The Assessment of Resource Capability in Rangelands

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Contents

List of figures

Preface

Trial and error have played a major role in the agricultural development of Australia over the past two hundred years. The early European settlers, confronted with a climate, soils and ecosystems very different from those they were used to, had no precedents to guide them in the establishment of farming systems. Over time, and with many successes and failures, people were able to identify which types of cropping or livestock enterprises were best suited to particular parts of the country. Many of these systems were highly productive, and were the foundations for the economic development of the nation.

Over the past two decades or so, there has been a growing realisation amongst farmers and the wider community that many of our agricultural systems, though productive, are not ecologically sustainable. There are many examples of continued depletion and degradation of natural resources which threaten the long-term viability of farming enterprises and the value of those resources for other uses. This realisation has led to a growing interest in understanding and assessing resource capability, so as to provide a sound basis both for resource allocation (determining the most appropriate use of natural resources) and to guide day-to-day management decisions and practice.

The opening of Australia's rangelands to extensive pastoralism has followed this pattern. In the absence of definitive, quantitative data, governments and graziers alike have had to base their judgments about rangeland use and management on trial and error. This is especially difficult in the rangelands because of the highly-variable climate, the influence of episodic events, and the difficulty of identifying the effects of management decisions except over long time-scales. Records show that in the past there have been periods of significant over-stocking with domestic animals and, in consequence, substantial degradation in some areas; for some regions this trend has now been reversed with rangelands now in better condition than previously, but there are also examples where the country has failed to recover from poor management in the past.

More recently, rangeland managers have had to consider new factors influencing their decision-making. There is a growing interest in alternative uses of the rangelands. The pastoral industries are becoming more aware of the need for, and potential market benefits of, proving their environmental soundness. There is a growing interest by the wider community in the long-term management of inland Australia. It is therefore not surprising that there is increasing interest in ways of defining the resource capability, or carrying capacity, of rangeland regions for different uses, and in finding improved methods for quantifying the effects of management decisions in order to provide the feedback that pastoralists and others need if they are to test and improve their decision-making.

This paper reports a short-term study on the assessment of resource capability in rangelands. The study considers the matter of resource capability within the context of land use planning. It recognises that measures of capability (carrying capacity) need to be quantified in relation to different potential land uses such that the costs and benefits of different uses and different mixes of uses can be assessed. The study also acknowledges that resource capability varies with the management objectives set, and with the range of outcomes (economic, ecological or social) desired. There is likely to be a wide range of possible carrying capacities within any rangeland region, or even in land units within that region, depending upon the outcome required in terms of maintenance or improvement of range condition as specified for any particular management objectives. This point is too often ignored, and consequently many interested parties (particularly non-resident stakeholders) have been dissatisfied with past land use decisions in the rangelands, and all too often alternative land uses are disregarded. At the same time, this issue represents a particular problem for range managers, because there are as yet no clearly-stated goals for the outcomes of rangeland management that are generally accepted or widely held amongst the Australian community. The National Rangeland Management Strategy is an important step towards creating a shared vision.

In order to make practical use of estimates of carrying capacity in the rangelands, the management objectives for different land use options must be defined clearly, the practical means of achieving those objectives must be known and available to managers, and the costs and benefits of the different options, both to the enterprise and to wider society, must also be transparent and known. The study reported here attempts to define these options and establish practical methods of achieving the corresponding objectives. The study was undertaken by Dr Lamar Smith of the University of Arizona, working with Dr Paul Novelly of Agriculture Western Australia, and was based in the Kimberley region of Western Australia. Dr Smith has a long experience in the development and application of techniques to assess carrying capacity and to monitor the effects of management, and has published widely on this topic. Moreover, his experience comes from an area where the conflicts amongst competing uses of rangelands are more pronounced than those in northern Australia at present. The methods he has developed have had to be transparent yet rigorous in order to ensure that land use and land management decisions can be understood by different stakeholders and defended by managers when necessary.

Drs Smith and Novelly have focused their attention on grazing by domestic stock by the pastoral industry, but the methods proposed can be adapted and used for other potential land uses in other areas. The authors have considered both potential carrying capacity (the estimated carrying capacity for a paddock or a property, if all pasture types are in good condition and the area fully developed) and current carrying capacity (the estimated carrying capacity for the same area under current range condition).

It seems likely that estimates of carrying capacity or other measures of resource capability will retain a subjective element in the foreseeable future. But, by adopting a standard framework with identified criteria, both land managers and other stakeholders in sustainable rangeland management will be able to derive resource capability guidelines for a series of agreed outcomes, will be able to assess the costs and benefits of different land uses and management objectives, and will then be in a much better position to decide which resource use options are acceptable and which are likely to be non-viable in economic, ecological or social terms.

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The Assessment of Resource Capability in Rangelands

Summary

The purpose of this project was to assist Agriculture Western Australia to develop a procedure for determining resource capability as a basis for the assessment and monitoring of rangelands in the grasslands of northern Australia, with special reference to the Kimberley region of Western Australia (WA). The report is based on analyses and observations made during March–June 1996 in Kununurra, WA.

Rangeland assessment by Agriculture Western Australia has mainly provided information for the management of grazing leases. In recent years there has been increasing interest in other uses and values of the rangelands, and increasing pressure on the government to report on the condition of the land and the sustainability of land uses. Therefore, a major aim of this project was to discover how rangeland assessment procedures could be modified to meet more effectively the needs of pastoral management, non-pastoral purposes, and the regional reporting of ecological conditions and effects on land use.

Our main recommendations are:

1. Existing land systems and land units should be organised into rainfall zones which reflect differences in the composition and potential productivity of vegetation.

2. Emphasis in classification and mapping should be shifted from pasture types to land units, and the state-and-transition approach to describing potential vegetation and reaction to management should be emphasised.

3. A system of classifying riparian areas by land units should be developed to complement the land-system approach.

4. A database of analytical and interpretative information for different land systems should be developed.

5. Field sampling procedures should be modified to obtain estimates of vegetation attributes and range condition that are more representative of individual paddocks/properties, and that also sample areas where there is no livestock production or it is a secondary objective of land management.

6. Additional data on the occurrence of species, on vegetation structure and on soil conditions need to be collected in field traverses to make data interpretation for non-livestock purposes possible.

7. A clearer purpose should be established for rating livestock carrying-capacity and for using the data to form policies.

8. Technical data and stocking rate information need to be improved. A number of suggestions are made.

9. A common system of range survey and monitoring should be developed for all northern Australia's types of savanna and grassland.

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Introduction

The purpose of this project was to assist Agriculture Western Australia in defining a procedure or template for the determination of resource capability of land as a basis for assessment and monitoring of rangelands in the grasslands of northern Australia, with special reference to the Kimberley region of Western Australia. The project proposal (The Assessment of Resource Capability in Rangelands) specified seven tasks:

1. The definition of the requirements of an adequate technique to provide a rangeland inventory and/or assess its capability, basing that definition on the probable uses of the area and relating it to the concept of variable or multiple use.

2. The collation of information on land systems and types of pasture with information on the current and historical stocking of specific sites.

3. The assessment of existing techniques and the identification of their limitations, particularly in their application to non-traditional uses.

4. Specification of the differences between existing and required techniques, a definition of the steps needed to overcome them and (where appropriate) the field-testing of such steps.

5. Comparison of the estimates of carrying capacity for domestic stock linked to inventory outcomes, with the resource capacities on areas which are known to be well managed for other purposes.

6. Identification of where the information to make assessments is lacking, and a listing in order of priority of the gaps in the necessary data.

7. The development of a final methodology for the outcomes for which appropriate information is available, and the listing of gaps in knowledge which can be dealt with in linked proposals.

Tropical woodland and grassland ranges in the Kimberley region of Western Australia, and in the Northern Territory and Queensland, have been used and managed primarily for extensive cattle production for over 100 years. Over that time there has been considerable degradation of the ranges, especially in more accessible and well-watered areas, because of lack of knowledge and of economic conditions which discouraged investment in managing the ranges more extensively.

In the past 20 to 40 years, ecological research and management experience have furnished the basis for methods of rangeland assessment which were aimed at the protection of the watershed and the sustainable use of these lands for livestock production. More recently, increasing interest in conservation biology and tourism have demonstrated the need for broadening the scope and objectives of rangeland resource-assessment.

Information is needed to serve three general needs:

1. to help guide livestock-grazing management for the benefit of livestock production while accommodating other uses and values;

2. to determine the resource capabilities and management effects for non-pastoral uses and values;

3. to provide a means of documenting and reporting on the status and sustainability of land uses of all types as a basis for public policy and accountability.

Procedure

This report is based on analyses and observations made during April–June, 1996 when the principal author was in Kununurra, Western Australia. The first step was to review written material describing the rangelands of northern Australia and the present methods of assessing their condition and carrying capacity. Next, completed range survey reports from the Kimberley were analysed to determine how well the estimated carrying capacities for cattle correlated with the actual stocking records, as reported to the Lands Department, and how they related to other features such as rainfall and land-system productivity.

Several field trips and numerous interviews were carried out to gain familiarity with the various rangeland types, range management problems and research studies, and the application of range assessment methods. These included:

- Trip to Kidman Springs Research Station (Northern Territory) with Andrew Craig and discussions with staff of the Department of Primary Industries and Fisheries.

- Trip to Derby Office of Agriculture Western Australia and participation in range survey on Fossil Downs Station.

- Participation in the Northern Australia Tropical Transect workshop in the Northern Territory with various researchers.

- Participation in field trials and discussions of the method of assessing soil condition with David Tongway (CSIRO Division of Wildlife and Ecology) and all range-assessment staff of Agriculture Western Australia on Margaret Downs Station.

- Visits to a number of other cattle stations (Newry, Spring Creek, Rosewood, Lissadell, Springvale) with research and extension people.

- Interview with Gordon Graham of the Department of Conservation and Land Management about information needs for conservation and wildlife purposes.

- Telephone interview with Allan Payne, Agriculture Western Australia, Perth, on details of the development of the current range-survey methodology.

After leaving Kununurra, visits were made to Alice Springs and Townsville to discuss rangeland assessment and other research with Dr Margaret Friedel, CSIRO Division of Wildlife and Ecology, and Dr Joel Brown, CSIRO Division of Tropical Pastures. Finally, the conclusions reached in preparing this report were greatly influenced by the history of successes and failures on the part of land management agencies in the United States in their efforts to implement rangeland assessment methodology.

Purpose and Guidelines for Rangeland Assessment

Agriculture Western Australia in the Kimberley region has carried out rangeland assessment mainly to provide information for the management of grazing leases. The same is generally true of rangeland assessment in other areas of northern Australia. Surveys and interpretations of rangeland condition, soil condition, and livestock carrying capacity have been based on paddocks and grazing leases because these are the management units of interest. Likewise, the monitoring sites for the Western Australia Range Monitoring System (WARMS) have been the 'key areas' for pastoral management, ie. important pasture types which are expected to show changes in vegetation or soils as a result of livestock grazing management. The emphasis has been on helping pastoralists to improve their management rather than on regulation or regional reporting.

In recent years there has been increasing interest in other uses and functions of the rangelands, such as wildlife, endangered species, watershed function, fire management, and the interaction of these with livestock grazing. Large areas have been set aside for aboriginal lands and for conservation areas where livestock are not grazed or where economic return from livestock is not the main emphasis. There has also been increasing pressure on the government to report on the condition of the land and the sustainability of current land uses. These changing values and demands have caused Agriculture Western Australia, and similar agencies in other areas, to re-think their approach to rangeland assessment and monitoring and to the ways in which the data are used.

The basic questions about possible changes in methodology and/or the collection of data include:

1. How should rangeland survey procedures and the collection of data about pastoral leases be modified to better serve the needs of management for livestock production, watershed protection and other purposes?

2. What modifications, if any, are needed to serve the management needs of conservation reserves and aboriginal lands?

3. How should sampling and/or the collection of data be modified to serve the need for monitoring changes in resource conditions and making regional reports?

4. How can the requirements for public reporting and accountability be reconciled with the protection of privacy and the property rights of lessees?

This report does not purport to answer all these questions, but it does work from the following assumptions and principles:

1. Any interpretations made from rangeland assessments in northern Australia, where land is mostly leasehold, are likely to be challenged by someone.

2. As far as possible, data collection should be value-free and based on well-defined attributes of resources and accepted principles of sampling and measurement.

3. As far as possible, value-judgments or interpretations of use should be kept separate from data collection and should be based on sound experience and scientific knowledge.

Summary of Current Rangeland Assessment Procedures

This section summarises the methods currently used for rangeland assessment and monitoring by Agriculture Western Australia in the Kimberley. A more detailed analysis forms Appendix A.

Classification and Mapping

Rangeland classification and mapping is based on the resource surveys carried out by CSIRO Division of Land Research and Regional Surveys (Speck *et al.* 1960; Speck *et al.* 1964; Stewart *et al.* 1970). All lands were mapped into *land systems* which are "an area or group of areas throughout which can be recognised a recurring pattern of topography, soils, and vegetation" (Speck *et al.* 1960). Land systems are composed of *land units.* A *simple land unit* has a particular soil and particular vegetation community associated with a particular topographic form. Sometimes similar land units are grouped in *complex land units.* The same land units may be found in different land systems, but in different combinations or proportions (Speck *et al.* 1960). *Pasture types* are also listed. These are general vegetation types grouped according to the dominant forage species.

Field Studies—Range Evaluation Site Method

Range surveys are based on techniques developed by Payne *et al.* (1974 and 1979) in a survey of range conditions of the West Kimberley area. That survey was based on two complementary methods: the Range Evaluation Site Method (RESM) and the Traverse Method (TM). The RESM consisted of a number of permanently located sites chosen to represent various pasture types and patterns on aerial photos. At each site the data recorded included:

1. land system, land unit and pasture type;
2. list of plant species classified as desirable, intermediate, undesirable (with respect to forage value);
3. list of tree and shrub species;
4. soil type and a description of any erosion observed;
5. an erosion index for wind erosion and water erosion;
6. pasture condition rating;
7. range condition rating ; and
8. photograph of site.

The *erosion index* was a rating of water or wind erosion based on a scorecard with a range of 0–25 points. *Pasture condition* was based on a scorecard which rated forage quality, forage quantity and forage vigour each on a scale of 0–25 points, for a possible total of 75 points. Plants were classified as desirable, intermediate and undesirable based mainly according to forage value. *Range condition* was a combined expression of erosion and pasture condition grouped into three range condition classes: good, fair and bad. Data from 387 of these sites were used to develop the range condition guides for the West Kimberley (Payne *et al.* 1974).

Traverse Method—Range Condition

The TM was used to gather range condition information over a large area of land in a short time. Traverses were conducted on as many roads and tracks as possible throughout the area. The technique involved visual assessment of erosion and pasture condition at approximately 1.6 km intervals from a vehicle moving at about 40 km/h. At each observation point the land system, land unit and pasture type were recorded and two assessors rated wind erosion, water erosion and pasture condition into four–five classes based on criteria similar to the RESM described above. These classes were then combined into range condition classes which represent a combination of soil and pasture condition.

The Traverse Method, along with the range condition guides developed by Payne *et al.* (1974), is the method used at present for range condition surveys of pastoral leases throughout the West, East and North Kimberley areas. However, no RESM study has been carried out in the East and North Kimberley, so these areas lack range condition guides developed specifically for the pasture types found there. The West Kimberley range condition guides have been extrapolated for use in the other areas, with some *ad hoc* adjustments based on professional judgement where needed.

Carrying Capacity Estimates

Carrying capacity estimates are based on the range condition survey information. Payne et al. (1979) developed carrying capacity guides for each range condition class for each pasture type in the West Kimberley. These ratings were based on the composition of desirable, intermediate and undesirable forage species, safe levels of use, and the relative palatability of each species or group of species. The total amount of forage production by pasture type and condition class was based on clippings of biomass.

Forage production was converted to *livestock units* (LSU) using a forage requirement of 4100 kg/year per LSU. The carrying capacity for a given pasture type can be obtained for each condition class from the tables developed in Payne's report.

These guides to carrying capacity are used for surveys throughout the Kimberley area, although there has been little or no additional study of forage production and/or utilisation to verify the validity of the estimates outside the area for which they were developed.

Two estimates of carrying capacity are made: *potential carrying capacity* (PCC) and *current carrying capacity* (CCC). PCC is the estimated carrying capacity for a paddock or station if all pasture types were in good condition and the area fully developed. CCC is the estimated carrying capacity for the same area with the current range condition, also assuming the area is fully developed. Thus, CCC cannot exceed PCC, and is usually considerably less, depending on the condition of the rangeland. 'Fully developed' means that all forage in the pasture type is reasonably accessible to livestock, ie. it is not excessively far from water or otherwise inaccessible.

'Land System' Method

In recognition of the fact that detailed guides to pasture condition and carrying capacity have not been developed specifically for the East and North Kimberley, a slightly different procedure has been adopted for some of the surveys in these areas. The traverses and field observations are the same as described above. The condition of the pasture type at each observation point is determined by the general criteria as previously described. However, instead of reporting the condition of each pasture type and the carrying capacity of each pasture type, the condition and carrying capacity are assigned on a land-system basis. The area (hectares) of each land system in the paddock or station is determined from published maps. A range condition class is assigned to the land system according to the average condition of each observation point encountered within the land system, regardless of pasture type. The carrying capacity for the land system in good condition is obtained from a published map of land systems which classifies them into five potential pastoral categories: unsuitable, very low, low, moderate and high, with a range of carrying capacities assigned to each potential class. The carrying capacity of each land system is then reduced by an arbitrary percentage for fair and poor condition. Land systems not traversed are assumed to be in good condition.

Western Australia Range Monitoring System (WARMS)

A later development is the system of permanent rangeland monitoring sites called WARMS. The system was initially developed for the shrublands in southern Western Australia, and then modified for the tropical grasslands in the north. Initially WARMS was intended to provide long-term trend data for management decisions on pastoral leases. More recently WARMS has been seen as providing data for regional reporting on range condition and trends. About 450 monitoring sites have been located in the Kimberley.

These were chosen to represent the major pasture types with emphasis on the more productive types for grazing purposes.

At each monitoring site the following data are collected:

1. Land system, land unit, pasture type

2. Frequency of plant species (% occurrence in quadrats)

3. Canopy cover of trees and shrubs greater than 1 m in height (Bitterlich gauge)

4. Photographs

Currently, incorporation of a rating system for soil condition is being developed which will have data on basal vegetation cover, ground cover types, spacing and width of obstructions to water flow, and soil surface condition (cryptogamic crusts, surface roughness, etc.) (Tongway and Hindley 1995). WARMS sites are generally re-measured every three years with one third of the sites read each year.

Complementary monitoring locations have been established on some pastoral leases. These consist of photo points which lease managers re-photograph at intervals as frequent as yearly. These monitoring points are strictly for the use of station managers to document management effects.

Remote Sensing

Satellite imagery is available at multiple dates throughout the year. Data are of two types. One gives a 'green index' which can be correlated with the amount and distribution of rainfall throughout the region. Such data could be of considerable help in interpreting monitoring data on a property or in a region. Satellite imagery is also available which shows bush fire occurrence. Such data can be used to monitor the extent and frequency of burning over time and to help explain other monitoring data.

Analysis of Stocking Rate Data

Stocking rate data were available from 97 pastoral leases in the Kimberley region for the period of 1984 through 1995. These data were furnished to the Lands Department by the owners or managers of the leases. Data reported were estimates of cattle numbers by age and sex class, and these numbers were converted to Livestock Units (LSU) by the Lands Department.

It was thought that an analysis of these data and a comparison of the actual stocking records with the carrying capacity of the properties estimated from range surveys would be useful. The actual number of livestock carried on a property over a period of years should reflect the manager's perception of the carrying capacity under current range conditions and level of development. Actual stocking was not expected to be the same as either the potential or current carrying capacity as estimated by the range surveys carried out by Agriculture Western Australia because those surveys assume 'full development' of the property. Nevertheless, either there should be some correlation between actual stocking and estimated capacities, or it may be possible to identify why the figures do not correlate on some properties. The reasons might include a low level of development, the amount of rainfall, the overall land quality and so on.

A number of analyses were carried out on various subsets of the properties and for a number of factors which might affect carrying capacity. The results of these analyses are reported in detail in Appendix B. In general, they were not very informative. The main conclusions were:

1. Procedures for calculating carrying capacity estimates need to be standardised. Carrying capacity for all properties where a survey was available were re-calculated using the 'land system' approach described above and the correlation between this 'standard' estimate and the estimate used in the report was determined. Although in general correlations were good, the wide divergence between carrying capacity by the standard method compared with the survey report shows that the method used to assign a carrying capacity to land systems, pasture types and condition classes has a major effect on the estimates.

2. The data available on actual stocking rates are not reliable enough to enable valid conclusions to be drawn on the effects of rainfall, land quality, availability of water, or other management factors on the stocking rates. Reliable data would enable these factors to be studied, so that interpretations of condition and trend data could be made, both on an individual property and regionally. Part of the problem with these data may be that the reporting is done in June each year.

At this time pastoralists are mustering and do not have time to give the reports careful attention, nor do they have good figures available on numbers at that time. Another problem is that social and economic factors may have more to do with actual stocking rates than the carrying capacity of the land. During the period covered by the data many leases were de-stocked because of the Brucellosis/Tuberculosis Eradication Campaign. Many properties were improved with fencing and water developments and the type of cattle was changed. Reduction of feral donkeys and buffalos also affected forage supplies. The existence of properties where livestock grazing is not strictly a commercial enterprise may also weaken the relationship between the actual stocking and the carrying capacity.

Recommendations:

1. Encourage lease managers to report data accurately and to provide other information to show whether the data represent full stocking. Changing the time of reporting to 1 January should help. In addition, managers must be assured that such data will not be used against them. Rather, data on stocking rates, sex and age distribution in herds, turnoff rates, etc. should be summarised by region and returned to the managers to assist them in comparing their operation with others in the area (see Wilson *et al.* 1984).

2. Further efforts should be made to analyse the relationships between rainfall, land systems, water distribution and other factors. Existing data could be stratified further than was done in this study. Also, actual stocking data might be improved by questionnaires or interviews with experienced graziers in the area of interest.

Data Needs for Non-pastoral Purposes

The inventory and monitoring methods used by Agriculture Western Australia have been primarily oriented towards providing information for managing cattle stations and for the regional reporting of the effects of livestock grazing on range conditions. The collection of data on pastoral leases has been guided by the assumption that cattle grazing is the primary influence on vegetation and soils and that the main objective of management is to improve forage production on a sustainable basis. There is a need, and an opportunity, to expand the scope of the survey and monitoring procedures to meet the needs of other land uses and conservation concerns, perhaps in collaboration with other agencies such as the Department of Conservation and Land Management (CALM).

The effects of the pastoral industry on vegetation, soil and wildlife will no doubt come under increasing scrutiny from environmental interests. It is therefore important that pastoral management consider the possible effects on other values, modify management plans to accommodate non-pastoral values, and document any success in improving environmental conditions. Thus, the inclusion of non-pastoral uses and values in the range survey and monitoring procedures is important to the interests of the pastoral industry itself, and that is sufficient reason to look at ways in which those procedures could be improved.

Not all land is included in pastoral leases; large portions of northern Australia are increasingly being included in aboriginal reserves or conservation reserves. These lands differ from pastoral leases only in that domestic livestock grazing is not the principal use (although some of them are grazed). All other processes and concerns are the same, namely fire occurrence, drought effects, riparian functions, water quality, feral animals and weeds, endangered species, etc. Thus, it seems that management of these lands could well employ a similar approach to rangeland surveys as a basis for decision making.

Any system of regional reporting of environmental conditions on rangelands (eg. WARMS) should include these non-pastoral lands as well. A uniform system of basic monitoring would be more efficient and more useful than if each government agency devised a different one. In fact, it seems worthwhile to try to establish a uniform system right across the tropical grasslands zone from the Kimberley to the Northern Territory and Queensland.

The following section discusses some of the non-pastoral values concerned and the kinds of information required by each.

Sustainability

The underlying principle of all natural resource management and conservation is that resources should be managed for sustainability. Viewpoints on the nature of sustainability differ, but a commonly accepted one is that our use and management of renewable resources should not diminish the options for future generations to use those resources. To most resource managers the use and modification of resources is compatible with sustainability as long as any changes induced are not irreversible. Irreversible changes are the result of soil degradation or the loss of genetic diversity. Both of these can be caused by forces beyond our control, such as landscape evolution or climatic change, and it is difficult to separate their effects from those of controllable factors such as fire and grazing.

The basic resources we manage are soil and vegetation. These, in turn, affect water and wildlife. "Vegetation may change but soils degrade" (Harrington, Wilson and Young 1984). The basic potential for producing vegetation is determined by the climate, topography and soil, but vegetation types may vary as a result of fire, grazing, weather, or other factors. The different vegetation communities which may occur on a site may represent several more or less steady states, with transitions among them determined by management and natural forces (Westoby *et al.* 1989). Each vegetation community (including those containing non-native species) has certain resource values and wildlife populations associated with it. This concept forms a useful basis for resource management purposes. Changes in purposes. Changes in vegetation (species, structure) may indicate changes from one state to another and these may be desirable or undesirable depending on management objectives. Vegetation change is not in itself indicative of environmental degradation or loss of sustainability. Most range scientists agree that soil degradation is the major cause of environmental degradation which is for all practical purposes irreversible.

Soil Degradation

The primary cause of soil degradation on most rangelands is erosion. Other causes can include leaching of nutrients, structural collapse, salinisation, etc. Unfortunately soil erosion is difficult to assess directly in the field for several reasons. One is that erosion is a natural process on most range sites so that our concern is to identify *accelerated erosion* which is an increase in the *rate* of erosion because of management. Another is that erosion occurs at varying rates and at unpredictable times, depending on rain or wind storms, which makes direct observation of erosion rates difficult. Another is that by the time evidence of erosion is observable some degradation may have already occurred.

Two types of field observation have been used to evaluate erosion or erosion hazard. One is the description of *erosion indicators* such as rills, gullies, scalding, gravel accumulation, pedestalling, soil deposition, etc.

These are the kinds of indicator presently used to rate wind and water erosion during range surveys in the Kimberley. Such indicators are relatively easy to rate visually in the field, but difficult to quantify without time-consuming measurements.

The second type is the use of vegetation and ground cover indicators of *erosion hazard* (the potential for erosion to occur). These include bare soil, litter and gravel cover, basal vegetation cover, soil surface condition, plant spacing, and structural type of vegetation. Most of these are fairly easy to measure quantitatively in the field but are indirect measures, ie. they do not measure erosion but are attributes known to influence the amount of erosion that can occur. Vegetation and soil surface attributes also have the advantage of being able to show 'trends' toward threshold levels of soil protection.

The methods being developed by CSIRO (Tongway and Hindley 1995) incorporate several of these vegetation/soil surface indicators and have proven to be reasonably fast and repeatable means of evaluating soil condition in the field.

Vegetation Change

Measuring vegetation change is fundamental to rangeland management whatever the management objectives or ecological processes involved. Monitoring change requires that the vegetation be precisely described at two or more intervals so that significant changes can be detected. From a management standpoint it is also necessary to establish what is causing any changes that are observed and to detect them in time to take corrective action. Because rangelands usually contain a large number of species, varied life forms (grasses, shrubs, trees, forbs), and are subject to high spatial and temporal variability and a variety of natural and management influences, it is necessary to consider carefully what attributes are measured, the time and place of measurement, the precision required to detect 'significant' differences, and the kinds of management decisions to be made as a result of the data. Because of time (and money) constraints it is not possible to measure everything we would like to know.

For livestock grazing management, desirable information includes the vegetation changes related to forage production, woody plant invasion, and poisonous or noxious plants. Other information needs are discussed in the following sections.

Biodiversity

Biodiversity is often promoted as a management goal for conservation but often without a definition (West 1993). Diversity may be considered on a number of scales, from the genetic to the world ecosystem. Rangeland monitoring can furnish information primarily at two levels: the community and the landscape.

Diversity at the community level refers either to species or life forms. Either can be described by the *number* of species or the *proportions* of species (or life forms), ie. richness or evenness indices. One requires a complete list of species or life forms and the other an estimate of composition (relative abundance). Composition can be based on density, cover, or biomass, each of which gives a somewhat different result.

The community diversity expected on a given land system is influenced by the variability of soil and microsites characterising the land unit and by the 'state' of the vegetation as a result of management and natural stresses. The WARMS data currently provide a species list and information on frequency by species, which gives some measure of community diversity. The traverse method does not give any information that can be used to express either species or life form diversity.

Diversity at a landscape level depends partly on the diversity within the communities that make up the landscape (discussed above) and partly on the diversity among communities in the landscape. Diversity at this level depends to a great extent on the number and pattern of different land units in the landscape and, secondarily, on the states of the plant communities on the various land units. The land system/land unit approach, along with range condition surveys, seems to offer a good basis for expressing the potential and actual biodiversity of an area.

Water

Water quality may be influenced by changes in vegetation types and/or soil erosion on rangelands as a result of natural processes or management. Rangeland monitoring generally aims at measuring the contributing factors on the catchment rather than direct measurement of water quality in the stream channel, reservoir or ground water.

Wildlife

'Wildlife' encompasses many kinds of animal which differ widely in their habitat requirements, range, and population dynamics. It is difficult to generalise about the most appropriate data for wildlife interpretations. Generally, data will be sought for one of two purposes:

1. to evaluate habitat for one or more species; or
2. to use the presence or abundance of a wildlife species as an indicator of ecosystem 'health'.

Habitat Assessment

Habitat for wildlife consists of two components: food (and water) and cover. These are called 'life requisites.' For primary consumers, food is related mainly to the kinds of plant available, for these determine the quantity and quality of food. Quality is often of greater importance than quantity. Secondary consumers and decomposers also depend directly or indirectly on the kinds and amounts of plants since this determines the habitat for their prey. 'Cover' refers to the need for suitable habitat for reproduction, escape from predators, etc. Such requirements often have more to do with vegetation structure than with species composition.

For example, some birds have highly specific needs for foliage density at certain levels above the ground for their nesting habitat. Again, some of these requirements have to do with soil type and geology. For example, burrowing animals may favour certain soil types, or those which hide or nest in rock crevices may favour certain rock formations.

The spatial arrangement of food, water and cover is also very important for some species. Food sources which are too far from water or from hiding or nesting cover may not be used. Food plants used during the growing season may not be the same as those used during the dormant season so that good habitat must have both within distances specific to the species. Distances between life requisites may be great for some species, eg. migratory birds, and very short for others, eg. lizards.

The data requirements for evaluating wildlife habitat are: vegetation species composition, vegetation structure, and the spatial relationship of various habitat requirements. Habitat suitability indexes can be derived for each species or group of similar species (guilds) from appropriate measures of vegetation and substrate attributes. However, it is not likely that routine rangeland inventories and/or monitoring are going to serve all the specific data needs of each species, especially since many of these requirements are poorly understood. It seems, however, that an estimate of habitat suitability for many species could be based on:

1. a catalogue of possible vegetation communities which can exist on each land unit (ie. the 'stable' states). Each of these communities would differ from the others in species composition and/or vegetation structure (life forms, size classes, etc.). Thus, each of these community types would have different intrinsic values for food or cover for each wildlife species, even though we may not know exactly what they are at present. Merely identifying the plant community type on a land unit would provide some information on the wildlife habitat

value of the current vegetation, as well as offering a basis for predicting the values of other possible community types.

2. a projection, based on the land unit, of the possible food and cover values for any wildlife species within a range of different community types. In addition, the land unit is characterised by particular soil, rock, and ground water conditions which further define its potential value for certain species of wildlife.

3. the recognition that, since the land system is defined as a pattern of land units, each land system should provide a basis for examining the spatial attributes of life requisites for various species. The type of land units, the plant community types present on them, and their spatial arrangement within the land system should be related to the kinds and diversity of wildlife species the land system might contain.

Wildlife as Indicators

Because of the difficulty of measuring all the possible parameters of wildlife habitat for a large number of species, and the lack of knowledge about how to interpret such measurements in terms of the requirements of many species, wildlife indicator species are sometimes used in two ways. One is to measure the fairly well-known habitat requirements of one species, and to assume that the quality of habitat for some other species is correlated with the indicator. This may be a valid assumption when species are functionally very similar, but it is questionable when they are not. In fact, habitat suitability for one species of wildlife may be inversely related to that of others, eg. shrub increase would benefit shrubland birds, but could disadvantage grassland birds.

The other use of 'indicator' species is to assume that the abundance of a particular wildlife species is related to the overall 'health', 'integrity', or 'proper function' of an ecosystem. Conservation biologists describe this as a 'keystone species'. There are some scientific studies which demonstrate the use of this concept, but it must be applied with caution because the whole concept of the health, integrity and proper function of an ecosystem is poorly defined and not generally accepted by ecologists.

For these reasons, and the fact that the direct observation of wildlife species in routine surveys and monitoring is not likely to provide much useful information, data collection on the occurrence of wildlife species is not recommended.

Fire

Fire is one of the major forces that shape vegetation and soils in northern Australia, together with weather and grazing. Therefore, for the purposes of interpreting range survey and monitoring data, it would be useful to know the fire history (time and intensity) of each area. Satellite imagery currently gives data on the location and timing of fires in the area. Whether such data are of sufficient detail to be useful for specific survey or monitoring sites has not been determined.

It would be useful to note evidence of recent fire at each observation point along the range survey traverses, ie. mortality or topkill of shrubs and trees. At permanent monitoring sites, a more complete description of fire effects should be made when a fire has occurred since the last reading of the plot. For example, mortality or topkill of shrubs could be quantified; frequency of dead butts of grass could be included as a category in the frequency transects, fire intensity could be estimated by height of fire scarring, and so on.

Understanding fire effects and recovery rates would be helped by visiting each permanent monitoring site as soon after a fire as feasible and either rerecording the data, or at least taking notes and photos of the burn. The assistance of lease managers would be helpful here

Wood Products

There is a substantial potential for wood products such as fuelwood, charcoal, and even some saw timber, but there is little present or prospective demand for such products in the region. Information on standing crops or growth rates of woody species is therefore probably not warranted beyond the basic data on species distribution and population changes which should be obtained for other purposes.

Poisonous and Noxious Plants

The occurrence and spread of noxious or poisonous plants concerns pastoral managers and conservationists alike. While detailed knowledge of the distribution and possible spread of these plants must usually come from specialised surveys, there are three needs that could be met through the inventory and monitoring efforts of the Agriculture Department. One is a complete species list at each monitoring site which would detect the presence of these species. Another is the notation of the presence and abundance of poisonous or noxious plants observed along traverse routes of the range surveys. The third is to identify those land units where different species of poisonous or noxious plants have been found as a basis for predicting where and how extensive spread might occur in the future.

All non-native species are considered 'weeds' by some people. There seems to be no scientific reason why non-native species should be considered undesirable, but it would be desirable to give special attention to documenting their occurrence or spread in the same way as poisonous and noxious plants.

Riparian Areas

Although most of the needs for data mentioned above apply to riparian as well as non-riparian areas, it is worth while to focus special attention on riparian areas for two reasons.

First, riparian areas are extremely important for the conservation of wildlife and fisheries, for water quality and erosion, for recreation, and for livestock production. Secondly, while riparian systems affect large areas, the area they actually occupy is relatively small. Thus range surveys and monitoring systems are apt to undersample these areas unless special efforts are made to acquire adequate data.

Riparian systems may be stream channels or isolated water points such as springs. Each is important but may have to be treated differently. Hydrologic regimes and the vegetation of riparian stream systems are affected by grazing, fire, sand and gravel operations and other influences within the riparian zone itself or on the catchment of the stream. 'Riparian function' is a term sometimes used to describe the processes occurring in riparian zones, such as bank protection, silt capture, slowing and storing runoff, regulation of water temperature, etc.

Most of these depend on the amount and type of protective vegetation in the stream channel or on the floodplain. Flood size, flood frequency and sediment yield are related to the climatic conditions, catchment size and geology, and the condition of the soils and vegetation on the catchment.

As with 'upland' land units, the first step in evaluating the condition of the riparian areas is to classify them into stream types so that the expected or 'normal' function of each can be identified. Each 'reach' of a stream has different characteristics. The expected type and amount of vegetation, erosion or deposition, and other features are different. As an example, the Rosgen system (Rosgen 1985) is often used to classify stream types in the USA. Attributes that can be monitored in a given reach of a stream include: vegetation structure, bank protection, sedimentation rates, peak flood height or discharge, depth to water table, cross-sectional area of channel, etc. Because of the linear nature of these features, low level aerial photos can be used to map or monitor some of them.

Monitoring programs could be easily expanded to include riparian ecosystems. Once classified, examples of major stream types could be monitored at permanent locations for regional reporting purposes. Incorporation of riparian data directly into the range condition surveys would be more difficult because of the limited area and difficulty of access of riparian areas. They should therefore be delineated by type on aerial photos. Pre-typing of the photos could be checked by ground or aerial field checks. 'Condition' of the riparian areas might also be visually assessed from helicopters or fixed wing aircraft, and documented by low-level aerial photos.

Springs and other isolated water points present a problem for survey and monitoring because of their small size and scattered distribution. At least their location should be noted on the survey maps and their general condition documented by visual assessment and/or photos.

Suggested Modifications to Present Methods

This section deals with some changes which could be made to existing methods to improve their usefulness and interpretability for pastoral and non-pastoral uses. Again, special reference is made to the Kimberley region.

Land Classification and Mapping

Land classification and mapping are based on land systems and land units, and these are the basic units for reporting and interpreting data for the range surveys conducted for management purposes and for regional reporting on land condition. As stated previously, the land unit is a particular topographic/ soil unit characterised by particular kinds or amounts of vegetation (Speck *et al.* 1960). Wilson *et al.* (1984) described land units as 'the fundamental basis of description' of rangelands. Differences in land units are defined by differing *capability* or *potential* to produce different kinds and amounts of vegetation. The vegetation type existing on a land unit is the result of historical influences such as drought, fire, grazing or other factors. Several different vegetation types (states) could exist on one land unit as the result of different management histories. The land unit serves as a basis for interpreting land capability, predicting response to management, and rating land 'condition', ie. the current state of soil/vegetation with respect to some desired and achievable state. Land units are therefore *taxonomic units* of land classification.

Land systems are *mapping units* composed of differing patterns of land units. The same land unit may occur in more than one land system, but in a different proportional area or in association with different land units. The land system describes the spatial relationship among different land units in a landscape.

In addition to topography and soil, climate also influences the kind or amount of vegetation which can be produced on a land unit. Rainfall is the main climatic variable in northern Australia. Thus, vegetation type on a particular combination of topography and soil depends on rainfall, and a significant change in vegetation due to change in rainfall should be the basis for describing a new land unit.

Delineation of land systems and land units in the Kimberley and Ord-Victoria Region in the Northern Territory has not directly taken into account the differences in rainfall. The land systems in the Ord-Victoria area were described as having a mean range of almost 300 mm of average annual rainfall and a six weeks average growing season from the driest to wettest part of the mapping unit; one land system had a range of 800 mm and 15 weeks of average rainfall and growing season. It is unlikely that one land unit would have the same vegetation potential throughout this range of rainfall.

Perry (in Stewart *et al.* 1970) recognised vegetation differences in three rainfall zones of >685, 380-685, and <380 mm. Also, Payne *et al.* (1974) recognised differences in productivity and/or species composition of some pasture types based on rainfall above or below 500 mm. These observations are evidence of a need to refine the classification of land systems, land units and pasture types.

Recommendations

1. **Existing land systems and land units should be stratified into rainfall zones which reflect differences in potential vegetation productivity and species composition.**

A 'first approximation' to this stratification could be accomplished by an arbitrary division of the area into rainfall zones corresponding roughly to those mentioned in the literature, eg. <350, 350–500, 500–650, 650–900, and >900 mm. Each land system and land unit would be restricted to one rainfall zone. Land systems which extend across two or more rainfall zones would be divided into several land systems. The same names could be retained by indicating a rainfall zone as part of the name, eg. Yeeda (500–50 mm), Yeeda (650–900 mm), and so on. Land units also would be restricted to one rainfall zone. An alternative to the use of such arbitrary classes would be to look for 'threshold' rainfall amounts, ie. approximate annual rainfall where the vegetation on a land unit changes to a different type. In this case, each land unit might have its own threshold. For example a sandy soil type might have only two significant plant communities in a range of 600 mm, while a clay soil might have three. Although this approach might be preferable from an ecological standpoint, it would obviously require considerable research effort to accomplish—an effort which might not have major practical benefits.

2. The emphasis in classification and mapping should be shifted from pasture type to land units.

The land unit is the basis on which vegetation potential and management response can be interpreted and predicted. Land units are differentiated because of differences significant to plant growth in such factors as rainfall, soil moisture supplying capability, erosiveness, run-on moisture and the like. Accessibility to livestock or other such use-specific criteria should not be used to define land units. Pasture types reflect the characteristics of the land and its management or other influences. Pasture type, however it may be defined, on a land unit may change because of fire, grazing or other factors. Separating the effects of land type from land use depends on defining land units by their ability to produce vegetation and respond to management. Vegetation types should be defined on the basis of species composition and/or life forms, not on their value for livestock forage, so that the classification of land units is more relevant to wildlife, predicting fire responses, and other uses.

This change would not reduce the usefulness of the classification for livestock forage assessment. Land units, and the various possible vegetation types which might occur on them because of management activities, would form the basis for implementing the 'state-and-transition' approach to the evaluation and prediction of management values and responses (Westoby *et al.* 1989).

3. A system of classification of riparian areas into land units should be developed.

Drainages and stream systems are already recognised as land units in many land systems. Criteria for classifying riparian land units may be different from those used on 'upland' situations. Water, either underground or in flow channels, is the defining characteristic of riparian areas, thus the depth of water, the seasonal availability of water, or quality of water may be important variables. Such characteristics are not only related to the adjacent land units, ie. the land system, but to influences from upstream. Vegetation, and riparian processes of erosion and sedimentation, may be highly influenced by the geomorphology of different types of stream reaches. A classification of stream reaches based on substrate, catchment size, flood size and return frequency, energy gradient, etc. would be a logical start as a basis for defining riparian land units (for example, see Rosgen 1985; Leonard *et al.* 1992; Winward and Padgett 1989).

4. A database of analytical and interpretative information for different land systems should be developed.

Land systems were originally used because they were a convenient way to map and assess large areas of land for the reconnaissance-level surveys carried by out by CSIRO. As knowledge improves and the need for more specific information increases, the land unit becomes more important because it constitutes the basic land type. However not all resource information can be determined strictly on the basis of the land unit. Some aspects depend on the kind and interspersion of different land units. For example, the value as food for birds or other wildlife of vegetation types produced on one land unit may depend on the existence of adequate hiding or nesting cover available on a different land unit within certain optimum distances. Similar situations may apply for livestock where, for example, vegetation on one land unit may be highly preferred over adjacent land units in one land system but less preferred when mixed with other types of land units in another land system. Land system mapping thus forms the basis for interpretative information about the spatial characteristics of various land types which cannot be obtained from land unit data alone. The use of land systems for this purpose has apparently not yet been developed.

Two types of research need to be carried out to develop this information base. One would be to develop ways to measure quantitatively the spatial attributes of land units within a land system. Concepts of landscape ecology and conservation biology should be applicable. Examples could be used to describe the pattern of land units (pattern size, continuity, etc.).

The second would be to integrate these attributes with the detailed data from individual land units (species composition, vegetation structure, land condition, etc.) to develop indices of the potential or current suitability of habitat or resource value ratings on the basis of a land system. Such data could be particularly useful for predicting probable habitat for endangered or other wildlife species, locating conservation reserves, extrapolation of monitoring data and so on.

Field Sampling—Traverse Method

The traverse method is done by driving on roads and tracks to sample as much of the area of a paddock or station as possible. It is recognised that this procedure does not result in a uniform or unbiased sample of either paddocks, leases or land units. The course of roads is influenced by terrain and the location of water points, yards, fences, homesteads and other factors. There does not seem to be any way to improve on these limitations of using ground transport.

Recommendations

1. **Aerial photos should be used in mapping land units to improve the accuracy of the base maps used for management planning and assessment.**

It is probable that land units can be identified accurately on aerial photographs of suitable scale and used to map land units (including riparian units), or at least to estimate the percentages of various land units in paddocks or land systems. Preliminary mapping can be done before the field survey and doubtful interpretations completed during the course of it. Because of the size of properties involved, aerial photos with scales larger than 1:50,000 are not likely to be practical. Black and white photos may be adequate, but colour photos are much superior for identifying the soil differences which form the basis for land units. The same photos can be used for the kind of land-system analysis described in the section on classification and mapping. Although present range condition probably cannot be determined from aerial photos, the photos would at least improve the accuracy of the land-unit survey which provides the basic data upon which all other resource interpretations are made.

2. **Use of helicopters or fixed wing aircraft should be considered to ground truth the base map and for condition surveys**

Helicopters could be used to validate land unit identification on base maps (photos) and even to extend the range condition surveys beyond established roads and tracks. With experienced observers, it might not even be necessary to land to make assessments. It is likely that observation from the air could identify patterns of resource degradation or use which are not readily apparent on the ground.

In particular, the classification of riparian land units and their condition could be facilitated by the use of helicopters, since such areas are often difficult to reach on the ground. The obvious drawback to helicopters is the cost, but this might be countered by the greater productivity of field time. Fixed wing aircraft are cheaper but generally operate at higher levels, fly faster and cannot hover or land when needed.

Data Collection—Traverse Method (Kimberley Region of WA)

At present, the information collected at each traverse point includes ratings of wind erosion, water erosion, and pasture condition. All three are based on 'scorecards' which allow each to be assigned to one of four or five classes according to written criteria. The erosion ratings depend on the observation of indicators of erosion such as scalding or stripping by wind, rills, gullies, and other features which can be observed quickly from a vehicle. No 'data' are collected in the sense that no direct estimates of a given attribute such as bare ground percentage, litter or vegetation cover are recorded. This is unfortunate for two reasons. One is that there is no estimate of quantitative value which might be used as input to runoff/erosion models or other types of data analysis. Given the time constraints there is probably nothing to be done to improve this situation. Secondly, the use of the same rating scale for all land units does not allow for recognition of any difference in inherent erosion rates on different land units. 'Moderate' erosion on a land unit with a high natural rate of erosion might be considered 'severe' on a land unit with a low tendency to erode, but there is no provision for recognising this difference at present.

It is probable that many observers, consciously or not, take the natural erodibility of the site into consideration when making the ratings, but this may vary among observers. The alternative is to develop a different set of criteria for each land unit (which would be cumbersome for this type of survey) or to rate each land unit according to its natural erosion rates. In the latter case the erosion ratings for each land unit could be interpreted in terms of the potential stability of the site.

Pasture condition is rated in five classes according to descriptions of species composition and the amount of bare ground. Abundant species are usually noted but no data are recorded on bare ground.

Species composition is rated by the relative proportions of desirable, intermediate and undesirable species present at the observation site. The observer has to know the forage value assigned to each species for each pasture type or land unit. Presumably, a given species might be classified as desirable on one land unit and less desirable on another.

Pasture condition is clearly intended to be related to the amount of forage for livestock, so its use for any other interpretation may be limited. No information is noted on woody species. The inclusion of forage species composition and ground cover in a single rating means that although pasture condition may be affected more by one than the other, there is no indication of which is the more important.

Recommendations

1. **Data collected at each observation point should include, at least, a notation of the prominent herbaceous species present.**

It is not feasible to get detailed composition data on all species, but recording a few of the most abundant species would provide a record of species occurrence that is not always available at present. This information on species would allow some interpretation of the data for other than pastoral purposes. It would also allow the opportunity, when sufficient information is available, to classify the present vegetation into community types (states) which would provide a basis for predicting response to management. The recording of data on species present would not preclude the current method of evaluating pasture condition, but it would furnish information for other data interpretations as well.

2. **Information should also be collected on shrubs and tree species by identifying the major species, density or cover class, and the presence of reproduction and/or mortality; indicators of fire occurrence should be noted.**

This information would be used for the same purposes as described above for herbaceous species. In addition, it could be used to monitor woody plant increases or decreases as a result of fire, grazing or other influences.

3. **Observations on soil condition should be recorded.**

The time constraint would not permit the recording of detailed observations. However, a 'scorecard' approach to recording soil cover (or bare soil), patchiness, and indicators of erosion (rills, gullies, etc) would provide a record that does not now exist.

4. **Riparian areas, classified by stream type, should be delineated on aerial photos for each paddock/station. The 'condition' of each should be assessed visually.**

Classification and mapping of riparian areas has already been discussed. Assessment of the status of 'riparian function' will depend on the development of criteria for visual assessment and interpretation for different stream types. It may not be feasible to carry out such assessment in the course of the usual traverse routes. Aerial photo interpretation along with aerial inspection may be an alternative.

Data Collection at Monitoring Sites

Recommendations

1. **Soil surface monitoring should be developed for monitoring sites following the approach of Tongway (Tongway and Hindley 1995), with suitable modifications if required**

2. **A complete species list, notes on fire occurrence and intensity, notes on shrub reproduction and/or mortality, and notes on livestock grazing should be included in the data collection**

Data Interpretation—Range Condition

Range condition is at present based on a combination of pasture condition and erosion ratings, that is, it may be influenced by erosion condition or pasture condition or both. Range condition is used as the basis for predicting carrying capacity. The ratings of pasture condition, and consequently, of range condition are based on the production of forage for livestock. Thus, these ratings reflect 'livestock forage condition' and do not necessarily have any direct relevance to other uses or values. Since the surveys have been, and will probably continue to be, primarily carried out for the purpose of evaluating pastoral management and planning for improved management, a rating of 'livestock forage condition' is appropriate. The following recommendations are aimed at improving the interpretability of the range condition ratings.

Recommendations

1. Ratings of water/wind erosion should be kept separate from pasture condition ratings rather than being combined into one rating of range condition

Erosion condition is rated because it relates to a soil conservation objective, not livestock production. It is conceivable that vegetation might be of low value for livestock forage but still provide adequate protection of the soil against erosion.

2. The criteria for pasture condition ratings should be clarified to distinguish between the effects of forage composition and productive vegetation cover. Plant vigour and reproduction should be considered as trend indicators, not as part of the condition rating.

In the Site Evaluation Method, composition, cover and vigour were all rated separately. In the Traverse Method, composition and cover are rated together. It is not desirable to mix these attributes. For example, the proportion of the existing vegetation that is comprised of desirable forage species is an attribute determining forage supply. The amount of ground surface producing vegetation is another. Forage supply can decline as ground cover declines, as the proportion of forage species declines, or both. The net effect on present forage production may be the same, but the nature of the problem and how it may respond to management could be quite different. For example, if a soil is uniformly covered with poor forage species, the problem may be lack of seed source for desirable species or competition with other species. If desirable species of forage are prominent, but vegetation is very patchy with large areas of bare soil or scalds between them, the recovery process is more likely to be related to soil properties.

Data Interpretation—Carrying Capacity

Recommendations

1. A clearer objective for rating carrying capacity should be established together with a policy for the use of the information

There are two kinds of use for a carrying capacity estimate: regulation and management planning. At present, carrying capacity estimates are not used for regulatory purposes. Because there are so many variables that influence how many livestock may be carried on a particular area of country, it is questionable whether any 'one-time' estimate of carrying is sufficiently accurate for regulatory purposes. It is preferable to set objectives for the condition of the land and monitor whether such objectives are being met by management.

Carrying capacity estimates are, however, useful for management planning and economic analysis. For example, a comparison of PCC with CCC gives an idea of the potential amount of improvement that could occur. The relative carrying capacity of paddocks can be estimated for grazing management. The economic feasibility of developing new waters or fences can be analysed by estimating the additional amount of carrying capacity obtained. Such information is of value to the Agriculture Department and the station owner, but of doubtful use to the public.

2. Technical data used in the estimation of carrying capacity need to be improved as follows if 'accurate' estimates are desired:

a. the relationship between 'range condition' and forage production for different land units and pasture types needs to be improved.

Some quantitative data were apparently developed for the West Kimberley, but few if any exist elsewhere. As discussed before, an emphasis on land units (which define the productive potential) would be helpful. Productivity could then be related to species composition or community types (states).

b. the percentage of use assigned to various forage species should be evaluated

'Proper use factors' (the percentage of use of a forage species when the range is properly grazed) vary according to the preference of the grazing animal, which may be affected by the season of the year, availability of other forage, and so on. Thus, it is difficult to establish percentages which apply to a species regardless of the associated species, type of grazing system, or other management factors. One alternative is to try to develop data which account for all these variables; the other is to accept that they are rough figures at best and just use about three categories, eg. 50%, 25% and 0%.

c. forage requirement per livestock unit should be carefully considered if accurate carrying capacity estimates are desired

Forage requirements (kg of dry matter per livestock unit per day or year) are used to convert available forage on a given land unit or condition class to carrying capacity estimates. A difference of 25% in forage requirement causes a 25% change in estimated capacity, regardless of all other factors involved.

The figure used in setting the carrying capacity values for pasture types in West Kimberley was 4,100 kg/LSU/year, or 11.2 kg/day. That figure is about 20% higher than most estimates of year-round average forage consumption on rangelands of about 9 kg/LSU/day or about 3,300 kg/year. This factor alone could have a considerable effect on the accuracy of carrying capacity estimates.

d. carrying capacity estimates should consider topography and development factors such as the distance to water and fencing

At present, both PCC and CCC are based on 'full development', ie. the assumption that all forage is accessible to livestock. While this is a useful concept, it means that estimates are not expected to correspond well with what a property will actually run under present levels of development and range condition. If it is desired to estimate an actual recommended stocking rate under present conditions, then livestock distribution must be considered. Distribution would be affected by water and fences as well as topography and pasture types.

e. better figures on actual stocking rates should be obtained

Actual stocking rates over a period of years give some indication of what the property will carry. Whether these numbers are sustainable or not can only be ascertained by analysing trends in range condition and, in some cases, livestock condition or turnoff rates. At any rate, reasonable figures on actual stocking would be helpful to refine methods of estimating the carrying capacity and to interpret range inventory and monitoring data. The cooperation of station managers in providing accurate data should be sought.

3. The carrying capacity for livestock should be one of the 'resource values' considered when developing data bases for vegetation communities, land units and land systems.

As described earlier, land units are the basic determinants of the productivity of the range. Each land unit may support several vegetation types or pasture types depending on its management history. Each of these types may have differing proportions of forage species and so, different potential carrying capacities. The actual useable forage on a given land unit may also depend on the land system, ie. which other land units are present. Thus a particular land unit may have a different value according to the land system. The season of use may also play a major role.

Template for Rangeland Assessment in Grasslands/Woodlands of Northern Australia

This 'template' describes a set of steps or procedures to form the basis of a rangeland inventory and monitoring system which will meet the needs of multiple-use management and of regional reporting. It summarises the suggestions and recommendations in the preceding sections.

A. Land Classification and Mapping

Classify and describe the permanent features of land types, including riparian areas, according to their ability to produce different kinds and/or amounts of vegetation. This process is independent of land ownership, use, or condition.

1. Land System Base Map

Prepare a land-system base map at a scale of 1:100,000–500,000. The base map may be derived from existing maps, but the requirement that land systems represent a pattern of topography, soils and vegetation should be rigorously observed.

2. Land Units

Land units (topographic-soil-vegetation units) should be described and named or numbered. Significant differences in the kind or amount of vegetation which can potentially be produced, including differences in response to disturbance, are the criteria for separating land units. Each land system (mapping unit) is defined by the kind and proportion of land units (taxonomic units) occurring within it. Land units may be mappable at scales of 1:100,000 or less; land units can be mapped from satellite imagery in some cases.

3. Riparian Systems

Classify and map riparian systems. Riparian systems are stream reaches with particular conditions of channel morphology, discharge and other geomorphic features. These should be mappable as linear features on relatively small-scale maps.

4. Riparian Units

Describe the different riparian units within each riparian system and the expected proportions of each. Riparian units are not mappable at practical map scales, and in any case may be dynamic in spatial position and proportions.

B. Describe States and Transitions for Each Land/Riparian Unit

This process will be continuous as research and experience provide additional knowledge. It may be seen as a framework for developing an information base upon which to assess ecological condition and resource values for both upland and riparian systems. Initially, the information may be crude and derived primarily from professional judgment, but it can be refined over time.

1. Identify and describe the various vegetation/soil states which could exist on each land or riparian unit. *Pasture types* dominated by certain species of both understorey and overstorey will constitute some of the 'states'.

2. Describe the transitions among the various states in response to management (eg. grazing or fire) and natural influences (eg. drought).

3. Identify those states and transitions (thresholds) which constitute degradation to unsustainable states or irreversible processes.

4. Develop resource value ratings for each vegetation state on each land unit, ie. use studies to estimate the livestock forage, wildlife values, biodiversity, etc. for each state on each land unit.

5. From the information in 4. above and from an analysis of the spatial aspects of land systems, develop biodiversity indices for different land systems.

C. Mapping and Characterising Pastoral Leases and Other Lands

1. Map land systems on the area to be surveyed. In most cases, this can be done at an acceptable level of precision from the maps developed in step A.1 above. If refinement is needed, satellite imagery and/or aerial photography can be used. Errors discovered in the course of ground traverses can be corrected.

2. Describe the land units present. Estimate the proportions of the various land units in each land system. These proportions should be specific for the management unit (lease) being surveyed; they may differ from the average over the entire extent of the land system. The proportions of land units in a land system within a paddock or property cannot be assumed to be the same as the average proportions described for the land system. The proportions of land units in a given paddock or property cannot be estimated from the proportions of traverse points falling in each land unit; traverse routes do not usually yield a representative sample of the paddock or property. Proportions can be estimated by mapping land units directly on satellite imagery or aerial photos or by spot checks on these images.

3. Map the riparian systems in the area to be surveyed and describe the riparian units expected in each. Riparian systems may be mapped (by linear extent at least) on aerial photos or satellite imagery.

4. Map all known pasture boundaries, bores, pipelines, yards, roads or other improvements which may affect the management of the area.

5. If necessary, check pre-mapping (land systems, land units, riparian systems, improvements) by fixed-wing aircraft or helicopter. Aerial checking may be carried out after preliminary mapping to familiarise surveyors with the area, or after field data collection, or both. Apparent differences in range condition and livestock distribution patterns could also be noted during such flights. Such flights would be particularly useful to estimate percentages of riparian units in riparian systems, and their condition.

D. Field Data Collection—Upland Traverses

1. With the preliminary mapping done, the next step will be to locate traverse routes. These should be selected to provide as representative a sample of land systems, land units, and condition classes as possible for upland (non-riparian) sites, and should take account of the current management systems and potential grazing distribution patterns.

2. Make field traverses. Record actual travel routes, location of improvements, boundaries of land systems, and, where feasible, boundaries between land units on GPS.

3. Make a soil/vegetation observation each kilometre. Record the location on GPS. Observe an area approximately 100 by 100 m, ie. mentally average the observations over this area. Move away from the road if it appears that livestock use is affected by the road.

4. At each observation point record:

   a. Land system, land unit, vegetation 'state'(ie. community type)

   b. List all herbaceous plant species which make up 10% or more of standing biomass (could be as many as 10 species, but more likely only two–four)

   c. List any weed or invasive exotic species observed

   d. List shrub/tree species. For each indicate a density class (eg. sparse, common, dense, very dense) defined in terms of numbers per hectare, and an age/size distribution class (eg. indicate relative amount in following classes: seedling, young, mature, decadent, dead)

   e. Record wind/water erosion classes as described by Payne *et al.* (1979)

   f. Record bare soil by amount and patchiness categories

   g. Note livestock use on palatable perennial grasses (none, light, moderate, heavy, severe)

   h. Determine and record 'pasture condition' (not range condition) by the method described by Payne *et al.* (1979)

E. Interpretation of Upland Traverse Information

1. Identification of land system, land unit and vegetation state (4a) are used as a basis for summarising data by these categories. Land systems, land units, and vegetation states on a given land unit all have certain intrinsic properties of diversity, productivity, etc. which are useful in predicting resource values and response to management. As information is accumulated, it may be that this information alone will provide as good an estimate of carrying capacity as any other.

2. The information on species, woody plants, etc. (b,c,d) is intended to help to identify vegetation state, and to provide a record of observations which can be used to predict the direction of change in vegetation in response to management (transitions). Although based only on estimates or classes, they are not mere value judgements. Thus these observations provide some objective record of what was actually on the ground at the time of the survey.

3. Recording use by livestock (g) is intended to help interpret cause and effect and to identify patterns of livestock use which can help in management planning. A one-time estimate of use is of limited value, but does not take long to make.

4. The observations of erosion and of the amount and pattern of bare soil provide an indication of the site's protection/degradation status which is independent of intended use or value. It would be better to record such estimates in absolute terms rather than in relation to the observer's concept of what is natural for the land unit. When enough data are available, the ratings of erosion and ground cover can be compared with other ratings on the same land unit to establish what constitutes an achievable goal for the unit, or where it stands with respect to a conservation threshold of degradation. Repeated surveys of the same property can show trends whether a threshold has been established or not.

5. All of these data can be summarised for an entire property or any paddock. In doing so, it is assumed that the areas of each land system and land unit are accurately known as described under part C above. It is also assumed that the traverses provide a representative sample of the land systems and land units present, which is often not the case. There seem to be only two ways to correct for lack of representative sampling in the traverse. One would be to supplement the ground traverse with low level aerial survey (eg. helicopters) to try to extrapolate experience on the ground to a wider area. The other is simply to use professional judgement to estimate how the information can be extended to the entire property. As long as the survey data are used primarily to guide management on the property where they are collected, these problems are not serious. If the information is intended to be used to characterise regional conditions and trends, the problem of bias is more serious.

6. Pasture condition should be used to estimate the carrying capacity for livestock. Pasture condition, as presently defined (Payne *et al.* 1979), includes both the size of the area that produces pasture and the proportion of that pasture which is good forage. Both of these attributes are recorded independently in 4b and 4f so that they remain as an objective observation. Pasture condition is a subjective value judgement which is useful for estimating current carrying capacity but not of much value for other purposes. There seems to be no reason to include the erosion rating in making a carrying capacity estimate, since productive cover is already considered.

7. Carrying capacity for livestock is an example of a resource-value rating. The 'state' of vegetation occupying a land unit is basically the same thing as the pasture types described by Payne *et al.* (1974), ie. pasture types are classified by the species composition and life form of the major forage plants. The amount and reliability of the forage available for livestock is assumed to be a function of the pasture type. The amount of forage available in a particular pasture type can be estimated by studies of biomass production and species selection by livestock (preference). Forage production in a pasture type can vary depending on the season of use, and the same pasture type may produce different amounts of forage on different land units. Therefore, forage production values for each pasture type should be specific to each land unit and season of use. Forage produced is converted to livestock units of grazing by assuming: (1) the proportion of forage which may be safely removed by livestock while leaving enough biomass for plant welfare and soil protection, and (2) the dry matter intake per day or month for a livestock unit. Both may vary according to the season of grazing and other factors.

This procedure may be used to estimate *potential carrying capacity* and/or *current carrying capacity* according to the pasture types now on the area, or to those which *could* exist on those particular land units given good management and sufficient time. Both potential and current carrying capacity assume 'full development', ie. that fencing, water developments and other factors are adequate to allow all available forage to be harvested by livestock without excessive use of any appreciable area.

8. 'Full development', as described in the paragraph above, is unlikely ever to occur. Thus, the actual carrying capacity estimates must take into account the topographic features, water distribution, fencing and other factors which influence animal distribution and management. Guidelines can be developed from utilisation studies to discount the value of forage according to the distance from water, the slope or other factors. Utilisation studies may also be used to show livestock distribution patterns within paddocks.

9. The procedures described in paragraphs seven and eight above rely on a number of factors (forage production and preference, livestock distribution, forage intake, etc.) which must all be estimated from studies, observations, or professional judgement. No two situations (and no two managers) are the same. Thus, carrying capacity estimates can never be very accurate or precise. They may be useful for purposes of planning or economic analysis but their limitations must be realised.

10. Other resource-value ratings can be developed in a similar fashion to estimates of livestock grazing capacity. The various vegetation states will be classified according to other attributes than pasture types, such as cover, height distribution, or woody plant density, in accordance with the use or the value of interest. Like estimates of livestock grazing capacity, the link between observable attributes and the value for a particular use will be estimated from research or by professional judgment. Also, values may be related only to a specific land unit, or on a landscape level which takes into account the spatial distribution of different resource needs. The latter is analogous to the consideration of water locations, topography, or fences for livestock. And finally, like estimates of livestock grazing capacity, other resource-value ratings for a particular area are not likely to be more than approximations, given the complexity of weather/ soil/vegetation patterns and the imprecise knowledge of the relationships and interactions among vegetation attributes and resource values.

F. Collection of Survey Data on Riparian Systems

1. Riparian systems, because of their linear configuration, difficulty of access, and small total area, will not usually be adequately sampled in the course of the traverses made in surveying upland areas. For this reason, they need to be considered separately.

2. The most practical way to obtain information on the proportions of riparian units and the 'state' of such units within riparian systems is by aerial survey. The best way would be to make low-level aerial photos of riparian corridors and then assess riparian unit types and vegetation status from the aerial photos. Accuracy could be checked by field checking on the ground or from a helicopter. The intensity of sampling (what portion of total stream lengths is sampled and what portion is field checked) would depend on the money available.

3. The principal actions to collect data for riparian systems are:

   a. Identify riparian units within the riparian system. These could be mapped on large-scale aerial photos, or their proportions estimated by use of a point sampling method.

   b. Characterise plant communities (vegetation states) on riparian units. These will mostly be dominated by semi-aquatic or woody vegetation.

   c. Characterise herbaceous ground cover for bank protection and sediment trapping.

   d. Estimate the percentage of banks which show signs of erosion or bank cutting.

G. Interpretation of Data on Riparian Areas

1. Data should be summarised and interpreted on the basis of similar riparian systems or stream reaches. The type of riparian system (stream reach) determines the potential for the existence of various riparian units and vegetation states.

2. Similar riparian systems can be evaluated by comparing the relative proportions of riparian units, vegetation types, ground cover types, and/or bank protection.

3. A single stream reach can be evaluated by looking at trends in these attributes over time.

4. Wildlife values or watershed functions may be assessed if the information exists to relate the observed attributes to these values.

H. Sampling Design and Collection of Monitoring Data

1. Long-term monitoring data can be collected to aid in property management or for regional reporting. The type of data may be the same in both cases but the sampling design may be different. Thus it is important to define the use of the data in order to establish a proper sampling design. The following kinds of monitoring are all possible:

   a. Monitoring solely for management guidance on individual leases. Monitoring locations are chosen to represent 'key areas' as well as some 'reference' areas or 'critical areas'. The key areas are considered 'typical' of the management situation; the others are chosen for special purposes. Monitoring of key areas should be directed at more productive country. Areas of low productivity or development may be ignored because they are not indicative of livestock grazing management. Data gathered by using this approach would not be representative for regional reporting and should not be made available to the public without the permission of the lessee. Lessees should be encouraged to gather their own data to the maximum extent possible.

   b. Monitoring for management guidance on individual leases and for reporting on the overall condition and trends of pastoral leases on a regional basis. The selection of monitoring sites would be similar to that above. The emphasis for regional reporting would be on the condition and trend of key areas averaged across a number of leases without specifically identifying any given lease. Data for individual leases should be available only to the lessee and the monitoring agency. Average values across a number of leases should be furnished to the public and policy makers.

   c. Monitoring to provide information on regional ecological condition and trends for all uses and values. In this case, the sampling design should be representative of *all* land systems and land units irrespective of their value for pastoral purposes. Such monitoring will provide no data of value for pastoral decision making in most cases, but it will provide data for conservation purposes and policy decisions.

2. Data collected at each monitoring site on non-riparian areas should include the following:

   a. Land system, land unit, vegetation 'state'

   b. Frequency of herbaceous species

   c. Canopy cover by species of woody species

   d. Density by size class and species of woody species

   e. Ground cover or soil surface condition

   f. Notes on indicators of fire occurrence and grazing.

3. Data collected at monitoring sites on riparian areas should include:

   a. Land system, riparian system, riparian units, vegetation state

   b. A measure of the soil/bank protection provided by vegetation

   c. Woody plant density by size classes and species

   d. Channel cross-section.

I. Interpretation and Reporting of Monitoring Data

1. Change in measured or estimated values can be documented for each monitoring location. Average changes for different land systems, land units, geographic regions, etc. can also be reported. When adequate information exists, these changes in measured attributes (ground cover, tree density, etc.) can be translated into changes in resource-value ratings. For example, an increase in the number of trees of certain species and size class may be assumed to increase the numbers of sites for cavity-nesting birds.

2. Results can be reported by land system, land units, land use category, geographic region, or other appropriate breakdown.

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Appendix 1

Kimberley Rangeland Resource Assessment—Analysis of Present Methodology

Foundations of the Methods Used in the Kimberley

This section is a description and critique of the basic methods for evaluating range condition and carrying capacity described in:

Payne, A.L., A. Kubicki, D.G. Wilcox and L.C. Short. 1979. "A report on erosion and range condition in the West Kimberley area of Western Australia". West. Aust. Dept. Agic. Technical Bulletin No. 42.
and
Payne, A.L., A. Kubicki, and D.G. Wilcox. 1974. "Range condition guides for the West Kimberley Area WA" West. Aust. Dept. of Agric.

Classification of Site Potential

Estimated potential forage production, which forms the basis for carrying capacity estimates is based on the classification of land systems and pasture types.

Land systems are mapping units described as "an area or group of areas throughout which a recurring pattern of topography, soils and vegetation can be recognised". Land systems are therefore complex mapping units composed of two or more *land units* or types. The land units are basically geomorphological units such as hills, footslopes, floodplains, etc. The land units typically support certain soil and pasture types. Land units are therefore conceptually very similar to the *ecological site* as used in the USA, although perhaps with more internal variability, while the land systems are somewhat analogous to the *Major Land Resource Area* used in the USA, although probably with less internal variability.

Pasture lands (or pasture types) are vegetation types characterised by a particular combination of life forms and/or dominant species. The emphasis is on the understorey plants, since this is forage-oriented classification, but overstorey species are usually indicated as well. (Ray Perry described a number of overstorey and understorey types and found that there was little correspondence between them). Pasture types are associated with land units within a land system. The same pasture type may be found in numerous land systems, usually associated with land units which are similar in terms of soils, topographic position and, probably, rainfall.

Pasture types are the basis for judging range condition and establishing carrying capacity estimates. It is assumed that each pasture type has a potential to produce biomass which is higher in 'good' condition than in 'bad' condition. The estimated potential carrying capacity of a land system is determined by the weighted average carrying capacity of pasture types which occur there, ie. the carrying capacity of each pasture type is multiplied by the average proportion of the land system occupied by the type.

Range Evaluation Site Method

In conducting the range condition survey of the West Kimberley, Payne *et al.* (1979) developed a detailed description of range condition. Locations where this method was used were documented for reference. Apparently this procedure was to serve as a basis of reference for the more subjective 'traverse method' actually used to conduct the survey. The Site Evaluation Method is based on the Deming 2-Phase Method formerly used by the BLM in the USA.

The Site Evaluation Method consists of a pasture rating and a soil rating. Pastures are rated according to quality, quantity and vigour/reproduction. Each of these three factors is rated on a 25 point scale (0,5,10,15,20,25) and added together to give an aggregate pasture condition score ranging from 0–75. Six condition classes were: 0–15,20–30,45–35,50–60,65–75 corresponding to very poor, poor, fair, good, and excellent, respectively. Soil was rated on the basis of type and severity of soil erosion on a 25 point scale, also broken into six classes of none, slight, minor, moderate, severe and extreme. Apparently, the two ratings were not combined but reported separately, eg. as 60/10.

Although this approach was patterned after the Deming Method, it is not the same. The Deming Method rated four factors each for vegetation and soils, with a possible score of 100 for each, then the two scores were combined to give an overall rating of range condition on a 200 point scale based equally on vegetation and soil. In this modification, it appears at first glance that vegetation is given three times the weight of soil, but in fact it is not since the scores are not added or averaged. Vegetation and soil are still given equal footing.

A major criticism of the Deming Method was that the eight different factors rated (four for vegetation and four for soil) were not all independent of each other. For example, ground cover might be in included in the criteria for two or three of the soil ratings, and thus, in effect, it is given more influence on the result than other attributes rated.

It appears that some of the same criticism could be made of the Site Evaluation Method. For example, forage quality is based on the proportion of the vegetation made up by desirable and intermediate forage species in the stand. Forage quantity is judged with reference to the capability of the site to produce pasture.

A high rating means that cover is predominantly of desirable species, with some intermediate species, and that the site is producing as much as it can be expected to produce. In other words, a sparse stand of desirable/intermediate species could result in an excellent rating if that was all the site was deemed capable of producing. However, ratings, quantity and quality all appear to be based mainly on the proportion of desirable, intermediate and undesirable species. To be independent, the quality rating should take into account only the composition (relative amounts) of the species, and the quantity rating should consider only the percentage of the ground that produces vegetation cover, irrespective of species, compared with the potential total cover for the site.

The rating of 'vigour and reproduction' seems to be an independent rating. It rates the apparent vigour, occurrence of seedlings, etc. of the various forage types, but does not consider their relative abundance or total ground cover. Some would argue that 'vigour and reproduction' are more appropriate indicators of 'apparent trend' rather than condition.

Traverse Method

The Traverse Method is a less intensive procedure designed for making surveys. The procedure for making the surveys was to drive along as many roads or tracks as possible. Ratings were made as each land system was entered and left, and at each mile (1.6 km) interval in between. The rating was an average of conditions during the previous mile traversed. It is not clear whether each observation of condition was meant to apply to only one pasture type, ie. whether the ratings within a land system could be summarised by pasture type or not. It is stated that the rating at each point represents the average condition since the last point, but there is no indication of what happens if the pasture type changes from one point to another.

At each rating point, three ratings were made: water erosion, wind erosion, and pasture condition. Each type of erosion was rated as nil, minor, moderate, or severe. Pasture condition was rated as excellent, good, fair, poor, or very poor depending on the composition of desirable forage species *and* the amount of bare ground, ie. quantity and quality simultaneously.

The 'total erosion' score was a combination of the two scores for water and wind erosion. If both were 'nil', the combined score was 'nil'. The total score was 'minor' if one score was 'minor' and one was 'nil', or both were 'minor'. The total score was 'moderate' if either of the two was 'moderate' and the other was 'nil' or 'minor'. If both wind and water were 'moderate' the total score was 'severe.' If either wind or water erosion was rated 'severe' the total score was 'severe'.

Total erosion and pasture condition were combined into a rating of 'range condition' in three classes, good, fair, and bad. If pasture were excellent or good and total erosion nil or minor, range condition was 'good.' 'Fair' range condition was produced by a combination of nil/minor erosion + fair/poor pasture; minor erosion + fair/poor pasture; or moderate erosion + good/excellent pasture. 'Poor' range condition resulted from nil/minor erosion + very poor pasture; moderate erosion + very poor, poor or fair pasture; severe erosion with any class of pasture.

Erosion Index for Each Land System

For each land system an erosion index (EI) is derived. The EI is the summation of the percentages of minor, moderate and severe total erosion (ie. percentage of nil is omitted) *plus* a 'severity index' which is the percentage of minor, moderate and severe totals weighted by an arbitrary 'severity factor' of 1 for minor, 2 for moderate and 6 for severe. When these are summed it gives a formula of:

$EI = 2\times1 + 3\times2 + 7\times3$
where: $\times1$ = % minor,
$\times2$ = % moderate, and
$\times3$ = % severe total erosion.

An EI is assigned for the whole land system as follows:

EI < 50	Nil
EI 50–150	Minor
EI 150–400	Moderate
EI > 400	Severe

The weighting factors (0:1:2:6) are admittedly arbitrary. Severe erosion is judged to be twice a bad as moderate and six times as bad as minor. No basis was given for these rankings. It is also not clear why the percentages of each type were added to the weighted percentages of each, resulting in the above formula rather than a straightforward summation of the weighted percentages, ie.

$$EI = 0(\times1) + 1(\times2) + 2(\times3) + 6(\times4).$$

Carrying Capacity Estimations

Carrying capacity estimates are based on total dry matter production, species composition by weight, and an expected dry matter utilisation percentage (ie. a proper use factor) for each species or group of species based on a safe level of use for desirable perennial species (ie. key species) for each pasture type. Topfeed is not considered.

Total dry matter production is a function of pasture type and range condition. It is recognised that production is variable within a pasture type according to rainfall and local variability in soil type and topography. Production figures are average values for a pasture type, presumably based on estimates in a variety of situations. It is assumed that total dry matter production also varies with range condition. In the example given for ribbon grass pasture, good, fair and bad range condition are estimated to produce 900 kg/ha, 500 kg/ha and 300 kg/ha, respectively. If the projected relationship of total production to range condition were based solely on the percentage of the area producing biomass (as reflected in the soil erosion rating and, to some extent, in the forage quantity rating), the predicted relationship between condition and production would be more direct. However, since the actual range-condition rating is a complex variable made of up forage quality, quantity, and vigour as well as erosion severity, it is not clear whether a predictable relationship is to be expected. (For example, some studies in the USA have shown that total biomass production is not well related to range condition based on species composition).

Species are classified as desirable, intermediate, or undesirable according to their forage value (palatability, etc.) and reliability. In the example shown, desirable species are perennials ranging from low to high palatability. Intermediate species may be perennials of low palatability or annuals of high palatability. Undesirable species are those which stock will not normally eat. Moderate to highly palatable perennials are given a PUF of 40% when the range condition is good or fair. Perennials of lower palatability (either desirable or intermediate species) were given a PUF of 20%. Highly palatable annuals (intermediate species) got a PUF of 70%. This high % reflects the observation that the annuals are preferred as fodder during the rainy season, with the diet shifting to perennials as the annuals dry out and disappear. Undesirable species are given no forage value.

Each PUF is weighted by the percent composition by weight of the species, and the result multiplied by the average production in kg/ha to give the kg/ha of forage produced by each species. The sum of the forage production by species gives total forage per hectare for the type. This figure is divided into the forage requirement per animal unit to give the carrying capacity in ha/cow unit or cow/units per square kilometre on a yearlong basis. The forage requirement used was 4,100 kg/CU per year, which is equivalent to about 11.4 kg (25 pounds)/day. For bad condition ranges the PUFs are adjusted downward from 40% to 20%, for the most palatable perennials, and from 20% to 10% for the less palatable ones. This is justified on the basis that the 'vigour' of these perennials is reduced in bad range condition and thus they require less intensive use. The total of cattle numbers is converted to cattle units when multiplied by 0.85. This factor is based on herd composition studies done for the Kimberley in 1966. It could be somewhat changed in 1996 due to higher calving percentages, younger maturity, reduced bull/cow ratios or other management factors. The likely tendency is for the factor to increase (eg. with a bull/cow ratio of 1:20, breeding heifers at two years and keeping cows in herd for an average of six years after calving, the ratio is about 0.90).

The approach described above is very similar to that used in forage inventories in the USA. The 'proper use factors' used in the example seem reasonable for conservative, yearlong use. The forage requirement of 11.4 kg/day is probably high for range cattle on a year-round basis, especially during the dry season when digestibility of forage is low. Most studies on rangeland show that intake probably does not exceed about 9 kg/day for a 450 kg animal on a year-round basis. Cattle in this area may not average 450 kg. So the forage requirement may be too high. Using 11.4 kg rather than 9 kg reduces the estimated carrying capacity by 25%.

The practice of reducing PUFs for ranges in bad condition is questionable. It is probably true that plants in lower vigour should not have as high a percentage of utilisation, although no literature has been seen to back that up. Plants on a bad condition range are not necessarily in poor vigour. If the trend in condition is upwards, they may be in good vigour. Since vigour was one of the factors used to establish range condition, and range condition already affects the carrying capacity by its presumed effect on total production, the lower PUF for bad range condition is questionable.

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Analysis of Procedures Currently in Use in the Kimberley Region

Method of Estimating Livestock Carrying Capacity

The procedures used by Agriculture Western Australia to estimate the carrying capacities of cattle stations in the East and West Kimberley are based on those developed for the West Kimberley by Payne *et al.* (1979). The general procedure will be described and some variations noted.

Two types of carrying capacity are estimated. The potential carrying capacity is that which could be carried when all the pastures are in good range condition and the station is fully developed (ie. distribution and other management problems have been minimised). Recommended carrying capacity is that which the station would support in current range condition with the station fully developed. Neither of these estimates, therefore, considers directly the distribution of cattle use. Heavily used areas are indirectly considered in the recommended carrying capacity because such use reduces range condition and therefore carrying capacity. Areas which receive little or no cattle use are generally rated in good condition and given full capacity. Recommended carrying capacity, therefore, does not insure that 'proper' stocking will occur on all parts of the range. Actual carrying capacity under current range condition and current development and management would tend to be overestimated by inclusion of unused areas. In compensation, it may be that the procedures used underestimate the actual amount of forage produced in areas of poor range condition where heavy use has occurred or is occurring. For example, intermediate and undesirable plants may receive more use than they are given credit for in favoured areas of heavy use. Likewise, the presence of abundant annuals detracts from range condition and thus lowers the estimated total herbage production. But on areas where erosion is not excessive, the change from perennials to annuals may not lower the quantity of forage by as much as is projected, but instead may shorten the useful grazing period. If cattle consume the annuals on accessible areas during the wet season, before moving farther out onto better condition country in the dry season, the presumed effects of range condition on forage production may be less than predicted.

Carrying capacity guides have been developed both for Pasture Types and for Land Systems. Payne *et al.* (1974) produced range condition guides for the pasture types of the West Kimberley. Estimated carrying capacities for each pasture type in good, fair, and bad condition were developed (see Table 4 in Payne *et al.* 1974). The same data were used to establish carrying capacities for each Land System by average condition class (see Table 4).

For example, the average percentage of each pasture type comprising each land system was estimated. These percentages were used to weight the carrying capacity of each pasture type to get an average for the land system. This procedure was followed for each condition class. In this process, it is assumed that all the pasture types in the land system are in the same condition class, although one could assign different condition classes to each pasture type.

An example of the use of these guides is found in the Resource Survey Report for a West Kimberley lease. In this case, recommended and potential carrying capacities were derived from the carrying capacity guides for pasture types. In each land system the percentage of each pasture type and the percentage of each pasture type in each condition class were estimated by the percentages of observations made in each by traversing the area.

In the East Kimberley, no range condition guides have been developed and there are no carrying capacity guides for pasture types in different condition classes. In this area at least two somewhat different procedures have been used. In the survey of one lease, the procedure was very similar to that used for the West Kimberley lease described above. The percentage of pasture types in land system and percentage of condition classes for each pasture type was determined by the proportion of traverse points in each. Apparently, the pasture types were quite similar to those described in the West Kimberley and so the recommended carrying capacities for pasture types and condition classes were based on those. When no traverse points were located in a given land system, the average pasture type percentages for the land system were used and all were assumed to be in good condition.

A somewhat different approach was used on a second East Kimberley lease. In this case the area of each land system apparently was determined by the percentage of total traverse points occurring in each land system. Carrying capacity was determined on the basis of land systems rather than pasture type. Maps of pastoral potential of land systems in the entire Kimberley Region (three maps) were published by Agriculture Western Australia. Land systems are classified as unsuitable, very low, low, moderate and high potential. For each class a range of carrying capacities is given, eg. moderate = 4–8 cu/sq km. This survey used these land system-based carrying capacities and adjusted them for range condition. A land system judged to be in good condition was assigned a carrying capacity near the upper end of the range of carrying capacities shown for that productivity class on the pasture potential map. Fair condition was given a capacity one half that of good, and poor condition one half of fair, ie. poor condition has a capacity only one quarter that of good condition.

There are several possible problems with either or both of the approaches described above. The first is that carrying capacity guides for both land systems and pasture types are not based on any detailed studies done for the East or North Kimberley. Basically, they are extrapolated from the West Kimberley studies of Payne *et al.* (1979). For example, in one of the East Kimberley surveys, the pasture types were similar to those in West Kimberley and were thus judged to have similar carrying capacities. In the other East Kimberley survey carrying capacity for each land system was taken from the map of pastoral potential which groups land systems by classes of productive potential. These maps were developed by Payne based on the work in the West Kimberley.

The carrying capacity estimates for each land system assume an average proportion of the various land units and pasture types within the land system. However, not every occurrence (mapped location) of a land system will have the same percentages, and the portion of a land system found on a given station or paddock will not necessarily have the same percentages of different pasture types as the average for the land system. Thus, if the area of paddock occupied by land system X has a higher than average proportion of a productive pasture type, the carrying capacity of the land system would be underestimated. This would not be as much of a problem if the carrying capacities were tied to pasture type first.

A problem which exists in the East Kimberley survey approach outlined above is that the percentage of pasture types and/or land systems is based on the percentage of traverse points which occur on them. As stated in both reports, there may be a bias here because the traverses are not randomly located. The same problem occurs with respect to the percentage of each pasture type and/or land system in each condition class. There is no guarantee that traverses do not tend to sample either better than average or worse than average range condition. The traverses may tend to overestimate the percentage of land systems and/or pasture types with good drainage and good access, ie roads and trails avoid rough, broken country and may also avoid land subject to flooding or bogging. On the other hand, since traverses often follow fencelines or roads which may lead from one bore or corral to another, the traverses are probably concentrated in the better, more developed country and the more heavily used (poorer condition?) country.

Carrying Capacity and the Distribution of Grazing

The recommended carrying capacity assumes full development and present range condition, while potential carrying capacity assumes full development and good range condition. These are both useful concepts since they recognise the potential for change in range condition. However, since most stations are not 'fully developed', whatever that exactly means, the actual proper stocking rate may not be the recommended stocking rate.

This brings up the whole problem of distribution, which is apparently ignored in these stocking rates. If a station or paddock is not 'fully developed' there will be areas which are unused or more lightly used because they are too far from water, or maybe for other reasons, such as rough country which will not be used unless fenced out separately. Uneven distribution can result from distance to water, slope, preference for certain pasture types or soils, location of fences, wind direction or insects, and from patch grazing. Patch grazing occurs when animals return to certain spots to graze because of fire or previous grazing which is not related to the other factors mentioned above. These are two different problems.

Uneven animal distribution can be solved to some extent by increasing the number of water points to minimise the travel distance from water to forage; by fencing pasture types or topographic types separately; by the location of salt and supplements, and so on. The goal is uniform moderate stocking. This can be achieved fairly well where pasture types and topography are uniform and water placement is frequent (as in improved pastures). On rangeland it can never be completely achieved, thus 'proper' stocking generally means that some areas will be lightly used and some overused (sacrifice areas). Key areas are typical and should represent the desired use. 'Development' will shrink the areas of underuse and overuse. In a paddock where use grades from none to severe, reducing stocking typically increases the area of no use or light use. It may reduce the area of overuse, but it will not eliminate it. Where areas of overuse are mainly caused by topography and/or the preferential selection of certain pasture types, rather than simply distance from water, reducing stocking is not apt to reduce the area overused at all unless stock reductions are drastic. The only ways to deal effectively with the overuse of favoured pasture types or topographic types is either to fence them out and manage them separately, or to use some kind of spelling program which allows the heavily used areas to recuperate vigour periodically.

Patch grazing is an entirely different problem. Patch grazing, as usually defined, is not the result of any lack of development of fences or waters, or of preferential grazing of certain pasture types or topographic features. It results in a uniform type of pasture where differences in attractiveness of the forage are the result of previous grazing, or in some cases fire, fertilisation, use of herbicides, etc. Usually patch grazing occurs when forage species are relatively coarse or unpalatable in maturity and when stocking rates during the growing season are not adequate to keep all plants in an immature state. The latter situation occurs universally on rangelands which are grazed yearlong, ie. where cattle are in one paddock for all the year or most of it. Patch grazing generally cannot be eliminated by increased 'development' if yearlong, or even season-long, grazing is continued. The only grazing management that can reduce it is to concentrate animals to force even utilisation, ie. a 'high utilisation grazing' strategy. This practice requires fairly intensive fencing and water development, as well as the frequent moving of cattle. Other practices which can be used are burning off ungrazed patches, mowing, fertilising and so on.The only one of these likely to be useful in most rangeland situations is burning.

The question of uneven distribution and/or patch grazing greatly complicates the concept of carrying capacity. Changing stocking rates may reduce the problems but usually does not eliminate them, even when stocking rates are reduced quite drastically. This is the basis for Savory's statement that ranges can be understocked and overgrazed, and his contention that 'overgrazing' cannot be eliminated by altering the stocking rate, only by changing the timing of grazing. He is correct. The approach of most range managers has usually been to aim at light to moderate stocking; improve the property with fencing, water, salt placement, etc. as much as is economically feasible; and accept some amount of overgrazed, degraded land (sacrifice areas). Some kind of deferred grazing or rest is usually used to minimise the impacts on the more heavily used areas. Such practices may reduce the problem of patch grazing, but will not eliminate it where the pasture types are particularly susceptible to it.

Observations on Methodology and Information Needs

1. 'Quantity' and 'quality' ratings used to arrive at pasture condition may not be independent when used in the Site Evaluation Method, and probably are not in the traverse method. If the two factors are to be rated and added together, they should be based on different attributes. The criteria for rating each of these factors need to be clarified so that they are independent of each other.

2. 'Vigour and reproduction' is also included as a factor in the Site Evaluation Method, but apparently not in the traverse method. Vigour is a very subjective attribute and difficult to define. Some indicators (reproduction, diverse age structure, etc.) may be 'good' when applied to 'desirable' species and 'bad' when applied to 'undesirables'. Thus 'vigour' tends to be value-driven. Reproduction in arid-semiarid environments is often highly episodic because of the rare occurrence of conditions suitable for plant establishment. 'Vigour' is probably best left out of range condition assessment and used only to estimate trends or to interpret monitoring results.

3. Calculation of an 'erosion index' for each land system is described. The derivation of the formula is confusing. Conceivably, such a rating could be used to report on the status of land systems, but that use has not been observed. Either the derivation of the formula needs to be examined and changed or its basis needs to be clarified.

4. Forage production vs pasture condition for specific pasture types. As stated before, there is confusion because quantity and quality of forage are somewhat confounded. Biomass production will decline as the area occupied by vegetation declines, ie. as bare ground increases. The 'usefulness' of the biomass for forage declines as the composition of the vegetation changes to less desirable species. Theoretically, these two factors could operate independently so that forage production could decline with a decline in either or both of the two factors. Because the criteria for rating these two factors are not distinct, the ratings are not independent, and this may cause the estimated carrying capacity for fair and poor condition pasture to be excessively reduced. More information is needed to predict total biomass production as a function of total plant cover and to separate this estimate from a 'utility' rating for livestock forage based on species composition. The changes in total biomass for different condition classes, and the effects of this on carrying capacity seem excessive compared to what has been found elsewhere.

5. 'Proper Use Factors' are perhaps inevitable if carrying capacities are to be based on estimates of usable forage production. They are not usually based on any scientific study, but represent best guesses of what is sustainable and realistic in the field. PUFs also vary depending on the season of grazing, wet-dry years, etc. For example, annuals might get a higher PUF on range used in the wet season than for dry season or year-round grazing. PUFs also do not relate to forage quality. Perhaps it would be simpler and more realistic to merely assign PUFs based on about three classes of forage preference 0%, 20% and 40% (these could be adjusted upwards in intensively managed grazing, but probably should not be altered for different condition classes).

6. The forage requirement used is 4,100 kg/LSU/year or 11.23 kg/day. That is probably too high for a year-round average, given the quality of the forage on offer. About 8–10 kg/day is probably more realistic.

7. The use of pasture types vs the use of land systems to estimate carrying capacity. There would seem to be no question that assigning carrying capacities to each pasture type by condition class would be the preferred way to estimate carrying capacity for a paddock or station. Since the 'range condition' is assessed on the basis of pasture type, the estimate of the proportion of pasture types and condition classes of each is available. The only reason for estimating carrying capacity by the average values for land systems and the proportion of condition classes within them seems to be that carrying capacity estimates (reliable ones at least) are not available except in the West Kimberley. They need to be developed for East and North Kimberley, and perhaps, refined for West Kimberley if this procedure is continued. Using land systems just adds one more level of uncertainty to the process.

8. Sampling adequacy. The estimates of area by range condition classes are based on the percentage of survey points which falls in each class. The percentage of pasture types is also based on this. The percentage of land systems is usually based on maps and thus depends on the adequacy of the map, not whether the survey covered a representative area. It is well recognised that the survey points may over- or underestimate certain pasture types and/or condition classes because these may be positively or negatively associated with topography, fences, water points, etc. which influence how accessible the area will be.

   A partial solution would be to map pasture types from aerial photos so that a reasonable estimate of their proportions in a paddock or station could be had. If a complete mapping is not feasible, perhaps a random sampling procedure could be used, ie map pasture types on a random selection of aerial photos on a station. This procedure assumes that the mapping could be done fairly accurately from aerial photos without much ground truthing, ie. it would not require additional travel outside the 'traversable' area to get it done. If adequate aerial photography does not exist, it might be possible to use video cameras to fly strips across the stations to get this information (as has been done to map riparian vegetation in the USA). Of course, this still does not solve the problem of estimating range condition in an unbiased way across the whole property. Aerial photos or video cameras are not likely to help this process. They might help to characterise *ground cover* on a large scale.

9. Water, fencing and management. The effects of these factors have been recognised because both the 'potential' and 'current' carrying capacity estimates assume 'full development' and uniform grazing use. Thus, neither PCC or CCC is an estimate of what the station will carry under present development and management. As long as livestock numbers are not regulated, that may be an advantage. That is, nobody is saying what the station will run under various management scenarios, only what its approximate limits under present range condition are, and how much it might improve in the future under good management. One thing that could be added would be an approximate distribution map based on arbitrary distances from water and perhaps topography. This could be done easily on GIS. There is some danger in doing this because it may not coincide very well with the actual use patterns of the stock, thus casting doubt on other estimates.

10. Land systems, land units, and pasture types. Land systems are complex mapping units which describe a pattern of land units which occur together. Land units are topographic units usually associated with certain soil types; since they are basically geomorphological units, they are not directly related to rainfall amounts. Pasture types (or other vegetation types) are generally associated with one or more land units within a land system. Land units and pasture types typically occur in more than one land system, eg. black soil plains land units or Mitchell grass pasture types may occur in several land systems. A land unit in one land system could have a different pasture type from a similar land unit in another land system if rainfall were different.The value of land systems is a) they are recognisable and conveniently mapped at scales which would not allow direct mapping of land units or pasture types, and b) they furnish a basis for predicting the various kinds of country one will encounter and how its various units are interrelated. Land systems are a good 'reconnaissance' level unit on which to integrate and plan at a broad scale. However, the utility of the land-system concept breaks down as the scope of interest is more focused on smaller management areas because the interpretation of such things as range condition and carrying capacity must focus more on the land unit/pasture type level.

    Pasture types are the basis for evaluating range condition and carrying capacity. Only 12 pasture types, based on dominant forage species, were used by Payne. They are comparable with those identified earlier by Ray Perry and others in the various land surveys of the Kimberley. Both Payne and Perry recognised that a given pasture type may occur on different land units in different land systems, and that the species composition (including overstorey) may vary in different land systems and precipitation zones. Payne assigned different carrying capacity ratings to the same pasture type according to the land system involved (see values for frontage grass, ribbon grass, short grass, curly spinifex, and limestone spinifex). An example of how the pasture types can vary is shown by the following quotation from the survey of Djarindjin Station:

    > "The Yeeda and Wanganut land systems are usually dominated by spinifex based

pastures but, in this case, very little spinifex was seen. The Yeeda land system should support a Ribbon grass (RGRB) pasture, but this pasture type is not found in high rainfall areas; in the absence of spinifex species the pasture has been identified as Ribbon Grass (RGRA) pasture.

The traverse data (Table 3) indicate that RGRA pastures cover a much greater proportion of the Yeeda land system than the proportion given for a standard Yeeda land system (Table 4). This is attributed to the very high rainfall of the Dampier Peninsula.

The Wanganut land system usually only supports the CSRG pastures but in this instance RGRA pastures were also identified. Again this variation is attributed to the high rainfall and absence of spinifex species."

It is apparent that differences in the association of pasture types with specific land systems and land units in those systems, as well as differences in the species make-up of pasture types has been recognised in the field, but has apparently not resulted in a formal effort to describe new pasture types based on site conditions, including rainfall.

11. Actual stocking records. It is apparent that the reported stocking figures leave something to be desired. Part of the problem with these figures may be the TB-Brucellosis eradication program which has caused changes in livestock numbers not typical for routine operations. Another problem relates to the sale of properties resulting in temporary destocking or reduced stocking and the transfer of animals between stations owned by the same company. These are real changes in numbers but make any assessment of realistic average values, effects of wet/dry years, interpretation of changes in range condition, etc. very difficult.

    Finally, there is some indication that graziers do not make much effort to report accurate figures, partly because of the difficulty of doing it at the time of year requested, and perhaps partly out of suspicion that the data will somehow be used against them. From the standpoint of interpreting range condition and carrying capacity data, it would be very useful to have better estimates of actual stocking. If a monitoring approach to determining carrying capacity is adopted, such data are even more essential.

12. Multiple use considerations. The current method of assessing range condition is aimed mainly at establishing recommended carrying capacities for cattle and, to some extent, as a basis for identifying management problems and opportunities for the cattle stations. The range condition assessment includes soil condition, and thus furnishes some basis for statements about sustainability, soil conservation, etc. Some other considerations for which data may be needed in the future include:

    a. Woody species—to interpret vegetation changes (ie. woody plant increases or decreases, fire effects, habitat for wildlife) and possible sources of wood or other tree products.

    b. Weeds—to document the occurrence or abundance of weedy, poisonous, or noxious plants, either exotic or native.

    c. Biodiversity—this is difficult to define, but present methods probably do not adequately document species occurrence and composition to provide much information on this subject.

    d. Soil degradation by erosion or structural damage—some information is currently collected, but there probably needs to be more.

13. Monitoring. Present monitoring efforts are aimed at providing a basis for decision making for property management. That is a valid objective and the effort should be emphasised and expanded. However, monitoring for such purposes is not usually located in the right places nor does it measure the right things as a basis for a regional reporting system to document the 'state' of the rangelands across the Kimberley. In other words, management-oriented surveys and monitoring data are difficult to aggregate upwards for regional reporting. One type of regional monitoring that is in place is the monitoring of bush fires and ground cover from satellite imagery. This appears to have great potential for broad-scale monitoring and reporting, but limited usefulness at the scale of a property.

Appendix 2

Kimberley Rangeland Resource Assessment—Analysis of Stocking Rate Data

Introduction

The objective of this study was to examine the relationship of estimated carrying capacity to actual stocking, and if possible, to discover other factors which could help improve the accuracy of carrying capacity estimates based on current range-survey procedures. This report consists of three parts:

1) A general description of the data available and procedures used;
2) Procedures and results of each data analysis, and
3) General conclusions based on the entire study.

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Description of Databases and General Approach

Actual Stocking Data

Stocking rate information was available from a total of 97 pastoral leases in the Kimberley region from 1984 through 1995. The data were those furnished to the Lands Department by the owners/managers of the leases. The data reported were estimates of cattle by age and sex class, and these were converted to Livestock Units (LSU) based on standard conversion rates. All of the analysis of stocking rates was based on LSUs.

The purpose in using these data was to get an estimate of how many LSUs each station had been running on average over a period of years, with the idea that this average number would be about what the manager considered to be the carrying capacity for the lease. Carrying capacity based on actual stocking records could then be used as an independent comparison to the carrying capacity estimates generated from range surveys of land systems, pasture types, and range condition.

Upon examination of these data, it was apparent that there were some potential problems with them:

1. Some leases had only reported data for 1–4 years out of the 12 year period.

2. Some leases showed large differences in LSUs from one year to the next: for example, 8,000 LSU in one year followed by 0 the next, and back to 5,000 head the next. Others had fairly constant numbers for several years which dropped to much lower numbers over the next few years. Wide fluctuations like this are not typical of stable range cattle operations. One explanation may be that the reporting period corresponded with the brucellosis/tuberculosis eradication program carried out in the Kimberley which resulted in large scale destocking of some leases and subsequent restocking. This period also involved a general trend to more intensive management, including the eradication of feral donkeys, changes in the breed of cattle, and widespread fencing into

smaller paddocks. Another explanation is that when properties are sold, cattle are sometimes sold off and the new owner may not be able or willing to restock the property fully. Weather (drought) could also be a factor. And finally, some leases are owned by companies which hold several leases and they may move cattle from one lease to another in fairly large numbers for various reasons and periods of time, so that a reduction on one lease is balanced by an increase on another.

3. Some leases are known to be stocked at levels far below their carrying capacity, for economic or other reasons.

4. It is probable that station managers vary considerably in the accuracy of the data they report. Data are reported for a 30 June inventory. This is not the ideal time for such data to be reported in the Kimberley because it is in the middle of the mustering season, so managers may not yet have accurate figures on numbers for the current year, making the task of determining accurate figures considerable at a time when demands from other work are at maximum.

In an attempt to eliminate those leases where data seemed dubious, the list was reduced by taking out those stations where the reported data seemed to show unusual fluctuations or where only a few years had been reported. Those stations known to be greatly understocked were also removed. This process resulted in a list of 33 stations where the data appeared to be fairly consistent. However, not all of these stations had range survey data available. Therefore, in order to have a larger number of data points for regression analysis and to avoid bias in selecting the stations to be included, a basic database was developed which consisted of 59 stations for which range survey data existed and data on actual stocking were available. In calculating an average stocking rate, all 0 values were excluded. When stocking data were fairly consistent for several consecutive years, then dropped to a much lower value for the remainder of the record, only the higher values were used.

Actual stocking data were used as a basis of comparison for carrying capacity estimates based on range surveys. The results must be interpreted with the deficiencies of the actual stocking data in mind. Future work on carrying capacity will require better estimates of actual stocking.

Range Survey Data

The results of range surveys of leases throughout the Kimberley were available in another database. This database included the following data:

1. Station name and total lease area (ha).

2. Land system names and area (% of total and ha) of each.

3. Range condition of each land system (% and ha of good, fair, poor) for stations on which a condition survey had been conducted.

4. Estimated Potential Carrying Capacity (PCC) and Current Carrying Capacity (CCC) for the lease expressed in LSU.

Potential Carrying Capacity is defined as the average LSU a lease would carry on a sustained basis if all the range were in good condition and the property were fully developed. Current Carrying Capacity is the average LSU a lease would carry given the current range condition assuming the property were fully developed. 'Fully developed' means that fencing and water development are adequate to permit reasonable use of all the forage available on the lease.

Two approaches were used to calculate PCC and CCC. In all cases, the proportion of land systems on a lease was determined from maps of land systems. In one approach, the PCC of each land system is based on the proportion of pasture types within the land system determined by traverses in the field.

Each pasture type is given a carrying capacity for good condition, and the proportion of the pasture types in the land system determines the carrying capacity assigned to the land system. For CCC each pasture type is rated according to range condition and a carrying capacity is assigned to each range condition class in each pasture type. The weighted average for the land system then determines the current carrying capacity for the land system on that lease or paddock. Most of the range condition surveys use this procedure. Carrying capacity figures for pasture types and condition classes are usually based on those published by Payne for West Kimberley, but are often modified by local conditions and professional judgement.

The second approach has been used on some leases where the locally developed carrying capacity data for pasture types are not available. Range condition is judged on pasture types on traverses. These data are used to rate the condition of each *land system*, ie. the condition of the land system is based on the average condition of pasture types sampled within it. Carrying capacity is assigned to the land system. The PCC is based on published maps so that land systems are classified into productivity classes. Thus, a land system classified as high potential would be assigned a PCC of 10 LSU/km^2, while one classified as moderate potential would be rated at 7.5 LSU/km^2. Land systems classified as unsuitable were given no carrying capacity. Standard reductions are made in each potential class for fair and poor range condition. This procedure was used to calculate PCC and CCC on all leases where sufficient information existed, regardless of how the original survey was made. Thus it was called the 'standard' method in the subsequent analyses.

Survey reports were available which had estimated PCC for 53 leases and CCC for 41 leases. These estimates were called the PCC-Report and CCC-Report regardless of the approach used to obtain the estimates. The 'standard' method was applied to existing data to obtain estimates of PCC-Standard on 61 leases and CCC-Standard on 37 leases.

The basic database used for the regression analyses consisted of 64 leases which had at least two of the following: actual stocking, PCC-Report or PCC-Standard. All leases with an estimate of CCC had some estimate of PCC.

Rainfall Data

Average annual rainfall (to the nearest 25 mm) for each lease was estimated from a map (Figure 1 in Kimberley Region Planning Study). Many stations are large enough to vary by 100 mm or more in annual rainfall according to the isohyets shown on this map. Thus, the average for the station was estimated from the map on the basis of its location with respect to the isohyets. This average location does not necessarily coincide with the station homestead.

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Regression Analyses

Report vs Standard Estimates of PCC and CCC

Figure 1 shows the relationship of PCC as estimated by the 'standard' method compared with that estimated by the range survey report for each of 50 leases (there are 51 data points, but one has no report data). PCC-Report was arbitrarily selected for the X axis. The regression equation is $Y = 1.17 + 0.83X$, with an r^2 of .68. As expected, there is a fairly close correlation of the two methods of estimating PCC; 68% of the variation in Y is accounted for by X. PCC estimated by the 'standard' method tends to be somewhat higher than PCC estimated in the survey report. This tendency is higher at lower stocking rates than at higher stocking rates. For example, if the report PCC was 1.00 LSU/km^2 the predicted PCC 'standard' would be 2.00. At a report PCC of 6.00 LSU/km^2 the predicted 'standard' value would be 6.15. *This trend would indicate that the discrepancy between the two approaches is probably due to different estimates of carrying capacity employed for lower potential land systems; reports are rating them lower than the standard method.* Four leases were substantially underestimated by the standard method compared with the survey report. One lease PCC was greatly overestimated by the standard method compared with the survey report. No explanation has been found for these 'outliers.' All are above average in estimated carrying capacity rate.

Figure 2 illustrates the relationship of CCC estimated by the two methods. These estimates show considerably better agreement than PCC. The regression equation is $Y = 0.11 + 1.00X$; $r^2 = 0.75$. Thus, there is very close to a 1:1 relationship with 75% of the variation accounted for. The equation indicates that CCC-Standard is 0.11 LSU/km^2 higher than CCC-Report. The *percentage* difference is higher at low carrying capacities than at high rates. CCC-Standard is substantially lower than CCC-Report for five leases and very much higher for one other.

Comparison of PCC with Actual Stocking

When carrying capacity is expressed as total LSU for a lease, PCC-Report is predicted from Actual Stocking by $Y = 2{,}836 + 0.63X$; $r^2 = 0.45$, with 50 stations included. This regression indicates that PCC-Report is fairly consistently related to Actual Stocking rates (45% of variation is explained). PCC-Report tends to be higher than actual stocking for leases running 7,500 LSU or less; above 7,500 LSU, PCC underestimates actual stocking rates. There are some stations which deviate considerably from this generalisation, however.

PCC assumes that all the range is in condition and the lease is fully developed. Therefore, it should establish the *upper limit* of carrying capacity. The tendency for larger leases (in terms of numbers) to be stocked above PCC would indicate that these leases tend to be overstocked or that PCC is very conservative on larger leases. The tendency for smaller leases to be stocked below PCC would indicate that these leases are nearer to proper stocking, or that small leases tend to be very conservatively stocked for some reason.

Figure 4 shows a similar relationship for PCC-Standard to Actual Stocking.

The regression equation is $Y = 4{,}402 + 0.57X$; $r^2 = 0.35$; sample size is 58 stations. In this case the fit of the data is not as good as for PCC-Report. Stations running less than about 10,000 LSU tend to have PCC-Standard higher than actual stocking and those over 10,000 LSU tend to run more cattle than estimated PCC. There are several stations which deviate substantially from the predicted PCC, especially where actual stocking exceeds 10,000 LSU; in fact, it appears from visual observation of the graph that little relationship exists between PCC-Standard and actual stocking for those stations with higher cattle numbers.

Figures 3 and 4 deal with PCC and Actual Stocking on the basis of LSU/lease, thus the reason for part of the relationship between PCC and Actual Stocking is that PCC tends to increase as the size of lease increases. When PCC and Actual Stocking are expressed as LSU/km^2 (Figure 5) the relationship between them is weakened ($Y = 3.05 + 0.31X$; $r^2 = 0.13$; 57 stations). As before, there is a slight tendency for PCC-Standard to be higher than Actual Stocking rate below a stocking rate of about 4.25 LSU/km^2, and for PCC to be less than Actual Stocking rate above that level. The weakness of the relationship however really means that predicted PCC bears little consistent relationship to actual stocking.

Comparison of CCC with Actual Stocking

It could be expected that Actual Stocking would be more closely related to CCC than to PCC, because CCC reflects the current condition, and presumably, carrying capacity of the range. *Figures 6 and 7* show the relationship of CCC-Report and CCC-Standard, respectively, to Actual Stocking. (For Figure 6, $Y = 2665 + 0.39X$; $r^2 = 0.29$; 39 stations; For Figure 7, $Y = 2{,}509 + 0.40X$; $r^2 = 0.39$; 34 stations). The relationship of CCC to Actual Stocking is actually somewhat weaker than that for PCC. Estimated CCC-Report and CCC-Standard are both less than Actual Stocking, especially for larger stations. This tendency would likely be even stronger if it were not for a few large stations which are outliers, that is they are stocking at about the estimated CCC or somewhat below that level.

Figure 8 shows the relationship between CCC-Standard and Actual Stocking on a LSU/km^2 basis. The equation is $Y = 2.66 + 0.07X$; $r^2 = 0.01$. This shows there is basically no correlation between the predicted current carrying capacity and actual stocking rates when expressed on a LSU/km^2 basis.

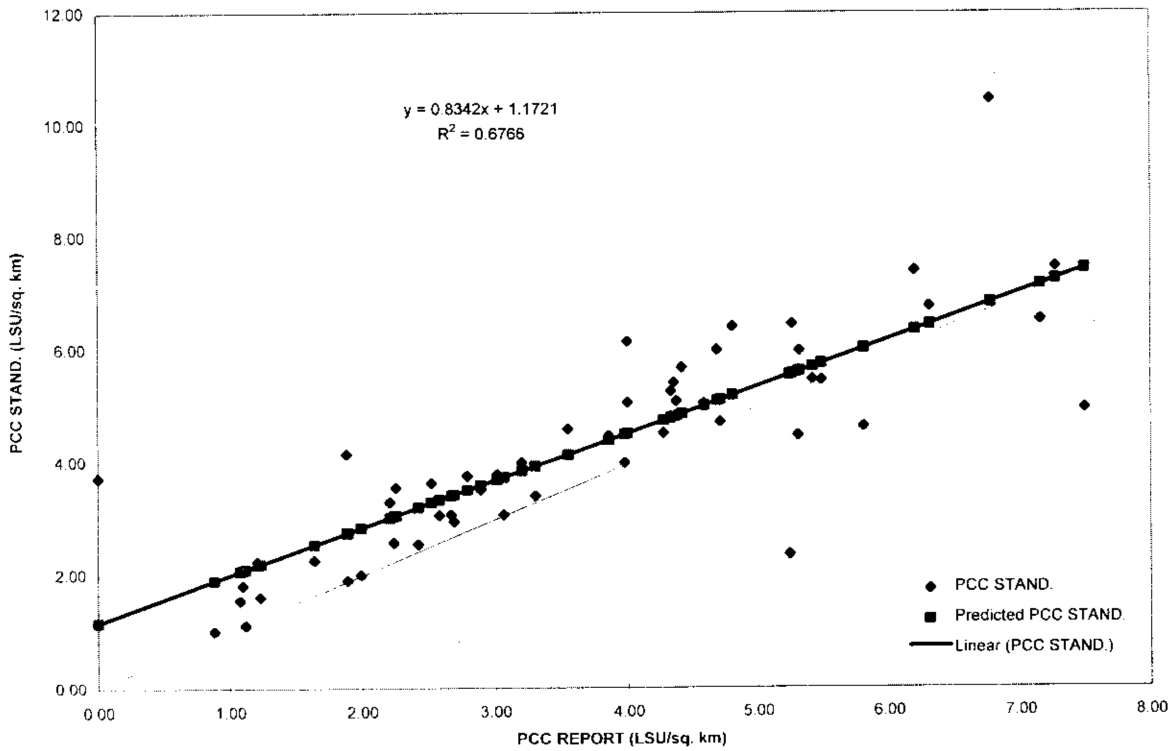

Figure 1. Relationship of potential carrying capacity estimated by the 'standard' method compared with that estimated in the survey report for 51 stations in the Kimberleys.

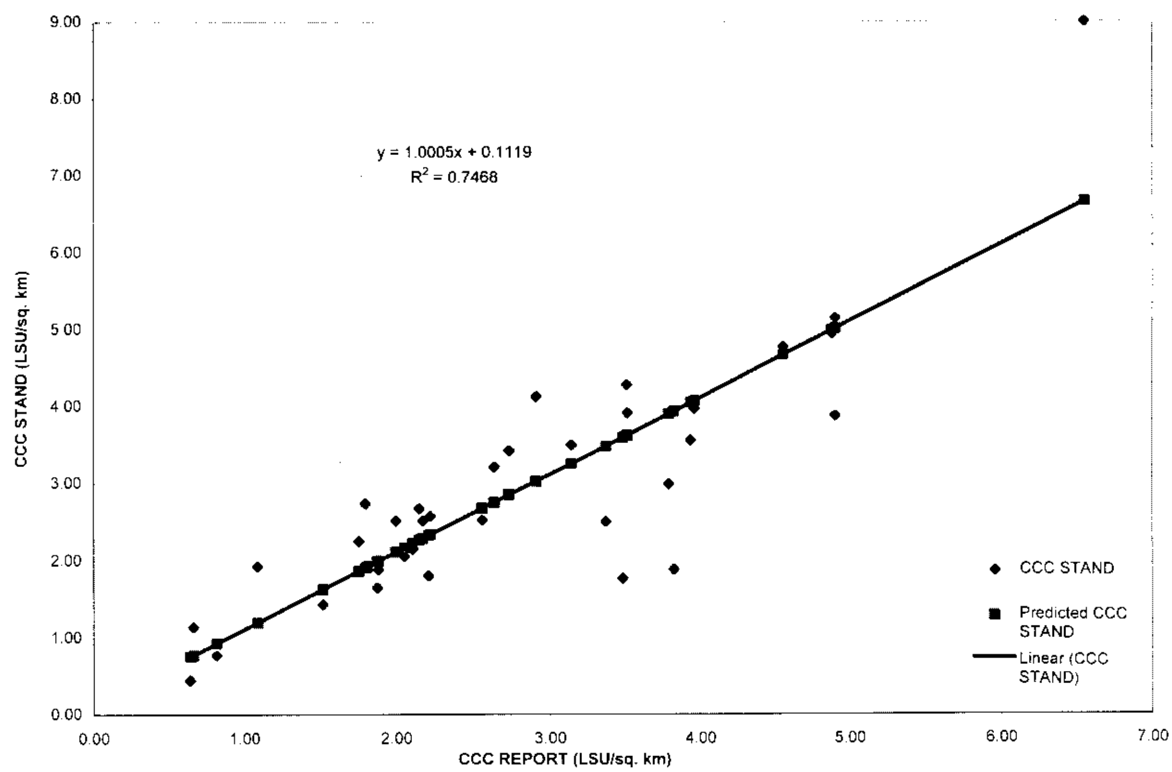

Figure 2. Current carrying capacity estimated by the 'standard' method compared with hat estimated in the survey report for 34 stations in the Kimberleys.

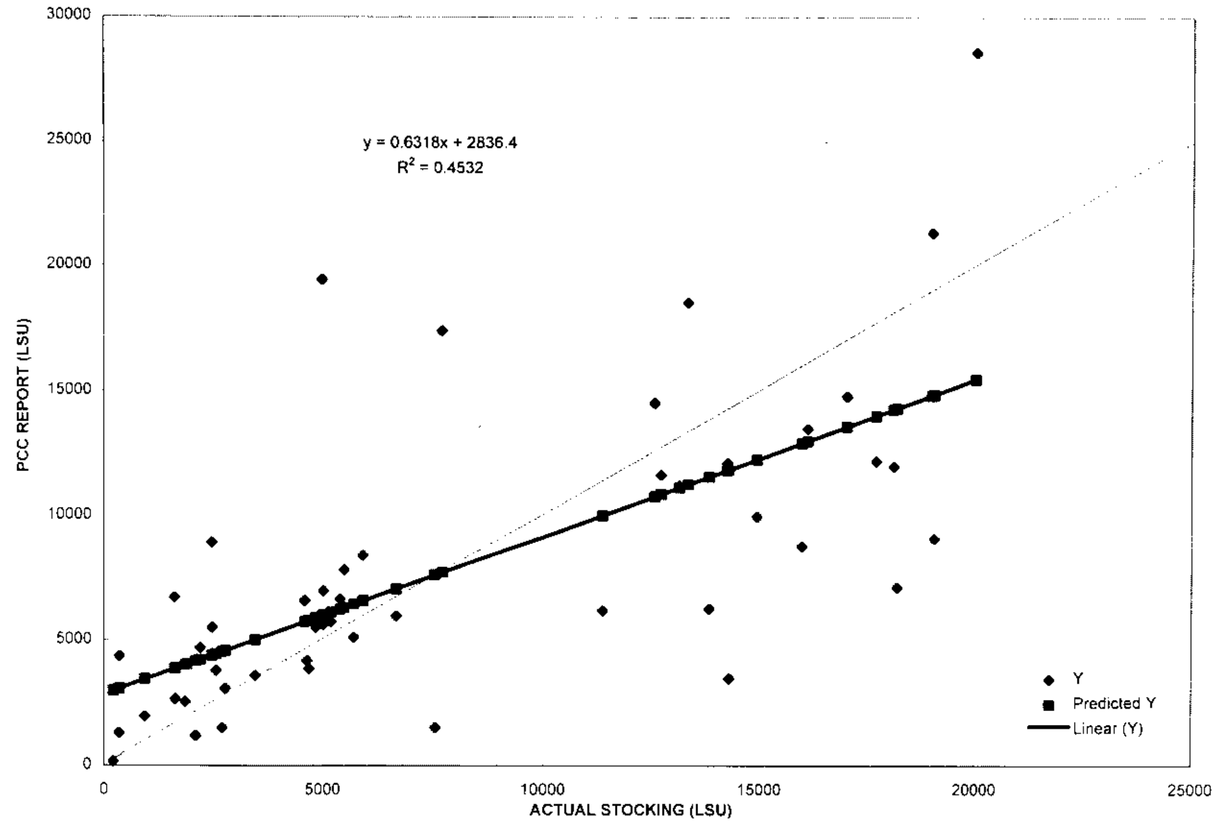

Figure 3. Potential carrying capacity estimated in survey reports for 34 stations in the Kimberleys.

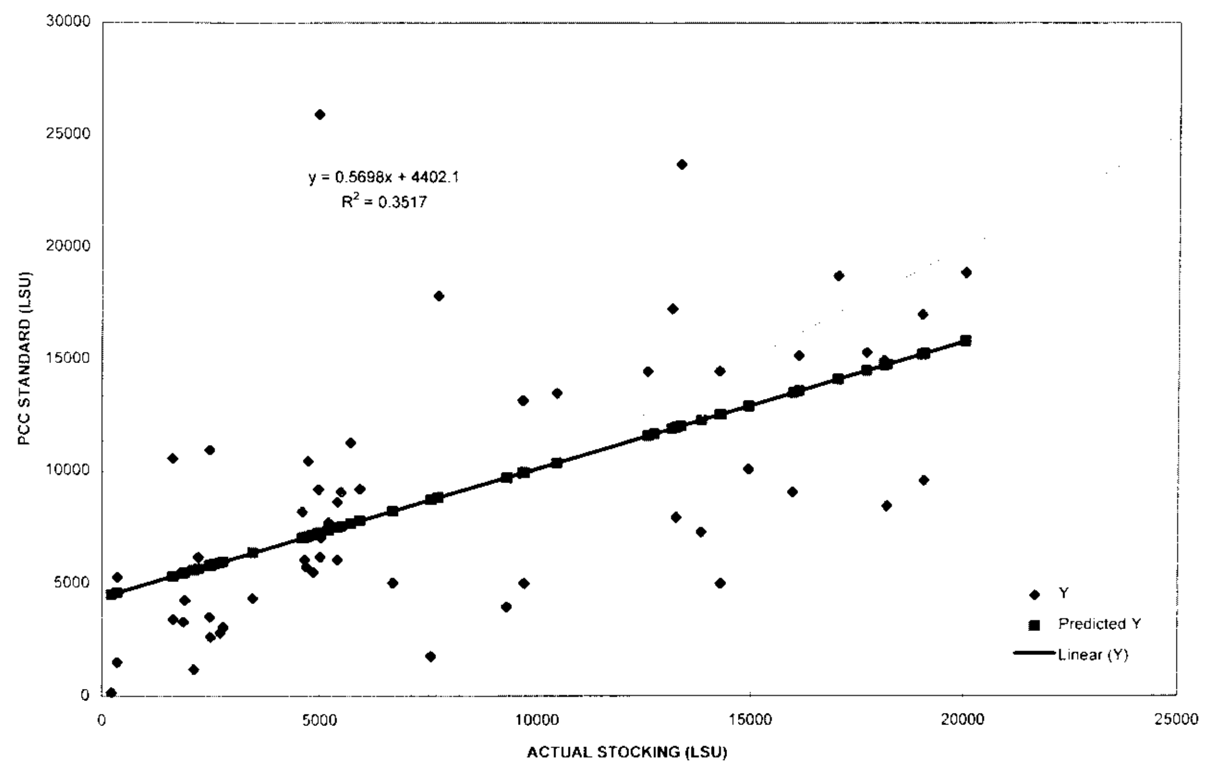

Figure 4. Estimated potential carrying capacity by standard method compared with reported actual stocking rate for 58 stations in the Kimberleys.

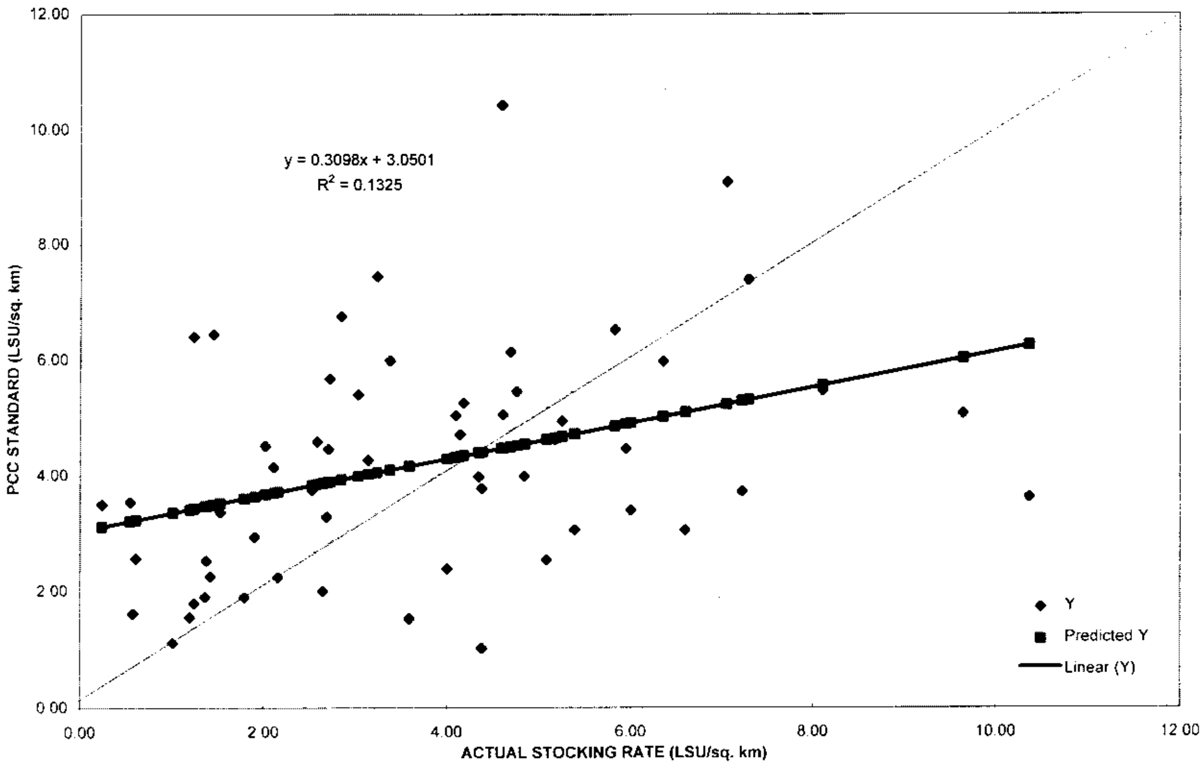

Figure 5. Potential carrying capacity estimated by the standard method compared with reported actual stocking rate for 58 stations in the Kimberleys.

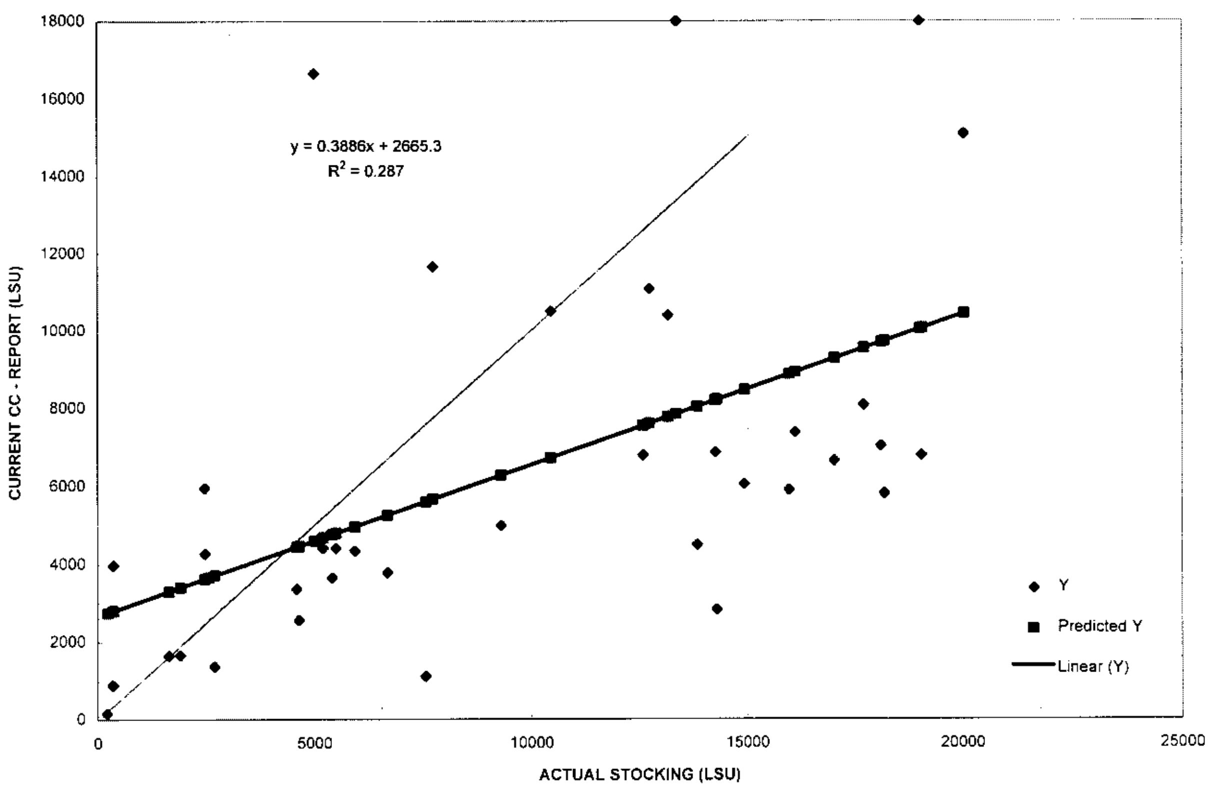

Figure 6. Estimated current carrying capacity from survey reports in relation to reported actual stocking rate for 39 stations in the Kimberleys.

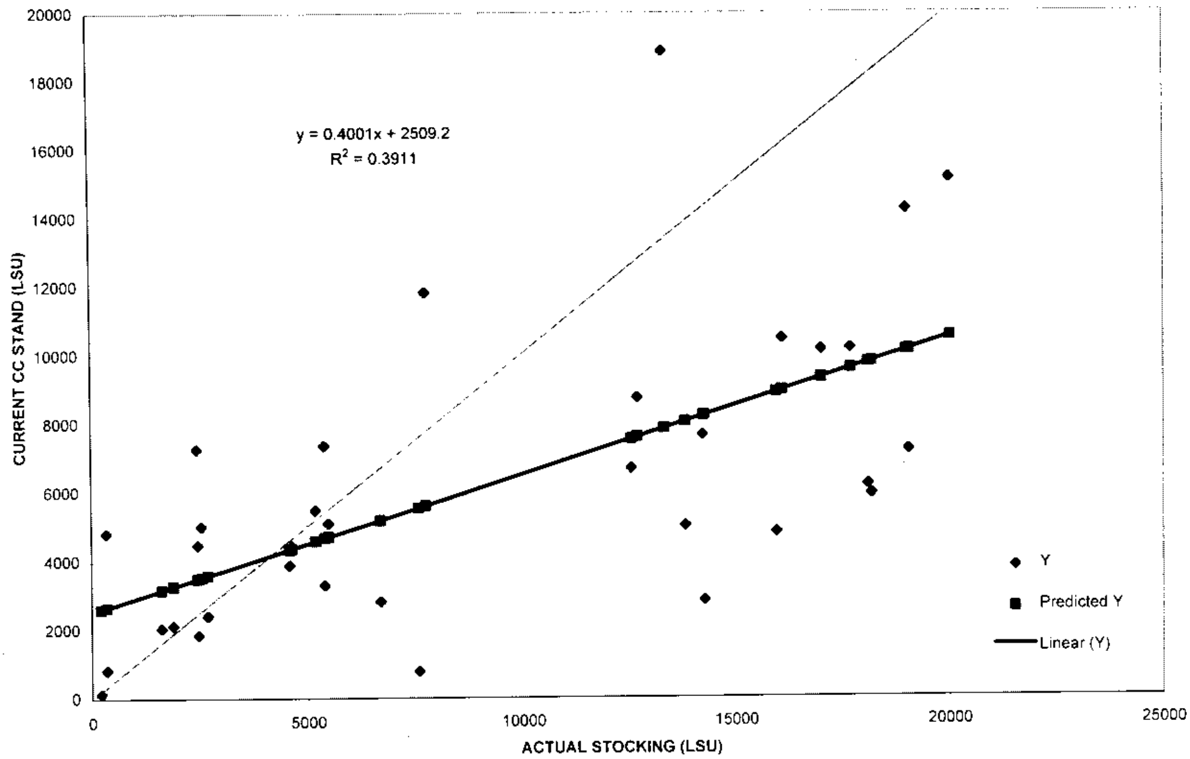

Figure 7. Current carrying capacity estimated by the standard method compared with reported actual stocking for 35 stations in the Kimberleys.

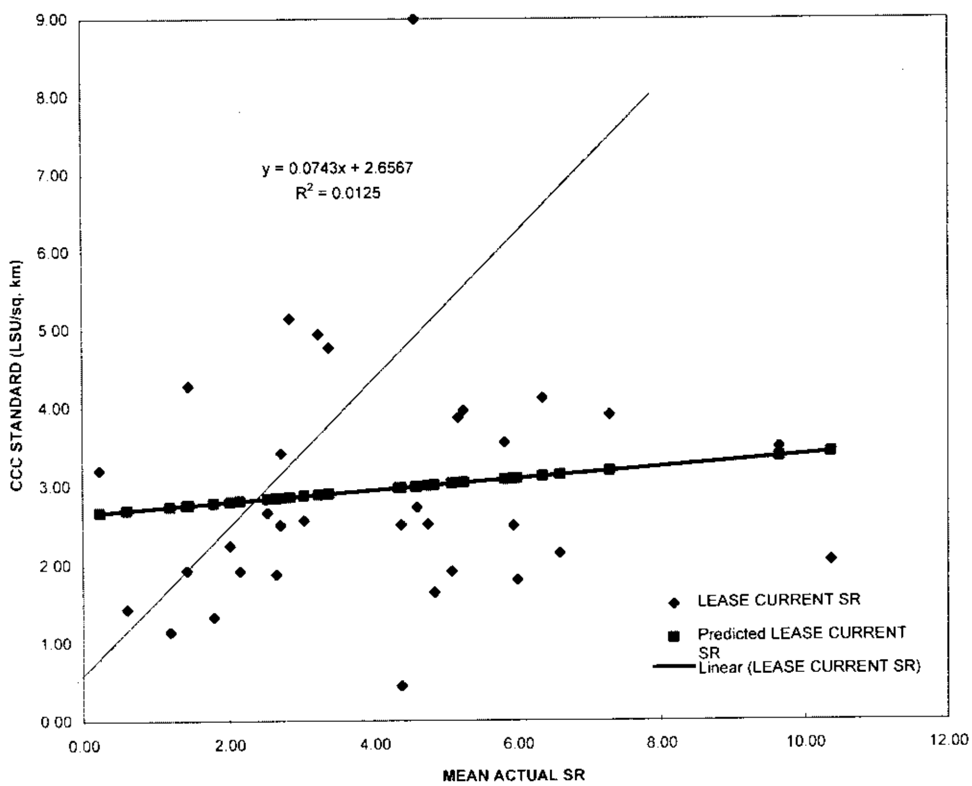

Figure 8. Current carrying capacity estimated by the standard method in relation to reported actual stocking rate for 33 stations in the Kimberleys.

'Range Condition' vs Actual Stocking

Poor range condition is caused, supposedly, by changes in vegetation and soil brought about in large part by 'overgrazing'. There might be a relationship then between the actual stocking rate and the range condition. A measure of range condition over an entire lease could be expressed by the ratio of CCC to PCC, ie. PCC is the estimated capacity if all is in good condition and CCC is the capacity in current condition. If the range is all good, the ratio is 1.0, if it is not all good the ratio will be less than 1.0. Figure 9 shows a regression of the ratio of CCC/PCC against actual stocking rate. There is no relationship (r^2 = 0.01). One way to express the degree of 'overstocking' would be to divided Actual Stocking by PCC. A ratio less than 1.0 would indicate that the station is stocked more lightly than the PCC estimate; over 1.0 it would indicate it is stocked more heavily than PCC. Figure 10 shows the 'range condition' factor (CCC/PCC) vs the 'overstocking' factor (Actual Stocking/PCC). Again, no relationship was found (r^2 = 0.02). *Figures 9 and 10* do not show any relationship between current stocking rates and current range condition. That does not prove that there is no relationship. First, some stations may have lowered their actual stocking because of poor range condition, ie. the poor range condition is the result of past grazing pressure rather than current. Secondly, it may be that the relationship of forage production to range condition is not adequately reflected in the adjustments used in the range survey procedure. Thirdly, the picture may be confused by differences in the kinds and proportions of pasture types on a station, their relative condition, and their different responses to heavy stocking. These interactions may be masked by the simple ratios used.

Carrying Capacity vs Rainfall and Land System Suitability

The current method of estimating carrying capacity does not directly take into account the average annual rainfall. Carrying capacity is based either on land systems or on pasture types and their condition. Some land systems and pasture types may occur primarily in lower or higher rainfall zones, so differences in their estimated capacity may be partly related to differences in rainfall. To establish whether estimated PCC increases with rainfall, the regression in Figure 11 was run. The relationship is very poor(r^2 = 0.04) with a slight downward trend, the opposite of what was expected.

Estimated PCC assigns no carrying capacity to land systems which are considered 'unsuitable' for livestock grazing. Therefore, a lease with a high percentage of unsuitable land systems would tend to have a lower PCC than one with a low percentage of unsuitable land systems, if other parts of the lease were similar.

If the percentage of unsuitable land systems (no assigned capacity) increased as rainfall increased, this might account for the lack of correspondence of PCC with average rainfall. Figure 12 shows the relationship of % of area classed as unsuitable to rainfall. This regression shows a positive trend with an r^2 = 0.31. Most of the stations with none or very low percentages of unsuitable land systems have rainfall of less than 700 mm, while stations with higher percentages tend to be scattered throughout the range of rainfall amounts. *Figures 13 and 14* show what happens when the percentages of unsuitable and very low potential land systems (Fig 13) or of unsuitable, very low and low potential land systems (Fig 14) are regressed against rainfall. There is no relationship at all (r^2 = 0 in both cases). The latter relationship would also mean that there is no relationship between the combined percentage of moderate and high potential land systems to rainfall, since this combination is the inverse of Figure 14.

Since PCC is based only on suitable range, it might seem logical to express the carrying capacity (LSU/ km^2) as the rate only on 'suitable' range (ie. PCC/ [100 - % unsuitable]). This value was also regressed against rainfall (Figure 15) and shows no relationship (r^2 = 0). All of these analyses failed to discover any relationship between rainfall and estimated carrying capacity when in good condition (PCC). Forage production would be expected to increase with rainfall, at least to some extent. That should give a higher potential carrying capacity unless other factors, such as forage quality, disease, insects, etc. become paramount. Actual stocking rates might shed some light on this question. This avenue was not pursued because, apparently, many of the stations in the higher rainfall zones are less developed and the actual stocking rates do not reflect potential as well as the low to moderate rainfall properties. Thus actual stocking rates may not be a good indicator of reaction to rainfall. It is not too surprising that PCC does not indicate the effect of rainfall since no direct consideration of rainfall is involved in the process.

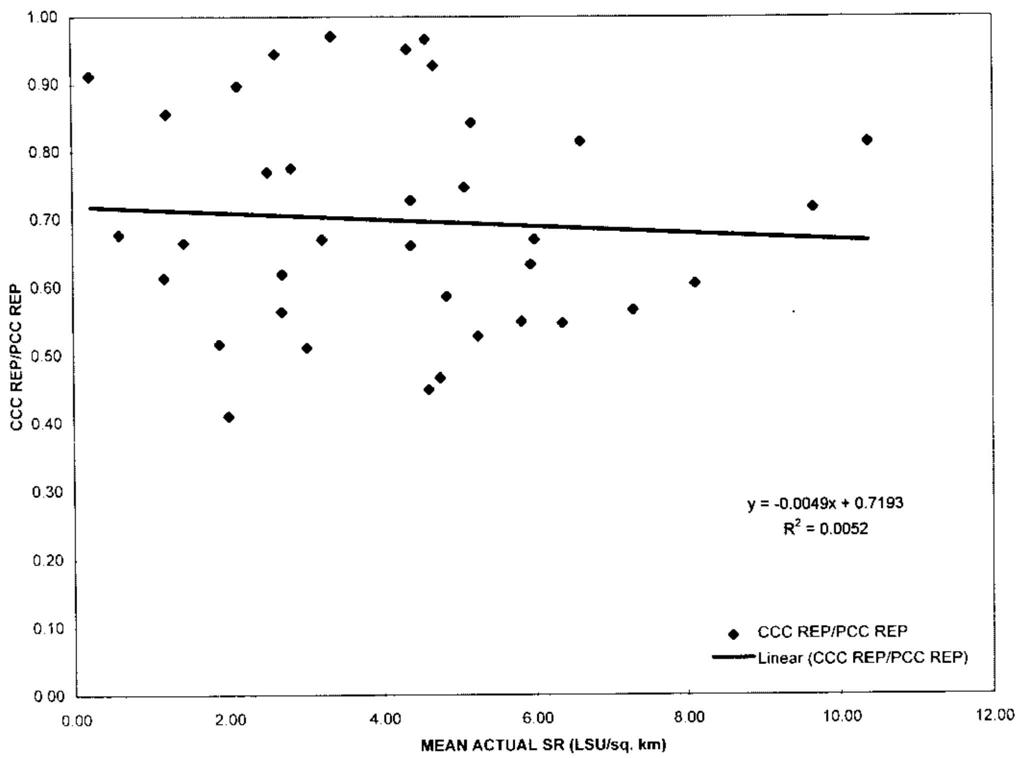

Figure 9. Ratio of current carrying capacity to potential carrying capacity in survey reports compared with reported actual stocking rates for 36 stations in the Kimberleys.

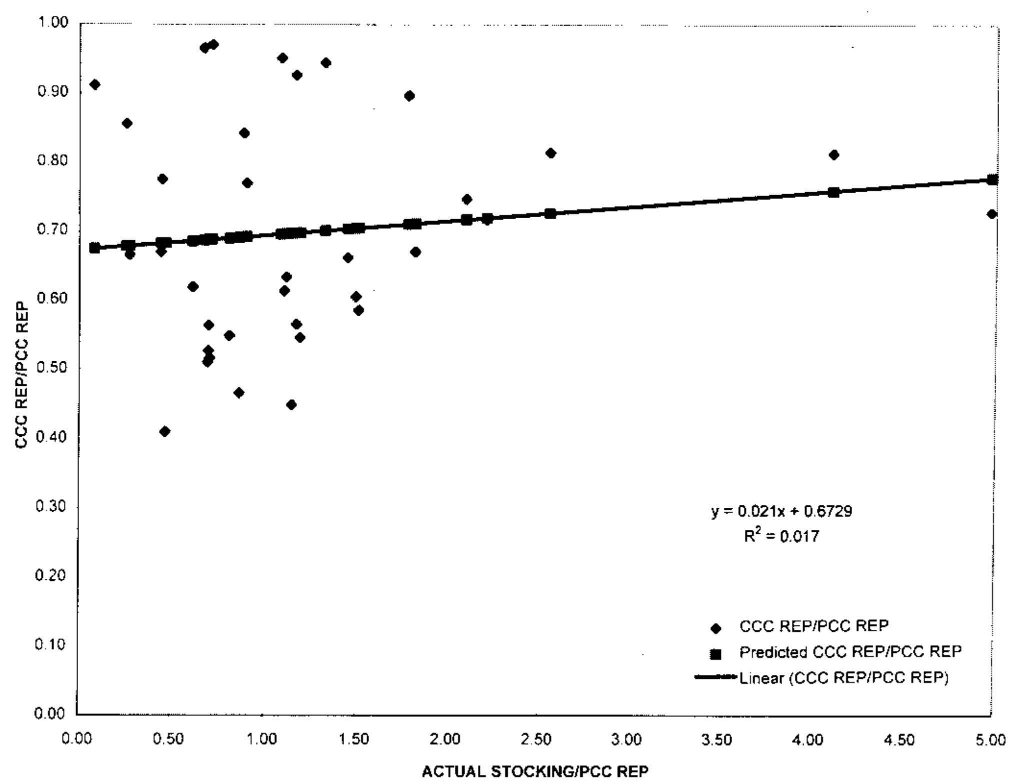

Figure 10. Ratio of estimated current to potential carrying capacity in relation to ratio of actual stocking rate to potential carrying capacity for 36 stations in the Kimberleys.

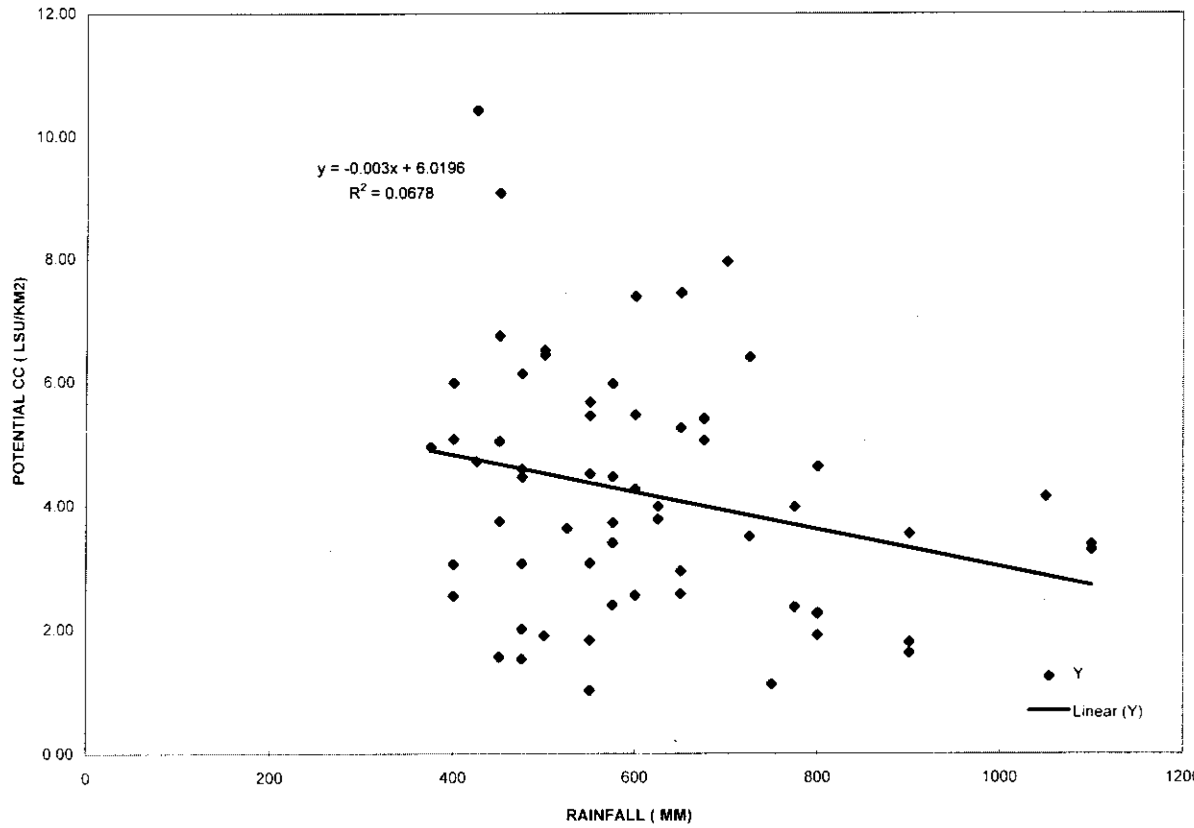

Figure 11. Estimated potential carrying capacity in relation to average annual rainfall for 62 stations in the Kimberleys.

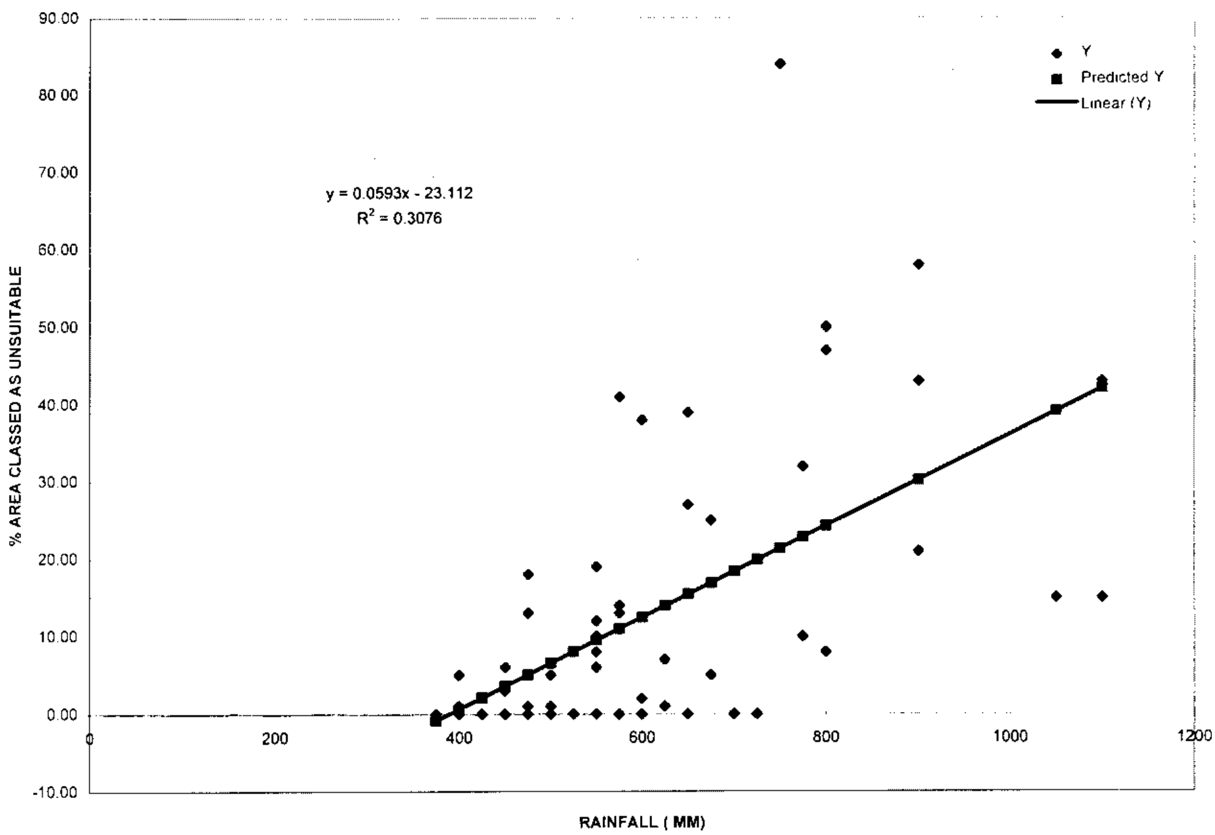

Figure 12. Percent of area classified as unsuitable for grazing in relation to average annual rainfall for 61 stations in the Kimberleys.

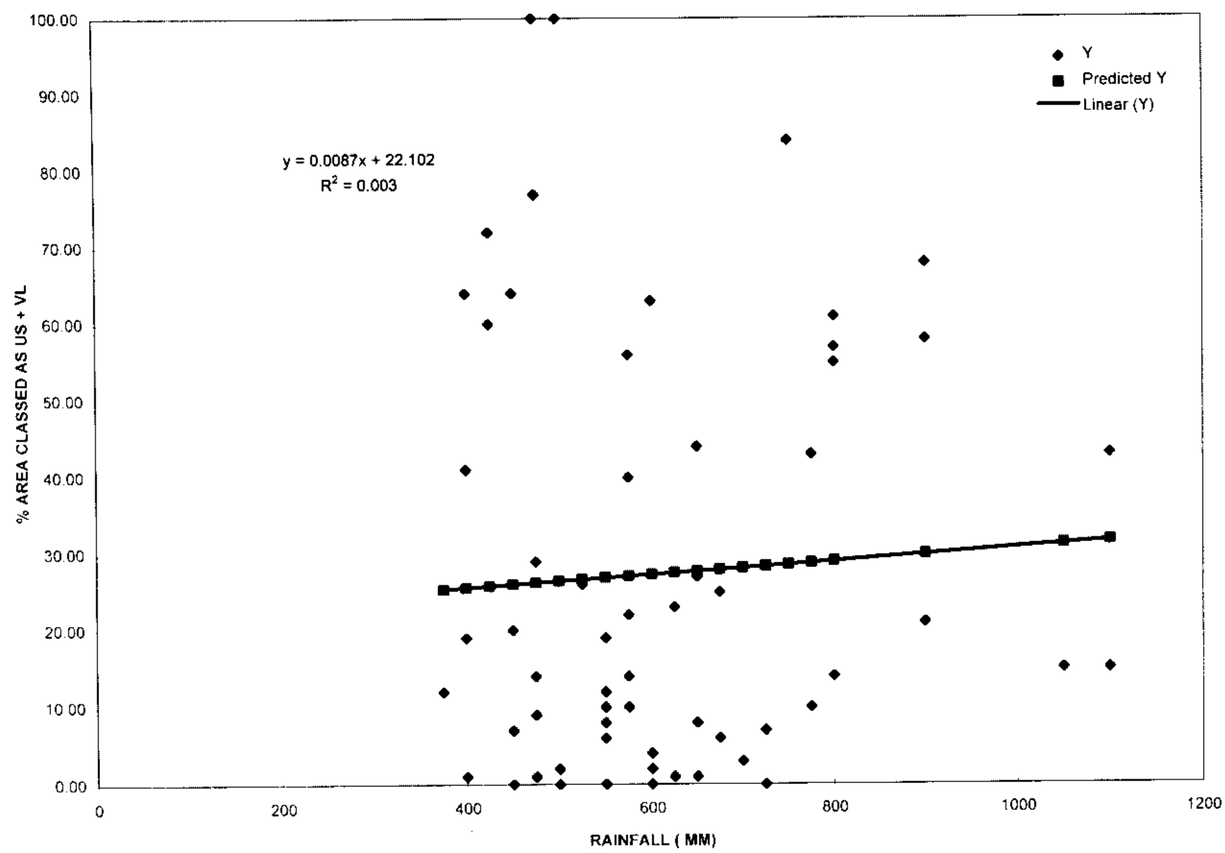

Figure 13. Percent of area classified as unsuitable or very low potential in relation to average annual rainfall for 61 stations in the Kimberleys.

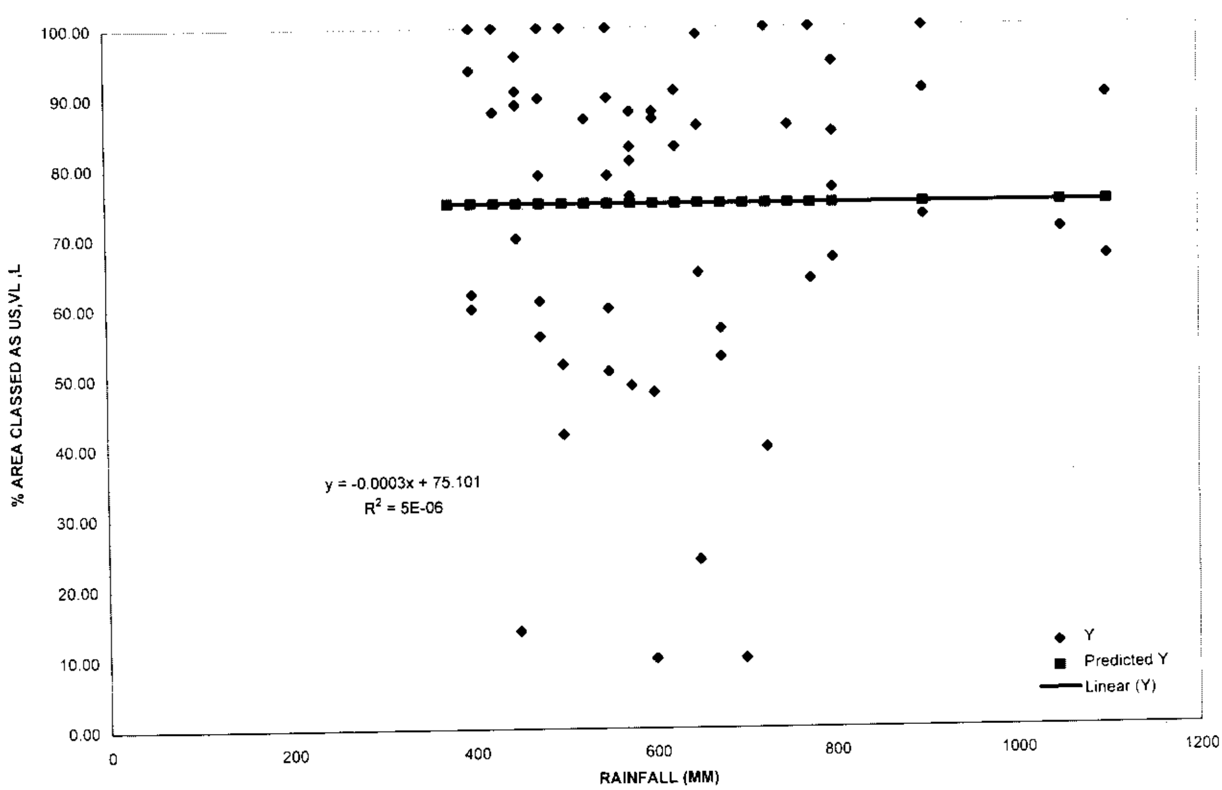

Figure 14. Percent of area classified as unsuitable, very low or low potential in relation to average annual rainfall for 61 stations in the Kimberleys.

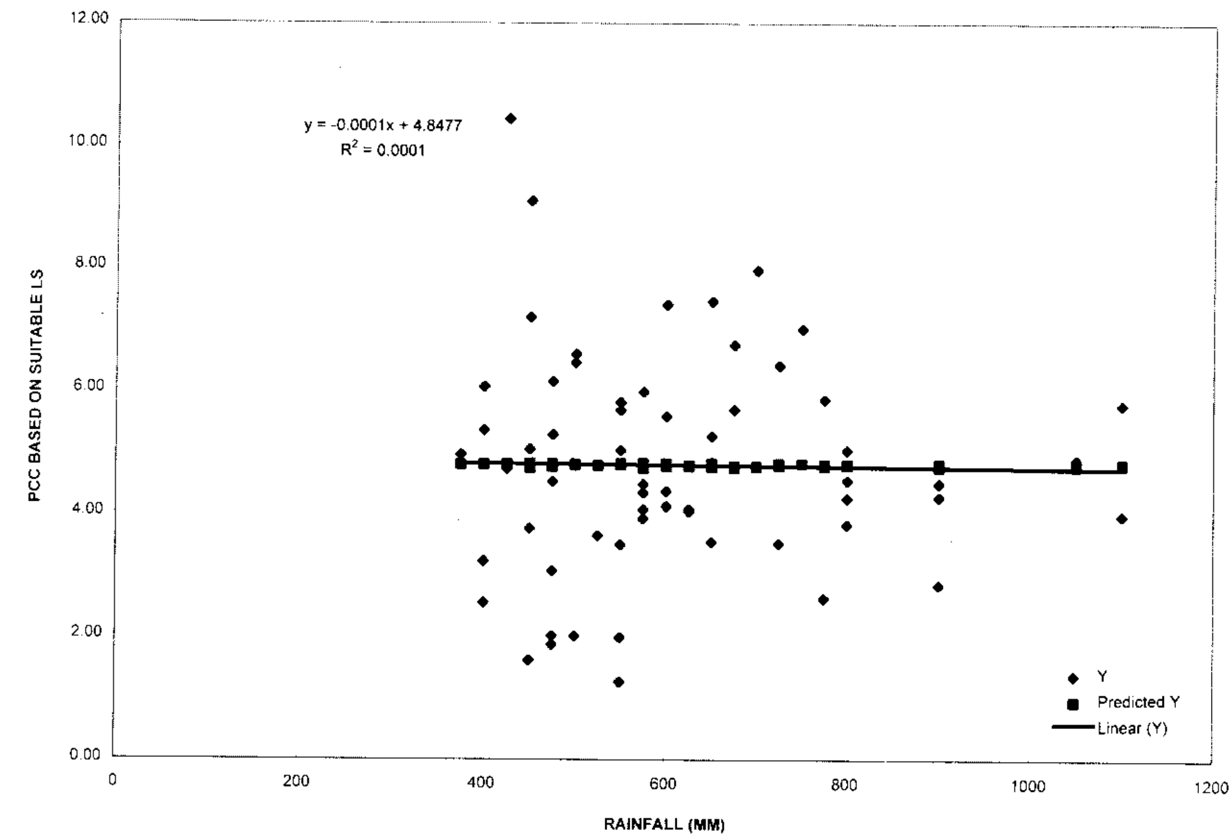

Figure 15. Potential carrying capacity of area classified as suitable for grazing in relation to average annual rainfall.

Conclusions and Recommendations

1. The differences between the 'standard' method and those estimates of PCC and CCC given in the reports agree fairly well. However, they are not the same and in some cases vary considerably. Since both are based on the same basic field data, the difference comes in how the estimates are calculated, ie. how carrying capacities are assigned to land systems and the values assigned to various pasture types and condition classes. These differences should be eliminated as far as possible so that the estimated capacity of a station is not dependent on who does the estimating and what assumptions they use.

2. There seems to be very little consistent relationship between the estimated PCC or CCC, by either method, and the Actual Stocking rates reported for stations. One explanation could be that actual stocking rates reported do not reflect what the real actual stocking rates are. Another is that real actual stocking rates are so dependent on the level of lease development and management, and upon other economic or social factors that they in fact bear little consistent relationship to any realistic biological assessment of carrying capacity.

3. The failure of estimated carrying capacity to be more consistently related to actual stocking may relate to the method of estimating carrying capacity itself. There is no apparent relationship between estimated carrying capacity and rainfall. Given the documented relationship of the average amount of rainfall to total biomass production in many places, this factor seems to deserve attention in the assessment of carrying capacity. Other possible problems include:

   - assigning no carrying capacity to unsuitable land systems, even though livestock do graze parts of them;
   - carrying capacity estimates for different pasture types, and the changes in forage production due to range condition, are not sufficiently based on local information;
   - grazing distribution is not directly built into the system, ie. differences in level of development of stations are not built into the system; and
   - the effects of management (timing of grazing, burning, patch grazing problems, etc.) are not considered.

All these can have major effects on actual carrying capacities.