Research for the Fire Management of Western Australian State Forests and Conservation Reserves

by A.M. Gill

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SUMMARY OF RECOMMENDATIONS

1. There needs to be an explicit program and procedure for the development of management plans, including fire-management plans, for conservation reserves and State forests.

2. The aims of management, in general, and of fire management in particular, should be made explicit for each reserve and State forest.

3. Research should be conducted into the most appropriate methods for obtaining reserve inventories appropriate to fire management.

4. In view of the importance of the disease *Phytophthora*, situations where traditional methods of fuel-break construction (involving soil disturbance) may be appropriate need to be determined.

5. The relative fire-control and conservation values of buffers under different forms of management should be investigated. Systematic fire-behaviour research should be conducted on the possibilities of burning no-break patches or buffers.

6. Experiments on the effects of selected fire regimes on conservation values in selected areas using replicated treatments should be conducted. Simultaneously, the consequences of these treatments to fire control should be quantified.

7. Fire-behaviour research should be continued in association with the National Bushfire Research Unit of CSIRO. The CSIRO is attempting to develop fire models suited to the major Australian fuel-types; local work should be consistent.

8. Research should be carried out to assess the potential use and impact of chemical fire retardants on the native flora, particularly that of the Sandplain.

9. The responses of the flora to fires should be systematically recorded on the basis of certain life-history characteristics of individual species. Appropriate bases for the prediction of animal types and numbers from floristic and/or structural data in fire-affected plant communities need to be determined.

10. The concept of 'experimental management' should be evaluated.

11. The most effective monitoring systems for nature conservation, within the context of fire-management for nature reserves, national parks and State forests, should be determined.

12. The use of computer-based fire-management systems (including 'expert systems', data bases, mathematical models and output options) should be investigated for their use in fire management in Western Australia.

INTRODUCTION

The formation of the Department of Conservation and Land Management (CALM) by the State Government of Western Australia through the amalgamation of the Forests Department, parts of the Department of Fisheries and Wildlife and the National Park Service in March 1985 brought some 15 million ha of diverse terrain under the management of the one authority. The major management tool in this diversity of landscapes is fire, a tool with a wide range of forms which can be applied in a multitude of ways. While fire may be a prominent part of the managers tool kit, it is also an important cog in the natural 'machinery' of landscape.

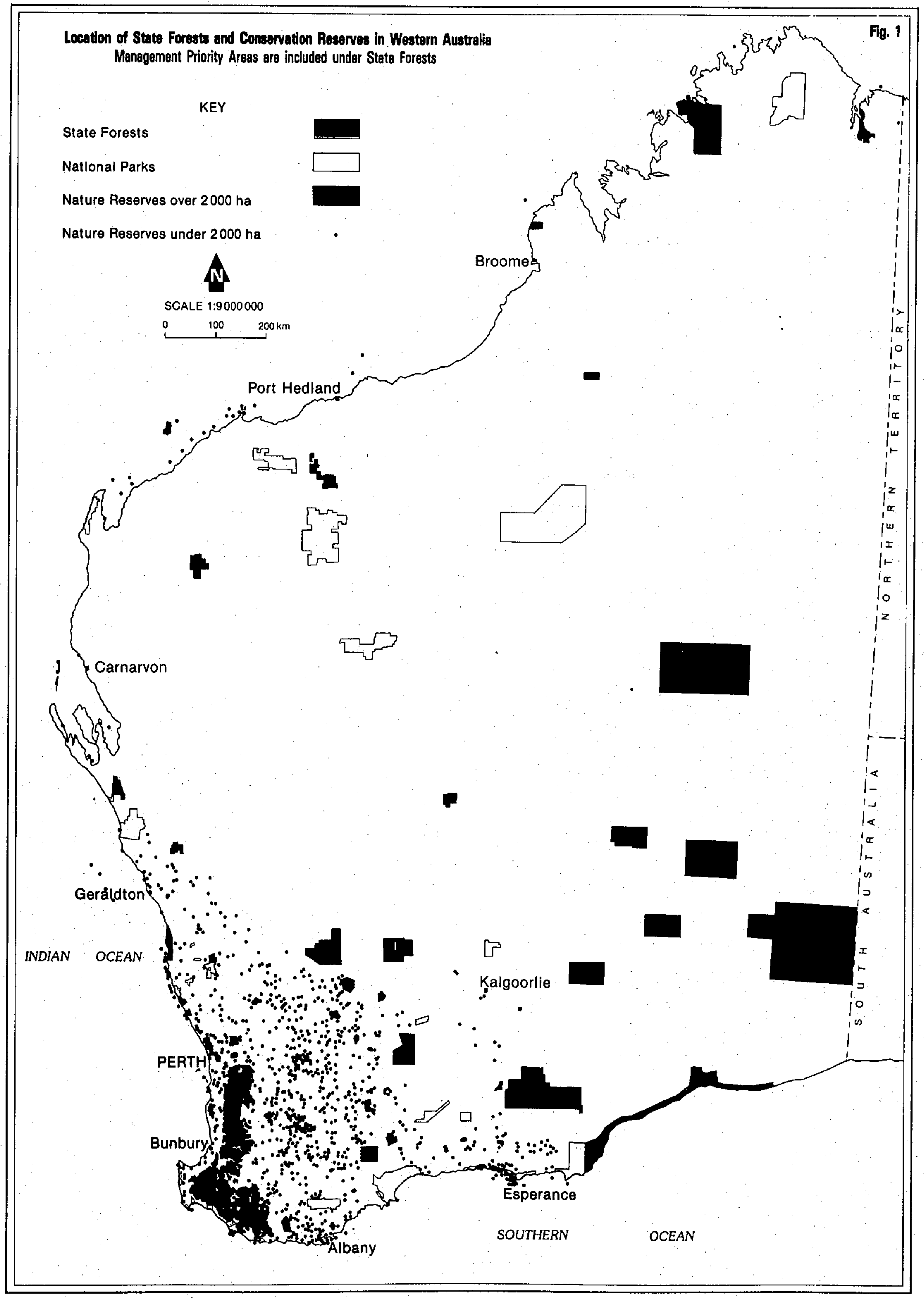
Recognising the importance of fire to conservation and silviculture, the potential threat of fires to life and property in particular areas, and the opportunities for a fresh look at fire research for management brought about by the administrative amalgamation of departments, this review was instigated. Specifically, this review was designed to make recommendations on fire research applicable to the management of lands under the control of Western Australian Department of Conservation and Land Management (C.A.L.M.). Before making any recommendations, it was necessary to understand the nature and extent of the resource under management, the aims of management, and the current use of fire in management. The legal context of land management, simply put, was that life and property were to be protected and that fire-management plans were required appropriate to the general purposes of land use as specified in legislation.

THE RESOURCE

Western Australia is a large and diverse State which extends from the tropical (13° S) to the temperate region (35° S) - a distance of about 2000 km - and spreads east-west up to about 1600 km. Climate varies from mediterranean to monsoonal, and from arid to wet but it was not always thus. The ancient rocks underlying much of the State support remnants and derivatives of 'fossil' soils which developed during a period of ubiquitous wet tropical conditions millions of years ago. With such a long history, it is not surprising that many of the soils of today are low in nutrients. What may be surprising to many, however, is that these 'fossil' soils often support a rich flora that is high in endemics and a fauna that is often distinctive. Today, scattered across this immense and diverse terrain are the lands under the responsibility of C.A.L.M. (Fig. 1).

Western Australia has only a small population concentrated in the southwestern corner, a fact of considerable importance to land management. It implies, in general, that understaffing for management of such a large area may occur (Burbidge and Evans 1976), that the knowledge base is small, that visitation by people is limited, and that active management in many areas is either unnecessary or impracticable. It also implies that there may be many areas of particular conservation value because they have been little altered by European man.

C.A.L.M. reserves fall into two main management categories where the emphasis is on either:



Location of State Forests and Conservation Reserves in Western Australia
Management Priority Areas are included under State Forests
Fig. 1
KEY
State Forests
National Parks
Nature Reserves over 2 000 ha
Nature Reserves under 2 000 ha
N
SCALE 1:9 000 000
0
100
200 km
Broome
Port Hedland
Carnarvon
Geraldton
INDIAN OCEAN
PERTH
Bunbury
Albany
Kalgoorlie
Esperance
SOUTHERN OCEAN
NORTHERN TERRITORY
SOUTH AUSTRALIA

(i) the production of wood products (in southwestern forests); or

(ii) the conservation of the biota.

In practice, multiple use is usual. Areas designated for wood production or conservation may also be used for water supply, honey production and recreation, for example. Areas designated for wood production, especially indigenous forests, may also be used for conservation of the biota. For convenience in this report, areas with an emphasis on the production of wood products will be called 'State forests', and areas with an emphasis on the conservation of the biota will be called 'conservation reserves' or 'reserves'. Thus although areas designated as National Parks have an important recreational component to management, as may some Management Priority Areas[1], both of these types will be considered under 'conservation reserves', below.

State Forests are found exclusively in the southwest of the State. They occupy about 1.6 million hectares of land, excluding MPAs, or 2.0 million hectares including MPAs, and may be described as[2]:

(i) Pine plantations (*Pinus radiata* and *P. pinaster*) in scattered locations within eucalypt forest, or on land previously farmed, and amounting to c. 55 thousand hectares;

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1. Management priority areas (MPA's) of the former Forests Department (cf. Fig. 1).

2. The figures used come from the Annual Report of the former Forests Department for the year to 30 June 1983. They include MPA's because the areas of the particular vegetation types in MPA's was not available.

(ii) Jarrah (*Eucalyptus marginata*) forest which is found in a generally continuous forest divided for convenience into the northern jarrah, the southern jarrah and the Sunklands jarrah, and collectively occupying c. 1.5 million hectares;

(iii) Karri (*Eucalyptus diversicolor*) forest in generally scattered locations in the far southwest high rainfall area, where it occupies about 150 thousand hectares, or 10% of the area of jarrah forest;

(iv) Eucalypt forests and woodlands of poor quality for wood production and found in the more inland, drier areas of the southwest where they occupy c. 250 thousand hectares.

The conservation reserves have an enormous diversity, not only of landscapes (in the broadest sense and therefore including the biota and climate) but also of size, land-use context, and proximity to settlements, towns and cities. The following points[3] emerge:

- over 1400 reserves are present;
- the largest reserve (Great Victoria Desert Nature Reserve) has an area of nearly 2.5 million hectares;

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3. These points result from a consideration of the reserves of Western Australia as listed in the computer files of the Australian Department of National Mapping (including a few non-C.A.L.M. areas), and information supplied by Walker and Cocks (1984) for appropriate 1:100,000 mapsheet areas (excluding most offshore areas and a relatively few others were data was not available).

- nearly 50% of the reserves are less than 100 hectares in area[4] - Fig. 2;

- nearly 90% of the total area is found in 23 reserves, which are generally remote from any population centre;
- 68 reserves are designated "island" and are mostly (63%) less than 100 hectares in area;
- 64 'management priority areas' with a priority for conservation activity have areas mostly between 1000 and 10 000 hectares; they occupy about 410 000 hectares;
- 73% of the reserves are in the 'wheat belt' and 20% in the wetter remainder of the southwest - together 93% of the total number of reserves but found in only a relatively small portion of the State.

MAJOR ENVIRONMENTAL PROBLEMS

The Mediterranean-climate portion of Western Australia, particularly, is host to a number of major environmental problems which affect the management of State forests and reserves. Induced salinity, a problem mainly of farmed land, will be ignored here but in some State forests and reserves there are

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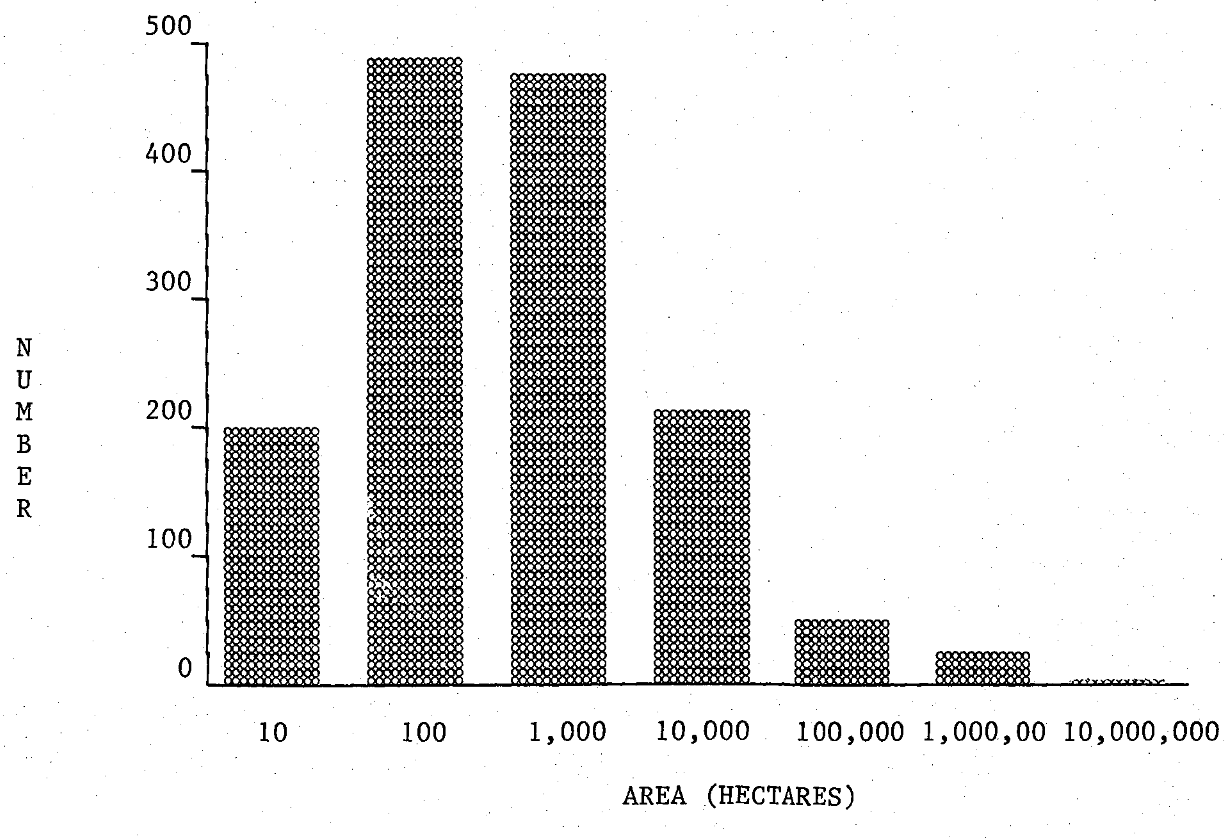
4. 'Areas' are not necessarily continuous: some reserves are found as a number of discrete blocks or as a series of islands.

Fig 2. Frequency distribution of areas of conservation reserves of Western Australia as listed on computer by Department of National Mapping, a listing assumed to be the same as that printed in Wilson (1984). A few of the reserves in these lists may not be the responsibility of the W.A. Department of Conservation and Land Management.

								Total
Number	194	489	471	213	48	20	3	1438
% Freq.	13.5	34.0	32.8	14.8	3.3	1.4	0.2	100
% Area	0.01	0.15	1.11	4.30	8.80	46.09	39.55	100
Number Islands	38	15	9	5	1	-	-	68



marked impacts of naturalized alien plants, the disease *Phytophthora cinnamomi*, and bauxite mining. Many people would include feral animals in their list of environmental problems but the impact of feral animals is generally unknown. More than 40 plant species are presumed extinct and over 80 are presumed endangered (Leigh *et al.* 1984). The question of fire is, of course, the main topic of this review and will be considered in detail throughout this contribution. Naturalized alien plants, *Phytophthora* and bauxite mining will be considered briefly below.

We may use 1829 as a convenient starting point for our consideration of naturalized alien plants because this was the beginning of European settlement and the start of a flood of alien plants into the landscape. By 1919 there were 130 spp. of naturalized aliens (Alexander *et al.* 1919); by 1931, 253 (Gardner 1931); and by 1981, about 800 (Green 1981). In the Perth region alone, Marchant (1984) noted the presence of 547 spp. of naturalized aliens - 27% of the flora. While these species may have only a low cover in many State forests and reserves, they do seem to be a feature of metropolitan reserves (Moore 1984), may dominate the native flora, and may affect the flammability of the plant community (e.g. in the non-C.A.L.M. reserve, Kings Park - Wycherley 1984).

Small groups of dead and dying trees and shrubs were observed in the jarrah forest in the 1920s but these patches became more widespread and of more serious concern in the 1940s with the large-scale introduction of heavy earth moving machinery (Carron 1985). The condition came to be referred to as 'jarrah dieback' and was eventually attributed to *Phytophthora cinnamomi* (Podger 1972). In the early 1970s, a forest hygiene program was introduced and detailed mapping of 'dieback' areas began (Carron 1985). In addition, large areas of conservation lands were infected or thought to be infected. "In the long term the disease poses a greater threat to native vegetation than does fire" (Havel 1979).

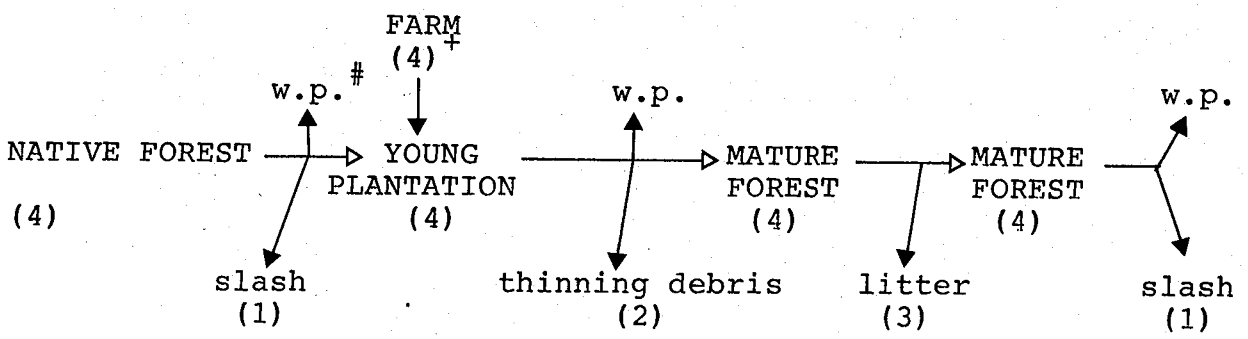
Open-cut bauxite mining began in the jarrah forest in about 1965 (Carron 1985). The areas cleared and mined per year were very small initially (tens of hectares) but have grown. Eventually, it is anticipated that about 100 000 ha or 7% of the forest will be involved although much of the forest has been, or is, under mining leases. After mining, the sites are revegetated with plantations of mainly eastern Australian eucalypts and local shrubs. Such 'rehabilitation areas' present fire-protection problems when establishment and growth is particularly successful.

CURRENT FIRE MANAGEMENT

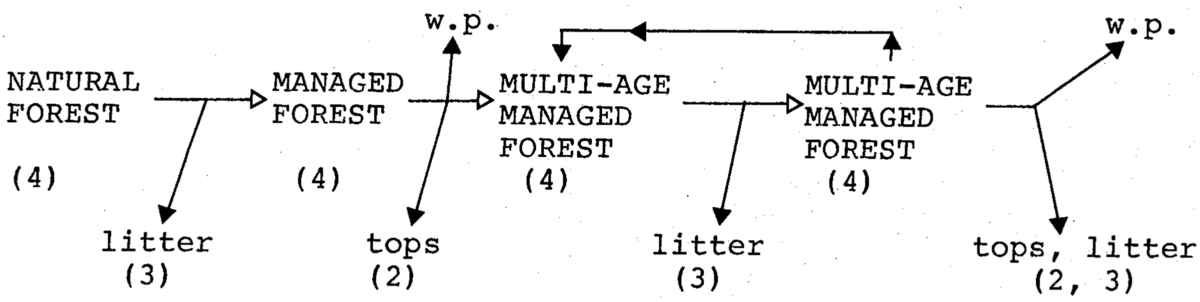
Most of the reserves, all of the State Forests and most of the people are found in the southwest of the State. Similarly, the vast bulk of fire management and fire research has been carried out in the southwest. Because of these facts, the points and examples below are necessarily drawn from the southwestern region.

Figure 3. Diagrammatic representation of the timing and circumstances of fire occurrences in State forests.

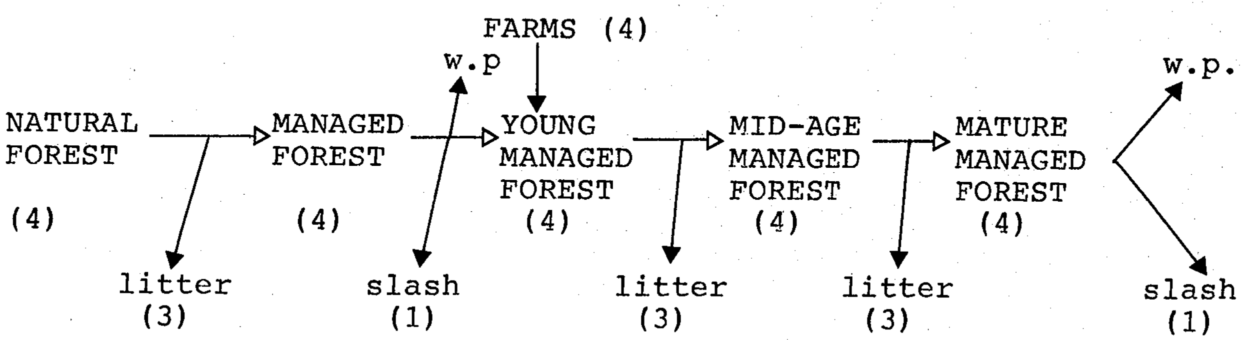
(a) *Pinus* plantations



(b) Jarrah (*E. marginata*) forest



(c) Karri (*E. diversicolor*) forest



+ Numbers represent fires in various fuel types. 1, slash fires; 2, top's fires; 3, litter fires; 4, forest fires.

'w.p.' represents 'wood products'.

(a) Areas with an emphasis on production of wood

The place of fire in the various silvicultural systems of State forests are outlined in Fig. 3. The fires* may be distinguished on the basis of the dominant fuel being burnt as:

(i) slash fires, i.e. fires burning in logging debris after clear felling;

(ii) top-disposal fires, i.e. fires burning in detached tops of trees, dead and on the ground as the result of selection logging or thinning; these fires occur over variable, usually unstated, percentage of an area being logged, and may follow a prelogging litter fire;

(iii) litter fires, i.e. burning in litter; at low intensity* (<500 kw/m - the typical fuel-reduction fire or 'control burn) they are ignited at 5-7 year intervals (Christensen and Kimber 1975) in jarrah and 6-8 years in karri (Breidahl 1983), frequencies which correspond to litter fuel accumulations of 7.5-8.5 and 17-19 t/ha respectively (F.J. Campbell, personal communication). Approximately 300 000 ha of forest land is burned[5] by prescription each year - about 20% of the total area of jarrah, karri and wandoo forests, the only hardwood forests to which these figures apply. About 5% of the area planted to pine is burned each year, mainly around the edges of compartments. (Appendix 2 illustrates the burning history of areas of jarrah

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*. Throughout the text, this symbol indicates that further information may be found in the 'glossary'.

5. The area designated as being burned is the area over which ignition has been attempted. The whole area may, in fact, not be completely burned.

and karri forests and, incidentally, points out the dangers of generalizing the figures for the interval between fires. Note that fire has been prescribed in jarrah forest for at least 50 years, even in relatively large areas, and that the emphasis has shifted from the non-timber, buffer* areas to those more productive of timber);

(iv) forest fires, i.e. fires burning in a range of undefined fuel types which may include litter, understorey, bark on standing trees and even tree crowns (unscheduled* or 'wild' fires with an intensity* dependent on weather and fuel condition but possibly up to 100 000 kw/m). About 15 000 ha of former Forests Department land has been affected in this way each year, i.e. about 1% total area.

(b) Areas with an emphasis on conservation of biota

Prescribed burning as a large-area fuel-reduction measure seems to have been very limited in conservation reserves of the former Department of Fisheries and Wildlife. Some prescribed burning, presumably for fuel reduction, has been carried out in lands of the former National Parks Authority , however, especially in the Stirling Ranges National Park where thousands of hectares have been burned. Areas of national parks and reserves where grazing leases are still held seem to have been deliberately burned presumably to enhance grazing values. Such areas are relatively rare being confined to the Shannon-D'Entrecasteaux National Park. The management priority areas of the former Forests Department have been subject to repeated prescribed burning: the most studied of these has been the Perup Fauna Priority Area.

Most management burning in lands of the former Department of Fisheries and Wildlife, and those of the former National Parks Authority in general, seems to have been for the purpose of creating buffers (as in Two Peoples Bay Nature Reserve, Appendix 3) in order to limit the chances of any single unscheduled fire burning the whole reserve, or to allow a greater chance for fire control to be successful around the perimeter of a reserve.

PARADIGMS OF FIRE MANAGEMENT

Experiences and ideas are the guides to future action, i.e. paradigms. It is important, then, to be sure that experiences and ideas are well founded and appropriate before being applied to a new situation. Below, the major paradigms of fire management in Western Australia are reviewed. Each of them was encountered at some time during the course of the review. Some were from managers and some were from research staff while others were ascribed to critics of current practice. These 'paradigms' were encountered in many guises and are presented here to stimulate thought and discussion. None of them was considered to be official policy of the Department, of course.

(a) 'Fuel-reduction burning reduces the hazard* to life and property to acceptable levels considering the climate of the region.'

This common paradigm of fire management in Australia has been written here in a precise form. It is often stated less precisely as 'control burning reduces the fire hazard', a seeming contradiction and an incomplete statement in the sense that a hazard must be to something or to someone and needs to be considered within the climatic context of the region. We may assume that if fires can be controlled, then the hazard to life and property is less than if fires cannot be controlled.

Three lines of evidence may be used to evaluate fuel-reduction burning in the forest areas of southwestern Australia: figures for areas burned by unscheduled fires and by prescribed fires as a function of time; fire-behaviour models; and risk analysis. Economic approaches to the subject are beyond the scope of this report.

The best figures available for the areas burned in forest of southwestern Australia were those in the Annual Reports of the former Forests Department. The figures for the total area burned by prescription rises from an average of c. 114 000 ha in the 1950s to c. 364 000 ha in the 1960s and fall to c. 314 000 ha in the 1970s. The area burned by unscheduled fires shows a peak of c. 193 000 ha in 1960-1, but the basis for the collation of statistics changed around 1970 such that trend analysis of the data is not possible.

Fire-behaviour models provide evidence of the importance of fuel reduction to fire behaviour. Byram (1959) proposed the formula:

$$INT = H \cdot w \cdot ROS$$

where INT is the fire intensity, H is the heat content of the fuel, w is the weight of available fuel per unit of area, and ROS is the rate of forward spread of the fire. This shows that the intensity of the fire goes up in direct proportion to the amount of fuel from the point representing no fuel, no fire. Because ROS is also directly proportional to w in eucalypt forests (Noble *et al.* 1980), INT becomes proportional to w^2. Such equations provide the principles but they do not provide the absolute values which are dependent on the weather as well. This deficiency can be corrected, with qualifications, using fire models in conjunction with daily weather records.

Daily weather data for the length of record available was obtained from the Commonwealth Bureau of Meteorology for Perth airport. The details of the computer programs used are to be found in Gill *et al.* (in prep.). The findings are overviewed in Appendix 4. They show that if fuel weight is below about 8 t/ha there are few days when fires will be uncontrollable.

(b) 'Fire behaviour in forests can be accurately predicted by the 'Red Book' of Sneeuwjagt and Peet 1979'.

The Forest Fire Behaviour Tables - or 'Red Book' - play an important, even central, role in moulding attitudes to fires in the southwest. They are important also for scientists attempting to model physical and biophysical processes for Australian forests. Presently, the data they contain cannot be verified by an outsider because only the best fit 'conclusions' are published in the book and the data on which it is based are simply not available in the literature. Because the knowledge they contain is expensive to obtain, it is essential that the original data on which the tables in the book are based be published either as the raw figures, or, preferably, as relationships showing the data points and the appropriate equations.

(c) 'Fuel-reduction burning has no detrimental effect'.

While this statement has been advanced historically to defend burning practices in some quarters, it invites the question of 'no detrimental effect on what and in relation to what?' In the past, it meant, perhaps, that there was no detrimental effect on wood production. Community attitudes have changed, however, and there is now considerable attention being given to the question of the effects of fires on plants (including fungi), animals (including insects), and other aspects of the ecosystem such as nutrients in the soil. Also, in the past, fuel-reduction burning was being considered in relation to unscheduled, intense forest fires, but there are now many more fire regimes* being considered in management including a wider range of intensity (Burrows 1985).

As an hypothesis for discussion, we can examine the idea that 'all fire regimes affect the biota similarly'. The effects of fires on soil nutrients will be treated separately, next.

(d) 'Prescribed fires do not cause a net loss of mineral nutrients'.

There has been much debate over the extent of losses of nutrients in slash fires (Australian National University 1981, Raison, 1981) and considerable concern over the possibility that deleterious losses of nutrients may occur with often-repeated litter fires (Raison *et al.* 1983). Debate seems inevitable because of the nature of the problem and the technical difficulties associated with the finding of a solution. Most concern is with the elements N, P and S because of the relative volatility of the first and last of these and the generally limiting quantities of P for organic productivity in Australian soils.

Difficulties associated with the reaching of solutions to the question 'what is the extent of nutrient change under different fire regimes' include the following:

- The amounts of elements above ground are low relative to the total amount in the ecosystem. For N, P, and S in karri forest, the percentages of these elements in the above-ground material were less than 10, 2 and 2 respectively (Hingston *et al.* 1979). For the same elements in jarrah forest, the respective percentages were relatively high for N (near 20) and S (near 8) - Hingston *et al.* (1981) but still small in absolute terms.

- Amounts of nutrients volatilized by fires are a small percentage of the total in the above-ground material for litter fires, and never 100% even for slash fires.

- Soil concentrations of mineral elements in most Australian soils are very low and the within-site variance large. For karri soils, Hingston *et al.* (1979) gave standard errors (expressed here as a percentage of the mean) of 26, 17 and 24 for N, P, and S respectively for the 0-5 cm depth. Seasonal variation may also occur for N at least (Stock 1985).

- Variation in the concentrations of mineral elements in plant material may also be substantial. Hingston *et al.* (1981) found that for the jarrah shoot system the standard error for P was 20% while that for the same element in fallen wood was 33%. "Fallen wood" was a large category at 130 t/ha.

- Large quantities of soil nutrients - especially P - may be inaccessible to plants. Twice the amount of P in the fine soil fraction, and 7 times the amount of S, was found in the coarse soil fraction by Hingston *et al.* (1981). In this extreme case in a lateritic soil, the nutrient was physically inaccessible to roots but in many other cases the nutrient is tied up chemically. Some authors have used 'available' nutrients as the basis for determining changes in amounts due to treatment.

- 'Available' nutrients in soils are estimated according to various chemical extraction procedures. Just which procedure is used for an element strongly affects the results. Concentrations are often extremely low and significant seasonal changes may occur (Stock, 1985, for N) in addition to the considerable spatial variability that can be expected. 'Available nutrients' in soils will change as the result of mineralization of organic matter in fire (Stock 1985 for N) and as a result of soil heating during fires (Humphreys and Craig 1981). 'Availability', in a plant physiological sense, will depend on the species involved, and their microbiological symbioses, as well as such factors as ambient temperature and water supply (Groves *et al.* 1983).

- Inputs of P and S from the atmosphere will usually be small and will be affected by the treatment of country around the study site as well as possibly being affected by the treatment applied to the site itself.

- Inputs to the study site for N may vary widely and may be substantial (Adams and Attiwill 1984). Changes in the N status of the ecosystem may be expressed in the soil and in the plants.

Assessing the effects of fires on the nutrient balance of the ecosystem ideally would involve large numbers of samples measured separately (for statistical purposes) for elements in the various components of the system - such as live and dead fuels, non-fuel organic material, and the soil profile - both before and after the treatment and in an untreated control area where a time-series of treatments is imposed. This is an enormous task and has never been done. Explicit mathematical models could be useful.

(e) 'All fire regimes affect the biota similarly'

The biota consists of vertebrates and invertebrates and vascular and non-vascular plants - many thousands of species in terrestrial Australia. The possible fire regimes* affecting much of this biota are also diverse because frequencies vary widely, intensities vary enormously and possible burning times during the year are variable both within particular localities and between localities in the State of Western Australia as a whole. To make the topic more manageable, we may recognize three broad component parts (plants, animals and the plant-animal interaction), four levels of organization (individual, population, species and community), and two groupings of methods (survey and experiment). At the 'individual' level of organization the effects of fires may be related to individual trees; at the population level, numbers of individuals at various life stages may be of concern; at the species level, the attributes of species may be the main focus; and, at the community level, attention may be directed to species composition, productivity or structure. For the methods, survey may enable long-term effects to be considered but the impact of spatial and temporal influences on the results are difficult to determine; experiment is more rigorous than survey but limited to short periods in most cases.

In this report, I do not attempt to review all the literature pertinent to Western Australia - for example, that on invertebrates - but do attempt to highlight illustrative examples.

Most fire-behaviour and fire-effects research in Western Australia has been in the jarrah forest. It is therefore not surprising that a number of scientific papers have been concerned with the effects of fires on jarrah itself. McArthur and Cheney (1966) surveyed damage to pole-sized trees after the important Dwellingup fire of 1961. They found that the proportion of physical damage to the total crop increased curvilinearly with increasing fire intensity. While these authors foreshadowed an "absolute loss of 5 years increment" where "50%

assessment of physical damage" occurred, Kimber (1978) found that scorched trees of similar size grew more rapidly in girth than those burned experimentally in an adjacent area. Kimber attributed his results to the dense crown regrowth of burned trees and the absence of flowering and fruiting in these trees (cf. control trees). Using repeated surveys, Abbott and Loneragan (1983) found that high intensity fires caused growth increases in some cases, decreases in others, but always caused more fire scars. On the other hand, repeated low intensity fires were neither detrimental nor beneficial to survival.

A common tall shrub or small tree of the jarrah forest which has been given added significance because of its susceptibility to *Phytophthora cinnamomi* (Shea 1975) is *Banksia grandis*. Aspects of the demography of *B. grandis* have been reported by Abbott (1985) while Burrows (1985 a) experimentally investigated its susceptibility to fires of various intensities. Burrows found that stem death rate was inversely proportional to diameter and directly proportional to intensity (to 1500 kw/m).

The practice of widespread fuel-reduction burning introduced after the Dwellingup fires of 1961 elicited the observation that the legume component of the northern jarrah forest, so prominent after intense fires, was being reduced by low intensity fires (Peet 1971). Decline of legumes raised concerns of a long-term decline in the nitrogen economy of the forest and of a decline in the potential to resist *Phytophthora* (Shea *et al.* 1979). Attention will be focussed here on *Acacia* spp. in the northern jarrah forest.

Increased germination following experimental fires of an intensity > 500 kw/m (cf. < 500 kw/m) has been shown by Christensen and Kimber (1975). Recently, successful germination has followed experimental fires at intensities < 500 kw/m^{-1} when these occurred over dry soil (L. McCaw, personal communication).

Many of the *Acacia* spp. of the northern jarrah forest are fire sensitive and short lived. While Skinner's (1984) results are for the southern eucalypt forests, the trends seem to be indicative for northern forests as well. Skinner's (1984) observations on individual plants over a period of 8 years showed that a number of *Acacia* spp. reached maturity and commenced seed production in 3 years but then quickly succumbed to senescence and death.

Studies of changes in a local flora with time have been rare. However, Bell and Koch (1980) examined a series of sites of known age since last fire in the northern jarrah forest. Species richness showed a peak in the sites 2 and 5 years after fire, showed 10% fewer species in a 7 year stand and slightly fewer species in 17 year and 46 year stands. Variance was not measured within all sites but the range of species number in the seven 5-year-old sites was 24-36.

The effects of fire regimes on animals are perhaps more difficult to study than those on plants because numbers of animals from any one species in an area are often low, fluctuate widely, are mobile and may occupy home ranges which encompass a variety of vegetation types.

Christensen and Kimber (1975) used survey techniques, mainly, in their study of fire regimes and fauna of southwestern forests. Their results showed a peak in macropods (western grey kangaroo and brush wallaby) 1 year after fire and a decline in numbers with increasing times since the last fire (up to 5 years). The mardo, (*Antechinus flavipes*), however was found more commonly in stands burned several decades earlier and had very low abundances in recently burned stands. Resident, breeding passerines were found to be very persistent despite an intense prescribed fire but thought to decline in numbers and richness in old stands. Quokka (*Setonix brachyurus*) numbers rose initially for a sequence of sites of increasing time since fire (to about 10 years), then fell to near zero by 15 years in the swampy areas studied. Such is not the case in swampy thickets at Two People's Bay Nature Reserve where they may persist for at least 40 years (Hopkins and Smith, in prep.). In southern jarrah, marri and wandoo forests, Christensen (1980) studied the woylie (*Bettongia penicillata*) and tammar (*Macropus eugenii*) - both medium sized marsupials - and found associations between the animals and habitat but no association between animals and fire directly. Woylies inhabited well-drained sites with moderate cover (50-80%) and some bare ground while tammars inhabited "thickets" of tall shrubs with bare ground or grasses beneath. Tammars were found in thickets of *Gastrolobium bilobum* and *Melaleuca viminea* mostly: these plant species depended on relatively intense fires for regeneration. Frequent, low-intensity fires have been postulated to be detrimental to tammars and woylies but no direct test of this has been reported. Similarly fire exclusion may be detrimental in the long-term but tammars do persist on offshore islands in the prolonged absence of fire and predators (Christensen 1980).

Near Albany, in the dense swampy drainage lines of Two People's Bay Nature Reserve are to be found the rare noisy scrub birds (*Atrichornus clamosus*). Hopkins and Smith (in prep.) have reviewed the circumstantial evidence linking fire regimes and populations of these and two other rare birds (*Dasyornis longirostris* - the western bristle bird, and *Psophodes nigrogularis* - the western whip bird). The scrub birds have increased dramatically in numbers since a policy of fire exclusion was introduced. The relationship between numbers and time since fire is not known but previously-occupied, better sites seem to be vacant for 4-10 years after fire has razed the vegetation. The time for re-establishment may be influenced by the supply of birds for colonization. Similar evidence exists for times of recolonization of the other two rare birds although their habitats are different from the scrub birds.

While animals may be directly dependent on a certain range of habitats, they may also influence that habitat significantly. Thus, small burned areas may be heavily grazed by kangaroos and/or grasshoppers (Hopkins and Smith, in prep.; Shea *et al.* 1979; Whelan and Main 1979) and kangaroos and tammars may influence fire frequencies within their habitats by their grazing activities (Christensen 1980). Where this interaction between burning and grazing will occur may be worth investigation.

This brief review serves to emphasize the importance of fire intensity (e.g. on jarrah performance), fire frequency (implied only, from time-since-fire data for quokkas for example) and timing of fire occurrence (e.g. for *Acacia* seed germination - soils wet or dry) and it records, by default, an absence of experimental work involving more than one fire. The review suggests that spatial considerations are important to the effects of fires (e.g. size of fire) and that the state of the ecosystem at the time of the fire is also important (e.g. sizes of trees). Aspects of plant demography of jarrah forest species were mentioned and the stage is set for demographic models of *B. grandis* and *Acacia* spp. The demography of *Dryandra sessilis, Hakea trifurcata* and *Leucopogon assimilis* is important to beekeepers and may be worth detailed research in shrublands. Detailed studies of *Banksia* demography, especially for rare species, are in progress at a number of sites (Lamont 1985). Aspects of animal demography, in relation to fires, for the woylie and tammar have been studied by Christensen (1980). At a species level, Christensen and Kimber (1975) have recorded percentages of the flora in various regeneration categories for jarrah and karri forests; Bell and Koch (1980) noted a high percentage of resprouting species in jarrah; and Bell *et al.* (1984) drew together the species and community data available for heathlands and shrublands. Hopkins (1985) has recently summarized what is known of the effects of fires on semi-arid woodlands on vegetation structure, floristics and fauna.

To conclude, all fire regimes do not affect the biota similarly but often it is not known at any depth how different fire regimes affect the biota. Demographic studies are important for rare species and species of economic importance; species' studies are important for the development of a monitoring program; community studies are important to assess structural change and to test ideas arising from species and demographic studies before they are adopted routinely.

(f) 'Patch or mosaic burning is desirable for conservation'

This idea is often raised when the applications of various studies are explored both in Western Australia (Christensen and Kimber 1975, Bell *et al.* 1984) and in ecosystems directly comparable to those in Western Australia but studied elsewhere (Hodgkinson *et al.* 1984, Saxon 1984). Given the interactions to be expected between size of fire area and intensity of grazing, certain sized patches could be detrimental to conservation. As far as this reviewer is aware, there is no direct, published evidence to support the mosaic concept in its effect on populations of animals or plants, or in its effect on fire behaviour. Often, the size of the patch - in or out of a mosaic - is not declared.

It seems to be assumed that Aborigines burned only very 'small' patches. Kimber (1983) in a study of patches created by Aboriginal burning in Central Australia suggested that "small patches" were up to 5-10 km^2 while larger ones were up to 30 or even 150 km across. Patch sizes were often vastly in excess of the sizes of the home ranges of most animals. Nomadic animals could take advantage of fresh grazing opportunity but many species are true to their original home ranges even when these are burnt (Christensen 1980). Patch shape could be important in any interaction between burning and animal performance also. Long narrow patches provide more perimeter and potentially cut across more home ranges (rather than burn them completely) cf. circular patches of the same area. Long narrow patches may be expected in discontinuous fuels and in high wind conditions. Patches created by Aboriginal burning are likely to have been diverse in size-range and shape according to diversity of vegetation and terrain, time of burning, distance from travel routes, Aboriginal food preferences and location within the State (regional vegetation types, climate, animals present etc.). Just how much vegetation was actually burnt with a 'patch' could be important also.

Assuming that a certain patch size is suitable is unwise at present: there is a need for the publication of any evidence available and for some careful research.

CURRENT RESEARCH

A brief outline of current research projects concerning fire in C.A.L.M. are listed in Appendix 5. Source documents were a list from the Protection/Production Research group, the proceedings of the "Wildlife Research Seminar" which listed research "programs" as of mid July 1985 for the Wildlife Research Branch, and the 1984 listing from Forest and Woodland Fauna Research in South-western Australia (W.A. For. Dept. Tech. Pap. 13). Also listed in Appendix 5 are subject areas of other interested parties consulted during the course of the review. Overlaps in interest are evident between researchers formerly within separate Departments. Development of joint programs in these overlapping areas, such as animal ecology, may be worthwhile.

OPTIONS FOR FUTURE RESEARCH

(a) Research Philosophy

The most appropriate type of research to a land management agency with a legal requirement to develop a management plan for each of its reserves, most of which remain unstudied, may be called 'developmental' research. Developmental research is applied research which may be expected to have application within 2 to 5 years of initiation. It is this type of research which will be emphasized below. Research with a 5-15 year period to application may be considered the main strength of CSIRO while fundamental or pure research may be considered the mainstay of research in tertiary institutions.

An emphasis on developmental research seems necessary for C.A.L.M. because of the legal requirement to develop management plans for all the conservation reserves in the State and the fact that less than 1% of reserves have management plans presently. At the present rate of about 8 new plans per year, and with the need for revision of plans every 5 to 10 years, the job will never be completed. The massive task ahead will be achieved most effectively if it is systematic and co-ordinated. <u>There needs to be an explicit program and procedure for the development of management plans, including fire-management plans, for all conservation reserves and State forests</u> (RECOMMENDATION 1). The sequencing of reserves and State forests for the planning process will depend on a number of factors which are outside the scope of this report but the procedure to be adopted for the development of a fire-management plan for each area is most pertinent to this report.

The long-term aim of C.A.L.M. could be seen as the development and implementation of management plans. Lack of a management plan could imply a lack of scientific management, although this is not necessarily the case. Because rational management depends on planning, options for developmental research in C.A.L.M. are discussed below in the light of the planning process for fire management.

(b) The Planning Process

The modern concept of planning may be briefly described as having the following steps: statement of aims, the assessment of resources available for the achievement of those aims, choosing between alternative operations, implementing the operations, monitoring the results of operations to discover operational proficiencies and deficiencies, researching the causes of deficiencies and suggesting remedies, and modifying operations in the light of experience and research. Such steps provide the basis for the discussion of research options for C.A.L.M., below.

(c) Aims of Management

The overall aims of management for the whole reserve and State forest systems must be stated if the subset of aims for fire management are to be appropriate. The aims for conservation reserves in Western Australia (using those for "national parks" which encompass those for "reserves" and "nature reserves") are "to preserve for all times scenic beauty, wilderness, native wildlife, indigenous plant life and areas of scientific importance and to provide for the appreciation and enjoyment of those things by the public and by such means as to leave them unimpaired for the future." (Wilson 1984). Further refinement of these aims, as far as the flora and fauna is concerned, and particularly for fire management, seems appropriate. Is the aim of management (for example) to have the landscape in the form it was in 1788, or, to maintain it as it was in 1985, or, to maintain a diversity of stages of secondary ecosystem development - all within the constraint of the protection of life and property?

At the level of the individual reserve, the detail of both the overall aims and the fire-management aims will vary according to visitor use, surrounding land use, the size of the reserve, historical uses of land, multiple-use opportunities, roading and building on the reserve, and the nature of the resources of the reserve. Aims for State forests will also vary with location etc. Recognizing this variety of circumstance, it is recommended that the aims of management, in general, and of fire management in particular, be made explicit for each reserve and State forest. (RECOMMENDATION 2). The best aims are those for which progress towards attainment can be measured.

(d) Assessment of Resources

The 'assessment of the resources available' may be in terms of knowledge, financial resources, manpower, roading, equipment etc. but, here, attention is directed initially toward the biological components of the landscape being managed because knowledge of these is lacking for most reserves. Assessment is most appropriately done at the species level and many methods of sampling and analysis need to be considered (Myers *et al.* 1984). It is essential that the aims of inventory be made clear. In the present case, three potentially overlapping aims may be distinguished:

(i) to discover which plants and animals are present and how abundant or rare they are;

(ii) to assess the landscape for fire-management purposes; and

(iii) to establish the basis of a monitoring program from which the effects of operations could be evaluated.

The first of these requires no further elaboration in the present context and there is already an excellent basis being established for this type of work in C.A.L.M. (McKenzie 1984). The second will be considered further in the next paragraph, while the third will be considered under the heading 'Monitoring', below.

The inventorying of reserves for fire-management purposes raises a number of important issues including: whether or not prescribed burning over large areas is necessary; if burning over large areas is to be practised then will it be prescribed for burning blocks with or without fuel breaks around the perimeter; will any proposed fire regimes pose a demonstrable hazard to human life, property, retention of fire within the reserve of ecological values? It is recommended that research be conducted into the most appropriate methods for obtaining reserve inventories appropriate to fire management (RECOMMENDATION 3). This information-gathering phase should be orchestrated by the planning unit. Further discussion of inventory is included under 'integrated computer-assisted, fire-management systems' below ('j').

(e) Alternative Operations: General

In all reserves and State forests, decisions will have to be made on methods to be used for any fire detection, any fire suppression, any fuel-break* construction, any imposed fire regimes* for buffers or broad areas, any 'mop-up'*, any 'rehabilitation', and all record keeping. The major research issues arising from this list are related to, or directly concern, questions of fuel breaks, buffers and broad-area prescribed burning.

(f) Alternative Operations: Breaks, Buffers and 'Burns'

In every State forest or reserve, there is, or will be a system of fuel breaks including roads, tracks, and natural barriers such as creeks, rock outcrops etc. (Fuel breaks consist of bare ground or permanent water courses or a combination of these.) May observers have suggested various systems of buffers (see below) and fuel breaks in order to prevent reserves from being completely burned on any one occasion. This may be an appropriate aim in many cases but, where there are many small reserves, it may be better to think of the management of a cluster of reserves as one unit rather than consider each individual reserve as a unit. Of course, breaks may allow firefighters to operate in greater safety to attempt control and may allow prescribed fires to burn out safely with a minimum of surveillance.

Current systems of breaks and buffers are mostly the legacy of past land uses and not the result of systematic and careful planning. In reserves, particularly - where vegetation is often low, conservation values are paramount, and the time-scale of management is in thousands of years - fuel breaks should be strategically sited (for fire-control purposes), be of minimal length, be curved (for aesthetic reasons), avoid steep slopes (erodable and difficult for laden vehicles to traverse), avoid crossing boundaries of areas affected by *Phytophthora*, avoid seasonally or permanently swampy ground, avoid locations of rare species of plants, have no dead ends, and have limited or non-obvious entry areas (to discourage casual use of a designated break cf. a track or a road). With the advent of suitable digitized terrain maps and other information, optimized solutions to these sometimes conflicting demands may be found.

The occurrence and spread of the dieback disease *Phytophthora cinnamomi* has important implications for the construction and maintenance of fuel breaks. Because soil disturbance and transport seem to be major factors in influencing the spread and expression of the disease, the use of fuel breaks in all areas may be questioned. Situations where traditional methods of fuel-break construction involving soil disturbance may be appropriate need to be determined (RECOMMENDATION 4).

Buffer areas - where fuel is reduced but not absent - are popular in Western Australia as areas where fire fighting is made easier or where fires may be expected to stop in some circumstances. Buffer areas were used in the jarrah forest before the advent of general prescribed burning (Appendix 2). Buffer areas are usually constructed between two fuel breaks up to 100 or more metres apart. 100 m is about the maximum distance for a firebrand to travel from a grassfire but much less than that possible in a forest fire (Luke and McArthur 1978). Buffers occur around perimeters or internally. Because they are so wide, they may occupy substantial areas, even substantial proportions of reserves. If a circular reserve of 100 ha had a 100 m buffer around the perimeter, it would occupy about one third of the reserve; if the reserve was 1000 ha in area, a 100 m wide buffer around the perimeter would cover about 100 ha - the total area of many reserves (Fig. 2).

There are many ways of creating buffers. Burning is the most common. The problem with burning alone as the management tool for buffers is that after the initial treatment, the relatively non-flammable buffer has to be burned adjacent to a relatively flammable vegetation beyond the buffer. For example, using the equations of Noble *et al.* (1980) for forests, a buffer with 10 t/ha fuel will burn at about 200 kw/m when the forest fire danger index is 10, but the fire intensity in adjoining vegetation with 20 or 30 t/ha at the same time would be 4 or 9 times this, respectively.

In association with burning, usually, buffers may be constructed by slashing (including use of the 'hydroaxe'), mowing, rolling, herbiciding, or chaining. To avoid the problem of widely different flammabilities of buffer and core vegetation after initial construction, the flammability of the buffer vegetation can be increased by rolling or herbiciding, or the flammability of the core vegetation can be reduced by wetting with water or retardant solution. The use of mechanical means to maintain buffers avoids the problem of fire escape - assuming that the machine does not ignite the vegetation accidentally - but may cost more financially. The use of retardants, especially those that are phosphate based, may have a negative effect on conservation values in areas with impoverished soils (Gill 1977), but this needs to be demonstrated (see also the next section).

It is recommended that the relative fire control and conservation values of buffers under different forms of management be investigated (RECOMMENDATION 5a).

In sensitive environments, buffers may be created by igniting fires along a transect at appropriate times of day such that spread fails when the required area has been burned due to the fire's arrival at natural fuel breaks or because of deteriorating weather conditions. Pilot trials of this method have shown promise in Queensland and in Western Australia (Fitzgerald River National Park), but much more work is needed on fire-behaviour prediction (for a range of fuels), and on the adequacy of weather forecasting in the regions of potential application. If no-break patch burning becomes desirable in hummock grassland or monsoon woodland, the impetus for this type of research is increased. It is recommended that systematic fire-behaviour research be conducted on the possibilities of burning no-break patches or buffers (RECOMMENDATION 5b). This could be done in association with other fire-behaviour research (see Recommendation 7 below).

The assessment of the value of buffer systems to fire control and conservation could be avoided to some extent if the core area could be prescribed burnt without compromising conservation values and with the achievement of demonstrably better fire control. Where core areas are burnt by prescription, the width of buffers may be substantially reduced - even to zero. With this in mind, it is recommended that experiments on the effects of selected fire regimes on conservation values in selected areas using replicated treatments be conducted. Simultaneously, the consequences of these treatments to fire control should be quantified (RECOMMENDATION 6). Perhaps the greatest priority for experiment is in reserves where naturalized aliens are common. Sandplain shrublands would also have high priority.

To assess the likelihood of control and escape, a knowledge of fire behaviour is necessary. For many fuel types nothing is known. Thus: fire-behaviour research should be continued in association with the National Bushfire Research Unit of CSIRO because of their attempts to develop models suited to the major Australian fuel-types; local work should be consistent (RECOMMENDATION 7). Perhaps heathland and hummock grassland fuels would have high priority in Western Australia. An integrated approach to fire-behaviour research in Australia as a whole, and the establishment of a national computerized fire danger rating system, is desirable. A common denominator for this research could be the local formal testing of relationships in the 'universal' Rothermel model (Rothermel 1972).

(g) Alternative Operations: Suppression and 'Mop-up'

The soils of Western Australia are ancient and thoroughly leached as a general rule but support a diverse and unique flora in the sandplains of the southwest in particular (Pate and Beard 1984). From the research of Heddle and Specht (1975), it would appear that some plant species are adapted to soils of low fertility to such an extent that higher fertilities imposed by additions of chemical fertilizers, especially phosphorus, may break the life cycle. Because fire retardants consist mainly of a solution of fertilizer at high concentration. It is recommended that research be carried out to assess the potential use and impact of chemical fire retardants on the native flora, particularly that of the sandplain (RECOMMENDATION 8).

(h) Alternative Operations - Fire Regimes for Management

The formulation of fire regimes for management is often difficult and controversial. Some resolution of difficulties is obtained when the detailed aims for each reserve or State Forest have been spelled out. Disagreement may remain even at this stage due to a general lack of knowledge of the responses of all plants and animals in an area even when it is considered well studied. It is recommended that the responses of the flora to fires be systematically recorded on the basis of certain life-history characteristics of individual species (RECOMMENDATION 9a). Such research may best be carried out in co-operative programs between C.A.L.M., the CSIRO and the University of Western Australia. Also, appropriate bases for the prediction of animal types and numbers from floristic and/or structural data in fire-affected plant communities need to be determined (RECOMMENDATION 9b).

Traditional research methods will not answer all the managers problems immediately but the manager can add to the data base of knowledge by practising 'experimental management'. The concept is simple but has far reaching consequences. Instead of treating a unit of landscape in one way only, the manager practising 'experimental management' will treat the area in two or more ways - like an unreplicated experiment. With good records, and even a simple monitoring scheme (see later, below), the manager, his critics, or a researcher can compare the effects and draw tentative conclusions. In other words, management is carried on in such a way that it is always adding to knowledge, never wasting an opportunity to learn. It is recommended that the concept of 'experimental management' be evaluated (RECOMMENDATION 10).

An appropriate range of fire regimes may be drawn up in the light of the aims for the management of the reserve, legal constraints, what is known of the fire climate and history of the reserve, and what is known of the responses of the biota to 'fire regimes'* (Gill 1975). The types, seasons of occurrences, frequencies, and intensities of fires may all be important in particular areas (Gill 1981). Where 'natural' conditions are to be simulated by prescription, it must be realized that fires would not have occurred at regular intervals and that ages of communities in relation to time since fire would not, therefore, form a simple arithmetic sequence: research overseas has shown that stand ages in a landscape little affected by man conforms to a negative exponential distribution (Van Wagner 1978).

There has been only limited research into what were natural fire regimes in Western Australian vegetation types, perhaps because opportunities are limited by technique. The range of techniques available includes growth analysis (including tree rings), air-photo analysis, sedimentology (± palynology), floral cycles (for *Xanthorrhoea* perhaps), written and photographic records, biotic sensitivities to particular fire regimes and anthropological interview.

(i) Monitoring

Without monitoring, management is like a ship without a rudder. In natural resource management however, the appropriate aspects of the ecosystem to monitor are not always clear - weeds, feral animals, populations of all species, invertebrates, lichens, large animals or something else? Where timber is the prime product - especially in exotic plantations - the item to monitor is obvious; where high-intensity fires are of concern, fuels and fire events need to be monitored; but, where nature conservation is the aim, there may be no obvious simple item to monitor.

Monitoring should be done in relation to the aims of management and these aims should be as detailed and well defined as possible (see RECOMMENDATION 2). An essential part of the monitoring systems is an appropriate record-keeping system.

Present monitoring in C.A.L.M. is very limited. Litter fuels are monitored before prescribed burning of forests and rare birds are carefully monitored at Two People's Bay Nature Reserve. A pilot program for monitoring plants has been reported (Goodsell *et al* 1985). There is no systematic monitoring system or series of systems for Western Australia. It is recommended that the most effective monitoring systems for nature conservation, within the context of fire-management for nature reserves, national parks and State Forests, be determined (RECOMMENDATION 11). It is suggested that the research be aimed towards the identification of a minimal set of items (e.g. litter fuels, common obligately-reseeding plants, particular rare animals, vegetation structure in aesthetically-sensitive areas etc.), at a minimal number of sites, to be measured as infrequently as possible by field staff or selected volunteers at minimal cost. Volunteers from conservation societies and the general public (even critics) could be particularly helpful in collaborative monitoring associated with 'experimental management'.

Monitoring techniques can include ground photographs which can have tremendous impact (e.g. Wimbush and Costin, 1979, for Kosciusko National Park in N.S.W.), aerial photographs and LANDSAT imagery (e.g. for fire occurrences and areas), counts of songs (e.g. for noisy scrub birds), counts of tracks, scats, nests or diggings, measurements of fuel weights and/or cover, trapping etc. Little has been written on practical monitoring systems for nature conservation but MacDonald and Brooks (1983) outline their experience in setting up a monitoring program in a South African game reserve. Life-cycle characteristics of plants and animals, and animal/habitat relationships should assist in the identification of potential indicator species. Obligately-reseeding plants with long juvenile periods, and fire-vulnerable slowly-reproducing animals, may be suitable as indicators, for example.

(j) Integrated, computer-assisted, fire-management systems

Any fire-management system may be seen to consist of a number of modules including those for biophysical data, fire-behaviour information, fire-suppression operations, prescribed-burning operations and fire effects. Each module would have its own monitoring and record-keeping systems. All modules would depend on an appreciation of the biophysical data.

Biophysical data may be for the terrain (slopes, aspects, elevations, drainages, roads, breaks and buffers), soils (types and depths), biological data (e.g. sizes, covers, richnesses), fuels (amounts, types), past fire areas, and weather variables of importance to fire behaviour. Within the usual planning cycle of a decade, only the biological data, fuels and weather would need assessment after initial inventory. Traditionally, records of terrain, fuels, past fire areas and biological data have been stored as maps. Even with current technology, all these data may be integrated into one storage and retrieval system which can generate maps.

Apart from the storage and retrieval of information, the computer may enable the automatic updating of fuels-data if the fuel-time curve is known. Other manipulations are possible. If systems of fire-behaviour using equations (such as those of Noble *et al.* 1980) or tables (such as that of Sneeuwjagt and Peet, 1979), are available, then simulations of fire spread using real terrain and weather data are possible (Kessell 1984). Similarly, fire effects may be predicted if the appropriate models and data bases are available: no system in Australia has reached this level yet, but schemes based on species attributes have been developed (e.g. Noble and Slatyer 1981).

To generalize, fire-management systems in the narrower sense above consist of data and manipulative programs to predict outcomes such as fire behaviour or effects. Similar systems could be used for the despatch of vehicles and the prediction of suppression effectiveness. Much is possible but how much is pertinent - for the planner, manager or scientist?

For many areas, no formal inventory or suitable manipulative programs exist. However, many managers, scientists and planners have empirical information and concepts which are incomplete in themselves, uncertain enough to be published or unavailable through formal channels. Such information and concepts can be collated and organized through 'expert systems'* (Walker *et al.* 1985). Expert systems consist of rules for what may be expected to occur (given particular weather, fuel and terrain conditions for example) which are logically sifted by a computer program. Such rules find their ultimate expression in equations (the "manipulative programs" above). The rules represent the state of knowledge of the ecosystem and may be updated at any time. They may be seen as an english-language expression of mathematical equations but at a cruder level of resolution than the equations. The rules provide a focus for the manager enabling him to repeatedly check the value of the information available and update it if necessary. The rules may be stored in the computer and made available to anyone: the knowledge is not lost when a competent manager moves on.

Available information about an area can be drawn together by a task force (such as the Manjimup Research Team who recently collected and collated information pertinent to the fire management of Dryandra State Forest - Burrows 1985b), then formulated into rules for management in a workshop with all the experts available. Finally the information can be entered into the computer as part of the 'expert system'. Data bases and mapping programs may be added to 'expert systems'. If detailed equations are available to explain parts of the system, they too can be added to 'expert systems'. It is recommended that the use of computerized fire-management systems (including 'expert systems', data bases, mathematical relationships and output options) be investigated for their use in fire management in Western Australia (RECOMMENDATION 12). Like inventories (see d above) orchestration by the planning unit is desirable.

'Expert systems' add an extra dimension to systems like PREPLAN (Kessell *et al.* 1982) because they can add empirical rules. The rules are explicit and are assigned a confidence level and a source. Presently, equations in mathematical models are not given explicit status unless accompanied by a formal publication. In the use of any computer management system it is desirable, even necessary, to have at least 2 people who know the limitations of the system as well as its strengths. Knowledge of the limitations assists managers to assign research priorities and design appropriate monitoring systems to glean pertinent information. All computer systems are for planning and guidance, not for directing decision making.

Knowing the limitations of a system means knowing the limitations of the data as well as the limitations of the equations or rules. To date, many systems rely on sampling and correlation rather than measurement at every point on a grid of thousands of points; it would be beneficial to the user to know when the result obtained was by observation or by statistical convenience. (This could be done by expressing the result as a probability from zero - don't know, to 1 - observed). Digitized maps may give slopes and aspects which are averages rather than point measurements and in many applications the difference could be significant. Scale is of great importance and should be considered in relation to the biophysical variables used. One data point in 1000 hectares would be inadequate in a small, variable reserve but may be less of a problem in a very large reserve of relatively uniform vegetation. Costs rise as numbers of points increase. Tutanning Nature Reserve shows enormous diversity in terrain and vegetation and a grid of data points has been established there (A. Hopkins, personal communication). The type of ecosystem being managed, and the detail of knowledge desired, may determine, in part, whether or not a computer management system is helpful. If an ecosystem is seen - for management purposes - as even-aged trees on a flat terrain with one fuel type (such as with a pine forest on the coastal plain), there may be little point to a computer system. If, however, the ecosystem is diverse and knowledge of where all rare plants are to be found, their condition, and how they respond to various fire regimes is required (for planning of buffers or breaks, for the conduct of suppression operations or for information of locations alone), a computer system could be of immense help. Similarly, the retrieval and manipulation of information on tree conditions, soil types, fuels etc. in a complex plantation may be aided by computer.

The importance of the different components of a computer-based system will vary according to the aims of management, the ecosystems concerned, the complexity of the operations involved, the staff available, the remoteness of the location, the size of the area, and the importance of experience to management. Thus, in designing a system it may be wise to develop it according to needs perceived for: inventory (and data bases); process models (such as fire behaviour models, models to predict inventory components at points not observed, and fuel/time models); 'expert systems'; record keeping (e.g. for fire histories); types of output (charts, maps, tables, figures on a screen etc.). Computer systems could be compared with those currently in use for areas producing wood products, recreational pursuits and conservation values.

(k) Research

The importance of publishing all careful and thorough developmental research in which aims are clear, in which data are not confused with interpretations of data, in which experiments are always replicated and include controls and in which a pertinent context is explicit, hardly needs mention. What may be expanded upon here, however, are possible new ways of inventory, data bases which may be of assistance, models which may assist planning, and the possible value of islands for research.

Remote sensing for inventory remains a potentially valuable tool. Apart from LANDSAT and conventional photography, new systems of remote sensing are being developed with finer resolution (as in recent space-shuttle missions) and with new capabilities e.g. pulsed lasars (for tree heights and topography). Any system that senses tree heights or vegetation height has immediate application to fire effects and forest inventory. Remote sensing with fine resolution may be of even more use for the recording of fire 'footprints' and assessing fuel weights in short vegetation (on the basis of cover and colour).

With the geometric increase in the capacity of computers and the dramatic drop in cost to storage ratio, many large data sets have become available to large numbers of people. For this report, a number of large data sets were found helpful. One was the list of all Australian conservation reserves which included their locations, areas, type, management authority, date of declaration etc. and another was ARIS (Walker and Cocks 1984) which lists various properties of 1:100 000 map-sheet areas including vegetation, soils, meteorological variables, land use etc. Further data bases used were the Australian fire bibliography of Drs. I.R. Noble and A.M. Gill and the lists of rare and threatened plant species in Australian of Dr. J.H. Leigh and colleagues. Planners and managers may find other data bases useful such as the 1:100 000 digital terrain maps and cadastral-boundaries maps available from the Australian Survey Office (or through the W.A. Department of Conservation and Environment).

Modelling has obvious application to fire management in the fire-behaviour field. Some other forms of modelling - such as species-characteristic or vital-attribute modelling (Noble and Slatyer 1981) - may assist in the formulation of policies for burning particular tracts. Similarly, demographic modelling may assist in the design of fire regimes for beekeeping, for rare-species conservation and for the study of the behaviour of potential indicator species; modelling allows for the simulation of the effects of a wide range of variables on the system of study as a guide to expected behaviour in the real system.

Islands off the Western Australian coast have particular potential as 'controls' in natural 'experiments' because they were generally uninhabited by Aborigines (Abbott 1980) but have many of the same species as the adjacent mainland. In many cases also they are free of introduced predators' thereby allowing, perhaps, the evaluation of the effects of predation on particular animals in the presence or absence of particular fire regimes (Christensen 1980). Freedom from fire for long periods has also produced surprises on islands as A. Hopkins (personal communication) has shown on the Recherche Islands. Artificial 'islands' long unburned, such as Amphion Block 6 in the jarrah forest, have been widely used (e.g. Christensen and Kimber 1975) and similar 'islands' of long unburnt vegetation may be useful also in other vegetation types (Muir 1985). Finally, the responses of communities on islands by sprouting or seeding may be different to those of similar communities on the mainland (Baird 1958) and research into such cases may help develop an appreciation of the role of particular fire regimes in shaping the characteristics of our flora and its dependent fauna today.

CONCLUSION

Amalgamation of the component departments now comprising C.A.L.M. has brought new opportunities for the sharing of skills, knowledge and experience. Because there is an enormous task ahead in the production of management plans, and revisions of management plans, research should be geared to the successful execution of the planning process.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Abbott, I. (1980). Aboriginal man as an exterminator of wallaby and kangaroo populations on islands round Australia. *Oecologia* 44, 347-54.

Abbott, I. (1985). Recruitment and mortality in populations of *Banksia grandis* Willd. in Western Australian forest. *Aust. J. Bot.* 33, 261-70.

Abbott, I. and Loneragan, O. (1983). Influence of fire on growth rate, mortality, and butt damage in Mediterranean forest of Western Australia. *For. Ecol. Manag.* 6, 139-53.

Adams, M.A. and Attiwill, P.M. (1984). Role of *Acacia* spp. in nutrient balance and cycling in regeneration *Eucalyptus regnans* F. Muell. forests. Parts I and II. *Aust. J. Bot.* 32, 205-23.

Alexander, W.B., Lane-Poole, C.E. and Herbert, D.A. (1919). Lists of the principal indigenous West Australian plants of economic importance and of naturalized aliens and weeds established in the State with their vernacular names. *J. Roy. Soc. W.A.* 6, 41-6.

Australia, Independent Enquiry into the Commonwealth Scientific and Industrial Research Organization, (1977). Report. Aust. Govt Publ. Serv., Canberra.

Australian National University (1981). "Environmental Effects of Clear-cutting Native Forest: an Evaluation of Current Research and Research Priorities. Report to the Australian Environment Council. 162 p.

Baird, A.M. (1958). Notes on the regeneration of vegetation of Garden Island after the 1956 fire. *J. Roy. Soc. W.A.* 41, 102-7.

Bell, D.T. and Koch, J.M. (1980). Post-fire succession in the northern jarrah forest of Western Australia. *Aust. J. Ecol.* 5, 9-14.

Bell, D.T., Hopkins, A.J.M. and Pate, J.S. (1984). Fire in the Kwongan. In: Pate, J.S. and Beard, J.S. (eds) "Kwongan. Plant Life of the Sandplain" pp. 178-204, Univ. W.A. Press, Nedlands, 284 p.

Bradshaw, F.J. and Lush, A.R. (1981) "Conservation of the Karri Forest". For. Dept. W.A., Perth.

Breidahl, R. (1983). Karri silviculture research: a review. Internal Report, For. Dept. W.A., Perth.

Burbidge, A.A. and Evans, T. (1976). The Management of Nature Reserves in Western Australia. *W.A. Dept. Fish. Wild. Rep.* 23, 32 p.

Burrows, N.C. (1985a). Reducing the abundance of *Banksia grandis* in the jarrah forest by the use of controlled fire. *Aust. For.* 48, 63-70.

Burrows, N.C. (1985b). Fire considerations in Dryandra Forest. C.A.L.M. Internal Rep. 113 p.

Byram, G.M. (1959). Combustion of forest fuels. In: K.P. Davis (ed.), "Forest Fire: Control and Use". McGraw-Hill, New York.

Carron, L.T. (1985). "A History of Forestry in Australia". Aust. Natl. Univ. Press, Canberra.

Christensen, P.E.S. (1980). The biology of *Bettongia penicillata* Gray, 1837, and *Macropus eugenii* (Desmarest, 1817), in relation to fire. *W.A. For. Dept. Bull. 91*, 90 p.

Christensen, P.E. and Kimber, P.C. (1975). Effect of prescribed burning on the flora and fauna of south-west Australian forests. *Proc. Ecol. Soc. Aust.* 9, 85-106.

Gardner, C.A. (1931). [*Enumerato Plantarum Australiae Occidentalis*] "A Systematic Enumeration of the Plants occurring in Western Australia". Govt Printer, Perth.

Gill, A.M. (1975). Fire and the Australian flora: a review. *Aust. For.* 38, 4-25.

Gill, A.M. (1977). Management of fire-prone vegetation for plant species conservation in Australia. *Search* 8, 20-6.

Gill, A.M. (1981). Adaptive responses of Australian vascular plant species to fire. In: Gill, A.M., Groves, R.H. and Noble, I.R. (eds) "Fire and the Australian Biota", Australian Academy of Science, Canberra.

Gill, A.M., Christian, K.C., Moore, P.H.R. and Forrester, R. (in prep.). Bushfire incidence, fire hazard, and fuel-reduction burning.

Goodsell, J.T., Hopkins, A.J.M., Brown, J.M. and Griffin, E.A. (1985). A system of monitoring for conservation reserves in Western Australia. In: C.A.L.M., "Wildlife Research Branch Research Programs 1985". p. 28.

Green, J.W. (1981). "Census of Vascular Plants of Western Australia". State Herbarium of W.A.

Groves, R.H., Beard, J.S., Deacon, H.J., Lambrechts, J.J.N., Rabinovitch-Vin, A., Specht, R.L. and Stock, W.D. (1983). Introduction: the origins and characteristics of Mediterranean ecosystems. In: Day, J.A. (ed) "Mineral Nutrients in Mediterranean Ecosystems". pp. 1-17 S. Afr. Natl Sci. Prog. Rep. 71, 164 p.

Havel, J.J. (1979). Vegetation: natural factors and human activity. In: Gentilli, J. (ed) "Western Landscapes". pp. 122-51. Univ. W.A. Press, Nedlands.

Heddle, E.M. and Specht, R.L. (1975). Dark Island heath (Ninety-Mile Plain, South Australia). VIII. The effect of fertilizers on compos'tion and growth, 1950-1972. *Aust. J. Bot.* 23, 151-64.

Hingston, F.J., Turton, A.G. and Dimmock, G.M. (1979). Nutrient distribution in karri (*Eucalyptus diversicolor* F. Muell.) ecosystems in southwest Western Australia. *For. Ecol. & Manag.* 2, 133-58.

Hingston, F.J., Dimmock, G.M. and Turton, A.G. (1981). Nutrient distribution in a jarrah (*Eucalyptus marginata* Donn ex Sm.) ecosystem in south-west Western Australia. *For. Ecol. & Manag.* 3, 183-207.

Hodgkinson, K.C., Harrington, G.N., Griffin, G.F., Noble, J.C. and Young, M.D. (1984). Management of vegetation with fire. In: Harrington, G.N., Wilson, A.D. and Young, M.D. (eds) "Management of Australia's Rangelands" pp. 141-56. CSIRO, Melbourne, 254 p.

Hopkins, A.J.M. (1985). Fire in the woodlands and associated formations of the semi-arid region of south-western Australia. In: Ford, J. (ed) "Ecology and Management of Fire in Natural Ecosystems of Western Australia". West. Aust. Instit. Tech., Perth.

Hopkins, A.J.M. and Smith, G.T. (in prep.). Effects of fire on the biota. In: Two People's Bay Management Plan.

Humphreys, F.R. and Craig, F.G. (1981). Effects of fire on soil chemical, structural and hydrological properties. In: Gill, A.M., Groves, R.H. and Noble, I.R. (eds) "Fire and the Australian Biota". pp. 177-200. Aust. Acad. Sci., Canberra.

Kessell, S. (1984). Fire management and planning using the PREPLAN modelling system. *Aust. Ranger Bull* 3, 5-6.

Kessell, S.R., Good, R.B. and Potter, M.W. (1982). Computer modelling in natural area management. Aust. Natl. Pks Wildl. Serv. Spec. Publ. 9.

Kimber, P.C. (1978). Increased girth increment associated with crown scorch in jarrah. W.A. For. Dept. Res. Pap. 37, 4 p.

Kimber, R. (1983). Black lightning: Aborigines and fire in Central Australia and the western Desert. *Archeol. in Oceania* 128, 38-45.

Lamont, B.B. (1985). Fire responses of sclerophyll shrublands - a population study approach, with particular reference to the genus *Banksia*. In: Ford, J. (ed.). "Ecology and Management of Fire in Natural Ecosystems of Western Australia". West. Aust. Instit. Tech., Perth.

Leigh, J.H., Boden, R. and Briggs, J. (1984). "Extinct and Endangered Plants of Australia". MacMillan, Melbourne.

Luke, R.H. and McArthur, A.G. (1978). "Bushfires in Australia". Aust. Govt Publ. Serv., Canberra. 359 p.

MacDonald, I.A.W. and Brooks, P.M. (1983). Monitoring for the detection of mammal overabundance in small conservation reserves. In: Owen-Smith, R.N. (ed.). "Management of Large Mammals in Conservation Areas" pp. 187-200, Haum Educational Publ., Pretoria.

McArthur, A.G. and Cheney, N.P. (1966). The characterization of fires in relation to ecological studies. *Aust. For. Res.* 2, 36-45.

McKenzie, N.L. (1984). Biological surveys for nature conservation in the Western Australian Department of Fisheries and Wildlife - a current view. In: Myers *et al.* (eds) Vol. 2, 88-117.

Marchant, N.G. (1984). Flora of the Perth region. In: Moore, S.A. (ed.). "The Management of Small Bush Areas in the Perth Metropolitan Area". pp. 1-5. W.A. Dept. Fish. Wildl., 124 p.

Moore, S.A. (1984) (ed.). "The Management of Small Bush Areas in the Perth Metropolitan Region". W.A. Dept. Fish. Wildl., 124 p.

Mount, A.B. (1972). The derivation and testing of a soil dryness index using run-off data. *Tas. For. Comm. Bull* 4, 31 p.

Muir, B.G. (1985). Fire exclusion: a baseline for change? In: Ford, J. (ed.). "Ecology and Management of Fire in Natural Ecosystems of Western Australia". West. Aust. Instit. Tech., Perth.

Myers, K., Margules, C.R. and Musto, I. (1984) (eds). "Survey Methods for Nature Conservation". CSIRO Div. Water and Land Resources, Canberra.

Noble, I.R., Bary, G.A.V. and Gill, A.M. (1980). McArthur's fire-danger meters expressed as equations. *Aust. J. Ecol.* 5, 201-3.

Noble, I.R. and Slatyer, R.O. (1981). Concepts and models of succession in vascular plant communities subject to recurrent fire. In: Gill, A.M., Groves, R.H. and Noble, I.R. (eds), "Fire and the Australian Biota" pp. 311-35. Aust. Acad. Sci., Canberra, 582 p.

Pate, J.S. and Beard, J.S. (1984) (eds). "Kwongan: Plant Life of the Sandplain". Univ. W.A. Press, Nedlands.

Peet, G.B. (1971). A study of scrub fuels in the jarrah forest of Western Australia. *W.A. For. Dept. Bull. 80.*

Podger, F.D. (1972). *Phytophthora cinnamomi*, a cause of lethal disease in indigenous plant communities in Western Australia. *Phytopathology* 62, 972-81.

Raison, R.J. (1981). More on the effects of intense fires on the long-term productivity of forest sites: reply to comments. *Search* 12, 10-14.

Raison, R.J., Khanna, P.K. and Woods, P.V. (1983). Losses of nitrogen during prescribed burning in a *Eucalyptus pauciflora* forest. *Proc. Ecol. Soc. Aust.* 12, 172-3.

Rothermel, R.C. (1972). A mathematical model for predicting fire spread in wildland fuels. *U.S.D.A. For. Serv. Res. Pap.* INT-115, 40 p.

Saxon, E.C. (1984). "Anticipating the Inevitable: a Patch-burn Strategy for Fire Management at Uluru (Ayers Rock - Mt Olga) National Park". CSIRO, Melbourne, 91 p.

Shea, S. (1975). Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of *Phytophthora cinnamomi*. *W.A. For. Dept. Bull.,* 85.

Shea, S.R., McCormick, J. and Portlock, C.C. (1979). The effect of fires on regeneration of leguminous species in the northern jarrah (*Eucalyptus marginata* Sm) forest of Western Australia. *Aust. J. Ecol.* 4, 195-205.

Skinner, P.R. (1984). Seed production and survival of some legumes in the forests of Western Australia. *W.A. For. Dept. Res. Pap.* 76.

Sneeuwjagt, R.J. and Peet, G.B. (1979). "Forest Fire Behaviour Tables for Western Australia". W.A. For. Dept., Perth.

Stock. W.D. (1985). *An Investigation of the Nitrogen Cycling Processes in a Coastal Fynbos Ecosystem in the South Western Cape Province, South Africa.* PhD. thesis, Univ. Cape Town.

Van Wagner, C.E. (1978). Age-class distribution and the forest fire cycle. *Canad. J. For.* 8, 220-7.

Walker, J., Davis, J.R. and Gill, A.M. (1985) (eds). *Towards an Expert System for Fire Management at Kakadu National Park.* CSIRO Div. Water and Land Resour. Tech. Memo 85/2.

Walker, P.A. and Cocks, K.D. (1984). Computerized choropleth mapping of Australian resource data. *Cartography* 13, 243-51.

Wallace, W.R. (1966). Fire in the jarrah forest environment. *J. Roy. Soc. W.A.* 49, 33-44.

Whelan, R.J. and Main, A.R. (1979). Insect grazing and post-fire plant succession in south-west Australian woodland. *Aust. J. Ecol.* 4, 387-98.

Wilson, J.L. (1984). Nature Conservation Reserves in Australia (1984). *Aust. Natl. Pks Wildl. Serv. Occ. Pap.* 10, 47 p.

Wimbush, D.J. and Costin, A.B. (1979). Trends in vegetation at Kosciusko. I-III. *Aust. J. Bot.* 27, 741-871.

Wycherley, P. (1984). People, fire and weeds: can the vicious cycle be broken? In: Moore, S.A. (ed.) "The Management of Small Bush Areas in the Perth Metropolitan Region". pp. 18-20. W.A. Dept. Fish. Wildl., 124 p.

GLOSSARY

. Buffer

A buffer is a fuel-reduced area, often between two fuel breaks, which surrounds a much larger area treated in a different way.

. Expert system

An expert system is a computer system that allows an enquirer to interrogate the stored knowledge of experts. The knowledge stored is not necessarily proven fact; it may be the opinions of the experts.

. Fire classification

Fires are classified according to the fuel being consumed, whether or not the fire was ignited for management purposes, and the desired effect of the fire. 'Intensity' may be used also but is considered separately under 'fire intensity'. The predominant fuels being consumed may be classified as: grass, shrub, litter, slash (residues from logging activities), or forest (undefined forest fuels or all forest fuels - litter, grass, shrubs, bark on trees, and even canopy leaves - at once). Fires ignited for management purposes may be called 'prescribed', 'control', 'planned' or 'scheduled'. 'Prescribed fire' has been preferred here. Fires may be prescribed for fuel reduction or for legume regeneration for example. Fires other than management fires are often termed 'wild' but this term tends to be associated with 'extreme intensities' which is not always the case with all headfires (i.e. burning with the wind), and never the case with the whole perimeter of any one fire (which shows a wide variety of intensity according to the direction of spread in relation to the direction of the wind. Fires, other than management fires, are here termed, albeit somewhat awkwardly, 'unscheduled' fires.

. Fire intensity

Often used are the terms 'hot' and 'cold' but these are rejected on the grounds that all fires produce temperatures in the surrounds that are higher that ambient, and that the bodies which are presumed to be 'hot' or 'cold' are never designated. Preferred terms are 'high', 'medium' and 'low' intensity or actual measurements according to the Byram (1959) formula.

. Fire regime

A fire regime is a particular combination of occurrences of fires experienced at a point and described in terms of fire frequencies, seasons of occurrence, fire intensities, and types (peat or above-ground).

. Fuel break

Usually called a "fire break", a fuel break is an area without fuel. Fuel breaks are often roads or tracks but can include such things as water bodies, sand dunes and rock exposures.

. Hazard

A hazard is a risk, chance, or threat to something or someone: it may concern injury to people, damage to property, or failure to achieve aims. A heavy fuel load may be considered a potential hazard to the achievement of some objective if ignited under particular weather conditions with an undefined frequency, but in this report 'hazard' is used in the more immediate sense of being related to the effects of any ignition under current conditions.

. Mop-up

Mop-up is the process of extinguishing fires in materials still alight after the flame front has been suppressed. Mop-up is done in order to prevent reignition of the perimeter of the fire area. Mop-up may involve the use of retardants, cutting of trees, and construction of further fuel breaks.

. Research types

The Birch Report on research in CSIRO (Australia, 1977), defined three types of research which have since been related to the time from inception of the research to the anticipated time of application by Dr Bob Ward. 'Tactical, problem-oriented' research has a short period between inception and application (within a few years); 'strategic, mission-oriented' research has a medium period to application (5 to 15 years), and 'fundamental' research has a long period to application. In the context of this review, 'developmental' research was found to be less misunderstood than 'tactical' research.

APPENDIX 1 : People consulted

The following are the people who were consulted alone or as members of small groups:-

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APPENDIX 2 Burning Histories of Forests in which the Emphasis is on Wood Production.

1. Burning history of a jarrah (*E. marginata*) forest.

Jarrah forests in their natural condition were probably uneven aged. Episodic regeneration associated with fires was likely. A feature, in comparison to karri would have been the presence of short lignotuberous plants of jarrah.

Exploitation of the jarrah forest for timber was, and is, by the removal of suitable logs from individual trees or groups of trees (selection logging). Fire exclusion was the norm from about 1920-54 (Wallace 1966) except for 'protective' burning along drainage lines. Prescribed litter fires for fuel-reduction purposes were introduced in the 1950s (Christensen and Kimber 1975). Pre-logging litter fires were policy in the 'exclusion' era but inter-logging periods were kept as free of fire as possible (Wallace 1966). After 1920, top-disposal fires followed logging (Wallace 1966).

An area of high quality jarrah on laterite about 15 km east of Dwellingup was chosen to illustrate burning history since 1937 when the first records were available. The block, of about 6 km square, was dissected by a series of shallow, seasonally swampy drainage lines. In particular, there was a large central flat valley about 5 km long and ½ km wide. The drainage lines presumably did not contain quality trees for timber production. Along the southern edge of the block was a railway line along which many unscheduled fires occurred. The block history is summarized in terms of the large central valley, other drainage lines and edges of the block, the railway line, and an area of productive forest in the southeast.

The large and flat central valley was burned by prescription in spring 1937, spring 1939, autumn 1941, spring 1943, and autumn 1946. An unscheduled fire burned through the area in January 1951. The last prescribed fire targeted on this area was in spring 1956. As portion of a larger area, this area was burned by prescribed fire in autumn 1964, spring 1970, spring 1973 and spring 1979.

Drainage lines were marked out for burning by constructing fuel breaks along each side. The intervening area was burned. Perimeter burning followed a similar practice. Such burning occurred in parts of the area in spring and autumn from 1937 - 1959.

The railway was burned by prescribed fire in a similar way to drainage lines as noted in the last paragraph. In terms of fire history, however, the area is distinctive in being associated with the many unscheduled fires, presumably caused by steam locomotives, from 1937 - 1953.

The chosen segment of 'productive' forest was burned by an unscheduled forest fire in January 1950 and again in January 1961. Prescribed litter fires up to about 3 km^2 began in portions of the productive forest in 1958. The chosen segment of productive forest was burned by prescription in spring 1962, spring 1970, spring 1973, and spring 1979.

From spring 1970, the whole block was treated simultaneously by igniting the area from the air.

The area is now portion of a 'disease risk zone'.

2. Burning history of a karri (*E. diversicolor*) forest.

Ring counts of virgin stands show that karri forests were uneven aged with peaks in the age-frequency distribution every 20-50 years (Breidahl 1983). Coupled with the observation that regeneration of karri by seed fails except after fire or soil disturbance, these data suggest that fires of sufficient intensity to bare the soil, but not kill all the canopy trees, occurred every 20-50 years. From such evidence and observational historical evidence, Breidahl (1983) came to the conclusion that the most likely fire history of the virgin karri forest was one of "rare, catastrophic fires" interspersed with "irregular mild fires" started by lightning or Aborigines.

Selective logging was practised in the post-European period probably along with some top-disposal burning. After about 1970, fuel-reduction burning ('litter fires') became routine (Bradshaw and Lush 1981) while top-disposal burning continued where selective logging was practised. However, also around 1970, there was a shift to clear felling of karri with subsequent slash fires. Now, the older regenerated forests of karri are pole size and carry litter fuel loads of the order of 10-15 t/ha and 'trash' loads of a similar amount ('trash' being the dead remains of a collapsed tall shrub layer and which is < 10 mm diameter). Experimental fuel-reduction burning has begun in these regenerating forests.

The relative youth of management systems in karri forests suggests that the use of clauses such as 'burned every 6-8 years' is unwise unless qualification is added to suggest future practice or time of origin of the practice. Furthermore, it is unwise to assume that the whole area to which the description is given actually experienced those conditions because burning is usually incomplete.

The records of an area of karri forest were sought to illustrate forest burning history. The area chosen was in Brockman Block, about 8 km southeast of Pemberton. From the maps supplied, the centre of this area burned in 1943 (litter fire?), 1948 (top disposal fire), 1949-50 (forest fire), 1965 (litter fire?), 1970 (litter fire) and 1980 (litter fire) or 6 times in 42 years - an average of once in 7 years. The area appears to have been subject to prescribed fuel reduction burning four times. It is well to remember that different areas are likely to show widely different fire histories according to logging practice, distances from settlements and local 'microclimates'. These data suggest that prescribed burning began much earlier in karri than noted in the text (1970).

APPENDIX 3 Fire History of Two People's Bay Nature Reserve.

These notes were compiled by Judith Brown from 'The History & Establishment of the Reserve' by G.R. Chatfield, C.A.L.M. files and aerial photographs.

Before European man arrived (1803) the Aborigines may have burnt areas for hunting purposes or to encourage new growth which attracted their prey. The early explorers, sealers and whalers found the Bay a sheltered anchorage with fresh water and meat. Wildfires could have escaped from their campfires and the fires used to process the whale oil in the Little and Waterfall Beach areas.

In the 1900s the area became an important picnic spot for the people of Albany and nearby farms. Except for quiet times during the wars, the Bay and reserve area has been popular for horseriding (prohibited in the 1960s), fishing, bushwalking and birdwatching. Campfires and barbecues were a risk until they were prohibited. Gas barbecues were installed in the late 1970s.

The neighbouring land started to be cleared soon after the Second World War. Burning the bush before clearing, and the burning of log piles after clearing, would have been a major part of the 'development' process. At least one fire (March 1970) and probably others in earlier times have escaped into the reserve. On the other hand several fires in the early 1960s were thought to have been started on the reserve with the intention of reducing the risk of a wildfire starting and spreading to the nearby private land.

A chronology of fires recorded in the area follows. The sources of information are bracketed.

Pre 1946 (from 1946 photograph)	Several small fires in the Mt Gardner area. Some would have occurred in the summer of 1945-46 while others were detectable as occurring up to 5 years previously.
	A larger fire, c. 1944, burned an area east of Lake Gardner. This may have also burnt the dunes.
	Causes: bushwalkers, lightning, fisherman, unknown, or Army training.
1961 (Webster[1])	'Fire along lake shore' (probably Lake Gardner).
1961-66 (Webster)	'practically annual fires in parts of the reserve closest to the farm' (Tandara).
Feb. 1962 (Webster)	Escape from a driftwood fire at the bottom of a large gully west of Mt Gardner burnt c. 1250 ha (boundaries not certain on 1965 photography).
20 Sept. 1964	Fire burnt from low thick scrub near squatters hut,

1. Mr H.O. Webster, a bird watcher of Albany.

(Webster & 1965 photog.)	in a SSE direction. Approx. 125 ha burnt. Squatters were removed in 1967.
Nov. 1964 (Webster)	An area not definable on 1965 photograph near the picnic ground was burnt from a fire which started on the beach.
Pre 1965 (Jan 65 mosaic & Dec 65 photog.)	Two fires south of Lake Gardner and the dunes, early 1964 or late 1963. Probably the southern one escaped from a fishermans beach fire. Some areas may have been burnt twice.
20 Dec. 1966 (McDonald[2])	Fire appeared to have been lit on a wide front south of the road. Manager and farmhand from Tandara were present. It burnt west of the Sinker Reef track through the dunes towards Nanerup. The following day it escaped towards Mt Gardner but was contained. Much of the area was burnt by 'back burns' lit by members of the local fire brigade.
c. 1967 (photog.)	Fire on the south coast, which probably started from the beach, was contained in some parts by the Rocky Pt track.

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2. Mr M. MacDonald, Fauna Officer for Albany followed by Mr A.T. Pearce.

18 Mar. 1968 (photog. Pearce[2])	Buffer burnt along parts of the Mt Gardner and Little Beach tracks.
24 Mar. 1968 (1969 photog. Pearce)	Probably escaped from buffer fire area and burnt an area 100-800 m wide in a SW direction to the coast. About 125 ha burnt.
11-17 Mar 1970 Burbidge[3] & Webster)	Escaped from Tandara (burning log pile) and burnt west of Lake Gardner (contained in the eastern front). Large backburn was west from buffer area east of the lake. Most of the southern sanddunes were burnt (800 ha burnt).
28 Mar. 1970 (Pearce)	Fire escaped from the north-west point of the reserve and burnt nearly to the road (about 40 ha burnt) (uncertain boundaries 1973 photography).
Sept. 1972 (1973 photog.)	Southern side of main road and parts of Sinker Reef track buffers burnt.
April 1974	Fire escaped from farm west of the reserve, crossed the Goodga River and burnt an area of the reserve north of Moates Lake.

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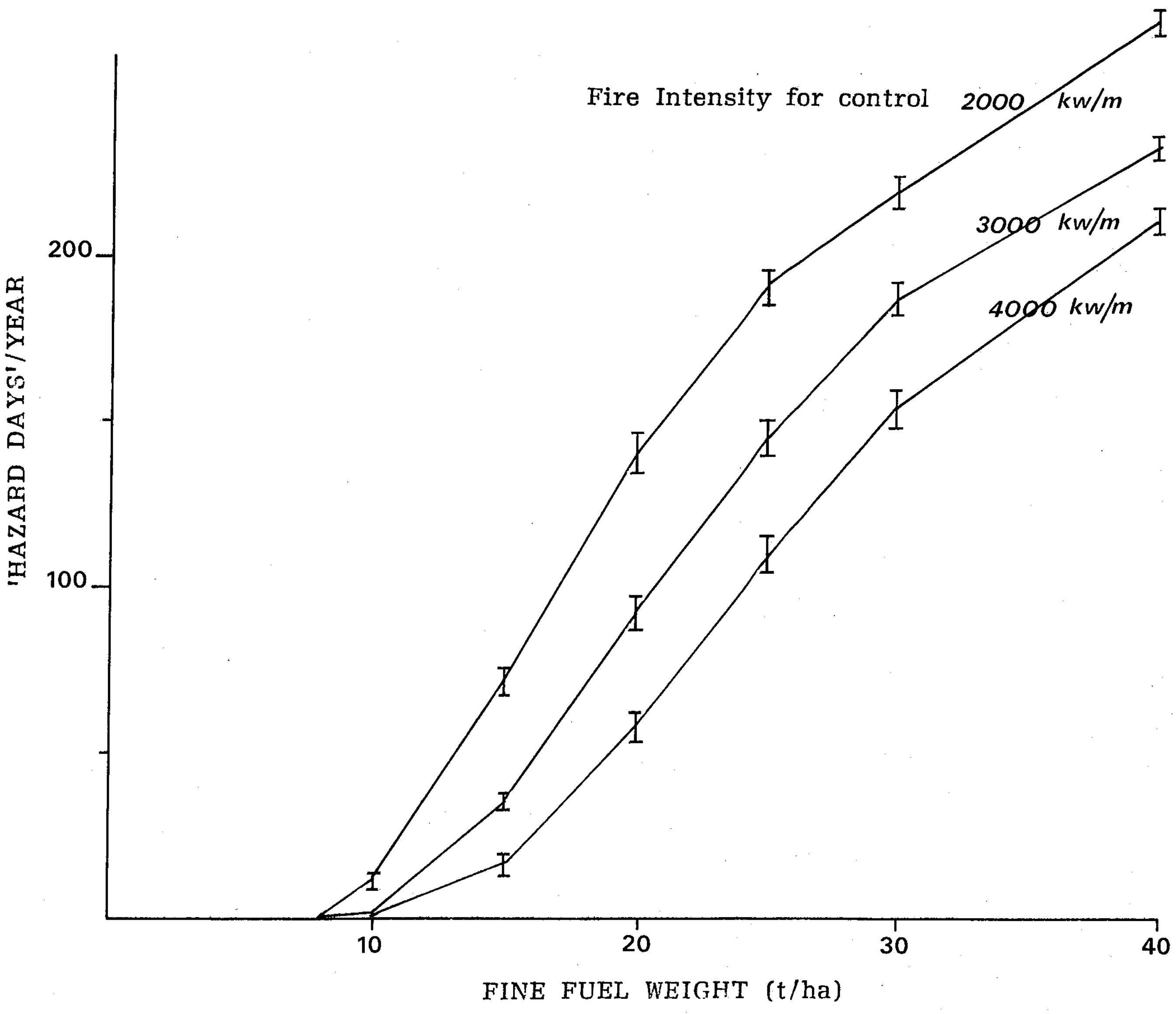
3. Dr. A. Burbidge, C.A.L.M.

Sept. 1978	Fire lit on the northern tip of the reserve by neighbouring farmer. Not a severe fire.
1976-83	Buffer strip in 12 parts formed as approx. 2 parts per year were burnt.

APPENDIX 4 Average number of days per year ('hazard days') on which fire control would fail given a particular intensity limit for control.

The graph shows the average number of 'hazard days' calculated over a 40 year period to 1985 against fine-fuel weight. Intensities were calculated according to the formula of Byram (1959) after calculating daily forest fire danger index at 3 pm according to the equations of Noble *et al.* (1980). The soil-moisture model of Mount (1972) was used. Weather data are for Perth airport. Fire control using the best equipment may be expected to fail when fire intensities exceed 3000-4000 kw/m. This analysis is tentative and is given for illustrative purposes only.



APPENDIX 5 Current fire research projects in C.A.L.M. and other relevant Institutions.

(a) C.A.L.M.

- Abbott, I. Effects of fires on litter- and soil-invertebrates, soil, trees.

- Brown, J. Fire history from *Xanthorrhoea* flowering and growth.

- Burrows, N.D. Fire effects on *Pinus radiata* and *P. pinaster*; estimation of amount and distribution of *Pinus* slash; fuel reduction in radiata slash; grassing trial in *Pinus* plantations; fire behaviour in Stirling Ranges and Lake Muir; fire-retardant durability; behaviour of large scale massed fire in jarrah'; laboratory studies of moving fire storms; jarrah and marri bark; fire resistance of *Banksia grandis*.

- Christensen, P. Animal succession following intense fire in karri forest; woylie and tammar populations following autumn fires in jarrah.

- Davey, A. Fuel reduction by scrub rolling and burning in bauxite rehabilitation areas.

- De Braganca, L. Efficiency of crushing versus burning *Pinus pinaster* for second rotation.

- Friend, J.A. Effects of fires on numbats.

- Hopkins, A.J.M. Effects of fires on vegetation at Barrow Island, Mt Lesueur, Middle Island (Recherche Archipelago), Tutanning Reserve, Two Peoples Bay Reserve; population structure and reproductive characteristics of "important" plant species in relation to fires; fire-management systems.

- Kinnear, J.E. Fire ecology of the woylie at Tutanning; fire ecology of rock wallabies at Dampier Archipelago and in the Pilbara; fire ecology of the tammar at Kalbarri.

- Liddelow, G. Effects of frequency and season of burning on scrub communities; effects of "controlled" burning on larger macropods; effects of an intense karri fire on the bush rat; effects of karri management on birds.

- Maisey, K. Effects of fires on termite numbers.

- Mason, M. Succession of animals following fire in ti-tree swamp.

- McCaw, L. Effects of fires on young karri; fuel drying in young karri stands; prescribed burning in young karri.

- Moore, R. Silvicultural alternatives for fuel-reduced buffers.

- Prince, R.I.T. Fire ecology (of plants and animals) on Dorre Island.

- Walsh, P. Heat penetration of *Banksia grandis* bark.

- Ward, B.G. Drying trial for forest litter.

(b) Other Institutions

- Bushfires Board. In association with the University of Western Australia, a study of fuel accumulation in the northern sandplain has been completed recently.

- CSIRO Forest Research (Wembley). Aspects of the nutrient cycling and nutrition of forest trees.

- CSIRO Forest Research (Canberra). The newly-formed National Bushfire Research Unit intends to study fire behaviour in all the main fuel types of Australia with a view to creating fire models and a more suitable National Fire Danger Rating System.

- CSIRO Wildlife and Rangelands Research (Helena Valley). An investigation of the problems of small isolated reserves.

- Murdoch University, Biology Department. Fire-related dynamics of small vertebrates in *Banksia* woodland.

- University of Western Australia, Botany Department. A number of theses and papers have concerned plant-species responses to fires, biomass accumulation and plant 'succession'. Such studies are expected to continue.

- Western Australian Institute of Technology, Biology Department. *Banksia* demography (especially rare species) and invertebrates in relation to fire.

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