (1974) published a review of a book entitled If Deer are to Survive. In that review, Egler said,

> There is a huge crevasse that separates the zoological field of wildlife management from the botanical field of wildlife habitat management. Despite the fact that each field is greatly dependent on the other, each marches on his own side, not aware that they should do more than gaze coyly at each other from a distance.

Evidence presented during the Symposium suggests that Egler's concerns no longer are as appropriate as they once were, at least in Mediterranean-type ecosystems.

Recently, Michael Soule and Bruce Wilcox (1980) edited a book, Conservation Biology, which possibly is the most important work in the field of resource management since Aldo Leopold's classic, Game Management. In the opening chapter, Soule and Wilcox state,

> Unfortunately, the emergence of conservation biology as a respectable academic discipline has been slowed by prejudice. Until recently, few academically oriented biologists would touch the subject. While wildlife management, forestry, and resource biologists (particularly in the industrialized temperate countries) struggled to buffer the most grievous or economically harmful of human impacts, the large majority of their academic colleagues thought the subject below their dignity. But academic snobbery is no longer a viable strategy, if it ever was. Because many habitats, especially tropical ones, are on the verge of total extinction, the luxury of prejudice against applied science is unaffordable.

Of course, most Mediterranean-type ecosystems have not yet suffered the plight of many tropical ecosystems (see Whitmore, 1980); improved interdisciplinary cooperation hopefully will preclude that possibility. Both as managers and researchers we must work toward a common goal: the sound and productive management of the world's Mediterranean-type ecosystems.

LITERATURE CITED

Egler, F. E. Wildlife habitat management, and deer. Ecology 55:684-685; 1974.

Hooper, J. K. Improving wildlife communications. Cal-Neva Wildl., Trans. 1974:1-8; 1974.

Leopold, A. Game Management. New York: Charles Scribner's Sons; 1933. 481 p.

Soule, M. E. and B. A. Wilcox, eds. Conservation Biology. Sunderland, Mass.: Sinauer Associates, Inc; 1980. 395 p.

Whitmore, T. C. The conservation of tropical rain forests. In Soule, M. E. and Wilcox, B. A., eds. Conservation biology. Sunderland, Mass.: Sinauer Associates, Inc.; 1980.

Review Comments[1]

Joseph R. Agozino[2]

I viewed the chaparral symposium from the multiple viewpoints of professional ecologist, designer, planner and practitioner of chaparral management programs, as well as private citizen with strong environmental viewpoint.

From this multiple perspective, I was first gratified that the symposium accomplished its stated objectives of technology transfer, mutual interchange and heightened awareness of chaparral as a functional ecosystem, and clearly one which is little understood by both agency personnel and the public as well.

I felt that the quality of the presentations was all right, but there is room for innovation in the exposition of scientific thought. To be more specific, I felt that there were too many graphs, tables, charts, etc., to assimilate well in the short presentation time, and perhaps the style of presentations were a little on the stuffy side.

I was a little disturbed by the dual session, free choice, thematic format since much of what would have been useful information for managers had to compete with the management oriented sessions. I think this should be changed in future symposia.

The ecosystem theme carried through the week's sessions with some memorable presentations by American and foreign scientists as well. Notably Richard Vogl dramatized a so called "shock, stagnation" syndrome, an arrested stage of plant succession characterized by long term dominance of weedy annual species. Vogl also stressed that chaparral systems suffer from many abuses associated with the poor public image which chaparral has.

Phillip Rundel's paper dealing with succession from the physiological standpoint demonstrated to managers that basic research ought to be the basis for conceptualizing all management schemes in chaparral ecosystem.

As program designer and manager, I was also looking for both specific information and conceptual models for structuring management programs. I am satisfied that both of the above were to be found in the program. I must state that there were some new things learned and/or other concepts which heretofore had been suspected but now confirmed. In this I credit our foreign researchers/managers with some truly outstanding presentations.

I think that this must be highlighted as the best feature of such a symposium, which is, after all, a thought expanding process. I also feel that this process was in evidence which I base on the many conversations with delegates before, during and after the sessions. I am convinced that I did hear some alteration of viewpoint if not attitude about mediterranean ecosystems. I believe this was most evident among managers, but that view might be biased.

I am guessing that de facto viewpoint shifts resulted mostly from both gentle remonstration, and ominous messages issued by researchers who collectively seem to evince the feeling that managers lack the scope and breadth of understanding about ecological processes, as well as specific data relevant to those same processes. In this I say only "let the chips fall where they may". I personally was not the least bit offended by this subtly, discernible viewpoint. I think that it was, after all, the intent of the symposium planners to create a favorable milieu for the transfer of technology and consciousness raising. I feel that those objectives were actualized. To what extent, only the future will tell.

I have one additional observation on this point and then I will pass on to more generalized subject matter. I come away from the symposium a confirmed believer in "experimental management" a term coined by Australian Scientist, A. M. Gill, in his Friday presentation. This concept to me has remained a transcendent theme which emerges as the single most important new direction for land managers in mediterranean ecosystems. Briefly I say this because: 1. Major mediterranean biotypes are badly depleted, 2. This results from the fact that mediterranean biotypes are in the path of major adverse social forces, 3. Scientific research and land management within mediterranean systems has been largely reactive with primary emphasis upon facilitating the socialization process. 4. Ecological research in mediterranean systems is still in its infancy and, therefore, has not been a moderating force in this process. 5. All of this boils down to historic and current management schemes which attempt to alter, destabilize and replace major components of the mediterranean ecosystem. In short, Pest Control emerges as the underlying theme of land management within the mediterranean ecosystem.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Resource Ecologist, Department of Parks and Recreation, Southern Region, State of California.

Experimental management seems to me to be not only the way to reverse old practices, but also can be readily integrated into existing management as a means for assumption testing and evaluation of gross impacts to ecological systems which result from our management schemes. I am heartily in favor of such "experimental management" which is nothing more than a scientifically credible monitoring process which helps establish acceptable management practices while isolating others which are unacceptable. With these observations, let me pass on to the question of future symposia.

What of symposia planners of the future? Their job will be to reconcile the growing differences between two great power bases which now operate within the context of mediterranean ecosystems. On the one hand are those forces mentioned in (3) above, the purveyors of socio-politico mandates which strive to develop and utilize ecosystem resources. Historically that power base has exerted a will aimed at controlling natural forces - taming recalcitrant nature, altering, changing, modifying again the Pest Control directive.

On the other hand is an emerging environmental ethic embraced by both citizen and scientist alike which tests old assumptions and challenges historic premises of land management.

I believe that future planners and program designers will meet their greatest challenge in developing an integrative approach to educating these two groups. I would suggest that some balance between open and frank discussion and more subtle, less direct methods will meet this need. Perhaps the services of a consulting psychologist who specializes in communication and group dynamics is worth considering.

All of this is to say firmly that I believe in the value of such exchanges and I would like to see this first attempt perpetuated. I am optimistic that persistent efforts will be rewarded. I personally hope to attend the next symposium.

In my closing statements let me speak as a private citizen who maintains the disquieting feeling that management of public lands today is not that good. Certainly lands held by the private sector are atrociously managed. Government does not seem to be able to effect much change in what I perceive to be a worsening picture. I feel as though the symposium enhanced that feeling and particularly since I now have a new awareness about the problems of land management in foreign fields.

Certainly this situation is perpetuated by the very bad image of our native shrub lands, the primary cover type in mediterranean systems. This bad image results primarily from those social factors outlined above which speak to the high habitation potential of chaparral lands and the pernicious growth habit of the mediteranean shrub complex, which unfortunately also appears to be rather homogeneous in color, texture and distribution, attributes which are sure to engender in some feelings of dislike while in others absolute detestation.

I also sense that there exists a kind of public attitude x government attitude syndrome which results in the perpetuation of this bad image about mediterranean landscapes with their associated drab cover types and unexciting faunal habitats. I somehow get the feeling that what we would really like to do with these systems is completely make them over to something more like our image of "what they should be", which is mostly different from what they really are.

Is it too much to ask for a symposium like this one to strive for a greater feeling of acceptance for this natural ecosystem and to somehow effect an altered state of consciousness about these lands in those of us who manage them? As a private citizen, I would only hope that the chief aim of future symposia will be to achieve this most exalted objective - to understand, to acquiesce, to live in harmony with our natural world. If those who attend such symposia do not do this, then who will?

Review Comments[1]

Leonard A. Newell[2]

I had a number of remarks prepared as of yesterday on the technical aspects of this symposium, and then something came up which made me throw those out and take a different tack for my summary today.

I think that we all have been enriched by the international flavor of this meeting. We have all felt, in watching the presentations by people from other countries, that while we are dealing with different species, and in some cases different problems entirely, we find a great many areas where our interests converge.

This international communication is a very valuable thing. The proof is the fact that every three or four years we find it necessary to have one of these symposia. There is, however, a need to communicate on a more frequent basis, and I think a lot of us feel that there are too few mechanisms for doing so.

One of the keynote speakers of this symposium suggested a Mediterranean Ecosystems Institute as a possible way of helping this international communication. Dr. Oechel thought a great deal about this idea, and came to me yesterday to suggest that we have a discussion on the International Institute idea with the international visitors. The occasion would be the dinner that was given by San Diego State University for the international guests last night.

International matters are something we can not just charge into; there are a lot of things that ought to be prepared for, and we hadn't much time. I'm afraid we didn't prepare as well as we wanted to; for instance, we didn't have interpreters or advance announcement of the meeting. Perhaps some of the guests felt like throwing us out of the room at times last night because we let them have a very nice dinner, get relaxed and then sprung this heavy discussion on them. Yet we thought that the International Institute was really an idea worth following, to see what the attitudes of the visitors were concerning this proposal.

The things that came out are very interesting, and I would like to report them to you. First we examined the question: is there a need for such a thing? There were several needs that were identified and that we generally agreed on. One of the strongest areas of agreement was in the area of student exchange: students from one part of the world going to another part of the world to study, under auspices and with the support of such an institute. We do not seem to have much of that interchange taking place now.

A second item that occurred very notably in the discussion was the fact that we do not have a good way of translating things from one language to another. A translation service could serve the international community very well by taking papers from one language and distributing them to people who can read them in another. The general idea of dissemination of information seemed to receive a good deal of support.

A third area that came up from several of the people who commented was the need for a journal or a newsletter on what is happening in the field of mediterranean ecosystems. Abstracts could be published. At present, it is possible that someone could publish a paper that another interested person in another part of the world would not find for five years or so. Such an institute could get this paper much more quickly into the hands of the people who are in need of it.

A final area of discussion as to what we need was the idea of more frequent face-to-face communication. Is there a way, with tele-conferencing and other kinds of methods, that small groups of people can get together, without spending days on airplanes and thousands of dollars on motels and other expenses, to exchange ideas from various parts of the world? These things are now possible with communication satellites. The information could keep flowing.

The other major topics discussed last night were the things that should be done <u>before</u> charging into setting up an institute. We heard that people from the European Countries in particular were very skeptical about new institutes; they have seen a great many efforts get underway, including IUFRO, MAB and other programs of the United Nations. These existing programs and institutes have been organized to deal with some of the needs we have. The cautions that we heard last night were: don't rebuild the wheel; have a look at these existing organizations: can they accommodate our needs, and if not, can they be adjusted to accommodate these needs?

A second suggestion was to establish a small permanent committee or board of directors (one person used the term "secretariat") to investigate the need for an institute. Publishing a simple newsletter, it was suggested, might be enough at this stage to let people chew on these ideas and see what comes back from them. This was brought up particularly in connection with

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Manager, Vegetation Management Program, California Dep. Forestry, the Resources Agency, Sacramento, California

the 1984 Symposium in Perth, Australia, which Dr. Specht mentioned earlier, as a way of helping people organize these international meetings. A newsletter would aid in getting the information passed around and in achieving good attendance at that symposium.

Finally, it was someone's very astute observation that we have to explore the aspect of international funding, both private and public, because of course we're not going to be committed to anything that we don't ourselves support. Thus, if it were funded solely out of California, the international community would not have a very strong sense of ownership in it. This is another area that has to be investigated.

To conclude, the information that we received last night will be assembled in written form. Walt Oechel and Gene Conrad are going to write a letter which appears to represent the sense of last night's discussion, and it will be circulated. We will continue the dialogue on the idea of an International Institute on Mediterranean Ecosystems, to see if there are some needs that could be met in such a way, or perhaps in some other way.

Perhaps as a result of such efforts, the next meetings that we have will be even more successful than this one. On behalf of Doctors Conrad and 0echel, I thank all of you who took part in the discussions and contributed your valuable thoughts.

Review Comments[1]

Robert Chandler[2]

My summary will be from a what I think is a very different perspective since I have lived in Southern California only two and a half years. I transferred to Los Angeles to set up our newest national recreation area in the Santa Monica Mountains. My introduction to a mediterranean ecosystem was right after the Agoura fire that burned some 26 thousand acres in Malibu, and the Mandeville Canyon fire which occurred at the same time. I remember looking at those charred hills and saying to myself, "My God, what have I gotten into?" It was not long before those same hills were ablaze with wildflowers and new growth. It was the beginning of a fascinating learning experience. I was at once impressed with the resilience and diversity of a mediterranean ecosystem and I felt a tremendous need to accelerate my learning. This symposium has certainly been a continuation of my education in this special area.

The focus of this summary then, is from the standpoint of putting together a national recreation area in a mediterranean ecosystem in the Los Angeles megalopolis. I am looking at the indicators that are present here that may apply to similar ecosystems in this country, and perhaps in other parts of the world as well. We need to have our antennae out to sense what is happening in these ecosystems as a result of mass urbanization. This will give us insight into the issues many of us, both scientists and managers, will face in the future as the migration to these areas continues. Consider, for example, the Southern California sun belt. It is attracting a tremendous number of people, businesses, and industries because it is a great place to live and work. The housing industry continues to grow rapidly in spite of the economy, and vast areas are being converted into subdivisions. We must understand the impact of this continual urban growth on the ecosystem, and, conversely, how the system affects those living in it. From my perspective, this urban/wildland interface is the area which needs increased attention by researchers and managers. I would like to see more emphasis in the future on the people as a part of these systems. One of the things that would have been useful at this symposium would be a look at how people live and recreate within mediterranean ecosystems.

Relating to the focus on people, there is a tremendous need for better educational methods so people begin to understand in common terms the dynamics and importance of mediterranean ecosystems. From what I have heard here it appears that in some areas scientists are working extremely well with managers in applying the increased knowledge to better manage the resource. However, I am concerned about how much of this good work is passed on to the public at large as information. I think it's principally the role of the managers to make sure that such information is shared with the public in an understandable form. We are all facing a time where budgets are not going to provide for a lot of publications. The major publications that are produced are technical papers which are useful but miss the mark in reaching average people living in these areas. We should be looking for new ways to communicate this information. Our public information staffs need to be more involved in getting the word out. Also, in relation to the need to look more closely at the urban/wildland interface, I would recommend that future symposiums include more land use planners, economists, sociologists, etc. I realize that time is a problem but this could be handled through a workshop format during part of the week.

There was an underlying focus on fire this week, and I think it's appropriate from what I understand of the progress in this area in terms of the application of research. Perhaps the next session will not need to be as heavily weighted in this area.

I would like to see more consideration of the esthetic qualities of mediterranean ecosystems. Millions of people come to places that are mediterranean ecosystems for recreation. The more the ecosystems are understood and appreciated, the more they will be seen as very special resources rather than just brush. Too few people see or understand the complex beauty of these dynamic biotic systems. Maybe this is not appropriate for a scientific/management symposium, but if we are going to reach the people that will ultimately determine the kind of support and funding for these important programs then we must give our attention to how these ecosystems are perceived. The more people understand the ecosystems, the more they will support research and the management programs we have been talking about this week. I'm not sure how that gets incorporated into this kind of symposium, but to understand something about the special nature of this resource is something that needs to be communicated to the public at large.

The people that I have worked with for a very short time in the Santa Monica Mountains really get turned on when they begin to understand the mountain resources. I believe these newcomers to mediterranean ecosystems are hungry to understand

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Superintendent, Santa Monica Mountains National Recreation Area.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

those systems. When you give them a little bit, they begin to appreciate the subtleties of chaparral and it's amazing to see how the desire for knowledge grows as they reach out for more.

There is also a need to consider the coastal marine resource as part of the mediterranean ecosystem where appropriate. Too often in planning for the Santa Monica Mountains we tend to stop at the Pacific Coast Highway, or it may be at the beach, without looking at the relationship to the marine offshore resource. The link between the near shore resources and the coastal uplands is too often neglected. Remote sensing techniques could be helpful to better understand water quality and coastal resources.

One of the values of these kinds of conferences is that we can "shop the competition" and take a look at who's doing what where. I hope that future conferences attract more managers. Looking at what is happening in similar areas should provide a great stimulus to our resource management systems. It is a kind of healthy competition that really pays off. I heard a discussion yesterday between two managers arguing about who had the biggest chaparral. That's good stuff and maybe next year the two will be discussing who has the best burn program or the best management program.

Since I'm the last speaker of the panel, I will conclude with the feeling that I am extremely impressed with the people that participated in this symposium. The level of commitment, and intensity, and human energy present was outstanding. The knowledge and enthusiasm of the speakers as they presented their papers and answered specific questions clearly established the quality of this symposium; and I appreciate being a part of it.

Laguna-Morena Demonstration Area: A Multiagency Chaparral Management Project[1]

Thomas C. White, Gary L. Larsen, and Kim K. Bergstrom[2]

Abstract; The disastrous Laguna Fire of 1970 caused government agencies and officials to recognize the need for comprehensive vegetation management programs designed to reduce the potential for large wildfires. In response the Laguna-Morena Demonstration Area was organized. The Demonstration Area represents ten federal, state and local agencies and private landowners seeking to demonstrate the newest available chaparral management tools and techniques. Projects focus on those techniques which have wide applicability to others facing similar vegetation management decisions.

Chaparral is a resource which requires unique management strategies and can provide many multi-resource benefits. Historically, however, chaparral has often been thought of as valueless or simply as a carrier of destructive fires. In the past, society has attempted to gain complete control over these fires through prevention and suppression without realizing that fire can only be delayed, not eliminated. Fire plays a fundamental role in the functioning of chaparral ecosystems. Long term management must acknowledge the importance of fire as the climax event in chaparral plant communities.

These philosophies are beginning to be integrated into the direction and policies of land management agencies concerned with chaparral. The following quote from the Forest Service, USDA, Draft Regional Plan for the Pacific Southwest Region, indicates Forest Service perspective regarding chaparral management activities.

> Management activities over the past 80 years in California chaparral have been focused primarily on protection from burning. This long term protection has resulted in extensive areas of decadent brush that is highly flammable and virtually impenetrable to wildlife, livestock, and man. Protection from burning has proven not to be a realistic means of preventing large conflagrations. The present rate of fuelbreak construction and prescribed burning has not been able to reduce fuel loadings to the extent necessary to reduce sizes of wildfires.
>
> Chaparral lands have capabilities for producing several multi-resource benefits that are now being realized below their potential. An increase in vegetation management activities to eliminate decadent chaparral stands will provide increases in water yield, decreases in flood flows and sediment yields, improved wildlife habitat, reduced fuel available for extensive wildfires and increased forage for livestock.[3]

This quote suggests the need for an active management program on the 20 million acres of chaparral and related vegetation types in California (Table 1). Both the Forest Service and the State of California are presently developing plans and programs to protect watersheds and communities from the threat of wildfire and associated floods while increasing the other benefits received from the chaparral lands.

Table 1-- Areas of chaparral and related vegetation types in California.[1]

	Acres	Hectares
Chaparral	9,866,000	3,994,000
Great Basin Sagebrush	5,021,000	2,053,000
Coastal Sagebrush (Soft Chaparral)	2,249,000	911,000
Woodlands (Hardwoods)	2,457,000	995,000
Total	19,643,000	7,953,000

[1]Wieslander, A.E.; Jensen, Herbert A. Forest areas, timber volumes and vegetation types in California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S Dep. Agric.: 1946, Forest Survey Release No. 4

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems; 1981, June 22-26, San Diego, Calif.

[2]Acting Program Manager, Laguna-Morena Demonstration Area, Forest Service, U.S. Dep. Agric., Alpine, Calif.; District Ranger, Steamboat Ranger District, Umpqua National Forest, Forest Service, U.S. Dep. Agric., Idleyd Park, Ore.; Public Information Technician, Laguna-Morena Demonstration Area, Forest Service, U.S. Dep. Agric., Alpine, Calif.

[3]Draft Regional Plan, Pacific Southwest Region. Forest Service, U.S. Dep. Agric., San Francisco, Calif. 1981.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The Laguna-Morena Demonstration Area is at the forefront in demonstrating large-scale comprehensive chaparral management. Much of what is being accomplished on this 130,000 acre (52,000 hectare) proving ground will aid vegetation managers around the world in developing strategies for managing this unique resource.

THE LAGUNA-MORENA DEMONSTRATION AREA

The Laguna-Morena Demonstration Area is the result of one of the broadest based efforts ever to focus on land management problems in California. It began with the disastrous 1970 Laguna Fire which claimed six lives, destroyed 382 homes and 1,200 structures, burned 176,000 acres in 36 hours, and stopped at the front door of San Diego. A task force of federal, state, county and city agencies, the University of California, private citizens and various associations was appointed by Governor Reagan to recommend actions for reducing the threat of wildfire. One of the recommendations was to begin a cooperative program to demonstrate and develop fuel management techniques on a large scale basis, resulting in the establishment of the Laguna-Morena Demonstration Area.

Six major goals were identified for the Demonstration Area:

- Reduce the catastrophic potential of wildfire
- Provide a forum for all who have an interest in wildland fuel management
- Demonstrate chaparral management techniques
- Monitor environmental impacts of large scale chaparral management
- Develop widely applicable guidelines for chaparral management
- Develop and test new techniques for chaparral management.

One of the initial challenges facing the Laguna-Morena Demonstration Area was the effective integration of vegetation management programs of several agencies and private landowners. Widely divergent management goals and philosophies and complex land ownership patterns caused an acute need for cooperative planning. After three years of work by ten federal, state and local agencies the Laguna-Morena Demonstration Area Coordinated Resource Plan, Managing Chaparral[4] was signed in March of 1980.

The plan details a complex combination of integrated resource and fire management strategies and outlines a range of activities to take place in the 200 square mile (520 square kilometer) Demonstration Area over the next 15 years. Although the fire problem was the driving force behind the establishment of the Demonstration Area, the goal of integrated resource management is not simply to limit the number and size of fires. It is also important to minimize social losses and to maximize benefits by emphasizing various combinations of fire suppression, fire prevention, land use planning, and fuel management tools such as prescribed burning.

Physical and Biological Setting

The 130,000 acres (52,000 hectares) of the Demonstration Area lie in eastern San Diego County in the Laguna Mountains, the northern end of the Peninsular Mountain Range which extends into Baja California (Figure 1). Elevations in the Demonstration Area range from 3000 to over 6000 feet. To the east the land drops off sharply to the Colorado Desert.

Climate in the Demonstration Area is classified as warm-summer to cool-summer Mediterranean. Average annual temperatures range from 53°F (12°C) to 610F (16°C) and average annual precipitation from 15-30 inches (380-760mm). Most of the rainfall occurs between October and April with an

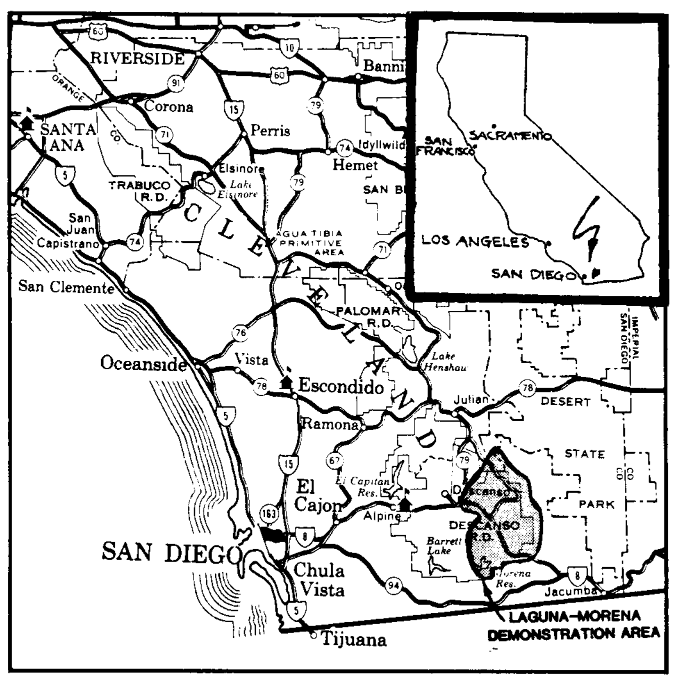


Figure 1--Location of Laguna-Morena Demonstration Area in California and in San Diego County.

[4]Managing Chaparral: Management plan and environmental analysis, Laguna-Morena Demonstration Area. On file, Descanso Ranger District, Cleveland National Forest, Forest Service, U.S. Dep. Agric., Alpine, Calif. 1979

occasional thunderstorm in the late summer months (Griner and Pryde 1976).

Each fall and winter high pressure systems to the north-east produce the infamous Santa Ana winds throughout southern California. During the worst periods these hot, dry winds can exceed 60 miles per hour (100 kilometers per hour). Large and difficult to control wildfires often result from these Santa Ana winds.

Vegetation in Laguna-Morena Demonstration Area ranges from soft chaparral at the lower elevations (California sagebrush-Artemisia californica, white sage-Salvia apiana, and California buckwheat-Eriogonum fasciculatum) to oak and pine-oak woodlands over 5000 feet (black oak-Quercus Kelloggii and Jeffrey pine-Pinus Jeffreyi). Most of the Demonstration Area is covered with various chaparral communities including the following species: chamise (Adenostoma fasciculatum), ceanothus (Ceanothus greggii and Ceanothus palmeri), scrub oak (Quercus dumosa), and birchleaf mountain mahogany (Cerocarpus betuloides). Most changes in vegetation communities result from variations in temperature, available water and nutrients, and soil type. The most significant factors influencing these variables are elevation, aspect and geology.

Chaparral soils in eastern San Diego County are generally formed from granitic, dioritic, and gabbroic rocks of the Southern California Batholith (Griner and Pryde 1976). These rocks give rise to coarse textured, weakly developed soils with low water and nutrient storage capacity. Some areas of schist are also found at higher elevations and usually indicate a less fertile soil. Deep soils formed in the valleys and near riparian areas are usually residual rather than depositional formations. Live oak woodlands are often associated with these pockets of deep soil.

The range of vegetation communities found in the Demonstration Area provide a variety of resource values. These include recreation opportunities, diverse wildlife habitats, livestock forage, watershed protection which minimizes erosion and enhances water quality, and scenic vistas that change with the seasons. In addition to the six overall goals, management of the Demonstration Area attempts to maintain and enhance these significant resources.

ACTIVITIES OF THE LAGUNA-MORENA DEMONSTRATION AREA

Activities on the Demonstration Area range in scope and complexity from the use of vegetation management tools such as the brush rake to scientific tools such as a computerized geographic-based information system. Many of these activities are moving the Demonstration Area toward accomplishment of the six major goals. Following is a summary of some activities as they relate to these goals.

Reduce the Catastrophic Potential of Wildfire

The general vegetation management strategy for fuels within the Laguna-Morena Demonstration Area involves breaking up large continuous stands of old growth chaparral and developing a mosaic pattern of different vegetation ages. By maintaining portions of chaparral in young vigorous growth stages the chance for a large wildfire is greatly reduced. By reducing the amount of fuel available, a wildfire will burn with lower intensity and will be easier to control. This strategy will not eliminate wildfires, although it can greatly reduce their potential for destruction.

In implementing projects, prescribed burning will be the major management tool. Ten thousand acres (4050 hectares) of existing fuelbreaks, along with roads and natural features including variations in plant communities, will act as control lines for large prescribed burns. In treating various plant communities differences in fire frequencies will be considered. Frequencies which will maintain existing communities range from approximately 10-50 years. For example, chamise chaparral appears to be adapted to a 15-20 year burning cycle while the scrub oak-mountain mahogany community may be adapted to a frequency of at least 40 years. The Tecate cypress has a 50-100 year fire cycle.[5] On the north slope of Guatay Mountain in the Demonstration Area stands of cypress have not burned for over 90 years. Physical characteristics including high water holding capacity of the soil and the north aspect, seem to have protected the site from fire.

Provide a Forum For All Who Have An Interest In Wildland Fuel Management

The Demonstration Area has drawn together many agencies and individuals with an interest in vegetation management. Ten agencies with land or program management responsibilities comprise the Laguna-Morena Demonstration Area: Forest Service-United States Department of Agriculture, California Department of Forestry, Soil Conservation Service, Bureau of Land Management, Bureau of Indian Affairs, California Department of Parks and Recreation, California Department of Fish and Game, University of California Cooperative Agricultural Extension, County of San Diego, Greater Mountain Empire Resource Conservation District. Three owners of large ranches are actively involved in program planning while other landowners participate in individual projects.

---

[5]Zedler, Paul H. Life history attributes of plants and the fire cycle: A case study in chaparral dominated by Cypressus fordesii. Paper presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. 1977 August 1-5; Palo Alto, Calif.

The Demonstration Area also provides opportunities for students, researchers, and the public to contribute ideas and gain knowledge relating to chaparral management. Since 1978, over one thousand people with professional interest in chaparral have toured the Demonstration Area. Eleven student interns have been involved in a variety of projects including wildlife monitoring, studying the effects of fire on plant succession, vegetation classification mapping and wood densification studies. In addition, field research studies have been conducted on the Demonstration Area by the Chaparral Research and Development Program of the Pacific Southwest Forest and Range Experiment Station.

The development of effective interagency cooperation has resulted from bringing together many interested people with various perspectives on fuel management. Broad scale coordinated resource planning has evolved through several phases as shown in figure 2. Initial contacts and communication networks were established through cooperation on interagency projects. Individual agency goals, philosophies, and guidelines were molded into project objectives that provided mutual benefits.

During the second phase of cooperation an overall philosophy for chaparral management was developed. The Laguna-Morena Demonstration Area Coordinated Resource Plan establishes these long-term goals, principles, and strategies.

The final phase of cooperation involves ongoing project planning and implementation. Each agency or landowner with an interest in a given project coordinate their efforts based on agency objectives and the goals developed in phase two. Cooperation provides several benefits for each participating agency. By sharing resources project costs can be significantly reduced. Projects can be completed with greater ease and fewer problems if natural rather than agency boundaries are utilized. And finally, by pooling professional knowledge and experience higher quality, more comprehensive planning and implementation results. This type of cooperation is necessary for successful comprehensive vegetation management.

Demonstrate Chaparral Management Techniques

One of the important functions of the Demonstration Area is to provide a place where land managers and the public can see on-the-ground chaparral management techniques in one area. The first three years emphasized resource planning and project implementation using a wide range of techniques. At the Buckman Demonstration Project sample plots demonstrate various mechanical, hand, and prescribed fire treatments. This area offers side by side comparison of a range of chaparral management methods. More extensive treatments can be seen on projects taking place throughout the Demonstration Area.

A second aspect of demonstration involves making activities more visible to the public, professionals, academia, and other resource managers. Currently, the Demonstration Area is emphasizing the transfer of information to these groups through several types of media. Tours are available to any interested group or individual. Hundreds will tour the Demonstration Area this year. Slide-tape programs, brochures, a self-guided auto tour, technical reports, and poster displays are being developed for various audiences on many topics. Those involved with these projects expect them to be useful to others facing similar vegetation management decisions.

Monitor Environmental Impacts of Large Scale Chaparral Management

Monitoring is being conducted at various intensities for all major projects on the Demonstration Area. Attainment of objectives and project costs are monitored for each project. Some projects undergo more intense types of monitoring. For example, effects of fire on deer and bird populations have been studied. Forage production and erosion rates have also been examined on plots following a fire. The Riverside Fire Lab, Pacific Southwest Forest and Range Experiment Station has monitored fire effects on projects such as the Kitchen Creek Prescribed Burn Project. Finally, overall program direction will be evaluated on a yearly basis in an annual report.

Develop Widely Applicable Guidelines For Chaparral Management

The field of chaparral management is in its infancy especially with regard to development of specific management guidelines. Most chaparral management projects have occurred on a more or less random basis with little broad level direction. A chaparral compartment examination and analysis process developed on the Laguna-Morena Demonstration Area will provide some of this direction.

A compartment ranges in size from 600 to 10,000 acres (240-4050 hectares) and is based on watershed boundaries. Within a compartment smaller units are identified which describe relatively homogeneous units of land based on soil type, vegetation, and slope. These units serve to give managers a rapid "feel" for the land and provide a system of easy access to a wide range of site specific data.

During a compartment examination information is assembled in a computer, resource units defined, and management goals and objectives identified. Inventory of each compartment will occur every 10 years with a resulting package of project proposals. During planning for an individual project, actions are identified to meet objectives already outlined during the compartment examination.

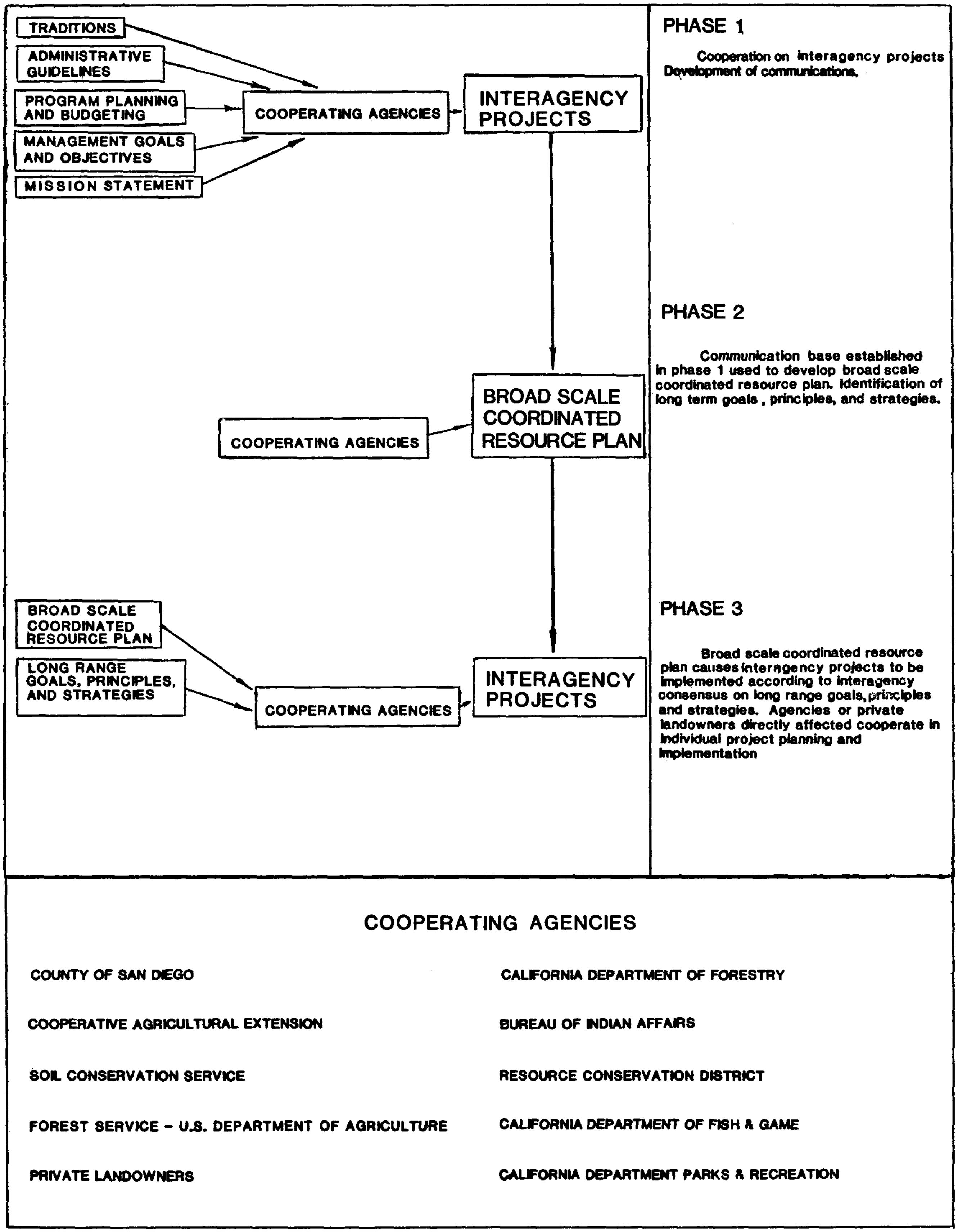


Figure 2--Evolution of Broad Scale Coordinated Resource Planning

It is likely that this process will be applied on a broad scale throughout California. The Demonstration Area has been instrumental in integrating the examination process into the Cleveland National Forest Land Management Plan and will assist in its development in the Pacific Southwest Region of the Forest Service.

Develop and Test New Techniques For Chaparral Management

The Demonstration Area is a proving ground for the application of new techniques in chaparral management. Some of the most notable techniques include the helitorch, use of goats for fuelbreak maintenance, and the use of chaparral as a wood fuel product in the form of densified pellets.

The helitorch is a thirty gallon drum of gelled gasoline slung beneath a helicopter. The gelled fuel is released from the drum and ignited as it falls to the ground. The helitorch provides a number of advantages over traditional burning methods including greater flexibility in firing patterns, prescription ranges, size of burn unit, and accessibility.

Browsing by goats has been demonstrated as an alternative to traditional methods of fuelbreak maintenance. Goats cause fewer environmental effects than chemical or mechanical methods, are an alternative to the unpopular use of herbicides, and provide a product in the form of meat and hides. The feasibility of using goats on a large scale still presents problems due to the large initial investment required to purchase the goats. Improved market conditions and better knowledge of goat husbandry could make this a more valuable tool.

The California Department of Forestry in cooperation with the Forest Service is beginning a wood energy demonstration program. Hand harvested chaparral from fuelbreaks and other treatment areas will be chipped and pressed into a wood product for use in fireplaces, wood stoves or campfires. An initial study[5] shows that only 17 percent of the potential energy will be used in the harvest and densification process. However, the economic feasibility of the project is not currently attractive. Increasing fuel costs could alter this in the future.

FUTURE DIRECTION OF CHAPARRAL MANAGEMENT

The Coordinated Resource Plan, Managing Chaparral, identifies the overall objectives and direction for the Demonstration Area until 1992. Identification of specific projects and demonstrations to accomplish the objectives will occur more frequently. For example, an Action Plan for Demonstration for fiscal years 1981-1982 lists 31 demonstrations to be completed during those years. Informal and ongoing evaluation of accomplishments and direction will occur in annual reports, monitoring reports, yearly Coordinating Group meetings, and during compartment examinations and project planning.

By 1990 all of the Demonstration Area will be under active management. Each compartment will have been inventoried and management activities implemented to maintain age class mosaics. The demonstration of integrated and coordinated resource management on chaparral lands is not intended to end with the activities taking place on the Laguna-Morena Demonstration Area. The tools and techniques developed here such as coordinated resource planning, chaparral management tools like the helitorch, and the compartment examination process, can be applied on all chaparral lands and related vegetation types throughout the Nation and the World.

LITERATURE CITED

Griner, Lee E.; Pryde, Philip R. Climate, Soils and Vegetation. In: Pryde, Philip R., ed. San Diego: An Introduction to the Region. Debuque, Iowa: Kendall, Hunt Publishing Company; 1976: 29-46.

[5]Riley, John G.; Moini, Samad; Miles, John A. An engineering study of the harvesting and densification of chaparral for fuel. Davis, Calif.: Department of Agricultural Engineering, Univ. of Calif. 1980.

A Conceptual View of the Development of Mediterranean-Type Ecosystems in Europe[1]

F. Duhme and T. M. Hinckley[2]

While we were working on the water economy of trees and shrubs in the Macchia of Southern Turkey, Province Antalya, we received an impression of the basic constraints for an overall development of this landscape. Because of the short duration of our stay in Turkey (3 1-month periods, October-November 1978, April-May 1979 and July-August 1979) and because of budgetary limitations, we were unable to undertake a comprehensive research effort on an ecosystem level. Therefore, important biological aspects such as nutrient cycling and socio-biological aspects such as urbanization trends, rural land use, etc. were not studied. So our contribution at this conference is based almost entirely on personal impressions of the environment as an entity, while being convinced that a better knowledge of the water economy of Macchia plants is at the moment of minor importance for the people living in this ecosystem.

The Mediterranean in North Africa, Southern Europe and parts of the Near East is very much different from all other mediterranean-type ecosystems of the world in some major respects:

- It has by far the longest history of very intense human use.
- It is still an area of underdeveloped countries with millions of people depending on this vegetation type more or less directly for their entire livelihood.
- There are very strong social, religious and economic dichotomies.
- Much of this land is an interface between semi-nomadic and subsistence farmers with their associated values and the tourist and associated tourist industries.
- There are substantial gradients in income and standards of living.
- There are strong conflicts between land managing agencies such as forest and national park managers and local citizens because land is removed from the private-individual-community sector and placed in the public sector.

Major development trends in these countries do not meet the needs of the people living in the rural Macchia environment. These trends include, to name but a few:

- Further urbanization with major social changes occurring in both rural and urban environments.
- Unwise development of tourism, thereby steepening and making gradients of income and social behavior increasingly significant.
- The use of high technology-energy intensive developments such as road construction, export crops and timber production which consume badly needed foreign money, reduce local employment and increase the dominance of foreign goods.

In summary, these developments bring "western" ideas without appreciating the needs, existing skills and available resources. We, as ecologists, claim a holistic view of our discipline and, therefore, should be involved in these problems. In fact, we seem entirely bound to academics and offer little help or insight. We erroneously hope and feel that other people are responsible for the transfer of our scientific knowledge to such special problems.

Today, ecological thought regarding Macchia vegetation is still bound to the idea of degradation from a much more desirable climax situation. Most people even tend to make the goat a classical symbol of this degradation. One might just as appropriately take another view.

The Macchia is an amazing, genetically diverse resource which at least partly originated through "disturbance" by man. This human-induced environmental stress definitely was and still is a driving force in the evolution of this ecosystem during the last 10,000 years. We have to bear in mind that disturbance by man was and is a major agent in such high species diversity and site heterogenity. Man himself probably should be looked upon as living more or less in harmony with this environment except perhaps during times of major social shifts. Therefore, the Macchia as a whole should be regarded as a system in equilibrium for long intervals. Although we do not presently know the role of Pinus brutia under premanagement conditions, we can assume that plantations of Pinus brutia on former Macchia landscape represent a possible major biotic degeneration and an apparent social alternation.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California

[2]Lehrstuhl fur Landschaftsokologie, Technische Universitat, Munchen, Germany and University of Washington, College of Forest Resources, Seattle, Washington, respectively.

What we want to point out is not a new philosophy in dealing with man-landscape-ecosystem interactions, but perhaps a different focus for ecologists and land managers dealing with mediterranean ecosystems. We would encourage them to view the problem in a different way, focusing on people as well as on the environment.

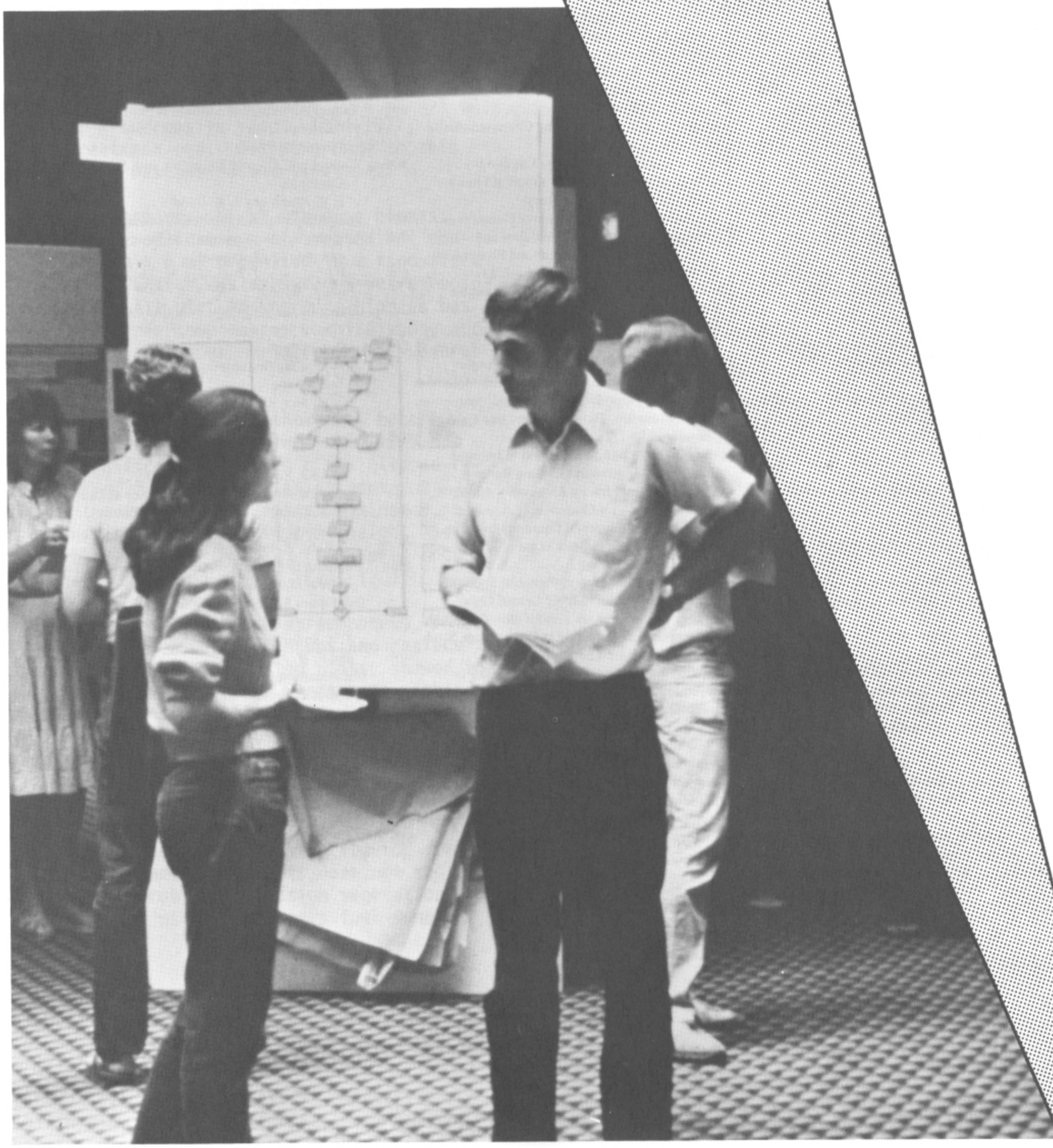
If we took such an approach, the first conclusion would be a reevaluation of existing resources and, as a consequence, the development of new management concepts for Macchia vegetation types. The next conclusion would be a translation of successional studies on heavily disturbed sites into practical reclamation work.

Regarding the people, there is a very strong need for alternative strategies. One possible strategy involves more labor-based concepts such as those championed by the International Labour Office in Geneva, Switzerland. This may apply to road construction, handicrafts and other activities. This low energy, low investment concept will lead to a new evaluation of labor and might change the balance of an underdeveloped country in the long run.

Developing more diverse concepts for afforestation could be another objective for future development. We think especially of afforestations with indigenous Macchia shrubs and trees serving for hardwood, firewood and browsing material if properly managed. Here the scientific work on the water economy of plants could be of some practical importance.

The development of tourism should first respect the physical constraints of the environment. Second, we need to know possible schemes for coupling touristic interests with the problems of the region. Tourism in itself may not solve economic or social problems. It may have a positive impact on some economical aspects, but may also cause more problems in the long run.

Poster Papers



Poster Papers

Biomass Response of Chamise (*Adenostoma fasciculatum* H & A) Chaparral to Clipping[1]

Theodore E. Adams, Jr., and Walter L. Graves[2]

Chamise is often the dominant species of California chaparral, and it crown sprouts vigorously after tops are removed by fire or other means. To determine the effect of top removal on chamise as a possible fuel management technique, two spring clipping treatments were applied to 3-year-old regrowth in a chamise stand recovering from wildfire in San Diego County. Clipping the 50-cm-high resprouts to a height of 30.5 cm for 4 successive years, 1974-1977, constituted treatment one. Clipping once to this height in 1974 was the second treatment.

Winter-season dry-weight standing biomass, including four replications of treated and control plots (3 m x 6 m) organized in a randomized complete block design, was measured 4 years beginning in 1975. All plot aboveground biomass was divided into three components: chamise above and below 30.5 cm, and other herbaceous and subshrub biomass.

The effect of clipping on chamise became apparent in 1977. Chamise biomass in 1977 and 1978 was significantly less in plots clipped repeatedly (Fig. 1). However, as an apparent result of the reduction of apical dominance, biomass of chamise below the clipping height was significantly greater (Fig. 2). Clipping once in 1974 had no lasting effect (Fig. 1, 3).

The herbaceous and subshrub component, which included grasses, forbs, subshrubs and residue from spring clipping in treated plots, showed no significant difference among treatments within years. By the end of the study in 1978, when this component was included with chamise, total biomass in plots clipped repeatedly was significantly less compared with unclipped plots (Fig. 3).

The results suggest annual spring top removal on 3-year-old chamise resprouts does not suppress growth of the shrub and companion vegetation sufficiently to justify this as a fuel management technique.

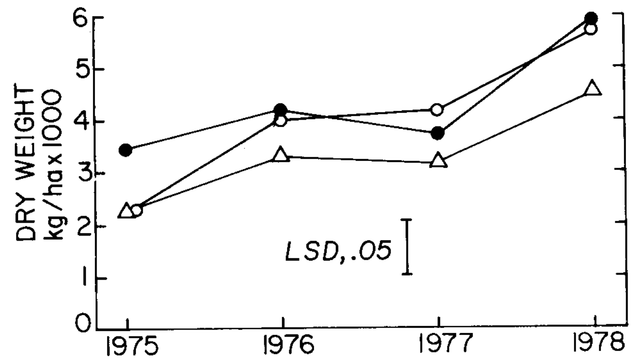


Figure 1--Chamise aboveground standing biomass in winter.

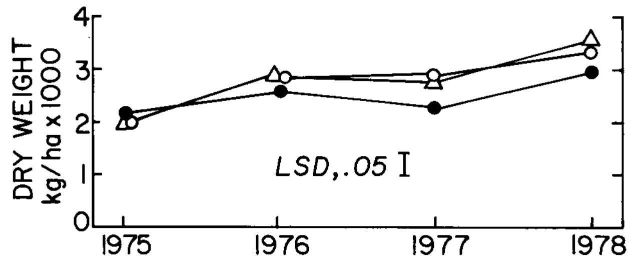


Figure 2--Chamise aboveground standing biomass in winter below 30.5 cm.

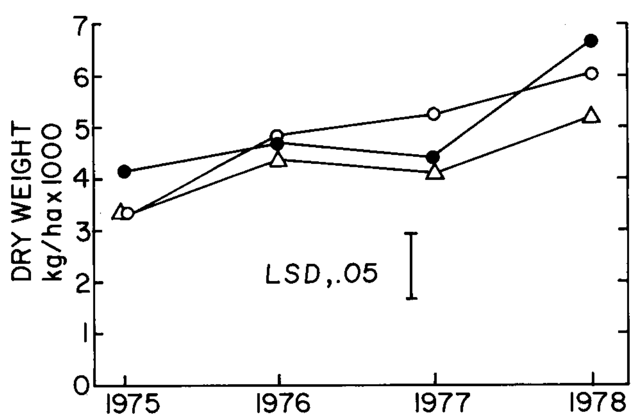


Figure 3--Total aboveground standing biomass in winter.

Control: ●

Clipped once: ○

Clipped repeatedly: Δ

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Extension Wildlands Specialist, University of California, Davis, California; Farm Advisor. University of California Cooperative Extension, San Diego, California.

Postfire Recovery of Chamise Chaparral in Sequoia National Park, California[1]

Gail A. Baker, Philip W. Rundel, and David J. Parsons[2]

Chamise (Adenostoma fasciculatum) recovers after a fire by resprouting from root crowns and establishing seedlings. Growth in chamise is largely determined by the seasonal patterns of its physiological condition. Therefore the season of burning may affect root—crown survival and resprout growth rates. The following study examines the effects of a fall and spring burn on root—crown survival and seedling establishment.

Field studies were carried out in the foothills of Sequoia National Park (Tulare County, California) in old—growth chamise chaparral. Experimental manipulations consisted of paired burn and clip treatments during November 1979 and June 1980. An unmanipulated control stand was monitored throughout the study. Dimensional analysis techniques were used to estimate pre—and post—burn biomass of shrubs.

Our data suggest that spring treatments induce considerably higher levels of shrub mortality than do fall treatments (fig. 1). This differential pattern of survival is related to the annual cycle of growth reserves in chamise. At the end of the spring growing season, root reserves of carbo-hydrates are depleted and may not be sufficient to ensure resprouting. Fall treatments do not cause this type of mortality since carbohydrate translocation to the root crown over the summer months allows a recharge of stored reserves.

In addition to the seasonal difference of root—crown survival there is a significant difference in survivorship between spring burn and clip treatments that was not present in the fall. We hypothesize that this differential pattern is related to the behavior of fire in the two seasons. Fall fires burn intensely and move quickly through the stand. Higher fuel moisture contents in spring mean that increased pre—heating times are necessary before combustion can take place. The slower speed of spring fires causes a greater depth of soil heating to occur and this appears to be the cause of the differential spring treatment mortality.

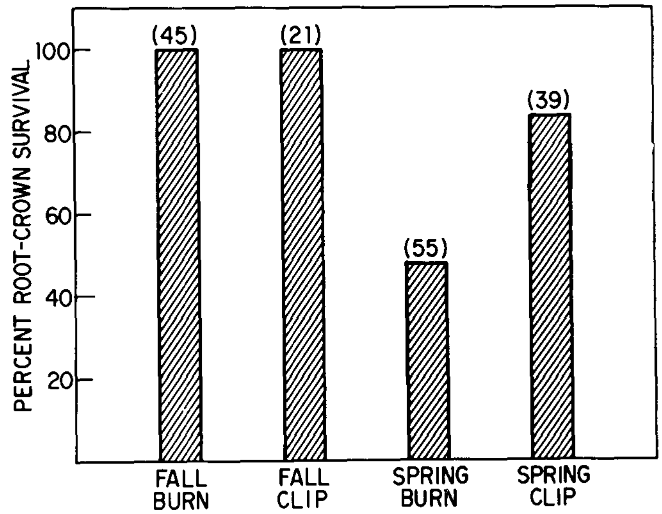


Figure 1--Percent of resprouting chamise root crowns following seasonal treatments. Numbers in parentheses indicate shrub sample size.

Pre—burn biomass of individual shrubs is a determinant of root—crown survival and post—burn growth rate. High mortality occurred in shrubs of the spring treatments whose pre—burn biomass was 1—5 kg. These smaller shrubs with hypothetically smaller carbohydrate reserves have a lower probability of surviving defoliation. Resprout biomass of surviving crowns at the end of the first season following fire is positively correlated with pre—burn biomass ($r = 0.60$, $y = 16.8(x) + 126.9$).

The lack of fire—induced mortality of our fall burn indicates that pre—burn shrub density is maintained, leaving little potential for seedling establishment. In the spring burn with less than 50 percent survival, establishment and successful growth of seedlings is of critical importance if succession is to restore prefire density.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean—type Ecosystems, June 22—26, 1981, San Diego, California.

[2]Research Associate in Biology and Professor of Biological Sciences, respectively, University of California, Irvine, Calif.; Research Scientist, Sequoia and Kings Canyon National Park, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The Impact of Human Activities on the Vegetation of the Algarve[1]

Luís S. Barreto and Helena P. Dias[2]

The Algarve is a very well differentiated Province of Portugal. Its singularity comes from its geology, geomorphology and climate. In the Algarve, we find six ecological districts: 1) the Southern (Algarvian) Coast; 2) the Western (Atlantic) Coast; 3) the "Barrocal"; 4) the Algarvian Highlands ("Serra"); 5) Monchique Mountain; and 6) the Eastern Plateau.

The main vegetation units found in the Algarve are Pinewoods (*P. pinaster* and *P. pinea*); Acacia woodlands *(A. pycnantha*); Eucalyptus woodlands (*E. globulus*); cork oak woodlands (*Q. suber*) with strawberry trees (*Arbutus unedo*); cork oak woodlants with cistus (*C. landanifer*); strawberry tree woodlands; " Barrocal" (shrub layer formed by holm oak, *Q. rotundifolia,* or carob tree, *Ceratonia siliqua*; cistus formations; Calluna vulgaris and Erica australis formations; mountain rangelands (*Pteridium aquilinum* and *Festusca ampla*); vegetation of stabilized dunes (*Juniperus phoenica* and *Genista hirsuta);* vegetation of mobile dunes *(Polygonum maritimum, Malcomia littorea, Lotus creticus);* cliff vegetation; saltmarshes.

This vegetation has been influenced by several peoples that have colonized the Algarve. The introduction of new plants (the fig tree, presumed to have been introduced by the Phoenicians; the chestnut by the Romans C. 200 BC; the olive tree by the Visigoths; the carob tree, almond tree, lemon tree, orange tree, rice, cotton and *Triticum durum* by the Arabs), the intensification of cereal crops (Romans, Arabs, Portuguese); irrigation, grazing, afforestation, the rights given by the kings to the local peoples, and more recently the development of tourism have each had a certain impact upon the Algarve's vegetation.

Rare and endangered plants in the Algarve can be grouped as follows:

Very rare and endangered plants: *Asplenium petrarchae, Loeflingia tavaresiana, Mathiola parviflora, Tuberaria major, Erodium laciniatum, Astragalus sesameus, Pinguicula lusitanica, Orobanche trichocalyx, Senecio lopezii, Hyacinthoides vicentina, Bellevallia hackelii, Avena hackelli.*

Rare and endangered plants: *Quercus canariensis, Quercus x marianica, Quercus faginea, Silene rothmaleri, Iberis sampaiana, Ilex aquifolium, Rhododendron ponticum subsp. baeticum, Linaria algarviana, Linaria saturoides, Merendera filifolia, Narcissus willkommii, Narcissus gaditana, Biarum galiani.*

Plants which are rare but whose potential for extirpation is apparently low at present: *Aristolochia baetica, Biscutella vicentina, Diplotaxis vicentina, Ulex argenteus subsp. erinaceus, Astragalus massiliensis, Convolvulos siculus, Trisetaria dufourei.*

Plants of limited distribution or uncertain status: *Silene rothmaleri, Asteriscus maritimus, Scilla odorata, Hyacinthoides non-scripta, Stipa tenacissima.*

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Forestry, Instituto Superior de Agronomia, Tapada da Ajuda, 1300 Lisboa, Portugal; and Botanist, Direcção-Geral de Gestão e Ordenamento Florestal, 1000 Lisboa, Portugal.

The Impact of Human Activities on the Fauna of the Algarve[1]

Luís S. Barreto and Lucio do Rosário[2]

By Mediterranean standards the Algarve is still very well preserved. In this region we can find 14 amphibians, 23 reptiles, 181 species of avian fauna and 13 mantras.

There are eight main wildlife habitats in the region: 1) *humid zones*: with 7 amphibians, 4 reptiles, 87 species of avian fauna and 4 mammals; 2) *cliff coast*: 23 species of avian fauna and 3 mammals; 3) *watersheds:* 6 amphibians, 3 reptiles, 27 avian species and 9 mammals; 4) *mountains*: 6 amphibians, 14 reptiles, 63 avian species and 11 mammals; 5) *eastern plateau*: 2 amphibians, 5 reptiles, 51 avian species and 6 mammals; 6) *western coast*: 9 amphibians, 8 reptiles, 64 avian species and 7 mammals; 7) *coastal plain*: 9 amphibians; 13 reptiles, 73 avian species and 7 mammals; 8) *beaches*: 13 avian species.

Man's impact on the fauna of the Algarve changes with the habitats. Among the most disruptive actions one can cite land development for dwellings and tourist resorts (especially near the coastline); destruction of vegetation in order to bring land under cultivation; afforestation with exotic trees and pines; degradation of cork oak woodlands; recreational camping (especially near the coastline); coincidence of the hunting season with the tourist season which leads to a very nigh concentration of hunters in the region; use of poisons and explosives in the streams; sand quarries; large dams.

The endangered species of the Algarve are: *Chameleon chamaleon, Porphyrio porphyrio, Fulica cristata, Padion haliaetus, Aquila heliaca (adalberti), Lynx pardina.*

The Algarve is also an important stopover along the routes of migratory species.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Professor of Forestry, Institute Superior de Agronomia, Tapada da Ajuda, 1300 Lisboa, Portugal; and Game Service, Direcção-Geral de Gestão e Ordenamento Florestal, 1000 Lisboa, Portugal.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Influence of Prescribed Burning on Small Mammals in Cuyamaca Rancho State Park, California[1]

Daniel J. Blankenship[2]

This study evaluated the responses of small mammal populations to disturbance or depletion of vegetation following prescription burns of April 24-30, 1978 and December 3 and 4, 1979. Results are based on 5430 trap nights.

The areas of study consisted of mixed conifer woodland with a chaparral understory in most places. The result of the fire was a reduction in shrubs (trees not affected) of 93 percent for the December 1979 burn and 91 percent for the April 1978 burn, based on evaluation 3 months and 1 year after the fire respectively.

The abundance of small mammals was reduced ($p < .02$) in the April 1978 burn as well as in the December 1979 burn when compared with controls (Table 1, Figure 1). The species composition did not differ significantly ($p > .05$) in the burned areas when compared with the controls (Table 2). The community did not show the regular pattern of postfire succession (brush species to grassland species) that is usually expected since the vegetation had not been completely altered by the light fire that is present under prescribed burning conditions. Consequently, very little damage results to the mammalian community structure when a carefully controlled fire is used. There was no significant difference ($p > .05$) in weight or sex ratios in the burn areas when compared with a control.

Table 1--Small mammal abundance for Control (C) and Experimental (E) study sites Al on East Mesa and B1-3 on Cuyamaca Peak Road.

Sample	Relative Abundance			
	Trapping Success		Total[1]	
	Ind./Trap Night (pct.)			
	C	E	C	E
Dec.'79 Al	3.33	0	3.33	0
Mar.'80 Al	1.05	1.58	1.05	2.64
May " B1,2	7.18	2.69	10.47	3.00
June " Al	2.77	1.04	5.03	1.38
July " B3	2.75	1.60	8.02	2.06
Sept." Al	1.40	1.14	4.59	2.93
Dec.'80 Al	2.97	1.48	8.62	3.27
X	3.00	1.30	5.87	2.18

"Total = Trapping Success and Recapture Success.

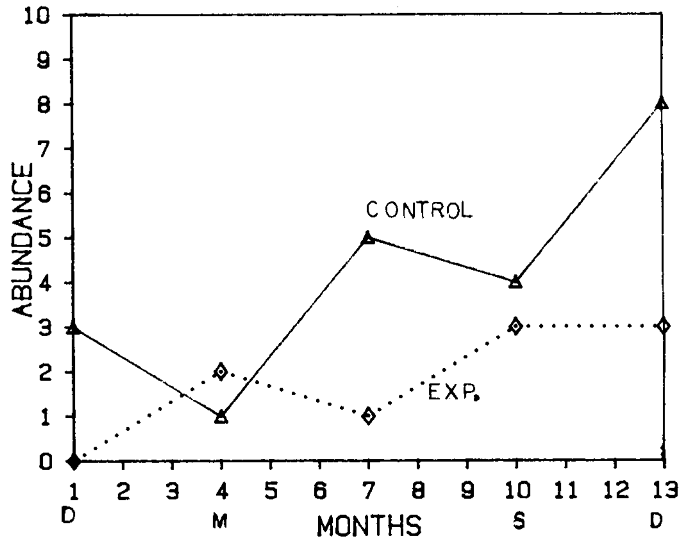


Figure 1--Graph showing relative abundance of animals for each month during the trapping period of December 1979-December 1980 on East Mesa study site.

Table 2--Percent composition based on total captures (N) of small mammals in study sites Al on East Mesa and B1-3 on Cuyamaca Peak Road. C=Control, E=Experimental.

Species	Composition	
	C (N=77)	E (N=37)
	pct.	
Al		
Peromyscus boylii	83.0	76.2
Perognathus calif.	9.7	4.8
Peromyscus calif.	2.4	-
Dipodomys agilis	4.9	14.3
Neotoma fuscipes	-	4.8
Spermophilus beecheyi	-	Incident
Eutamias merriami	-	Incident
B1-3		
Peromyscus boylii	94.4	100.0
Perognathus calif.	2.7	-
Neotoma fuscipes	2.7	-

The quantity of litter on the forest floor was found to be an important factor in maintaining maximum density in a population of mammals. In one study site (April 1978) where the density and composition of the vegetation did not differ from the control, there was still a reduction in the abundance of small mammals. This indicates that the reduction could possibly be attributed to the loss of litter and ground cover in the burn plots.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Graduate student in Biology, Loma Linda University, Loma Linda, California 92354.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Soil Resources and ORV Use Planning in Southern California National Forests[1]

Robert Blecker, James O'Hare, Tom Ryan, and Jeff Spector[2]

National Forests are mandated by law to develop land management plans according to specific rules and regulations (36 DFR Part 219, September 17, 1979). The regulations dictate that areas and trails will be classified according to whether or not off-road vehicle (ORV) use will be allowed. The four Southern California National Forests are in the planning process now.

The Forest Service must also respond to Executive Orders (E.O.) 11664, "Use of Off-Road Vehicles on the Public Lands" (2/8/72) and E.O. 11989, "Off-Road Vehicles on Public Lands" (5/24/77). These two E.O.'s require positive action on the part of the Forest Service in the management of ORV's on public lands.

The Los Padres National Forest (LPNF) has developed an ORV plan to meet the objectives of land management planning and Executive Orders. The Forest has signed and designated trails suitable for ORV use, closed and rehabilitated all hill-climbs and trails unsuitable for ORV use, and trained ORV enforcement officers to patrol and manage ORV use areas.

In the Ballinger Canyon area the LPNF has implemented a rehabilitation and monitoring program that will serve as a model for the remainder of the Forest's ORV use areas. Soil erosion is monitored using the California Division of Forestry's 3F erosion bridge method. Several monitoring methods are used to measure the impact ORV activity has on the land. The method used by the LPNF is the 3F method developed by the California Division of Forestry. Equipment consists of a level, two heavy steel stakes, and a length of welding rod. The level is modified so that it fits over the stakes, and ten holes equally spaced are drilled to fit the rod. The rod is inserted in each of the drilled holes. The distance from the top of the level to the end of the rod is measured. Changes in this measurement with time determine the erosion rate. The 3F method is used to measure the natural erosion rate on the badlands in Ballinger Canyon.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Hydrologist and Soil Scientist, respectively, Los Padres National Forest, Goleta, California; Soil Scientists, Angeles National Forest, Pasadena, California.

LPNF has modified the 3F method by using a 2x4 board to measure erosion impact on wide trails. Where deep channels or gullies are found, the sage tape technique is used. A measuring tape is placed across the study area, and the distance from the tape to the soil surface is measured. The heavy rope is used as a safety line on hill climbs with slopes greater than 60 percent. The Soil Conservation Service has a guide for rating soils for ORV activity. The LPNF has amended and expanded these guides to fit local conditions. The Speedy moisture meter is used to measure soil moisture conditions that could change as a result of ORV activity. A core sampler is used to measure changes in soil compaction. In heavy soils, compaction has been found to a depth of 0.4 foot. This compaction could result in increased runoff from the site and cause an impact to onsite and offsite resource values.

Soil piping is a characteristic of some of the heavier textured soils. The soil is high in exchangeable sodium (Na) and shrink/swell clays. Surface cracking as a result of the high clay content facilitates the channeling of water within the subsoil. This, in combination with the dispersion action of sodium, causes piping.

When the heavy soils are compacted, runoff increases, which aggravates the piping problem. For the past two years hill climbing has been reduced extensively by the LPNF management policy. Hill climbing activity has had an impact on the area immediately adjacent to the Ballinger Campground. The soils on many of the hill climbs near Ballinger Campground have a heavy texture and an annual plant community. These two factors lend the area to short recovery period (1-2 years) once the ORV activity is removed. The harsh site conditions of steep slopes and shallow sandy soils at many other Southern California ORV use areas may increase the recovery time for hill climbs and trails to five or even ten years. The trails also exhibit this ability to recover, given some rehabilitation. Rehabilitation structures such as waterbars play an important part in ORV trail management. Waterbars need constant maintenance to withstand the impact from trail bike use.

Where trails are narrow or have been washed out, watershed improvement structures are used to maintain the trail and make it safe for use. Dead native plant material is placed and compacted within the rills to control erosion on the steeper trails. Twenty to thirty percent material tends to wash out if not properly anchored. Since bikes will not run in rills, the trails may widen over time if they are not maintained.

The issue of the use of public lands for ORV activities is national in scope. While this is a single focus issue, there are two very important components--social and environmental--which must be considered. The Forest Service will continue to implement policies as directed by our ORV planning and management effort. We will continue to seek the balance needed for both the social and environmental needs that man has for himself and for his environment.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Vegetation Change on Santa Cruz Island, California: The Effect of Feral Animals[1]

Robert W. Brumbaugh and Norman J. Leishman[2]

Coastal sage scrub and chaparral communities on Santa Cruz Island, California, have been substantially modified by feral sheep grazing within the last 130 years. The sheep population rapidly increased after a probable introduction in the early 1850's as part of a large-scale sheep ranching program. By 1870, at least 45,000 sheep were on the island (U.S. Census of Agriculture 1870). Other estimates of sheep population on the 61,000-acre island during the late 19th century range between 45,000 and 100,000 (Brumbaugh 1980). Today feral sheep are confined to the more rugged, less accessible northwest and northeast mountains and marine terraces. Fewer and fluctuating numbers of sheep remain on the hilly southern portion while sheep are excluded from the central valleys.

A sizeable reduction of brush cover on south-facing slopes north of the Central Valley is evident in the comparison of photographs taken of the Central Valley in 1869. An extensive chaparral cover with patches of coastal sage scrub is shown in the 1869 photographs. The coastal sage scrub (e.g., *Artemisia californica*) has been especially affected by feral sheep grazing. Comparison of photographs taken in 1869 with recent photographs show complete destruction of coastal sage on the heavily grazed south-facing slopes along the Central Valley. Only 6 percent of Santa Cruz Island is presently covered by coastal sage scrub (Minnich 1980). Regeneration of coastal sage is occurring on some portions of the island in response to sheep removal from selected areas within the last 25 years.

A more extensive chaparral cover existed in 1869 than exists today on the slopes immediately north of the Central Valley. Changes are species selective. *Adenostoma fasciculatum* has been especially susceptible to feral sheep impacts, while *Quercus dumosa* and *Heteromeles arbutifolia* have suffered less attrition. In addition, the 1869 photographs show that chaparral plants lacked the arborescence characteristic of much of the woodlands today. Brumbaugh (1980) and Minnich (1980) have suggested a role of fire on the island, prior to the advent of sheep grazing, as a reason for this lack of arborescence. There is abundant charcoal in late Holocene sediments and on many almost barren ridgetops. It is also possible that late 19th century management practices included controlled burning in order to provide more sheep pasturage. The woodland slopes shown in the historic photographs have not been burned during the last half century.

Stature of *Quercus dumosa* and *Adenostema fasciculatum*, two abundant species in the chaparral woodland, increases with grazing intensity as does the chaparral community as a whole. Their stature was examined in contrasting regimes (heavily, moderately, and lightly grazed) across a large north-south belt in the middle of the island. Trunk diameter, number of trunks per shrub, and canopy areas of the two species were recorded in 4-meter-wide belt transects. Only populations on north-facing slopes were sampled in order to help reduce variation caused by unmeasured environmental factors. The two species have responded similarly to grazing pressure with respect to magnitude of stature variation within the 3 grazing regimes. However *Adenostoma fasciculatum* is more susceptible to eradication as indicated by a paucity of basal sprouts in heavily grazed areas. In the heavily grazed areas shrubs tend to have a noticeable browse line and a definite trend toward increased trunk diameter, canopy area, and height. A younger aced population has become established in areas where sheep have been reduced in number over the past 25 years.

There is a rapid response in areas completely removed from feral sheep use. Three exclosures in heavily grazed shrub-savanna communities were sampled over a two-year period after construction (Brumbaugh 1980 and Leishman 1981). Vegetation changes included an increase in herbaceous cover within the exclosure. In addition, *Quercus dumosa* and *Heteromeles arbutifolia* immediately sprouted at their bases and within 3 years the pruned appearance was greatly diminished.

LITERATURE CITED

Brumbaugh, Robert W. Recent geomorphic and vegetal dynamics on Santa Cruz Island, California. *In* Power, Dennis, ed. A multidisciplinary symposium on the California Islands. Santa Barbara, Calif.: Santa Barbara Museum of Natural History; 1980: 139-158.

Leishman, Norman J. Effects of feral animals on woody vegetation, Santa Cruz Island. California. M.A. Thesis (unpublished); Univ. of California, Los Angeles; 1981. 71 p.

Minnich, Richard A. Vegetation of Santa Cruz and Santa Catalina Islands. *In* Power, Dennis, ed. A multidisciplinary symposium on the California Islands. Santa Barbara, Calif.: Santa Barbara Museum of Natural History; 1980: 123-137.

U.S. Census of Agriculture. Ninth census of the United States. Sacramento, Calif.: Calif. State Library: 1870; schedule of agric. recapitulation, Santa Barbara County (microfilm); vol. 2.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Department of Geography, California State University, Northridge, California; and Department of Geography, University of Hawaii, Manoa, Honolulu, Hawaii.

Life History and Seed Dispersal of *Dendromecon rigida*[1]

Stephen H. Bullock[2]

Longevity, fecundity and reproduction were studied in bush poppies (Dendromecon rigida Benth.) focusing on a site burned in 1970 in the Santa Monica Mountains (densities up to 38 plants per m^2, fig. 1); 15 other populations were examined from San Diego to Shasta counties.

Germination is normally restricted to the first winter after a fire. Seedling growth rates are high, total dry weight averaging 8.5 g at age 1 yr (Otay Mtn, 1980; compared to 1.45 g for Ceanothus and 0.12 g for Cupressus forbesii). However, adults are usually less than 2m height.

Reproduction can begin in the second spring. The plants are self-compatible and the flowers are unspecialized. Seed set averaged 7.6 per fruit at age 3 yr and 6.3 at 8yr; no geographic trends appeared but means ranged from 2.9 to 10.7. Mean weight of the oil-rich seeds ranged from 10.1 to 15.8 mg. The number of fruits per plant was small, barren plants being common (46 percent at 3yr, 39 percent at 10yr). However, a sparse population on San Jacinto Mtn had many plants with >100 fruits.

Survivorship was 95 percent at age 3yr, 21 percent at 7yr, and 5 percent at 10yr. The causes of adult mortality in undisturbed stands are obscure. Fire kills all except seeds; various herbivores and seed predators are known.

The seeds are dispersed by explosive fruits and by gravity, and are also collected by ants, principally carpenters (Camponotus spp) and harvesters (Pogonomyrmex subnitidus). Ants consume a caruncular appendage in their nests and discard the intact seed, Camponotus in subterranean middens and Pogonomyrmex on surface middens. Camponotus provides burial and predator avoidance, but Pogonomyrmex moves longer distances, often uphill to ridge-top nests. Birds and rodents are predators of the seeds. Experiments showed that ants were more ubiquitous foragers than vertebrates: Visitation to baited stations was 67 and 30 percent respectively. Ants were also more thorough than vertebrates: Removal of bait seeds was 55 and 18 percent respectively. Birds may focus their foraging on aggregations of seeds discarded by Pogonomyrmex.

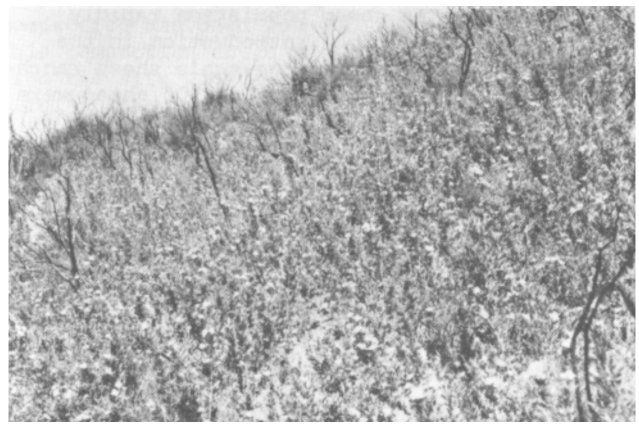


Figure 1--This stand extended over several km^2 at varying densities, including perhaps 5 million Dendromecon.

Figure 2--Pogonomyrmex loses a negligible percent of the seeds during transport.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems

[2]Adjunct Faculty, Botany Department, San Diego State University, San Diego, California 92182

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Seasonal Progressions in the Water Relations of Deciduous and Evergreen Perennials in the Northern California Chaparral[1]

Howard W. Calkin and Robert W. Pearcy[2]

Perennial plants native to Mediterranean climates should exhibit behavioral adaptations allowing survival during drought periods. Buffering of cell volume and turgor is thought to be important for maintenance of metabolism (Zimmermann 1978). Stomatal reactivity and osmotic adjustment interact with environment to buffer cell volume and turgor.

In this study, a pressure bomb (Tyree and others, 1973) and null balance diffusion porometer were used to follow the seasonal progression of osmotic adjustment and stomatal reactivity. Toyon (Heteromeles arbutifolia M. Roem) is an evergreen sclerophyll shrub. Redbud (Cercis occidentalis Torr. ex Gray) is a winter-deciduous shrub and buckeye (Aesculus californica (Spach) Nutt.) is a drought-deciduous small tree. These plants exhibiting different adaptive syndromes were growing together in the G.L. Stebbins Cold Canyon Reserve in the Vaca hills of northern California.

Figure 1 shows diurnal courses of water potential and leaf conductance for two days. This 6-week span illustrates the trends seen throughout the rest of the season (Table 1). In general, as the season progressed, stomatal opening became more restricted to morning hours, and the magnitudes of the morning peak and mid-day plateau decreased. Leaf water potentials became more negative and for Heteromeles and Cercis reached values near their turgor loss point. Aesculus leaves maintained turgor pressures of at least .5 MPa (72.5 psi) all season.

The seasonal drop in osmotic potentials (ΨTLP) and plant water potentials was greatest in Heteromeles, intermediate in Cercis and least in Aesculus. During the next winter and spring, the water potential of Heteromeles recovered, but the osmotic potential of the leaves from the previous spring remained low (data not shown). Daily water loss was similar for Cercis and Heteromeles, decreasing after May. In April, Aesculus had a total transpiration much higher than the other species; but already in May, water use had decreased by 60 percent and was much lower than in the other species.

In Heteromeles and Cercis both stomatal and osmotic adjustments contribute to the buffering of cell volume and turgor. Osmotic adjustment played little role in Aesculus.

Table 1--Seasonal changes in osmotic potential (ΨTLP), leaf conductance and daily transpiration during 1979

Date	Aesculus			Cercis			Heteromeles		
	ΨTLP[1]	g[2]	Ts[3]	ΨTLP	g	Ts	ΨTLP	g	Ts
Apr 25	-1.3	11	4.3	-1.3	7.2	2.7	-1.6	4.2	1.9
May 20	-1.4	10	2.1	-1.6	7.0	4.3	-1.9	6.9	3.4
Jul 5	-1.6	4	2.8	-2.3	6.0	3.7	-3.1	3.7	3.1
Aug 8	-1.7			-2.6	5.3	2.5	-3.4	3.0	3.0
Oct 17	-2.5				4.2	1.1	-3.9	3.0	1.8

[1]Water potential at turgor loss point MPa.

[2]Leaf surface conductance to water vapor mm/sec (averaged over mid-day hours).

[3]Total daily transpiration Kg/m[2] leaf surface.

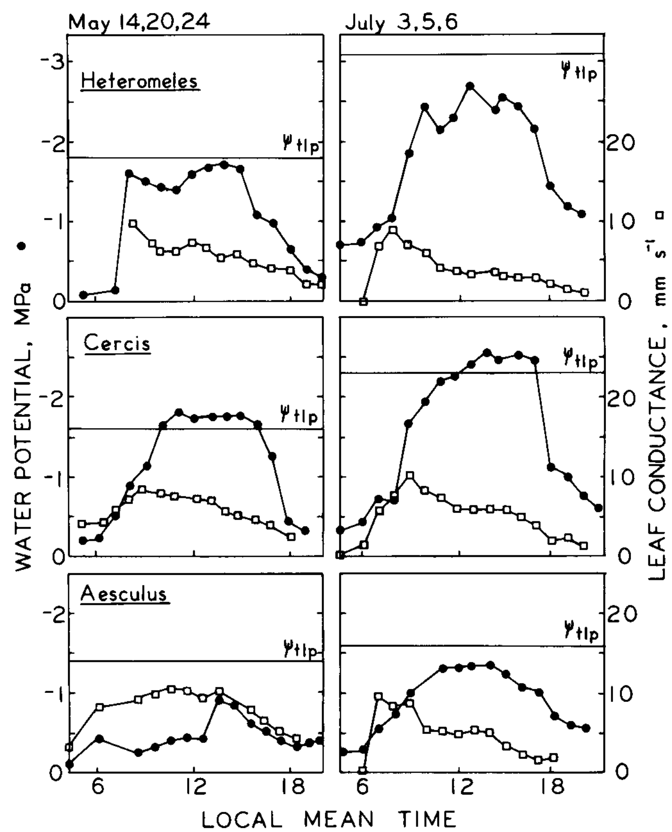


Figure 1--Daily courses of water potential and leaf conductance illustrating the seasonal changes.

LITERATURE CITED

Tyree, M.T.; Dainty, J.; Benis, M. The water relations of hemlock (Tsuga canadensis). I. Some equilibrium water relations as measured by the pressure bomb technique. Can. J. Hot. 51:1471-1480; 1973.

Zimmermann, U. Physics of turgor- and osmo-regulation. Ann. Rev. Plant Physiol. 29:121-148; 1978.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Regents Fellow in Plant Physiology and Associate Professor of Botany, respectively, University of California, Davis, California.

Distribution of Grasshoppers (Orthoptera: Acrididae) Along Environmental Gradients in a Mediterranean-Type Ecosystem[1]

Susan L. Coon[2]

In the past, most studies of faunal distributions along environmental gradients have analyzed large, taxonomically diverse groups of animals, such as birds and insects. This study analyzes the distribution of the family Acrididae (grasshoppers), a large group of species with relatively similar behavior and food preferences.

The vegetation and soil characteristics of nine field sites on the east (rain shadow) slope of the San Jacinto Mountains, California, ranging in elevation from 65 meters below sea level to 1920 meters above sea level, were earlier studied by R. B. Hanawalt and R. H. Whittaker. Grasshopper species were sampled by "sweeping" the vegetation along a randomly chosen transect and by searching for specimens for a specific timed interval at each site. Collected specimens were preserved for identification and analysis. Environmental variables including temperature, precipitation, relative humidity, and percent soil moisture were also recorded.

Grasshopper species tended to be more widely distributed along the elevational gradient than plant species, with some grasshopper species found at as many as six elevations, but no plant species found at more than three elevations.

Species richness, the number of species present at a site, was very low at the lowest elevations, increased to a maximum at mid-elevations, and decreased again at the highest elevations. A regression line (r = 0.30) showed a general trend for the number of species to increase as elevation increased (fig. 1). There was a positive correlation between the number of grasshopper species present at a site and the percent of ground covered by herbs (r = 0.52) and semi-shrubs (r = 0.46), the most important food sources for grasshoppers.

Acridid abundance, the total number of grasshoppers of all species present at a site, tended to decrease with increasing elevation (r = -0.42), (fig. 2). This may be explained by the fact that along the elevational gradient, total percent vegetation cover, especially percent cover by trees, increased with elevation. The increase in total vegetation cover was correlated with a decrease in herb cover and semi-shrub cover, the food sources of the grasshoppers.

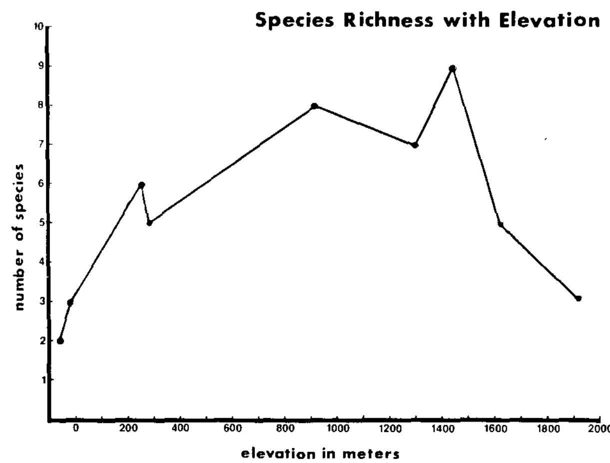


Figure 1--Species richness with elevation.

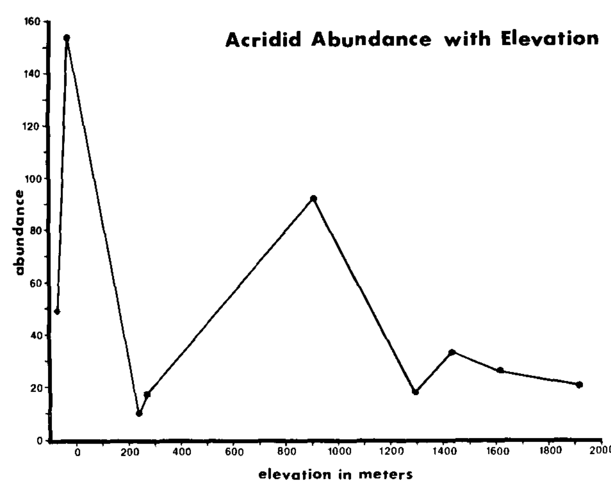


Figure 2--Acridid abundance with elevation.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Graduate Student, Department of Geography, University of California, Los Angeles, California, 90024.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

A LANDSAT Approach to Mapping Vegetative Fuel Type and Density Classes[1]

Michael J. Cosentino[2]

Maps that accurately describe the physical characteristics of the vegetative cover within the Mediterranean-type ecosystem of Southern California are needed to drive computer simulation models of wildland fires. Remotely sensed data can provide spatial maps of vegetative characteristics. These vegetative characteristics contain valuable information concerning factors which influence fire behavior. Landsat data, including a synthesized standard deviation "texture" channel, was used to produce a physiognomic classification of vegetative fuel types and densities (relative crown closure) for a 7.5-minute quadrangle area in the Angeles National Forest in Southern California.

Digital Landsat data was precisely registered to terrain data derived from orthophotoquads. The Landsat data was resampled to 50 meter cells such that each cell represented approximately .27 hectares (.6 acres) on the ground. A fuel-type classification scheme was devised based upon the discrimination capabilities of the Landsat sensor by first identifying 129 unique spectral "types" inherent in the data, and then labeling each type according to actual ground conditions as interpreted on 1:24000 color infrared air photos. Similar type-labels were grouped into 12 distinct fuel type and relative density classes.

The accuracy of the classification was determined by selecting over 500 random points and comparing the mapped fuels information with actual ground conditions. The overall accuracy of almost 90 percent was the result of several factors: 1) individual fuel type and density classes which contained spectral variation due to illumination and reflection geometry, were expressed as a large number of classes with low variance rather than a small number of classes with high variance, thus reducing the impact of differential illumination due to topography and sun angle; 2) spectral classes derived from the Landsat classification were described in terms of actual ground conditions and then aggregated into fuel classes rather than forcing the spectral classes into pre-determined fuel type systems or models; and 3) highly accurate registration of the Landsat data to the orthophotoquad allowed for precise location of the spectral classes on the ground, which greatly facilitated the labeling process.

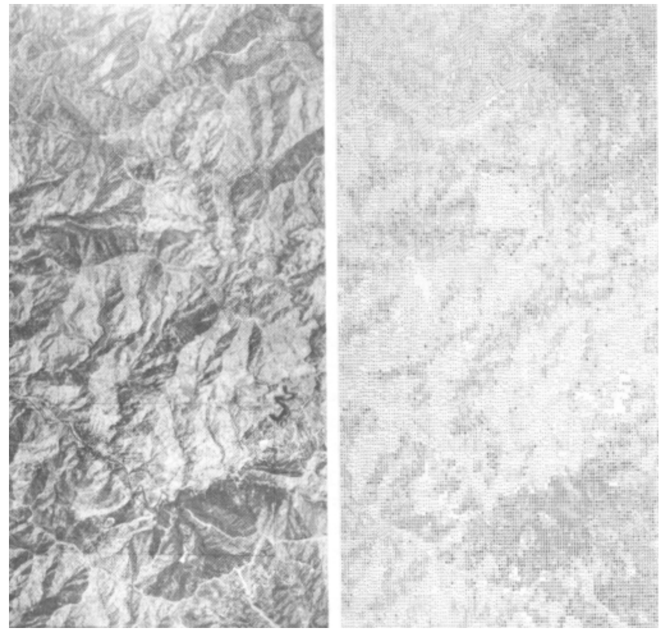


Figure 1--Portions of a standard USGS orthophotoquad and a precisely registered Landsat fuels classification. Fuels data can be reproduced on transparencies for overlay with the map and used in pre-attack planning, or input as digital data to computerized fire simulation models.

Table 1--Landsat-based Fuel Type/Density Classes

Mixed Chaparral / Low (density)
Mixed Chaparral / Medium
Mixed Chaparral / High
Mixed Chaparral / High - w/ Oaks / Medium
Mixed Chaparral / Medium - w/ Mixed Trees / Low
Mixed Chaparral / High - w/ Mixed Trees / High
Mixed Conifers / Medium
Soft Chaparral / High
Soft Chaparral / Medium
Soft Chaparral / Low
Grass
Sparse-barren

Table 2--Fuels Map versus Field Observations

LANDSAT CLASSIFICATION ACCURACIES
FOR FUEL TYPE AND DENSITY

GROUND CONDITION 4/81

LANDSAT CLASSIFICATION 6/78	Mixed Chaparral Low Density	Mixed Chaparral Medium Density	Mixed Chaparral High Density	Mixed Chap. - High W/ Oaks - Medium	Mixed Chap. - Medium Sparse Mixed Trees	Mixed Chap. W/ Mixed Trees - High Density	Mixed Conifers Medium Density	Soft Chaparral High Density	Soft Chaparral Medium Density	Soft Chaparral Low Density	Grass	Sparse / Barren	TOTALS # Correct / # Observed	% Correct
Mixed Chaparral Low Density	26	2							1				26/29	89.6
Mixed Chaparral Medium Density	2	60											60/62	96.8
Mixed Chaparral High Density		1	63			4							63/68	92.6
Mixed Chap. - High W/ Oaks - Medium		1	4	38									38/43	88.4
Mixed Chap. - Medium Sparse Mixed Trees		2			24								24/26	92.3
Mixed Chap. W/ Mixed Trees - High Density			5			43							43/48	89.6
Mixed Conifers Medium Density			3				48						48/51	94.1
Soft Chaparral High Density		3						38	2				38/43	88.4
Soft Chaparral Medium Density		3						2	65	2			65/72	90.3
Soft Chaparral Low Density									4	32			32/36	88.9
Grass										10	22		22/32	68.8
Sparse / Barren										1		8	8/9	88.9
Overall Accuracy													467/519	89.9

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Staff Research Associate in Remote Sensing, University of California, Santa Barbara, Calif.

Effects of Fire on Certain Physical Properties of Selected Chaparral Soils[1]

Dan M. Duriscoe, Wade G. Wells II[2]

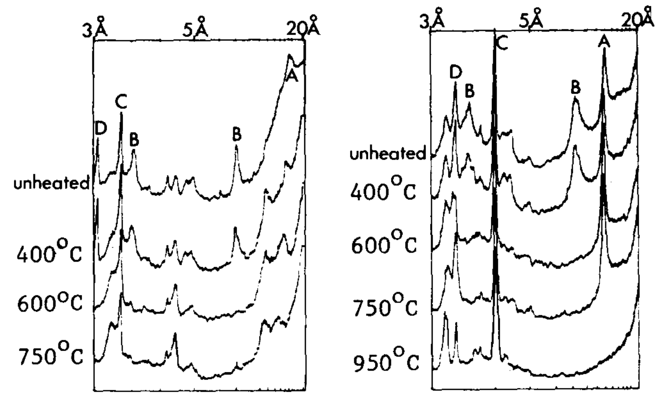
The effects of heating to wildfire temperatures on the particle size distribution and mineralogy of soils were investigated in the laboratory. Samples from the San Dimas Experimental Forest and the Pine Canyon study area of the Los Padres National Forest were subjected to temperatures of from 400° to 800° C. Particle size analysis was performed on heated and unheated control samples, with results summarized in table 1.

Table 1--Percent by weight of sand, silt, and clay in chaparral soils heated for 10 min.

	Pine Canyon soil			San Dimas soil		
Temperature	Sand	Silt	Clay	Sand	Silt	Clay
Unheated	61.4	26.6	12.0	38.8	43.4	18.6
400° C	68.4	30.3	1.3	43.7	51.0	5.3
600° C	72.7	26.8	0.5	40.7	51.6	7.7
800° C	77.0	23.0	0.0	44.5	50.8	4.7

Soils from both areas display a shift in particle size distribution when heated. Most notable is the reduction in the amount of clay present before and after heating. The effect is most dramatic in the Pine Canyon soil, which contains 12 percent clay: after heating to 800° C, no measurable clay could be detected. The percentage of sand-size particles increases proportionately with the decrease in clays, while the silts remain essentially unaffected. Lumping or fusion of clay particles upon heating as a possible cause of this phenomenon has been reported by other researchers (Sertsu and Sanchez 1978), but the mechanism by which it occurs is not clear.

Changes in clay mineralogy were identified using x-ray diffraction analysis. Heating the Pine Canyon soil to 600° C resulted in the decomposition of calcite, dehydration and collapse of kaolinite, and partial decomposition of smectite. Higher temperatures led to further collapse of the smectite structure in a stepwise fashion (fig. IA). Clays from the San Dimas soil were found to contain mica as well as kaolinite. Heating again resulted in the dehydration of kaolinite at 600° C, while collapse of the mica structure occurred between 800° and 950° C (fig. 1B).



1A. Pine Canyon Soil
- A smectite
- B kaolinite
- C quartz
- D calcite

1B. San Dimas Soil
- A mica
- B kaolinite
- C cristobalite
- D quartz

Figure 1--X-ray diffractograms of the clay fraction of the soils investigated.

These results suggest that soils on steep slopes may become less stable after fire because the cohesive influence of the clays is diminished. Particle size shifts have not been detected in field samples, but there is reason to believe that they occur. Dunn and DeBano (1977) report temperatures of 800° C at the surface and 350° C at 2 cm depths during prescribed burns. Increases in both dry ravel and rill formation on freshly burned slopes have been reported, and both can be initiated by failures at depths of 2 cm or less (Wells 1981). Both of these erosion processes may be caused or enhanced by this shift in particle size distribution.

LITERATURE CITED

Dunn, P. H.; DeBano, L. F. Fire's effect on biological and chemical properties of chaparral soils. In Mooney, H. A.; Conrad, C. E., eds. Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems, 1-5 August 1977, Palo Alto, California. Washington, D.C.: Forest Serv., U.S. Dep. Agric. Gen. Tech. Rep. W0-3; 1977; 75-84.

Sertsu, S. M.; Sanchez, P. A. Effects of heating on some changes in soil properties in relation to an Ethiopian land management practice. Soil Sci. Soc. Am. J. 42:940-944; 1978.

Wells, W. G. II. Some effects of brushfires on erosion processes in coastal southern California. In: Erosion and sediment transport in Pacific Rim steeplands. Christchurch, New Zealand: IAHS Publ. 132; 1981; 305-342.

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2] Resources Management Technician, Sequoia-Kings Canyon National Park, National Park Service, U.S. Department of Interior, Three Rivers, Calif.; and Hydrologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Asymbiotic N_2 Fixation and Nitrogen Content of Bulk Precipitation in Southern California Chaparral[1]

Barbara A. Ellis[2]

The nitrogen (N) budget for southern California chaparral remains uncalculated. Particularly evident is the lack of understanding concerning the importance of asymbiotic N_2 fixation, which has not been evaluated in southern California to date. Similarly, few measurements of N input by atmospheric deposition exist for inland chaparral sites.

Limiting factors of asymbiotic N_2 fixation seem to be energy (carbon) and soil moisture (fig. 1). Assays with unamended soil cores did not always indicate N_2 fixation. However, rates of N_2 fixation in unamended soils when measurable, indicated that N_2 fixation may fluctuate year to year. Experiments under a range of controlled environmental conditions should clear this uncertainty.

Deposition of N from bulk precipitation (dry fallout + rainfall) is not correlated with rainfall intensity in this study due to inadequate frequency of sampling (fig. 2). Values from May 25, 1978 through Nov. 2, 1978 reflect N concentration primarily in dry fallout. The extent to which the NO_3 ion in bulk precipitation may originate from local sources of dust, though thought to be minimal, should be considered in an interpretation of the results.

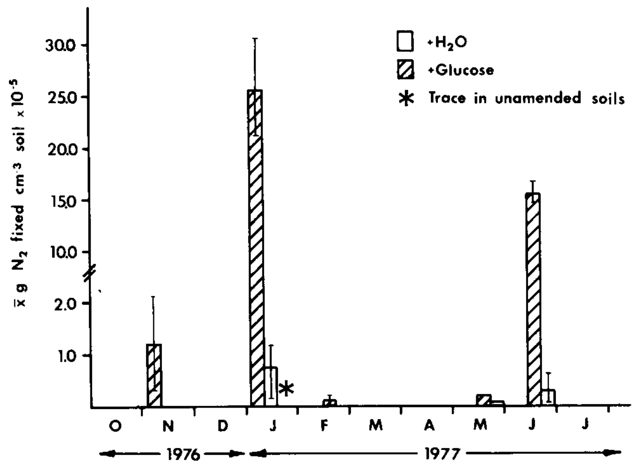


Figure 1--Comparison of N_2-fixing activity (C_2H_2-C_2H_4) in glucose and water amended soil cores. (C_2H_2 concentration 0.1 atm.; ambient pO_2 incubation conditions; assay duration ca. 65 h)

Estimated annual deposition of total N by bulk precipitation is ca. 3.6 kg N/ha/yr, far in excess of contributions from symbiotic N_2 fixation by *Ceanothus greggii* (0.1 kg N/ha/yr) and from asymbiotic N_2 fixation (0.5 kg N/ha/yr, unamended soil cores). The importance of symbiotic N_2 fixation by angiosperms, especially legumes, in early post-burn stands has yet to be thoroughly investigated. Since carbon seems an important limiting factor for asymbiotic N_2 fixation (fig. 1), the role that these microorganisms may play in replenishing N losses in carbon-enriched early post-burn soils poses an intriguing question.

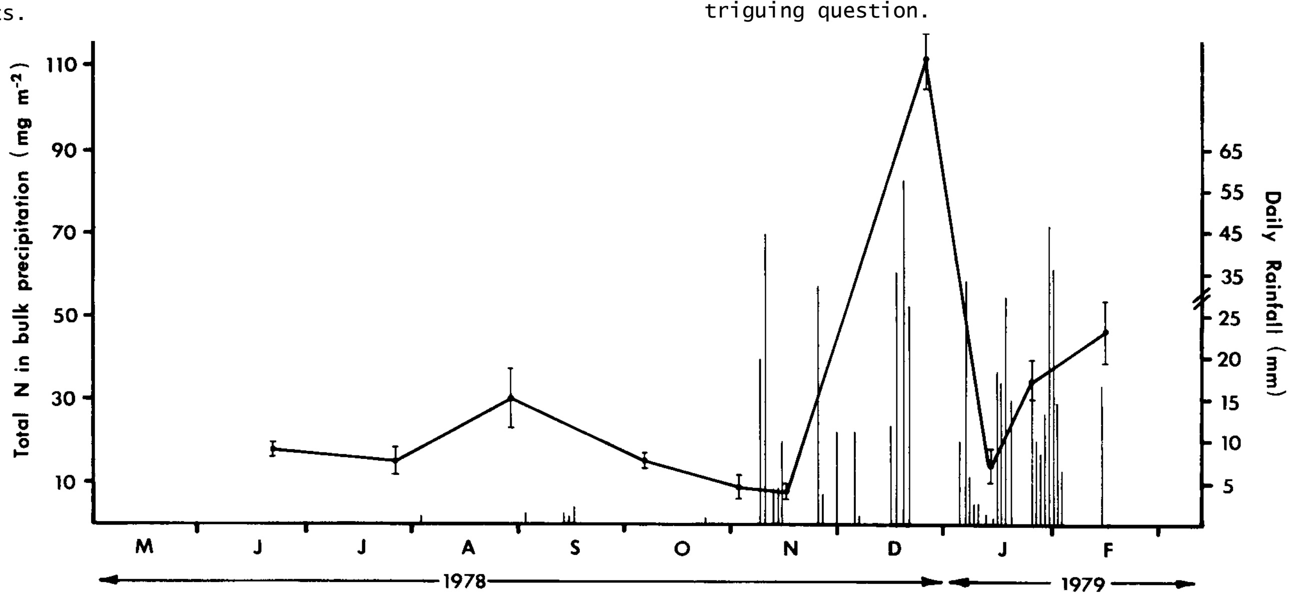


Figure 2--Total N (TKN and NO_2^- + NO_3^-) in bulk precipitation. First five data points represent ionic concentration of total N in dry fallout only (Vertical bars = Standard Error).

Acknowledgments: This research was supported by NSF Grant DEB 77-13944.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Botany Department, San Diego State University, San Diego, California

Nutrient Cycling in Montane Evergreen-Oak Forest at La Castanya (Montseny, Catalunya, NE Spain)[1]

L. Ferrés, F. Rodá, C. Verdú, and J. Terradas[2]

We are studying the circulation of N,P,K,Ca,Mg, and Na in an evergreen-oak (*Quercus ilex* L.) forest in the montane stage of the Montseny mountains. All sampling is made in a 0.23 ha experimental plot (41° 46' N, 2° 24' E) at 660 m a.s.l. near the bottom of a 30°, W-facing slope. Slope within the plot is gentler (7-20°). The soil is a brunisol on schist bedrock. Annual rainfall is *c*. 900 mm. Mean annual temperature is *c*. 9°C. Summer drought is present. The sea is at 27 km. The site now experiences acid rain (mean volume-weighted pH is 4.7). The Barcelona conurbation is at 25-50 km. *Q. ilex* is the only tree species in the plot.

Canopy is closed, dense (2010 boles dbh>5 an/ha), and 9-13 m high. Dominant trees have 17-27 cm dbh. Basal area is 26.6 m^2/ha. Undergrowth is very sparse. Litter (11 t/ha) accumulates on the forest floor. Part of the plot was under cultivation in the past, but it was abandoned probably >100 years ago. The stand was later coppiced. Present age of the trees is unknown, but they are probably <60 years old.

Results are shown in figure 1. Biomass and mineralomass refer to trees of dbh >5 cm. All fluxes are averages of 2 years of study (June 1978-May 1980). Compared with the lowland, limestone-underlain, older *Q. ilex* forest at Le Bouquet, France (Lossaint and Rapp 1971), our stand is much lower in biomass; mineralomasses of the 6 elements; whole-tree concentrations of P, Ca, and Na; Ca litterfall flux; Na precipitation flux; and K, Ca, and Na throughfall fluxes. Whole-tree concentrations of N, K, and Mg are within 20% of those at Le Bouquet. All Mg fluxes are very similar at both stations. Litterfall and K flux in litterfall are higher at La Castanya.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]The first three authors are teaching assistants of Ecology; last author is Associate Professor of Ecology, all of them at the Universitat Autonoma de Barcelona, Bellaterra, Barcelona, Spain.

LITERATURE CITED

Lossaint, P.; Rapp, M. Répartition de la matière organique, productivité et cycles des éléments minéraux dans des écosystèmes de climat méditerranéen. *In*: Duvigneaud, P., ed. Productivity of forest ecosystems. Paris: Unesco; 1971; 597-617.

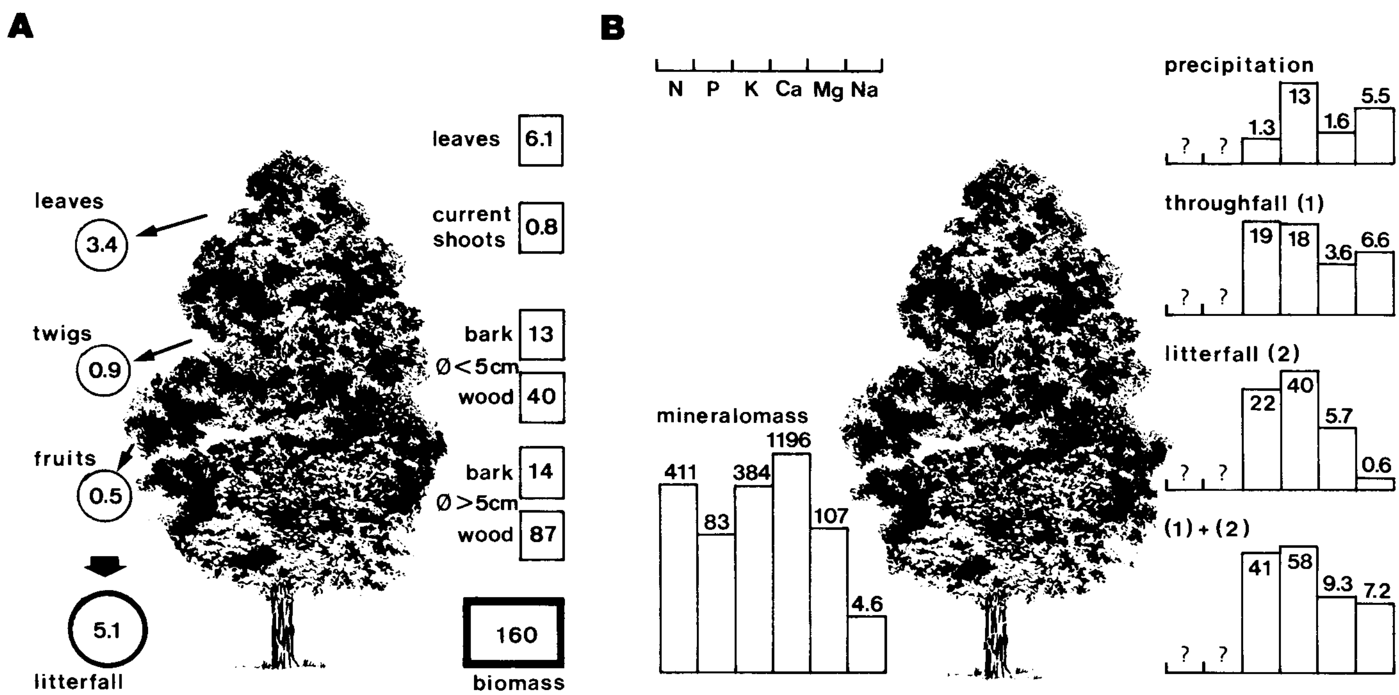


Figure 1--(A) above-ground tree biomass (t/ha) and litterfall (t/ha/yr). (B) mineralomasses (kg/ha) and mineral fluxes (kg/ha/yr) in the montane evergreen-oak forest at La Castanya (Montseny, Catalunya).

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Ecosystems Management, Renewable Resources, and Urban Habitats[1]

Larry Fishbain[2]

Historically technology has been developed with a short-sighted disregard for its effects on natural systems. These systems provide the raw materials which make modern urban society possible, and any damage done to them limits the potential of future human development. Impending shortages of food, energy, and mineral resources; pollution; and the increase in environmentally aggravated diseases are just the most visible signs of these self-imposed limits.

The use of technology to manage renewable resources will require a new framework for evaluating its costs and benefits, one which considers long-range implications as well as immediate monetary costs, one that takes into account such social costs as the effects on human health and personal satisfaction.

The following are a few guidelines for technological development that meets the needs of a healthy human and natural environment. Some relate specifically to the Mediterranean-type ecosystem and urban problems of the San Diego/Tijuana Region. This is certainly not the only model for development, nor is the model complete. We hope this work will stimulate thinking in this area.

Air

We all breathe the same air. Because elements of the ecosystem are interactive, air pollution soon becomes water and soil pollution. Air pollution reduces the useable solar flux, thereby robbing us of needed energy potential. Air pollution must be stopped at the source, yet pollution abatement practices which merely turn air pollution into a solid waste disposal problem are not solutions.

Water

Water resource management in the San Diego/Tijuana Region is almost nonexistent. Urban areas here are 90 pct. dependent upon imported water supplies, yet experience damaging flooding with every substantial rainfall. Urbanization has contributed to increased runoff and a reduction in groundwater storage potential. Water storage is inadequate for any long-term disruption in imported supplies. Present plans call for the construction of expensive facilities to increase water imports from areas where local demand is also increasing, and supplies are not assured. There is legitimate concern that these facilities will cause serious environmental damage at the source of supply.

The use of local water supplies will require a comprehensive program including improvements in air quality; control of substances in common use that might pollute runoff; management of floodplains to control and store runoff, and prevent damage to buildings, roads, and aquifers, while preserving estuary and other wildlife habitats.

An integral part of water management must be a program of water reclamation. San Diego's present sewage system is operating over capacity while 99.9 pct. of sewage volume is just water. Recognizing this as a source problem can relieve pressures on sewage capacity, and the majority of water can be recycled more easily.

Present sewage treatment facilities produce methane gas, only a small part of which is utilized. Dilution of nutrients by excess Water reduces the amount available for gas production, and necessitates the disposal of the excess water. If the plumbing system handled only toilet wastes, present methane digester capacity could fully utilize available nutrients. By excluding toxic materials from the waste stream digester residue containing valuable soil nutrients can be used in agriculture.

Grey water from sinks and baths, and storm runoff could then be treated separately in oxidation ponds. Aquatic biomass from these ponds can be used to increase methane production, and

[1]Presented at the International Symposium on the Dynamics and Management of Mediterranean-type Ecosystems June 22-26, 1981, San Diego, California

[2]Larry Fishbain, Co-founder and Co-director, The Ecological Life Systems Institute, and the San Diego Center for Appropriate Technology
P.O. Box 15991, San Diego, CA 92115

treated water is suitable for irrigation.

Industry which produces toxic wastes must reclaim and reuse its own water.

Food

A healthy agricultural system is a healthy ecosystem. There is a diversity of plant and animal life adapted to the conditions of soil, water, and climate. The soil is kept fertile by the recycling of basic nutrients, and pests are kept under control by natural enemies.

Modern agricultural practices are unhealthy monocultures, supported by a constant supply of biocides and force feeding of fertilizers and water. These practices are energy intensive, increasingly expensive, destructive to the ecosystems they supplant, and surrounding ecosystems as well.

Integrating agriculture with other urban activities can help solve many urban problems. Using reclaimed nutrients and water from sewage for soil fertility and irrigation reduces water pollution and imported water demand. Recycling of organic wastes into compost also helps save valuable canyons from becoming landfills. Employment opportunities are created near population centers, food requires less transportation, processing, storage, etc., all of which saves energy and reduces costs,

Energy

Sunlight is the energy that sustains all ecosystems. Properly developed it can drive the machinery of urban industrial society, replace fossil fuels and nuclear power, and improve the quality of life. Developed improperly it can be as destructive to ecosystems as strip mining. Large energy "plantations" of windmills, biomass farms, or solar collectors have the same limitations as monoculture agriculture. Sited far from population centers they lose efficiency and require new transmission facilities.

A decentralized, diversified solar energy program including liquid, gaseous and solid fuels from biomass, wind and the direct use of the sun can be located near urban areas to provide safe, clean, dependable energy, jobs, and a healthier environment.

Industry

Industrial production should be geared to the use of local materials, energy, and labor. Product utility, longevity, and recyclability, and the health effects on workers and users must be given high priority. Any toxic byproducts of manufacture must be kept within the production facility for reclamation and reuse. The true social and environmental costs of production must be borne by the industry and not externalized as waste, pollution, and disease.

Summary and Conclusion

A healthy ecosystem provides the guidelines for its own management, and the keys to improving the conditions of human life as well. The need for a healthy "environment" and the need of the World's people for adequate food, shelter, health care, and personal fulfillment are not exclusive needs, but are one in the same.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The Effects of Ryegrass on Erosion and Natural Vegetation Recovery After Fire[1]

Clayton R. Gautier[2]

Excessive transport of sediments from recently burned chaparral watersheds during intense winter storms has long been a serious problem in southern California. As part of a state-wide program, the California Department of Forestry and other government agencies have been seeding burned watersheds with fast-growing annual plants since 1956 to reduce sediment yields during floods. The assumption behind the "emergency revegetation" program has been that increasing plant cover in the first few years after fire reduces hillslope erosion rates and, hence, the quantity of material available for sediment discharge. Few quantitative data exist, however, to support this assumption and there is doubt that seeding is effective enough to justify its cost. Moreover, there is concern that seeding burns may increase hillslope erosion later in the fire cycle by retarding the recovery of the native shrub vegetation. The purpose of this study was to determine whether seeding annual ryegrass (Lolium multiflorum), the most commonly used species, a) reduces erosion rates in the first year after fire, and b) interferes with the post-burn recovery of the native vegetation sufficiently to retard reestablishment of native plant cover.

The study was performed in southwestern San Diego County within a recent (1979) burn. Measurements of rainfall, erosion and the vegetation were taken throughout the 1979-1980 growing season in 4 large experimental plots (half seeded with ryegrass at the standard 8 lb/acre rate and half left unseeded) located within the burn.

Because of above-average rainfall and generally cool climatic conditions at the study site, ryegrass establishment was excellent. End of season cover in the seeded treatments of the 4 experimental plots (comprised almost completely of ryegrass) ranged from 39 to 86 percent. In controls, end of season cover was substantially less, ranging from 20 to 35 percent. High cover values in seeded treatments (both early and late in the season) apparently reduced hillslope erosion. Mean soil surface displacement (measured with an erosion bridge) was consistently lower in seeded treatments than in controls once ryegrass plants grew to a sufficient size (late February) to intercept rainfall (Figure 1). Seeding, however, also substantially increased shrub seedling mortality (from 59 percent in controls to 91 percent in seeded treatments) and apparently reduced end-of-season cover of resprouting shrubs in north facing plots (Table 1).

Table 1. Shrub resprout cover. Asterisks indicate statistically significant differences (P<.01) from control values.

Aspect	Plot	Cover (percent)	
		Seeded	Control
North	1	6*	20
	2	9*	31
South	1	4	8
	2	10	7

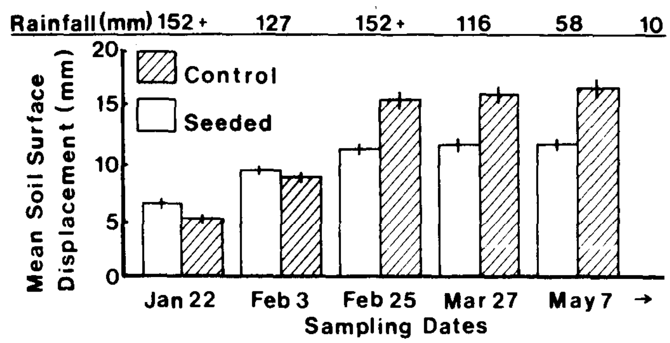


Figure 1. Soil surface displacement averaged (without considering sign) over all plots. Vertical bars approximate 2 standard errors. Rainfall occurring during each interval is shown above.

Although ryegrass seeding seems to be able to reduce hillslope erosion in the first year after fire if climate conditions are conducive to ryegrass establishment and growth, this early post-burn erosion control may be obtained only by sacrificing control of future longterm hillslope erosion. Reducing shrub seedling density and slowing the recovery of resprouting shrubs will retard the reestablishment of native plant cover after fire. Loss of shrub seedlings may be especially important since they contribute greatly towards rapid recovery of the shrub canopy even though many may be eliminated from the stand through thinning. Because there is a reciprocal relationship between cover and erosion rates (documented in this study and elsewhere), slowing the recovery of shrub cover will almost certainly result in increased erosion rates once ryegrass disappears from the vegetation (2--3 years). Increasing erosion rates during the interval beginning a few years after fire and ending with canopy closure (or another fire) would be counterproductive from an erosion management point of view since all hillslope erosion occurring throughout the fire cycle contributes to the size of sediment loads discharged during floods.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]San Diego State University, Dept. of Biology, San Diego, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Insect Herbivory and Polyphenols in Three Mediterranean-Type Ecosystems[1]

J. P. Glyphis and G. M. Puttick[2]

Some recent tropical ecological studies have suggested that forest vegetation growing on low-nutrient substrates contains high levels of digestibility-reducing "defensive" compounds. Theoretically, a plant drawing nitrogen from a very low-level nutrient pool should conserve this nitrogen in some way. This could be achieved, for example, by lowering the dietary quality for primary consumers. Mediterranean-type ecosystems with their characteristic low soil nutrient status are interesting from this point of view. We therefore examined a range of plants in three mediterranean-type shrublands for total polyphenols and insect herbivory.

Our data show a clear relationship between soil nitrogen and plant polyphenol levels in South Africa, France and California (Table 1). Insect herbivory correlates significantly with plant polyphenol levels in South Africa ($r = -0.64$, $p < 0.01$, $n = 20$) but not in France ($r = -0.37$, $p > 0.1$, $n = 16$). The relationship between insect herbivory and plant "quality" is certainly also dependent on other factors such as leaf nitrogen and phosphorus, fibre and moisture content. We are currently testing these for their possible effects on herbivory.

Table 1. Soil nitrogen(%), soil C:N ratios, and total polyphenols(mg/g fresh weight Tannic acid equivalents) in plant species collected at the end of the growing season in South Africa, France and California.

	Plant Polyphenols			Soil Nitrogen	Soil C:N
	Mean	S.D.	n		
Strandveld (South Africa)	117.9	76.1	13	0.013	21.1
Maquis (France)	56.9	21.6	12	0.330	18.0
Garrigue (France)	54.8	15.0	25	0.320	14.7
Chaparral (California)	52.2	19.0	17	0.300	1.9

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22 - 26, 1981, San Diego, California.

[2]Biological Sciences Dept, Stanford University, Stanford, CA 94305 and Zoology Dept, University of Cape Town, Rondebosch 7700, South Africa. (Presently at Stanford University)

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Landscape Analysis and Ecosystems Management at Portola Valley Ranch[1]

Nancy M. Hardesty[2]

Portola Valley Ranch is a 450-acre planned unit development of 200 homes designed around a magnificent hilly oak woodland site with spectacular views of San Francisco Bay and coastal mountains. Because many nearby towns have undermined their oak woodland heritage with insensitive development, the Town of Portola Valley enforces stringent environmental standards to protect its natural wealth. Portola Valley Ranch exceeds town standards in preservation of native vegetation and strict use of native plants for landscaping.

Landscape analysis and design criteria for the project involve 1) preservation and perpetuation of existing oak woodland, 2) preservation and perpetuation of existing watersheds and natural drainage patterns, 3) open space analysis for grassland and native oak maintenance and fire management, and 4) visual resource inventory.

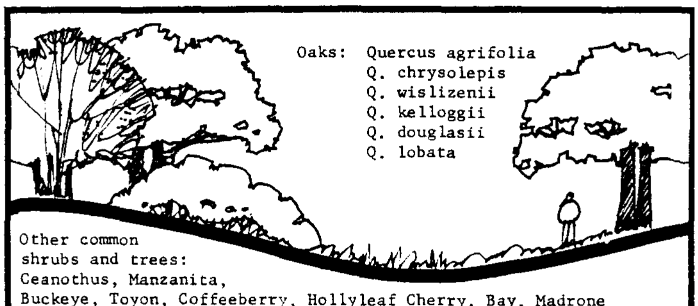
Site vegetation consists of a 250-acre ridge of dense oak-madrone woodland, permanently dedicated to open space, and 200 acres of "monarch oaks" and rolling grassy hills with fingers of oak woodland. Six types of California native oaks exist on the site: Quercus agrifolia, Q. chrysolepis, Q. wislizenii, Q. kelloggii, Q. douglasii and Q. lobata. An oak chart developed to study these oaks summarizes habit, habitat, character, ecological niche, landscape use and fire tolerance.

Oak management guidelines outline procedures for 1) field assessment of individual oaks, 2) construction and landscape planting near existing oaks, 3) watering of existing oaks, 4) planting of new oaks, and 5) contract growing of plant materials. Oak analysis, management and design guidelines have been adapted into "Nature Notes" for distribution to project homeowners on such subjects as acorn planting and plant communities.

Watershed and watercourse preservation and management are equally as significant as oak woodland preservation in this drought vulnerable location. An early project design and engineering team decided against storm sewers which would carry runoff away from native oaks and down into the San Francisco Bay. Later, watershed management guidelines were compiled to achieve these goals: 1) maintenance of natural watercourses, 1) storage of water in ponds, ditches, creeks, 2)design of subdivision drainage systems to direct water into existing drainage channels.

Design guidelines for watercourse preservation suggest 1) curbless roads, minimal non-absorptive pavement and minimal compaction to help recharge ground water, 2) tree preservation, erosion control seeding, native plant landscaping and mulching to help stabilize slopes for water and soil retention, 3) on-site drainage swales controlled with storm water dispersers, mini-dams and wattling. Wattling bundles of live, native riparian twigs are buried in trenches in project drainage swales, creeks and ponds; installation in December takes full advantage of California winter rains for optimal soil moisture and rooting conditions. Wattling field days, under the supervision of the landscape architect, have involved both project staff and homeowners.

Landscape analysis and ecosystems management at Portola Valley Ranch have enabled builder, homeowners and townspeople to develop, use and appreciate this unique site. Equally important, guidelines, concepts and techniques developed for the project are now part of town policy and homeowner land management programs,



ECOLOGICAL ZONE FUNCTIONS:

1. Watershed recharge (east-facing slopes).
2. Maintenance of water quality.
3. Nutrient recycling.
4. Growth processes filter air pollutants.

DESIGN GUIDELINES:

1. Require native plants for species preservation.
2. Establish open space corridor/fire breaks between trees: 30-50' corridors required, as roads, trails, easements.
3. Plant placement/fuel management under oaks:
   a. Avoid medium story woody fire ladder plants.
   b. Avoid vertical and/or resinous plants (including pines).
   c. Avoid resinous ground cover plants near low branching trees.
   d. Limit lawns near oaks to drought tolerant grass mixes.

TOWN IMPACT:
Fire protection of heritage oaks.

MAINTENANCE SUGGESTIONS:
Monitor tree pruning to avoid fuel loading.

Figure 1--Foothill Oak Woodland Fire Management Design Criteria

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Owner, Toyon Landscape Architecture and Ecosystems Management, Palo Alto, California.

Photosynthesis and Water Relations of Mature and Resprout Chaparral Vegetation[1]

Steven J. Hastings and Walter C. Oechel[2]

Photosynthesis leaf conductance, and water potential were measured in the field over time, on mature (ca 34 years) aid resprouts of Arctostaphylos glandulosa Eastw Quercus dumosa Nutt.. and Adenostoma fasciculatum H. & A . The experimental site is within the U.S. Forest Service's Laguna-Morena Demonstration area of the Cleveland National Forest in southern California U.S.A.. 78 kilometers east of the coast of San Diego. Calif. It is characterized as a mixed chaparral community located on an east-facing slope at ca. 1400-meter elevation. Plots of the mature vegetation were marked off (250 meters wide, 675 meters long) and the aboveground biomass removed by either handclearing or controlled burning Measurements were typically made from sunrise to sunset. A null balance porometer, Sholander pressure bomb, and carbon-14 dioxide were utilized to measure leaf conductance, water potential, and carbon dioxide uptake, respectively.

Water potentials in mature vegetation exhibited a similar seasonal pattern among species, decreasing from a maximum value during May-June to minimum values during October-November. However, water potentials in the resprouts (due to fire and handclearing) were significantly higher than in the mature vegetation throughout the duration of the seasonal drought typical of chaparral-type ecosystems. It was concluded that a reduction in the aboveground biomass due to top removal decreased the transpiration surfaces of the resprouts, thereby decreasing water loss and increasing water potentials.

In June. maximum photosynthetic rates by resprouts due to fire were 5, 2.5 and 3 times greater than mature species of A. fasciculatum, Q. dumosa, and A. glandulosa, respectively. These differences diminished with time until burn resprouts and mature rates were equal in August and September for A. fasciculatum and A. glandulosa. However, in November their rates had increased until burn resprouts of A. fasciculatum were 3 times greater than the mature, while in A. glandulosa they were 5 times greater. The photosynthetic rates of the mature plants either decreased or remained constant throughout the duration of the drought. As mentioned earlier, water stress was not a factor for the resprouts and does not explain the observed depression in photosynthetic rates during the drought period. Photosynthetic rates of Q. dumosa post-fire resprouts were less than the mature vegetation for most of the drought. This is attributed to an infestation of powdery mildew (Sphaerotheca lanestris) which resulted in dieback of many of the shoots of the post fire resprouts.

Leaf conductance values were low and relatively constant in mature A. fasciculatum and A. glandulosa during the drought, while in mature Q. dumosa aid all species of resprouts studied, leaf conductance values were higher and more variable. It appears that at higher water potentials, additional factors interact with a plant's tissue water status in controlling stomatal behavior.

Lower water stress alone cannot explain the higher rates of photosynthesis in burn resprouts of A. fasciculatum and A. glandulosa versus mature plants. If this was the case, one would have predicted similar photosynthetic rates in the two field manipulations. The resprouts due to hand clearing generally exhibited rates similar to the mature vegetation, while the post fire resprouts showed higher rates of photosynthesis. It is hypothesized that the higher rates are due to nutrient enhancement, primarily as nitrogen in the ash resulting from the burning of the aboveground biomass. Measurements of soil nutrients before and after the controlled burn revealed a 10-fold increase in soil ammonia-nitrogen. Table 1 presents data collected in June and October for the various treatments aid species.

Table 1-Photosynthesis (Ps, $mgCO_2 \cdot g$ dry $wt.^{-1} \bullet h^{-1}$). conductance ($cm\ s^{-1}$) and water potential Ψ, bars) in A. fasciculatum (A.f.). A. glandulosa (A.g.) and Q. dumosa (Q.d.) in mature (1) and resprouts after fire (2) and hand-clearing (3).

Species & Treatment		Ps June	Ps Oct.	Cond. June	Cond. Oct.	Ψ June	Ψ Oct.
A.f.	1	6.0	3 .5	0.178	0.120	-12.1	-57.0
	2	33.0	11.5	0.461	0.357	- 5.2	-24.3
	3	6.3	2.4	0.361	0.258	- 9.2	-29.3
A.g.	1	4.4	1.3	0.207	0.219	-16.0	-56.3
	2	12.1	3.9	0.114	0.685	-13.8	-18.2
	3	10.5	1.6	0.101	0.376	-16.3	-19.7
Q.d.	1	4.3	2.8	0.093	0.512	-12.8	-34.7
	2	10.3	2.3	0.283	0.500	- 5.5	-12.3
	3	6.6	6.5	0.309	1.372	- 4.1	-12.2

ACKNOWLEDGEMENTS

We thank Philip J. Riggan for soil nutrient data and aid in the design and establishment of the field plots and Paul H. Dunn for identification of the powdery mildew, (U.S.F.S., Pacific Southwest Forest and Range Experiment Station, Glendora, California.) Support was provided by grants from the U.S. Forest Service and the National Science Foundation.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Research Associate and Research Professor, respectively, Systems Ecology Research Group, San Diego State University, San Diego, Calif., 92182.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Vegetation Dynamics of a California Island[1]

Elizabeth Hobbs[2]

Vegetation change between 1929 and 1970, in terms of increase or decrease in foliar cover of woody vegetation, was mapped from air photos for a portion of Santa Cruz Island, California (fig. 1).[3] The vegetation of this area includes forests of Bishop pine (Pinus muricata) as well as chaparral and groves of ironwood (Lyonothamnus floribundus).

Cattle, horses, sheep and pigs were brought to the island in 1853. Since that time, the sheep and pigs have become feral. Their effects are clearly seen on the landscape. Dead logs, branches, and snags provide evidence of the former vegetation. Exposed roots of trees and shrubs suggest significant loss of top-soil. For this portion of the island there is no record of forest or brush fires having occurred within historic time. Vegetation loss has apparently been caused exclusively by grazing, trampling, and undermining of roots by erosion.

Fences were erected in the late 1950's. Sheep removal from the fenced areas had variable success. Vegetation recovery in areas where sheep removal was successful resulted in striking contrasts between vegetation at fence lines. Since the effective removal of sheep from Christy Canyon, the Bishop pine forest has increased in cover, largely due to better seedling survival. Based on size and age data collected in 1977-78, it is estimated that most of the trees in this forest are less than thirty years old (Hobbs 1978). In contrast, the pine population on Sierra Blanca and Ragged Mountain is in serious decline, and the slopes of these mountains are almost completely bare.

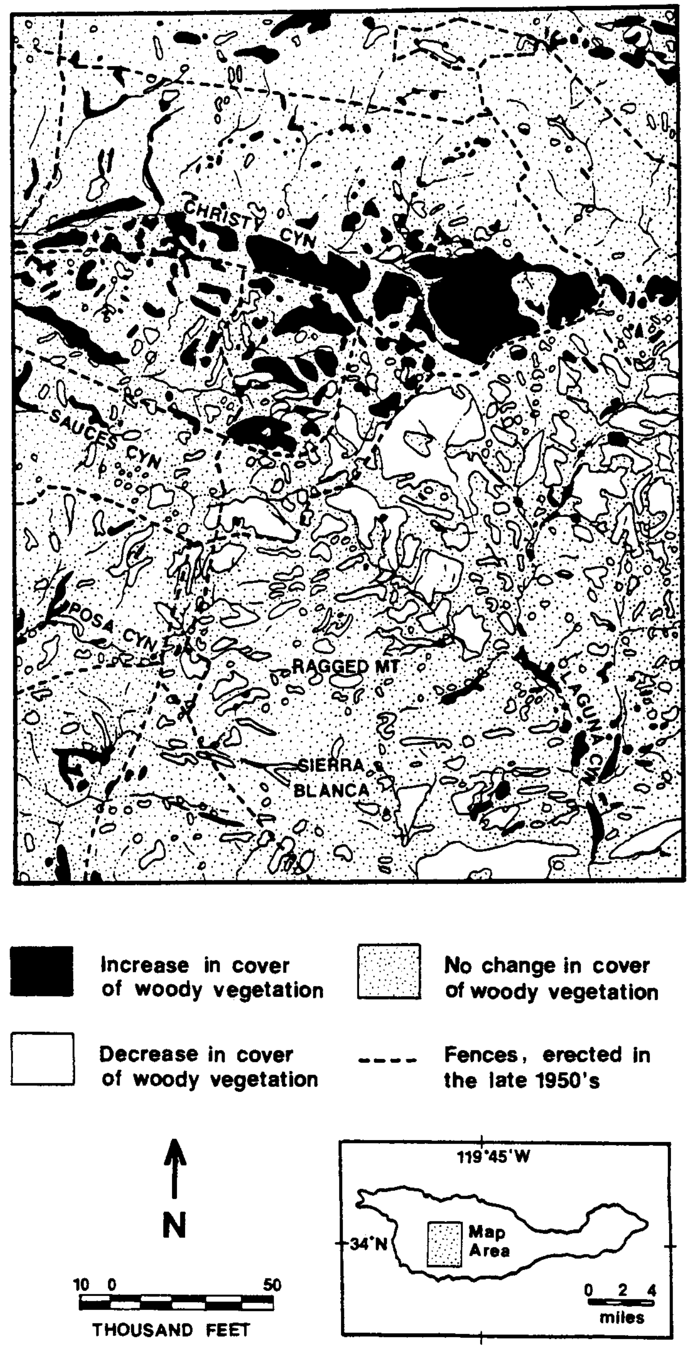


Figure 1--Vegetation Change: 1929 to 1970, portion of Santa Cruz Island, California.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Graduate Student, Department of Geography, University of California, Los Angeles, Calif.

[3]Black and white air photos, Fairchild Collection, Whittier College, 1929, 1:20,000 and color infrared air photos, Geography Department, UCLA, 1970, 1:20,000.

LITERATURE CITED

Hobbs, Elizabeth R. The effects of feral sheep grazing on Bishop pine (Pinus muricata) forests, Santa Cruz Island, California. Los Angeles, Calif.: University of California, M.A. Thesis; 1978. 61 p.

The Effect of Fuel Management on Nutrients in a Chaparral Ecosystem[1]

David Y. Hollinger[2]

The effects of 3 fuel management techniques on the nitrogen, phosphorus, potassium and magnesium pools of a chaparral ecosystem were studied. The study site was located at an elevation of 480 m in Foothills Park in the Santa Cruz mountains, approximately 42 km SE of San Francisco. Annual precipitation at the site averages somewhat more than 500 mm. Stand age was 42 years.

Treatments were carried out on plots varying in size between 50 and 200 square meters in December of 1979 and January of 1980. These consisted of prescribed burning, mechanical chopping (vegetation chopped to pieces less than 15 cm and left in place) and hand clearing (vegetation removed). Adjacent plots were left as controls. Plots were sampled in 6 to 10 locations per plot just before and after treatments and again at the end of the rainy season. Total nitrogen was determined by the micro-Kjeldahl method, and total phosphorus by the molybdate method. Potassium and magnesium were determined by atomic absorption spectrophotometry of perchloric acid digests.

Harvest measurements of a 100 square meter plot indicated a total standing biomass of approximately 41,000 kg /ha. Pretreatment litter mass was comparable at about 40,000 kg /ha. Pretreatment pool sizes of the various nutrients are shown in table 1.

The prescribed burning led to a reduction in biomass of approximately 35 percent and a reduction in litter mass by about 15 percent. Approximately 270 kg./ha N moved out of the vegetation and litter pools; of this perhaps 50 kg /ha moved to the deeper soil layers while the remainder (about 6.3 percent of total N in vegetation, litter and soil to 15 cm) was lost. About 48 percent of the P in the vegetation (16 kg /ha) moved to the litter and deeper soil layers. This is only about 1.5 percent of the system total P, although it may represent a much greater proportion of the exchangeable P in the system. Values for K and Mg were 69 kg/ha and 32 kg/ha respectively. Mechanical chopping led to an initial doubling of litter biomass. N, P, K and Mg were conserved with little loss from the system by the end of the season. At that time approximately 25 percent of the chopped biomass had decomposed, releasing between 40 and 60 percent of the various nutrients. Hand clearing led to a loss of all of the standing biomass. Nutrients lost included approximately 6.8 percent of the total system N, 3.1 percent total system P, and 1 percent or less total system K and Mg.

Table 1--Pretreatment nutrient pool sizes

Compartment	Total N	Total P	Total K	Total Mg
	Kilograms/hectare			
Vegetation	237	34	155	57
Litter	554	68	397	383
Soil				
0-5 cm	1102	291	4680	4720
5-10 cm.	811	362	5060	5870
10-15 cm.	776	344	5200	5570

Fuel managers should be aware that hand clearing leads to the loss of system nutrients and can result in decreased site fertility. Burning can result in overall system nitrogen loss but initially releases N and other minerals, temporarily increasing site fertility. N fixers such as *Lotus* spp. tend to restore system N. Site fertility and productivity could conceivably be controlled by selectively encouraging or eliminating these species. Mechanical chopping appears to maintain site fertility but may result in an increase in importance of species adapted to the slower nutrient mineralization rates.

Acknowledgments: I wish to thank the Rangers of Foothills Park and other employees of Palo Alto, Ca. for their assistance in this project. Funding was provided by the city of Palo Alto.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Graduate Student of Biology, Stanford University, Stanford, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

The Effects of Photosynthesis and Water Relations on Plant Distribution[1]

James L. J. Houpis[2]

The adaptive responses of photosynthesis to the environment can be translated into increasing carbon assimilation. This increases energy and carbon, and thus increases competitive ability and vegetation cover. However, the effects of carbon gain are moderated by controls of water loss. Thus, seasonal photosynthetic rates in conjunction with a water use efficiency ratio should be correlated with species distribution. This study was to investigate this premise in relation to the present distribution of four chaparral species. The four species studied and their associated percentage of cover (at the elevation of 800 to 1000 min San Diego County) are Adenostoma fasciculatum (66 percent), Arctostaphylos glauca (12.7 percent), Ceanothus greggii (15.8 percent), and Rhus ovata (5.6 percent).

To determine the thermal and light dependence of photosynthesis and water use, in situ, gas exchange analysis in conjunction with Vaisala Humidity Sensors was used. Sampling was conducted during four measurement periods (fall, winter, spring, and summer) using six replicates of each species. It should be noted that the species were measured sequentially rather than concurrently.

Since it was impossible to constantly measure photosynthetic rates for all four species throughout the year, two indirect methods were developed to characterize seasonal photosynthetic traits that can be correlated to plant distribution. The first was the thermal acclimation potential ratio, henceforth referred to as TAPR. This indirect index of acclimation is used because the acclimation of photosynthesis among the four species is not directly comparable due to different sampling periods for different species. The index is the ratio of the change in the photosynthetic thermal optimum between two contrasting measurement periods, to the change in mean daily temperature (corresponding to the months in which the photosynthetic data was collected). The resulting TAPR are A. fasciculatum with 43.2 percent, C. greggii with 34.8 percent, A. glauca with 29 percent, and R. ovata with 22.4 percent.

The second method involved an empirical model in which yearly photosynthetic rates were estimated. The model estimated yearly photosynthetic rates for A. fasciculatum with 72.3 g CO dm^{-2} yr^{-1}, C. greggii with 40.6 g CO_2 dm^{-2} yr^{-1}, A. glauca with 29.2 g CO dm^{-2} yr^{-1}, and R. ovata with 28.3 g CO_2 dm^{-2} yr^{-1}. Although the orders of both TAPR and yearly photosynthesis are indicative of cover, the magnitudes of rates are not on the same order as the percentage of cover would indicate.

Water use efficiency was calculated to further understand the percent distribution (in this case water use efficiency is the ratio of transfer resistance of water to that of carbon). It was shown that throughout the year A. glauca had a higher WUE than any other species. This most likely would account for the fact that the percentage of cover of A. glauca is closer to that of C. greggii (and higher than R. ovata) than the photosynthetic rates alone would indicate. A. fasciculatum had a lower WUE in the winter than the other three species, but a higher WUE in the sunnier than two of the species. This strategy effectively eliminates these species from the more xeric habitats that are associated with a higher percentage of cover of A. fasciculatum.

If photosynthesis and WUE traits play an important role in determining plant distribution, one would expect A. fasciculatum to occur in the more xeric habitats. There are two main reasons for this. First, A. fasciculatum has a substantially higher photosynthetic rate than the other species, but lower above-ground tissue. Thus, it can be assumed that a greater percentage of A. fasciculatum's photosynthate, as compared to the other species, is being allocated to the roots. Secondly, with A. fasciculatum's low WUE in the winter months, it is effectively lowering soil moisture and the water table, thus making water increasingly unavailable to competitors of A. fasciculatum. A. fasciculatum adapts to this situation by increasing its WUE in the summer. These factors make A. fasciculatum a superior competitor in the xeric habitats. However, because of its short stature, it is a poor competitor in the mesic, more closed canopy habitats, due to light limitations. In the mesic habitats, neither A. glauca nor C. greggii should be favored in percent cover because neither predominates over the other in both photosynthesis and WUE. R. ovata has a low WUE and photosynthetic rates, and would be unable to avoid drought to any great extent through root development or physiological responses to water stress. Therefore, one would expect R. ovata to occupy areas where moisture tends to collect (e.g. rock crevices, slope bottoms).

This scenario is what is observed in the field. Thus, from this preliminary study, it can be concluded that both photosynthetic rates and water use efficiency are playing an interactive role in determining the present distribution of these chaparral species.

---

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2] Research Assistant, Department of Forestry and Resource Management, University of California, Berkeley, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Variation in Acorn and Seedling Characteristics of Two California Oaks[1]

Serena C. Hunter and Robert Van Doren[2]

Variation within and among plant species is caused by the genetic makeup of the plants and by their environment. Patterns of variation may be indicative of evolutionary trends and can guide man in his use of the species. Two studies were initiated in 1980 to get some idea about the amount and distribution of natural variation within two oak species, Quercus kelloggii and Quercus agrifolia, in southern California. The findings of these pilot studies will help to direct the design, emphasis, and scope of future investigations.

PROCEDURE

Acorns were collected around the first of October from 11 Q. kelloggii mother trees distributed among 3 stands on the San Bernardino National Forest. The stands were at elevations ranging from 4500 to 6300 ft. Measurements were taken on 10 acorns from each mother tree to determine acorn shape, size, dry weight, and moisture content. Thirty acorns from each tree were stratified for 70 days at 35° F and then germinated in separate 3-by-3-by-14-inch pots in a greenhouse. Top emergence rates and height growth were monitored for 5 months. A similar procedure was followed with acorns from eight mother trees distributed between two Q. agrifolia stands at elevations of 3200 and 3400 ft. Their acorns were collected during the last 10 days of October and stratified for 45 days.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Forester and Physical Science Technician, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

RESULTS

Q. kelloggii

Results for the Q. kelloggii samples indicated significant differences in acorn lengths and in acorn dry weights among mother trees. However, acorns from the same tree appeared to be very similar in size, shape, and weight. Percent emergence and time to emergence varied within and among stands. Five months after planting, emergence of acorns from the 11 mother trees ranged from 20 to 93 percent. In general, emergence was poorer for acorns with higher moisture contents. Average acorn moisture content for the 11 mother trees ranged from 37 to 66 percent. In spite of a later collection date, acorns from the high elevation stand showed the highest moisture contents, and slowest germination rates, and produced the fewest seedlings.

Seedling height at 5 months also varied by mother tree. For progeny from the 11 mother trees, average height ranged from 4.7 cm to 7.9 cm. Height growth of the seedlings was positively correlated ($R = 0.63$) with acorn dry weight.

Q. agrifolia

Analyses of variance for the Q. agrifolia samples indicated within-stand differences in acorn length, time to emergence and percent emergence, and total height at 5 months. Between-stand variation was small in comparison with tree-to-tree differences within stands. Percent emergence of acorns from the various Q. agrifolia mother trees ranged from 3 to 93 percent. The average height of seedlings among mother trees also ranged substantially--from 4.5 cm to 9.9 cm at 5 months after planting. The average moisture content of the acorns from the eight mother trees ranged from 45 to 65 percent. Acorns with lower moisture contents were more likely to germinate and to produce taller seedlings.

For both the Q. kelloggii and Q. agrifolia seedlings, most or all of the height growth was accomplished within a few weeks after top emergence. Therefore, height measurements taken at 5 months were, in many cases, the same as measurements taken at 2 months. Whether taller seedlings will lose their height advantage during future growth flushes is yet to be seen.

Results of this small study suggest that substantial variation can exist within stands of both Q. kelloggii and Q. agrifolia for the variables measured. Variation among progeny from the same tree appeared to be much less. Collection and germination of acorns from these same mother trees will be repeated in future years to test for year-to-year environmental differences.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Pasture Improvement and Prevention of Fires in Maquis: A Corsican Case Study[1]

Richard Joffre and Jean-Baptiste Casanova[2]

The maquis (shrubby evergreen vegetation type) is the result of progressive evolution of the vegetation since cultivation was abandoned as well as regressive evolution under the effect of fire. Indeed, during the last century, the agro-pastoral system where cereal cropping and livestock production were closely associated has been replaced by a more and more extensive use of land where only livestock production survives.

The low animal pressure and the free grazing system do not permit the control of the encroachment and provoke a decrease of the amount of pasture available. In order to regenerate the range and make it accessible to the herds, the shepherds use fire in an uncontrolled manner which gravely disrupts the ecosystem: erosion, development of pyrophytic brushes.

EXPERIMENTAL DESIGN

Following research described in Long and others (1978), an experiment is being carried out since 1978 near Corte (Corsica). The object is to evaluate the possibility of creating pasture without tillage (frequent high slopes) nor fire, from maquis of low pastoral value. These pastures are located in such a way that they also serve as fuelbreaks.

In the experimental zone (7 ha), the initial vegetation was low maquis (1.5-2 m) made up of Cistus monspeliensis L. and Erica arborea L. under a sparse cover of Quercus suber L. Shrubs made up 30 to 100 percent of the cover depending of vegetation type. The vegetation was mulched in April 1978, fertilized (100 kg ha^{-1} $year^{-1}$ of N and P_2O_5), fenced off and rotationally grazed by 50 dairy ewes and 200 dairy goats. A second mulching was done in the summer of 1979.

PHYTODYNAMICS

The more interesting points are

– The very rapid domination of herbaceous over shrubs. The evolution of floristic list in different sites depends on the initial amount of shrub cover and original floristic diversity.

– The qualitative improvement of the grazing value (ranging from 0 to 100) is due to the development of palatable species such as Dactylis glomerata L. and Trifolium subterraneum L.

– The edible herbaceous phytomass increased from 0.3 tons of dry matter ha^{-1} in 1978 to 5.5 tons in 1980.The stocking rate, expressed in Corsican sheep unit ha^{-1} $year^{-1}$ goes from 0,2 in 1978 to 4.2 in 1980.

Table 1-- Trends of cover and grazing value (from Claudin and Casanova, 1980, Joffre and Casanova, 1981)

	1977	1978	1979	1980
cover of herbaceous (pct.)	14	80	95	100
cover of shrubs (pct.)	81	17	7	1
grazing value	2	11	29	32

GRAZING MANAGEMENT

In the conditions of Corsican breeding system it seems necessary to render the improved zones complementary to areas of maquis, as much for sociological as for technical reasons. But, in any case it is important to avoid waste and range degradation, to have a high stocking rate and a rotational grazing. Only an integrated land management will lead to a significant reduction of pastoral fires in Corsica.

LITERATURE CITED

Claudin, J; Casanova, J-B. Améliorations pastorales dans le Venacais-Cortenais (1978, 1979). 1980; DGRST-PNRC, Ajaccio, 211 D.

Joffre, R; Casanova, J-B. Creation de paturages améliorés à partir d'une cistaie sous chêne-liège 1981; DGRST-PNRC, Ajaccio, 29 p.

Long, G.A; Etienne, M; Poissonet, P.S; Thiault, M.M Inventory and evaluation of range resources in maquis and garrigues.1978;Proc.of 1st Intern. Rangeland Congress. Denver, Co. p. 505-509.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Range Ecologists, Parc Naturel Régional de Corse, 20231 Venaco, France.

Response of *Adenostoma fasciculatum* and *Ceanothus greggii* to Nitrogen and Phosphorus[1]

W. M. Jow, G. S. McMaster, and J. Kummerow[2]

The importance of nutrient availability in altering carbon allocation and growth of mediterranean scrub species has frequently been stressed but rarely tested. Nitrogen (80 kg/ha) and phosphorus (40 kg/ha) were applied in the early spring of 1978 to a 23-year-old stand dominated by Adenostoma fasciculatum and Ceanothus greggii var. perplexans to examine the effects of N and P additions on biomass production and carbon allocation of the two dominant species.

In the first year a combination of N+P resulted in the greatest increase in total new shoot biomass for both species, although in the second year this treatment produced shoots whose biomass were below the level of the unfertilized control plots (Fig. 1). The effects of N and P fertilization varied not only among the species but between years. Nitrogen significantly increased shoot biomass for both species in the first year but only in A. fasciculatum were significantly larger new shoots observed in 1979. Phosphorus has a relatively greater effect on C. greggii in the first year, producing a significantly greater shoot biomass, but no increased shoot biomass was found for either species in 1979. This difference in absolute biomass production between 1978 and 1979 cannot be explained by differences in precipitation, which was abundant in both the winters 1978 and 1979.

Phosphorus fertilization resulted in increased leaf and stem growth in C. greggii while the reproductive biomass (flower buds or seeds) was not significantly altered by N or P. The low response of C. greggii to nitrogen fertilizer may reflect the well-documented nitrogen-fixing capacity of symbiotic Actinomycetes in the roots of many Ceanothus species.

On the other hand, nitrogen increased both leaf and stem production in 1978 A. fasciculatum shoots while a decrease in inflorescence production occurred in this treatment. Conversely, phosphorus stimulated the formation of reproductive biomass.

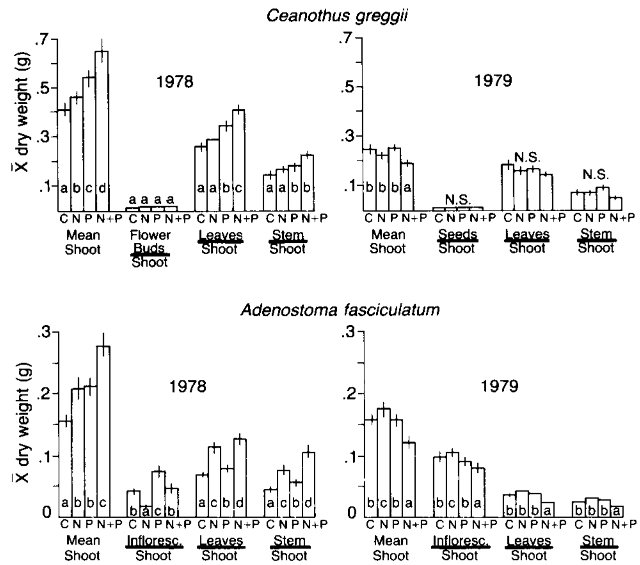


Figure 1. Individual new shoot biomass of C. greggii and A. fasciculatum produced in 1978 and 1979. Biomass values are expressed as mean grams per individual new shoot (± 1 SE). Statistical groupings within a shoot fraction are designated by lowercase letters according to a non-parametric equivalent to the Newman-Keuls multiple comparison test. Identical letters indicate statistically similar means (a = .05). N.S. denotes no statistical difference according to a Kruskal-Wallis test.

New shoot biomass of A. fasciculatum and C. greggii was significantly increased by the application of N and P. Estimates of the stand's response to N and P were made based upon the number of new shoots. Results show that N and P additions alter the number of new shoots, but the number is inversely related to new shoot biomass. The overall effect is that yearly production per m^2 canopy area of A. fasciculatum is increased by nitrogen and C. greggii by phosphorus. Current management options for the chaparral include the possibility of biomass harvesting for energy use. Based upon our results harvest would be increased by the addition of modest amounts of fertilizer, although the cost effectiveness of such fertilizer application is questionable. The long-term effects of fertilization on population patterns are unknown.

Acknowledgments: This research was supported by NSF Grant DEB 77-13944.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California

[2]Botany Department, San Diego State University, San Diego, California 92182

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Silvicultural Biomass Plantation: A Renewable Fuel Source[1]

Michael L. Kirkley, Norman H. Pillsbury, and Walter R. Mark[2]

Wood has long been recognized as a major source of energy around the world. It traditionally has been the most important source of energy in the early development of most countries, and in many countries it still comprises a major source of fuel for some uses. Today in the United States fossil fuels have all but replaced wood as a major fuel source. However, with increases in demand, along with the uncertainty of imported energy supplies and prices, investigation into environmentally acceptable, domestically produced, renewable energy sources is needed. The establishment and operation of energy plantations offer a reliable source of energy from woody biomass.

THE ENERGY PLANTATION CONCEPT

Tree species selected for biomass production must be resistant to insect and disease, demonstrate rapid growth and have high energy yield during short rotations, and respond to intensive cultural treatments. Hardwood species are thought to have the greatest potential for energy farming. They have the added advantages of not competing with timber and product uses of commercial conifer species and they can be coppiced. Sane of the hardwoods being examined in trial plantings in the United States include *Alnus, Eucalyptus, Platanus,* and *Populus.* A number of *Eucalyptus* species appear most promising in California. Of the 700 plus species in the genus, perhaps 20 or 30 could be used in the various climate regimes of California (Pillsbury 1980). Tree spacing in the plantation may range from 400 to 11,000 or more trees per acre. The energy plantation must be of sufficient size to guarantee a reliable long-term supply of fuel, on scheduled demand, to the power plant. Additional support acreage for storage, road network, and facilities ranges from 10 to 40 percent over the planted area.

Energy yield from plantations is a subject of much debate. Values used for California range from 5 to 13 dry tons/ac/yr depending upon species selected, spacing, cultural treatments, fertilization, irrigation, soil and site quality, weed control, and rotation age at harvest. Under ideal conditions, some say it may be possible to produce up to 22 dry tons/ac/yr (Fege 1979). The cost of producing energy feedstocks is equally debatable. Regional differences are created by land lease, interest and taxes, transportation costs and distances, the cost of investment, land steepness, and water availability. Although no reliable estimates are available for marginal lands in California, cost per million BTUs is $1.20 to $2.50 based on 17 million BTUs per dry ton, while 1985 costs for coal are projected at $1.50 per million BTUs.

CAL POLY ENERGY PLANTATION

In 1979 a 20-acre biomass energy plantation was established at California Polytechnic State University, San Luis Obispo. The objective of the study is to evaluate the growth response of eleven species of *Eucalyptus* at eight different spacings, utilizing pre- and post-emergent herbicides and mechanical means of weed control. The results will provide information on optimum spacing, cultural treatment, and fertilization to maximize biomass energy production on rotations ranging from 4 to 7 years.

The plantation is non-irrigated and is located on marginal land previously used for livestock production. The predominate soil type is a Los Osos variant clay-loam with slopes ranging from 5 to 22%, with a predominately south-facing aspect. Extensive site preparation was undertaken prior to planting with up- and downslope and cross-slope ripping of the site to an approximate depth of 2.5 feet (0.76 m). Round-up, a non-selective post-emergent herbicide, was applied to eliminate existing grass and broadleaf growth (Mark *et al* unpublished).

A Nelder circular plot design was developed to provide eight planting densities ranging from 400 to 11,000 trees per acre. Each plot is 0.23 ac (0.09 ha) in size and contains 240 trees. The species planted included *Eucalyptus camaldulensis* (Dehnh.), *E. cinerea* (F. Muell. ex Benth), *E. citriodora* (Hook.), *E. globulus* var. '*compacta*' (Labill.), *E. polyanthemos* (Schau.), *E. pulverulenta* (Sims), *E. stellulata* (Sieb. ex DC.), *E. viminalis* (Labill.). One of these species was randomly selected and planted in each plot. A total of 25 plots were planted allowing replication of species and cultural treatments. Plots were given split fertilizer treatments, one half receiving 10-gram tablets and the other receiving 21-gram slow release fertilizer tablets, both with a 20/15/5 (N/P/K) formulation.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Graduate Research Assistant, Associate Professor, and Associate Professor, respectively, Forestry Program, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

Tree planting was completed in the winter of 1980. Both pre-emergent herbicides and mechanical means were used to control competing grasses and forbs. Twelve additional plots were planted in the spring of 1981. The species planted included *Eucalyptus globulus, E. melliodora* (A. Cunn. ex Schau.), *E. paniculata* (Sm.), and *E. sideroxylon* (A. Cunn. ex Woolls). A pre-emergent herbicide was used to control competing vegetation.

PRODUCTIVITY EVALUATION

Measurements of productivity were limited to height and diameter for the first year. Selective cutting for correlation between height, diameter, weight, and energy yield will be made the second year. Similar data will be collected in the subsequent years. The cutting will allow study of the coppicing characteristics of the species being tested. Cuts will be made at various times of the year to determine the best timing to obtain maximum sprout numbers and vigor. The effects of species, spacing, planting dates, fertilizer treatments, and weed control on growth and yield will be analyzed.

An economic evaluation of the project will be conducted. Basic input cost groups such as labor, capital and materials expenditures, maintenance, operation, and harvest expenses will be recorded. The cost data and yield data will be used to determine production costs per million BTU's for various species, spacing, and cultural combinations.

LITERATURE CITED

Fege, A.S., *et al.* 1979. Energy Farms for the Future. J. of Forestry (June, 1979).

Mark, W.R., Pillsbury, N.H. and M. Kirkley. unpublished. Silvicultural energy plantation establishment Cal Poly, San Luis Obispo Progress Report. Wood Energy Program, California Department of Forestry, Sacramento, Ca, 36 p.

Pillsbury, N.H. 1980. A Summary of the potential and Problems of Silvicultural Energy Plantations in California. Presented at the July, 1980 CEC Biomass/Synfuels Workshop, Sacramento, CA.

The Mediterranean Ecosystem and the People: Resource Management in Santa Monica Mountains Natural Resource Area, California[1]

Kheryn Klubnikin, David Ochsner, and Robert Chandler[2]

The boundary of Santa Monica Mountains National Recreation Area, administered by the National Park Service, U. S. Department of the Interior, encompasses a Mediterranean-type ecosystem with significant scenic, recreational, educational, scientific, natural, archeological, and public health values. In the Establishment Act, Public Law 95-625 (16 USC 460kk), the United States Congress recognized that there is a national interest in protecting and preserving these benefits for the residents of and visitors to the area. This legislation mandated that the recreation area will be managed in a manner which will preserve and enhance its scenic, natural, and historical setting and its public health value as an airshed for the Southern California metropolitan area while providing for the recreational and educational needs of the public.

The Santa Monica Mountains form a complex geological unit. The evolution of the mountains is marked by repeated episodes of deposition of marine sediments, uplifting, regression of the sea, erosion, and the transgression of the sea to deposit new sediments. These episodes were interspersed with periods of faulting and folding of sedimentary beds due to the movement of the Pacific Plate and the North American Plate along the San Andreas Fault, and the intrusion of magma into the sedimentary beds. The Santa Monica Mountains are one of the ranges in California in an east-west alignment.

The mountains are a diverse botanical island that is representative of the California Floristic Province. Vegetative communities include chaparral, coastal sage, oak woodland, oak grassland-savannah, riparian woodland, beach and dune, southern coastal salt marsh, freshwater marsh, grassland and rocky intertidal. Five of these communities are considered critical in California for preservation.

Much of southern California's native wildlife still survives in the mountains. A small population of mountain lions remains as do extensive populations of birds of prey. The Santa Monica Mountains are significant in the Pacific Flyway as resting and feeding areas for migratory birds, as is Mugu Lagoon at the western end of the Range.

A broad spectrum of human uses is represented in the Santa Monica Mountains. In pre-European times the mountains and the sea sustained the Chumash and Gabrielino native American coastal cultures. The Hispanic occupation brought about a drastic change in the cultural history of the mountains with the virtually complete subjugation of native Americans. Current land uses include a broad range of urban development, rural homes, high density recreation, and the preservation of open space and natural and cultural features. The present jurisdictional arrangements are very complex.

Within this context, the National Park Service encourages new and innovative concepts of ecosystem maintenance through cooperative planning. These concepts are intended to encourage private and governmental entities to design actions that perpetuate the integrity of the inherent resources. Resource management projects include monitoring surface water quality, delineation of wildlife corridors, determination of research needs, monitoring air quality, the role of fire in the mountains (including prescribed fire), preservation of the cultural continuum, and assessment of the environmental impacts of human uses in the mountains.

Educational programs are vital to the success of the Santa Monica Mountains National Recreation Area for resource-based recreation activities and for conservation of Mediterranean-type ecosystems. Over 70 colleges and universities and approximately 10 museums and research facilities are within easy reach of the area. Through present educational programs school children and other visitors are given experiential understanding of the natural world and the human cultures that occupied the mountains and coast. These programs include traditional nature walks, seminars featuring scientists, coastal walks, musical interpretations and a recreation transit program that brings inner city residents into the Santa Monica Mountains.

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2] Environmental Specialist, Resource Management, Chief, Resource Management, and Superintendent respectively, Santa Monica Mts. Nat. Rec. Area.

Species Diversity and Stratification to Improve Grazing in Mediterranean Chilean Range[1]

Sergio Lailhacar, Héctor Manterola, Alfredo Olivares, and David Contreras[2]

An important area of the mediterranean Chilean range, approximately 4 million ha, mainly in the arid zone, is being affected by a strong process of desertification. The zone affected extends between parallels 32° and 36° S.

Climatic conditions are typical of a mediterranean-type zone, with rainfall between June and September, at an average of 200-250 mm. Twenty-seven percent of the total rain occurs in fall, 53 percent in winter, and 17 percent in spring. Normally every year has about 7 months of drought, and the incidence of drought years is very high. These climatic conditions have induced the development of a typical matorral-type vegetation, characterized by a herbaceous stratum, actually very low in annual biomass production, and a woody one, with a wide variety of species.

The herbaceous stratum has been severely affected by overgrazing, and some species have disappeared or are rarely found. Dominant genera actually present are Erodium, Vulpia, and Oxalis. Less common, but still present are Tricetobromus, Bromus, Lolium, Koeleria, and Avena. Almost extinguished are Medicago, Trifolium, Trigonela, Hosakia, and Adesmia.

The woody stratum has been affected by wood cutting, either for firewood or to clean the fields for further cultivation. Also, animals such as goats have produced a negative effect on the matorral. The dominant genera are Bahia, Baccharis, Puya, Adesmia, Muehlenbeckia, Heliotropium, Trichocereus, and Haplopappus. In some areas that were under cultivation, some toxic species such as Cestrum palgui appear.

Less degraded matorrals can be found toward the south where Acacia caren steppe starts. The vegetation has not been so degraded and some microphanerophytes such as Azara celastrina, Maytenus boaria, and Lytrea caustica are found.

Under these conditions, the ecosystem has changed its morphology and composition, and productivity, expressed as stocking rate capacity, or edible dry matter production, has significantly decreased. Continuous human pressure on the ecosystem, either through wood harvesting, overgrazing, or cultivation, has produced an accelerated erosion process that in many situations cannot be easily stopped or reversed.

EDIBLE BIOMASS PRODUCTION

Most of the areas considered in this study are low in biomass production, which is also very dependent upon amount and distribution of rainfall. Average forage production is about 0.7 to 1.2 ton/ha/yr, but it has been seen that under experimental conditions (modifying the rainfall system and management), production can be increased to 3 to 4 ton/ha/yr. The main herbage genera that actually produce this biomass are Erodium, Vulpia, and Bromus. Most of the palatable genera are on a low stand or have disappeared (Medicago, Trifolium, Tricetobromus) and genera such as Raphanus, Lamarkia, Capsell, and Amsimckia have invaded the land.

The nutritive value of the available forage has wide variation through the year, related to the vegetative cycle. Energy is always the most limiting factor for animals, and fluctuates between 1.2 and 2.5 kcal/gr organic dry matter. The crude protein content is also a limiting factor, especially during the dry season. When pasture is the preblooming state, the protein content is about 10 to 14 percent, and decreases to 3 to 4 percent after pasture gets dry. Crude fiber goes from 10 percent to 30 percent for the same periods.

ANIMAL PRODUCTIVITY

Current ecological conditions only allow the development of extensive animal production systems, based either on goats or sheep, depending upon rangeland conditions. In the area where the degradation is higher, farmers raise goats, producing cheese or selling the kids. Small flocks of sheep are present in some better areas. As the pasture conditions improve, sheep replace goats because they bring a higher price for meat.

The average stocking rate for the worst condition varies from 0.1 to 0.3 sheep/ha, and for better conditions, from 0.5 to 1.5 sheep/ha. Goats can make use of shrubs, so are not so much affected as sheep during critical periods, but both goats and sheep have very low yields because of chronic under nutrition, reproductive performance, and sanitary problems.

There are some periods during the year when animals cannot meet their nutritional requirements, especially during the last third of the gestation period and during lactation, producing high lamb or kid mortality. Adults also die when starvation continues too long.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems

[2]Facultad de Ciencias Agrarias, Veterinarias, y Forestales, Universidad de Chile, Santiago.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

RESEARCH STRATEGIES TO DEAL WITH THE PROBLEM

The first strategy studied was based on the introduction of foreign forage genera, such as *Phalaris*, *Trifolium*, *Lolium*, and *Sorghum* in order to replace the natural pasture. It did not work because those genera did not become adapted to the climatic conditions, mainly to the low rainfall level. After that, a new strategy was started, based on the transformation and modification of the ecosystem but trying to produce the least alteration in its structure. The idea was to produce a diversification of species and stratification of them in order to optimize the use of solar energy, water, and soil minerals. This procedure, together with an improvement in rangeland management and water collection systems, is the basic action needed to partially solve the problem.

In order to replace some of the inedible brush with others more valuable, a worldwide collection of native and foreign shrubs was tested. After an evaluation process, it was concluded that *Atriplex repanda*, followed in rank by *Atriplex numularia* and *Atriplex semibaccata*, fitted very well in the conditions where they were needed.

Atriplex repanda is a native species from the north of Chile (400 km from Santiago). It is a saltbush with very high palatability for sheep and goats; this has almost produced its extinction. This saltbush grows all year, but the growth rate is significantly higher during the summer. In late fall and winter, its growth is minimal. The nutritive value is very high, with a protein content of 18 to 21 percent in the leaves, 11 to 12 percent in the stems, and 8 to 9 percent in the seeds. The crude fiber of the edible portion is about 23.6 percent.

The most relevant characteristics of this species are

- --its high resistance to dry conditions
- --its ability to make available green forage and protein, during the most critical period in the pasture
- --its high palatability
- --its habits of growth, that provide protection against weather

Taking into account these advantages, the government, through its Forestry Agency, has developed special legislation in order to encourage the settlement of this plant in the arid and semiarid zone of Chile. At the present time, more than 15 million ha have been planted.

RESEARCH RELATED TO *ATRIPLEX REPANDA*

One of the problems that scientists have found in *Atriplex* is the very low seed germination rate, no higher than 5 percent. Studies have been made to detect the presence of inhibitors or some special dormancy mechanism. It has been shown that age of seed plays an important role in germination of *Atriplex*, 3-year-old seed having a higher germination percentage compared with 1- or 2-year-old seed.

Another interesting problem studied was the density of plants. It was observed that in a high density stand, there is marked competition between plants, which reflects on their growth and persistence through the years. Studies have shown that an adequate density can fluctuate between 700 and 1200 plants per hectare. This will produce a yield of 1.0 to 1.5 tons dry matter per hectare. Rainfall and soil conditions are the main factors affecting density.

In relation to the use of *Atriplex* by animals, two studies have been done up to date. One is on grazing intensity, and the other on the response of animals to *Atriplex* feeding during the period of highest nutritional requirement. The first was related to when and how many times should *Atriplex* be used to get the best response in terms of plant longevity. Studies indicated that these shrubs could be grazed any time of the year, but once in a year, for maximum productivity and longevity. Used twice a year, *Atriplex* produces more edible material, but plants are significantly affected. The second problem of utilization was how to integrate this supplementary saltbush to the annual cycle of the animal, especially during the critical periods. It has been seen that pregnant ewes perform better when they have access to *Atriplex* during the last third of the gestation period. Lambs are born with higher weight and growth is faster, indicating an effect on lactation.

Also, in other phases of the animal productive cycle, *Atriplex* has shown a significant effect on animal performance.

CONCLUSION

After 20 years of study, it can be concluded that it is possible to replace some of the ecosystem components with others of greater suitability, without any significant alteration of its morphology and functioning. It produces an improvement of the natural pasture, provides another ecological niche, and animals perform better.

REFERENCES

Gasto, C. J.; Silva, G. M.; Cariedes, E. Santiago, Chile: Facultad de Agronomía, Univ. Chile: 1968; Boletín Téchnico 28. 19 p.

Gasto, C. J.; Contreras, T.D. Santiago, Chile: Facultad de Agronomía, Univ. Chile: 1972; Boletín Téchnico 35. 61 p.

Gasto, C. J.; Contreras, T. D. Santiago, Chile: Facultad de Agronomía, Univ. Chile: 1979; Boletín Téchnico 42. 99 p.

Olivares, E. A.; Gasto, C. J. Santiago, Chile: Facultad de Agronomía, Univ. Chile: 1977; Boletín Téchnico 34. 00 p.

Coastal Sage Environmental Conservation—The Navy's Experience at Point Loma[1]

Ronald La Rosa[2]

San Diego's Point Loma, a relatively undeveloped three-mile peninsula, has been a military reservation since 1852. Through the Naval Ocean Systems Center (NOSC), the Navy and Point Loma have been linked through research and development. NOSC has recognized its responsibility to preserve, protect and improve the 507 acres that are entrusted to them. In recent years, their commitment to this responsibility has been a planned and executed program to assure that the natural state of the land is protected.

The Navy's four-year program has resulted in the installation of hundreds of native trees and shrubs, most of them rare and endangered species, to enhance the environment and increase biological productivity. Steps have been taken to correct erosion problems through revegetating disturbed soil, restoring natural contours, and improving drainage patterns to check run-off and soil loss.

ENVIRONMENTAL PLANNING

The NOSC Environmental Resources Conservation Program was implemented through a multidisciplinary team approach consisting of engineers, planners, and an environmental specialist augmented by a soil scientist, architect and contracts administration staff. Master planning provided the framework for the division of conservation activities into annual phases: Phase I involved an initial study of resources and environmental needs assessment; Phase II concentrated on installation of plant material; Phase III activities were a culmination of the previous phases as well as the beginnings of three experimental projects; and Phase IV focused on erosion control and runoff management. After a phase-end evaluation, the Master Plan was revised accordingly. The program's underlying philosophy was one of minimizing research costs and maximizing on-the-ground conservation efforts.

COASTAL SAGE CONSERVATION

Enhancement of NOSC lands went beyond simple "beautification". Components of wildlife management, engineering geology and landscape architecture were combined to provide an action-oriented, ecological approach to land use planning and environmental protection. Nearly 2,000 plant species including Torrey pine (Pinus torreyanna) shown in Figure 1, California sycamore (Platanus racemosa), Wild cherry (Prunus illicifolia), Coast white lilac (Ceanothus verrucosus) and Encilia (Encilia californica) were planted on wildlands and disturbed sites. In wildland sites, irrigation consisted of drip-type systems; landscaped areas were watered by impact-type heads. In addition, a repository for rare and endangered flora displaced by development in the region was created.

Project Results

The environmental enhancement of disturbed areas through the installation of forbs, shrubs, and trees resulted in the dramatic increase of wildlife species benefiting from successive vegetation. Shrubs and trees planted as seedlings, one-and five-gallon as well as twenty-four-inch containers, have had to date a success factor of 90 percent. (Losses were due to burrowing animals and pockets of clayey soils underlying loamy areas.) Landscape, revegetation and wildlife plantings have, over the years, become established to provide food plots, wildlife shelter, aesthetic screens and stabilization of soil.

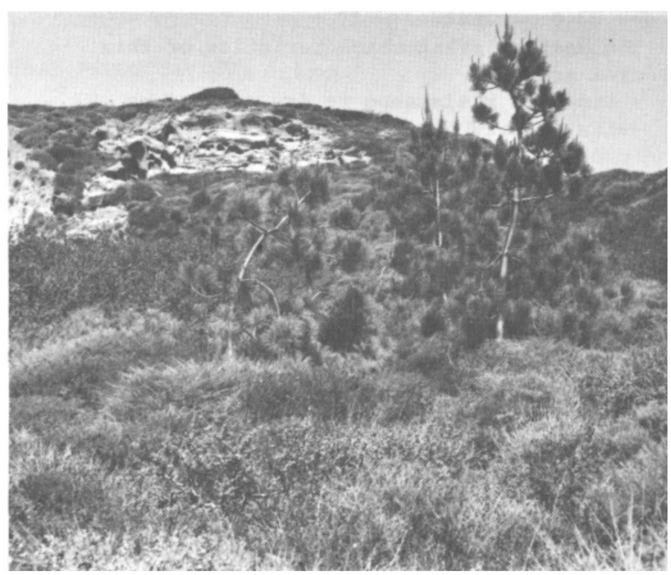


Figure 1--Torrey pines, installed by hand to protect existing shrubs, create aesthetic wildlife habitat in the low-profile coastal sage of Point Loma, San Diego.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Environmental Management Specialist III, Department of Public Works, County of San Diego, San Diego, California.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Photosynthetic Production of Perennial Species in the Mediterranean Zone of Central Chile[1]

William T. Lawrence, Jr., and Walter C. Oechel[2]

The carbon balance of a plant is a key parameter, integrating the biotic and abiotic interactions of the individual with its intrinsic physiological rates of photosynthesis and respiration. In the field, carbon balance cannot be directly measured, but it is calculated by summing the carbon gained or lost by all plant tissues under the given set of environmental conditions. In Chile we have begun such a carbon balance study by gathering a season of basic data on the CO2 exchange of above-ground parts of some of the dominant shrub species.

Both leaves and several size classes of stems were measured *in situ* with an infrared gas analysis system to determine their CO_2 exchange under a range of light and temperatures. The stems are an often overlooked, but nonetheless important component of the plant carbon balance as they respire, losing carbon, and in some cases may photosynthesize.

A wide range of life forms were examined, including *Satureja gilliesii*, a drought-deciduous subshrub; *Trevoa trinervis*, a drought-deciduous, green-stemmed shrub; *Colliguaya odorifera* and *Litraea caustica*, both evergreen shrubs; and *Mutisia linearifolia*, a composite vine.

As would be expected, the species fall out over a range of leaf photosynthetic rates, but more interestingly, every one of the shrubs shows a net gain of carbon by stems at least one temperature. Both *Lithraea* and *Colliguaya* have the lowest stem photosynthesis rates, but when positive, they are 9 and 5% respectively of the leaf rate. *Satureja* also has a low rate, but maintains the positive 3-5% level all across the temperature range. *Trevoa's* current-year stem rate is 30-38% of that of the ephemeral leaves, and a rate for older stems is fully 10% of the leaves, so even when the leaves are shed at the onset of drought, a strongly photosynthesizing surface remains.

The stem photosynthesis of the shrubs varies strongly with light intensity. Both the light response and the stem gas exchange diminish rapidly with stem age, probably due to decreased conductance of CO_2 by the thickened bark.

Stem photosynthesis would naturally be of less importance in older stems as they are increasingly shaded by canopy development. Once a stem no longer provides carbon through photosynthesis, it can then only be mechanical support, and it becomes a carbon sink. A large bulk of respiring stems can be costly, but some of our data indicates a reduction in respiration on an area basis as stems age, thus effectively reducing some carbon loss associated with non-green support stems.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Doctoral Candidate and Research Professor, respectively, Systems Ecology Research Group, San Diego State University, San Diego, CA 92182.

Table 1. CO_2 exchange for leaves and current and last year's stem age class for the fie Chilean species. Both dark respiration (Rd) and full-sun gas exchange (Ps) are tabled in mg $CO_2 \cdot dm^{-2} \cdot h^{-1}$ ± one standard error. Photosynthesis is represented by a positive CO_2 flux. Measurements were made at 5, 15, and 25°C air temperatures in a thermoelectrically cooled cuvette system near Santiago, Chile.

Species	Tissue	Rd	Ps	Rd	Ps	Rd	Ps
		5°		15°		25°	
Trevoa	leaves	-0.34±0.02	14.53±1.31	-0.30	18.45±1.28	-0.88±0.53	18.03±1.84
	current	-0.20±0.10	4.36±1.11	-1.97±0.22	7.07±0.49	-4.44±0.74	5.76±1.64
	last	-2.08±0.28	1.52±0.08	-4.43±0.43	2.48±0.29	-11.26±1.12	-1.77±0.36
Satureja	leaves	-0.60±0.02	6.11±0.41	-1.80±0.10	10.97±0.37	-4.28±0.19	17.37±0.17
	current	-0.75±0.13	0.25±0.05	-1.43±0.11	0.34±0.11	-2.53±0.13	0.87±0.09
	last	-0.17±0.03	-0.22±0.04	-0.76±0.06	-0.31±0.05	-1.98±0.10	-0.37±0.11
Collig.	leaves	-0.71±0.01	14.72±2.69	-1.77±0.12	14.76±1.69	-5.50±0.40	23.75±2.50
	current	-0.43±0.16	0.18±0.11	-1.40±0.24	-0.59±0.09	-4.35±0.22	-2.62±0.39
	last	-0.52±0.15	-0.51±0.35	-1.81±0.16	-0.82±0.53	-3.79±0.18	-1.91±0.39
Lithraea	leaves		3.32±0.48	-0.29±0.06	11.99±1.38	-1.17±0.08	13.74±1.18
	current	-1.74±0.22	-1.17±0.46	-1.48±0.32	-0.35±0.35	-2.36±0.41	1.17±0.08
	last	-0.86±0.09	-0.51±0.05	-1.22±0.11	-1.20±0.32	-2.90±0.39	-2.42±0.96
Mutisia	leaves	-0.05±0.03	5.88±0.26	-0.30±0.01	9.45±0.54	-0.75±0.32	9.79±0.74

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Modeling Postfire Succession in Coastal Sage Scrub[1]

George P. Malanson[2]

Coastal sage scrub in the Santa Monica Mountains regenerates following fire primarily through resprouting from root crowns. Dominant shrubs are variable in post-fire resprout and seedling regeneration and also in continual seedling establishment. Such differential reproductive success in both the immediate post-fire environment and in the succeeding years should result in a changing relative abundance of species. Thus fire interval should be an important factor in determining the relative abundance. A constant fire interval should result in a dynamic equilibrium species composition, but might exclude some species if the interval is very long or short; a variable fire interval should create a shifting abundance that may allow the coexistence of a greater number of species.

The model being constructed is based on the regenerative success of the species, in the first post-fire years and through time. Fire intensity will be considered in setting the initial post-fire densities of resprouts and seedlings. These densities will then be iterated at 5-year intervals using a Leslie matrix of fecundity and survivorship (fig. 1).

$$\begin{bmatrix} f_0 & f_1 & \cdot & \cdot & \cdot & f_n \\ p_0 & 0 & \cdot & \cdot & \cdot & 0 \\ \cdot & p_1 & & & & \cdot \\ \cdot & & \cdot & & & \cdot \\ \cdot & & & \cdot & & \cdot \\ 0 & & & & p_{n-1} & 0 \end{bmatrix} \begin{bmatrix} n_{0,t} \\ \\ \\ \\ \\ n_{n,t} \end{bmatrix} = \begin{bmatrix} n_{0,t+1} \\ \\ \\ \\ \\ n_{0,t+1} \end{bmatrix}$$

f - probable fertility function
p - probable survival function

Figure 1--Leslie matrix of age-dependent fecundity and survivorship with age class population vectors.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, Calif.

[2]Graduate student, Department of Geography, University of California, Los Angeles, Calif. 90024

The entries in the Leslie matrix will be based on postulated graphs of age-dependent natality and mortality (cf. fig. 2) which in turn will be based on known age structures for species populations. A small number of age structures are being sampled by counting the xylem rings of the largest basal branch of all the individuals of a given species dominant on a 25x25 m site. The entries will be computed as logistic functions of extant shrub cover; total shrub cover will limit the reproduction of all species. For this purpose a relationship between density and cover on different age sites is being established through size distributions for intercepted plants as the longest chord perpendicular to a line transect. For the most important shrubs (Artemisia californica Less., Encelia californica Nutt., Eriogonum cinereum Benth., Salvia leucophylla Greene, and S. mellifera Greene) at least 3 different age 25x25 m sites on which a species is dominant or co-dominant are being sampled along 4 randomly located transects.

With each iteration the densities and foliar cover of the species will be incremented, the relationship depending on the age of the stand. In this form the Leslie matrix embodies the assumptions that competition for space through regenerative strategy is the primary process controlling species relative abundance. Through time relative abundance will shift toward the optimal combination of fecundity and survivorship, and this prefire relative abundance will affect the new initial post-fire densities. The model will predict foliar cover of species given various hypothetical or observed fire history scenarios. The predictions will be tested against actual abundances on sites of known fire history in the Santa Monica Mountains. The form and direction of variation in abundance will be of equal interest to ecologists and land managers.

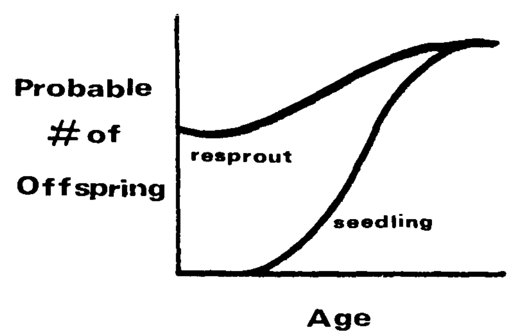


Figure 2--An example of a postulated natality graph.

Acknowledgements: Support for this study is from NSF grant 76-81712 to W.E. Westman.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Vegetation Responses to Prescribed Burning in Cuyamaca Rancho State Park, California[1]

Bradford D. Martin[2]

This study reports the results of light-intensity prescribed burning on the vegetation of 3 jeffrey pine-black oak woodland sites in Cuyamaca Rancho State Park, California. The 1.2 ha Oakzanita burn, 85 ha Granite Springs burn, and 6 ha Paso Picacho burn were measured for tree and shrub density and basal area in June, 1980, 6 months, 1½ years, and 2 years following burning for the 3 sites respectively (fig. 1). Each burn site measured was compared against equivalent unburned control plots to help assess the effects of the burning. Density of saplings, seedlings, and herbaceous vegetation was also determined for the woodland understories. Dominance and relative dominance of herbaceous foliar cover in meadow areas were obtained to determine the recovery of the perennial bunch grasses.

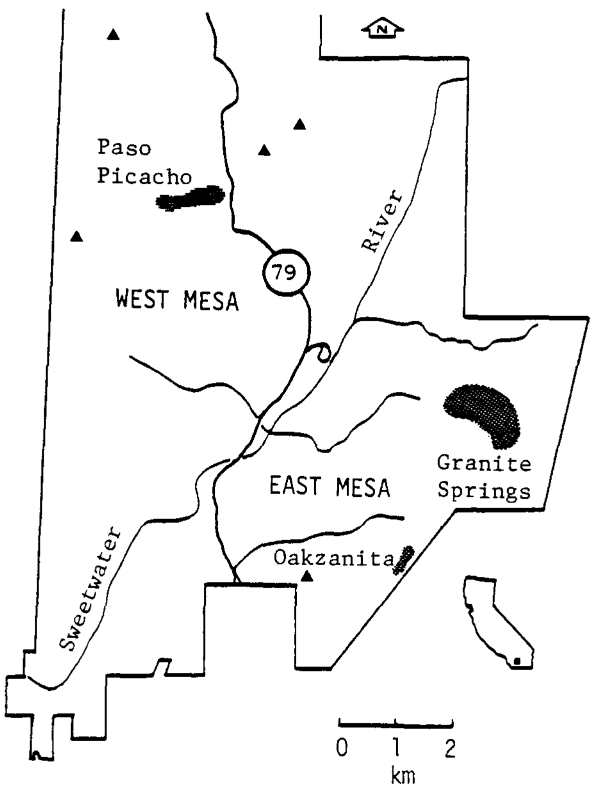


Figure 1--Locations of the Paso Picacho burn, Granite Springs burn, and Oakzanita burn in Cuyamaca Rancho State Park, California.

The greatest change which took place as a result of the burning was a significant reduction (P<.05) in density and basal area of shrubs in the understory (table 1). The dominant shrub, *Arctostaphylos pungens* (non-sprouting), averaged a 93 percent density reduction in the burn sites compared to the control sites. Other shrubs such as *Arctostaphylos glandulosa*, *Ceanothus leucodermis*, *Ceanothus palmeri*, *Cercocarpus betuloides*, and *Rhamnus californica* were also reduced to a lesser extent. Except for a slight reduction in the number of trees with very small trunk diameters at breast height (2-8cm), tree density and basal area were not affected by the burning (table 1).

Table 1--Mean density and dominance (based on basal area) of shrubs and trees in 100m^2 control and burn quadrats at all 3 burn areas.

Area	Density		Dominance	
	control	burn	control	burn
	no/ha		Mean pct.	
Paso Picacho				
Shrubs	480	43	0.12	0.02
Trees	1039	1165	0.59	0.62
Granite Springs				
Shrubs	31	3	0.005	0.001
Trees	369	345	0.36	0.45
Oakzanita				
Shrubs	3529	240	0.25	0.03
Trees	374	407	0.22	0.21
TOTAL				
Shrubs	4040	286	0.38	0.05
Trees	1782	1917	1.17	1.28

Shrub and tree sapling density was significantly reduced (P<.05) in burn sites when compared to control sites. Mean density of tree seedlings was also generally decreased in burn sites except for *Quercus agrifolia*, *Quercus chrysolepis*, and *Quercus kelloggii*, which increased in some study sites in the most recent burn. Shrub seedlings (*Arctostaphylos pungens* and *Ceanothus palmeri*) were very infrequent in all control and burn areas. Density and diversity of herbaceous vegetation were generally increased as a result of the burning. Bunch grasses in meadow areas recovered quickly from the removal of dead grass in bunches by the fire. *Muhlenbergia rigens* (a bunch grass) recovered 143 percent of the live foliar cover 3 months following one burn.

The results of this study indicate that prescribed burning done in woodlands can eliminate shrubs in the understory without affecting trees.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Graduate Student in Biology, Loma Linda University, Loma Linda, California 92354.

Fire in the Ecology and Management of Torrey Pine (*Pinus torreyana*) Populations[1]

Gregory S. McMaster[2]

Fire has been an important historical and biological factor in southern California for many centuries, but the frequency and intensity of fires remains uncertain. The role of fire must be incorporated into any management consideration, particularly for areas such as the Torrey Pines State Reserve in San Diego, Calif., which is charged with maintaining the naturally rare Pinus torreyana in its native habitat.

This summary will present three lines of evidence to support the hypothesis that crown fires have had a strong selective role on recruitment in Torrey pine stands and the implications for management alternatives in the Reserve: 1) significant recruitment in an area of a crown fire, 2) limited seedling establishment between fires, and 3) the delayed seed dispersal traits of the cones.

In 1972 4.8 ha were burned with complete mortality of the 93 adult Torrey pines in the area. Sampling in 1981 revealed that the burned stand has apparently replaced itself (Table 1), particularly since no mortality has been observed from 1979 to 1981, mean seedling height has increased from 1.54 m in 1979 to 2.40 m in 1981 and some establishment is still occurring (two 1981 seedlings were found).

Table 1. Seedling establishment following a 1972 crown fire with complete adult mortality. The burned area was first sampled in May 1979 and then resampled in May 1981. Seedling estimates for the area immediately adjacent to the burned area includes all individuals 20 years and less.

	Burned	Unburned
Live seedlings/ha	66	0.8
Adults/ha	20.8 (dead)	29.5

Sampling in other unburned stands recorded relatively few seedlings (Table 2). Establishment in 1978 was exceptionally above normal (28/ha) and correlates well with the near record rainfall and large seed crop for that year. However, less than 25% of the total seedlings established in 1978 (including those outside of the stands studied) were still alive by June, 1981. Seedling establishment declined drastically to less than 1/ha in 1979 and 1981. The reduced establishment noted in 1979 and 1981 appears to be more typical and is supported by the sapling densities which represents establishment for the last approximately 15 years. A mean establishment rate of .6 seedlings/ha/yr is yielded if a constant rate of establishment is assumed. The majority of seedlings and saplings discovered in the Reserve (about 93%) are found in microsites with no shrubs or dense herbaceous cover and the survival rate of seedlings in open areas is greater than those with dense vegetation nearby. Further, seedling density is correlated with the amount of open ground within a stand. These data show that establishment is much higher in burned than unburned areas. This holds for both total number of seedlings established and the proportion of live seedlings to adults which is 3.17 for the 1972 burned area and 0.17 for the unburned areas when combining 1978-81 data.

Table 2. Seedling establishment between fires. Sapling data were recorded in 1978 and are those individuals older than one year that have not reached reproductive age, approximately 15 years. Adult densities vary over time as the size of the sample areas was increased. Estimates of live seedlings are through May 27, 1981.

	Year of Establishment			
	1978	1979	1981	Saplings
Total seedlings/ha	28	0.3	0.5	9
Live seedlings in 1981/ha	10	0.0	0.0	9
Adults/ha	58	58	61	58

Torrey pine cones can be retained on the tree for as long as 15 years after pollination, and cone opening is only about 75% complete 2 years following seed maturity. About 77% of the total seed crop in 1978 was contained in cones one year or more past maturity. Serotinous or closed-cones are considered to be an adaptation to crown fires in areas with little establishment between fires. The retained seed is available for the period immediately following a fire when the probability of successful establishment is greatest. The existence of delayed seed dispersal in Torrey pine is consistent with the hypothesis of sporadic crown fires.

The probable historical importance of crown fires to Torrey pine presents a dilemma to the Reserve management since intense conflagrations are rarely acceptable, particularly in an area with an urban interface. The only alternative that can be foreseen is to attempt experimental controlled burns of lesser intensity in order to see if this will be acceptable in place of crown fires.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]Biology Department, San Diego State University, San Diego, California 92182

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Growth and Maintenance Costs of Chaparral Leaves[1]

Jose Merino[2]

Deciduous and evergreen species coexist in mediterranean-type ecosystems. Their leaves differ considerably in a number of central properties. In order to assess the benefit one leaf type has over another in a given habitat, the costs of producing and maintaining the leaf must also be taken into account. Here I compare the costs of building and maintaining leaves of drought deciduous (Lepechinia calycina and Diplacus aurantiacus) and evergreen (Heteromeles arbutifolia) mediterranean-climate plants.

For calculating the respiration components, I adopt the model

$$SRR = Rg\ SGR + Rm$$

where Rg and Rm are the coefficients of growth and maintenance respiration, SRR is the specific respiration rate and SGR the specific growth rate of the leaf.

RESULTS AND DISCUSSION

There were no significant differences among the Rg values of the three species on a weight basis (table 1). The average total cost per gram of leaf tissue for all the species is 1.76 g of glucose (0.52 from respiration and 1.237 from molecular skeletons) (table 2).

Table 2--Total growth cost

	g gluc/g dw	g glue/m^2
March		
L. calycina	1.72	91.58
D. aurantiacus	1.82	118.26
May		
L. calycina	1.72	128.14
D. aurantiacus	1.82	209.85
H. arbutifolia	1.71	146.89

The results indicate that the hypothesis that evergreen leaves are more expensive to construct than deciduous ones may not be generally true. This may be due to the high concentrations of resins or terpens in the deciduous species which were studied. Those components are presumably involved in such functions as drought resistance, herbivore protection and, perhaps, flammability.

The maintenance cost values found in this study are significantly higher than those calculated by others for different chaparral species (table 3).

The lower maintenance cost of the evergreen species may be important in the plant's long term success, because many evergreen leaves endure extended periods in which photosynthetic CO_2 gain is very low.

Table 3--Maintenance cost

	g gluc/g dw/day	g gluc/m^2/day
March		
L. calycina	0.0339	1.8204
D. aurantiacus	0.0199	1.3015
May		
L. calycina	0.0227	1.6911
D. aurantiacus	0.0190	2.1907
H. arbutifolia	0.0174	1.4907

Table 1--Respiration coefficients expressed on a weight and area basis

	Rg	Rm	Rg	Rm
	g CO_2/g dw	µgCO_2/g dw/s	g CO_2/m^2	µg CO_2/m^2/s
March				
L. calycina	1.071	0.5750	57.51	30.88
D. aurantiacus	0.620	0.3378	40.54	22.08
May				
L. calycina	0.740	0.3851	55.13	28.77
D. aurantiacus	0.855	0.3232	98.58	37.27
H. arbutifolia	0.646	0.2958	55.49	25.41

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26,1981, San Diego, California.

[2]Assistant Professor of Ecology, University of Seville, Faculty of Biology, Seville, Spain

New Approaches to Harvesting Chaparral for Energy[1]

J. A. Miles and G. E. Millen

Harvesting chaparral for fuel requires meeting constraints which will require new machines and systems. In addition to being economically feasible, the systems must keep the fuel as clean as possible because even a very small amount of soil or rock will make the biomass unacceptable for combustion or gasification. Any rock may also be very detrimental to intermediate processing equipment. The system must also be able to harvest chaparral on a variety of terrain types without major changes in road systems. Finally, in sane areas, minimum impact systems which do little soil disturbance and leave root systems intact are essential to protect soil and water quality.

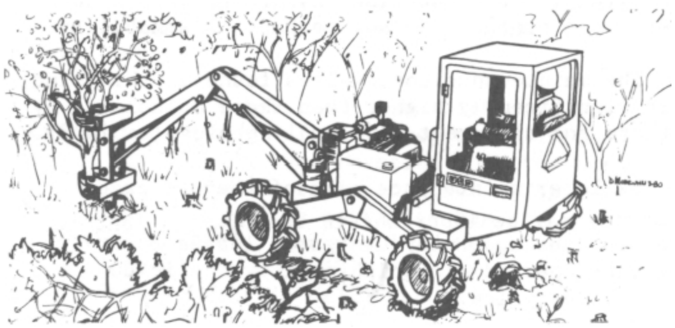


Figure 1--A very light weight vehicle is used to cut and windrow chaparral.

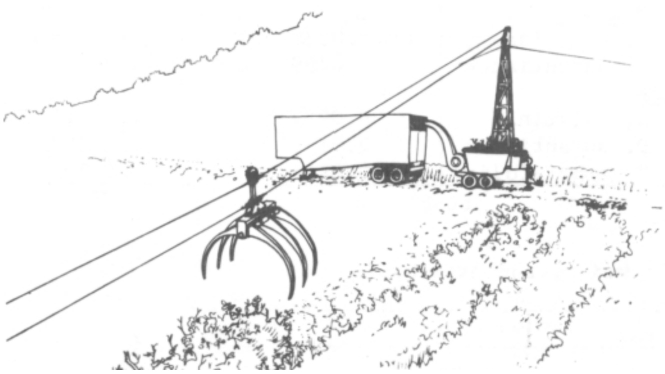


Figure 2--The biomass is moved to a landing site using a cable system which can move over the area with reasonable speed and very little impact.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26,1981, San Diego, California.

[2]Assistant Professor of Forest Engineering and Extension Specialist in Agricultural Engineering, respectively, University of California, Davis.

Figure 3--The biomass is placed into a module builder, adapted from the cotton industry, distributed and compressed into a unit 7½ feet wide, 30 feet long and 8 feet high.

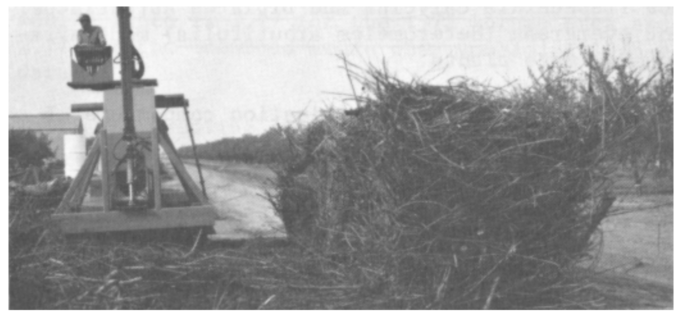


Figure 4--A free standing module, having a density of 8 to 10 lb /ft^3, ready to be picked up by a transport vehicle.

Figure 5--To increase biomass density, the material may first pass through a tub grinder, then into the module builder.

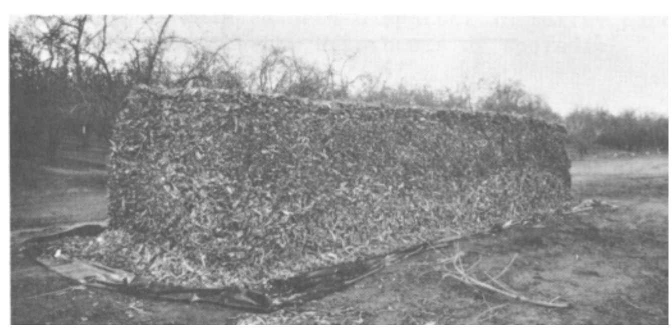


Figure 6--The resultant free-standing module has a density of 25 to 30 lb /ft^3.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Ponderosa and Jeffrey Pine Foliage Retention Indicates Ozone Dose Response[1]

Paul R. Miller and Robert E. Van Doren[2]

Ozone is the component of photochemical air pollution responsible for damage to tree species comprising the mixed conifer and pine types of southern Sierra Nevada and southern California mountains. In these forests ponderosa pine (Pinus ponderosa (Laws.) and Jeffrey pine (P. Jeffreyi Grev. and Balf.) are the most sensitive to ozone. The purpose of this study was to examine needle injury symptom development leading to premature senescence and abscission as a function of ozone dose and intraspecific variation of ozone sensitivity.

Thirteen ponderosa or Jeffrey pine saplings or small pole-sized trees were selected at each of 5 plots located in the San Bernardino National Forest along a gradient of decreasing ozone dose. The experimental plot locations and respective mean seasonal ozone doses (parts per million-hours) for 1976, 1977, and 1978 were: Dogwood (DWA), 244.3; Tunnel 2 Ridge (T-2), 222.8; Camp Angeles (CA), 208.0; Deer Lick (DL), 191_.8; and Camp Osceola (CAO), 166.4. The individual ozone sensitivity of trees at each plot was recognized by segregating them into categories defined by the average number of annual needle whorls retained in the lower crown at the outset of the three-year observation period. Incremental increases of the percent of the total needle length with chlorotic mottle (ozone) symptoms were measured for each needle age at biweekly intervals from mid-June to early September. Incremental values were summed to obtain the seasonal increase. Counts of needles of different ages remaining in their respective whorls were made at the beginning and end of each summer season to provide information on abscission rates.

Results show that: 1) needle injury symptom development of the trees was significantly different among four chronic injury categories resulting from exposure to the range of ozone doses experienced at the five plots; and 2) the abscission rates with all chronic injury categories combined have a positive correlation with the gradient of increasing seasonal doses represented by the five plots.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-25, 1981, San Diego, California.

[2]Research Plant Pathologist and Physical Science Technician, respectively, Chaparral R and D Program, Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Riverside, California.

The example of needle injury symptom development for 1977 in Table 1 illustrates the important effect of inherent tree sensitivity to ozone as represented by the average number of annual needle whorls retained. Significant injury to current year needles was experienced only by trees of the most sensitive category. The rate of injury increase is most rapid for one-year-old needles in all chronic sensitivity categories.

Table 1--Mean percentage of the total needle length with ozone injury symptoms for the current and

Number of Annual Needle Whorls Retained	Needle age	
	One-year-old	Current Year
	Percentage of total length injured	
	1	
1	91.4A	33.2 A
2	53.7 B	5.2 B
3	25.6 C	0.8 B
4	23.7 C	0.1 B

[1]Means with same letter are not significantly different.

Needle fall (abscission) was most dramatic after two seasons of exposure when visible needle injury had reached 80-90 percent. Most abscission occurred over the winter. In Figure 1 the relation of increasing needle loss to increasing ozone dose is evident with the exception that CA with a slightly lower dose than T-2 had a greater loss of needles. This result cannot be explained by any single variable, however the influence of winter conditions on abscission is the least defined variable and requires further investigation.

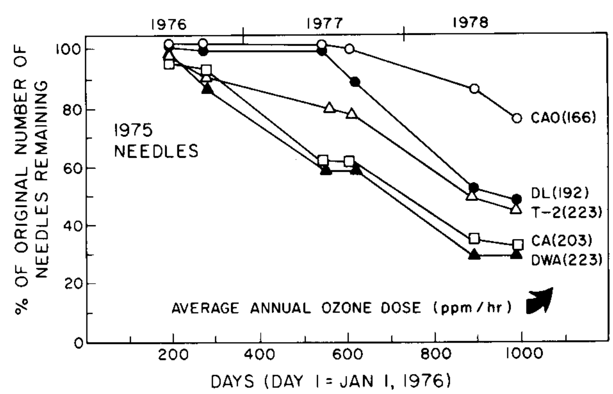


Figure 1--Needle abscission rates for a population of ponderosa and Jeffrey pines including all ozone sensitivity categories in relation to the ozone doses experienced at 5 plots.

These results provide better quantification of the population response of these pines to chronic ozone doses under field conditions, and suggest that silvicultural prescriptions should identify and conserve ozone tolerant individuals.

Consumption, Digestion, and Utilization by Yearling Goats of Oak (*Quercus coccifera*) Foliage at Three Phenological Stages[1]

Anastasios S. Nastis and Leonicas G. Liacos[2]

Kermes oak (Quercus coccifera L.), a small tree occurring, in general, in shrub form, is a dominant species of brushlands which occupy several million hectares of land in the Mediterranean area. This plant gives a relatively good browse production and is consumed in varying quantities by domestic and wild animals (Liacos and Moulopoulos 1967, Nastis 1981). However, its nutritional value has not been fully assessed.

Oak browse harvested at three discrete phenological stages was offered fresh to yearling goats. Feed intake and excretions were measured during 10-day digestion trials. Nitrogen content was determined for feed, feces, and urine. Feed and fecal samples were analyzed for gross energy content (A.O.A.C. 1960) and urinary energy was calculated according to Street et al. (1964).

Results

Voluntary intake by goats was found to be significantly (P 0.05) higher when animals were consuming the spring diet (74 $g/BW^{.75}$) as compared to the summer diet (55 $g/BW^{.75}$), while fall diet (59 $g/BW^{.75}$) was not significantly different from either of them. This variation in intake might be attributed to the differences of the rate and extent of feed digestion (digestion coefficient 69, 51 and 52 respectively). Digestion was closely related to crude protein content (7.9, 6.4 and 7.1 percent respectively), and to soluble carbohydrates but inversely related to structural carbohydrates and lignin.

Intake rates of kermes oak browse collected in spring and fall were higher from that of an alfalfa diet (Nastis 1977) while intake of kermes oak collected during summer was not different. Probably, intake rates were higher because browse was fed in its natural green form.

Nitrogen intake was significantly higher for spring than for summer and fall diets. In a similar way nitrogen digested (73.9 percent) and retained (51.9 percent) for spring diet were significantly higher than for summer (43.9 and 15.1 percent) and fall (42.0 and 0.0 percent) diets. This indicates that net nitrogen retention was influenced by browse quality, which undoubtedly varied indifferent phenological stages.

Energy balance for browse collected in spring has shown that digested (75 percent) and metabolized energy (49 percent) were significantly higher (P, 0.05) than for simmer (51 and 20 percent) and fall (50 and 5 percent)diets.

Animal weight gain had a similar trend to feed, nitrogen and energy intake and their digestibility. Although nitrogen consumption per kg of body weight is higher for the browse collected in spring and fall in comparison to an alfalfa diet (Nastis 1977), weight gain was always lower and even a loss was observed for the summer and fall diets. This was attributed to the high proportion of nitrogen lost as metabolical fecal component and the limited metabolized energy of kermes oak browse.

LITERATURE CITED

A.O.A.C. 1960. Official methods of analysis (9th ed.). Association of Official Agricultural Chemists. Washington, D.C. 832 p.

Liacos, L.G. and Ch. Meulopoulos 1967. Contribution to the Identification of some range types of Quercus coccifera L. Thessaloniki.

Nastis, A.S. 1977. Consumption, Digestion and Utilization by Goats of the Dry Matter and Nitrogen in Diets Containing Oak (Quercus Gambelii) Foliage and Estimation of in Vivo Digestibility of Oak-Containing Diets by Micro-Digestion Techniques. MS Thesis. Utah State Univ.

Nastis, A.S. 1981. Mediterranean shrublands. Presented at the FAO-Cooperative network on pastures and forage production, Sub-network on mediterranean pastures. Thessaloniki.

Street, J.C., J.E. Bucher and L.E. Harris. 1964. Estimating urine energy from urine nitrogen. J. Anim. Sci. 23: 1039-1041.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean type Ecosystems.

[2]Senior Lecturer and Professor of Range Management, University of Thessaloniki, Greece.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Postburn Vegetation Along Environmental Gradients in a Southern California Shrubland[1]

John F. O'Leary[2]

Ten thousand hectares of chaparral and coastal sage scrub in the central Santa Monica Mountains burned in fall, 1978. Following an exceptionally wet winter, the post-burn landscape was covered by a heavy flush of herbaceous vegetation. High geologic and topographic diversity in this area prompted several questions regarding this herbland phase. Does composition of post-burn vegetation vary along an elevational gradient, aspect and substrate held constant? Does composition vary between sites due to substrate differences, aspect and elevation controlled? Can changes in floristic similarity be attributed to aspect if substrate and elevation don't vary?

Twenty-two sample sites were stratified by two substrate-types, andesite and sandstone, two aspects, NNE. and SSW.; and elevation at 150 meter intervals between 95 and 875 meters. Floristic resemblance between sites was computed by using a percentage-similarity index. Progressive comparison of sites encountered along the elevational gradient to the lowest site of a particular substrate and aspect yielded mixed results (Figure 1). As expected, floristic resemblance decreased as elevation increased with south-aspect andesite and north-aspect sandstone sites. Sites along the south-aspect sandstone gradient fluctuated while those along the north-aspect andesite gradient increased, probably due to the elevational range sampled being less than the mean amplitude of the dominant species.

Floristic resemblance of sites located on differing substrates having identical aspects and elevations produced different results (Figure 2). On southerly aspects, dissimilarities between such sites were initially high, but decreased regularly with elevational increase. Greater rainfall and cooler temperatures associated with elevational gain may provide additional soil moisture which could compensate for the more xeric nature of sandstone-derived soils and the substantial differences in each substrate-type's nutrient status.

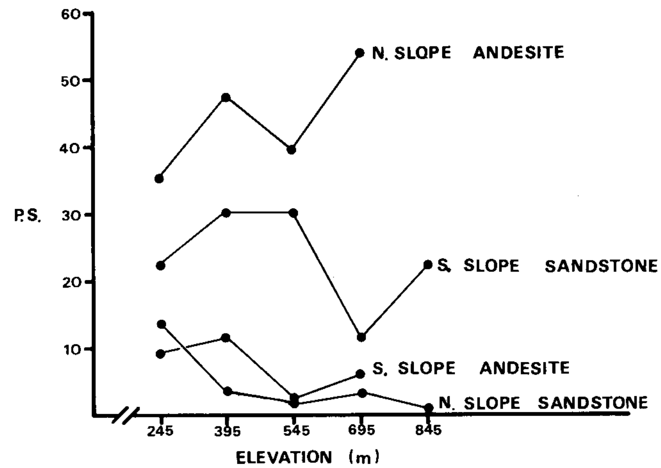


Figure 1--Percentage similarity of sample sites encountered along elevational gradient compared to lowest sites (95 meters).

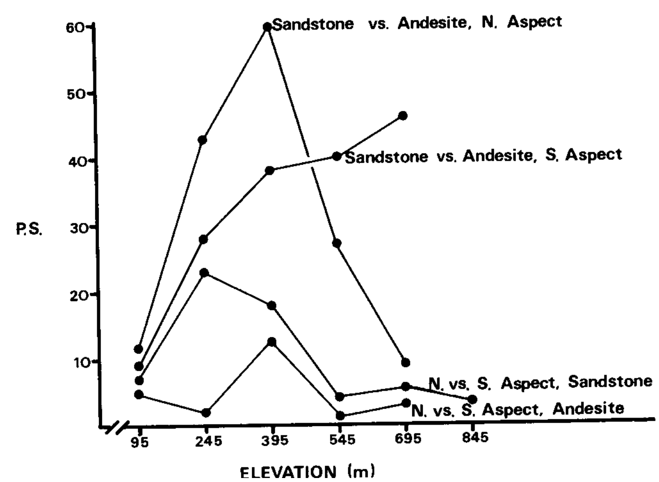


Figure 2--Floristic similarities of sites having different substrates, aspect and elevation being identical, and of sites having opposing aspects, substrate and elevation being identical.

The greatest dissimilarities were found on opposing aspects when elevation and substrate were similar. Dominant post-burn herbs appear to possess narrow soil-moisture and micro-climatic tolerances, and most exhibited distinct aspect preferences (e.g. Chaenactis artemisiaefolia and Phacelia parryi). Some preferred a specific substrate-type in addition to a particular aspect (e.g. Eucrypta chrysanthemifolia and Calystegia macrostegia).

Acknowledgements: This study was supported in part by a Grant-in-Aid of Research from Sigma Xi.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, Calif.

[2]Graduate Student, Department of Geography, University of California, Los Angeles, Calif., 90024.

Reseeding of Burned Mediterranean Brushlands in Greece[1]

Vasilios P. Papanastasis and Anthony C. Pittas[2]

There are two major types of mediterranean brushlands in Greece, phrygana and the evergreen sclerophyllous brushlands. Phrygana are open-scrub communities and occupy the driest part of the precipitation gradient. Evergreen brushlands are dense communities and occupy the wettest part of the precipitation gradient. They include maquis and the kermes oak (Quercus coccifera L.) brushlands.

Large areas are burned by wildfires in both these types every year. Existing management policy anticipates reforestation of the burned areas either by artificial or mainly by natural means (through regeneration of the native vegetation) and allows no grazing by the domestic animals. This policy, however, does not protect the burned areas since natural revegetation takes a relatively long time, when the potential for soil erosion is very high.

Over the last few years experiments were made in several burned brush sites around the country in order to investigate the possibilities of securing a temporary vegetative cover by seeding right after the fire improved annual or perennial grasses and legumes. This cover will not only protect the soil from erosion but it will also provide abundant and nutritious forage to the domestic and wild animals.

This paper summarizes the up-to-now results of the reseeding experiments over both the phrygana and the evergreen brushlands.

[1]Presented at the Symposium on Dynamics and Mamanagement of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Range Scientist, Forest Research Institute, Vassilika, Thessaloniki, Greece; Director, Ministry of Agriculture, Athens, Greece.

PHRYGANA

Seedings were done at three different sites dominated by the dwarf shrub Sarcopoterium spinosum (L.) Spach. and at one site dominated by the half-shrub Phlomis fruticosa L. All sites were burned by wildfires in the summertime and they were planted during the early fall months.

The species used were a mixture of the annual grasses Blando brome (Bromus mollis L.), California bromegrass (Bromus carinatus Hook.), Italian ryegrass (Lolium multiflorum Lam.), and Wimmera ryegrass (Lolium rizidum Gaud.). The seeds were broadcasted at a rate of 20 Kg/ha.

It was found that all species germinated and established quite well but only in places where white ash was deposited following the wildfire. On the contrary, in places where black ash was formed, indicating an incomplete burn, either the species did not germinate or they germinated but the seedlings died soon due to the heavy competition by the native vegetation.

It is concluded that reseeding should be restricted to only those sites where the burning is complete and a layer of white ash is deposited on the ground after the wildfire.

EVERGREEN BRUSHLANDS

They were seeded on two sites burned by wildfires, one in a typical maquis and the other in an open kermes oak brushland; also, a third site in a dense kermes oak brushland burned by a controlled fire. The species planted were the annual grasses Italian and Wimmera ryegrasses and Blando brome and the perennial ones orchardgrass (Dactylis glomerata L.), Hardinggrass (Phalaris tuberosa L.), and smooth brome (Bromus inermis Leyss.). In addition the legumes rose clover (Trifolium hirtum All.) and birdsfoot trefoil (Lotus corniculatus L.) were used.

It was found that most of these species secured a good vegetative cover and an increased herbage yield in the burned study sites. Perennials got established and performed better in places with deep soil and less than 25 per cent slope. (Papanastasis 1978, Liacos et al. 1980).

LITERATURE CITED

Liacos, L.; Papanastasis, V.; Tsiouvaras, C. Contribution to the conversion of kermes oak brushlands to grasslands. For. Res. 1(2); 1980. (In Greek).

Papanastasis, V. Potential of certain range species for improvement of burned brushlands in Greece. Proc. 1st Int. Rangeland Congress;1978 :715-717.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Factors Affecting Germination of Southern California Oaks[1]

Timothy R. Plumb[2]

Successful propagation of California oaks (Quercus spp.) requires that factors controlling germination be identified. To accomplish this, several laboratory and greenhouse studies were run to determine (1) how close to acorn maturity (here considered to be the time of acorn drop) viable acorns can be harvested, (2) the effect of cold treatment (stratification) and removing the acorn shell (pericarp) on viability, and (3) the effect of moisture content on long-term acorn storage.

DATE OF COLLECTION AND ACORN TREATMENT

The acorns of southern California oaks, depending on species, ripen between September and November. Ripening time varies from year to year depending on growing conditions and elevation. Early trials indicated germination is hastened by removing the tip of the acorn pericarp. A later test using Quercus dumosa Nutt. acorns showed that (1) viable acorns could be picked at least 1½ to 2 months before normal drop, (2) the tip of the pericarp needed to be removed from immature acorns to obtain satisfactory germination, and (3) when the acorns were mature, pericarp removal was unnecessary (table 1).

Between July 14 and October 19, 1978, I ran another collection test using Q. kelloggii Newb., Q. chrysolepis Liebm., and Q. wislizenii A. DC. acorns. Acorn moisture content (fresh weight basis) declined from a July 14 high of 70 to 80 percent, to 40 percent on the last collection date of each species. At planting, detipped acorns were placed in moist vermiculite in plastic bags at a temperature of about 24° C. When stratified, viable acorns could be picked as early as July 27 for Q. kelloggii and August 10 for Q. chrysolepis and Q. wislizenii; unstratified acorns did not germinate unless collected 2 to 4 weeks later.

ACORN STORAGE

Early picked Q. dumosa acorns were stored in plastic bags at 4° C for 6 to 12 months with limited success. Most of the acorns germinated within 1 to 2 months but produced an unacceptable mass of twisted, moldy roots, shoots, and acorns.

I ran tests to determine the effect of air drying on the viability of immediately planted and stored acorns. In one test, acorns harvested in early September were dried to different percentages of their initial fresh weight (IFW) ranging from no drying (100 percent) down to 40 percent of IFW in 10 percent increments. Acorns from each moisture class were sown immediately or placed in cold storage and removed at 2-month intervals for sowing. No acorns dried to 40 percent IFW germinated, but those dried to 50 percent IFW germinated when sown immediately (acorns in this moisture class were not stored). No acorns dried to 60 percent IFW germinated during storage and 90 percent germination was obtained after 8 months of storage. Most acorns dried to 80 percent had germinated in cold storage within 6 months, while 84 percent of the undried acorns had germinated within 2 months.

Table 1--Germination of intact and partially shelled acorns harvested at different dates

Acorn treatment	Germination, by harvest date				
	8/17	8/31	19/14	9/28	10/12
	Percent				
Intact acorns	15	4	0	20	90
Tips removed	50	89	86	100	95

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Plant Physiologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Control of California Scrub Oak with Soil-Applied Chemicals[1]

T. R. Plumb and J. R. Goodin[2]

In two tests, pelleted, soil-applied herbicides were used to prevent sprouting of California scrub oak (Quercus dumosa Nutt.).[3] A trial broadcast application of 12 lb active ingredient (a.i.) of picloram (4-amino-3,5,6-trichloropicolinic acid) pellets per acre prevented sprouting of scrub oak stumps. Further tests were designed to confirm these results and to determine minimum effective rates of picloram and other pelleted herbicides such as fenuron (1,1-dimethyl-3-phenylurea) and karbutilate [tert-butylcarbamic acid ester with 3-(m-hydroxyphenyl)-1,1-dimethylurea].

In the first test, three rates of fenuron, picloram, and karbutilate (high and low rates are listed in table 1) were broadcast applied in December 1968 to a total of twenty-seven 40- by 40-ft plots. Herbicide effect was monitored on 20 oak plants in each plot. The area had been burned in a wildfire in 1967. At the time of treatment, oak regrowth was 1 to 3 ft tall and occasional grass and other herbaceous plants were present.

Results 3 years after treatment (table 1) show that an average plant kill of 70 percent or greater was obtained with per acre rates of fenuron at 30 lb (a.i.), picloram at 8 and 12 lb, and karbutilate at 8, 16, and 24 lb. Oak response to picloram was considerably more rapid than it was to fenuron and karbutilate, and 25 to 50 percent of the plants were dead within 8 months of treatment, compared to only 0 to 2 percent kill for the other herbicides. Rate of plant kill was also directly related to the amount of herbicide applied, with most kill occurring within 24 months at the high rates. At the low rates, more than 50 percent of the kill occurred between 24 and 36 months.

There were obvious differences among herbicide effects on herbaceous vegetation 1 year after treatment. A dense stand of grass had been established on the picloram plots, while the karbutilate plots were bare. Fenuron did not noticeably affect grass establishment at the low rate but inhibited it at the higher rates. A dense grass cover was present on all plots within three growing seasons, with the exception of those that received the high rate of karbutilate; those were still bare. After 5½ years, there was a dense cover of grass on all plots; after 7 years, there was a stable grass cover with no invasion of woody plants where initial shrub control had been obtained.

The complete soil sterilization resulting from broadcast application of karbutilate was undesirable. A second test was run on an adjacent site in April 1969 to determine the amount of oak control obtained with karbutilate applied at 8 and 16 lb a.i. per acre in a 2½- and 5-ft grid pattern. Good oak control was obtained with both rates in the 2½-ft pattern and with 16 lb at 5 ft. Karbutilate did not prevent grass establishment throughout the major portion of the plots. However, the treated spots themselves were still bare 7 years later with a few grass plants beginning to invade the "8-pound" spots.

Table 1--Response of sprouting scrub oak trees to soil-applied herbicides and subsequent grass production

Herbicide	a.i.[1] per acre	Dead plants 24 months	Dead plants 36 months	Grass weight at 30 months
	Lb/acre	Percent		Lb/acre
Fenuron	10	9	22	350
	30	57	82	800
Picloram	4	18	44	1090
	12	73	78	740
Karbutilate	8	35	71	1060
	24	98	100	0

[1]a.i. = active ingredient.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Plant Physiologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Riverside, Calif.; and Associate Professor of Biology, Texas Tech University, Lubbock, Tex.

[3]This summary reports on herbicide research; it does not recommend their use or imply that these uses are registered.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Range Experimental Dynamics, Management and Hydrology in "Garrigue" of *Quercus coccifera* L. (S.-France)[1]

P. Poissonet, J. Poissonet, M. Thiault, and S. Rambal[2]

The "garrigue" of Quercus coccifera is a dense shrubby evergreen vegetation; under humid and sub-humid mediterranean climate, generally situated on limestone areas. It is used for extensive pasture (about half a sheep per ha) or abandoned, 97 % of the total aerial weight is composed of shrubs and the rest (3 %) of herbaceous vegetation. From time to time, it is burnt, but, consequently, little by little, this practice diminishes the fertility.

OUR RESEARCHES

Their aims are to open the vegetation, to favour herbaceous species and to increase the number of sheep per ha. So, two experimental phases have been taking place from 1969 till now.

First experimental phase

The hypotheses are the following: first, to break up aerial vegetation allows us to open the shrubland, and then fertilization and cutting allow us to keep the vegetation open, to decrease the percentage of shrubs, and thus to increase that of the herbaceous species. So, the aerial material was broken up in 1969. The area was divided in 63 plots (10 x 5 m each). Two factors were tested at three levels:3 dates of successive cuttings and 3 levels of fertilization (0, 100 and 200 kg of N, P,05 and K20 per ha, per year), according to a factorial design, from 1,69 till 1976.

The main results are:

. Breaking up and cuttings allow to open vegetation

. From 1970 till 1976, the not-fertilized plots give 500 kg DM per ha per year, on an average, the moderately fertilized ones 2,400 kg, the highly fertilized ones 3,000 kg.

. At the end of the experiment, the ratio $\frac{\text{herbaceous dry weight}}{\text{total dry weight}}$ reaches 50 % in the not-fertilized plots, 90 % in the moderately fertilized ones and 95 % in the highly fertilized ones.

. The maximum number of sheep (from calculations) is 2 per ha in the not-fertilized plots and 3,5 in the fertilized ones.

. In all cases, the quality and quantity of vegetation are better for sheep than the ones after burning.

. The leguminosae are never numerous.

In conclusion, breaking up, cuttings and fertilizations are interesting processes to open the "garrigue" and to increase the livestock, but it is necessary to try these processes with flock on large plots, replacing cutting by grazing.

Second experimental phase

The hypotheses concern the second part of the above conclusions plus differences about the hydrological system between the natural garrigue and the experimental garrigue.

In 1974, after breaking up aerial material, 12 hectares were subdivided in 4 plots for rotating a flock - 3 sheep/ha-, with the moderate level of fertilizing. Moreover, twelve access tubes for neutron moisture gauge were set up, with a self-propelled wagon drill, beyond the root range (five meters for the deep-rooted evergreen species like kermes scrub-oak):4 access tubes in the natural garrigue and 8 in the experimental garrigue.

In 1976, another similar experiment began, with 5 sheep/ha.

The results are:

. It is necessary to break up aerial shrubs every three years if there are 3 sheep/ha, every four years if there are 5 sheep/ha.

. The increase of the pastoral value is slower but lasts longer with sheep than with cuttings. It reaches 7 sheep per ha, after five years of experiment.

. The quantity of bare ground is decreasing and the one of herbaceous species is highly increasing, specially Arrhenatherum elatius (L.) Mert. et K., but almost no leguminosae.

. During the vegetative period, the total actual evapotranspiration is 10 % higher in the natural garrigue than in the experimental one. So, the increase of hydrogeological resources (i. e. deep percolation beyond the root zone) is not negligible in the experimental garrigue: from $6.1 \times 10^3\ m^3/Km^2$ to $113.5 \times 10^3\ m^3/Km^2$ during the experiment years.

In conclusion, the experimental garrigue feeds 5/sheep/ha against half a sheep/ha in the natural garrigue and the water balance is comparatively excedentary. However, 5 sheep/ha are not able to perfectly control the shrubs, and the leguminosae are not numerous.

GENERAL DISCUSSIONS

. Is the excedentary water balance to be employed to produce more herbaceous food? If the answer is positive, how is it possible?

. How to perfectly control shrubs by means of animals ? To increase the instantaneous livestock by an obligatory shrub-browsing after grass-browsing, by trampling and by litter? To use another type of animals or several ones (goats, cows, horses)?

. Are the leguminosae going on increasing, little by little? What is the manner to favour their increase: seeds, oligo-elements or general increase of fertility ?

---

[1]-Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California

[2]-Researchers, Centre d'Etude Phytosociologiques et Ecologiques Louis Emberger, B.P. 5051 34033 - Montpellier - Cedex - FRANCE

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Effects of Sulfur Dioxide Pollution on California Coastal Sage Scrub[1]

Kris P. Preston[2]

The effects of sulfur dioxide emissions (up to 0.13ppm for 25 yr) from an oil refinery were studied near Santa Maria, on the rural central coast of California. Injury to individual shrubs of Salvia mellifera and changes in community structure and foliar composition were measured at varying distances downwind from the refinery. A Gaussian plume rise model and soil pH indicated that maximum $S0_2$ ground level concentrations (GLCs) occurred between 1300 and 1600 meters downwind of the refinery stacks.

Polynomial regressions were used to plot changes in community and damage parameters with increasing distance from the pollution source. Figure 1A illustrates the changes in species diversity along the $S0_2$ gradient. The curve for species richness (R^2=.80, P <.001) peaks where maximum $S0_2$ GLCs occur. In contrast, the curve for Simpson's index (R^2=.77, P< .001) reaches its lowest value in this area. Polynomial curves for percent perennial cover (R^2=.82, P< .001), percent annual cover (R^2=.83, P < .001), and percent cover of exotic species (R^2=.86, P <.001) are given in figure 1C. Perennial species, for the most part, showed a decline in percent foliar cover in the area where maximum $S0_2$ GLCs occurred. However, annual and exotic species cover peaked in this part of the gradient. Three types of response curves were discerned for the 21 most abundant species (figure 1B). Tolerant species (curve A) reached their maximum foliar cover where $S0_2$ GLCs were highest. These included Chorizanthe california (R^2=.64, P < .0l) and Bromus rubens (R^2=.78, P <.001). Species whose foliar cover values were maximum at further distances from the pollution source were classified as sensitive (curve C). Among these were Haplopappus ericoides (R^2=.73, P <.001), Artemisia californica 4R^2=.76, P < .001), and Salvia mellifera (R^2 =.76, P <-001). Intermediately tolerant species, such as Lotus scoparius (R^2=.37, P <.05) and Horkelia cuneata (R^2=.80, P 4.001) were most highly correlated with curve B.

Damage resulting from chronic $S0_2$ stress to Salvia mellifera, a coastal sage dominant, was also extensively studied. Stomatal resistance was found to be significantly lower on the polluted sites with a concomitant 35 percent increase in the mean transpiration rates of Salvia compared to the pollution-free control sites. Plant height, internodal length, leaf size and frequency, and reproductive capacity as measured by the number of flower whorls per flower spike, were also found to be significantly reduced on the polluted sites when compared to the control sites (P=.01). Reductions in photosynthetically active tissue, reproductive capacity, and increases in transpiration rates accounted for 68 percent of the variation in the foliar cover of Salvia along the $S0_2$ gradient. The evidence indicates that these factors decreased the shrubs' ability to compete with the more r-selected annuals. As such, the annuals gained a competitive advantage over perennials and greatly increased their relative abundance in the most polluted sites. The $S0_2$-stressed coastal sage community consequently retrogressed to where it floristically and structurally resembled an early post-fire seral stage.

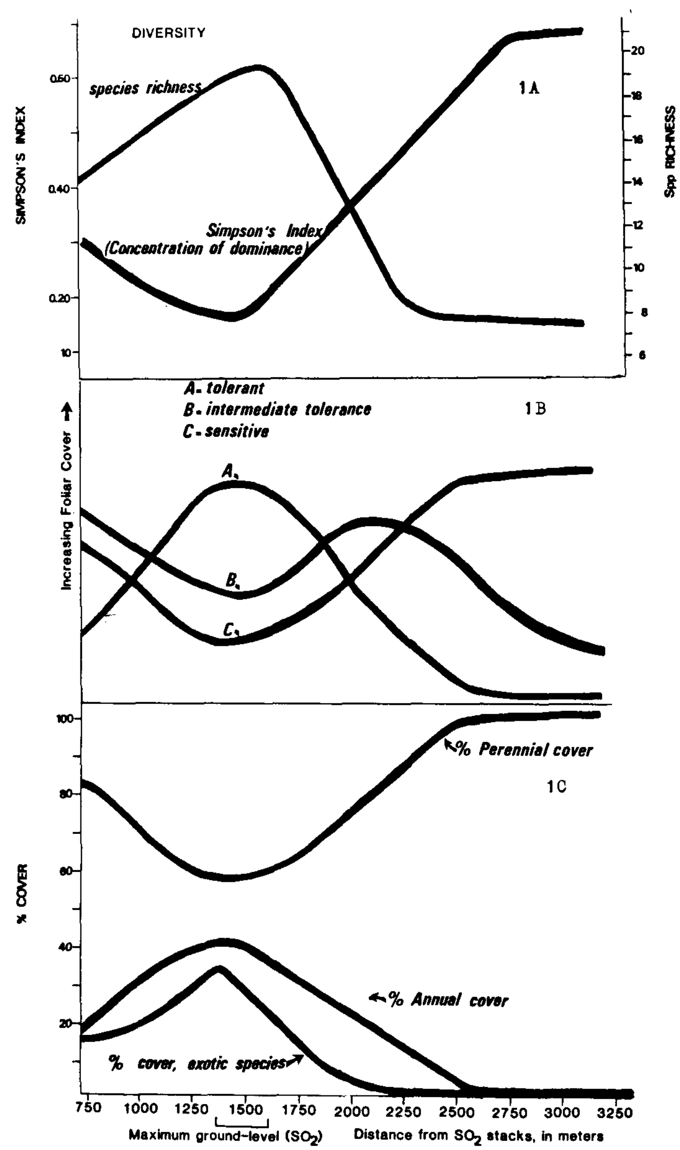


Figure 1A,B,C. Polynomial curves fit by the least squares method.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Graduate student, Dept. of Geography, University of California, Los Angeles, California 90024 USA

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

A Method for Determining When to Implement a Technology[1]

Carol Rice, Gary Elsner, Ed Thor, and Carl Wilson[2]

This paper presents a procedure that can be used by fire managers to help decide whether to implement new firefighting technologies. A two-step method is used. The first step identifies whether the agencies in an area consider the system useful and desirable in terms of fulfilling their needs. The second step identifies the benefits and implementation costs, thus providing an economic basis for the decision whether to adopt the technologies. The procedure uses local conditions (local costs fuels, weather and resource values) whenever possible. The benefits and costs are determined by a change in resource values due to implementation, a change in costs, and other "spin-off" effects.

In the past, fire management decisions could be made primarily on a biological basis. However, new fire suppression policies mandating cost effectiveness makes economic evaluation essential. The two models presented outline a procedure by which this evaluation can be made.

The two models presented support a new USDA Forest Service project, FIRETIP (Firefighting Technologies Implementation Project). The project's objectives are to provide information about modern firefighting technologies; to assist other federal agencies and states in analyzing costs and benefits of implementation; developing work plans for implementation; and developing proficiency in the technologies.

The six technologies to be transferred in the FIRETIP project are products of FIRESCOPE (Firefighting Resources of Southern California Organized for Potential Emergencies). The specific technologies are

(1) A Decision-Making Process that provides a vehicle for many agencies to implement the technologies in a practical manner. The Decision-Making Process furnishes a structure and method for agencies to cooperate to an extent never before realized and still maintain complete autonomy and identity.
(2) A Multi-Agency Coordinating System, (MACS), by which collective regional decisions on emergency priorities and firefighting resource allocations are made. It is a central point for collecting, screening, and processing essential data, coordinating public information and training programs. The system also provides pre-planning assistance.
(3) and (4) A Situation Status Summary Reporting System (SITSTAT) and a Resource Status Reporting System (RESTIT) that summarize "what's happening" in the region for allocating firefighting resources. SITSTAT deals with the numbers and types of emergencies; RESTAT indicates where equipment and personnel might be obtained to handle those emergencies.
(5) A Fire Modeling System (FIREMOD), that provides accurate fire behavior predictions. The program supplies an initial assessment of fire potential. In addition, FIREMOD can act as a second opinion to supplement judgment and observation.
(6) An Ortho Photomapping System, that provides a standardized set of maps and orthophotos tailor-made to meet emergency response needs.

DESCRIPTION OF MODELS

The feasibility model aids the user in determining which fire-prone areas are likely to want to use these new technologies. First, the fire damage potential of the area is assessed. There fire damage potential is high, the benefits accrued from applying a new technology may also be great.

The technology transfer specialist then made contact, introduces the technology, and if there is interest, obtains pertinent background information on the physical area and agencies involved. This step is needed so that applications of the technologies can be designed to meet real needs and abilities to change.

Next, the specialist will visit the area to conduct a feasibility analysis, assuring all the appropriate personnel from agencies to be involved are included. Key individuals are polled to determine their feelings about the applicability of the technologies. Descrip-

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, California.

[2]Proprietor, Wildland Resource Mgt., Walnut Creek, Calif.; President and Chairman, Resource Perspectives Inc., Lafayette, Calif.; Forest Fire Consultant, Berkeley, Calif.

tions of the technologies are included in the guide. Topics to discuss are offered that could bring out opinions as to the system's applicability. Finally, guides are given for interpreting expected responses.

At this point the technology transfer specialist makes a feasibility recommendation. The recommendation will be based on whether the local needs are filled by the technologies and whether any obstacles to implementation exist. The recommentation will be presented to each of the agencies, where feedback is incorporated into the final decision.

If local adoption of a technology is judged feasible, the second step of the procedure, a benefit/cost analysis, is conducted. A guidebook provides complete step-by-step instructions and worksheets for completing the analysis. Designed for completion by a non-economist, this step does require some knowledge of resource values and firefighting costs in the area.

Resource categories are delineated in the area. Categories might be "brush and scattered residential", or "timber along primary corridors". The participants then develop data on total number of fires per year by size for each resource category.

Future trends are then developed from the historical data and knowledge of local trends. For example, more fires of each size category may be expected in "brush and scattered residential" because acres and risk in that resource category will have increased.

The participants are asked to combine the documented benefits of the new technologies (decreased response times, more appropriate equipment available, etc.) with their knowledge of their own area to determine average effects on fire size. Differences in fuel types, access, weather, and other local conditions are the criteria for this adjustment.

The reduction in burned area is then multiplied by a net resource value change per acre and also used to determine a change in total suppression costs.

Costs and organizational cost savings of the implementation of the new technologies are then estimated. Costs of implementation in the area of original development are provided, and participants are then asked to consider local conditions (salary levels, existing equipment, etc.) to calculate local implementation costs for each technology. All the various changes in costs and benefits are then combined to determine whether adoption of the technology would be justified economically.

This two-step process assures that technologies considered for an area are needed, feasible, and cost effective. It avoids conducting detailed analyses in those situations where the technology is not appropriate, and yet provides the economic information needed prior to deciding to adopt a new technology.

Nitrogen Relations in *a Quercus dumosa* Chaparral Community[1]

Philip J. Riggan and Ernest Lopez[2]

The balance and availability of nitrogen in a chaparral community may be strongly affected by management practices. Accelerated nitrogen loss or reduced nitrogen fixation could lead to long-term degradation of the chaparral and its watershed values. Yet little is known about the rate of primary production or nitrogen cycling properties of several important chaparral communities. To provide such quantitative data, we have estimated the rates of biomass accumulation, nitrogen uptake, and fire-associated nitrogen loss in well-stocked stands of Quercus dumosa.

SITE AND METHODS

The research site is located at an elevation of 1340 to 1580 m on an east-facing hill slope at Kitchen Creek in the Cleveland National Forest. The site is dominated by mixed chaparral with a large proportion of Quercus dumosa. It last burned in 1944. Three vertical strips on the hill slope were burned by prescription November 13-14, 1979. Maximum recorded fire temperatures at the litter surface averaged 720° C. Estimates of pre- and postfire biomass in aboveground vegetation were made by evaluating regressions of biomass as a function of shrub basal area with the basal area distributions from each of five 64 m^2 plots. First-year resprout growth was estimated as a function of prefire shrub basal area. Litter mass estimates were made from 26 quadrats of 0.25 m^2 each. Nitrogen determinations were made on modified Kjeldahl digests with a Technicon Autoanalyzer II.

RESULTS

Quercus dumosa stands at this site accumulated biomass at an average annual rate of 0.53 MT ha^{-1} over 35 years. The first-year biomass accumulation rate was 5.3 times greater than this long-term average. Aboveground biomass at this site was moderate; 14 percent of the biomass was accounted for by foliage. Nitrogen accumulated in aboveground vegetation and litter at an average annual rate of 13.4 kg ha^{-1}. The biomass and nitrogen content of the litter were high, respectively 20 and 12 times that found in live foliage.

With the foliage of mature plants retained less than 1½ years, and nitrogen concentrations of 1.15 and 0.6 percent in dormant-season and senescing foliage, the annual nitrogen supply to new foliage from internal redistribution was calculated to be 14.7 kg ha^{-1} and that from uptake and other storage sources was estimated to be 16.0 kg ha^{-l}. Net uptake to foliage the first year after fire is approximately the same (table 1). Mature and resprouting burls lost 23 percent (6.7 kg N ha^{-1}) of their nitrogen content during the growing season from June through October; this may have been an important source of nitrogen for growing tissue.

Prescribed fires at this site produced moderately high soil surface temperatures, yet burning conditions were just severe enough to carry fire in the stand. Fire consumed 60 percent of the aboveground vegetation biomass and 75 percent of the forest floor mass. Fire-associated volatilization losses accounted for 25 percent of the nitrogen in the aboveground vegetation, litter, and upper 10 cm of the soil.

Table 1--Nitrogen and biomass distributions in pre- and postfire Quercus dumosa

	Prefire		Postfire		Fire loss		Resprout growth	
	Biomass	Nitrogen	Biomass	Nitrogen	Biomass	Nitrogen	Biomass	Nitrogen
	MT ha^{-1}	kg ha^{-1}	MT ha^{-1}	kg ha^{-1}	MT ha^{-1}	kg ha^{-1}	MT ha^{-1}	kg ha^{-1}
Aboveground	18.5 ± 1.3	87.6 ± 6.0	7.4 ± 6.0	26.8 ± 2.0	11.1 ± 0.8	60.9 ± 4.5	2.8 ± 0.2	27.3 ± 2.3
Foliage	2.7 ± 0.2	30.7 ± 2.6	0	0	2.7 ± 0.2	30.7 ± 2.6	1.1 ± 0.1	15.4 ± 1.4
Burl	13.3 ± 0.9	28 ± 1.8						
Litter	53 ± 7	382 ± 68	14 ± 1.4	65 ± 7	39	317		
Soil (0-10 cm)		1586		1448		138		
Total (less burl)		2056		1540		516		27

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Soil Scientist and Ecologist, respectively, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Glendora, Calif.

Transpiration and Diffusion Resistance of Leaves of *Quercus ilex* L. at La Castanya (Montseny, Catalunya, NE Spain)[1]

R. Save, R. Rabella, E. Gascon, and J. Terradas[2]

We have followed the transpiratory behaviour of the evergreen-oak Q. ilex one day each week from february 1980 to april 1981 in an experimental plot at Montseny (41°46'N, 2°24'E; altitude, 660m; exposition, W). We measured transpiration (TR) by quick weighing method (Huber, 1927; Stocker, 1956) and diffusion resistance (Rd) with Lambda L1-56 autoporometer.

The 1980 TR values (in g H_2O g dry weight^{-1} min^{-1}) satisfied a linear trivalent correlation with temperature and relative, humidity (Rh) according to $TR = 0052 - 0,023\ Rh + 0,42\ T$, with $r = 0,976$. The T observed values are comprised between 7 and 30°C and the Rh values between 45 and 100%.

TR and Rd show similar highly correlated behaviour with a TR midday reduction and Rd similar increment, as a result of stomatal closure. At high canopy levels, average daily TR is a little smaller than at lower levels, but confidence intervals overlap. We can explain this by xerophytic regulation and reduced cuticular transpiration in accordance also with Berger (1977) results. Stomata are closed in average behind a 16.5% water saturation deficit and cuticular TR is nearly 7% of total TR by an atmospheric evaporation of 1.1 mm/h.

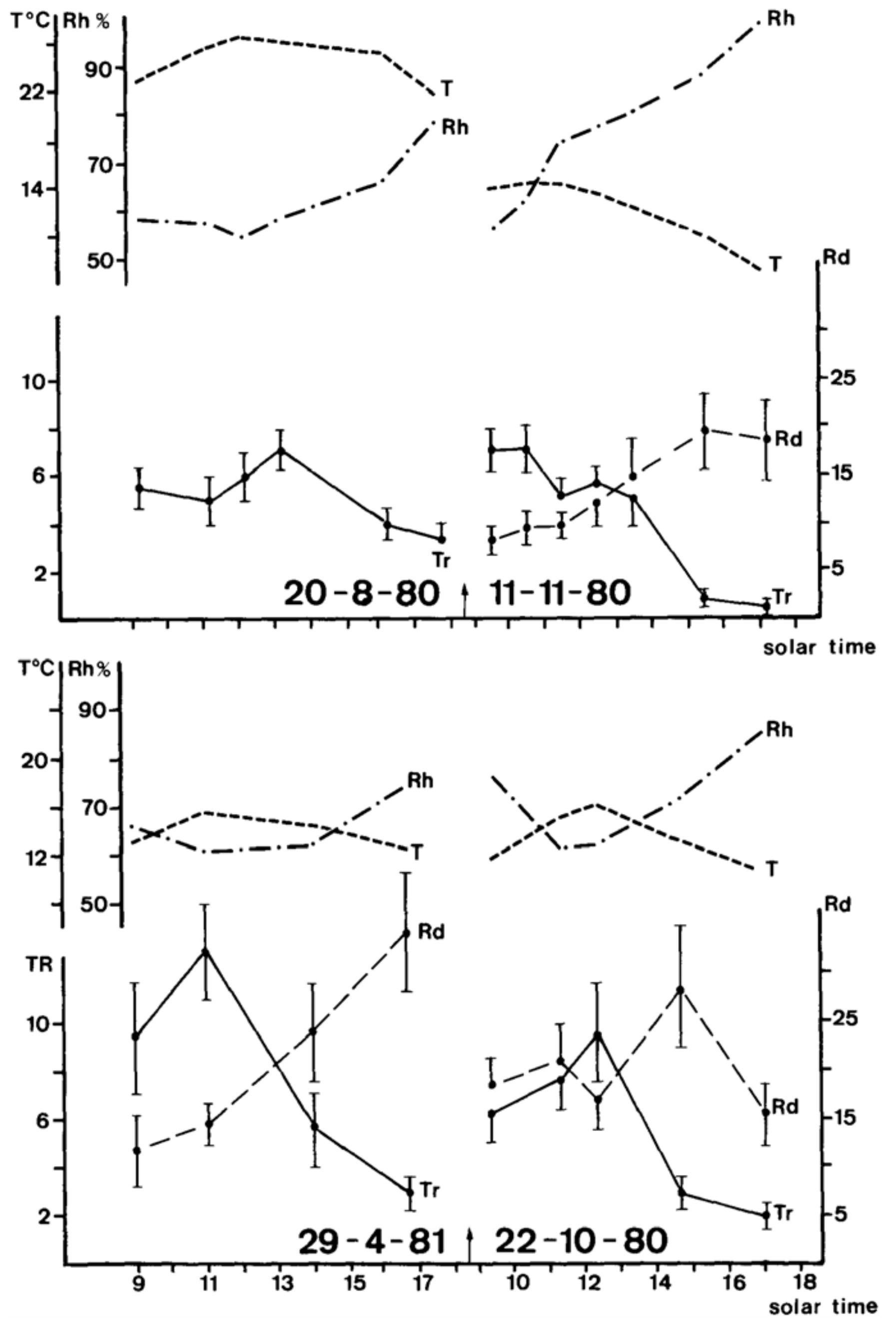
LITERATURE CITED

Berger, A. Régime hydrique. In: Moyse, A. Les processus de la production végétale primaire. Paris: Bordas 1977.

Larcher, W. Transpiration and photosynthesis of detached leaves and shoots of Quercus pubescens and Quercus ilex during desiccation under standard conditions. Bull. Res. Counc. of Israel 8D, 1960.

Larcher, W. Ecofisiología vegetal. Barcelona: Omega 1977.

Slavík, B. Water Exchange between Plant Roots and Soil. In Methods of Studying Plant Water Relations 253-257p. Berlin: Springer Verlag 1974.



Daily evolution of TR, Rd, T and Rh for some typical days at La Castanya. See text for symbols.

[1] Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2] The first three authors are collaborators; last author is Associate Professor of Ecology at the Universitat Autonoma de Barcelona, Bellaterra, Spain.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Approach to Public Involvement for Greenbelts[1]

Jean M. Schwabe[2]

The Challenge

Throughout the United States, development is spreading into the wildland areas. Often the only remaining lands are the steep hillsides adjacent to metropolitan areas. In chaparral ecosystems, this creates an extreme fire hazard for human lives, property, and natural resources.

Many development features, such as landscaping, access, building materials, and greenbelts[3], can be used to provide more fire-safe communities while permitting growth in the foothills.

The Angeles is surrounded by the Los Angeles metropolitan area. Population growth puts pressure on local government to allow development on the chaparral-covered hillsides. It is unrealistic in our area to expect growth to stop. Communities can plan for safer hillside areas by incorporating greenbelts, and other fire-resistant development features, into General Plans and zoning ordinances.

Public Involvement

It is important to inform and involve the public and local governments about fire hazards and greenbelt zoning. We have developed several visual displays on greenbelt planning which can be effective with citizens and professionals.

We first wrote an informational brochure about greenbelts and developed a slide tape. A contractor mapped a twenty-mile strip of the Tujunga Ranger District to show land suitable for a greenbelt zone.

A two-mile section of this greenbelt zone was developed into a three-dimensional scale model. The model shows the interface area of a portion of the San Gabriels and portrays many uses of a greenbelt, including parks, cemeteries, nurseries, appropriately designed subdivisions, equestrian trails and orchards (fig. 1).

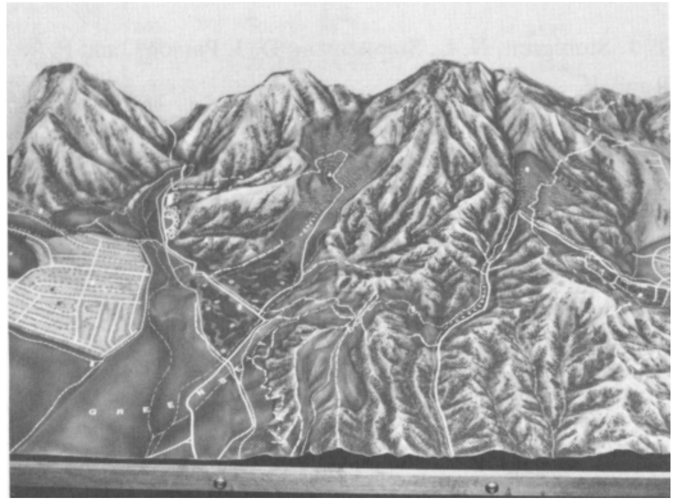


Figure 1--Greenbelt Model

Then, our landscape architecture department designed a display of a fire-safe Conceptual Subdivision. The board is approximately 3 feet by 4 feet, done in pastels on a photographic print. It can be used with planning departments and the public. Greenbelts buffer the periphery of the subdivision, making the homes more fire safe. A variety of uses is shown on the greenbelt. It is unlikely that a subdivision would have so many amenities, but we wanted to show the many options available to homeowners and builders. Gardens, softball fields, orchards, equestrian facilities, maintained open space and tennis and pool facilities are shown. We designed the subdivision to have more density than the zoning originally specified, because of the fire-safe design of the homes, landscaping, and surrounding greenbelts. Municipalities can award more density to developers if fire-safe features are proposed, much like density bonus incentives are given to developers for low income housing.

Focus of Public Involvement Activities

In working with local government, we emphasize the flexibility of greenbelt planning. Planning commissions are encouraged to develop fire-safe greenbelt areas which meet the community's need -- be it for recreation, housing or agriculture. Communities are encouraged to be flexible in developing zoning and economic incentives for greenbelt areas.

It is difficult to implement greenbelt zoning when development pressures and land values are extremely high. Communities now beginning to experience growth in the chaparral covered foothills need to plan for interface areas soon, or the opportunity will be lost. Coordinated planning by agencies and local government, with effective public information programs, needs to be emphasized

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22--26, 1981, San Diego, Calif.

[2]Community Planner, Angeles National Forest, Forest Service, U. S. Department of Agriculture, Pasadena, Calif.

[3]Bands of land on private or public property, at least 300 feet wide, which serve as a fire-resistant buffer zone between the wildlands and adjacent urban development.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Using Stem Basal Area to Determine Biomass and Stand Structure in Chamise Chaparra[1]

T. J. Stohlgren, N. L. Stephenson, D. J. Parsons, and P. W. Rundel[2]

Assessment of structural characteristics of chaparral is important in predicting fire effects and planning prescribed burns. Chamise (Adenostoma fasciculatum), the most common constituent of California chaparral, has been analyzed for twig and branch size class distribution, fuel loading and density, and chemical composition (Countryman and Philpot 1970). In San Diego County, Wakimoto (1978) used volume measurements to estimate shrub biomass. However, when we applied this method to chamise in the southern Sierra Nevada, we found the correlation to be inadequate due to assymetrical shrub growth forms. We then investigated a simple non-destructive technique of using basal stem diameters and basal stem area to predict above-ground shrub biomass (Brown 1976).

We randomly selected a $64m^2$ plot of mature chamise (over 60 years old with 110 percent ground cover) in the foothills of Sequoia National Park. The diameter of all basal stems at 30 cm above ground was measured for each shrub and converted to total stem basal area. Percent dead was estimated to the nearest five percent and each shrub was then cut above the burl and weighed to the nearest 0.1 kg. Basal stem diameters and wet weights of 11 additional randomly selected mature chamise shrubs found in other areas of the Park were also measured to increase our sample size. Subsamples of live and dead material were oven dried to constant weight to derive correction factors for converting wet to dry weights. A standard linear regression was used to correlate stem basal area, stem diameter, and shrub volume with biomass on a dry weight basis.

For the 39 shrubs sampled in our study plot a correlation of $r^2 = 0.93$ was found between stem basal area and dry weight (fig. 1). The correlation between stem diameter and dry weight was weaker ($r^2 = 0.82$). The 11 additional shrubs used to increase the sample size improved the stem basal correlation ($r^2 = 0.94$). This improved the regression equation from $y = 0.18x + 0.11$ (fig. 1) to $y = 0.18x + 0.06$ to adequately predict shrub biomass (y, in kg) from stem basal area (x, in cm^2).

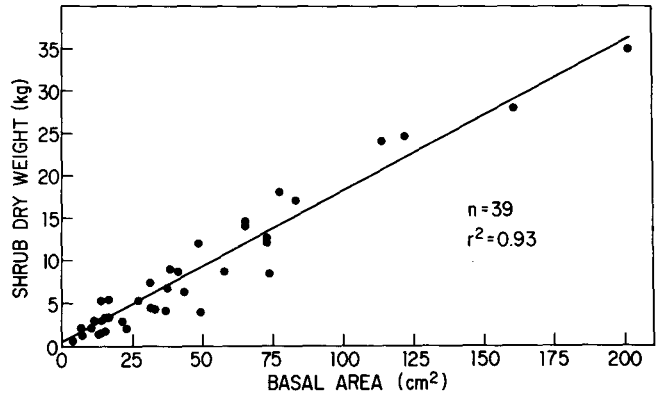


Figure 1--Relationship between basal area and shrub dry weight.

Chamise stand characteristics that can be estimated using our stem basal area method include densities, biomass per ha, and a stand structure profile of the number of individuals by dry weight class. For example, from our original study plot we estimate 6,100 shrubs per ha and 52,000 kg/ha dry weight biomass. We found an inverse-J shaped distribution of shrubs by size class with a few dominant shrubs and larger numbers of smaller shrubs, similar to the findings of Schlesinger and Gill (1978) for Ceanothus megacarpus.

While the validity of our correlation for chamise shrubs in other areas, as well as for other shrub species, has yet to be tested, the method has the potential to be a valuable tool for chaparral fire research and management. We intend to pursue this approach in additional studies of stand structure as a function of environmental variables, including past fire frequency.

LITERATURE CITED

Brown, J. K. Estimating shrub biomass from stem basal diameters. Can. J. For. Res. 1976; 6(2):153-158.

Countryman, C. M.; Philpot C. W. Physical characteristics of chamise as a wildland fuel. USDA Forest Service Res. Paper PSW-66; 1970. 16 p.

Schlesinger, W. H.; Gill, D. S. Demographic studies of the chaparral shrub, Ceanothus megacarpus in the Santa Ynez mountains, California. Ecology; 1978. 59(6):1256-1263.

Wakimoto, R. H. Responses of southern California brushland vegetation to fuel manipulation. Ph.D dissertation, Univ. of Calif. Berkeley, Ca.; 1978. 238 p.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Research Technicians and Research Scientist, respectively, National Park Service, U.S. Department of Interior, Three Rivers, Calif.; Professor of Ecology, University of California, Irvine, Calif.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Microcommunity Patterns in Coastal Sage Scrub[1]

Arnold R. Troeger[2]

Microcommunity pattern refers to the arrangement of coassociated species in the landscape at scales ranging from a fraction of a meter to several meters. This poster presents the results of a study on the microcommunity patterns of California coastal sage. The microcommunity pattern study is one aspect of a larger study to assess the diversity and pattern relationships of coastal sage and to compare these results to similar communities elsewhere in the world.

The microcommunity pattern index (Table 1) measures the intermingling of species groups through space and was measured as follows: First, species groups were identified by classifying the individual 1 X 1 quadrats in a 20 meter long belt transect into 8 groups using Twinspan (a polythetic divisive classification program). Next, the floristic class to which each quadrat belonged was mapped along the belt transect. Thirdly, the number of times adjacent quadrats along the transect belonged to different floristic groups was divided by the maximum possible number of changes (19)(Westman 1975).

Micrommunity pattern was determined on 7 0.1 ha sites of coastal sage scrub of three ages (3, 7, 23-4 y). The microcommunity pattern index did not change significantly with age. There was a significant correlation between age and changes in floristic cover across the site, as measured by the first axis of the Decorana ordination (r=.55, P=.11). This indicates that despite significant changes in floristic composition with age, the scale of microcommunity patterning is not changing.

The "ecological distance" between floristic groups can be measured as the distance between midpoints of occurrence of the groups along an ordination axis. These ecological distances, relativized by ordination axis length, remain constant with age. This indicates that spacing of the floristic groups along the first major ordination axis remains relatively even, despite changes in the beta diversity. The standard deviation in mean ecological distance (s.d.) between floristic groups in site 5 is lower than for other sites, implying a regularity in floristic change among groups on this site. The factor most likely to be operating at this scale is competition. Site 5 is located on a northeast facing slope where environmental conditions are most mesic. Because site 5 had the highest species richness (31 spp./.l ha vs. X=12.3 spp/.l ha for the other 2 mature sites), interspecific competition may be higher, causing a more even spacing of floristic groups along the ordination axis.

Table 1--Summary of the microcommunity pattern statistics.

sites	length of ord. axis	mean distance between row s x	s.d.	mean dist. ord. axis	microcommunity index
3 yrs old					
1	285	40.71	27.41		.526
2	209	22.46	20.56		.842
mean	247	31.58	24.22	.128	.684
7 yrs old					
3	362	46.19	33.85		.526
4	429	51.29	29.14		.737
mean	395	48.74	31.58	.123	.631
> 20 yrs					
5	210	28.35	17.00		.684
6	206	29.43	23.64		.737
7	216	21.00	23.47		.474
mean	210	26.26	21.59	.125	.632

The average alpha diversity at 1 m^2 (Figure 1) decreases with age. At 3 yrs. individual plants tend to be small and post-fire species tend to be abundant, allowing for a high number of species at the 1 m^2 scale. A few long-lived post-fire species are still present at 7 yrs. but most of the annuals have been eliminated, contributing to a decrease in alpha diversity.

Beta diversity measures the species turnover along an environmental gradient and is usually expressed as half changes (B.C.) in species composition. Beta diversity reaches a peak at around 7 yrs., strongly suggesting a higher floristic heterogeneity between patches at the 1 m^2 scale at this age. One explanation for this may be the spatial segregation of post-fire followers from mature phase dominants at this time.

LITERATURE CITED

Westman, W. E.; Pattern and diversity in swamp and dune vegetation, North Stradbroke Island. Aust. J. Bot. 23:339-345; 1975

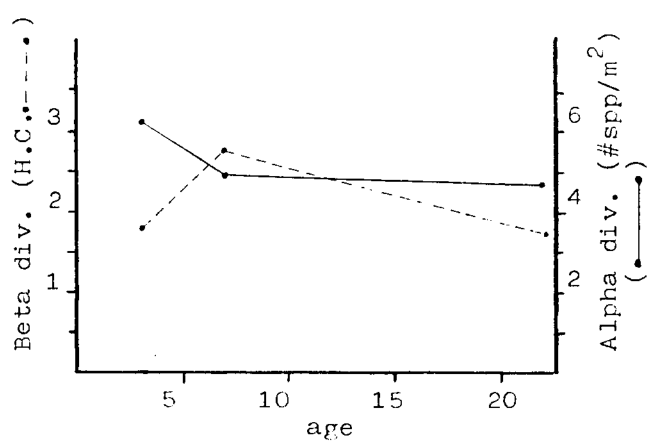


Figure 1--Alpha and Beta diversity vs. age.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Graduate student, Dept. of Geography, University of California, Los Angeles, California 90024 USA

Restoring and Managing Indigenous Plant Communities at Malibu Creek State Park[1]

Wayne Tyson and George Rackelmann[2]

The California Department of Parks and Recreation is exploring new ways to meet the two major, but conflicting goals of the state park system (landscape preservation and recreation) at the lowest possible cost. Indigenous vegetation may have significant economic advantages as well as potential carrying capacities as high or higher than alternatives in some situations. Practical methods are needed to restore, modify and manage indigenous plant communities for an increasing number of applications.

The traditional approach to preserving the natural landscape has been to limit access. Recreation demands access, and the demand has been increasing faster than the supply of park land. When the recreation load exceeds the capacity of the natural landscape to repair itself, the result is increased cost and degradation or loss of the landscape resource.

The usual approach to meeting excessive recreational demand loads has been to replace inigenous plant communities with exotic landscaping, though recent practice has included individual "native" species. This is an expensive procedure to construct and maintain, and it often does little to improve carrying capacity. The perpetual maintenance required intentionally limits species diversity by eliminating all species not on the landscape plan. Significant quantities of water and other resources are required, and the natural landscape resource is destroyed.

At Malibu Creek, the alternative of restoring, modifying (for increased carrying capacity) and managing indigenous plant communities is being explored. The part of the site selected for development of picnic and camping areas has been disturbed for most of this century by grading, plowing, cattle grazing and movie-making (site is a former major studio "movie ranch"). Vegetation in these areas is mostly alien grasses and forbs. Areas which are relatively undisturbed will be preserved for appropriately lower levels of use.

The objective of this project is to (1) increase indigenous plant associations in disturbed areas; (2) lower the cost of development, management and maintenance; (3) accommodate recreation needs within the carrying capacity (increased by modification where necessary) of the restored indigenous plant community. As much as possible, the general goal is to restore the site to as near those which existed prior to disturbance as possible, including reduction of alien species populations.

The restoration of self-sufficient plant communities requires consideration of existing environmental conditions and the development of techniques appropriate to them to be successful. Ordinary gardening and landscaping methods are fundamentally inappropriate. The mere introduction of indigenous seeds or plants will not necessarily produce a viable, self-regenerative plant community--or even a successful stand of the species "selected." The planting program must be carefully timed and designed for a high level of survival. Species composition and density should be carefully determined as to habitat, its changing nature and carrying capacity in terms of soil moisture potential. It may not be advisable to plant all species at one time. Timing and conditions required by the species concerned, rather than administrative convenience, should determine the program, but enough latitude often exists to satisfy practical scheduling concerns. Adjustments are often necessary, but absolute precision isn't necessary. Fairly good mimicry of some of the rather sloppy natural processes involved may be the most we can do. Beyond that, that which is out of our control is in control.

Some field trials were initiated in February of 1981. Plant communities include valley grassland/valley oak savanna, southern oak woodland, coastal sage scrub and chaparral. The main species/associations are *Stipa pulchra*, *Quercus lobata*, *Elymus triticoides*, *Quercus agrifolia*, *Rhamnus californica*, *Artemisia californica* and *Heteromeles arbutifolia*.

Initial emphasis has been placed upon *Stipa pulchra,* since this grass produces a large and reliable seed crop and is suitable for the largest part of the project. Field plots have been established to evaluate the cost-effectiveness of several methods, including seeding by broadcast and drilling on cleared, uncleared and mulched sites as well as the planting of seedlings grown in two different soils and container types on cleared and uncleared sites at various densities. A 300' x 100' plot was planted with seedlings at 1/100 square feet. Trial plantings of other species were made on a smaller scale. The project will be expanded in the fall of 1981 when soil moisture and other conditions are at optimum.

We have gratefully drawn upon the work of many researchers, including W. James Barry, Harold F. Heady, V. L. Holland and R. H. Robinson. Much more such work is needed.

---

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems: An International Symposium, June 22-26, 1981, San Diego, California, U.S.A.

[2]Manager, Regrowth Associates, San Diego, CA and Senior Landscape Architect, California Dep't. of Parks and Recreation, Sacramento, CA 95811.

Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

Integration of Chaparral Vegetation Data Into Land and Fire Management Decisionmaking[1]

Thomas C. White[2]

A management compartment examination procedure is being applied in the field on the Laguna-Morena Demonstration Area (L-MDA). L-MDA is a cooperative interagency program designed to demonstrate both new and existing techniques of chaparral management. Approximately 130,000 acres of land are included in the L-MDA representing many ownerships and management responsibilities.

It is the purpose of this poster to demonstrate how chaparral vegetation and other resource information collected in a compartment inventory can be effectively integrated into land and fire management decision making.

A CONCEPTUAL MODEL OF COMMON VEGETATION ASSOCIATIONS

A classification system was developed by the Pacific Southwest Forest and Range Experiment Station to standardize terminology used to describe chaparral and related vegetation types (Southern California Vegetation Classification System-SCVCS). This common language facilitates technology transfer both within and between agencies. The classification system is hierarchical so that each level of description can be generalized to the next higher level. The four levels defined in order of increasing specificity are formation, series, association and phase. Figure one is a model describing chaparral plant communities in L-MDA at the formation series and association level. This is a conceptual model. The species distributions shown are not rigorously defined.

The model shown in Figure one was successfully used to reclassify the vegetation mapping units of the 1969 Soil-Vegetation Survey into the Southern California Vegetation Classification System.

INTEGRATION OF THE VEGETATION MAPPING SYSTEM INTO THE PLANNING PROCESS

The vegetation mapping system is integrated into the planning process by means of a Resource Capability Unit (RCU). An RCU is a mapping unit describing a relatively homogenous unit of land designed to give land managers easy access to a wide range of site specific data. This information is stored on a computer to allow easy manip-

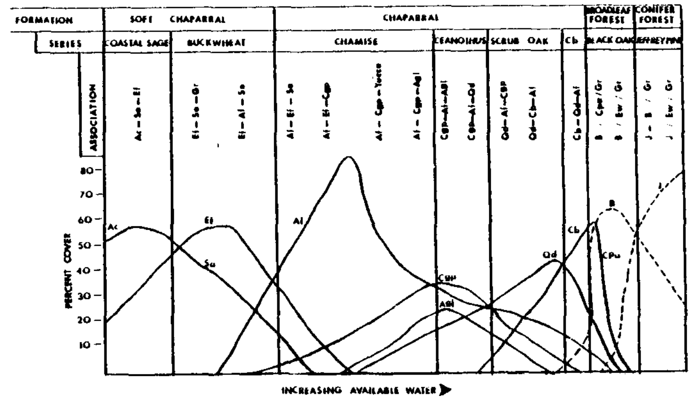


Figure 1--Conceptual Model of Vegetation Associations in Chaparral of Related Formations Laguna-Morena Demonstration Area.

ulation of the data. The RCU also serves as a device to give planners and managers a rapid "feel" for the land by providing a framework for integrating previous field experiences with resource data. Compartment examinations are the preliminary phase of project planning. Existing information is assembled and organized in the compartment exam. Resource Capability Units are delineated and management goals and objectives are identified. (The final output of a compartment exam from management perspective is a package of project proposals). Project proposals are then selected for formal decision making on a priority basis, as determined by the overall program level strategic plan for formal decision making which includes detailed alternative formulation, environmental effect assessment and alternative selection.

CONCLUSIONS

One of the important lessons drawn from experience in L-MDA planning is that lack of resource data is not necessarily the limiting factor for high quality chaparral management. The real limiting factor is ability to integrate existing data into a meaningful information system which is intimately linked to management decisions. The process described above is an example of how integration can be accomplished through comprehensive interdisciplinary examination of existing resource information and management goals.

References

Forest Service, USDA, Cleveland National Forest Managing Chaparral: Management Plan and Environmental Analysis--Laguna-Morena Demonstration Area, San Diego, Calif.; 1979

Forest Service, USDA, Cleveland National Forest. Soil Vegetation Survey Cleveland National Forest, San Diego, Calif.; 1969

Paysen, Timothy E., et. al. A Vegetation Classification System for Southern California. Berkley, Calif., Pacific Southwest Forest and Range Exp. Stn., Forest Service, USDA: draft document 1979.

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-Type Ecosystems, June 22-26, 1981, San Diego, California.

[2]Acting Program Manager, Laguna-Morena Demonstration Area, Forest Service, USDA, Alpine, California, 92001

Conrad, C. Eugene; Oechel, Walter C., technical coordinators.
Proceedings of the symposium on dynamics and management of Mediterranean-type ecosystems, June 22-26, San Diego, California. Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 637 p.

The symposium, held at San Diego State University, provided information about the Mediterranean-type ecosystems found throughout the world. In the papers, and in brief summaries of poster displays, both researchers and managers addressed concerns relating to vegetation, fauna, soils, hydrology, fire, and planning. A Review and Follow-up section presents general comments of selected participants.

Retrieval Terms: Mediterranean climate, chaparral, plant succession, wildlife, soils, hydrology, fire management, biomass