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Tree-grass relationships along a rainfall gradient - *Linda Cafe and Rodd Dyer*

Managing native vegetation communities with prescribed fire - *Rodd Dyer*

Economic benefits of burning and stocking rate options on pastoral productivity - *Rodd Dyer, Mark Stafford Smith and Andrea Johnson*

Stocking rates and carrying capacity - *Rodd Dyer*

Spatial grazing patterns and fire - *Robyn Cowley and Rodd Dyer*

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Abbreviations

AE – Animal equivalents. A standard animal is defined as a 455 kg steer, which consumes a maintenance diet of 57.1MJE/day. A lactating animal is equivalent to 1.4 AEs, so the average breeder is defined as 1.3 AEs.

ASG – Arid short grass

CO_2 – carbon dioxide

DM – Dry matter

EDS – Early dry season

GBA – Grass basal area

GIS – Geographic information system

GLM – Grazing Land Management

GRASP – GRASs Production pasture growth model (Littleboy and McKeon 1997)

KPIAC – Katherine Pastoral Advisory Committee

LDS – Late Dry Season

LWG – Live weight gain

N – Nitrogen

NPV - Net present value

PAWC – Plant available water capacity

PGBA – Perennial grass basal area

PVB - Present Value of benefits

PVC – Present value costs

PWP - Permanent wilting point

RBG – Ribbon-bluegrass

RMS – Route mean square

TBA – Tree basal area

TSDM – Total Standing Dry Matter

TUE - Transpiration use efficiency

VRD – Victoria River District

YMA – Year moving average

Abstract

This document summarises the findings of a five year project to develop guidelines for improved management of native pastures under grazing in the Victoria River and Sturt Plateau districts of the Northern Territory. The study was sponsored by Meat and Livestock Australia and conducted by the NT Department of Business Industry and Resource Development between 1996-2001.

Principal subjects studied were the calibration of pasture production models and their use in the estimation of carrying capacity, the competitive interaction between trees and grass, and the use of fire to manage woody vegetation and influence grazing patterns.

The emphasis in the project was on developing practical recommendations for the NT pastoral industry. Key parameters that drive pasture growth were identified and pasture growth models developed for several pasture communities. It was shown that woody thickening in the absence of fire results in increased competition for soil moisture and nutrients, and reduced pasture production.

Guidelines for the use of fire as part of the management system were developed, and the economic implications of long term burning and stocking rate options explored. A pilot map-based software program was developed, as a tool for estimating paddock carrying capacity under flexible stocking and burning strategies and other development scenarios.

The technical information arising from this project has been incorporated into MLA's Grazing Land Management training package. This package, which was launched in early 2004,specifically focused on the Victoria River District. .

Executive Summary

Research undertaken in the Victoria River District (VRD) of the Northern Territory has improved our basic understanding of how the grazing lands function and provided guidelines for better management. A number of valuable tools for researchers and land managers have been developed. Key parameters that drive pasture growth have been identified and pasture growth models have been developed for several key pasture communities. It has been shown that in the absence of fire woody thickening reduces pasture production as a result of increased competition for soil moisture or nutrients. Although many woody communities are adapted to periodic burning, the prescribed use of fire has been demonstrated to have an important role in the management of tree-grass balance and pasture condition. Guidelines concerning its use as part of a management system have been developed. The identification of safe utilisation rates from grazing trials, development of software applications and the use of pasture growth models have contributed to methods for estimating paddock carrying capacity. Factors that determine the distribution of grazing pressure throughout extensive heterogeneous paddock, and means to manage grazing, have been investigated. Despite this progress changing global, industry and market trends require new and innovative research to ensure that productive, healthy grazing lands are maintained.

Pasture production can now be modelled in the VRD (Chapter 2)

The GRASP modelling process provides a quantitative means of estimating pasture production within defined levels of reliability. This process has not been previously available in the VRD.

Factors influencing primary productivity in the VRD (Chapter 2)

- Soil type heavily influences plant available water capacity (PAWC), with red earths having the lowest PAWC of the studied soil types, and basalt cracking clays the highest.
- Perennial grass pastures generally had higher total standing dry matter at the end of the growing season than did annual species pasture (annual short grasses and forbs). Some exceptions occurred.
- Soil fertility, as reflected in the soil chemical properties, indicates the soils studied to be among the more fertile soils of the Northern Territory;
- Seasonal pasture production was influenced by location, year, species composition, plant density and soil type;
- Perennial grass based pastures generally had highest productivity levels (2712kg/ha) and annual species (grasses and forbs) were more prone to variations in abundance due to seasonal conditions and/or management (e.g. burning). These observations highlight the vulnerability of pastures containing high proportions of annual species to less than favourable seasonal conditions.
- Burning annual grass dominated pastures can result in destruction of seed bank, and diminished plant germination and establishment;
- As the level of sustained utilisation by grazing animals increases, a mixture of annual grasses and forb species progressively replace the desirable perennials. On the cracking clay soils forbs tend to dominate as perennial grass basal area declines, while on red earths annual short grasses make up the major component of the pasture sward when perennial grasses decline.

Developing Estimates of Carrying Capacity (Chapter 2)

Outputs possible from the model include annual and running averages of pasture growth over time showing the seasonal fluctuations in growth. Once validated, the models developed in this study can then be used, in conjunction with estimates of appropriate utilisation rates to determine long-term carrying capacities of land types important for grazing in the VRD.

*Tree-grass competition for moisture **and** nutrients will impact on pasture production and quality (Chapter 3)*

This study showed that competitive tree-grass interactions for soil moisture **and** nutrients can influence pasture yield and quality in high and low-rainfall savannas. Tree removal resulted in significantly higher pasture growth and pasture quality when nutrient availability was increased, however increased biomass production was accompanied by lower pasture quality when nutrient constraints following tree removal remained unchanged. The implications of the field results suggest that tree thickening will increase tree-grass competition for soil moisture **and** nutrients and cause either a decline in pasture yield and/or pasture quality in both humid and semi-arid savannas. The dominance of moisture or nutrient limitations to pasture growth and quality will be determined by complex tree-grass interactions with site factors such as existing tree density, seasonal rainfall, soil fertility and pasture community. The GRASP model can be used to investigate these interactions and changes

Grass growth is limited mostly by nutrients in high-rainfall, and soil moisture in low-rainfall areas (Chapter 3)

These results confirm the hypothesis of Mott *et al.* (1985), and results in Section Two (Ecology and Management of Native Pastures), that potential pasture growth in humid monsoon tallgrass pastures is constrained mainly by nutrient availability. Both empirical and simulated impacts of tree-grass interactions suggest that woody thickening will reduce pasture growth and/or pasture quality due to competition between trees and grass for limited available nutrients. Because grasses under nutrient constraints diluted plant nitrogen to very low concentrations, enabling continued growth, increases in tree competition may result in declining pasture quality prior to a drop in biomass production.

In contrast, as rainfall declines, increasing tree populations are most likely to reduce pasture growth through increased competition with grasses for soil moisture. The results confirm that the amount and distribution of rainfall have the most significant impacts on tree-grass competition and potential pasture growth in lower rainfall areas and during intra-seasonal dry periods (Scanlan & McKeon 1993). High rainfall increased availability of soil moisture and potential grass production. However pasture quality is likely to be lower due to N dilution.

Grass nitrogen concentrations are diluted to low levels under nutrient constraints to maintain growth (Chapter 3)

Nitrogen-use efficiency is an indicator of the plant’s ability to dilute nitrogen levels to sustain growth under nutrient limitations. Grass nitrogen use efficiency appears to be higher when nutrient availability is limited by low soil fertility and/or tree competition, enabling growth and development to continue, but reducing grass nutrient concentration.

Tree removal increased grass yield over a five-year period (Chapter 3)

Tree removal resulted in a significant increase in pasture production. Based on results from other studies, it was expected that initial pasture yield increases following tree removal would be short-lived, before run-down of nutrients would cause yields to decline over time, as observed by Winter *et al.* (1989). Nutrient run-down may have been avoided in this study as there was no offsite removal of nutrients from grazing, and the perennial grass species present efficiently translocate nutrients to their roots at the completion of the growing season. This highlights the importance of the competition for nutrients, particularly nitrogen, in the tree and grass relationship in the tropical savannas (Winter *et al*. 1989).

Is tree clearing a viable option? (Chapter 3)

Unlike north-eastern Australia, responses to woodland clearing have generally been considered uneconomical in northern Australia due to low stocking rates, poor quality of grasses and initial results that indicated limited long-term response to tree clearing (Norman 1966, Winter et al.1989)**.** Although grass production was increased for several years in this study following tree removal, pasture quality may decline due to nutrient dilution over the long term by ‘nutrient harvesting and export’ by grazing animals. Based on the simulated competition between tree and grass layers there appears to be both environmental and economic benefits for adopting strategies to manage tree and shrub thickening and encroachment over the long term (See Economics Section 5). For this purpose, under current grazing conditions, fire is the most economical way to manage woody thickening (See Fire Section 4 and Economics Section 5).

Prescribed burning can be used to manage woody vegetation (Chapter 4)

Although some woody plant species in pasture communities such as ribbon-blue grass and arid short grass are fire resistant, burning can be used to manage woody structure (canopy height and cover) through plant top kill, rather than reducing plant density from mortalities.

In most cases perennial grass pastures in good condition are resilient, and benefit from, periodic dry season burning. In contrast arid short grass pastures in poor condition (dominated by annual species) respond adversely to burning, with large reductions in ground cover.

Fire has a clear role in the management of woody vegetation thickening in the VRD, particularly in ribbon-blue grass pasture communities that have resilient perennial based grass pastures. The decision to use fire in ASG pasture communities is a trade-off between suppressing ever-increasing tree and shrub growth and avoiding possible short-term deleterious impacts on pasture condition.

Maximising the effectiveness of burning (Chapter 4)

The effectiveness of prescribed burning operations is influenced by initial woody structure, burning conditions and fire frequency. Top kill is maximised from high intensity fires, but as plants become taller they become more resistant to burning.

Woody plants should be controlled with fire before they exceed 200 cm in height. The most effective burning conditions for woody cover reduction are high fuel loads (> 2500 kg/ha) and fuel cover levels (60%), during high temperature, low humidity and constant breeze conditions of the late dry season.

The most extreme reductions in woody height and cover over the short term are achieved by frequent burning (eg biennial). However, over the long-term, below average seasons and deteriorating pasture yields and condition may reduce fire effectiveness and pasture productivity with biennial fire. In terms of woody management, less frequent (5-10 years), but higher intensity fires may have sufficient impact compared to more regular (2-4 years) less intense fires, and are on average be less disruptive to grazing management. Fire frequency however is ultimately determined by seasonal rainfall amount, rate of woody regrowth and pasture accumulation and pasture species response.

Pre- and post-burn pasture management (Chapter 4)

Management of pasture fuel load and cover levels, prior to and following burning, is an important part of grazing management. This will increase the effectiveness of burning and reduce the potential for post-burn overgrazing and degradation of burnt areas.

The most appropriate burning regime for woody vegetation management is a rotational burning program within paddocks. Sections divided within paddocks can be burnt in rotation at appropriate intervals. However, this depends on the size of paddocks. For example, all of small cell grazed paddocks would need to be burnt.

Fire can be used to alter grazing patterns (Chapter 7)

Fire can be used to transfer, and better distribute grazing pressure into under-utilised areas, reducing the potential degrading impacts of high utilisation rates surrounding water points, or preferred soil types. Alternatively, burning enables paddocks to be stocked to their full capacity, providing livestock are not forced to walk long, energy consuming distances to burnt areas.

Rotational fire management issues (Chapter 7)

The application of rotational with 25% utilisation did not appear to negatively influence pasture condition during the good seasons experienced in the study. However, it may lead to a decrease in pasture condition over the long-term, and should be monitored carefully in poor seasons. Care should be taken when applying rotational fire. In particular

- don’t burn areas that are already preferred by cattle, as this can lead to excessive overgrazing in burned areas following fires
- to facilitate recovery following fire, new burns should not be located adjacent the previous seasons burns, because areas adjacent burned areas are also grazed more heavily

Burning has long-term economic benefits (Chapter 5)

Exclusion and suppression of fire in savannas over the long-term is likely to result in negative ecological and economic impacts. Over time, the suppression of fire results in increasing tree basal area, and subsequent declining and highly variable pasture growth, animal performance and economic returns.

In comparison, late dry season burning is an effective tool for vegetation management and over the long-term will yield economic benefits. However there is little difference in economic returns between late, early and no burn regimes during the first 15-20 years of implementation. Furthermore, the overall adverse impacts of fire exclusion are masked during above average seasons, when economic benefits between no burn and other burning regimes were similar.

There are trade-offs between short-term versus long-term impacts of burning (Chapter 5)

Although prescribed burning clearly has an important role in savanna function and long-term pastoral productivity, the absence of significant economic benefits in the short-term reduces the incentives for pastoral managers to adopt fire as part of grazing land management.

Frequent wildfires reduce woody vegetation but can be disruptive to management and ecologically undesirable (Chapter 5)

The frequency, extent and costs of wildfires are most effectively reduced by frequent, early dry season burns. However these regimes are less effective for managing tree and shrub cover. In contrast late-dry season burns are most effective for management of woody vegetation. However wildfire risk remains high as highly cured grass fuel must remain unburned throughout most of the dry season. By suppressing tree cover, wildfires provide ecological and economic benefits, compared to long-term fire exclusion.

Appropriate stocking rates are critical for enhancing economic returns and sustainability (Chapter 5)

Identifying optimum stocking rates is important for both short-term economic returns and long-term sustainability. In terms of economic productivity, it is only when optimum stocking rates have been identified that appropriate burning regimes are most beneficial. It is clear that as stocking rates exceed optimum levels, not only does animal productivity decline, but also the potential effectiveness of fire as a management tool is rapidly reduced.

Although the impacts from overstocking on pasture productivity and economic returns may not occur immediately, or even in a few years, the negative feedbacks of over-utilisation reduce net returns from ten years and thereafter, particularly during below average seasons.

Understanding carrying capacity estimates will facilitate sustainable use (Chapter 4)

While stocking rates and utilisation levels throughout the VRD were generally appropriate for the favourable seasonal conditions experienced during the 1990's, paddocks observed with high stocking rates and/or poor water distribution are likely to result in pasture degradation and poor animal performance during drier periods. To ensure sustainable and productive grazing it is important that carrying capacity estimates, on a paddock basis, be made for a range of seasonal conditions. Paddock stocking rates and pasture condition should also be recorded annually and compared against carrying capacity estimates. If possible, estimates of available pasture biomass and utilisation could also be used to fine-tune stocking rates.

Factors influencing carrying capacity (Chapter 4)

For each location, the estimation of carrying capacity process should account for the amount and variability of rainfall and pasture growth, pasture type and condition and tree competition influences. The use of pasture growth models with historic climate data sets can greatly facilitate this understanding.

Because livestock waters are sparsely distributed within large and extensive paddocks in the VRD, it is critical to account for water point distribution in paddock carrying capacity estimation processes. Using GIS to calculate the paddock area or proportion within a specified distance to water accounts for both the number and spatial distribution of watering points and provides a simple indicator of grazing patterns, pasture condition and livestock productivity.

There are now tools to assist estimation of carrying capacity on a paddock and property scale (Chapter 4)

A range of tools including digital spatial resource and infrastructure data, pasture growth models and prototype carrying capacity calculator and mapping applications, enable land managers to consider the impact of seasonal variability and risk when determining long-term stocking rates, as well as providing the option of adopting more flexible stocking options. This may provide for increased productivity while ensuring the pasture resource remains in good condition.

Flexible stocking strategies vs. set stocking (Chapter 4)

Flexible stocking strategies, that aim to match stock numbers to seasonal feed availability, may provide opportunities for short-term increases in stocking rate during good seasons, while maintaining pasture condition and animal productivity during below average seasons. These strategies would be relatively complex to implement and may have only limited net benefits compared to an appropriate, long-term fixed stocking strategy.

Current knowledge of safe utilisation levels limits estimations of carrying capacity (Chapter 4)

The main limitation with the use of carrying capacity estimations are that only general utilisation guidelines are available for use in carrying capacity estimation. Although there are some general estimates of utilisation rates, more information is required regarding utilisation rates for different pasture types, condition and season combinations.

1. Introduction

Background and Approach

The emphasis of the previous Meat Research Corporation NAP2 project, *Developing sustainable beef production systems for the semi-arid tropics of the Northern Territory (NTA 022)* was to initiate research that would enable development of burning strategies to control native woody shrubs, understanding the competitive relationship between trees, shrubs and pastures and development of pasture growth models that would be used to assist carrying capacity estimation.

Continuing work within NAP aimed to further develop these research areas and to incorporate available results and information into development of management guidelines and tools that fit within whole property management. Several delivery approaches were taken to ensure effective technology transfer and promotion of management systems (See Communication Strategy in attachments).

In order to maintain industry relevance and shape the direction of ongoing rangeland research in the VRD (Victoria River District, Northern Territory), significant industry consultation was undertaken. This included members of the Katherine Pastoral Industry Advisory Committee (KPIAC), Victoria River District Conservation Association and regional Best Practice groups. The NAP2 program was officially endorsed by KPIAC.

Project work was carried out throughout the Victoria River District and Sturt Plateau region of the Northern Territory between June 1996 and 2001. The majority of research sites were located at Victoria River Research Station (Kidman Springs) and Mt Sanford station, with others located on surrounding cattle stations. Two producer demonstration sites (Gorrie and Elsey stations) were located in the Sturt Plateau. Figure 1.1 shows the location of pastoral leases within the Victoria River District and Sturt Plateau in the Top End of the Northern Territory.

Project Aim

To encourage the adoption of sustainable grazing management on pastoral properties throughout the Victoria River and Sturt Plateau regions of the Northern Territory.

Project Objectives

The original project objectives are reported in full below.

INDUSTRY GOAL

To ensure that by 2001, throughout the Victoria River District and Sturt Plateau regions of the Northern Territory that:

I. 90% of all players in the pastoral industry are aware of the importance of sustainable grazing management practices.

II. 50% of pastoral leases have partially or completely adopted relevant sustainable grazing management practices.

PROJECT OBJECTIVE 1:

To ensure by 2001, throughout the VRD and Sturt Plateau regions

I. The majority (>65%) of pastoral land managers have an increased understanding and knowledge of local pasture communities and basic grazing ecology and management in order to promote sustainable management based on sound ecological principals.

II. That >80% of pastoralists have access to a simple and practical information booklet, an information site on the internet or have participated in active participation and learning at interactive on-property field day-workshops

OBJECTIVE 2:

To ensure by 2001, throughout the VRD and Sturt Plateau regions:

I. That 50% of pastoral managers have investigated the economic viability of a range of sustainable grazing management options using a range of Decision Support Systems (DSS) in a whole-property framework on a case-study basis.

II. That 30% of pastoral managers have made significant changes in grazing management as a result of economic analysis of sustainable management options.

OBJECTIVE 3:

To ensure by 2001, throughout the VRD and Sturt Plateau regions:

I. 80% of pastoral properties have documented current paddock and property stocking rates and made general assessments of land condition and animal production.

II. 80% of pastoral properties have developed individual estimates of livestock carrying capacity on a paddock, property and land type basis

III. 50% of pastoral properties will have utilised an understanding in carrying capacity information to develop and implement conservative stocking rate or strategic stocking strategies.

OBJECTIVE 4:

To ensure by 2001, throughout the VRD and Sturt Plateau regions that

I. 80% of producers are aware of the principles and best practice of controlled burning by providing a relevant and practical fire management manual and presenting information at on-property workshops, field days and shows.

II. 50% of pastoral managers have trialed or implemented controlled burning as part of property management.

OBJECTIVE 5:

I. To ensure that by 2001, throughout the VRD/Sturt Plateau region the majority (>80%) of land managers and administrators are aware of the increase, cause, impact and potential cost of unchecked woody plants.

OBJECTIVE 6

II. To ensure that by 2001, throughout the VRD/Sturt Plateau region, 50% of pastoral leases have developed or implemented strategic grazing management plans as a result of active participation in whole paddock demonstrations of sustainable grazing management options.

These complex and unwieldy objectives were simplified down to the following which are reported on in this report.

To ensure by 2001, throughout the VRD and Sturt Plateau regions

1. the majority (>65%) of pastoral land managers have an increased understanding and knowledge of local pasture communities and basic grazing ecology and management.

2. that 50% of pastoral managers have investigated the economic viability of a range of sustainable grazing management options using a range of Decision Support Systems (DSS) in a whole-property framework

3. 60% of pastoral properties have documented current paddock and property stocking rates and developed individual estimates of sustainable livestock carrying capacity.

4. 70% of producers are aware of the principles and best practice of controlled burning by providing a relevant and practical fire management manual and presenting information at on-property workshops, field days and shows.

5 that the majority (>80%) of land managers and administrators are aware of the increase, cause, impact and potential cost of woody plants.

6. that 50% of pastoral leases have developed or implemented strategic grazing management plans as a result of active participation in whole paddock demonstrations of sustainable grazing management options.

Achievement of Objectives

A major DBIRD survey of NT producers planned for late 2004 is expected to document current land management practices and be able to provide statistical evidence of the degree to which each of these objectives has been achieved.

Study Location

The Victoria River District is located approximately 400-500 km south-west of Darwin, Australia between the latitudes of 15^{o} and 19^{o} S and longitude 129^{o} and 132^{o} E. The region covers 125 000 km^{2} extending from the Sir Joseph Bonaparte Gulf in the north, to the Tanami Desert in the south (Figure 1.1).

Climate

The VRD is located largely within the semi-arid tropics. Average annual rainfall for most of the region is less than 750 mm. However, rainfall varies from 1200 mm in northern coastal areas to 375 mm in the most inland areas (Figure 1.2). Rainfall intensity and reliability also decreases with distance inland and southward from the coast. The variability of annual rainfall is low by Australian standards.

The distribution of rainfall is strongly seasonal with 85% of total rainfall occurring in the summer “wet season”, between December and March. During the winter “dry season”, June-August there is no rain in most years. In some years the high incidence of lightning, without significant follow-up rainfall during this time can result in the ignition of wildfires across large areas.

Landforms and soils

The VRD landscape is a mix of grassy plains, rolling savannas, rocky spinifex country, mesas and plateaus. Almost half the area is rugged country with rock outcrops or relatively shallow stony soils. The remaining lands are undulating to flat and are utilised extensively for pastoralism. These lands consist of either (a) gently undulating plateau surfaces with lateritic soils, (b) erosional plains on which moderate to deep soils have formed by weathering on underlying rock or (c) alluvial plains along major stream valleys and along the coast (Paterson 1970).

Soils throughout the VRD are strongly influenced by parent material and topography. Shallow skeletal soils are characteristic of well drained, steep hilly country, while deeper soils are largely confined to poorly drained, flatter country. Duplex soils are found along channel banks and levees of major drainage lines. These soils have high pastoral productivity but are typically very susceptible to erosion. Soils throughout the VRD are generally low in phosphorus (Karfs 2000).

Vegetation

The vegetation throughout the VRD can be broadly described as a mix of savanna woodland and grasslands. The structure and composition of vegetation is strongly related to soil type and rainfall. Woodland vegetation is dominated by *Eucalyptus* and *Acacia* species and varies in height between 6-25 m. Change in woodland species, and decline in height structure occurs along the rainfall gradient from northern wetter coastal areas to southern arid inland regions Grassland vegetation exists on cracking clay soils and is taller and denser north of the 700 mm isohyet. In southern areas receiving < 400 mm rainfall, low woodlands give way to shrublands. Dense riparian vegetation grows in narrow bands along drainage lines and contains a mixture of eucalypt and non-eucalypt species.

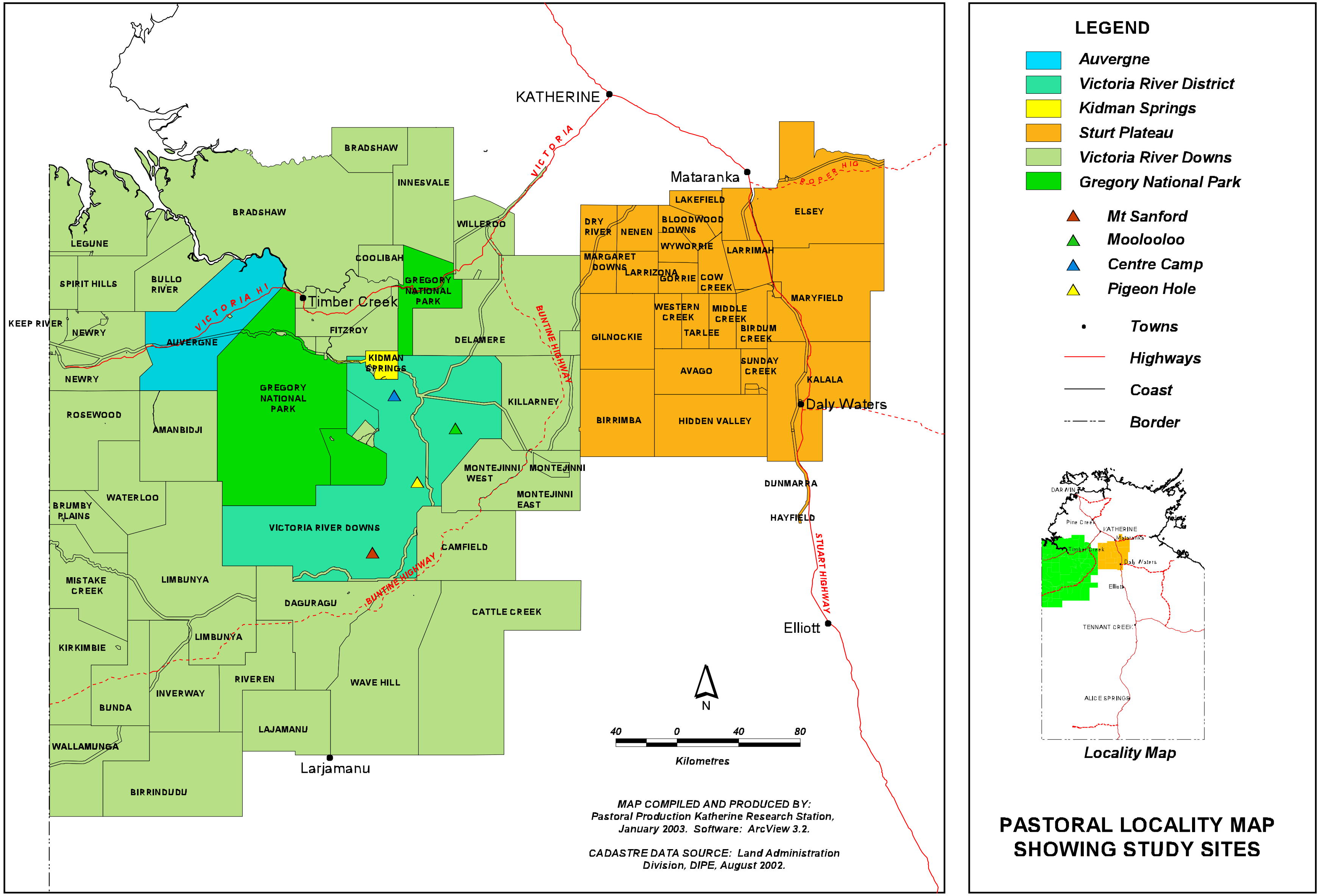


Figure 1.1: Map of Victoria River District and Sturt Plateau region.

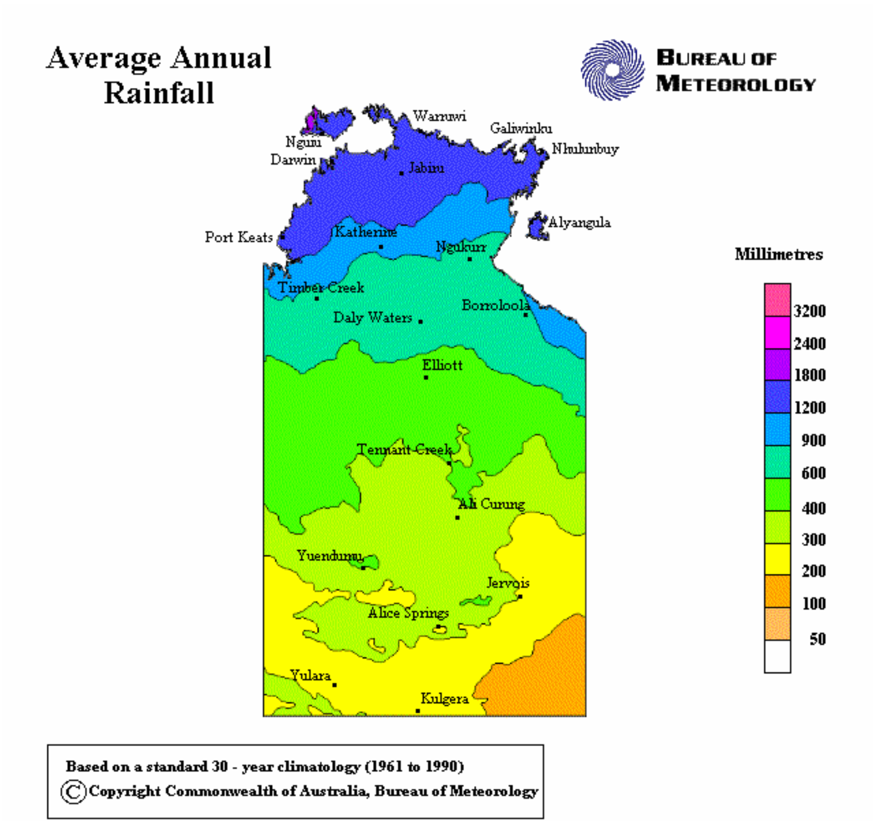


Figure 1.2: Average annual rainfall for the Northern Territory.

Land use and ownership

With the introduction of domestic cattle in the 1880s, pastoralism quickly became the dominant land use. This continued until 50 years ago when increases in conservation, Aboriginal and military land use designations resulted in a decline in the relative proportion of land for pastoral use. Today approximately 14,000 km^2 or 11% of the VRD is under the management of Aboriginal Land Trusts and is used for both Aboriginal pastoral and traditional purposes. Generally the rugged less productive lands were designated for conservation purposes. Gregory National Park and Keep River National Park are important flora and fauna reserves and occupy over 13,000 km^2 within the VRD. The acquisition of former pastoral properties in the 1990s by the Department of Defence has increased military land use in the district.

The pastoral industry

The VRD pastoral industry is based on extensive cattle production from native grass pastures. There are 33 properties in the VRD region with a total cattle population of over 300,000 head. The VRD supplies more cattle to the live export market than any other pastoral district in the Northern Territory.

In recent years rapid growth of the live cattle export markets has been a key development. Production systems are focused on raising younger steers and heifers for Asian markets. In 1997 live cattle exports from Northern Australia totalled 680,000 head, a massive nine-fold increase from levels in 1990. This represents a total value of $322 million (MRC 1997). The major destination for live cattle from Northern Australia in 1997 was Indonesia, which accounted for around 60% of all exports. As a result of the Asian currency crisis in August 1997 live cattle exports from Northern Australia to south east Asia plummeted to 346,000 for 1998. Although new markets in the Middle

East were developed, exports to Indonesia and the Philippines fell to 7% and 25% respectively of the previous year's numbers. Since then export numbers have slowly been increasing but have yet to return to previous levels.

Seasonal conditions (1996 – 2001)

Seasons throughout the VRD between 1993 and 2001 were characterised by a succession of excellent rainfall years and growing conditions. Rainfall was either very near, or above the top 30% decile in all but one or two of the last ten years, depending on location (Figures 1.3 and 1.4). These conditions stimulated significant improvement in land condition and high levels of animal productivity throughout the district. We are aware that care must be taken with the interpretation of research results collected in such exceptional circumstances, and results should be viewed in this light.

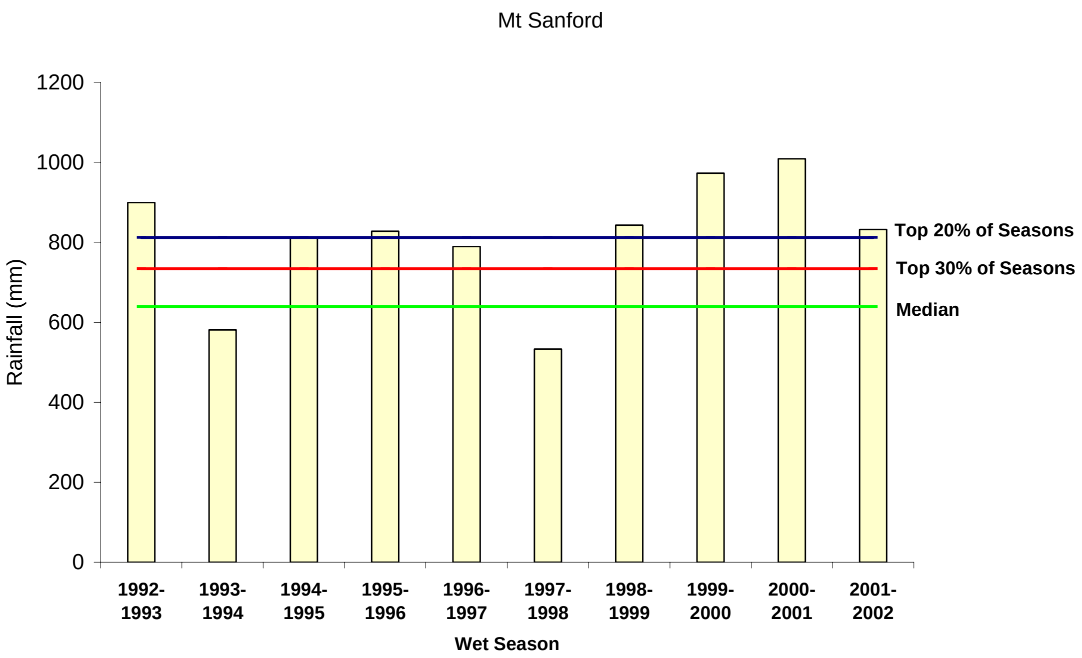


Figure 1.3: Rainfall at Mt Sanford from 1992-2002.

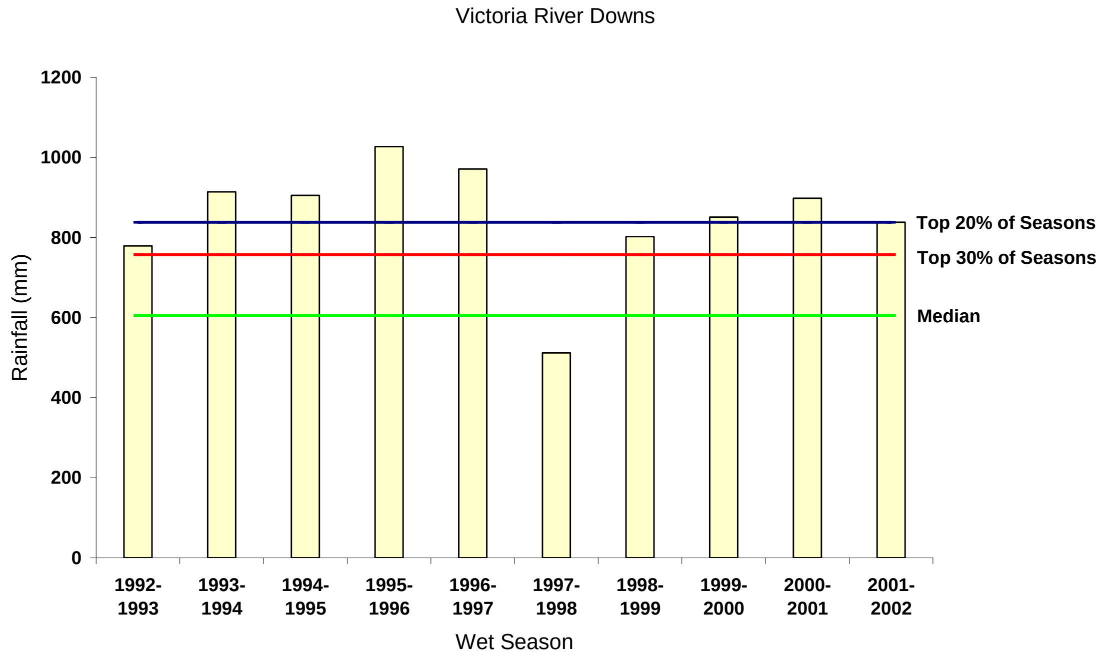


Figure 1.4: Rainfall at Victoria River Downs from 1992 - 2002.

2. Native Pastures - Ecology and Management

Introduction

Several authors have noted that overriding climatic constraints and inherently low fertility soils combine to limit the agricultural development of land in the Victoria River District (Perry 1970, Bauer 1985, Tothill *et al.* 1985). A feature of northern Australia is the high year-to-year and decade-to-decade variability in climate and pasture production. This variability is a major source of risk in term of herd management, business management and resource degradation (Day *et al.* 2000). The greater the ability of cattle managers to match grazing animal demands with available feed reserves, and to anticipate feed shortages, the more likely native pastures will be managed to combine efficient production with long-term sustainability.

Developing grazing strategies that are suitable to such a climatic regime is a challenge. Graziers experience is often limited to 10-30 years, an insufficient period to experience the full range of seasonal variability. To address this challenge, a long-term view is required to comprehend the full spectrum of variation in seasonal pasture growth. Thus, the main value of pasture modelling is the use of historical climate records to extend the knowledge of seasonal pasture growth beyond living memory, and hence improve the understanding of what may occur in the future. From this, real-time monitoring of pasture growth can help identify likely periods of degradation as they occur, and measures to alleviate such degradation can be taken.

One framework for assessing the impact of management on native pasture communities is to employ a systems model of pasture growth. Such an approach allows us to examine possible impacts of events (managerial or natural) on pasture productivity for times and places that have not been covered by traditional experimentation and, in the VRD, this is almost the entire region. One such model is the GRASP (GRASs Production) model (Littleboy and McKeon 1997). It is well tested in northern Australia, primarily though in Queensland. This model combines a soil water balance with a pasture growth sub-model to provide estimates of a range of variables including biomass production under given climatic conditions. It is necessary to derive parameters for this model and to test the calculations for the VRD.

McKeon *et al.* (in prep) list a number of applications of the GRASP model relating to the management of grazing on the native pasture lands of northern Australia:

- objective assessment of drought and degradation risk;
- simulation of grazing management options including seasonal forecasting;
- assessment of safe carrying capacity;
- evaluation of the impact of climate change and CO_2 increase; and
- reconstruction of historical degradation episodes.

Of these applications of calibrated GRASP models, simulating grazing management options, seasonal forecasting and assessing safe carrying capacity are the most relevant to the VRD.

Project Objective this chapter addresses

To ensure by 2001, throughout the VRD and Sturt Plateau regions that the majority (>65%) of pastoral land managers have an increased understanding and knowledge of local pasture communities and basic grazing ecology and management in order to promote sustainable management based on sound ecological principals.

Study Aims

- Develop a better understanding of the factors that govern native pasture productivity in the Victoria River District of the Northern Territory, and in so doing, allow for improved decisions by land managers on the long-term safe utilisation of their pasture resources.

- Collect the basic climate, soil and plant data required to quantify the main parameters which govern the growth of native pasture communities important for grazing in the VRD;

- Calibrate the GRASP pasture growth model for these pasture communities and evaluate the accuracy of the GRASP calculations; and

- Estimate from long-term (~40 years) historical climate records the probabilities of pasture growth at three locations for the major pasture communities and soil types in the district.

Methods

Twenty-one study sites were established in the Victoria River District (VRD) in 1993 and 1994 at five locations (Mt Sanford, Kidman Springs, Victoria River Downs, Rosewood Station and Auvergne Station) (Figure 2.1). Sites represented a range of soils and pasture communities used for grazing in the region (Table 2.1).

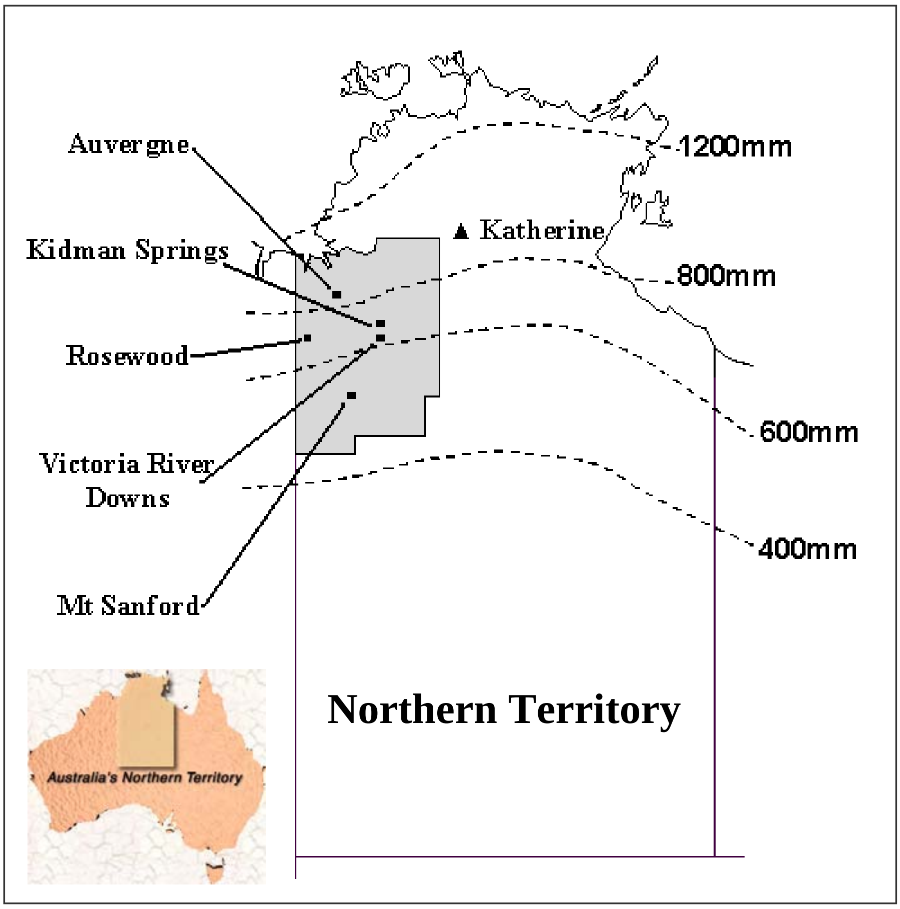


Figure 2.1: The five main locations of study sites within the Victoria River District (shaded area). Dashed lines represent approximate average rainfall isohyets (Source: adapted from Bureau of Meteorology data).

Measurements of total pasture biomass, green biomass, green cover, pasture height, soil water and standing pasture nitrogen (N) concentration and N yield were made according to the Swiftsynd methodology (Day and Philp 1997) between 1993 and 1996 (two seasons per exclosure). Using this field data, GRASP was calibrated for all Swiftsynd sites and years, general soil and pasture types and the entire VRD, and then evaluated.

Table 2.1: Native pasture study sites according to vegetation and soil classifications.

Site	Vegetation Community (Wilson *et al*. 1990)	Pasture Community (Tothill and Gillies 1992)	A Description of Aust. Soils (Northcote 1979)
1	Eucalypt low woodland with grass understorey	Ribbon grass/Golden Beard grass	Red Smooth-ped Earths
2	Eucalypt low woodland with grass understorey	Ribbon grass/Golden Beard grass	Red Smooth-ped Earths
3	Grassland	Mitchell Grass	Red Self-mulching Cracking Clays
4	Grassland	Mitchell Grass	Red Self-mulching Cracking Clays
5	Grassland	Mitchell Grass	Brown Self-mulching Cracking Clays
6	Grassland	Mitchell Grass	Red Self-mulching Cracking Clays
7	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
8	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
9	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
10	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
11	Eucalypt low woodland with grass understorey	Annual Short Grassland-Low Open Woodland	Calcareous earths
12	Eucalypt low woodland with grass understorey	Ribbon grass/Golden Beard grass	Red Smooth-ped Earths
13	Eucalypt low woodland with grass understorey	Annual Short Grassland-Low Open Woodland	Red Smooth-ped Earths
14	Eucalypt low woodland with grass understorey	Ribbon grass/Golden Beard grass	Red Massive Earths
15	Grassland	Bluegrass-Browntop	Red Self-mulching Cracking Clays
16	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
17	Grassland	Bluegrass-Browntop	Brown Self-mulching Cracking Clays
18	Grassland	Bluegrass-Browntop	Red Self-mulching Cracking Clays
19	Eucalypt low woodland with grass understorey	Ribbon grass/Golden Beard grass	Red Smooth-ped Earths
20	Eucalypt low woodland with grass understorey	Bluegrass-Browntop	Grey Self-mulching Cracking Clays
21	Grassland	Bluegrass-Browntop	Grey Self-mulching Cracking Clays

Results and Discussion

Results include field data from swiftsynd sites, model parameters for the GRASP model that describe the processes driving plant growth, and calculated probabilities of seasonal pasture production in the VRD.

Table 2 summarises the variability in soil and plant field measurements and GRASP model parameters between sites.

Table 2.2: Summary of results of field measurements and model calibration.

Variable	Minimum	Maximum	Median
Field data			
Rainfall (mm)	538	1062	792
PAWC-total profile(mm)	73.4	315	203
PAWC-per unit depth (mm/m)	123	350	218
TSDM (kg/ha)	736	4282	2549
N uptake (kg/ha)	6	37	21
PGBA (%)	0	6.0	1.9
GRASP parameters			
TUE (kg/ha/mmT)	8	16	10
%N@0Grow (%)	0.45	1.35	0.7
SWIX@0Grow	0.01	0.3	0.3
Nup/100mmT (kg/ha/100mmT)	6	18	10
GY@50%GC (kg/ha)	500	2550	1600

PAWC – plant available water capacity
TSDM – total standing dry matter
N uptake – maximum nitrogen uptake
PGBA – perennial grass basal area
TUE – transpiration-use-efficiency
%N@0Grow – nitrogen content at which growth stops
SWIX@0Grow – soil water index at which growth stops
Nup/100mmT – nitrogen uptake per 100mm of transpiration
GY@50%GC – green yield (dry matter) at 50% green cover

Field data

- Comprehensive datasets of climatic, soil and pasture variables have been collected, much of it for the first time in such detail for the VRD. On its own, such data represents a significant advance in the knowledge base of the district’s resources.
- Sites can be grouped according to a range of criteria – climate regime, soil type and species composition were used to classify sites in this study.
- Rainfall was average to well above average for all locations during the study period.
- Soil type heavily influences plant available water capacity (PAWC), with red earths having the lowest PAWC of the studied soil types, and basalt cracking clays the highest.

- Perennial grass pastures generally had higher total standing dry matter (TSDM) at the end of the growing season than did annual species pasture (annual short grasses and forbs). Some exceptions occurred.

Models of native pasture growth were calibrated for 42 site-by-year combinations on important grazing lands in the Victoria River District of the NT. From these calibrated models, general parameter sets for soil types, species groups and the VRD as a whole have been determined (Table 2.3) and the accuracy of model outputs assessed against measured field data (Figure 2.2). For more details refer to Dyer *et al.* (2001a).

Model calibration

- A general VRD parameter set accounts for only 35% of variability observed in end-of-growing-season pasture growth. By applying soil- or species-specific parameter values we are able to improve the accuracy of the predictions to 45% and 58% respectively (See observed versus predicted TSDM Figure 2.2).

- Nitrogen uptake and dilution are complex processes and simulation results did not represent measured data in many cases.

- Reliability of simulations is yet to be tested against field data collected during low rainfall years.

- A greater understanding of the factors that govern pasture growth in the VRD has been gained through the calibration process.

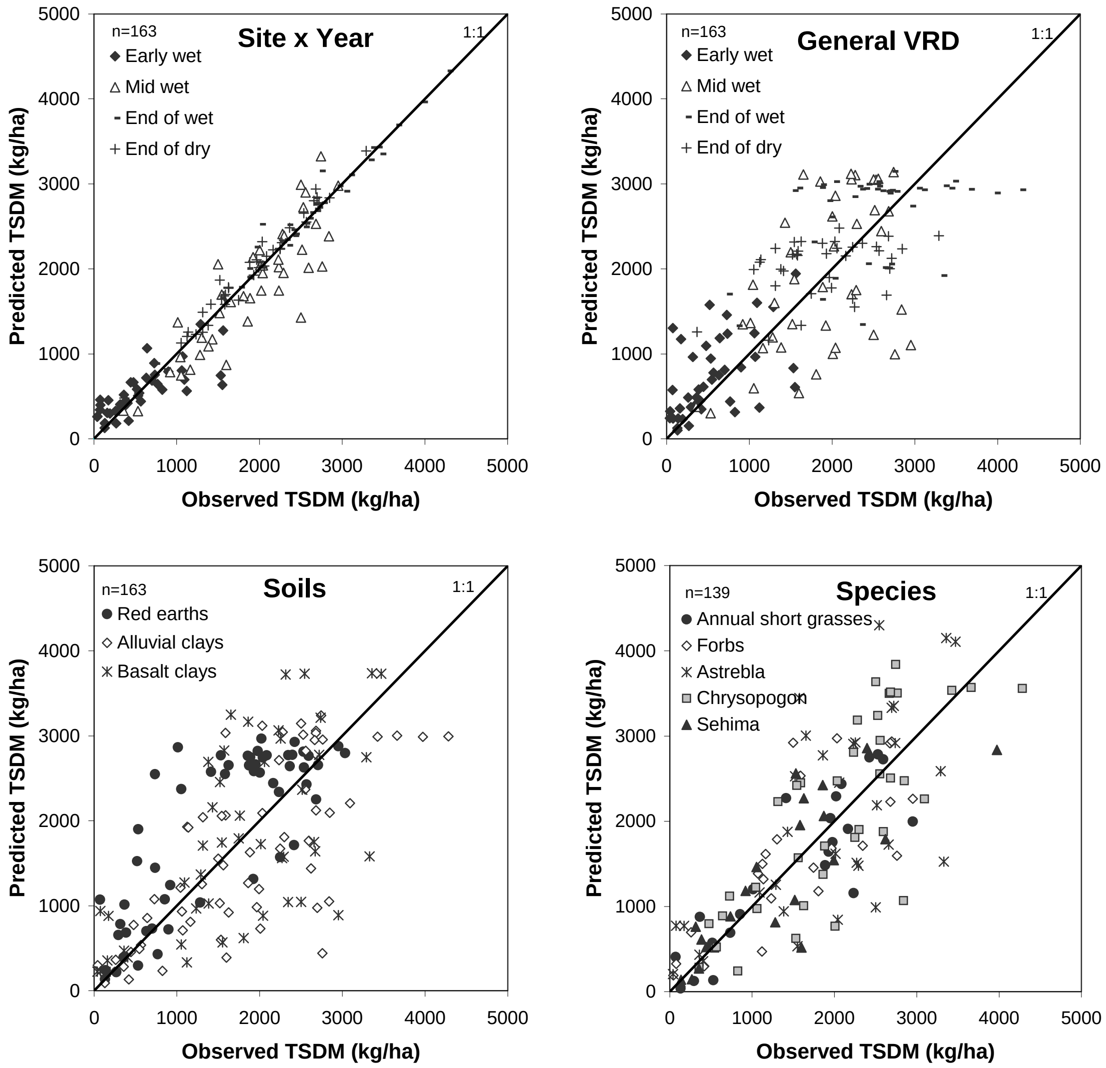


Figure 2.2: Plots of observed versus, predicted total standing dry matter (TSDM) for different parameter sets.

Table 2.3: Generalised parameter values the whole VRD and for soil and species groups.

Parameter	Pmtr No.	General VRD	Red earths	Alluvial cracking clays	Basalt cracking clays	Annual short grasses	Forbs	*Astrebla*	*Chrysopogon*	*Sehima*
Soil parameters										
Depth of layer 3 (mm)	022	385	217	500	383	500	500	500	500	500
Air dry layer 1 (mm)	019	4	3	4	5	3	4	5	5	4
Wilting point layer 1* (mm)	029	9	8	10	10	8	9	10	11	8
Field capacity layer 1 (mm)	026	41	32	44	48	35	43	48	46	32
Wilting point layer 2 (mm)	030	41	35	44	43	39	35	45	48	32
Field capacity layer 2 (mm)	027	147	112	153	180	127	147	190	162	120
Wilting point layer 3 (mm)	031	54	19	72	68	40	65	100	76	53
Field capacity layer 3 (mm)	028	145	54	188	184	123	175	250	200	135
Runoff (Yes/No)	270	No	Yes	No	No	Yes	No	No	No	Yes
Cracking (Yes/No)	035	No	No	Yes	Yes	No	Yes	Yes	Yes	No
PAWC Layer 1 (mm)		32	24	33	38	27	34	38	35	23
PAWC Layer 2 (mm)		106	77	109	137	88	112	145	114	88
PAWC Layer 3 (mm)		91	35	116	117	83	110	150	124	83
Total PAWC (mm)		229	137	258	291	197	256	333	273	194
Average PAWC (mm/10cm)		23	19	26	33	20	26	33	27	19
Plant growth parameters										
Perennial grass basal area (%)	005	2.72	3.90	2.58	2.73	6.72	1.06	2.87	2.96	1.73
Potential regrowth rate / unit PGBA (kg/ha/day/basal%)	006	8.43	7.67	7.50	8.80	2.50	12.00	8.25	7.40	7.67
Potential regrowth rate (kg/ha/day)		22.9	29.9	19.4	24.0	16.8	12.8	23.7	21.9	13.3

Parameter	Pmtr No.	General VRD	Red earths	Alluvial cracking clays	Basalt cracking clays	Annual short grasses	Forbs	*Astrebla*	*Chrysopogon*	*Sehima*
Transpiration-use-efficiency (kg/ha/mmT)	007	10.8	10.5	11.0	10.8	8.7	13.0	11.0	10.5	10.8
Soil water index at which growth stops	149	0.16	0.20	0.30	0.01	0.01	0.01	0.01	0.30	0.30
Soil water index at which cover is restricted	009	0.95	0.72	1.00	1.00	0.43	1.00	1.00	1.00	1.00
Nitrogen parameters										
N uptake at 0 mm of transpiration (kg/ha)	097	3.5	3.7	4.5	2.4	2.3	6.0	2.8	4.9	1.8
N uptake per 100mm of transpiration (kg/ha/100mmT)	098	10	11	9	12	9	13	11	10	8
Maximum nitrogen uptake (kg/ha)	099	23	21	24	25	21	37	28	28	14
Maximum nitrogen content in plants (%)	100	2.6	2.5	2.5	2.7	2.5	2.5	2.8	2.5	2.5
N content at which growth stops (%)	101	0.7	0.7	0.8	0.7	0.8	1.2	0.6	0.7	0.5
N content at which growth is restricted (%)	102	0.8	0.8	0.9	0.8	0.9	1.3	0.7	0.8	0.6
N content, min. in green & max. in dead (%)	110	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Minimum N content in dead (%)	111	0.6	0.6	0.5	0.5	0.8	0.8	0.5	0.5	0.4
Sward structure parameters										
Green standing dry matter at 50% green cover (kg/ha)	045, 046, 271	1499	1367	1440	1745	667	1200	1669	1520	1767
Height of 1000kg/ha standing DM (cm)	096	12	12	12	13	11	9	13	12	18
Detachment parameters										
Leaf detachment (kg/kg/day)	128, 130	0.0022	0.0007	0.0026	0.0018	0.0010	0.0038	0.0015	0.0028	0.0020
Stem detachment (kg/kg/day)	129, 131	0.0022	0.0007	0.0026	0.0018	0.0010	0.0038	0.0015	0.0028	0.0020

Long-term probabilities of seasonal pasture growth

Probabilities of pasture growth for these general parameter sets have been calculated from long-term records (38 years) of historical climate data. (See Tables 6.2-6.3 showing probabilities of pasture growth in the Stocking Rate Section 6). Table 2.4 shows a summary of long-term simulation results based on models developed for some VRD land types. These probabilities represent a climate gradient across the VRD and demonstrate the role of rainfall and nitrogen availability in driving pasture growth in the region.

Table 2.4: Summary of long-term simulation results.

Simulations	**Kalkaringi (Mt Sanford)**	**Victoria River Downs**	**Auvergne**
Long-term average rainfall	475	638	818
SSPG range (kg/ha)	36 – 4373	871 – 4373	1655 - 4373
Water limited growth (% of seasons)	63	42	5
Nitrogen limited growth (% of seasons)	37	58	95

SSPG – simulated seasonal pasture growth

Sensitivity analysis of GRASP confirms the conclusions of the comprehensive review of savannas by Mott *et al.* (1985) that pasture productivity is primarily restricted by nutrient availability in the higher rainfall areas in the north of the district (for example Auvergne and Katherine). Water supply increasingly restricts growth along the climate gradient to the more arid south (for example Victoria River Downs then Mt Sanford).

Climate gradient

Differences in plant growth purely as a result of climate are essentially due to rainfall – that is, available soil water supply is the major limitation to plant growth. Location, and therefore climate and subsequent soil water supply, strongly influence plant growth in lower rainfall years and less so in higher rainfall years.

- Plant growth is rarely limited by soil water supply at Auvergne in the northern VRD, whereas it often limits growth at Mt Sanford in the southern VRD.
- Nitrogen availability is the primary limiter to plant growth when soil water supply is adequate.

Soil type

- Plant available water capacity determines the likely growth in lower rainfall years and is therefore a major determinant of pasture growth at Mt Sanford in the southern VRD, and a minor influence at Auvergne.
- The upper limits to seasonal pasture growth vary according to the values for maximum N uptake and the N content at which growth stops.

Several key determinants of growth in relation to moisture and nutrient availability have been identified for the VRD:

- Nitrogen parameters determine the upper limits to seasonal pasture growth, with total N uptake (MaxN) by plants and the N content at which growth stops (%N@0Grow) being the major factors. GRASP is very sensitive to these parameters.

Transpiration-use-efficiency (TUE) and soil water index at which growth stops (SWIX@0Grow) determine seasonal pasture growth in lower rainfall seasons where soil water supply limits growth.

Industry Implications

Pasture production can now be modelled in the VRD

The GRASP modelling process provides a quantitative means of estimating pasture production within defined levels of reliability. This process has not been previously available in the VRD. While of immense practical value, the results of this study also have considerable scientific value as the modelling process has helped provide a deeper understanding of the climate-soil-pasture inter-relationships of the VRD. Water balance, pasture transpiration, plant cover, and nitrogen supply are all better described than previously. The model calibration process revealed how these system elements drive plant growth in the district.

The main implications from the model calibration are:

- Species characteristics appear to be the closest predictors of pasture growth and nitrogen uptake, but the accuracy of these predictions can be quite variable;
- Plant-available soil moisture shows little sensitivity to generalisation, but differences exist between soil types;
- Reliable simulation of TSDM at the paddock or land type scale, requires some measure of N uptake by the pasture;
- Classification of land and pasture types improve most simulations and indicate that inherent differences exist between locations in the VRD and these real differences in soils and vegetation must be accommodated in any simulation modelling approach.
- A general model of the entire VRD resulted in low correlations between simulated and measured data for each presented variable (i.e. soil water, TSDM and N uptake); and
- Nitrogen parameters determine the upper limits to seasonal pasture growth, with total N uptake (MaxN) by plants and the N content at which growth stops (%N@0Grow) being the major factors. GRASP is very sensitive to these parameters.

Factors influencing primary productivity in the VRD

- Soil type heavily influences plant available water capacity (PAWC), with red earths having the lowest PAWC of the studied soil types, and basalt cracking clays the highest.
- Perennial grass pastures generally had higher total standing dry matter (TSDM) at the end of the growing season than did annual species pasture (annual short grasses and forbs). Some exceptions occurred.
- Soil fertility, as reflected in the soil chemical properties, indicates the soils studied to be among the more fertile soils of the Northern Territory;

- Seasonal pasture production was influenced by location, year, species composition, plant density and soil type;
- Perennial grass based pastures generally had highest productivity levels (2712kg/ha) and annual species (grasses and forbs) were more prone to variations in abundance due to seasonal conditions and/or management (e.g. burning). These observations highlight the vulnerability of pastures containing high proportions of annual species to less than favourable seasonal conditions.
- Burning annual grass dominated pastures can result in destruction of seed bank, and diminished plant germination and establishment;
- As the level of sustained utilisation by grazing animals increases a mixture of annual grasses and forb species progressively replace the desirable perennials. On the cracking clay soils forbs tend to dominate as perennial grass basal area declines, while on red earths annual short grasses make up the major component of the pasture sward when perennial grasses decline.

Developing Estimates of Carrying Capacity

Outputs possible from the model include annual and running averages of pasture growth over time showing the seasonal fluctuations in growth (Figure 2.3).

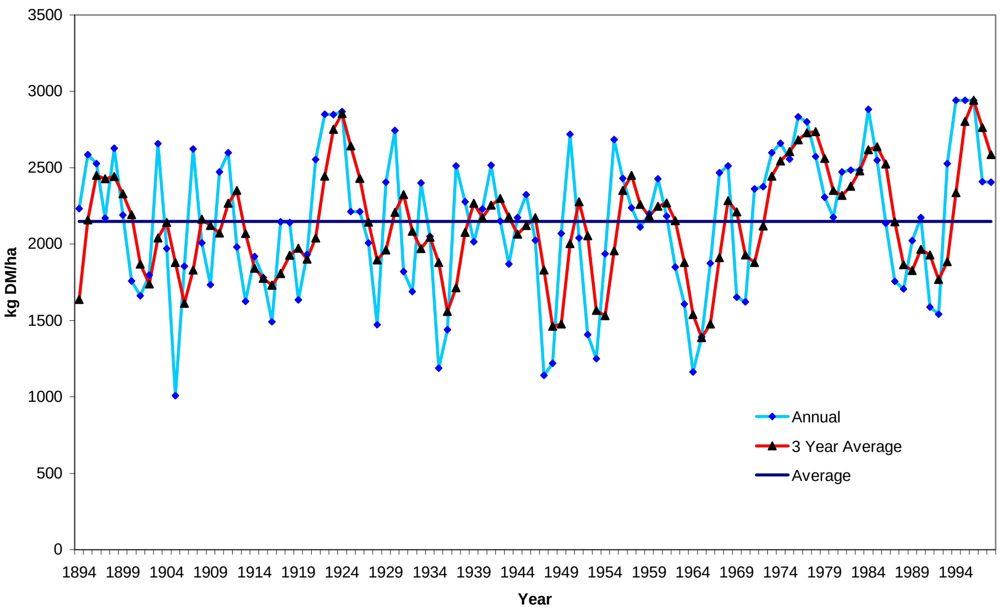


Figure 2.3: Annual seasonal, three-year running average (3YMA) and long-term average pasture growth modelled using GRASP for ribbon-blue grass pastures at Victoria River Downs station over 106 years.

Once validated, the models developed in this study can then be used, in conjunction with estimates of appropriate utilisation rates to determine long-term carrying capacities of land types important for grazing in the VRD.

Technical Implications

Making the models useful

- Validation of the parameterised models in this study with independent data will clarify the reliability of model simulations.

- Long-term pasture growth probabilities combined with grazier experience would allow for the development of safe carrying capacities for long term sustainability of pasture resources.

- Spatial application of GRASP together with climate forecasting provides a framework for identifying risks of land degradation in real time, thus allowing for preventative or harm-minimisation actions to be taken.

Validation of models

Using a systems modelling framework, probabilities of seasonal pasture growth for a range of climate regimes, soil types and pasture communities have been calculated (as mentioned above). However, these probabilities of pasture growth have not yet been validated with independent data-sets. Such validation would strengthen the understanding of model reliability when applied to times and locations other than those measured in this study.

Estimating Safe Utilisation Levels

The key factor in determining carrying capacity is the safe level of pasture utilisation (pasture eaten as a proportion of pasture grown) that provides both profitable animal production and minimal risk of degrading the pasture resources.

As GRASP simulates growth in the absence of grazing, calculation of actual utilisation rates at a given grazing pressure (stocking rate) is misleading, because grazing during the growing season reduces pasture growth to less than what GRASP would simulate with no grazing. One approach is by obtaining expert opinion from land managers in the region on appropriate stocking rates (and thereby pasture intake) for each land type and combining this with probabilities of pasture growth to estimate long-term safe levels of pasture utilisation. Other approaches use historical stock densities from case study properties and grazing trial results to determine levels of utilisation. Examples of using GRASP to determine carrying capacity and flexible stocking rates are provided in Section 6.

Studies in other regions of northern Australia, principally Queensland, (Scanlan *et al*. 1994, Johnston *et al*. 1996, Hall *et al*. 1998) have derived general utilisation rates using GRASP modelling and producer experience. However, given the extensive, heterogeneous nature of paddocks in the VRD region, combined with high turnover of managers, producers may have difficulty in estimating stocking rates according to land type and long-term seasonal conditions (see Stocking Rate Section 6).

Results in this study have revealed a range of pasture productivity levels according to soil type and pasture species composition, with fertility (N uptake) being a major determinant. Investigation into the relationship between fertility of land and pasture types and subsequent safe levels of utilisation can reveal whether higher fertility pastures are able to withstand higher levels of utilisation. Such information will then enable land managers to apply differential levels of grazing pressure and thereby achieve greater productivity from their grazing enterprise without an increased risk of pasture degradation.

Linking pasture production models to animal performance

McKeon and Johnston (1990) point out that carrying capacity and individual animal performance are not necessarily correlated, as they are determined by different factors. Linking model calculations to an animal production model (e.g. Hendricksen *et al.* 1982), will further unravel the complex relationships involved in beef cattle production from native pastures in the VRD.

Modifications to the methodology and simulation processes

Results of this study highlight the importance of several factors governing pasture growth in the VRD, and revealed some difficulties in simulating these. Further development of the GRASP model to better represent the influence of these factors would ultimately improve the model's performance.

- The division of dry matter pools (particularly green) into a number of species components rather than the current single 'species soup' approach, would enable better expression of the differences in individual species responses.

- A greater understanding of the influence of rainfall distribution and its impact on the growth patterns of individual species (particularly annual grasses and forbs) may be beneficial. This, if incorporated into the GRASP model, would result in more accurate simulations as most pastures in the region have more-or-less stable perennial grass content, while the abundance of annuals fluctuates according to climatic conditions during the growing season. Long-term simulations, particularly involving the dynamic effect of seasons and grazing on pasture composition and productivity in subsequent years, could be a very powerful tool and reveal some of the long-term consequences of short term or point disturbances or damage to the pasture resource.

- Probabilities of seasonal pasture growth in this study are based on the assumption that plant basal area and pasture species composition are constant over time. Both seasonal conditions and grazing pressure strongly influence these parameters, and incorporating these in a dynamic fashion in GRASP would improve the accuracy of the long-term simulations.

Differentiation of the pasture sward into individual species would allow use of more specific parameter values (eg. %N@0Grow, TUE) thus improving simulation results.

A number of points need to be borne in mind when interpreting the long-term probability of growth figures. The following assumptions have been made during the calculation of seasonal pasture growth:

- No account has been made for the effect of previous seasonal conditions on pasture growth in following seasons. That is, PGBA and species composition do not change from season to season – they remain constant throughout. In reality, successive high rainfall seasons usually result in an increase in plant basal cover and often changes in species composition. Both these factors can have considerable impact on seasonal pasture growth. Conversely, low rainfall seasons can reduce plant basal cover and also result in different species composition changes.
- All simulations for pasture growth are in the absence of grazing. In reality, most pastures in the VRD are grazed all year round and this has some impact upon pasture growth and species composition, particularly when utilisation rates are high in lower rainfall years. As above, no account is taken of the influence of grazing on species composition or PGBA.
- No account is taken of the effect of fire/absence of fire on pasture growth. Observations during this study indicate that fire on annual short grass pastures can result in reduced plant growth

the following year, most likely due to reduction of the seed bank. In perennial grass pastures, absence of fire for many years can lead to tying up of nutrients in dead plant material and may cause a reduction in plant growth due to reduced nutrient availability.

- Trees are not considered in the simulation process. However, much of the landscape is open woodland and trees have some localised competitive effects.

Outputs

- Parameter sets for GRASP for a number of land types in the VRD and comprehensive soil, climate and pasture databases.
- *Managing grazing in northern Australia: a graziers guide*. Ian Partridge, QDPI, 1999.
- *Growth and Safe Utilisation of important native pasture grazing lands in the Victoria River District of the Northern Territory*. PhD Thesis in prep. Cobiac, M.D. Adelaide University, Australia.
- *The Aussie GRASS Northern Territory and Kimberley Sub-project Final Report*. Rodd Dyer, Linda Cafe and Andrew Craig, QDNRM, 2001.

3. Tree-grass relationships along a rainfall gradient

Introduction

Tree and shrub thickening is occurring in grazed savanna woodlands in the Katherine and VRD regions (Lewis 2002, Fensham 1990, Bastin *et al*. 2003). Increasing woody vegetation cover can reduce pasture production and livestock carrying capacity (Scanlan *et al*. 1994), adversely impact native habitats and biodiversity (Dyer *et al.* 2001) and increases the difficulty of livestock mustering. Despite the adverse impacts of increases in woody vegetation, trees and shrubs have important savanna functions relating to carbon sequestration, nutrient cycling, prevention of soil erosion, salinity abatement and provision of habitat for native flora and fauna (Scholes & Archer 1997).

Grass production is influenced by rainfall (amount and distribution) and soil characteristics (fertility, depth and water holding capacity) (Littleboy & McKeon 1997). Therefore increasing tree competition for soil water has the potential to reduce pasture production. In the seasonal wet-dry tropics woodland tree-grass competition is generally not thought to impact on grass production (Scanlan & McKeon 1992). For example, unlike pasture responses to tree clearing in north-eastern Australia, Norman (1966) and Winter *et al.* (1989) found tree removal in monsoon tallgrass savannas in Katherine did not result in long-term increases in grass yield. Such responses could be attributed to negligible competitive impacts between trees and grasses for soil moisture during the growing season. But Mott *et al.* (1985) proposed that the climatic potential yield of grasses in northern monsoon tallgrass savannas is often limited by nutrients (mainly nitrogen) rather than water availability. Therefore it is possible that increasing tree cover will limit grass production through increased competition for nutrients.

Determining appropriate management responses to woody thickening in north-western Australia requires an understanding of tree-grass competition and the ability to predict impacts of changes in woody vegetation on pastures. This study aims to quantify the effects of tree density on plant available soil moisture and grass production at two sites with differing rainfall, and to provide sufficient data to calibrate and validate the tree effects in the GRASP pasture production model.

Project Objective

By 2001 the majority (>80%) of land managers and administrators are aware of the increase, cause, impact and potential cost of unchecked woody plants.

Study Aims

- Quantify the effects of tree density on soil moisture and pasture production at two locations with distinctly different annual average rainfall.
- Provide sufficient data to calibrate and validate tree effects within the GRASP pasture growth model for the pasture communities sampled.
- Utilise GRASP to extrapolate tree effects across a range of climate, soil and vegetation systems.

Methods

Location and design

Tree-grass study sites were established at Katherine Research Station and Kidman Springs (Victoria River Research Station) during 1995 and 1996 (Table 3.1). Each location represents different rainfall-understorey zones within the semi-arid/sub-humid climate gradient, but both are influenced by seasonally wet-dry climates, and contain open Eucalypt woodland (tree basal area 11-24 m^2/ha at 30cm) with a vigorous native perennial grass understorey. At each location two replicated sites were established.

Table 3.1: Site and vegetation characteristics in treed plots for the tree grass relationship trial areas at Katherine Research Station and Kidman Springs (Victoria River Research Station).

Location	Katherine Research Station	Kidman Springs
Average annual rainfall	970mm	690mm
Location	14^{o}28'S, 132^{o}18'E	16^{o}7'S, 130^{o}57'E
Sites	Paige and Dixon	Loungers Hill and Native
Understorey type	Monsoon tallgrass	Tallgrass
Soil type	Red earth	Red earth and Alluvial Loam
Overstorey type	Eucalypt woodland	Eucalypt woodland
Tree density (stem/ha)	1500 and 2100	2622 and 1111
Tree basal area (m^2/ha)	12.4 and 17.2	11.2 and 24.2

Uniform areas of tree and shrub density were selected at each site. A 60 m x 60 m area was cleared of all standing trees and shrubs using a chainsaw. Felled debris was removed from the plots and remaining stumps poisoned with herbicide (Tordon). A 30 m x 30 m plot in the centre of the cleared area was chosen as the sampling plot and fenced to prevent livestock grazing. An adjacent uniform uncleared 30 m x 30 m plot was also chosen and fenced. All plots were burnt with a low intensity fire at the end of each dry season to remove remaining standing pasture and litter. Recurring tree regrowth was sprayed with herbicide to maintain the cleared plot tree basal area at zero throughout the experiment.

Tree species, height, basal area, diameter at breast height, and stem number was measured in both uncleared plots and in cleared plots prior to clearing. The SWIFTSYND (Day & Philp 1997) sampling methodology was used to collect soil and pasture parameters from each plot on six occasions during the growing season for two growing seasons for each site. Data were collected over 5 wet seasons (1995-2000) for the first sites (Katherine Paige and Kidman Loungers Hill), 4 wet seasons (1996-2000) for the second Katherine site (Katherine Dixon) and 3 wet seasons (1996-1999) for the second Kidman site (Kidman Native).

Results and Discussion

Seasonal conditions

Average seasonal rainfall for the period of data collection at Katherine sites (1190-1230mm) was considerably higher than at Kidman Springs (820-840mm). Although rainfall was near average or above average in most years (Table 3.2), considerable within-season variation in rainfall occurred. In particular, the 1995/96 wet-season in Katherine was a little below average, but also contained several lengthy dry periods, followed by very intense rainfall events and high run-off.

Table 3.2: Seasonal rainfall (mm) for each site during the experiment

Study site	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000	Study average	Long term average
Katherine Paige	821	1521	1227	1071	1306	1189	970
Katherine Dixon	N/A	1491	1223	1094	1324	1283	970
Kidman Loungers Hill	757	666	689	899	1093	821	690
Kidman Native	N/A	615	701	745	1288	837	690

Impact of tree competition on available soil moisture

Tree removal increased volumetric soil moisture (0-100cm depth) by an average of 7.5% for Katherine and Kidman Springs (Figure 3.1) but increases were only significant in Katherine during 1995/96 and 1999/2000 (Table 3.3). During these years tree water-use (transpiration) during below average monthly and seasonal rainfall significantly lowered soil moisture in treed plots compared to cleared sites. During higher rainfall years between 1997 and 1999 there was no significant difference in soil moisture between treed and un-treed plots. These fluctuating affects can be clearly observed in Figure 3.1 for the Paige site in Katherine. Overall, available soil moistures ranges for treed and cleared plots at Katherine were higher (22-26 cm^3/cm^3) than at Kidman Springs (18-19 cm^3/cm^3) and reflected the higher average rainfall and seasonal wet-dry fluctuations.

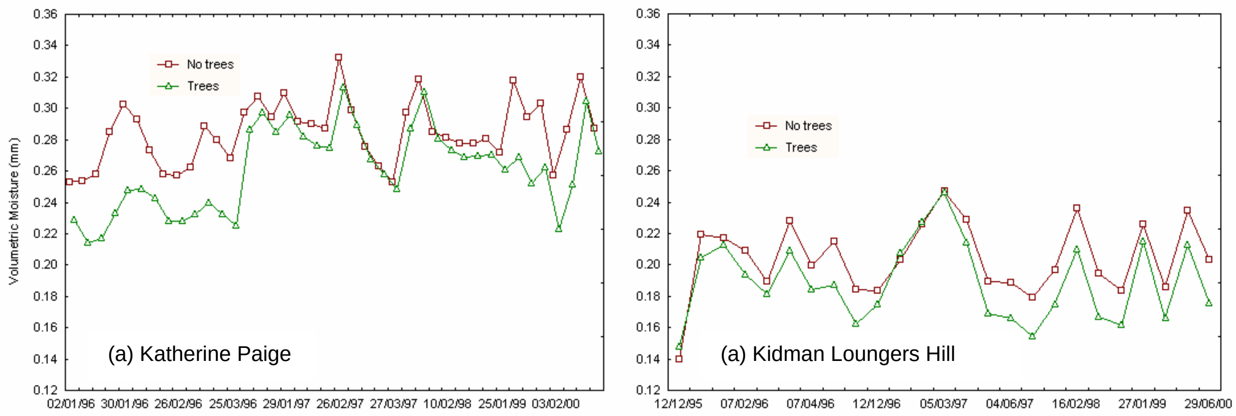


Figure 3.1: The impact of Trees and No trees treatments on volumetric soil moisture (0-100cm) in wet season months for (a) Katherine Paige and (b) Kidman Loungers Hill .

Table 3.3. Average volumetric soil moisture (cm^3/ cm^3) (means and standard errors) across rainfall seasons for Katherine (Paige and Dixon) and Kidman Springs (Loungers Hill) sites.

Year	Trees	No Trees	n	
Katherine – Paige				
1995/96	0.23 ± 0.01	0.26 ± 0.02	26	***
1996/97	0.26 ± 0.04	0.27 ± 0.04	19	
1997/98	0.26 ± 0.03	0.27 ± 0.03	13	
1998/99	0.25 ± 0.02	0.25 ± 0.03	2	
1999/2000	0.26 ± 0.02	0.29 ± 0.02	15	***
Katherine –Dixon				
1996/97	0.23 ± 0.05	0.25 ± 0.05	19	
1997/98	0.26 ± 0.06	0.27 ± 0.05	13	
1998/99	0.22 ± 0.04	0.24 ± 0.05	2	
1999/2000	0.26 ± 0.03	0.28 ± 0.04	15	*
Kidman Springs – Loungers Hill				
1995/96	0.19 ± 0.02	0.20 ± 0.03	9	
1996/97	0.19 ± 0.03	0.21 ± 0.03	8	
1997/98	0.18 ± 0.02	0.20 ± 0.02	4	
1998/99	0.19 ± 0.03	0.21 ± 0.03	2	
1999/2000	0.19 ± 0.03	0.22 ± 0.02	2	

(Denotes significant differences between Tree and No Tree treatments: * P <0.05; *** P< 0.0001)*

Impact of tree competition on pasture production

Removal of trees increased pasture yields by 35-70 percent across all sites (Table 3.4). Between years peak pasture yields reflected seasonal rainfall distribution, but were higher in cleared plots for sixteen of the seventeen site by year harvests (Figures 3.2 & 3.3). Wilcoxan matched pairs tests indicated that dry matter yields in cleared plots were significantly greater than the treed plots for Katherine Paige ($p<0.001$) (Figure 3.2), Katherine Dixon ($p<0.01$) and Kidman Loungers Hill ($p<0.001$) (Figure 3.3), but were not significant for Kidman Native ($p>0.05$), probably due to unusual local site factors. The treed plot at Kidman Native was inadvertently situated in a subtle drainage line, making it a sink for moisture and nutrients carried in overland flow. Native legumes also contributed a high proportion of total species composition, which made nitrogen comparisons between it and the cleared plot difficult. For these reasons, Kidman Native is not referred to when drawing conclusions from the broader study.

Table 3.4: Average differences of tree and pasture characteristics observed in “No Trees” and “Tree” treatments at study sites in Katherine and Kidman Springs, VRD.

	Katherine				Kidman Springs			
	Dixon		Paige		Loungers		Native	
	No trees	Trees	No trees	Trees	No trees	Trees	No trees	Trees
TBA (m^2/ha)	-	17.2	-	12.4	-	11.2	-	24.2
Pasture Yield (kg/ha)	3019	2089	3621	2013	2462	1637	5053	4253
Total N (kg N/ha)	15.6	8.2	15.5	9.0	5.6	5.6	13.0	17.7
N %	0.56	0.41	0.47	0.45	0.26	0.40	0.32	0.45
Years (n)	4	4	5	5	5	5	3	3

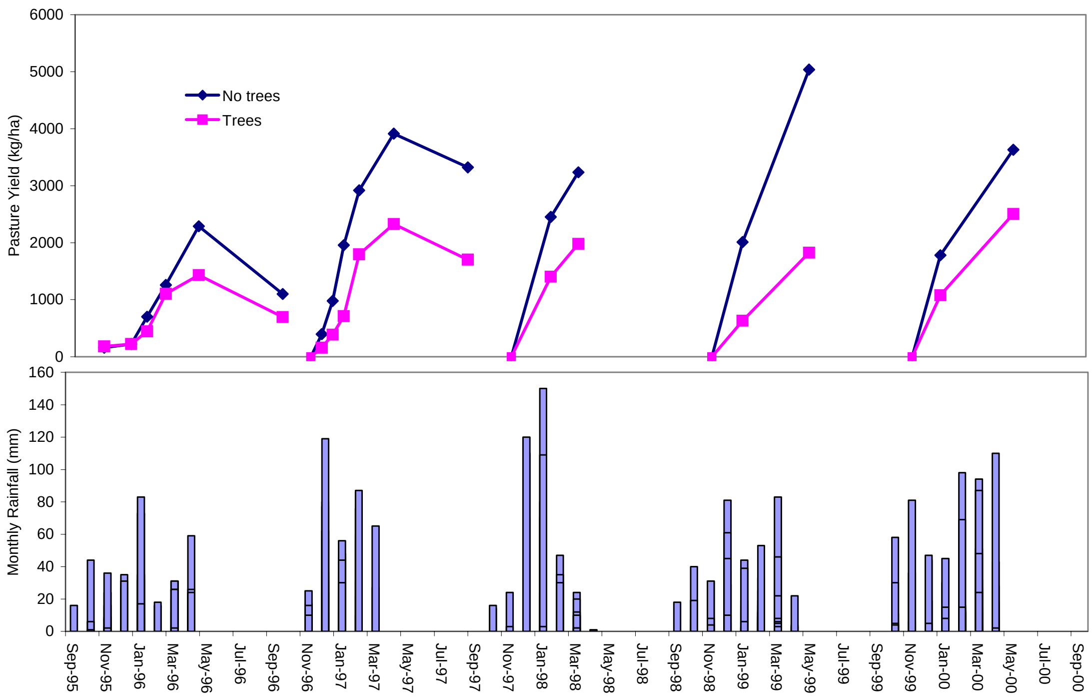


Figure 3.2: Measured pasture yield for “Trees” and “No trees” treatment plots and monthly rainfall between 1995/96 and 1999/2000 at Katherine (Paige site).

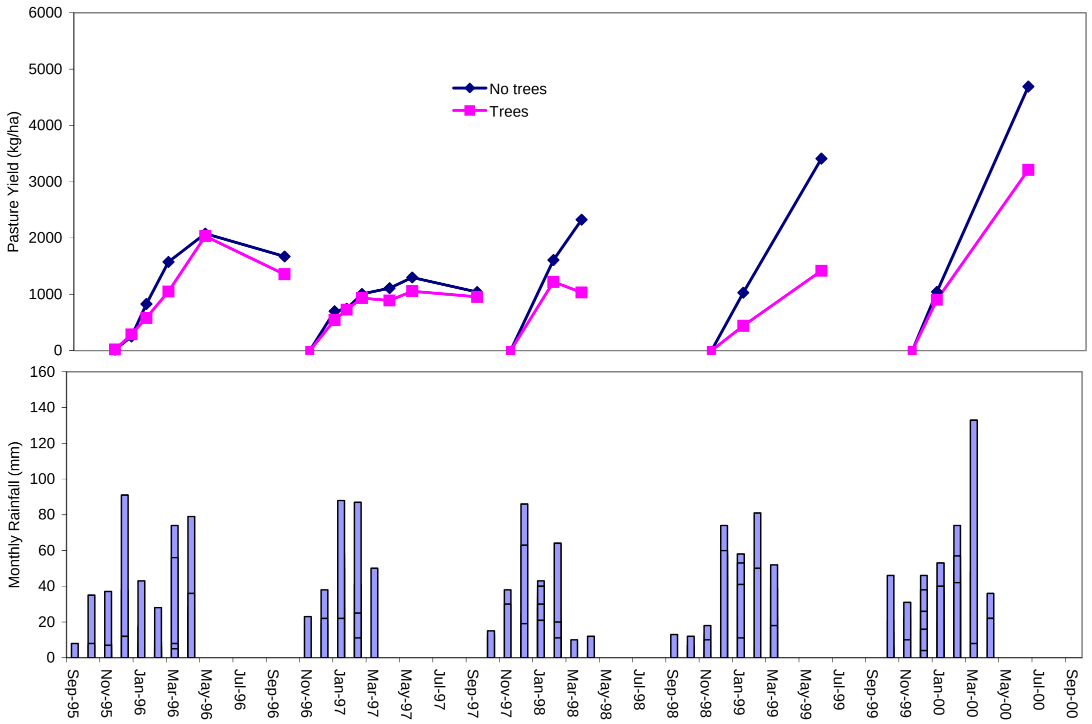


Figure 3.3: Measured pasture yield for “Trees” and “No trees” treatment plots and monthly rainfall between 1995/96 and 1999/2000 at Kidman Springs, VRD (Loungers Hill site).

Impact of tree competition on grass basal area and species composition

Grass basal area (GBA) increased in all ‘Tree’ and ‘No Tree’ plots following exclosure and the subsequent prevention of grazing, except for the treed plot at Loungers Hill. (Basal area was not measured at VRRS Native after 1997 and is not shown). However, GBA was significantly greater in cleared plots (Figure 3.4, $p<0.05$, Wilcoxan Matched Pairs test). For example, at the Katherine Dixon site, GBA started at 1.3% (following removal of grazing), and after two seasons had increased to 6.4% in the treed plot and 11.6% in the cleared plot.

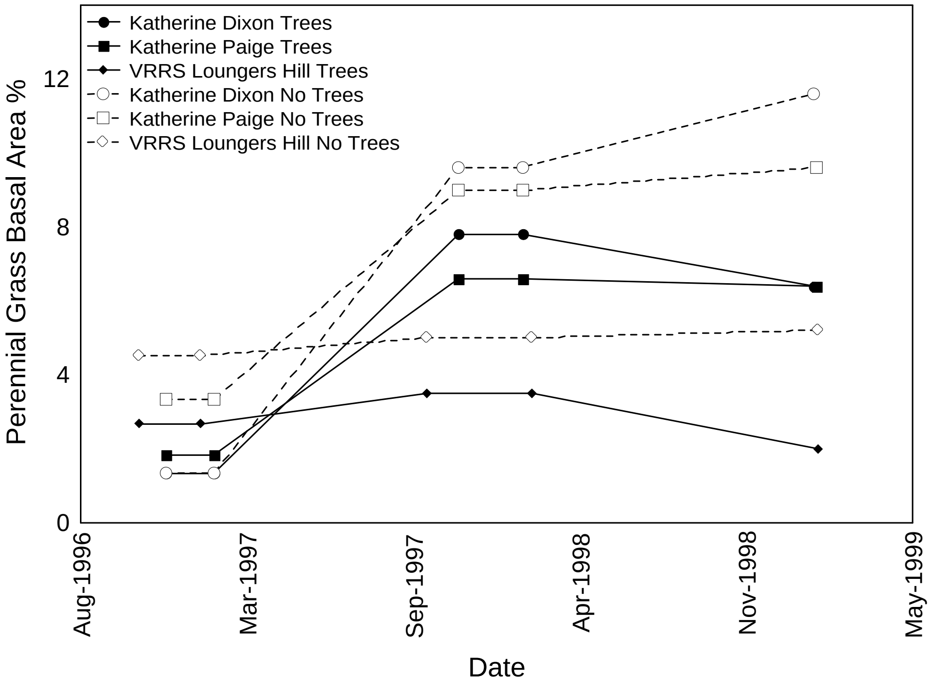


Figure 3.4: Change in perennial grass basal area through time in cleared and treed plots.

Pasture species composition varied between sites, and through the trial. However, trends were similar between treed and cleared plots, indicating that composition changes through time reflected exclosure from grazing, the effects of annual burning to remove carry-over dry matter, or seasonal trends rather than clearing treatment (Appendix 1, Figures 12.1-12.6). The unpalatable *Chrysopogon latifolius* decreased at all sites where it was present and *Sehima nervosum* either deceased or was stable, while the palatable *Themeda triandra* increased at Katherine sites and *Dichanthium fecundum* increased at Kidman native. *Heteropogon contortus* increased at Kidman Native, and was stable or slightly decreased at other sites. Herbs only contributed a small proportion of the composition and decreased at all sites, except at Loungers Hill, where they increased, especially in the treed plot. Grasses in cleared plots were observed to have more advanced phenological development, with earlier onset of flowering and seeding compared to grasses within treed plots (Figure 3.5).

Figure 3.5. Differences in pasture biomass and stage of phenological development between Tree (above) and Trees Removed (below) treatments at Katherine Paige site in February,1997.

Impact of tree competition on nitrogen availability and uptake

Nitrogen uptake (N yield) and nitrogen concentration at peak yield (nitrogen use efficiency) varied between the Katherine and Kidman sites (Table 3.4). Tree removal significantly increased total nitrogen yields at the Katherine site (Paige: $p<0.001$, Dixon: $p<0.05$), but N yields were similar between “Tree” and “No tree” plots at Loungers Hill ($p>0.05$). At peak yield nitrogen concentrations were highest in cleared plots in Katherine, yet on average were higher in treed plots at Loungers Hill (Table 3.4). However here responses varied between years.

Increased nitrogen availability at Katherine sites is most likely due to rapid breakdown of dead roots and the removal of competition for nutrients in cleared plots, however it is unclear why there was no increase in nutrient availability, nor a consistent trend in nitrogen levels at the Loungers Hill site. Average total N yield for Loungers Hill (5.6 kg N/ha) was very low compared to values reported for 21 sites in the VRD (median 21 kg N/ha; minimum 6 kg N/ha, Cobiac in prep), indicating very poor soil fertility and nutrient availability compared to other soil and pasture types. At this site *Sehima nervosum* contributed over 80% of total species composition in the cleared plots (Figure 12.1, Appendix 1). *Sehima* is commonly found on poor fertility soils, has low nutritive value and was found to have the lowest pasture N yield values reported from a range of pasture communities studies throughout the VRD reported in Section Two.

A possible explanation for the apparently contrasting nutrient responses to tree removal between the Katherine and Kidman sites can be presented as follows. In the presence of trees, pasture growth at Katherine was limited mainly by nutrients (nitrogen), and possibly by soil moisture during abnormally dry periods during the growing season. Under such low nutrient availability the completion of growth, maturity, flowering and seeding stages required the dilution of plant nitrogen to very low concentrations. Removal of trees significantly increased the availability of nitrogen (and soil moisture), overcoming constraints to growth and resulting in phenological development occurring several weeks earlier (See photo above). Because of the increased availability of nutrients, significantly higher peak grass yields were achieved without diluting nitrogen levels to such low levels as grass in treed plots. The end results being higher grass biomass and nitrogen yield combined with higher grass N content in cleared plots.

Grass production at Loungers Hill was constrained by soil moisture and very low nutrient availability, particularly in the presence of trees. Although tree removal did not increase nitrogen availability, pasture yields were increased by 50%. One possible explanation is that removal of tree competition resulted in small increases in moisture availability (as shown in Figure 3.1.b) during the growing season that promoted continued grass growth. However, higher yields were only possible by the dilution of plant nitrogen to very low levels (0.26%) because total nitrogen availability had not increased and the severe nutrient constraint remained.

Simulating tree-grass competition with GRASP

In this study the empirical field data from Katherine were used to validate tree effects in the GRASP model using average plant parameters derived from native pastures in Queensland. Soil water and rainfall intensity parameters were derived from the field measurements. Although simulated estimates of peak yield agreed with observed measurements across treatments and sites (Figure 3.6), the model underestimated peak yields under trees (1675 kg/ha TSDM compared to observed 1894kg/ha TSDM). Without calibration the model accounted for a very high proportion of variation within seasons and between years and sites for soil water (r^2=0.9, RMS=13 mm, n=113) and standing dry matter (r^2=0.86, RMS=285 kg DM/ha, n=112).

Within the GRASP model, total nitrogen uptake (MaxN) and the nitrogen content at which growth stops (nitrogen use efficiency; %N@0Grow) determine the upper limits of simulated seasonal grass production. The field results showed that when constrained by nutrient availability rather than soil moisture (eg “Trees” in Katherine and “No Trees” treatments at Loungers Hill, Kidman Springs), grass production was supported by dilution of plant nitrogen levels to values lower than previously assumed within GRASP (ie lower %N@0Grow). Total nitrogen yield in grass pastures (MaxN) may also increase following tree removal. Therefore the study indicated changes in tree-grass balance at any one location can significantly influence both MaxN and %N@0Grow parameters within the GRASP model.

When nitrogen use efficiency values masured for grass under trees (%N@0Grow) were included in the model, GRASP more accurately simulated the average effect of trees, but did not simulate the observed year-to-year variation in peak dry matter and nitrogen yields (Table 12.1, Appendix 1). A temporal plot of green yield for Katherine Paige (Figure 3.7) indicates some variation between predicted and observed values in treed and no-tree sites. A major source of variation not simulated by the model was the rapid change in nitrogen yield that occurs around peak dry matter yield.

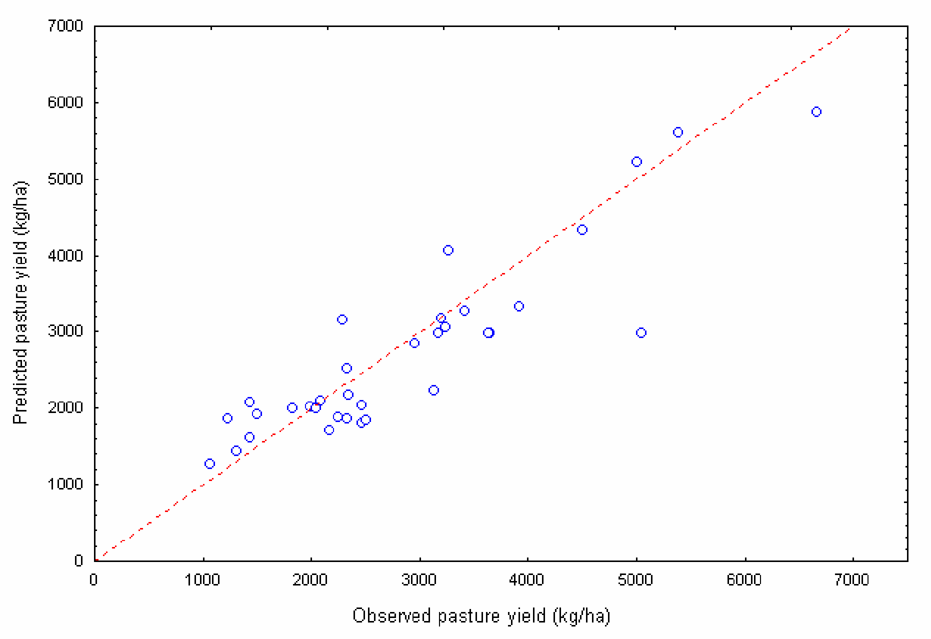


Figure 3.6: Relationship between predicted pasture yields simulated using GRASP and observed pasture growth measurements for "Trees" and "No Trees" treatments in Katherine and Kidman Springs. (Adjusted r^2 = 0.81; P< 0.001).

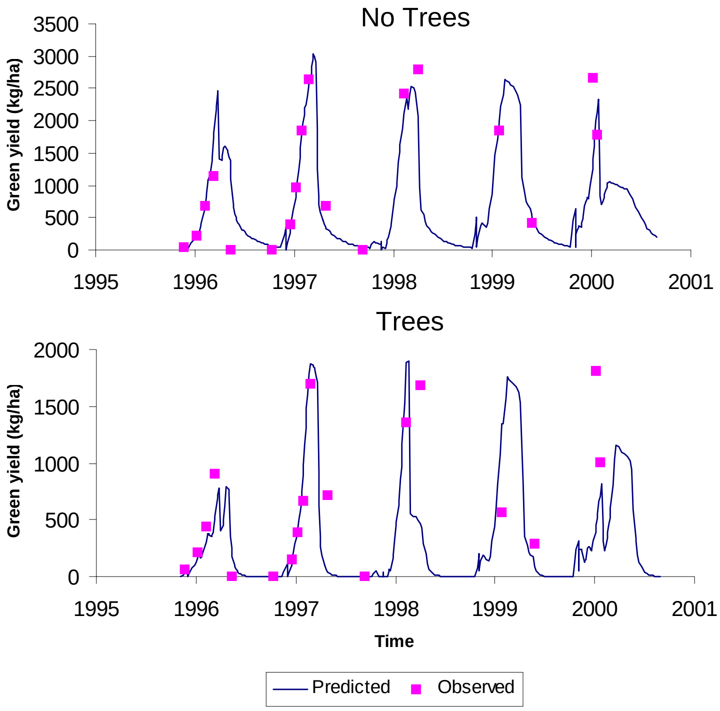


Figure 3.7: The relationship between predicted green yield simulated with GRASP and observed green yield for "No Trees" and "Trees" treatments at Katherine, Paige site. (Note different scales on y axis).

The Katherine growth parameters were then run at Kidman Springs as a validation exercise (Model 1, Table 12.2, Appendix 1). The model underestimated the yield under trees at the Loungers Hill site, and underestimated the yield in both treed and cleared plots at the Native site. When locally derived parameters of moisture, nutrient availability and plant growth were included in the model, pasture yields were more accurately simulated (Model 2, Table 12.2, Appendix 1).

Examples using GRASP

The GRASP study indicated that more detailed inputs of tree-grass effects and local nitrogen parameters may be necessary to accurately simulate changes in tree-grass balance over time and obtain accurate predictions of peak yield (and pasture quality) on an individual site x year level. Despite this, the performance of the model suggested that GRASP can be used with some confidence to examine the broad impacts and interactions between tree basal area (TBA), seasonal rainfall, soil/pasture type and pasture growth. For example the differential impacts of TBA on pasture growth for two savanna communities with different soil characteristics (calcareous red earth and an alluvial gray clay) at the same rainfall location (Katherine) are simulated in Figure 3.8.a. Here the GRASP predictions indicate that pasture growth will decline for TBA increases between 2 and 20 m^2/ha in a Tippera tallgrass pastures on red soils in humid savanna. This response reflects the low soil water holding capacity and fertility status of this soil type. In contrast, similar tree increases have little impact on pasture situated on alluvial gray clays. The impact of increasing TBA can also be compared across locations with different seasonal rainfall (Figure 3.8.b).

In this way the GRASP model not only provides a basis for ongoing model validation, development and improvement, but also can be used to identify future research priorities. The model also can be used to explore a range of practical environmental and management applications such as aiding estimation of livestock carrying capacities and the economic evaluation of vegetation thickening and prescribed burning strategies (detailed in Economics Section 5).

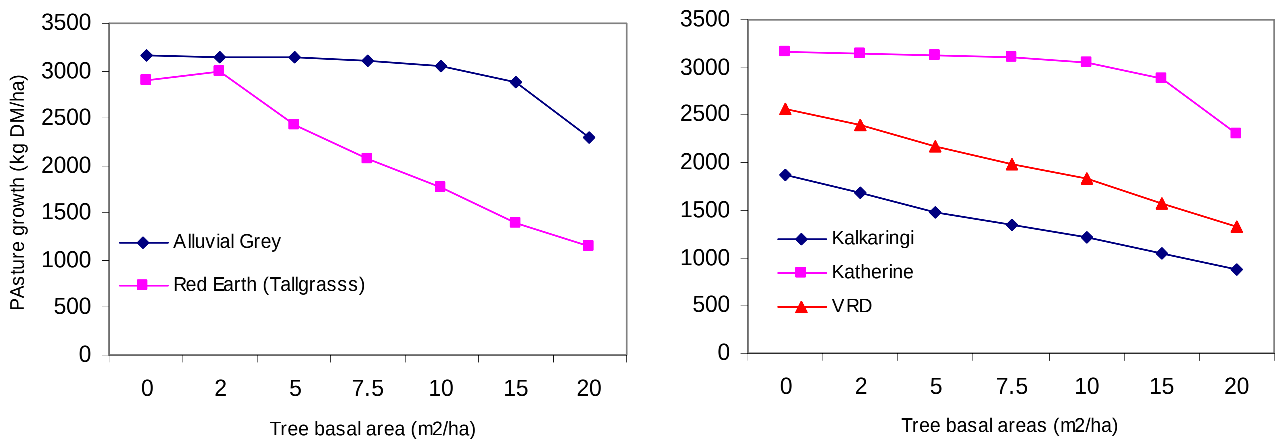


Figure 3.8: GRASP simulated impact of tree basal area on pasture growth for (a) two pasture communities at Katherine and (b) for an alluvial grey soil pasture community at three rainfall locations (Katherine 960mm, VRD 645mm; Kalkaringi (425mm).

Industry Implications

*Tree-grass competition for moisture **and** nutrients will impact on pasture production and quality*

This study showed that competitive tree-grass interactions for soil moisture **and** nutrients can influence pasture yield and quality in high and low-rainfall savannas. Tree removal resulted in significantly higher pasture growth and pasture quality when nutrient availability was increased, however increased biomass production was accompanied by lower pasture quality when nutrient constraints following tree removal remained unchanged. The implications of the field results suggest that tree thickening will increase tree-grass competition for soil moisture **and** nutrients and cause either a decline in pasture yield and/or pasture quality in both humid and semi-arid savannas. The dominance of moisture or nutrient limitations to pasture growth and quality will be determined by complex tree-grass interactions with site factors such as existing tree density, seasonal rainfall, soil fertility and pasture community. The GRASP model can be used to investigate these interactions and changes

Grass growth is limited mostly by nutrients in high-rainfall, and soil moisture in low-rainfall areas

These results confirm the hypothesis of Mott *et al.* (1985), and results in Section Two (Ecology and Management of Native Pastures), that potential pasture growth in humid monsoon tallgrass pastures is constrained mainly by nutrient availability. Both empirical and simulated impacts of tree-grass interactions suggest that woody thickening will reduce pasture growth and/or pasture quality due to competition between trees and grass for limited available nutrients. Because grasses under nutrient constraints diluted plant nitrogen to very low concentrations, enabling continued growth, increases in tree competition may result in declining pasture quality prior to a drop in biomass production.

In contrast, as rainfall declines, increasing tree populations are most likely to reduce pasture growth through increased competition with grasses for soil moisture. The results confirm that the amount and distribution of rainfall have the most significant impacts on tree-grass competition and potential pasture growth in lower rainfall areas and during intra-seasonal dry periods (Scanlan & McKeon 1993). High rainfall increased availability of soil moisture and potential grass production. However pasture quality is likely to be lower due to N dilution.

Grass nitrogen concentrations are diluted to low levels under nutrient constraints to maintain growth

Nitrogen-use efficiency is an indicator of the plant’s ability to dilute nitrogen levels to sustain growth under nutrient limitations. Grass nitrogen use efficiency appears to be higher when nutrient availability is limited by low soil fertility and/or tree competition, enabling growth and development to continue, but reducing grass nutrient concentration.

Tree removal increased grass yield over a five-year period

Tree removal resulted in a significant increase in pasture production. Based on results from other studies, it was expected that initial pasture yield increases following tree removal would be short-lived, before run-down of nutrients would cause yields to decline over time, as observed by Winter *et al.* (1989). Nutrient run-down may have been avoided in this study as there was no offsite removal of nutrients from grazing, and the perennial grass species present efficiently translocate nutrients to their roots at the completion of the growing season. This highlights the importance of the competition for nutrients, particularly nitrogen, in the tree and grass relationship in the tropical savannas (Winter *et al*. 1989).

Is tree clearing a viable option?

Unlike north-eastern Australia, responses to woodland clearing have generally been considered uneconomical in northern Australia due to low stocking rates, poor quality of grasses and initial results that indicated limited long-term response to tree clearing (Norman 1966, Winter et al.1989). Although grass production was increased for several years in this study following tree removal, pasture quality may decline due to nutrient dilution over the long term by 'nutrient harvesting and export' by grazing animals. Based on the simulated competition between tree and grass layers there appears to be both environmental and economic benefits for adopting strategies to manage tree and shrub thickening and encroachment over the long term (See Economics Section 5). For this purpose, under current grazing conditions, fire is the most economical way to manage woody thickening (See Fire Section 4 and Economics Section 5).

Technical Implications

- Continue to monitor annual pasture production at peak yield, at least from Katherine sites, to determine whether higher yields in cleared plots are maintained or decline over the longer-term. *Being Implemented.*

- Investigate further the impacts of trees on grass nutrient availability in high rainfall areas by comparing field measurements of total nitrogen and nitrogen use efficiency values from known areas of tree thickening, thinning and natural woodland.

- Develop aerial or remotely sensed methods to monitor tree basal areas and cover to detect long-term vegetation changes.

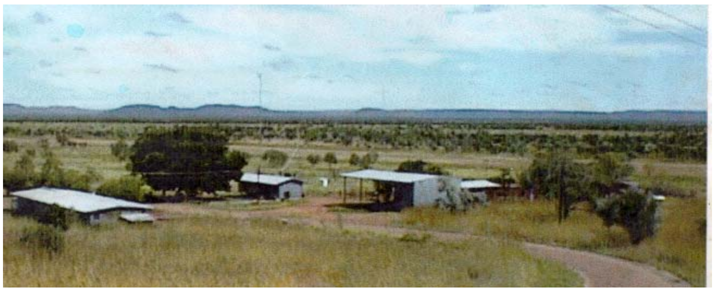
4. Managing native vegetation communities with prescribed fire

Introduction

Anecdotal and scientific evidence suggests that tree and shrub thickening is occurring throughout savanna woodlands in the Victoria River District (VRD) of the Northern Territory (Figure 4.1). Recent studies of tree cover changes from temporal sequences of historic and contemporary landscape and aerial photography show that woody increases are significant throughout the VRD and have occurred over the last 40-50 years (Lewis 2002, Fensham 1990). One possible explanation is that deliberate exclusion of fire and/or the reduction of fuel loads from more intensive grazing, have resulted in a reduction in the incidence, extent and intensity of landscape fires in recent decades. These changes to established fire regimes may have contributed to, if not been the main cause, of woody plant increases. Other hypotheses suggest woody vegetation cover fluctuates as part of long-term cycles driven by extreme seasonal variations and/or climate change. Competition from trees and shrubs for soil moisture and nutrients has been shown to reduce grass growth (Tree-grass Relationships Section 3) and hence have important impacts on carrying capacity. While the prescribed use of fire was considered an option for land management, little was known of fire impacts on trees, shrubs and pastures in the VRD, nor the most appropriate fire regimes for specific vegetation management objectives.

1968

1990



1998

Figure 4.1: Woody vegetation change between 1968 and 1998 at Kidman Springs (Victoria River Research Station) in the Victoria River District.

Project Objectives

To ensure that by 2001, throughout the VRD/Sturt Plateau region the majority (>80%) of land managers and administrators are aware of the increase, cause, impact and potential cost of unchecked woody plants.

80% of producers are aware of the principles and best practice of controlled burning by providing a relevant and practical fire management manual and presenting information at on-property workshops, field days and shows.

Study Aims

The aim of the study was to examine the impact of different fire regimes on pastures and woody vegetation in two pasture communities in the Victoria River District of the Northern Territory.

1. Investigate the effect of fire season and frequency on pasture condition and woody vegetation.

2. Determine the impact of natural fuel loads on woody plant response following burning

3. Investigate the relationship between fuel load, fire intensity and plant response of the invasive woody shrub rosewood (*Terminalia volucris*) in a fuel manipulation experiment.

4. Produce a publication providing practical burning management guidelines for land managers

Methods

A program of long-term fire research was established in late 1993 on Victoria River Research Station (Kidman Springs). A major component of the work investigated the impact of fire frequency, fire season and fire intensity on woody plants and pasture condition in grazed arid short grass (ASG) and ribbon-blue grass (RBG) communities (Figure 4.2).

The ribbon-bluegrass (RBG) site is a savanna grassland-shrubland situated on grey cracking clay. It is described as undulating country on limestone or shale, typical of the Argyle land system (Stewart *et al.*1970). The site is dominated by mid-height perennial grass species such as *Chrysopogon fallax* (ribbon-grass), *Dichanthium fecundum* (blue grass), *Sehima nervosum* (white grass), *Panicum decompositum* (native millet) and annuals *Iseilema* spp. (Flinders grass) and *Dichanthium sericeum* (Queensland blue grass). Woody vegetation is dominated by low-mid height species, such as *Terminalia volucris* (rosewood) and *Bauhinia cunninghamii* (bauhinia).

The arid short-grass (ASG) site is located on calcareous red earth and is characteristic of open eucalypt savanna woodland in undulating country on limestone or shale described as the Humbert land system (Stewart *et al.*1970). This site supports an arid short-grass pasture community dominated by *Enneapogon polyphyllus* (limestone grass) with patches of *Heteropogon contortus* (black spear grass) and *Dichanthium fecundum*. *Brachyachne convergens* (summer couch) and *Sporobolus australasicus* (fairy grass) dominate heavily utilised areas, especially following poor rainfall seasons. The red earths are shallow and stony with a woody overstorey dominated by *Eucalyptus pruinosa* (silver leaf box), *Corymbia terminalis* (inland bloodwood), *Carissa lanceolata* and *Hakea arborescens*.

The impact of fire on pasture variables was investigated for each year individually between 1994 and 1999 using ANOVA, with an unbalanced design. A second experiment quantified the relationships between fuel characteristics (fuel load and cover), fire intensity and woody plant response. A third experiment manually manipulated fuel loads in small plots dominated by *Terminalia volucris* (rosewood), a shrub increasing on grey cracking clay grasslands. Detailed fuel, weather and fire behaviour measurements were taken during experimental burns in the early and late dry season. From these studies important fuel-fire-weather-vegetation responses were quantified, models developed and general prescribed burning recommendations made.

Arid Short Grass

Ribbon Blue Grass

Figure 4.2: Typical arid short grass low eucalypt woodland and ribbon blue grass, low open shrubland communities at Kidman Springs in the VRD.

Results and Discussion

A detailed account of the experimental method, results and conclusions can be found in Dyer (2002). General summaries and burning recommendations for these, and other pasture communities throughout northern Australia can be found in Dyer *et al.* (2001c). Some key findings are outlined below.

Effects of fire on trees and shrubs

Tree and shrub responses in both communities were influenced mainly by fire intensity and plant height. Mortality was significantly determined by plant height in the ASG community only. Smaller plants were more susceptible to burning as plant mortality was inversely proportional to plant height (Figure 4.3). Fire behaviour variables such as fuel load, fire frequency or burning season did not increase plant mortalities in either pasture type. Mortality rates following burning averaged 2% in RBG and 5% in ASG (Table 4.1). Mortality rates for *Bauhinia cunninghamii* (bauhinia) and *Carissa lanceolata* (conkerberry) were 3% and 5% respectively, and higher compared to 1% for *Terminalia volucris* (rosewood).

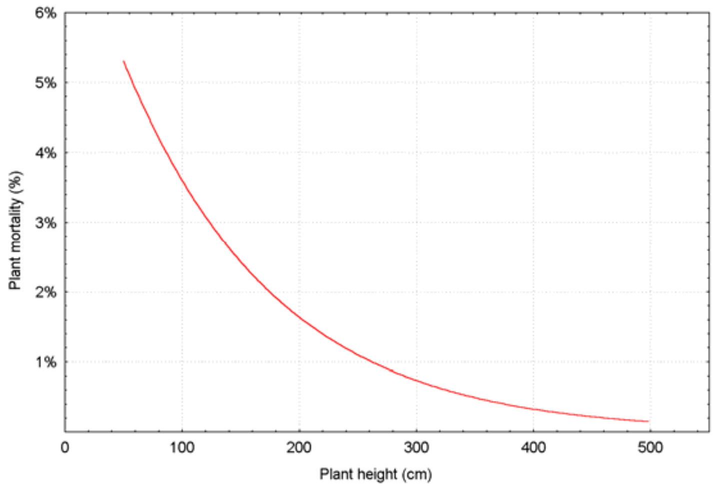


Figure 4.3: The relationship between tree and shrub plant height (cm) and plant mortality following burning in arid short grass pastures.

Table 4.1: Mortality of tree and shrub species following burning

Tree/shrub species	Mortality (%)	Mortality (n)	Total N
Bauhinia cunninghammi	3.3	8	239
Carissa lanceolata	5.3	22	418
Eucalyptus pruinosa	2.1	1	48
Terminalia volucris	0.7	4	557
Hakea arborescens	1.9	3	160
Eucalyptus terminalis	0.0	0	15
Average/Total	2.6	38	1437

For most species death of aerial branches and vegetative resprouting from the plant base (top kill) would occur if fire damage burned and charred the majority of leaves. Top kill was therefore significantly influenced by plant height and factors that influence fire intensity (fuel load, fuel cover and season of burn). Therefore despite seemingly low plant mortality levels, fire induced top kill can be used to manipulate woody canopy cover and plant height in both pasture communities. A series of multivariate logistic models were developed that enable prediction of expected top kill rates (Figure 4.4) and were used to develop general prescribed burning recommendations (see below).

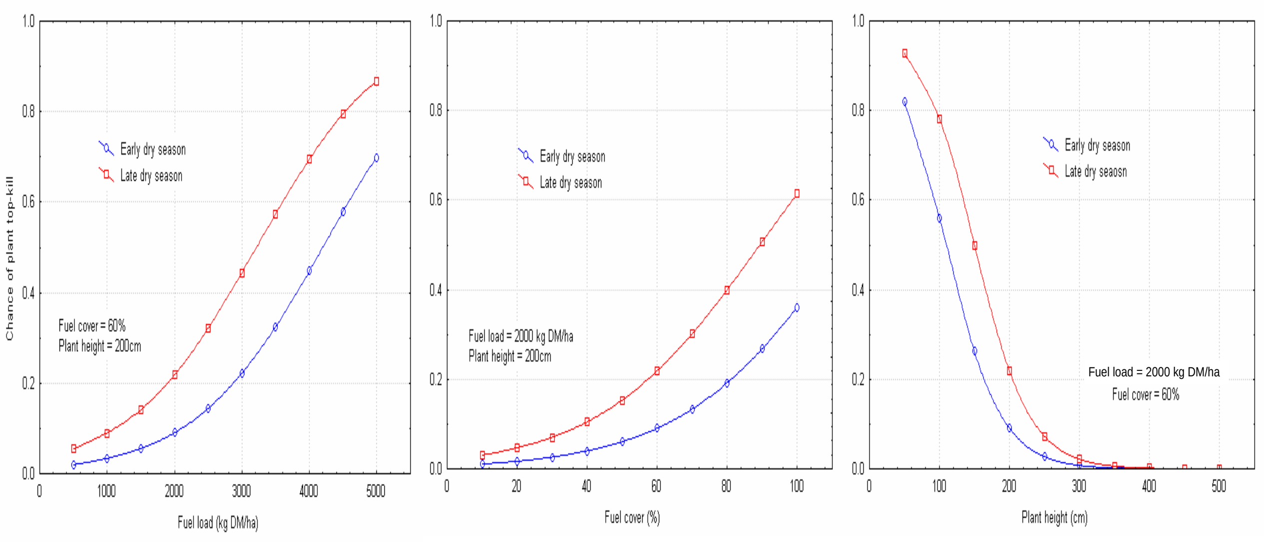


Figure 4.4: Predicted probability of plant top kill in response to change in (a) fuel load, (b) fuel cover and (c) plant height for both early and late-dry-season burns.

Without burning, native woody plant growth/regrowth continued at the rate of between 10-20 cm per year for all species less than 200 cm in both RBG and ASG pasture communities. Although obvious recovery of woody plant height was observed in plots unburnt for 5 years, no increase in plant density was detected. Woody cover varied markedly between fire treatments after eight years in July 2002 (Table 4.2 and Figure 4.5).

Table 4.2: The impact of fire regime on total tree and shrub canopy cover (per cent aerial cover) measured from aerial digital video images in ribbon blue grass and arid short grass pasture communities in May 1999. B0 – Control, unburned for at least five years. B2a – Burnt twice in successive burns followed by at least three years unburnt. B2 – Burnt twice with two years recovery between burns. B3 – Burnt three times in five years. Different superscripts denote significant differences between treatments.

Pasture type				Burning Frequency	
	B0	B2a	B2	B3	Effect
Ribbon blue grass	9^{a}	8^{ac}	7^{bc}	7^{bc}	$P < 0.05$
Arid short grass	19^{a}	13^{b}	13^{b}	9^{b}	$P < 0.01$

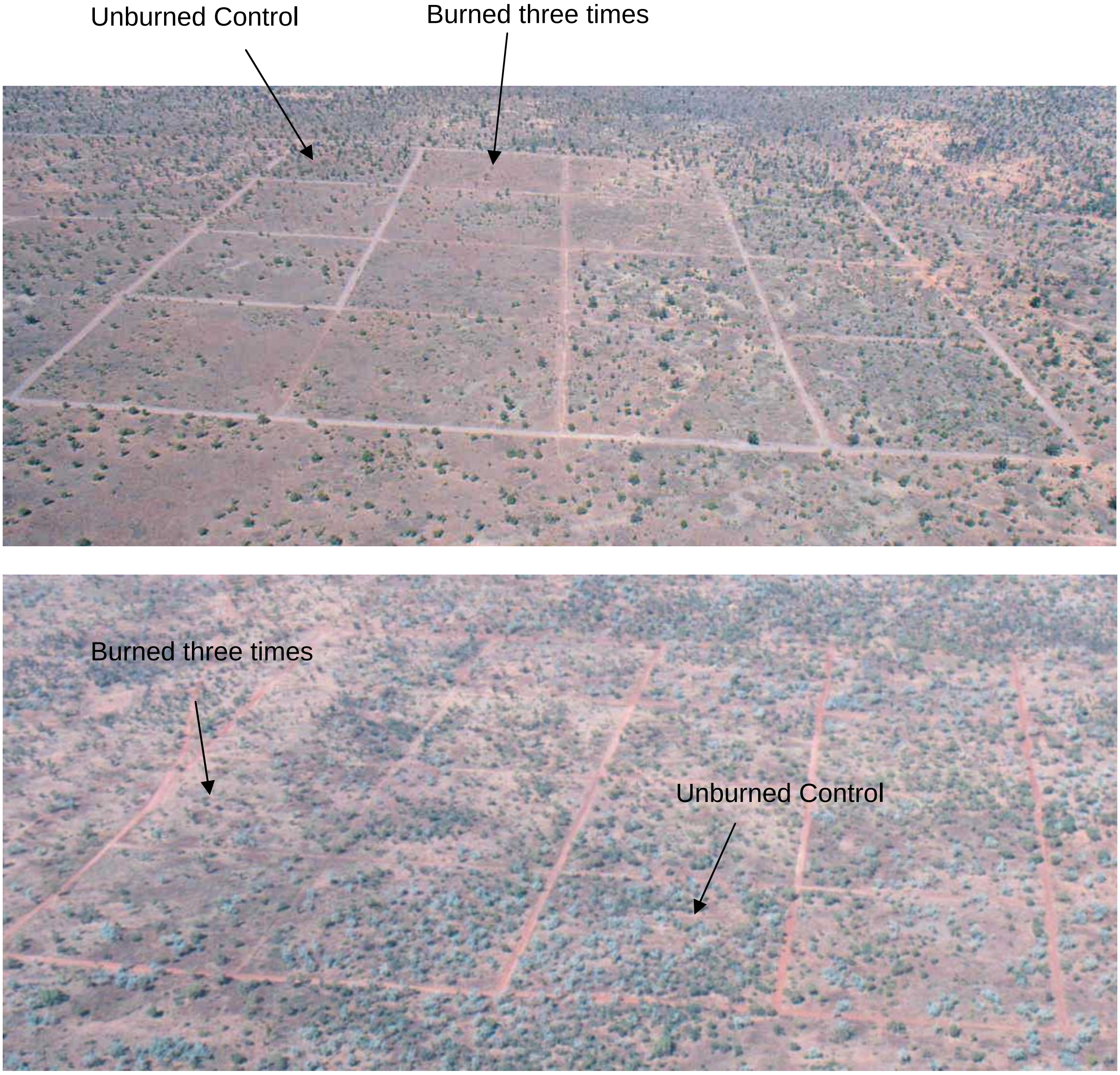


Figure 4.5: Aerial view of ribbon short grass (top) and arid short grass (bottom) burning trial sites, showing the impact of fire frequency and season on woody cover condition in July 2002.

Influence of weather on fire damage to trees and shrubs

In another experiment it was determined that weather variables at the time of burning such as wind speed and relative humidity, as well as fuel load and tree height, also significantly influence plant top kill (Figure 4.6). These relationships were also modelled using multivariate logistic regression. These relationships between weather and fire impact quantitatively explain the general tendency for burns to be more intense and destructive when weather conditions are dry and windy, particularly during the late dry season. The use of these models enables better prediction of vegetation responses following burning based on prevailing weather and fuel conditions (Table 4.3).

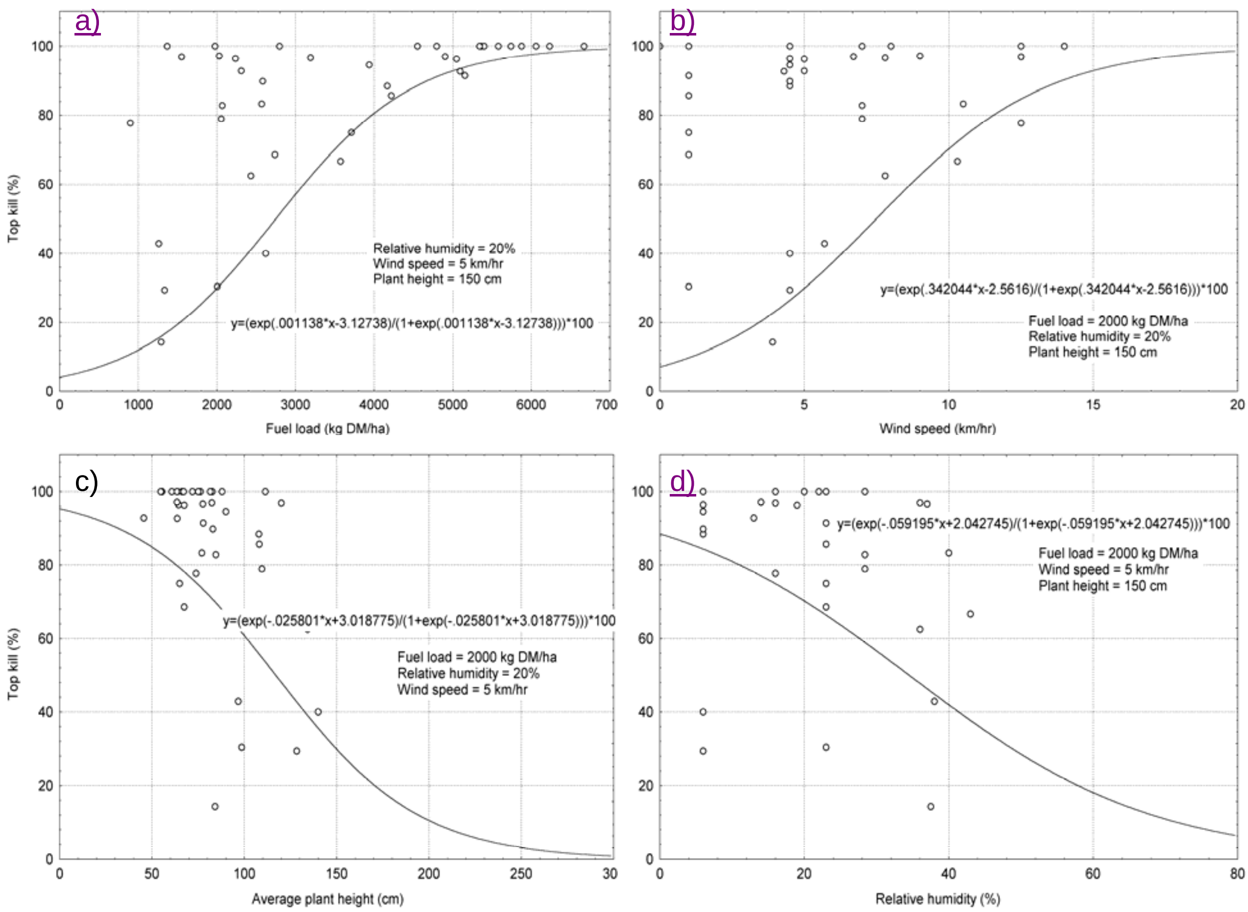


Figure 4.6: The relationship between (a) fuel load, (b) wind speed, (c) plant height and (d) relative humidity, on measured shrub top kill (%) from individual plots (scatter plot); and predicted top kill (response curve) estimated from multiple logistic regression equation using "'average" fixed values for non x variable inputs. (NB Only the variable of interest is plotted against top-kill with all variables held constant, hence the appearance of a poor fit in some cases)

Table 4.3: Burning conditions (relative humidity, wind speed, fuel load and fire intensity) necessary to achieve an 80% top kill of woody plants of increasing height classes in the Victoria River District.

Maximum tree-shrub height (cm)	Relative humidity (%)	Wind Speed (km/hr)	Fuel load (kg/ha)	Fire intensity (kW/m)
50	30	5	2200	1000
100	30	8	2500	1400
150	30	10	3000	2200
200	30	12	3500	3000
300	30	15	4900	4600
50	50	8	2400	1100
100	50	10	2900	1800
150	50	12	3400	2600
200	50	13	4300	3500
300	50	15	5900	5300

Impact of fire on pastures

The impact of burning on pasture yield, cover and annual-perennial mix was very different between black soil and red soil pasture communities following six years of burnings treatments (Table 4.4).

Standing dry matter in both communities fluctuated in response to season and fire (Figure 4.7). In ASG pastures, single or successive burns resulted in significant short-term declines in standing dry matter (Figure 4.7b) (and cover) however recovery during two above average growing seasons negated the previous negative fire impacts. Higher burning frequency (B2 and B3) appeared to favour relative increases in annual grasses in ASG pastures (Table 4.4) however in 1999 differences in yield, cover and perennial-annual composition were not significant. There was no significant difference in pasture responses between early (June) and late (October) dry season burns. To enhance the perennial composition of ASG pastures less frequent burns (every 5-6 years) during periods of above average rainfall and under low-moderate grazing pressures may be required.

Table 4.4: The impact of fire frequency regimes (B0, B2a, B2 and B3) on pasture yield, cover and species composition in 1999 of (a) arid short grass and (b) ribbon-blue grass pastures.

(a) Arid short grass	B0	B2a	B2	B3
TSDM (kg DM/ha)	1368	1163	1390	1508
Cover (%)	57	49	54	65
Dicots (%)	22.3	21.0	26.9	26.9
Perennial grass (%)	59.5	61.9	47.6	46.9
Annual grass (%)	17.8	17.0	25.4	26.1
(b) Ribbon-blue grass	**B0**	**B2a**	**B2**	**B3**
TSDM (kg DM/ha)	2040 [a]	2224 [a]	2088 [a]	1689 [b]
Cover (%)	80	81	80	77
Dicots (%)	6.5	5.3	3.2	4.8
Perennial grass (%)	85.7	89.3	89.1	82.5
Annual grass (%)	5.5 [a]	5.4 [a]	7.8 [a]	12.6 [b]

Different superscripts denote significance levels at the P < 0.05 level
B0 Control: Unburnt for at least five years
B2a Burnt twice in successive burns followed by at least three years unburnt
B2 Burnt twice with two years recovery between burns
B3 Burnt three times in five years

By 1999 frequent burns in RBG pastures (three burns in six years; B3), showed a 15% reduction in total yield ($P < 0.05$) and higher annual grass composition ($P < 0.05$) compared to all other treatments (Table 4.4), but there was no difference in perennial grasses. This is despite perennial grasses comprising 65% of total yield in B3 treatments compared to 87% in unburnt plots the year prior in 1998. From observation of grazing behaviour it was hypothesised that the cause of lower yields and increased annuals in frequently burnt plots resulted from continued preferred grazing of palatable perennial grass regrowth on regularly burnt plots. Less intense fire regimes (B2a and B2) had no effect on yield, cover or annual-perennial grass composition. Burning every 4-6 years prevented the accumulation of old pasture generally ignored by grazing animals.

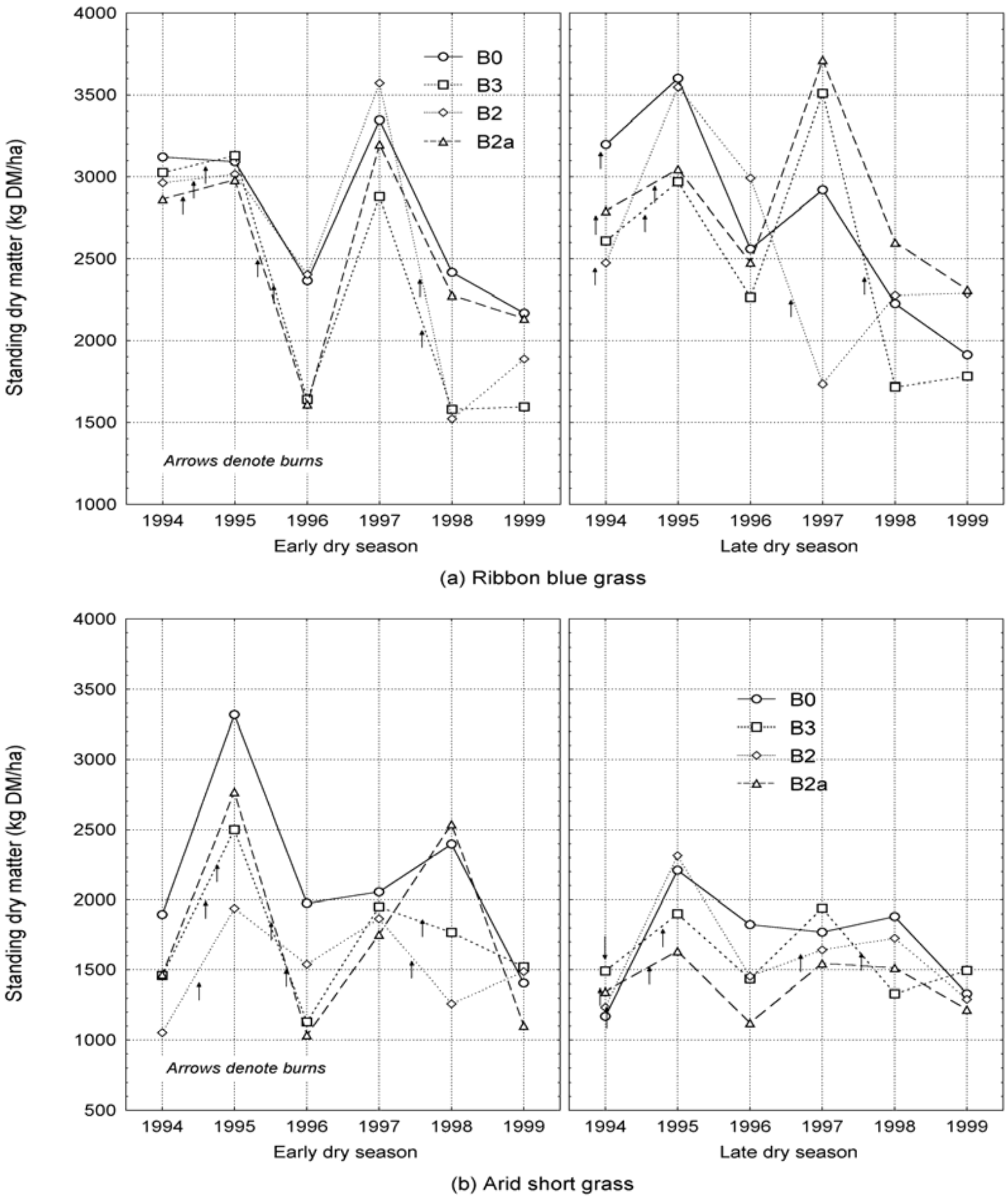


Figure 4.7: The effect of fire frequency (B0, B2, B2a and B3) and season (early-dry and late-dry-season) on annual standing pasture dry matter in June for (a) ribbon-blue grass and (b) arid short grass sites.

Industry Implications

Prescribed burning can be used to manage woody vegetation

The results of fire studies at Kidman Springs demonstrate that, although some woody plant species in pasture communities such as RBG and ASG are fire resistant, burning can be used to manage woody structure (canopy height and cover) through plant top kill, rather than reducing plant density from mortalities.

In most cases perennial grass pastures in good condition are resilient, and benefit, from periodic dry season burning. In contrast ASG pastures in poor condition (dominated by annual species) respond adversely to burning, with large reductions in ground cover.

Fire has a clear role in the management of woody vegetation thickening in the VRD, particularly in ribbon-blue grass pasture communities that have resilient perennial based grass pastures. The decision to use fire in ASG pasture communities is a trade-off between suppressing ever-increasing tree and shrub growth and avoiding possible short-term deleterious impacts on pasture condition.

Maximising the effectiveness of burning

In terms of fire behaviour the studies showed that the effectiveness of prescribed burning operations is influenced by initial woody structure, burning conditions and fire frequency. Top kill is maximised from high intensity fires, but as plants become taller they become more resistant to burning. Woody plants should therefore be controlled with fire before they exceed 200 cm in height. The most effective burning conditions for woody cover reduction are high fuel loads (> 2500 kg/ha) and fuel cover levels (60%), during high temperature, low humidity and constant breeze conditions of the late dry season.

The most extreme reductions in woody height and cover over the short term are achieved by frequent burning (eg. biennial). However over the long-term (with the inevitable below average seasons), frequent fire may cause deteriorating pasture yields and condition which could reduce fire effectiveness and pasture productivity. In terms of woody management, less frequent (5-10 years), but higher intensity fires may have sufficient impact compared to more regular (2-4 years) less intense fires, and are on average less disruptive to grazing management. Fire frequency however is ultimately determined by seasonal rainfall amount, rate of woody regrowth and pasture accumulation and pasture species response.

Pre- and post-burn pasture management

Management of pasture fuel load and cover levels, prior to and following burning, are an important part of grazing management. This increases the effectiveness of burning and reduce the potential for post-burn overgrazing and degradation of burnt areas. The most appropriate burning regime for woody vegetation management is a rotational burning program within paddocks. Sections divided within paddocks can be burnt in rotation at appropriate intervals. However, this depends on the size of paddocks. For example, all of small cell grazed paddocks would need to be burnt.

Technical Implications

This study has improved the basic understanding of fire ecology and management in two important pasture communities, however there are still important future research questions and needs.

- Although the trial has continued over nine years, little is known of pasture and woody responses in below-average seasonal conditions. Therefore it is strongly recommended that the burning trial at Kidman Springs continue to be maintained, the treatments implemented and some basic monitoring undertaken. *Being implemented*.

- Paddock-scale research into the effectiveness (ecological and economic) of using rotational burning to manipulate woody vegetation and the grazing distribution of livestock throughout extensive heterogeneous paddocks and under intensified grazing systems should be made a priority.

- It is not known whether woody increases are due to seedling recruitment or release of sucker suppression. Although this may not be directly relevant to grazing management, fuel and burning strategies could be implemented to maximise the effectiveness of woody control if recruitment episodes were known to be associated with particular rainfall conditions or seasonal sequences.

- The impact of post-burn grazing intensity and timing on pasture recovery (late wet, early dry and late dry seasons) is currently unquantified for VRD pastures.

- Further investigations on the impacts of burning and slope on water infiltration, run-off and soil erosion are required to determine whether prescribed burning is sustainable over the long-term.

- Research into the impacts of diurnal weather influences, dew formation and pasture moisture content on fire behaviour will improve the effectiveness, safety and timing of prescribed burning operations.

The Kidman Springs burning trial provided an invaluable extension and communication tool. Regular field days and site visits to trials enabled land managers and researchers to see fire impacts first-hand. The sites have contributed to an increased awareness and changed perceptions among land managers regarding the beneficial role fire can play. Many properties are now experimenting with prescribed burning regimes. While pastoral managers may accept that fire has a role in management, they now require assistance with defining management objectives, appropriate regimes and implementation. For many pastoral properties the adoption of prescribed burning raises a number of industry needs that will require attention in the near future: These include:

- Obtaining access to information and support to enable managers to develop **and implement** appropriate fire management plans on their properties.

- Overcoming the logistical, capital, equipment, skill and risk factors associated with implementing extensive prescribed burning operations over large heterogeneous areas.

- Justifying the increased operating costs of establishing fire breaks within paddocks and undertaking prescribed burning operations.

- Managing the wildfire risks and liabilities associated with implementing prescribed intensive fires.

- Effectively monitoring effectiveness of burning programs in terms of woody vegetation change, pasture condition and animal productivity.

- Adequately assessing and managing the trade-off between grazing intensity and burning extent and frequency.

- Managing and dealing with cross-boundary fire risks, conflicts and management objectives.

- Getting access to suitable fire weather forecasting information, particularly regarding wind speed.

Outputs

- *Fire and Vegetation Management in Pasture Lands of the Victoria River District, Northern Territory*. Dyer, R.M.D. Masters Thesis, The University of Queensland 2002.

- *Savanna Burning: understanding and using fire in northern Australia*. Rodd Dyer, Jacklyn, P., Partridge, I., Russel Smith, J. Williams, R. Tropical Savannas CRC, 2001.

5. The economic effectiveness of burning and stocking rate options on pastoral productivity over the long-term

Introduction

Stocking rate and fire regimes are two of only a few management options available to pastoral land managers in northern Australia savannas. Identifying and implementing stocking and burning strategies that are both sustainable and economically viable, over time and space, is critical due to the large, and widespread impact they have on both the environment and animal productivity. However, pastoralists may be reluctant to burn when faced with the trade-offs between using grass for fuel or forage, despite an increasing appreciation for the ecological role of fire and its positive impacts. There is also a significant element of risk associated with implementing fire in savannas that potentially could discourage savanna burning.

The complex interrelationships that exist between seasonal variability, tree density, pasture growth, grazing pressure and animal productivity are increasingly being understood. Despite this management implications, and economic consequences of current and potential fire and stocking regimes have previously not been described for the VRD. This study aimed to integrate knowledge from researchers, land managers and fire agencies with computer-based models developed from recent pasture, fire and grazing research in the VRD (Sections 2-4) and elsewhere. This collective knowledge “system” was used to evaluate the ecological impact and economic effectiveness of a range of stocking and fire management scenarios in a whole property context. The study concentrated on the potential benefits and costs associated with changes in tree-grass balance arising from interactions between pasture productivity and fire, grazing and management (Table 5.1). There are a range of other fire impacts that have either positive or negative impacts on economic returns of pastoral enterprises and/or social welfare generally (Table 5.1), but these are difficult to assign an economic value to and hence are not considered in detail as part of this study.

Project Objectives

To ensure that by 2001, throughout the VRD/Sturt Plateau region the majority (>80%) of land managers and administrators are aware of the increase, cause, impact and potential cost of unchecked woody plants.

That 30% of pastoral managers have made significant changes in grazing management as a result of economic analysis of sustainable management options.

Study Aim

The aim of this study was to evaluate the economic effectiveness of a range of sustainable fire and grazing management options using a range of Decision Support Systems in a whole-property framework

Table 5.1: Valued and unvalued costs and benefits of the simulation of savanna fire and stocking management

Valued costs and benefits	Unvalued costs and benefits
• Animal productivity, turnoff and income	• Impact of pasture quality changes on animal productivity
• Prescribed burning costs	• Impacts of altered grazing distribution on pasture quality and animal productivity
• Wildfire control costs	• Impacts of fire regimes on soil erosion and pasture productivity
• De-stocking costs	• Changes to habitat and biodiversity
• Mustering costs	• Contribution of smoke and gaseous emissions to global warming
	• Aesthetic values
	• Regional fire management costs

Methods

Treatments

The biophysical and economic impact from eight burning (Table 5.2) and eight fixed stocking rate scenarios (0, 2, 5, 7.5, 10, 12.5, 15 and 20 AE/km^2) were examined in an integrated modelling framework for a generalised case study property in the central VRD. Simulations were undertaken at the paddock level and aggregated to represent a property. Each simulated paddock comprised four sectors into which soil-pasture type, tree basal area and pasture condition were defined (Table 5.3).

Table 5.2: Description of modelled prescribed burning strategies

Treatment	Burn frequency*	Wildfire Risk	Description of prescribed burning strategies
No Burn	0	0.1	No prescribed burning, low wildfire risk
LDS 50%A	2	0.5	Prescribed LDS, 50% of paddock annually
LDS 25%A	4	0.5	Prescribed LDS, 25% of paddock annually
LDS 25%B	8	0.5	Prescribed LDS, 25% of paddock biennially
EDS 50%A	2	0.5	Prescribed EDS, 50% of paddock annually
EDS 25%A	4	0.5	Prescribed EDS, 25% of paddock annually
EDS 25%B	8	0.5	Prescribed EDS, 25% of paddock biennially
Wildfire 50%	Random x fuel	0.5	LDS wildfire risk only

**Fire burn frequency in years. Stocking rates held constant at 10 AE/km^2, paddocks comprised 2 x red soil and 2 x black soil sectors.*

Model development

The GRASP pasture model (Littleboy & McKeon 1997) was used to develop a table of annual predictions of pasture growth and potential animal liveweight gain (LWG) values for a range of tree basal areas, pasture condition and soil/pasture scenarios. One-hundred years of daily climate data for Victoria River Downs station was used for the simulation. Annual changes in initial tree basal area conditions were determined from empirical relationships developed from tree and burning research at Kidman Springs (see Fire Section 4) and used to predict tree response (growth, mortality, top kill and TBA change) from fuel load and burning season conditions.

Pasture utilisation was estimated as the proportion of modelled pasture growth (obtained from GRASP) consumed by livestock each year. Total potential forage consumption (intake) was calculated as the product of stocking rate (10 AE/km^2) and annual forage intake (3800 kg

DM/head/yr = 365 * 2.5% Daily feed intake * 420kg LW). Perennial grass composition was used as an indicator of pasture condition. Annual changes in the proportion of perennial grasses were calculated as function of wet season utilisation estimates based on rules proposed by Ash *et al.* (1996).

Livestock mortality and branding rates were estimated as a function of annual live weight change using the HerdGrasp relationships (Stafford Smith et al. 2001) originally based on the data reported by Gillard and Monypenny (1988) but tuned to the VRD for HerdGrasp. Potential cattle live weight change (Pot. LWG; kg/hd/yr) was estimated for each year by the GRASP model and was adjusted (Adj. LWG) each year according to the magnitude of annual (U, proportion) utilisation rates using the equation below (*cf*. McKeon *et al.* 2000):

$$Adj.\ LWG = Pot.\ LWG - 365 * 0.2061 * U$$

Utilisation rates were in fact calculated separately for wet and dry seasons. This approach essentially simplifies the full process representation in GRASP but ensures that seasonal conditions, pasture growth, tree cover, pasture condition and fire impacts all still provide feedback to influence livestock live weight change through their impact on annual utilisation rates, and LWG in turn affects the herd population dynamics.

Table 5.3: Description of simulated property

Property parameter	Parameter description/value
Property location	Victoria River District (VRD station
Property size (km^2)	2000
Number of paddocks	20
Paddock size	100
Initial tree basal areas (TBA) (m^2/ha)	5 for both red and black soil
Initial perennial grass (%)	90
Soil-pasture type	Red calcareous / arid short grass (50%) Grey cracking clay / ribbon blue grass (50%
Burning seasons	Early (June) Late (October)

Prescribed burns in the integrated model were implemented throughout the simulation according to the defined treatment frequency and season, although burns would only occur if minimum fuel load conditions were present. Based on expert knowledge and remotely sensed fire history images between 1993 and 2002 (G Allan *pers. comm.*), the risk of a wildfire occurring in any particular year was set to 50% for prescribed burning and wildfire scenarios. The risk value was set at 10% for the No Burn treatment to represent almost total fire exclusion. Wildfire risk was also influenced by fuel conditions (< 1000 kg DM/ha, no risk; > 2000 kg DM/ha, greatest risk). Wildfires were applied during the late dry season. A wildfire event in any year was determined by the generation of a set of random numbers between 0 to 1 generated each year throughout the simulation period. Random numbers exceeding the wildfire risk probability value would trigger a wildfire event subject to fuel load constraints. Results for each treatment were generated from an average of ten replicates of random number sequences to account for the influence of wildfire variability.

Economic evaluation

The economic assessment of burning options was determined using a change-in-output technique that compared the net present value (NPV) of the NO BURN base-line scenario with a range of fire treatments over time (Sinden and Thampapillai 1995). A fire treatment would be considered economically feasible if the final NPV ≥ 0. The treatment providing the greatest NPV was considered economically superior within the assumptions of the analysis. Annual net benefits were estimated for each year of the simulation from the difference between annual net livestock revenue (LR) and partial (fire related) costs. Cost calculations included expenses associated with mustering (MC), implementation of prescribed burns (PC), wildfire control (WC) and de-stocking (DC). These all were influenced by changes in tree basal area, and the sequence of prescribed burns and wildfires.

$$\textit{Net Benefit} = LR - (MC + PC + WC + DC)$$

Annual net benefits were discounted at a social discount rate of 5%, and then summed to provide a cumulative Net Present Value (NPV) for each treatment; a future study should assess the sensitivity of results to this discount value. NPV values between treatments were compared, neglecting changes in residual property value (although theoretically important, changes in pasture condition still have limited effects on property values in the region so far). Comparisons of economic net benefits between treatments were also made in years 10, 30 and 96 of the simulation to investigate differences in economic viability over short-term and long-term horizons.

Estimates of fire related costs were obtained from land managers and fire agencies. Costs included preparing firebreaks and undertaking prescribed burns, controlling wildfires, destocking paddocks following loss of greater than 50% of grass and mustering costs under varying tree cover conditions. Costs for each activity were calculated proportional to paddock and fire size. Total costs imposed were therefore dependant on the sequence of prescribed burns and wildfires over the study period. Livestock sales were based on simulated turnoff rates at constant prices, and were the only income source. Annual livestock turnoff was influenced in the model by tree, pasture and fire factors that in turn affected utilisation rates and animal productivity.

Changes to the fire and stocking regimes, as well as initial starting values and assumptions, enabled recalculation of all biophysical and economic variables over the one-hundred year simulation period.

Results and Discussion

Prescribed burning and wildfire scenarios

Effects on animal production and net benefits

The study indicated that savanna burning can increase economic net benefits to pastoralists over the long-term by 8 -15% in present value terms, assuming constant stocking rates at moderate levels (Table 5.4). While late-dry season burning regimes were most beneficial economically, early-dry season burning still provided advantages over a No Burn regime. Compared to the differences between early and late dry season burning, the advantages of increased fire frequencies were considerably lower. Prescribed burning and wildfires scenarios resulted in increased costs compared to a No Burn option. However these disadvantages were offset by larger proportional increase in livestock turn-off and revenue.

Table 5.4: Accumulated present value of benefits (PVB: livestock sales) and total costs (PVC), and Net Present Value (NPV; \$/km^2) between simulated long-term prescribed burning and wildfire scenarios.

Benefits-costs (\$/km^2)	NO BURN	LDS 50% A	LDS 25% A	LDS 25% B	EDS 50% A	EDS 25% A	EDS 25% B	W/FIRE 50%
Livestock sales (PV)	16,143	19,268	18,995	19,101	18,018	17,855	18,194	19,086
Costs (PV)	1,378	2,235	2,323	2,472	1,879	1,938	2,100	2,512
Net Benefit (Sales – Costs)	14,765	17,033	16,672	16,629	16,139	15,917	16,094	16,574
Net Benefit – No Burn		2,268	1,907	1,864	1,374	1,152	1,329	1,809
% increase of No Burn		15%	13%	13%	9%	8%	9%	12%

PV = Present value

Economic benefits from enhanced livestock sales were greatest for biennial, late-dry season burning (LDS 50% A) and wildfire scenarios. This advantage flowed from improved average live-weight gain, branding rate and mortality figures (Table 5.5). Compared to fire exclusion, (No Burn), all fire regimes had lower utilisation rates (Table 5.5), which led to increased long-term cattle performance, higher turn-off figures and greater livestock sales.

Table 5.5: The impact of simulated, prescribed burning and wildfire scenarios on long-term average cattle productivity variables.

Fire regime	LDS 50% A	LDS 25% A	LDS 25% B	EDS 50% A	EDS 25% A	EDS 25% B	NO BURN	W/FIRE 50%
LWG (kg/hd)	107	105	106	96	95	97	83	106
LWG (kg/km)	10.7	10.5	10.6	9.6	9.5	9.7	8.3	10.6
Branding (%)	68.5	67.2	67.6	62.2	61.4	62.9	54.3	67.4
Mortality – Wet* (%)	7.6	7.7	7.7	8.3	8.4	8.2	9.3	7.8
Mortality – Dry* (%)	2.6	2.6	2.6	3.0	3.0	2.9	3.6	2.7
Turnoff (%)**	26.0	25.3	25.5	22.6	22.2	23.0	18.3	25.4
Utilisation (%)	17.7	18.1	18.0	19.8	20.1	19.6	22.3	18.2

** Refers to lactation status i.e. "wet" or "dry" cattle ** Average proportion of 20,000 head herd size turned-off each year*

The relative costs of mustering, de-stocking, wildfire control and prescribed burning varied between fire regimes (Figure 5.1). Costs were highest with wildfire and late dry season scenarios, and lowest for biennial early dry season burning. Increased mustering costs were a feature of increasing tree cover associated with long-term fire suppression (No burn). Early season burns and increased burning frequency reduced wildfire control and de-stocking costs.

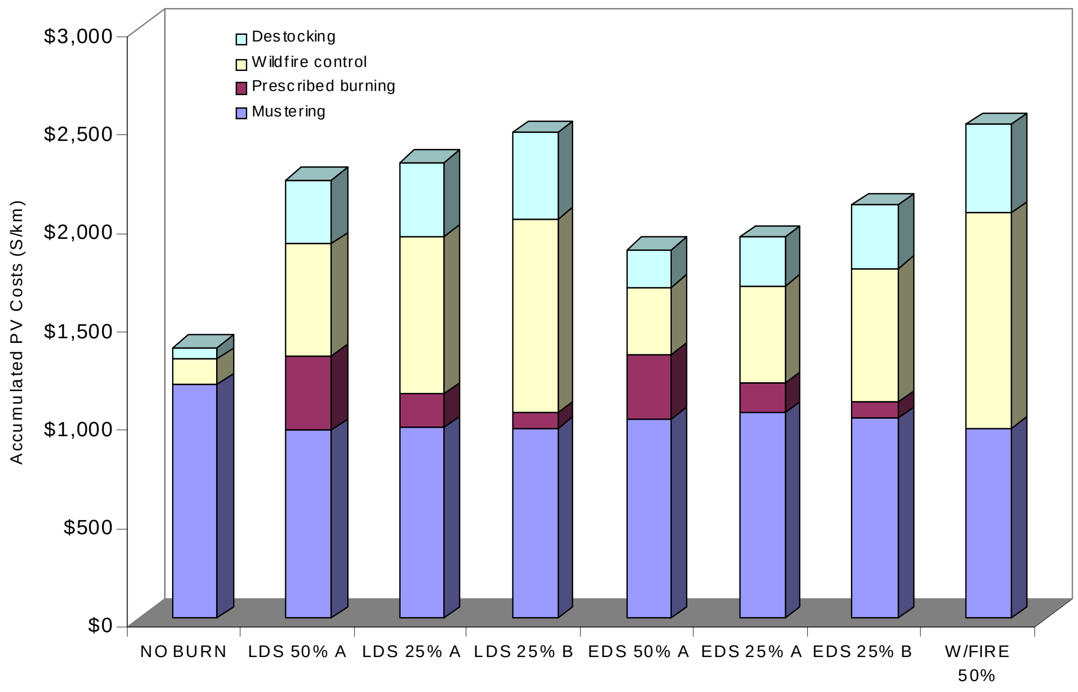


Figure 5.1: Simulated costs of fire and grazing management with different fire scenarios.

Increasing the frequency of early dry season burns was most effective at reducing the frequency of both wildfires and destocking events. Prescribed late-dry season burns resulted in only a marginal reduction of wildfire frequency and destocking events, compared to a high wildfire risk and no prescribed burning.

Late-dry season, biennial burning (LDS 50% A) resulted in the highest and least variable flow of average (undiscounted) net benefits ($/km^2) over time (Figure 5.2). In contrast, fire suppression (No Burn) resulted in net benefits declining over time, particularly during below average seasons. The ecological explanations for this are discussed below.

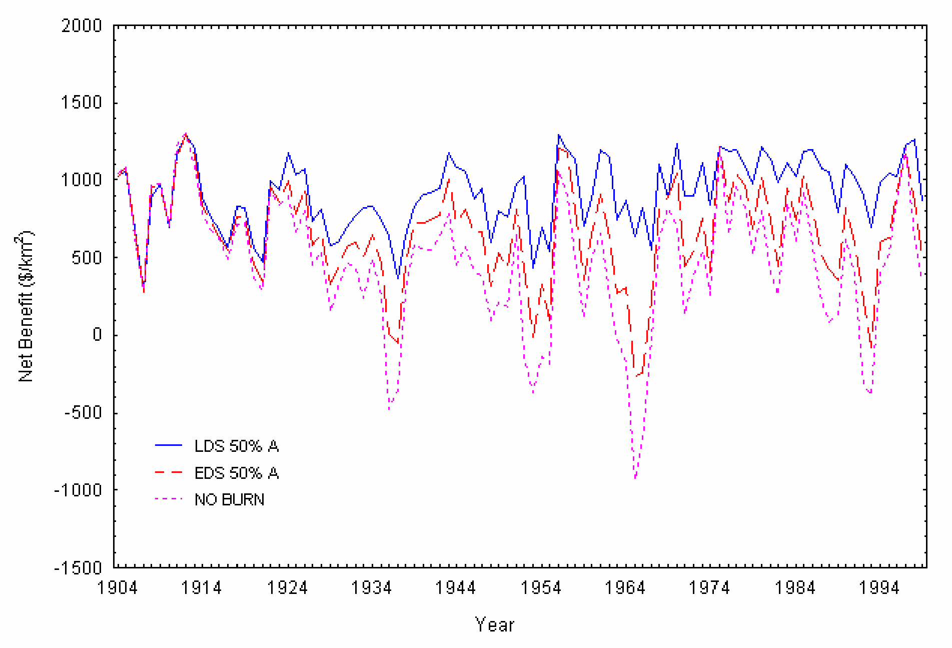


Figure 5.2: The impact of different fire regimes on simulated average net benefit ($/km^2) over time.

Tree and pasture effects

The long-term results showed that fire exclusion (No Burn) leads to increasing TBA, declining perennial grass composition and lower pasture growth (Figure 5.3). In contrast frequent late-dry season burns (LDS 50% A and WILDFIRE) gradually suppressed TBA to low levels, while maintaining pasture condition and relative pasture growth. Early-dry season burning (EDS 50% A) was less effective and resulted in a gradual increase in TBA to levels between the No Burn and late-dry season fire scenarios. Both No Burn and EDS 50% A resulted in a rapid decline in perennial grass composition within 10–15 years. This response is most likely due to a collapse in pasture condition from grazing utilisation thresholds being exceeded consistently as a result the suppressive impact of higher tree basal area on pasture growth. Early burning also removes forage earlier in the season and therefore increases subsequent wet season utilisation rates, further promoting pasture decline, especially of red soil pastures which are more sensitive to grazing.

Although the large seasonal fluctuations in pasture growth was the most obvious feature for all fire regimes (Figure 5.3), it is obvious after the first 10-15 years, growth under No Burn and EDS 50%A regimes declines progressively as TBA increases and competition for moisture and nutrients increases. The greatest reduction in growth occurs in below average seasons, when competition for moisture is greatest. Despite this, pasture growth was similar between burn and non-burn treatments during favourable seasonal conditions, for example periods of the 1990’s.

Stocking rate scenarios

Effects on animal production and net benefits

The results from this study indicate that long-term economic returns are influenced more, by stocking rates, than fire regime choices. When accumulated NPV for fire regimes was simulated and plotted for a range of stocking rates (Figure 5.4) economic benefits were maximised at around

10-12 AE/km^2, after which returns declined very sharply. In comparison, the economic benefits from burning were smaller and only obvious over a narrow range of stocking rates at maximum NPV. At lower stocking levels burning, regardless of regime had almost no influence on economic return. The differences between fire regimes were reduced at stocking rates above 12.5 AE/km^2.

The effect of increasing stocking rates was to increase livestock sales (Table 5.6), by improving animal productivity, animal turnoff and returns per square kilometre up to threshold levels (Table 5.6), after-which further increases reduced all production variables (Figure 5.3). This is typical of many “traditional” stocking rate response curves (Figure 5.5, Hall *et. al.* 1998) and can be explained by the relationship between individual animal performance and utilisation levels. When stocking rates exceeded 10-12.5 AE/km^2 utilisation increased to levels where a decline in perennial composition resulted in reduced individual animal live weight gain, lower branding rates, higher mortality and depressed turn–off rates. In contrast animal productivity was optimised at 10 AE/km^2.

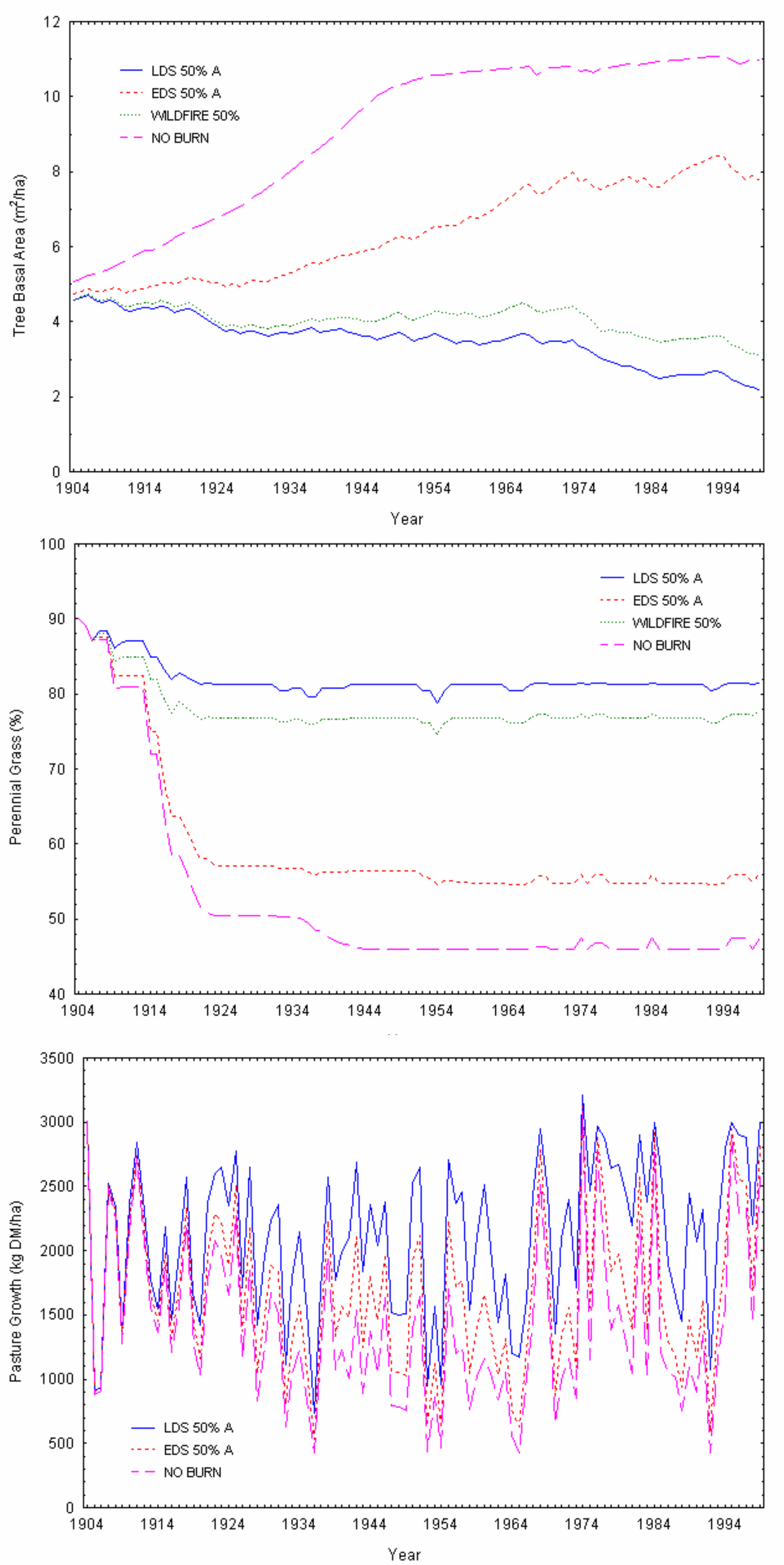


Figure 5.3: The impact of different fire regimes simulated tree basal area, perennial grass composition and pasture growth change over time

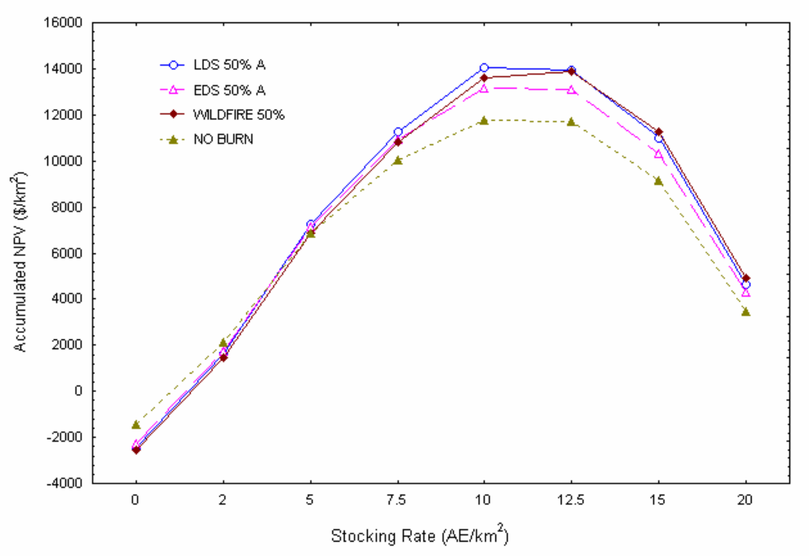


Figure 5.4: Accumulated net present value for different stocking rate scenarios after a 100 year simulation for four different fire regimes.

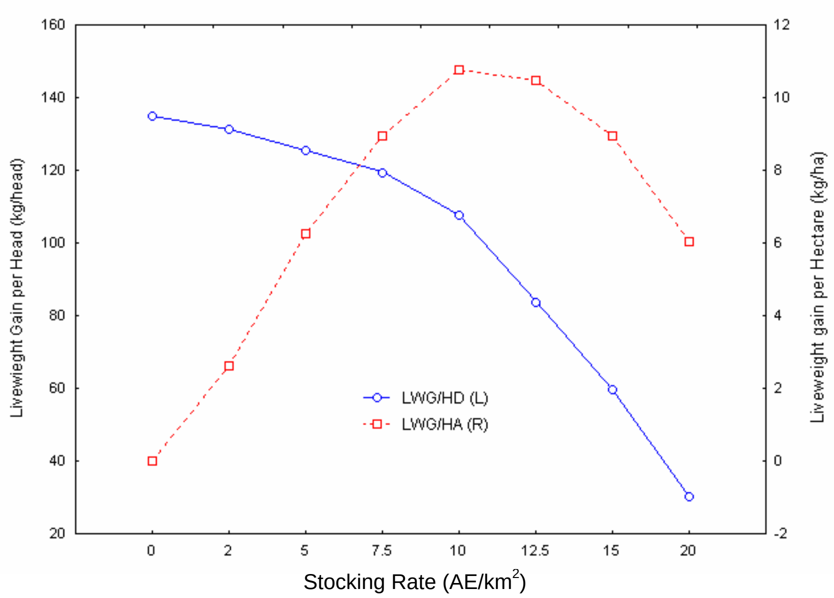


Figure 5.5: The impact of increasing stocking rate of per head (kg LWG/HD) and per hectare (kg LWG/ha) livestock production

Although total costs were highest at stocking rates between 5 – 10 AE/km^2, the greatest average economic net benefit per unit area was obtained with stocking rates of 10 AE/km^2 due to optimum turn-off (Table 5.6). Higher stocking rates increased mustering costs and other variable costs (supplement, vaccines and fodder), while costs associated with prescribed burning and wildfire control declined. The highest stocking rate (20 AE/km^2) resulted in a fall in economic net benefit, due to rapidly falling animal productivity and livestock sales (Table 5.7). The costs of prescribed burning and/or wildfire control represent a net loss for zero stocked treatments, as there is no income stream.

Table 5.6: Accumulated present value of benefits (PVB: livestock sales) and total costs (PVC), and Net Present Value (NPV; $/km^2) between simulated long-term prescribed burning and wildfire scenarios.

Benefits-costs ($/km^2)	0.0	2.0	5.0	7.5	10.0	12.5	15.0	20.0
Livestock sales (PVB)	0	4,730	11,203	15,913	19,268	19,497	17,086	12,028
Costs (PVC)	2,462	2,485	2,471	2,422	2,235	1,823	1,582	1,409
PVB – PVC	-2,462	2,246	8,733	13,491	17,033	17,674	15,504	10,619
Net benefit above (PV)		4,708	11,195	15,953	19,495	20,136	17,966	13,081

Table 5.7: The effect of stocking rate on average, long-term cattle productivity variables.

Stocking Rate (AE/km^2)	0.0	2.0	5.0	7.5	10.0	12.5	15.0	20.0
LWG (kg/hd)	135	132	126	120	112	70	60	40
LWG (kg/km)	0	3	6	9	11	9	9	8
Branding (%)	81	80	78	75	71	46	41	30
Mortality – Wet *(%)	6.7	6.8	6.9	7.1	7.4	10.7	11.9	14.8
Mortality – Dry* (%)	2.2	2.2	2.3	2.4	2.5	4.7	5.8	8.3
Turnoff (%)**	0	6	15	22	27	17	15	5
Utilisation Rate (%)	0	3	8	12	18	27	40	57

** Refers to lactation status i.e. "wet" or "dry" cattle ** Average proportion of 20,000 head herd size turned-off each year*

Increasing stocking rate from 5 to 10 AE/km^2 greatly increased average economic benefits (Figure 5.6) over time. Economic benefits are obtained immediately, unlike the long-term benefits arising from implementing burning regimes (*cf*. Figure 5.2). Higher stocking rates (particularly from 10 –15 AE/km^2) resulted in higher inter-annual variation of economic returns, as well as greater frequency and magnitude of economic losses.

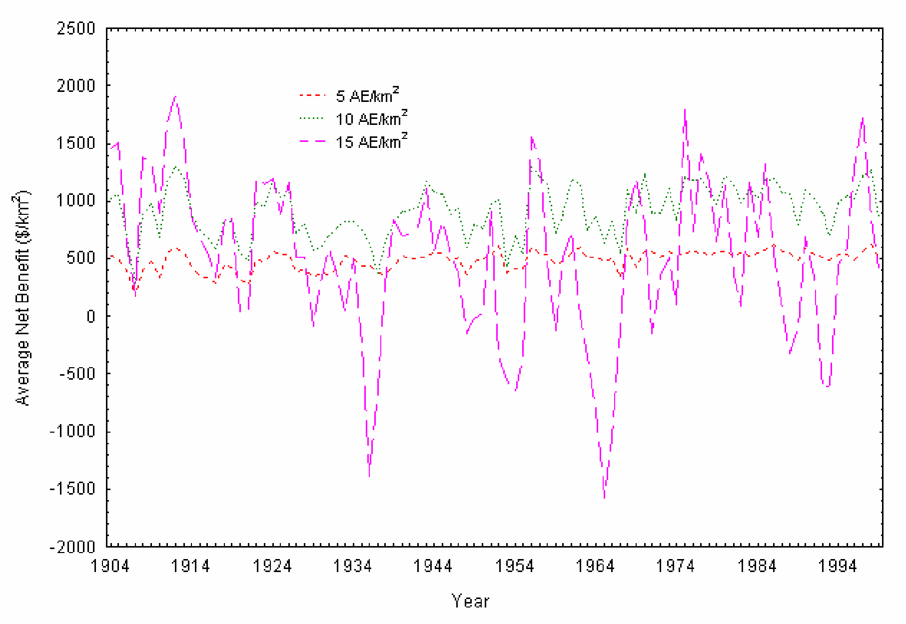


Figure 5.6: The impact of stocking rate options on simulated average net benefit ($/km^2) over time.

Impacts on trees and pastures

Over the long-term, higher stocking rates regularly exceeded threshold utilisation values (> 25-30%). A plot of utilisation rates over time (Figure 5.7) shows that increasing stocking rates from 10 to 15 AE/km^2 greatly increases the number of years where safe utilisation levels are exceeded, increasing the risk of pasture degradation. This resulted in increasing tree cover (TBA), and lower pasture growth and perennial composition (Figure 5.8).

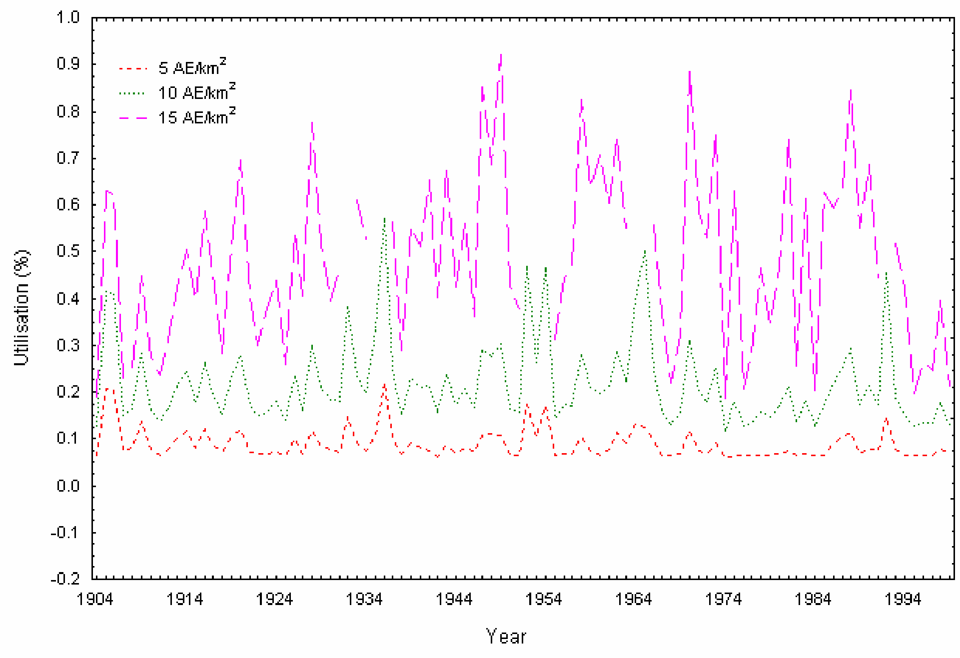


Figure 5.7: Simulated utilisation over time under different stocking rate scenarios.

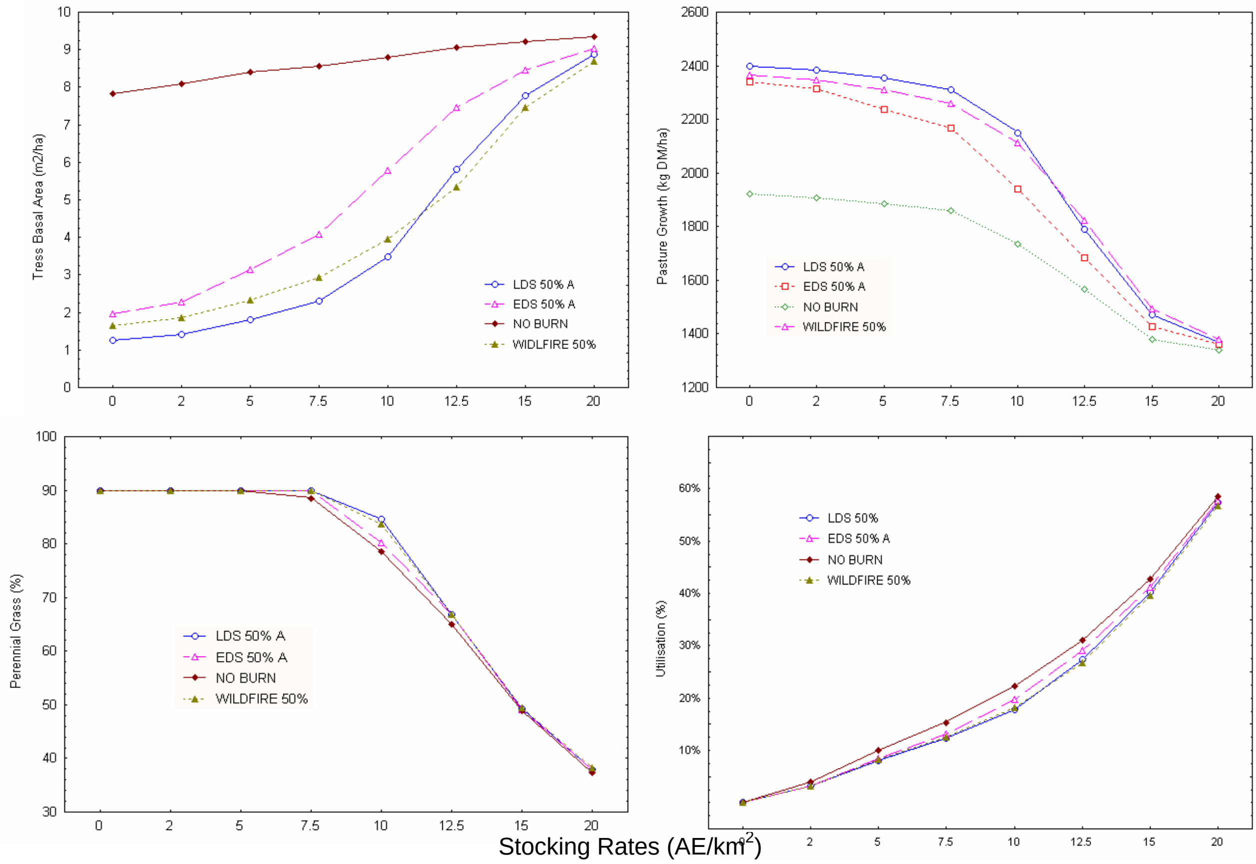


Figure 5.8: The impact of increasing stocking rates on (a) pasture growth, (b) tree basal area (c) % perennial grass and (d) utilisation at the completion of a one hundred year simulation study for four different fire regimes.

For stocking rates less than 10 AE/km^2 there was little long-term impact of fire or grazing on pasture growth and perennial grass composition. At low stocking rates, prescribed burning resulted in significant reductions in tree cover. At 2 AE/km^2 and 10 AE/km^2, 23% and 40% respectively of the paddock areas were able to be burned each year on average, enabling tree cover to be reduced by 37% and 73% respectively during the simulation period.

While lower stocking rates provide more fuel for prescribed burning, they were less effective in reducing the frequency of wildfires. Where wildfire risk is high (WILDFIRE 50%), wildfire and destocking events occurred in 30-35% of years when stocking rates were 10 AEkm^2 or less. Although wildfire frequency declined from 30% to 13% with stocking rates over 10 AE/km^2, less than 8% of the paddock could be burnt each year with prescribed burns. Collectively this completely reduced the effectiveness of the prevailing fire regime (LDS 50%A), increasing tree cover by 76% at 20 AE/km^2 over the simulation period.

This study considered only one important fire-savanna-productivity interaction (tree-grass balance), with a limited combination of initial climate, pasture and tree assumptions. The results therefore should be viewed as general responses requiring further investigation, rather than absolute stocking and fire management recommendations. A number of important fire effects were not valued and included in this study. For example this study did not attempt to quantify the impacts of different fire and grazing regimes on biodiversity, pasture quality, soil erosion, and other social services such as tourism, recreation, greenhouse gas emissions and global warming.

The impact of discounting future benefits and costs in the NPV suggests that the short-term gains flowing from additional income at higher stocking rates, may offset the longer term costs associated with lower turn off and higher mustering costs resulting from increasing tree cover and lower pasture growth. Although discounting benefits and costs to present day values over a one-hundred year period means the values have little use in absolute or practical terms, they provide a valuable comparison between treatments and reflect the realistic inclination of producers to discount benefits and costs that are realised over longer-term planning horizons.

Industry Implications

Burning has long-term economic benefits

Results from this study suggest that exclusion and suppression of fire in savannas over the long-term was likely to result in negative ecological and economic impacts. The model simulation indicated that over time, the suppression of fire resulted in tree basal area increase and declining and more variable pasture growth, animal performance and economic returns. These responses were particularly extreme during below average seasons, when large economic losses occurred from the collapse in pastoral productivity. Because of the slow onset of pasture and livestock productivity impacts from increasing trees, there was little difference in economic returns between late, early and no burn regimes during the first 15-20 years of implementation. In comparison, the model showed that late dry season burning was an effective tool for vegetation management, and over the long-term yielded considerable economic benefits. Furthermore, the overall adverse impacts of fire exclusion are masked during above average seasons, when economic benefits between no burn and other burning regimes were similar.

There are trade-offs between short-term versus long-term impacts of burning
Although prescribed burning clearly has an important role in savanna function and long-term pastoral productivity, the absence of significant economic benefits in the short-term reduces the incentives for pastoral managers to adopt fire as part of grazing land management. This may be especially true in areas where managers are under pressure for short-term productivity increases, and may only stay on one property for a relatively short duration (<5 years). In comparison owner managers or long-term managers may be more inclined, or willing to implement fire regimes as they are more likely to observe and benefit economically from the results over a number of years. For this reason quantitative and photographic monitoring of pasture condition and landscape change over time becomes a very important tool, whereby managers, can observe the long-term impacts of previous management, even though they themselves may be caretakers of the land for a relatively short period.

Frequent wildfires reduce woody vegetation but can be disruptive to management and ecologically undesirable
The results showed that wildfires, by suppressing tree cover provide some ecological and economic benefits, compared to long-term fire exclusion. Land managers generally aim to minimise wildfires however as they have limited capacity to control their timing, frequency, extent, distribution and impacts either spatially or temporally. Wildfires are rarely distributed evenly throughout the landscape and over time. Their incidence and extent are often unpredictable. Wildfires therefore may rapidly damage and degrade biodiversity in fire prone habitats that are burnt at high frequency and intensity, while areas of heavy and consistent grazing are almost never burnt. The regional costs of managing and fighting wildfire are significant, but were not included in this study. The frequency, extent and costs of wildfires are most effectively reduced by frequent, early dry season burns, however these regimes are less effective for managing tree and shrub cover. In contrast late-dry season burns are most effective for management of woody vegetation, however wildfire risk remains high as highly cured grass fuel must remain unburned throughout most of the dry season.

Appropriate stocking rates are critical for enhancing economic returns and sustainability
Despite the ecological importance of burning, this study indicated that identifying optimum stocking rates is important for both short-term economic returns and long-term sustainability. In terms of economic productivity, it is only when optimum stocking rates have been identified that appropriate burning regimes are most beneficial. It is clear that as stocking rates exceed optimum levels, not only does animal productivity decline but the potential effectiveness of fire as a management tool is rapidly reduced.

Although the impacts from overstocking on pasture productivity and economic returns may not occur immediately, or even in a few years, Figure 5.6 shows that the negative feedbacks of over-utilisation began reducing net returns from ten years and thereafter, particularly during below average seasons.

Technical Implications

A range of activities is recommended to improve the model for use in scenario analyses and for incorporating results of future fire and grazing research. These include:

- Validate model assumptions and simulation results with land managers and researchers

- Run simulations for a greater range of rainfall locations, tree basal areas, soil and pasture type combinations

- Further develop the tree-fire response model by calibrating FLAMES for the VRD

- Incorporate within the model presently unvalued benefits and costs and impacts on grazing distribution.

- Develop the model for use as an optimisation tool to identify superior management scenarios

Outputs

- *This study developed a model that represents the interactions between seasonal variability, fire behaviour, tree response, pasture growth and condition, grazing utilisation and animal productivity in a grazed savanna ecosystem in northern Australia. It successfully integrated simplified versions of several existing models, results of local research and expert knowledge to permit the economic evaluation of the tradeoffs given various fire treatments. The modelling framework also enabled the random nature of wildfire events to be determined and allowed fire and livestock management costs and revenue to be quantified.*

- Economic predictions resulting from a range of long-term fire and stocking rate management scenario.

6. Stocking Rates and Carrying Capacity

Introduction

Grazing and stocking rate decisions generally occur at the paddock level. In the VRD, paddocks are generally large and often contain a considerable range of land types that vary greatly in their grazing potential. There are a number of methods varying in accuracy and complexity, used to estimate land type carrying capacity, which can then be multiplied by the area of each land type to provide an estimate of paddock carrying capacity. Carrying capacity estimates should be both productive and sustainable and are influenced by factors such as pasture productivity, nutritive value, palatability and resilience to grazing which in turn are influenced by rainfall amount, soil type, pasture composition, land condition and tree density. Estimates of carrying capacity are considered “potential” because they assume that livestock have reasonable access to water throughout the entire paddock. Throughout the VRD this is rarely the case. It is therefore necessary to estimate “actual” carrying capacities that account for the number and distribution of water points.

This section is divided into four parts.

(1) An assessment of stocking rates and estimated carrying capacities in the VRD, based on producer survey data.

(2) An outline of the development of a prototype software application designed to assist producers to estimate and manage paddock stocking rates and carrying capacities.

(3) A demonstration of how pasture growth models described previously in the report can be used to assist in the estimation of land type carrying capacities.

(4) A comparison of the implications of fixed and flexible stocking strategies. This is reported in detail in Appendix 2.

Project Objectives

Study Aims

I. Describe current paddock and property stocking rates and make general assessments of land condition and animal production.

II. Develop individual estimates of livestock carrying capacity on a paddock, property and land type basis.

Methods

(1) Assessment of stocking rates and carrying capacity

In 1997 a survey was undertaken on 14 pastoral properties throughout the Victoria River District to record paddock stocking rates and grazing land management practices (See Attachments for survey report). The sampled properties were located predominantly in the southern VRD, which although drier (< 500mm seasonal rainfall) than northern areas, were dominated by productive Mitchell grass pastures situated on basalt and alluvial soils. No accounting was made for the number and location of water points within paddocks. Property managers were also asked to estimate a long-term carrying capacity for dominant land types (land systems). A summary of paddock size, stocking rates and estimated carrying capacity was made. Using digital paddock infrastructure and water point data, ESRI ArcView was used to determine the proportion of paddock area within 3 km and 5 km of natural and man-made water sources for 40 paddocks on

Mount Sanford station. A more detailed account of historical stocking rates and land type and water point distribution influences in relation to carrying capacity estimation for Mount Sanford station can be found in a detailed case study undertaken by Leeanne Goody in the Attachments.

(2) Development of software for estimating paddock carrying capacity

To assist the process of calculating property carrying capacity and stocking rates a prototype stocking rate calculator and mapping software application was developed. The software package integrates paddock scale land unit or land system resource data tables generated from spatial GIS data with land type carrying capacity estimates and paddock livestock records using a relational database (Microsoft Access). This software component is known as SR Calc and calculates estimates of paddock land type area, stocking rate and carrying capacity. Software development was undertaken with the assistance of a Visual Basic and an Arc View Avenue programmer.

A detailed collection of spatial resource data is available for the Katherine region (including the VRD and Sturt Plateau) and is administered by the Department of Infrastructure, Planning and Environment (DIPE). The availability of such data provides a unique opportunity to assist carrying capacity estimation at the property and paddock level. Data held by DIPE include:

- Digital land resource data at the land system (complete coverage) and land unit scales (good coverage)
- Digital pastoral infrastructure data showing roads, fence lines and major improvements
- Digital topographic and drainage data layers

To enable carrying capacity estimation based on land type, the area of individual land types (land systems and/or land units) within paddocks was estimated using ESRI ArcView to intersect digital land type and paddock infrastructure polygon coverages. Tabulated data was exported as a Dbase file for use in both SR Calc and SR Map. Carrying capacity recommendations provided by the Northern Territory Conservation Commission (now Parks and Wildfire, DIPE) were assumed for each land system, while preliminary “best estimate” values were assumed for land units to enable system functionality during development.

Tabulated resource, stocking and carrying capacity summaries generated by SR Calc can be displayed as reports, or are available for the automated construction and display of property and paddock maps in SR Map, a customised extension within Arc View 3.2.

(3) Using pasture growth models for estimating carrying capacity and stocking rates

Livestock carrying capacity, over the long- and short-term is a function of factors that determine pasture growth and appropriate levels of grazing utilisation. The GRASP pasture growth model, calibrated for several productive land types in the VRD (see Table 2.3, Section 2), was used to simulate historical pasture growth for a range of rainfall locations and growing conditions throughout the VRD. The effect of different soil and pasture types, pasture conditions and tree basal-areas were also incorporated and simulated with the model.

Annual pasture growth values from GRASP over the one-hundred year period were ranked and distributed into deciles (Table 6.2 for alluvial clay and Table 6.3 for arid short grass). Using constant livestock feed intake values of 2.5% of live weight (based on 1 adult equivalent, AE; 450kg animal), a matrix of utilisation and stocking rate values were then calculated from pasture growth estimates in a Microsoft EXCEL spreadsheet. From this table stocking rates at varying levels of utilisation, or utilisation levels at specific stocking rates can be obtained for increasing pasture growth deciles (levels of seasonal risk) for a particular location and pasture community. This enables pastoral manager’s attitudes to risk and uncertainty regarding seasonal rainfall variability and land type to be incorporated into carrying capacity estimation.

Results and Discussion

(1) A description of paddock attributes, stocking rates and carrying capacity estimates in the VRD

Most pastoral managers surveyed in the VRD kept detailed paddock livestock records, but only a few recorded stocking rates as part of daily management. Despite ongoing infrastructure development, paddock sizes and stocking rates reflect the extensive nature of VRD pastoral properties. Paddocks averaged 200 km^2 in size and ranged from less than 10 km^2 to 625 km^2. Paddocks less than 200 km^2 accounted for 87% of total paddocks and over 50% of the 13,925 km^2 surveyed. Herd size per paddock ranged from less than 200 AE's to over 3000 AE's. Approximately 40% of paddock herds however comprised over 1000 AE's.

From the properties surveyed stocking rates varied considerably between properties and with paddock size. Paddock stocking rates in the VRD averaged 11 AE/km^2 and ranged from less than 5 AE/km^2 to over 35 AE/km^2. Of the 134 paddocks surveyed, 50% were stocked over 10 AE/km^2 and over 10% greater than 20 AE/km^2. Based on estimates of seasonal pasture growth throughout the VRD, these stocking rates represent utilisation levels of 12.5% and 25% respectively. Higher stocking rates may be sustainable during periods of above average pasture growth, but if maintained over the long-term, utilisation levels would exceed 30-40% on average. This would almost certainly result in rapid pasture degradation, particularly in grazing sensitive pasture communities, in paddocks with poor pasture condition and poor water point distribution or during several years of below average rainfall.

Stocking rates were typically higher in smaller paddocks (< 100km^2) (Table 6.1). Smaller paddocks represented 27% of the total area surveyed and generally contained more productive pasture types and had superior water distribution. Paddocks greater than 200 km^2, which are most likely to represent poorer, less productive pastures had stocking rates less than 5 AE/km^2.

Table 6.1: Average stocking rates across a range of paddock sizes in the VRD

	Paddock Area (km^2)					
	0-50	50-100	100-200	200-300	300-400	>400
Mean	12.6	14.3	9.6	4.9	4.0	2.7
SEM	1.1	1.3	0.8	1.8	0.3	0.4
n	37	45	36	3	6	7

SEM = standard error of the mean; n = number of paddocks

Based on paddock and water point data for Mount Sanford station it was found that, on average, 60% of each paddock was greater than 3 km distance to water, while 30% of each paddock was greater than 5 km to water (Figure 6.1). Evidence suggests that spatial grazing pressure in paddocks is determined by water point distribution (Pickup & Bastin 1997), (See Spatial Grazing Section 7), along with other influences such as land type (Pickup & Bastin 1997), topography (Coughenour 1990), position of supplements, areas of burnt regrowth (Andrew 1986) fencelines and roads (Owens *et al.* 1991). Under recent seasonal and stocking conditions grazing pressure (utilisation) usually decreases with increasing distance to water, often with little or no grazing occurring at distances greater than 3-5 km (Fisher 2001). The results from Mount Sanford indicate most paddocks have large areas that are remote from water. This is reasonably typical of paddocks throughout the VRD. While these areas may be less productive land types in some cases, observations indicate that large areas of productive pastures generally remain ungrazed or under-utilised. Such uneven distribution of water and grazing may have the advantages of providing forage reserves or good condition pasture during drought periods, as well as zero grazing areas for enhancement of habitat biodiversity. However, better water point distribution may provide opportunities for utilisation of previously under-used areas and a sustainable increase in stocking rate or provide an opportunity to improve overall paddock pasture condition and animal productivity without increasing stocking rates.

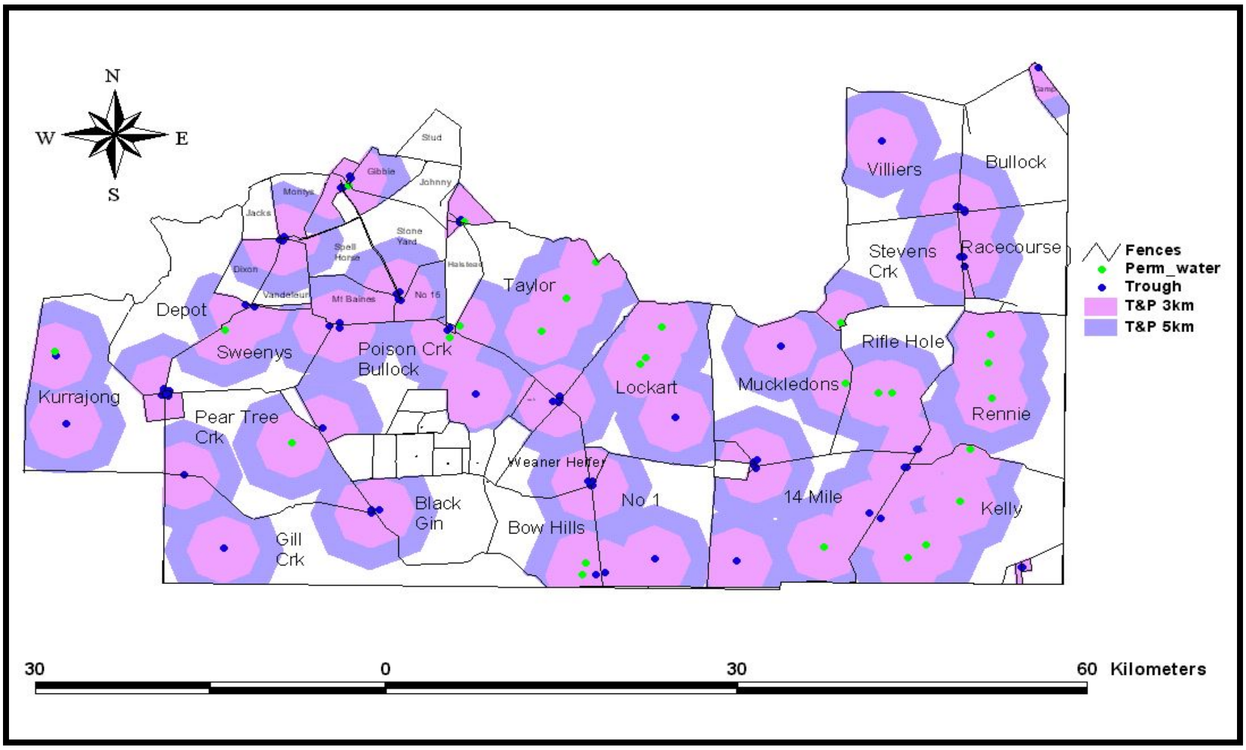


Figure 6.1: Watered areas on Mt Sanford Station.

Pastoral manager estimates of carrying capacity for VRD land systems were in general agreement with estimates historically used by the Northern Territory Pastoral Land Board (PLB) sourced from the NT Conservation Commission (now DIPE) for both poor (low carrying capacity), and better quality (higher carrying capacity) land types (Figure 6.2). There was however considerable difference between manager's and PLB estimates for arid-short-grass land systems (marked in Figure 6.2). This is likely due to the large variation in land condition, productivity and perceived resilience to grazing of these pasture types.

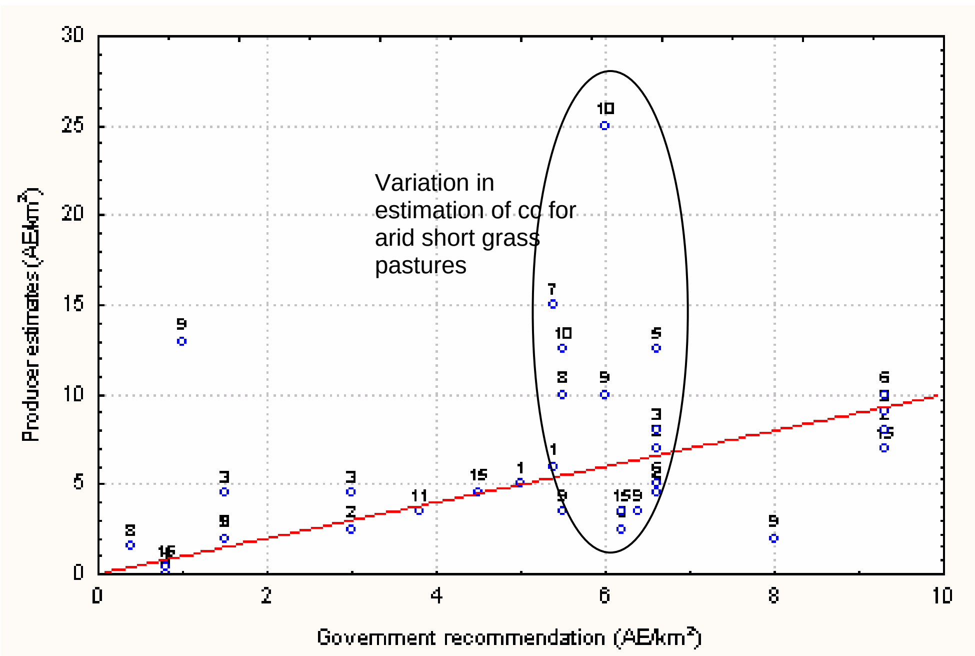


Figure 6.2: The relationship between producer and Northern Territory government estimates of carrying capacity (AE/km2) for land systems (Perry 1970) in the VRD. (Plotted subscript numbers indicate individual pastoral properties).

Although the relative ranking of pasture types was considered useful, pastoral managers generally found it difficult to estimate absolute carrying capacity values for single land types. Stock numbers were normally estimated on a whole paddock basis, with managers automatically accounting for the dominant land types, and other features each paddock contained.

Development of software for estimating paddock carrying capacity

The development of the SR Calc and SR Map application enables a range of powerful stock and paddock calculations and manipulations (Figures 6.3-6.6). Specifically, SR Calc and SR Map:

1. Calculate the area of different land types within existing paddocks sourced from digital GIS land resource data (land systems and land units)
2. Calculate paddock stocking rates in adult equivalents (AE’s) based on livestock records and animal classes
3. Enable estimated carrying capacity values to be assigned to individual land types (and land conditions)
4. Calculate paddock carrying capacity based on land unit carrying capacity estimates and proportion of each land type within the paddock
5. Calculate a stocking ratio that compares current stocking rates with estimated carrying capacity
6. Enable the automated construction and display of property and paddock maps displaying resource, stocking and carrying capacity data
7. Provide a mapping Paddock Tool that rapidly recalculates the area of land types within new, subdivided or merged paddocks
8. Provide a mapping Paddock Tool that calculates the area within distance bands to water based on the number and spatial location of water points

Land resource, infrastructure data and stocking data has been processed and incorporated within SR Calc and SR Map for a number of pastoral properties. Using ArcView as the mapping platform enables integration of additional spatial and point property data that can greatly assist management decisions, asset management and record keeping. Such data could include monitoring site photos and records, remotely sensed fire scars and fire history maps, NDVI greenness images, bore and water location and infrastructure.

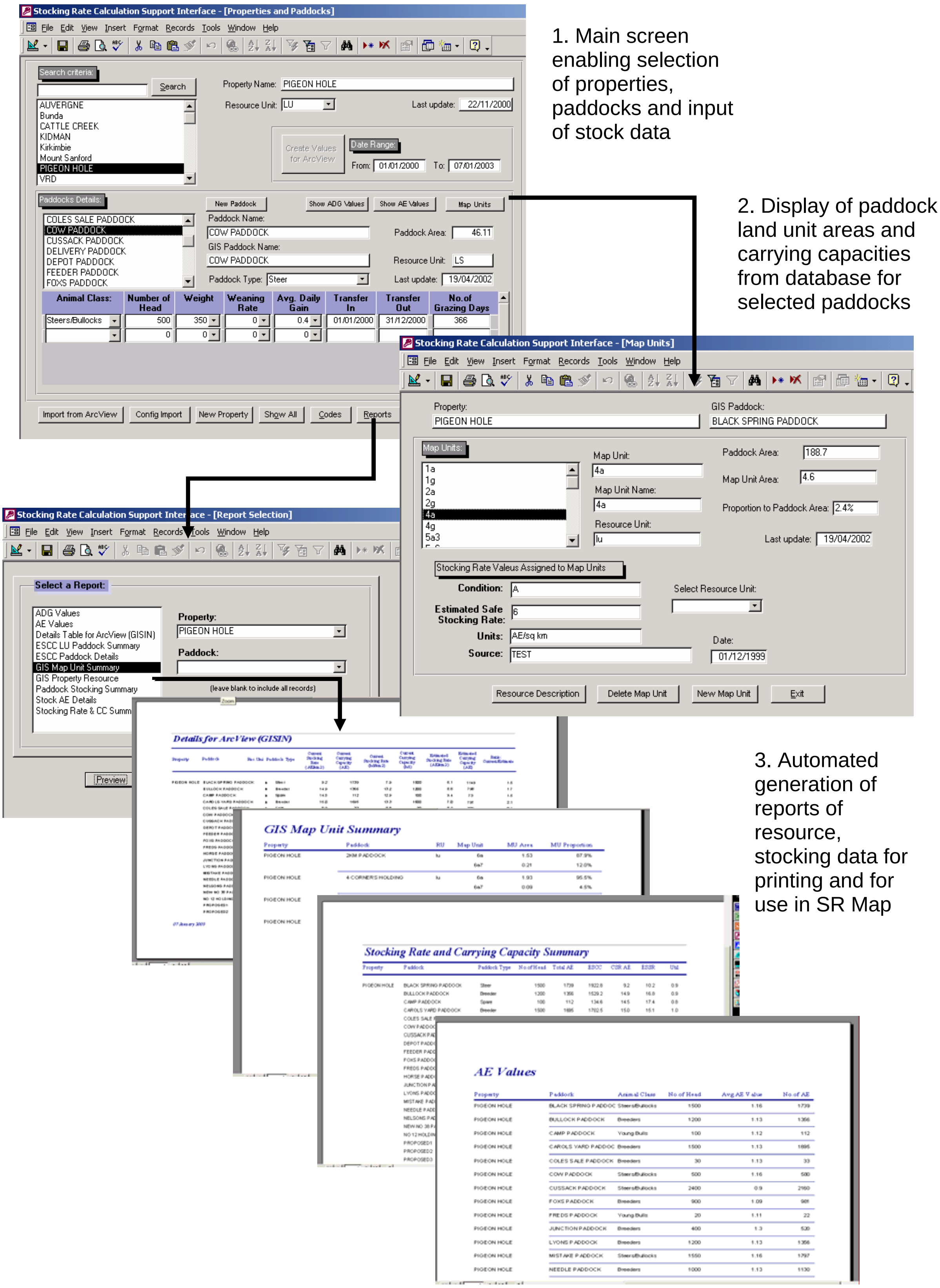


Figure 6.3: Based on an Access database, SR Calc enables integration of land type carrying capacity estimates with paddock stock records and land type data supplied from GIS to automatically calculate reports of land type areas, stocking rates, carrying capacities and stocking ratios within paddocks.

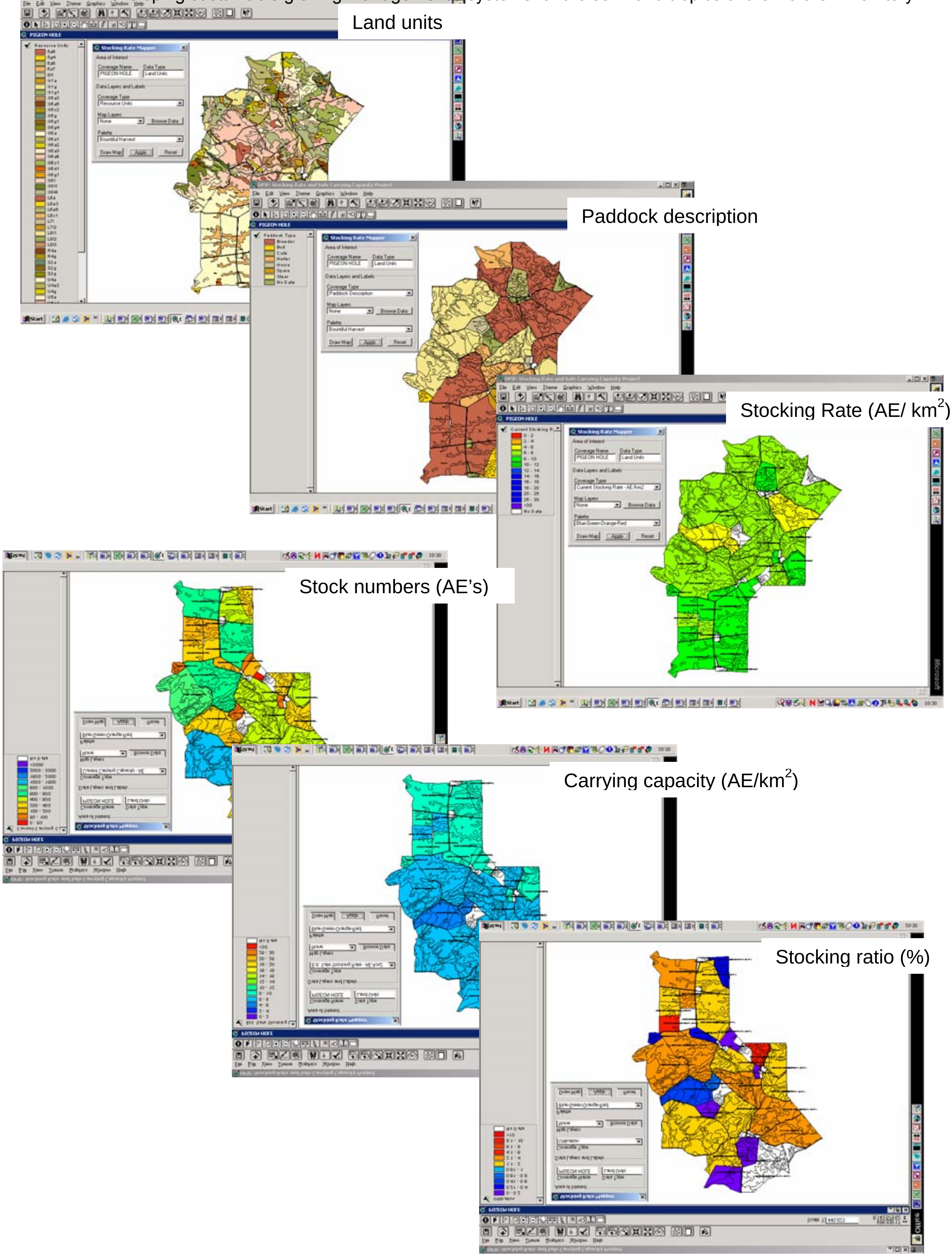
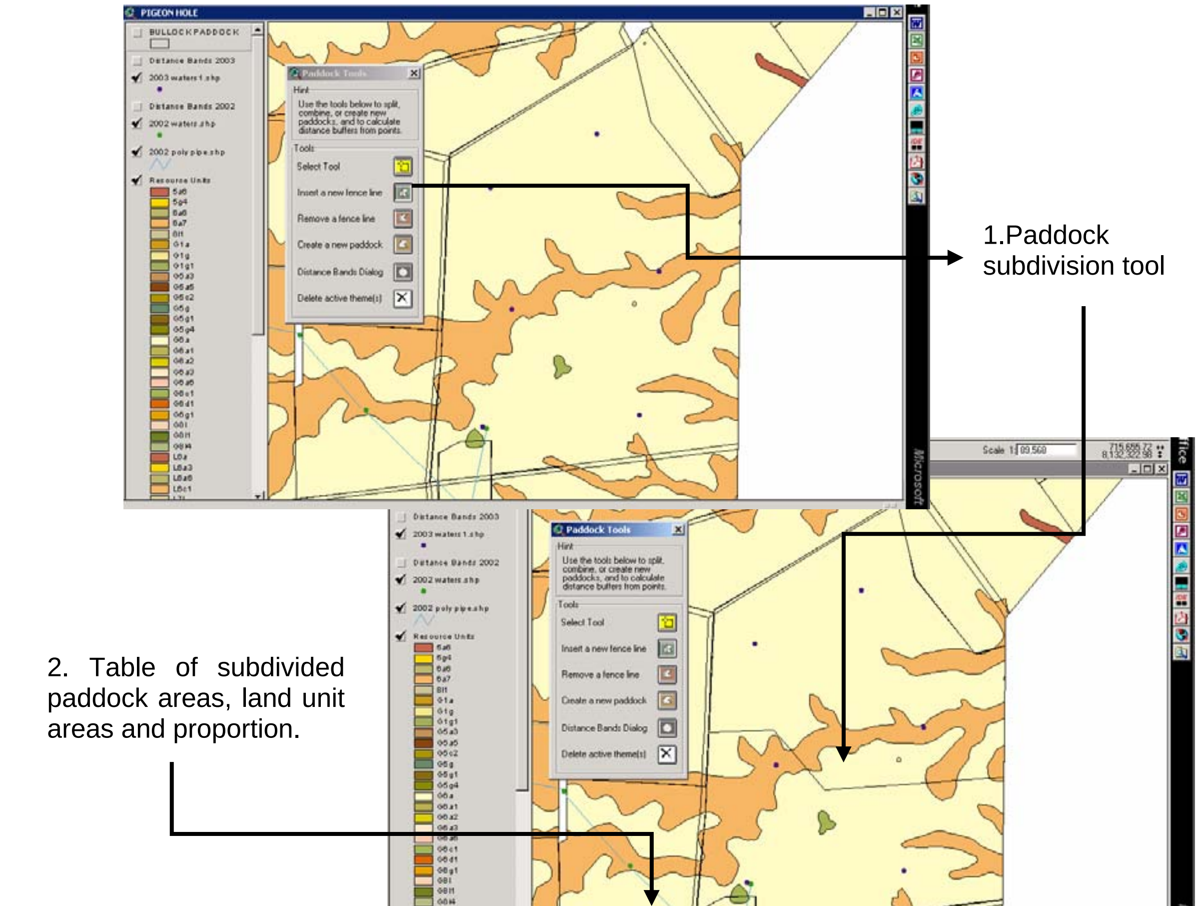


Figure 6.4. The SR Map extension in ArcView enables automated construction and display of a range of property resource and stocking data as maps via a link to SR Calc (Access database).



Property	Paddock	Map_unit	Paddock_area	Map_unit_area	Map_unit_prpn
PIGEON HOLE	BULLOCK PADDOCK	G6a	44.58	33.73	0.8
PIGEON HOLE	BULLOCK PADDOCK	U6a7	44.58	4.61	0.1
PIGEON HOLE	BULLOCK PADDOCK	G6a	44.58	3.42	0.1
PIGEON HOLE	BULLOCK PADDOCK	G6a	45.64	4.40	0.1
PIGEON HOLE	BULLOCK PADDOCK	U6a7	45.64	7.58	0.2
PIGEON HOLE	BULLOCK PADDOCK	G6a	45.64	30.58	0.7

Figure 6.5: The Paddock Tool within SR Map can be used to subdivide paddocks and insert new fence lines, then recalculate new paddock and land unit areas. Paddocks can also be merged or new paddocks created, then land unit areas created with the Paddock Tool.

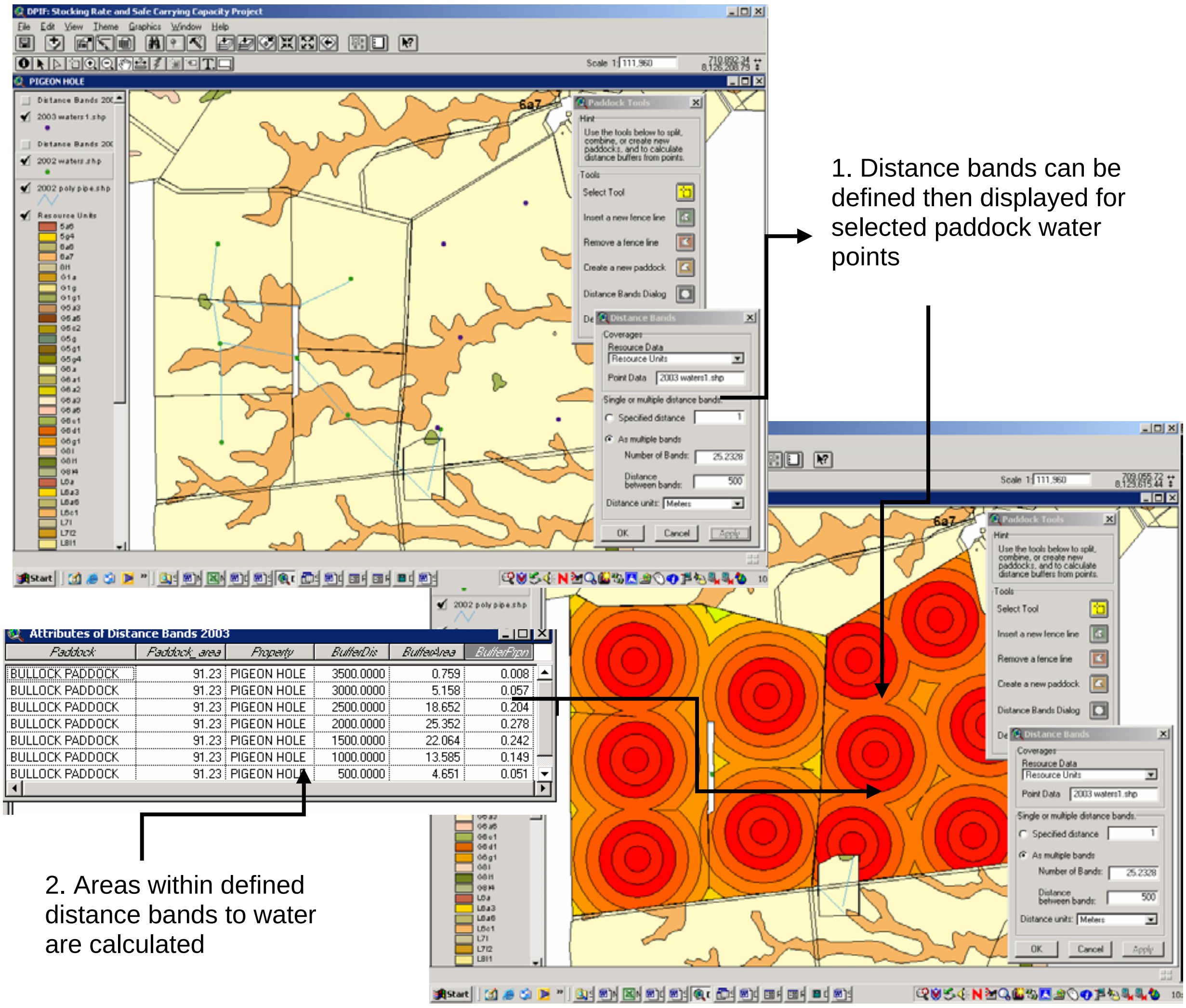


Figure 6.6: The Distance Bands button in the Paddock Tool of SR Map can be used to calculate and display the area within defined distances to one or multiple water points within paddocks.

Using pasture growth models for estimating carrying capacity and stocking rates

GRASP model outputs shown in Figure 6.7 demonstrate that pasture growth, and therefore carrying capacity, is influenced most by variation in rainfall, both seasonal (rainfall deciles) and spatial (location), but was also affected by declining pasture condition and increasing tree basal area. There is less variation in potential growth between pasture communities, although they will differ considerably in nutritive value, resilience to grazing and preference to grazing livestock.

For setting a long-term carrying capacity for a land type and location, a risk averse manager may decide to stock conservatively, and prefer to remain within a 20 percent recommended utilisation levels in 80 percent of possible pasture growth years (decile 80). For an alluvial clay soil, from Table 6.2 he/she would therefore select a stocking rate of 10 AE/km^2, which would be expected to be sustainable for the majority of seasonal conditions. A less risk averse manager may be willing to remain within recommended utilisation levels (20%) for only 50 percent of year (decile 50) and would stock at 15 AE/km^2. Alternatively a manager willing to manipulate stocking rates with seasonal conditions may wish to estimate a short-term stocking rate that remains within specified utilisation levels for a particular above-average or below-average pasture growth period. Therefore a stocking rate that would remain within the 20 percent utilisation in a top 20 percent pasture growth period (Decile 20, 2906 kg DM/ha) would be 19 AE/km^2. Such a strategy however may require rapid and large changes in stocking rate when seasonal conditions change to avoid serious declines in livestock productivity and pasture degradation.

Although in many cases appropriate utilisation values are not known with certainty, best estimates can be used for various communities. While current research aims to provide better utilisation estimates, the use of pasture growth models, stocking and utilisation tables, provides managers with an indication of the impact of seasonal variability and pasture type on pasture availability and potential carrying capacity for their particular location and situation. Stocking rate and utilisation tables based on GRASP models calibrated for the Northern Territory have been generated for use in MLA’s Grazing Land Management (GLM) course material. This provides a framework for managers to monitor changes in land condition and set and adjust stocking rates and carrying capacity, based on best utilisation estimates, in an adaptive fashion.

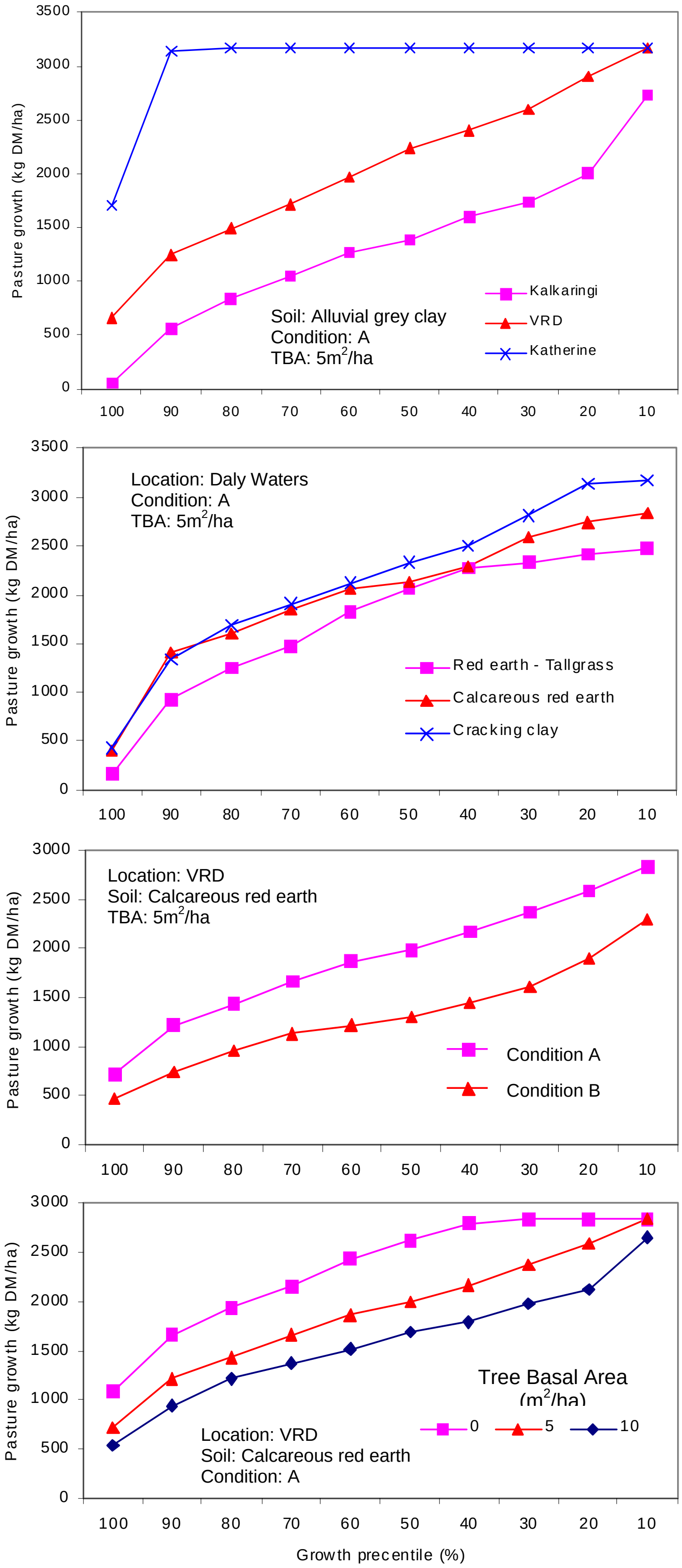


Figure 6.7: The effect of seasonal rainfall (location), soil/pasture type, land condition and tree basal area on pasture growth. Data is presented in deciles of pasture growth based on 97-year simulation of GRASP.

Table 6.2: Estimated stocking rates and utilisation based on modelled growth of perennial grass pasture in A condition on alluvial grey clay at Victoria River Downs (VRD).

(Tree basal areas = $5m^2$). Deciles based on 97-year GRASP simulation using daily climate data from VRD.

Decile	**Rainfall**	**Growth**	Predicted stocking rates (AE/km) with increasing Utilisation (%)							Predicted utilisation (%) with increasing stocking rates (AE/km)				
			1%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**1**	**5**	**10**	**15**	**20**
100	271	667	0	1	2	3	4	5	7	5%	23%	46%	69%	92%
90	390	1252	0	2	4	6	8	10	12	2%	12%	24%	37%	49%
80	455	1492	0	2	5	7	10	12	15	2%	10%	21%	31%	41%
70	508	1710	1	3	6	8	11	14	17	2%	9%	18%	27%	36%
60	537	1975	1	3	6	10	13	16	19	2%	8%	16%	23%	31%
50	630	2241	1	4	7	11	15	18	22	1%	7%	14%	21%	27%
40	678	2408	1	4	8	12	16	20	24	1%	6%	13%	19%	25%
30	722	2607	1	4	9	13	17	21	26	1%	6%	12%	18%	24%
20	774	2906	1	5	9	14	19	24	28	1%	5%	11%	16%	21%
10	878	3178	1	5	10	16	21	26	31	1%	5%	10%	14%	19%
Average	629	2170	1	4	7	11	14	18	21	1%	7%	14%	21%	28%
Maximum	1295	3366	1	5	11	16	22	27	33	1%	5%	9%	14%	18%
Minimum	198	702	0	1	2	3	5	6	7	4%	22%	44%	66%	87%

Table 6.3: Estimated stocking rates and utilisation based on modelled growth of arid short grass in condition B on shallow calcareous red earth at Victoria River Downs (VRD).
(Tree basal areas = 5m^2). Deciles based on 97-year GRASP simulation using daily climate data from VRD.

Decile	**Rainfall**	**Growth**	Predicted stocking rates (AE/km) with increasing Utilisation (%)							Predicted utilisation (%) with increasing stocking rates (AE/km)				
			1%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**1**	**5**	**10**	**15**	**20**
100	271	478	0	1	2	2	3	4	5	6%	32%	64%	96%	128%
90	390	745	0	1	2	4	5	6	7	4%	21%	41%	62%	82%
80	455	970	0	2	3	5	6	8	9	3%	16%	32%	47%	63%
70	508	1137	0	2	4	6	7	9	11	3%	13%	27%	40%	54%
60	537	1222	0	2	4	6	8	10	12	3%	13%	25%	38%	50%
50	630	1318	0	2	4	6	9	11	13	2%	12%	23%	35%	47%
40	678	1456	0	2	5	7	9	12	14	2%	11%	21%	32%	42%
30	722	1616	1	3	5	8	11	13	16	2%	9%	19%	28%	38%
20	774	1904	1	3	6	9	12	16	19	2%	8%	16%	24%	32%
10	878	2307	1	4	8	11	15	19	23	1%	7%	13%	20%	27%
Average	629	1443	0	2	5	7	9	12	14	2%	11%	21%	32%	42%
Maximum	1295	2936	1	5	10	14	19	24	29	1%	5%	10%	16%	21%
Minimum	198	581	0	1	2	3	4	5	6	5%	26%	53%	79%	106%

Industry Implications

Understanding carrying capacity estimates will facilitate sustainable use

While stocking rates and utilisation levels throughout the VRD were generally appropriate for the favourable seasonal conditions experienced during the 1990's, paddocks observed with high stocking rates and/or poor water distribution are likely to result in pasture degradation and poor animal performance during drier periods. To ensure sustainable and productive grazing it is important that carrying capacity estimates, on a paddock basis, be made for a range of seasonal conditions. Paddock stocking rates and pasture condition should also be recorded annually and compared against carrying capacity estimates. If possible, estimates of available pasture biomass and utilisation could also be used to fine-tune stocking rates.

Factors that influence carrying capacity

For each location, the estimation of carrying capacity process should account for the amount and variability of rainfall and pasture growth, pasture type and condition and tree competition influences. The use of pasture growth models with historic climate data sets can greatly facilitate this understanding.

Because livestock waters are sparsely distributed within large and extensive paddocks in the VRD, it is critical to account for water point distribution in paddock carrying capacity estimation processes. Using GIS to calculate the paddock area or proportion within a specified distance to water accounts for both the number and spatial distribution of watering points and provides a simple indicator of grazing patterns, pasture condition and livestock productivity.

There are now tools to assist estimation of carrying capacity on a paddock and property scale

A range of tools including digital spatial resource and infrastructure data, pasture growth models and prototype carrying capacity calculator and mapping applications, enable land managers to consider the impact of seasonal variability and risk when determining long-term stocking rates, as well as providing the option of adopting more flexible stocking options. This may provide for increased productivity while ensuring the pasture resource remains in good condition.

Flexible stocking strategies vs set stocking

A modelling comparison of fixed and flexible stocking rate strategies implemented using GRASP over a one-hundred year simulation period (Appendix 2) showed that there are several difficulties with implementing flexible stocking systems. Unless reliable seasonal forecasting is utilised these strategies tend to be reactive, based on the preceding seasons rainfall and forage production. Therefore pastures may be over-utilised or under-utilised for short periods unless adjustments are made. Large fluctuations in stock numbers may occur as attempts are made to match grazing pressure with forage production. In extensive systems, such large changes in livestock numbers are almost impossible in terms of logistics, ability to access, and availability of appropriate stock.

There is also the risk of buying when prices are high and selling when prices are low. These systems may be most appropriate for large pastoral companies that have a network of stations, who have the increased need and ability to transfer livestock between stations situated in different climate zones and pasture types. However until better seasonal forecasting tools are available for use in the VRD, stocking strategies will either have to remain fixed and conservative or remain reactive in nature.

If flexible stocking strategies enable increased utilisation rates, while maintaining pastures in good condition their adoption may be justified. However more intensive levels of management and monitoring would be required. The benefits of flexible stocking may arise from the ability to maintain higher utilisation levels without causing decline in pasture condition. Economic benefits arise from improved animal productivity over the long-term, due to maintenance of pasture condition (A. Ash *personal communication*).

Current knowledge of safe utilisation levels limits estimations of carrying capacity

The main limitation with the use of carrying capacity estimations are that only general utilisation guidelines are available for use in carrying capacity estimation. Although there are some general estimates of utilisation rates, more information is required regarding utilisation rates for different pasture types, condition and season combinations.

Technical Recommendations

Improvement in carrying capacity estimates could be achieved by the integration of the GRASP model linked to land units and land systems. This would enable individual paddock simulation of pasture production and utilisation that reflect the spatial and temporal variations in rainfall, soil, pasture type, condition and tree cover. It would enable both alternative estimates of long-term carrying capacity, but also assist short-term stocking decisions and enable monitoring of utilisation levels.

It would require

- Keeping digital pastoral infrastructure data up-to-date
- Generation of reliable carrying capacity estimates for land systems and land units
- A significant effort to input paddock livestock numbers and classes within the system
- Accounting for variations in carrying capacity due to pasture condition
- Inclusion of carrying capacity adjustments based on paddock distance to water distribution with the application
- It would enable comparison of various paddock fence line and water development scenarios.

7. Spatial Grazing Patterns and Fire

Introduction

Managing utilisation of pasture by cattle is perhaps the most important factor in sustainable grazing. Managing spatially uneven utilisation across large poorly watered paddocks with multiple land types and geologies is particularly challenging. Many factors influence where cattle graze such as land type (Pickup & Bastin 1997), boundaries such as fences (Pickup & Bastin 1997) and steep hills (Coughenour 1991) and waters (Pickup & Bastin 1997). In the northern grazing lands fire is an additional important component of the system that is known to influence cattle distribution (Andrew 1986).

Fire is a useful tool for controlling the cover of woody plants (Dyer *et al.* 1997), which compete with the pasture layer for water and nutrients (Cafe *et al.* 1999). The use of rotational fire has been recommended to manage woody vegetation (see Fire Section 4), and to move cattle away from preferred areas. However, the impacts of landscape scale and complexity in extensive pastoral systems on these recommended grazing and rotational burning strategies have not been determined and may significantly alter their potential effectiveness, practicality and sustainability.

Project Objectives

80% of producers are aware of the principles and best practice of controlled burning by providing a relevant and practical fire management manual and presenting information at on-property workshops, field days and shows.

Study Aims

The aim[1] of this study was to investigate the influence of soils, pasture, distance to water, burning and previous grazing on spatial variation in grazing distribution throughout extensive, heterogeneous paddocks.

Objectives

1) Determine the impact of

- underlying soil and pasture type
- location of watering points and supplements

on spatial patterns in grazing distribution and

2) Determine whether fire can be used to influence cattle distribution at the paddock scale

2) Examine how burnt areas recover following fire.

[1] The primary aim of this study was to promote the implementation of sustainable grazing management options. Study paddocks were established on four pastoral properties to demonstrate, and explore the impact and practicality of various fire and grazing management strategies at extensive scales. A major experimental objective within these sites was to investigate factors that influenced the spatial distribution of grazing pressure at extensive scales.

The implementation of burning strategies in demonstration paddocks located on commercial pastoral properties provided many important practical lessons, but was less productive in terms of useful experimental results for a number of reasons. General summaries of results from these sites can be found in previous Annual Reports (see attachments). In contrast the demonstration paddocks within the Mount Sanford Stocking Rate Demonstration Site provided a more controlled and manageable experimental environment that provided useful data and results of high quality. The results of this work are reported below.

Methods

Demonstration Locations

The study was conducted in two experimental paddocks within the Mount Sanford Stocking Rate Demonstration site (Table 7.1), in the VRD. Both paddocks were used as demonstration sites. Although average stocking rates between paddocks were similar, grazing management and utilisation rates differed. Annual rotational fire was implemented at a paddock scale in Wedgetail. The impacts of fire on grazing patterns in Wedgetail paddock were measured and compared with patterns in an adjacent unburned control paddock, Budgie.

Table 7.1: Paddock information.

Paddock	Date started	Area (km^2)	Average utilisation %	Management
Wedgetail	June 96	4.9	26.5	Flexible stocking rate (aim for 25% utilisation) & rotational burning
Budgie	October 98	4.2	19.5	Set stocked (15 hd/km) and no burning

Wedgetail and Budgie Paddocks are composed of *Astrebla* dominated grassland with scattered trees and shrubs on cracking clays, arid short grass pasture and open woodland on shallow red earth's and stony and spinifex hills (Wilson *et al.* 1990) (Figures 7.1-7.2). Wedgetail has a water trough on the south-western fenceline, while Budgie's trough is located in the centre of the paddock. Mineral supplement blocks were located within 200m of the troughs (Figure 7.3).

Figure 7.1: Hill in Budgie Paddock surrounded by red soil and scattered trees.

Figure 7.2: Rodd Dyer monitoring vegetation inside an exclosure in Wedgetail Paddock on black soil.

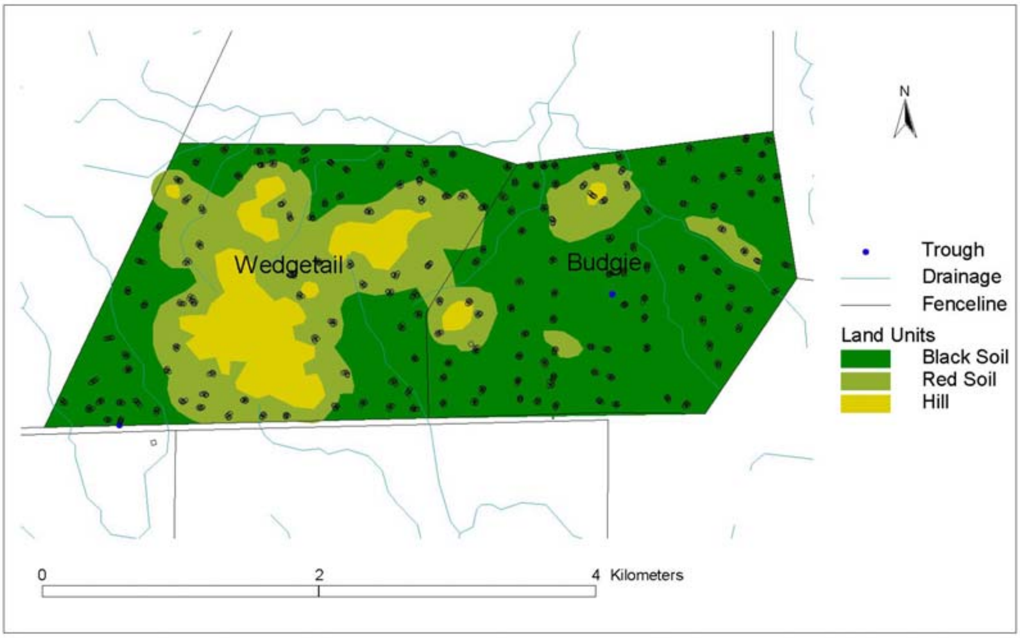


Figure 7.3: Land units and an example of the sampling distribution (from September 2000) in Wedgetail and Budgie Paddocks.

Different patches of Wedgetail were burned in rotation in September or October of 1996, 1997, 1999 and 2000 (Figure 7.4). All of the 1999 burned area, and 58% of the 2000 burned area was also burned in October 1997 as a result of wildfire. The rest of the paddock was either burned only once, or not at all (2%).

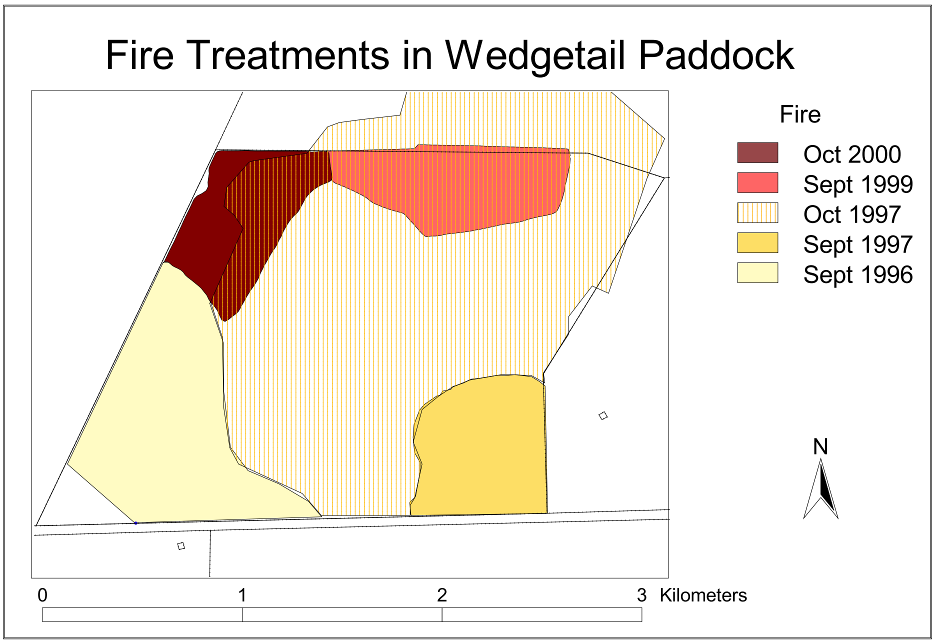


Figure 7.4: Fire in Wedgetail Paddock.

Data collection and analysis

Spatially referenced pasture observations were collected in both Wedgetail and Budgie paddocks using GPS. Observations were calibrated with pasture sampling (BOTANAL) undertaken on fixed monitoring points and exclosures in each paddock. Each sample area was assessed for ground cover, total standing dry matter (TSDM), the top four plant species contributing to TSDM and grazing intensity in early and late dry from 1997 – 2001. Figure 7.3 shows the land units at the site and an example of the sampling point distribution from September 2000. Hills were assumed to be unused by cattle and were not sampled.

Total and species yields were not normally distributed, and cover and grazing were ranked variables, hence non parametric statistics were employed. The Mann-Whitney U Test was used to test for differences between paddocks and Kruskal-Wallis Anova was used to test for differences between time periods. Features that were thought to be attractive to cattle were tested for their influence using distance correlations. The effect of distance to water, recently burned areas, fencelines and drainage were examined using Spearman's Rank Correlation. Kruskal-Wallis Anova was used to test for differences between soil types.

ArcView Spatial Analyst was used to create spatial information such as distance to water and burned areas, and time since fire. Additionally inverse distance weighted nearest neighbour interpolation was used to create maps of vegetation and grazing variables.

Results and Discussion

Factors influencing grazing

Effect of soil type, and the influence of fire on soil related grazing patterns

Black soils had higher pasture yields and cover than red soils at the site (Tables 14.1-14.2, Appendix 3), reflecting the innate differences in their fertility and water holding capacity (Section 2). It was expected that cattle would have preferences for certain soil types. However in the absence of fire there was little difference in grazing between red and black soil types in Budgie, except on one occasion when cattle grazing was higher on black soil and one occasion when it was higher on red soil (Table 14.3, Appendix 3). It was anecdotally thought that cattle used the red soils more during the wet to escape the boggy conditions on the black soil flats. If this was so, one might expect that grazing would be higher on red soils in the early dry, and this would change to there being no difference in grazing between soil types, or to grazing being higher on the black soils by the late dry. There is no evidence that this is occurring on these sites. Rather, in Budgie Paddock, the opposite occurred. This does necessarily mean that cattle spent more time on red soils in the late dry. Similar levels of grazing on the two soil types could result in higher grazing of the red soil pastures, as they produce lower yields per hectare than black soil pastures. Another explanation for the absence of an effect of grazing on high ground during the wet, may be that cattle spend time on the hills, which we generally avoided in our sampling regime. The lack of clear preference between pasture/soil types is interesting, and is contradictory to anecdotal evidence.

In Wedgetail where mostly black soil areas were being burned, grazing was generally higher on black soils, and this did not change seasonally. This may reflect a change in grazing preference to burned areas (which happened to be mostly black soil areas).

Effect of waters and the influence of fire on water related grazing patterns

In Budgie paddock (where there was no fire) areas closer to water showed higher grazing intensity and lower yield, cover and palatability compared to areas further from water (Table 7.2, Figures 7.5-7.8). There were, however, indications of changes in grazing distribution through the year. Graphs of yield and grazing verses distance to water through time (Figures 14.1-14.2, Appendix 3), indicate that in the early dry, grazing was focused around the waters, but by the late dry, grazing had extended to the paddock boundaries.

The grazing response in Budgie paddock is of interest because of the steep gradient in grazing pressure within a relatively short distance from water (Figure 14.1, Appendix 3). Although grazing pressure was very high close to water, there were high values for yield and cover levels less than 1000m away. Clear grazing gradients are often expected in large heterogeneous paddocks with poor water distribution, but they obviously also can exist in smaller paddocks with good access to water, when low utilisation levels, stock numbers per water point and good pasture conditions enable adequate grazing choice in close proximity to waters. It would be expected that if stock numbers per water point increased, and areas containing preferred pasture components became limiting closer to waters, grazing pressure would progressively be transferred to greater distances from water. Such reserves of pasture may become a valuable buffer in times of drought, but also force animals to walk long distances between feed and water in large paddocks during drier times and exacerbate overgrazing of pastures closer to water.

There were fewer water related grazing gradients in Wedgetail (rotationally burned) compared to Budgie (non burn) (Tables 7.2-7.3). In general, yield and cover were either not correlated with distance to water, or were higher closer to water (See Figures 7.5-7.8, Tables 7.2-7.3) suggesting that there was less concentration of grazing close to water. However, in one year when the fire in the previous season was situated close to the trough, and on one occasion when fire had covered most of the paddock (1997), Wedgetail had similar distance to water yield patterns to Budgie. Cover patterns were also similar between paddocks when Wedgetail had been burned close to the trough (1996 and 1997), and on one occasion when fire was far from the trough (2001).

The pasture results from Wedgetail paddock indicate that rotational burning can alter the usual pattern of concentrated grazing around water points. Wedgetail's trough placement in the corner of the paddock meant that it had a much greater maximum distance to water than Budgie paddock. Despite this, distance to water had minimal impact on grazing intensity, pasture yield and cover throughout the paddock. This suggests that fire attracted grazing to burnt areas, even if these areas were far from water. However it is not possible to definitely attribute this response to fire alone, as paddocks also differed in water placement, barriers (hills), cattle gender, utilisation levels and land system composition.

Table 7.2: Correlation between vegetation and grazing variables with distance to water in Budgie Paddock (no burn). Spearman's Rank Correlation.
*** P<0.001, **P<0.01, * P<0.05.

	All Years	Oct 1998	April 1999	Oct 1999	Apr 2000	Sept 2000	May 2001	Oct 2001	May 2002	Oct 2002
n	4064	407	595	536	491	480	460	399	428	268
Yield (kg dm/ha)	.11 ***	.23 ***	.15 ***	.23 ***	.29 ***	ns	ns	ns	.23 ***	ns
Cover (%)	.19 ***	.30 ***	.22 ***	.34 ***	.45 ***	.28 ***	.23 ***	ns	ns	ns
Grazing score	-.25 ***	-.32 ***	-.24 ***	-.43 ***	-.53 ***	-.21 ***	-.23 ***	-.15 **	-.12 *	-.43 ***
Perennial Yield	.06 ***	.19 ***	ns	.16 ***	.15 ***	ns	-.12 *	ns	.11 *	.14 *
Annual Yield	.09 ***	ns	.16 ***	ns	.35 ***	.11 *	ns	.16 **	.11 *	-.14 *
% Perennial Yield	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Palatable Yield	.12 ***	.17 ***	.18***	.11*	.26***	.10*	ns	.13 **	.27 ***	ns
Unpalatable Yield	-.05 ***	.12 **	-.10*	.13**	ns	-.10*	-.25***	-.19 ***	-.12 *	ns
% Palatable Yield	.14 ***	ns	.18***	ns	.21***	.16***	.21***	.24 ***	.24 ***	ns

Table 7.3: Correlation between vegetation and grazing variables with distance to water in Wedgetail Paddock (rotational fire). Spearman's Rank Correlation.
*** P<0.001, **P<0.01, * P<0.05.

	Fire Sept 96 ↓		Fire Sept & Oct 97 ↓					Fire Sept 99 ↓		Fire Oct 00 ↓				
	All Years	Aug 1997	Oct 1997	Mar 1998	April 1998	Oct 1998	April 1999	Oct 1999	Apr 2000	Sept 2000	May 2001	Oct 2001	May 2002	Oct 2002
n	4651	191	237	265	352	407	527	444	508	440	418	422	364	267
Yield (kg dm/ha)	ns	.32 ***	.57 ***	-.46 ***	ns	.17 ***	-.14 **	-.13 **	-.33 ***	ns	ns	ns	ns	-.21 ***
Cover (%)	-.09 ***	.32 ***	.38 ***	-.40 ***	-.15 **	ns	-.21 ***	ns	ns	ns	.16 **	-.19 ***	-.33 ***	-.13 *
Grazing score	-.13 ***	-.34 ***	-.54 ***	ns	-.11 *	-.39 ***	-.37 ***	-.35 ***	-.19 ***	ns	ns	-.11	.45 ***	.13 *
Perennial Yield	ns		.46 ***	ns		.18 ***	ns	-.21 ***	-.23 ***	ns	ns	ns	ns	-.30 ***
Annual Yield	ns		ns	-.20 **		ns	.14 **	.16 ***	ns	ns	-.18 ***	ns	ns	.19 **
% Perennial Yield	.04 *		.21 **	.25 ***		.13 **	ns	-.22 ***	ns	ns	.24 ***	ns	ns	-.21 ***
Palatable Yield	-.04 *		.34 ***	-.34 ***		ns	ns	-.20 ***	-.23 ***	-.14 **	ns	ns	.21 ***	-.24 ***
Unpalatable Yield	.05 **		.47 ***	.24 ***		.20 ***	ns	.09 *	ns	ns	ns	ns	ns	ns
% Palatable Yield	ns		-.17 *	-.18 **		-.17 ***	.11 **	-17 ***	ns	-.14 **	ns	ns	.13*	-.15

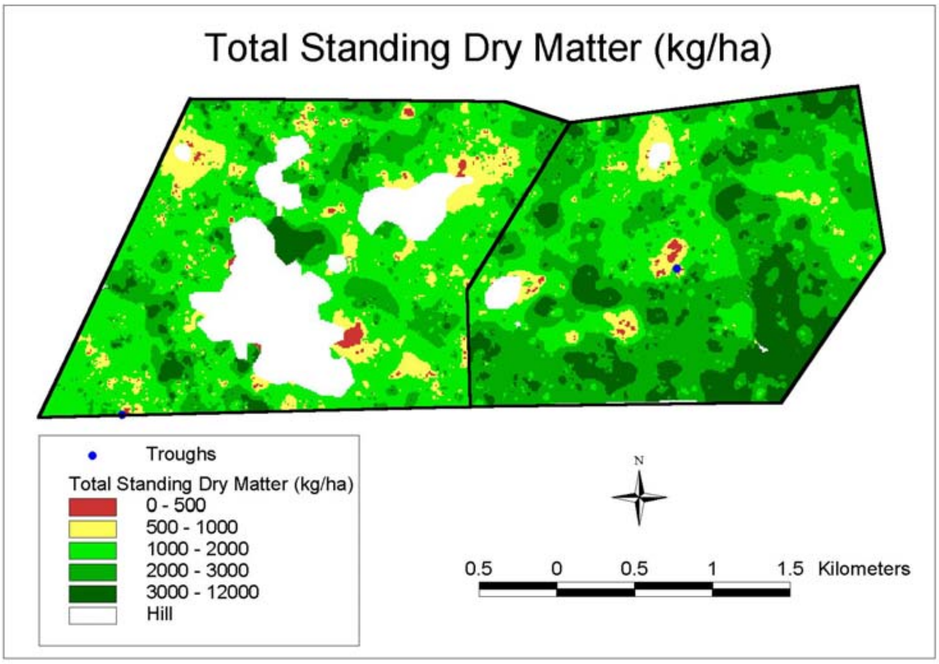


Figure 7.5: Interpolated Yield in Wedgetail (rotational fire, left) and Budgie (no burn, right). (Using all data sets).

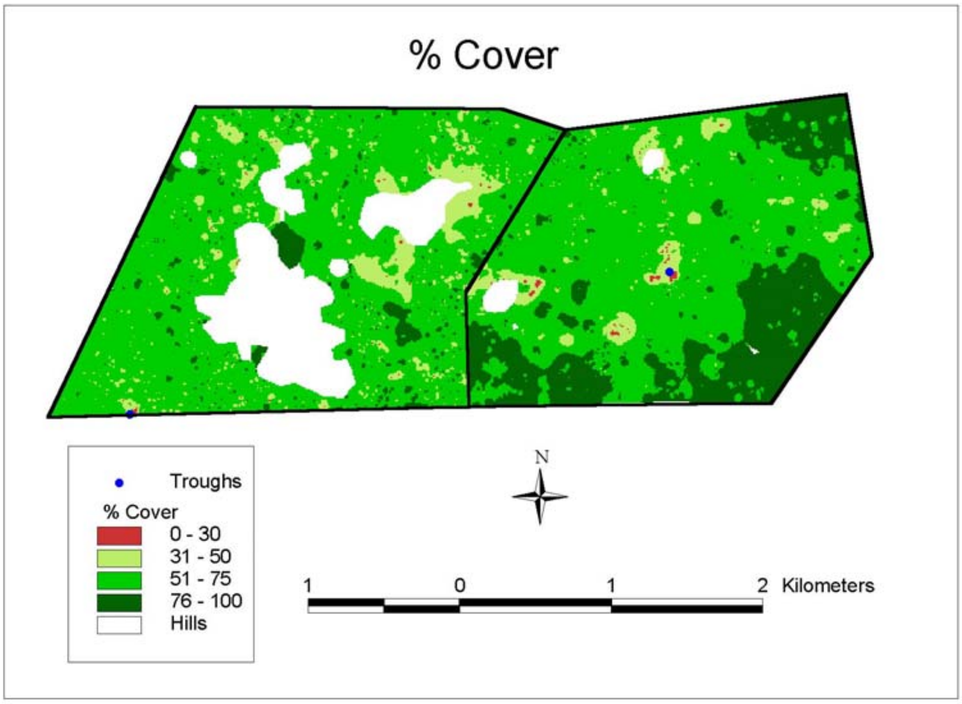


Figure 7.6: Interpolated Cover in Wedgetail (rotational fire, left) and Budgie (no burn, right). (Using all data sets).

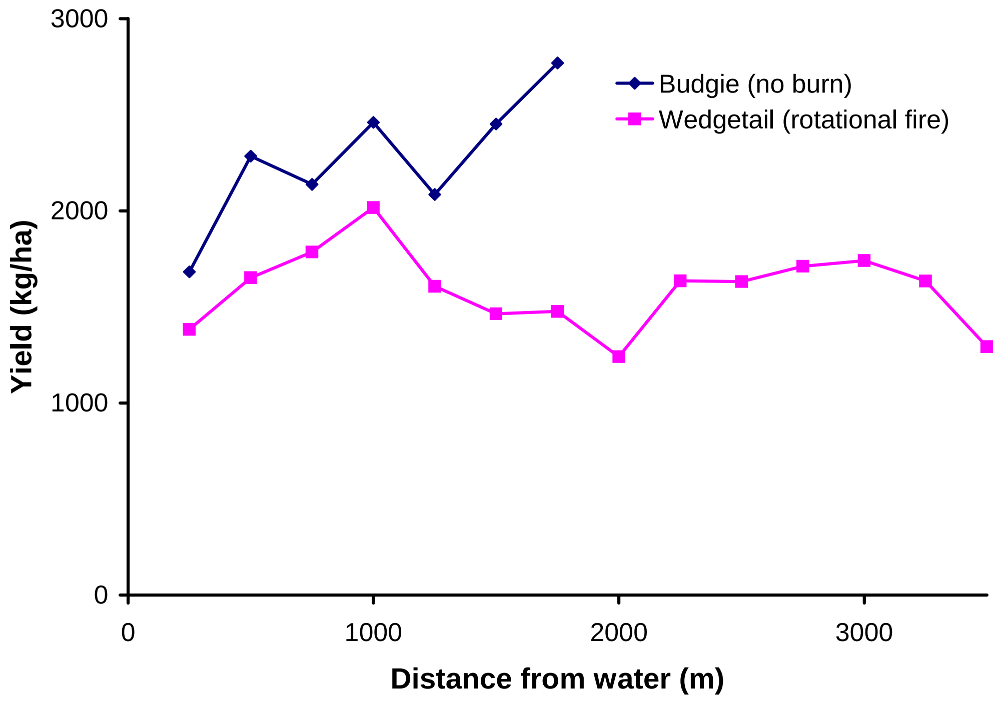


Figure 7.7: Average yield with distance from water (average all times, over 250m distance classes) in Wedgetail (rotational fire) and Budgie (no burn).

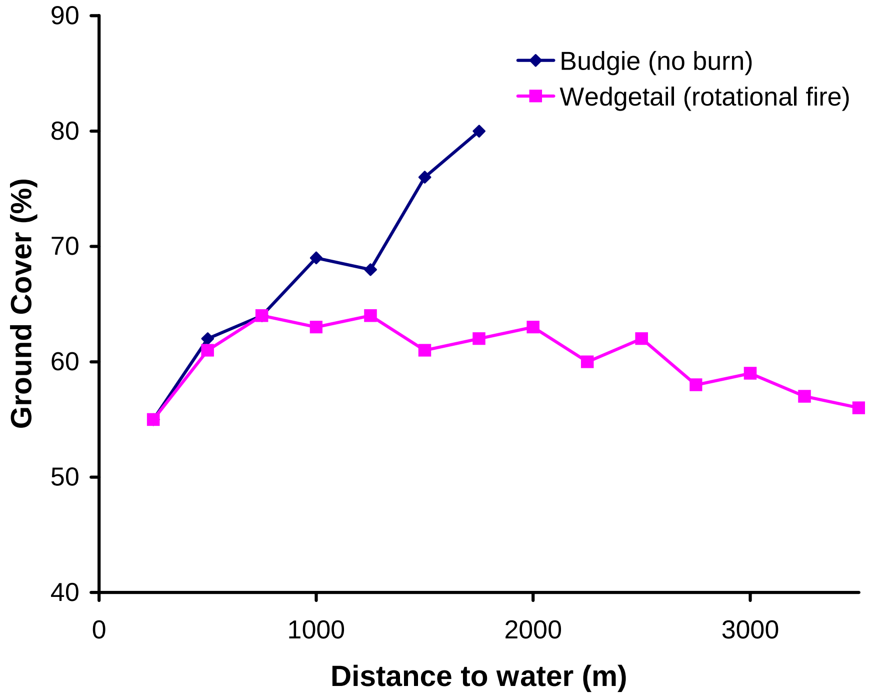


Figure 7.8: Average cover with distance from water (average all times, over 250m distance classes) in Wedgetail (rotational fire) and Budgie (no burn).

Recovery following fire in Wedgetail

General differences between burned and unburned paddocks

Despite the different management regimes there was little difference in the relative proportion of pasture groups between paddocks. Generally, standing yield and cover were significantly higher in Budgie than in Wedgetail (Table 7.4). This is not surprising given the effect of higher grazing levels and fire removing biomass and cover in Wedgetail.

Table 7.4: Variation in mean yield and cover between paddocks
(Average of all years and seasons from October 1998). Mann-Whitney U Test *** P<0.001.

	Yield	Cover %
P	***	***
Budgie (No burn)	2241	67
Wedgetail (Rotational burn)	1624	60

Species composition was similar between the sites, although Budgie had a higher percentage of Astrebla spp., *Dichanthium sericeum* and *Iseilema spp.*, and a lower percentage of *Aristida latifolia* and *Dichanthium fecundum* than Wedgetail (Table 14.4, Appendix 3). There was some difference in the relative proportion of pasture groups between paddocks, with slightly more palatable perennials in Budgie (Table 7.5).

Table 7.5: Percent composition of pasture functional groups.

	Budgie (No burn)	Wedgetail (Rotational Burn)
Palatable perennials %	37	30
Unpalatable perennials %	32	37
Palatable annuals %	21	19
Unpalatable annuals %	3	7
Herbs %	3	4

However, while vegetation variables fluctuated through time, there was no evidence that the burned paddock had different trends through time to the control (see for example % palatable Figure 7.9), which suggests that differences were natural variations between sites rather than resulting from the application of fire in Wedgetail.

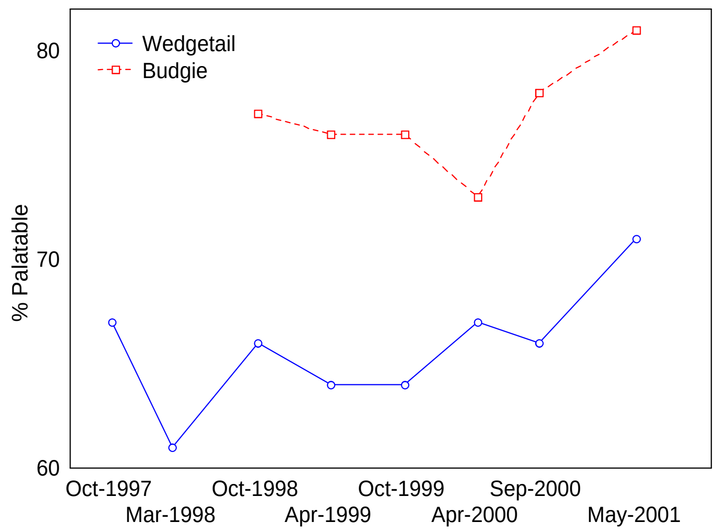


Figure 7.9: Change in % palatable species composition through time in Wedgetail (rotational burn) and Budgie (no burn) paddocks.

Recovery of burned patches through time

Areas burned in the previous year were more heavily grazed than unburned areas and areas burned two or more years ago (P<0.001 Table 7.6). The initial attractiveness of burnt areas appeared to have dissipated or even reversed two years after burning. This is probably influenced by more recent fires in other areas of the paddock and the differentiation between areas burned two years ago and areas burned longer ago or not burned becoming less defined. Of particular note was that in October 1997 following when fire was adjacent to the trough, post fire grazing was severe (score=5) in the burnt area. This indicates that placement of fire in or adjacent to already highly utilised areas (such as near waters) compounds the attractiveness of the area for cattle, and should be avoided to prevent over-utilisation and degradation. Generally though grazing was only one score heavier in recently burned areas than surrounding areas, which indicates that cattle didn't graze burned areas exclusively.

Table 7.6: Time since fire and grazing intensity in Wedgetail Paddock.
Kruskal Wallis Anova. 0=no grazing, 1=slight grazing, 2=moderate grazing, 3=heavy grazing, 4=very heavy grazing, 5=severe grazing.

	Unburned	Burned in previous year	Burned two or more years ago
Median Grazing Score across all time periods	2	3	2
Range in median grazing score for all time periods	1-3	2-5	0-3

When data from all time periods were combined and averaged for each period of time since fire, yield and cover initially decreased sharply following fire and the introduction of grazing in Wedgetail (Figures 7.10-7.11). Yield recovered by 18 months, however cover was still increasing through time three years following fire. Lower yield and cover in burnt areas is probably a result of both the removal of previous seasons carry-over material by fire, as well as the increased grazing of burnt regrowth which may reduce post-fire pasture growth. The slower recovery of cover compared to yield may be due to the time required for a build up of litter. Mitchell grassland decomposition turnover rates are in the order of 1.5-3 years. Hence litter cover levels could be expected to build up for three years following fire.

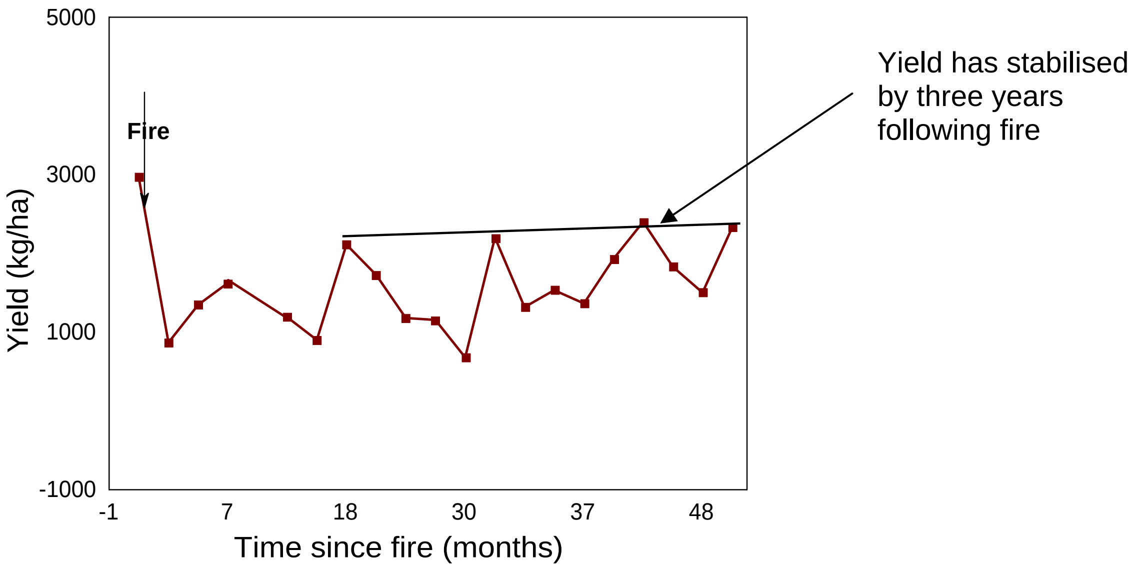


Figure 7.10: Change in yield through time following fire in Wedgetail.

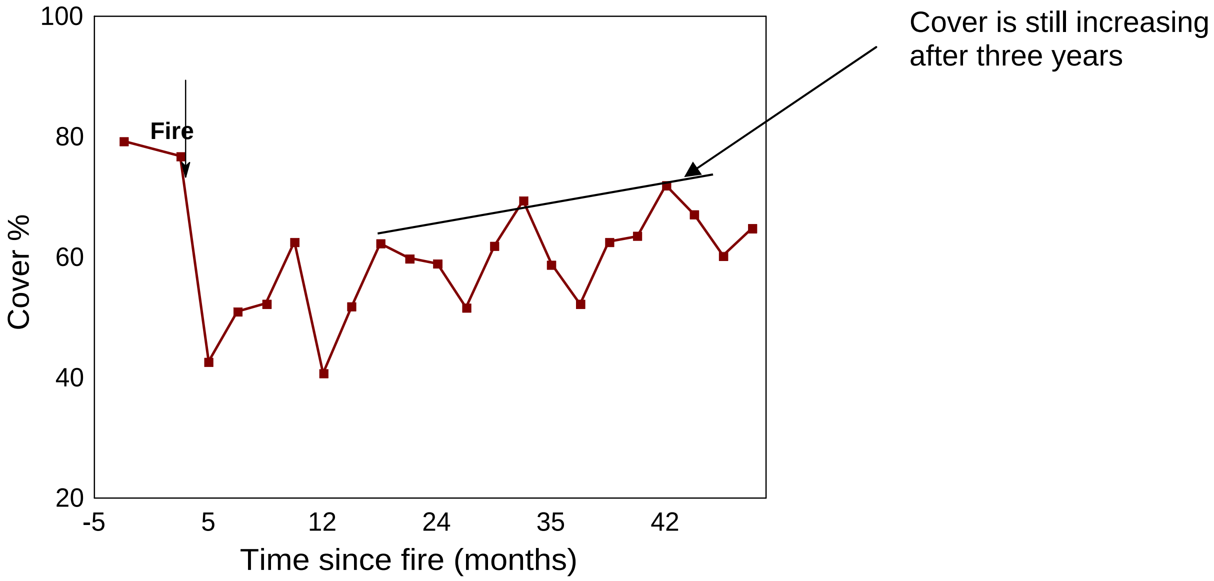


Figure 7.11: Change in cover through time following fire in Wedgetail.

Linear regression models predicting yield and cover recovery following burning from data collected in October 2000 and May 2001, indicate that yield and cover recovered in 2-3 years after fire (Table 7.7, Figures 7.12-7.13). Models for perennial and annual yield and palatable and unpalatable yield showed similar responses (Table 7.7). The time to recover from fire will vary depending on post fire grazing intensity (which varies depending on size of burned patch and placement of fire relative to areas already attractive to cattle), soil type, rainfall and the distribution of rainfall in relation to the time of fire. In this study Wedgetail was burned at the end of the dry, and rain fell soon after in November and December. Hence regrowth could occur within a couple of months of fire. This is useful for a couple of reasons. It minimises the period soil is exposed and the time without feed for stock on burned areas.

Table 7.7: Effect of time since fire (TSF) on vegetation and grazing variables.

Linear Regression. *** P<0.001, **P<0.01, * P<0.05.

Date	**May 2001**		**Sep 2000**	
n	**7/6**		**6/5**	
Variable	**Equation**	**R^2 P**	**Equation**	**R^2 P**
Yield	$Yld=((-7.96/TSF)+7.98)^e$	0.99 ***	$Yld=((-7.5/TSF)+7.5)^e$	0.99 ***
Cover	$Cov=((-4.33/TSF)+4.33)^e$	0.99 ***	$Cov=((-4.21/TSF)+4.21)^e$	0.99 ***
Perennial Yield	$PY=((-7.86/TSF)+7.88)^e$	0.99 ***	$PY=((-7.43/TSF)+7.44)^e$	0.99 ***
Annual Yield	$AY=((-5.04/TSF+4.97)^e$	0.86 **	$AY=((-4.36/TSF)+4.37)^e$	0.97 ***
% Perennial		ns	%P=(10.88/TSF)+89.24	0.71 *
Palatable Yield	$PY=((-7.69/TSF)+7.68)^e$	0.99 ***	$PY=((-7.16/TSF)+7.15)^e$	0.99 ***
Unpalatable Yield	$UPY=((-6.28/TSF)+6.36)^e$	0.97 ***	$UPY=((-6.07/TSF)+6.11)^e$	0.98 ***
% Palatable	%P=(-165.8/TSF)+78.44	0.89 **		ns

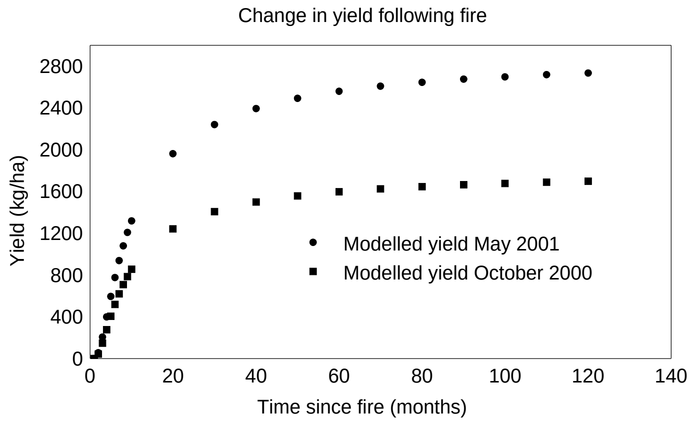


Figure 7.12: Modelled change in Yield following fire.

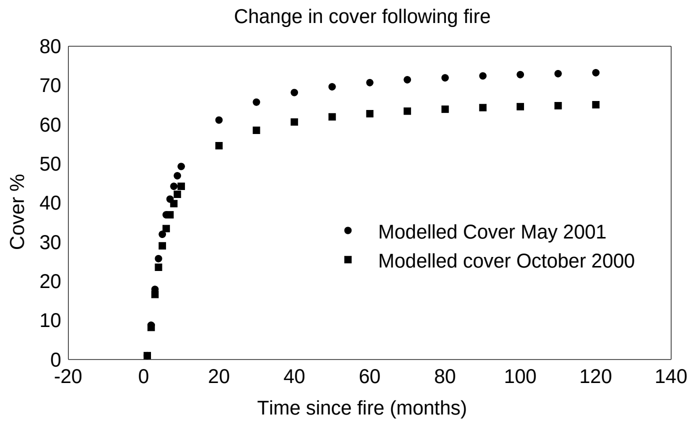


Figure 7.13: Modelled change in Cover following fire.

This study showed that it is possible to implement a rotational burning program in combination with moderate-high stocking rates and pasture utilisation levels without causing pasture deterioration and lower animal productivity (unpublished DBIRD data) in the short-term. It is not clear from this study however whether burning and/or higher utilisation levels, especially of palatable perennials is damaging to long-term pasture condition, particularly since seasonal conditions during the trial were well above average. Under “normal” management for similar pasture types and rainfall zones, the risk associated with using fire would be reduced by implementing lower frequency of prescribed burning regimes than used under experimental conditions in this trial.

Areas adjacent burned areas also have higher grazing

Burned areas are attractants for cattle (Andrew 1986) and can have an influence on cattle distribution similar to waters. That is, cattle like to graze the burned areas, and in moving to and from grazed areas, cattle tend to graze areas close to burned areas more than areas away from burned areas. This was the case, except following a wildfire in October 1997 that covered most of the paddock. Yield and cover were significantly lower closer to recently burned areas in 4 out of 7 and 6 out of 8 of the observed dates respectively (Table 14.5, Appendix 3). On the occasions when distance to most recent fire was correlated with vegetation variables, such as in August and October 1997, the most recent fire had been close to the water trough, so the effect of fire and water locations would have been compounded. In 1998, 2000, and 2001 while feed was green (up to the early dry), areas close to the recent fire were more likely to be of lower yield and cover, presumably from higher grazing adjacent burned areas. However by the late dry the impact of the need to drink water from the trough on the other side of the paddock appears to have outweighed the attractiveness of burned areas in the paddock.

Industry Implications

Fire can be used to alter grazing patterns

Fire can be used to transfer, and better distribute grazing pressure into under-utilised areas, reducing the potential degrading impacts of high utilisation rates surrounding water points, or preferred soil types. Alternatively, burning enables paddocks to be stocked to their full capacity, providing livestock are not forced to walk long, energy-consuming distances to burnt areas.

Rotational fire management issues

The application of rotational fire with 25% utilisation did not appear to negatively influence pasture condition during the good seasons experienced in the study. However, it may lead to a decrease in pasture condition over the long-term, and should be monitored carefully in poor seasons.

Care should be taken when applying rotational burning. In particular

- make sure burnt areas are large enough to sustain the total numbers of cattle in the paddock ie. the stocking rate per burned area should not be too high
- rest areas (don’t burn) for at least 4-5 years between successive burns
- note that other factors such as location of waters and land type will also influence grazing distribution
- don’t burn areas that are already preferred by cattle, as this can lead to excessive overgrazing in burned areas following fires

- to facilitate recovery following fire, because areas adjacent burned areas are also grazed more heavily, burns should not be located adjacent the previous seasons burns.

Technical Implications

The use of fire should be tested at commercial scales to see if it is a viable way to move cattle around the landscape in very large paddocks. If so, rotational fire has the potential to greatly reduce infrastructure development costs. For example a paddock could be partitioned into two / three components that are rotationally burned to move cattle around. Because cattle tend to graze burned areas more heavily, this could have the effect of moving cattle between three separate paddocks, albeit without the fencing.

The dataset should be further analysed to develop models of factors influencing landscape use by cattle. This could then be used in decision support systems to highlight areas that are more likely to be heavily utilised by cattle, so that infrastructure development and land and fire management can be used to manage grazing distribution.

The two paddocks should be monitored without fire to distinguish whether differences in spatial patterns are due to burn treatments or differences in paddock and management characteristics. *Implemented: data collected to October 2002 (two years following last fire in Wedgetail), but still to be analysed and written for publication.*

8. General Conclusion

A trend towards increased levels of productivity and infrastructure development in the northern pastoral industry has been occurring in an effort to meet increasing demands, reduce the unit costs of production, increase the efficiency of production and maximise returns. This trend is likely to continue, albeit along with increasing public and industry concerns over both local and global sustainability issues.

One obvious consequence of these pastoral industry changes is increased utilisation of native pastures. Lack of knowledge and poor management under such systems has the potential to result in widespread land degradation. A priority for future research should be to develop and test technologies which could enable higher utilisation of native pastures in a manner which ensures both productive and healthy grazing lands. This incorporates work aimed at identifying acceptable and productive levels of utilisation for different pasture communities, improving the spatial distribution of grazing pressure within paddocks or in areas currently not grazed, and developing reliable means of estimating carrying capacity for different land types. Research should also aim to develop and test cattle management options which cope with seasonal variability deliver improved sustainable pasture utilisation, such as wet season spelling and flexible stocking strategies.

As increased productivity and development progress there is a real risk that the use of management tools such as fire will be dismissed, as grass is increasingly utilised as forage. Under such situations increased grazing pressure and reduction in fire would almost certainly lead to irreversible woody thickening, and declining land condition over a relatively short period. Understanding the impacts of fire and its implementation in more intensive systems is therefore a priority.

The need for spatial monitoring systems for use at the paddock, property and regional level is essential in situations where higher utilisation levels are occurring. The integration of existing technologies provides an opportunity to develop monitoring and decision-making systems that accounts for seasonal variability. Such systems also need to recognise and incorporate the latest developments in seasonal climate forecasting. Activities to address these issues should be undertaken in an integrated framework across northern Australia. A combination of on-property research, practical demonstration, and scenario and trade-off modelling as well as the development of best practice guidelines would support sustainable increase in productivity and development of the northern pastoral industry.

Awareness and Adoption

The stated project aim was to encourage the adoption of sustainable grazing management on pastoral properties throughout the Victoria River and Sturt Plateau regions of the Northern Territory. Although no post-project quantification of awareness and adoption change was undertaken there is anecdotal evidence suggesting that the project achieved its aim. Producer involvement in field days at long-term research sites and in on-property research and demonstrations over a number of years has indicated a noticeable change in producer perceptions regarding changes in woody vegetation and the prescribed use of fire. Producers appear to be increasingly experimenting with, and applying fire as a management tool and making enquiries regarding the use of fire and management of woody plants.

Evidence of an increased awareness in sustainable grazing management has been the strong demand in one-day producer Rangeland Management schools delivered by the Department. Results and knowledge learnt from the project have also made a significant contribution to the Grazing Land Management (GLM) education package developed for pastoralists in northern

Australia by Meat and Livestock Australia. This will ensure the transfer of technology directly to land managers across northern Australia into the future.

Integration of project tools into individual property planning was demonstrated by the key role of pasture growth models and project findings in the Safe Utilisation Workshop undertaken by Heytesbury Beef. The findings of the project also contributed to the development of a collaborative research project between Heytesbury Beef, Department of Business, Industry and Development and CSIRO. A wide range of publications, reports and journal articles have been prepared and distributed to producers, researchers and policy makers (see Chapter 10). The significant contributions from the project findings to the *Savanna Burning - Understanding and Using Fire in Northern Australia* provide a lasting reference to for pastoral managers in the northern savannas of Australia.

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11. Data

Section	File / slide name	File / data type	Where held	File Location	Data held
2. Native Pastures	Attachments\Data\Native Pasture Modelling\SWIFTV97.MDB	MS Access Database	Katherine Research Station	Attachments\Data\Native Pasture Modelling\SWIFTV97.MDB	Swiftsynd site, vegetation and soil data
2. Native Pastures	MS01H1Q1 – AUV21H8Q8	> 2000 Slides	Katherine Research Station	Slide hangers in Filing cabinet	Images of 8 quadrats and 4 of each exclosure for 7-9 harvests at 21 swiftsynd sites
3. Tree-grass relationships	Attachments\Data\Treegrass\TREEDB2.MDB	MS Access Database	Katherine Research Station	Attachments\Data\Treegrass\TREEDB2.MDB	All data and spreadsheet used in prep of data
3. Tree-grass relationships	various	GRASP files and related data	Katherine Research Station	L:\Animprod\NTA022\Treegrass\Grasp\	GRASP files and related data
3. Tree-grass relationships	various	GRASP files and related data	Katherine Research Station	L:\Animprod\NTA022\Treegrass\Grasp\Grasp02\	Final mrx files relating to grasp models developed by Ken Day and Greg McKeon
3. Tree-grass relationships	various	Digital images	Katherine Research Station	L:\Animprod\Images\Treegrass\	Photos of transects and quadrats and other aspects of sites
3. Tree-grass relationships	various	Slides	Katherine Research Station	Slide hangers in Rangelands Filing cabinet	Photos of transects and quadrats and other aspects of sites
3. Tree-grass relationships	various	Prints	Katherine Research Station	Photo albums	Photos of transects and quadrats and other aspects of sites
4. Fire	Attachments\Data\Fire\Fuel		Katherine Research	Attachments\Data\Fire\Fuel manip data	

Section	File / slide name	File / data type	Where held	File Location	Data held
	manip data summary.xls		Station	summary.xls	
4. Fire	Attachments\Data\Fire\Fuel manip fire data.XLS		Katherine Research Station	Attachments\Data\Fire\Fuel manip fire data.XLS	
4. Fire	Attachments\Data\Fire\Shruburn shrub summary.xls		Katherine Research Station	Attachments\Data\Fire\Shruburn shrub summary.xls	
5. Economics of fire and stocking rates	Attachments\VRD Fire Model\VRD Fire Model 2002-03-13.xls	Excel	Katherine Research Station	Attachments\VRD Fire Model\VRD Fire Model 2002-03-13.xls	Model for calculating economic outcomes of fire and stocking rate scenarios
5. Economics of fire and stocking rates	Attachments\VRD Fire Model\GRASPflames_b.xls	Excel	Katherine Research Station	Attachments\VRD Fire Model\GRASPflames_b.xls	Grasp output for varying location, deciles, soil type, condition, rainfall and TBA
5. Economics of fire and stocking rates	Various			Attachments\SR Map and SR Calc\	Stoking Rate Calculator database and GIS files
7. Spatial Grazing Patterns	Attachments\Data\Spatial Grazing Patterns\Budgie&WedgieGPS.mdb	MS Access Database	Katherine Research Station	Attachments\Data\Spatial Grazing Patterns\Budgie&WedgieGPS.mdb	All pasture and locational data

12. Appendix 1: Tree grass relationships

Table 12.1: The observed and model predicted pasture dry matter yield (kgDM/ha) and nitrogen yield (kgN/ha), and observed pasture nitrogen concentration (%) for both Katherine sites at the time of peak dry matter yield each growing season.

		Peak DM Yield		Pasture N Yield		%N
Site	Date	Observed	Model	Observed	Model	Observed
Without Trees						
Paige	10/05/96	2288	3165	15.2	17.9	0.66
	27/03/97	3915	3337	19.4	20.7	0.50
	09/03/98	3234	3066	21.0	17.6	0.65
	26/05/99	5036	2991	7.6	14.4	0.15
	29/05/00	3630	2991	14.5	13.3	0.40
Dixon	12/03/97	2332	2183	23.5	17.8	1.01
	06/03/98	2946	2856	17.1	19.3	0.58
	25/05/99	3635	2991	9.1	14.3	0.25
	2905/00	3161	2991	12.6	13.2	0.4
Average		3353	2952	15.6	16.5	0.51
With Trees						
Paige	10/05/96	1431	1612	6.6	10.2	0.47
	27/03/97	2326	1877	11.5	10.0	0.50
	09/03/98	1979	2020	15.8	10.7	0.80
	26/05/99	1825	2003	3.7	9.5	0.2
	29/05/00	2504	1854	7.5	10.0	0.3
Dixon	12/03/97	1498	1924	7.2	9.1	0.48
	06/03/98	2236	1884	13.1	10.0	0.59
	25/05/99	2460	1808	4.9	9.2	0.20
	29/05/00	2161	1723	7.6	10.0	0.35
Average		2047	1856	8.7	9.8	0.43

Table 12.2: The observed and model predicted pasture dry matter yield (kgDM/ha) and nitrogen yield (kgN/ha), and observed pasture nitrogen concentration (%) for both Kidman sites at the time of peak dry matter yield each growing season.

		Peak DM Yield			Pasture N Yield			**%N**
Site	Date	Obs	Model 1	Model 2	Obs	Model 1	Model 2	Obs
								Without Trees
Loungers Hill	24/05/1996	2079	2047	2097	8.3	12.38	8.6	0.40
	04/06/1997	1300	1448	1452	3.9	8.48	4.9	0.30
	08/041998	2327	1978	2529	3.5	12.57	9.2	0.15
	17/06/1999	3412	2285	3273	6.8	10.61	7.8	0.20
	29/06/2000	3190	2319	3189	N/A	10.22	6.9	N/A
	Average	**2461**	**2015**	**2508**	**5.6**	**10.9**	**7.5**	**0.26**
Native	18/03/1997	3124	1294	2233	18.8	16.86	20.0	0.60
	09/04/1998	6659	1682	5879	6.7	14.91	23.7	0.10
	17/06/1999	5375	2427	5605	13.4	11.25	22.8	0.25
	Average	**5053**	**1801**	**4572**	**13.0**	**14.3**	**22.2**	**0.32**
								With Trees
Loungers Hill	24/05/1996	2032	683	2015	6.2	7.4	5.7	0.30
	04/06/1997	1055	592	1283	3.2	3.8	3.5	0.30
	16/02/1998	1220	886	1867	7.3	7.1	7.6	0.60
	17/06/1999	1420	792	2091	5.7	5.3	5.1	0.40
	29/06/2000	2460	1506	2051	N/A	6.7	4.7	N/A
	Average	**1637**	**892**	**1861**	**5.6**	**6.1**	**5.3**	**0.40**
Native	18/03/1997	3263	753	4079	24.5	7.1	16.3	0.75
	19/03/1998	4999	544	5229	17.5	5.9	20.9	0.35
	17/06/1999	4497	1253	4332	11.2	6.3	17.5	0.25
	Average	**4253**	**850**	**4547**	**17.8**	**6.5**	**18.3**	**0.45**

Model 1 results show initial validation output when Katherine parameters were used, and model 2 results are after calibration with Kidman data.

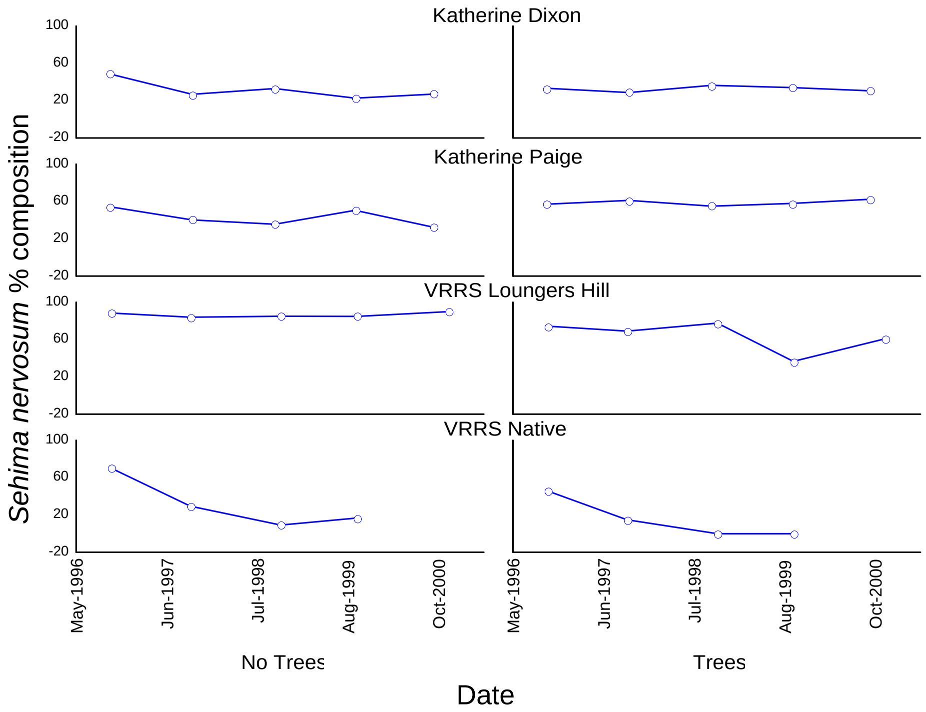

Figure 12.1: *Sehima nervosum* percent composition at different sites and treatments through time.

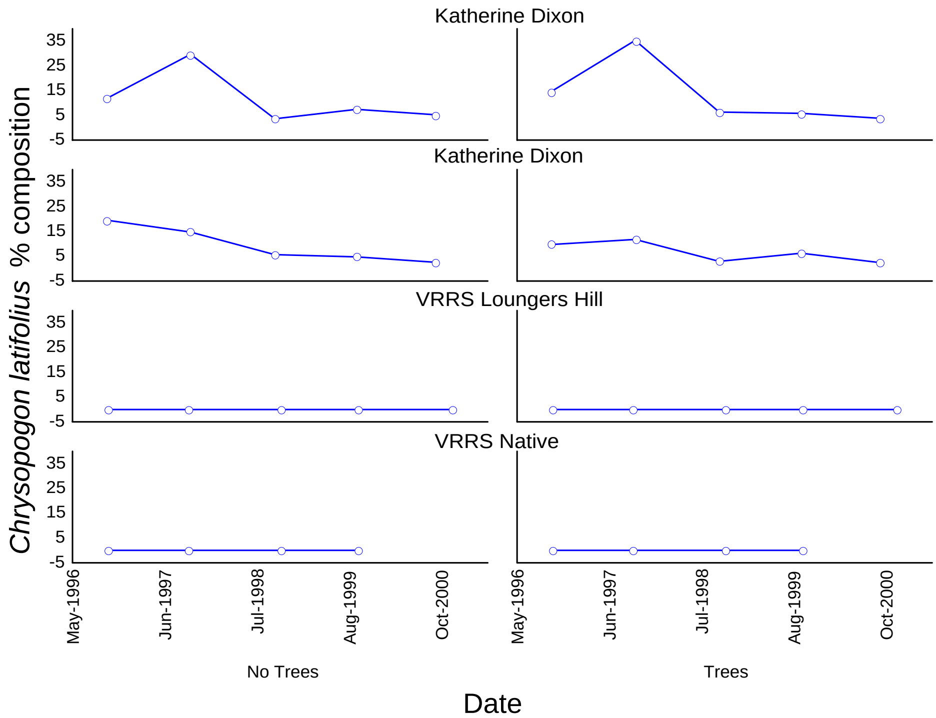

Figure 12.2: *Chrysopogon latifolius* percent composition at different sites and treatments through time.

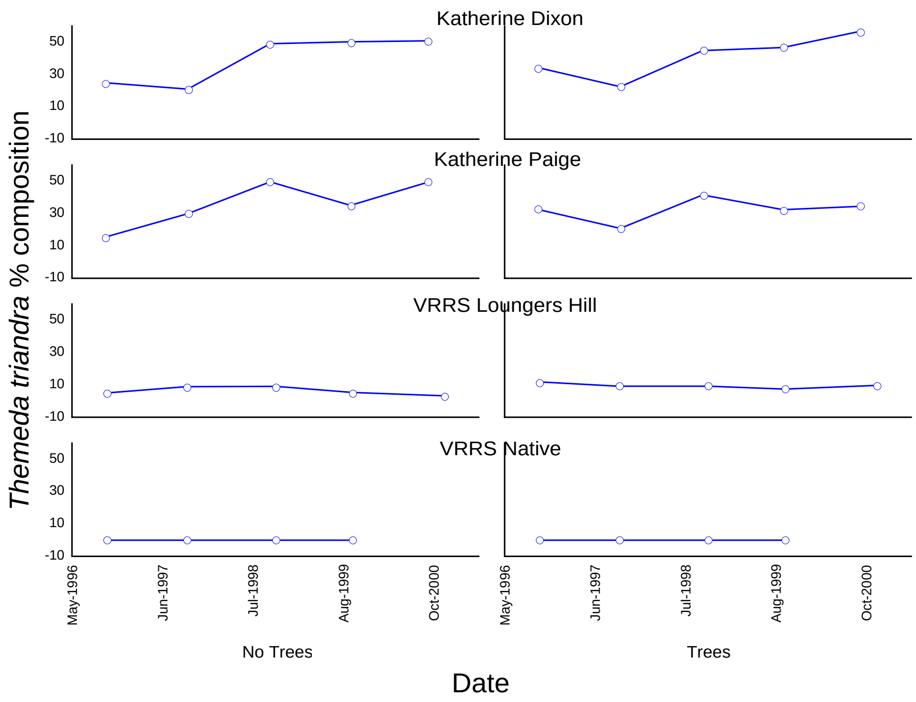

Figure 12.3: *Themeda triandra* percent composition at different sites and treatments through time.

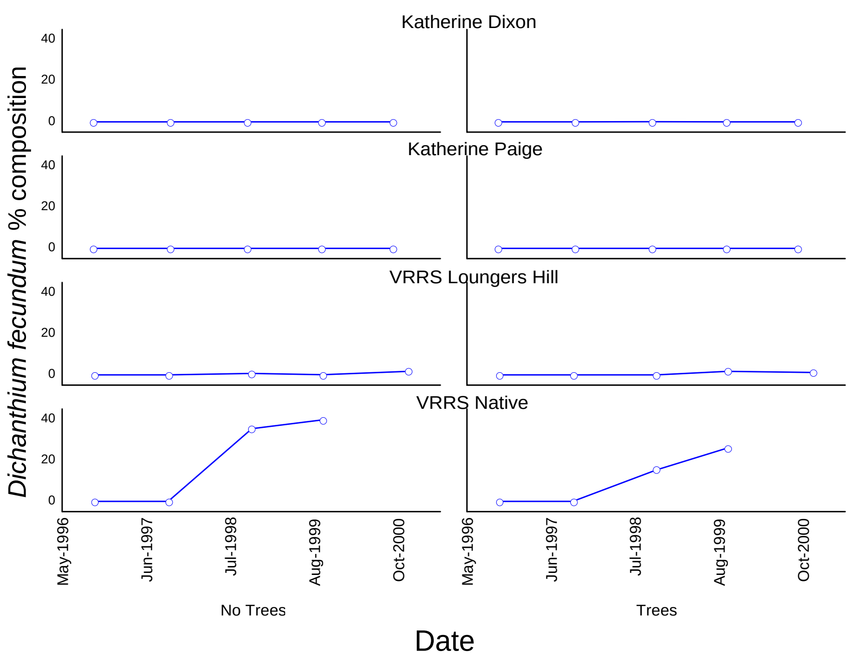

Figure 12.4: *Dichanthium fecundum* percent composition at different sites and treatments through time.

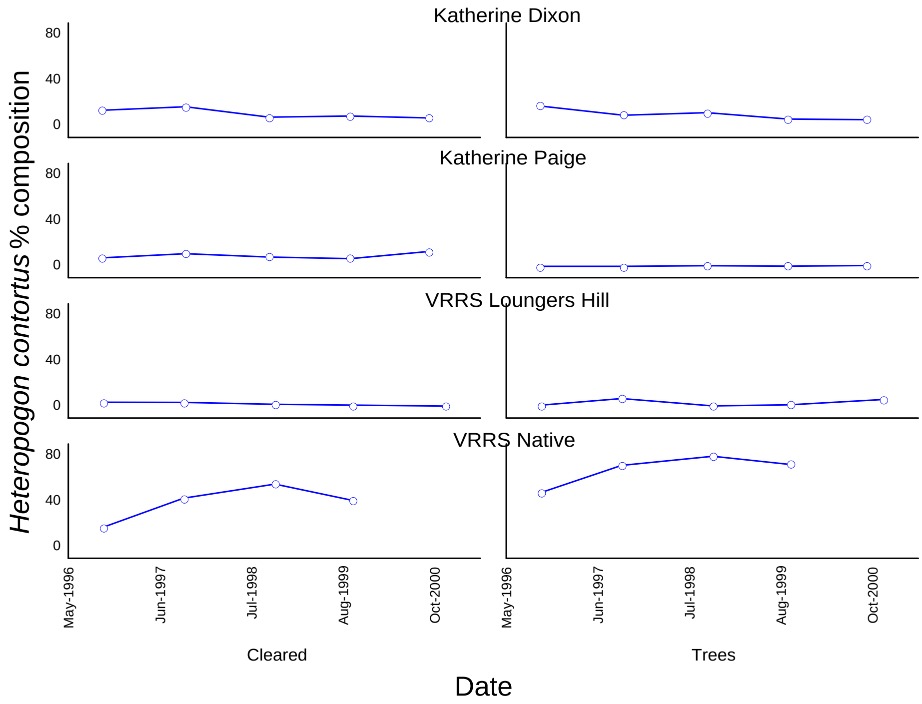

Figure 12.5: *Heteropogon contortus* percent composition at different sites and treatments through time.

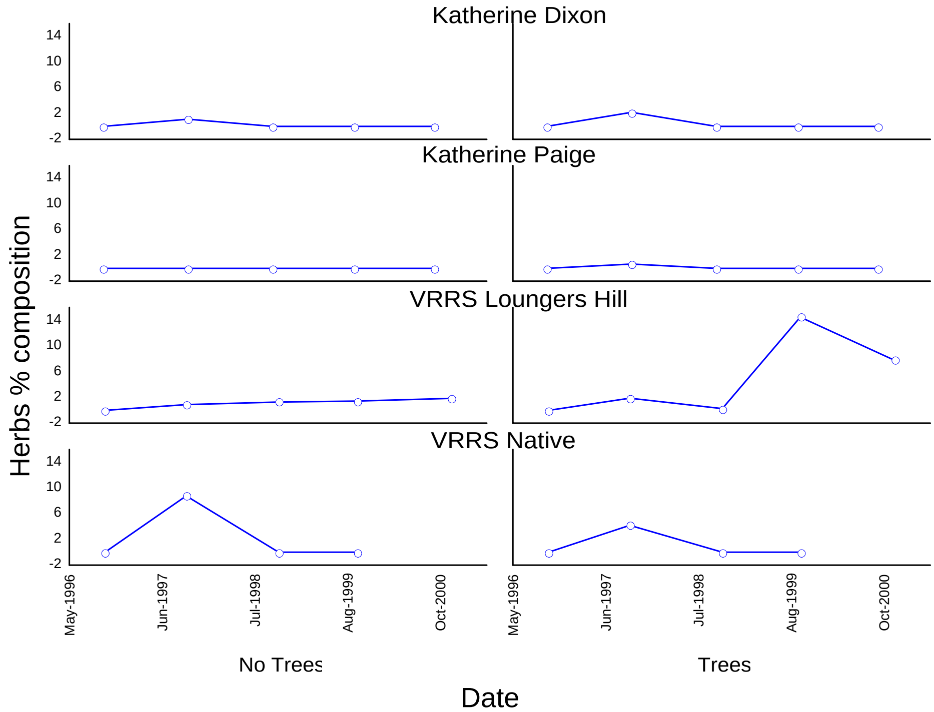

Figure 12.6: Herbs percent composition at different sites and treatments through time.

13. Appendix 2: Stocking Rates Comparison of fixed and flexible stocking strategies

Introduction

Both long-term carrying capacities and seasonal stocking rates must account for seasonal cycles of pasture growth to avoid the potentially damaging impacts of pasture degradation. Fixed stocking rate strategies involve no significant change to the number of animals grazed in a paddock from year to year. Stocking rates are set at levels thought appropriate for long-term production and sustainability based on rainfall, soil and pasture conditions. An appropriate fixed stocking rate should ensure "appropriate" levels of pasture utilisation for all but the worst seasons to ensure that pasture condition is maintained, yet avoid under-utilising potential forage. Flexible or opportunistic stocking strategies involve matching grazing pressure to seasonal pasture growth and forage availability by adjusting stocking rates up or down with the aim of ensuring safe levels of utilisation and achieving optimal economic returns in most years. In this study a flexible stocking rate strategy was devised using an annual stocking rate indicator based on a simulated three-year-moving-average of pasture growth. This strategy represented an attempt to maintain utilisation rates within safe levels, maintaining pasture condition, while taking advantage of good seasons by increasing stocking rates, then reducing levels during below average seasons.

Methods

Examples of annual utilisation rates were calculated for three fixed-stocking rate strategies (5, 10 and 15 AE/km^2) based on simulated annual growth of ribbon-blue grass pastures on cracking grey clays over a one-hundred year period, at Victoria River Downs station. Comparisons were made between each stocking level as to the average level of utilisation and the frequency which each exceeded 20% utilisation, a level assumed to be appropriate for this pasture community.

A three-year moving average (3YMA) of modelled pasture growth was also investigated for use as an indicator for adjusting seasonal stocking rates between three predetermined levels. The indicator stocking rate was calculated for each year over a one-hundred year period based on a 3YMA pasture growth value and an estimated "safe" utilisation rate (20%). By using the 3YMA of pasture growth, the stocking rate indicator accounted for cumulative impact of the three preceding seasons and is less variable over time when compared with the annual "safe" stocking rate estimates in Figure 45. This effectively evened-out the extreme peaks and troughs of stocking rate changes between good and poor seasons. To apply the indicator, each year after simulating the 3YMA pasture value, the stocking rate indicator determines whether stock numbers should be increased, decreased or maintained, between three predetermined stocking levels, and depending on the preceding seasons growth conditions. For this example, three stocking levels were arbitrarily chosen at 10, 12.5 and 15 AE/km^2 and were calculated to be within "safe" utilisation levels (ie. <20%) in 90%, 60% and 20% of years respectively. The lowest stocking rate is regarded as a base value, on which whole property herd structure is calculated. This flexible strategy was compared to a comparable fixed strategy.

Results and Discussion

Annual growth of ribbon-blue grass pasture was simulated using the GRASP model and climate data for the VRD and demonstrates large seasonal fluctuations in feed availability (Figure 14.1). Calculation of a three-year moving average of growth, reduces the large variations in annual conditions but shows clearly periods of above and below average growing conditions.

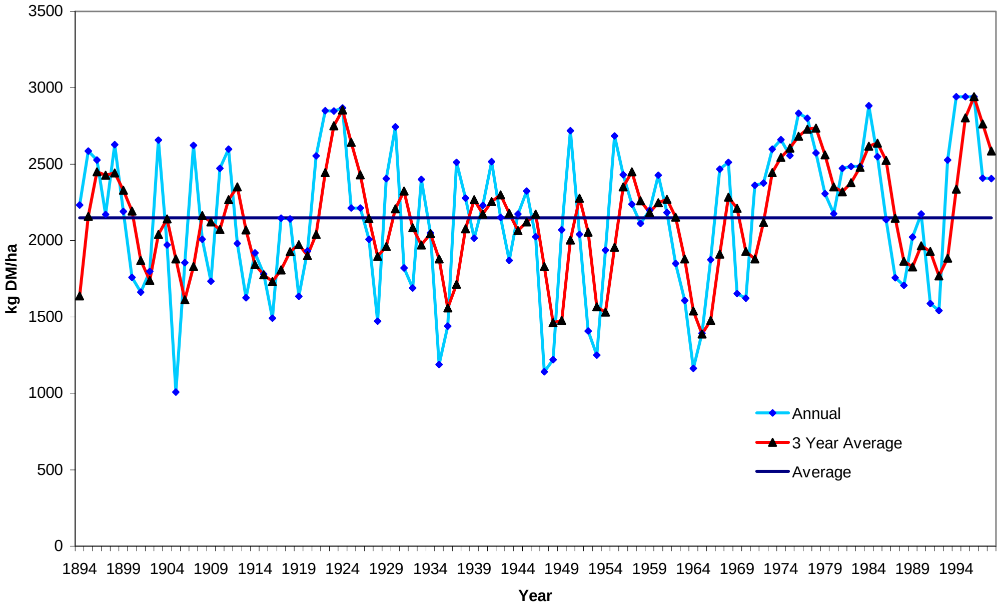

Figure 13.1: Annual, three-year moving average (3YMA) and long-term average pasture growth modelled using GRASP for ribbon-blue grass pastures at Victoria River Downs station over 106 years

Fixed stocking strategies

Based on the historical simulation of pasture growth, Figure 14.2 shows that annual utilisation rates for each fixed stocking level fluctuate greatly with seasonal conditions. If 20% is assumed to be a safe utilisation rate, stocking rates of 5 and 10 AE/km^2 are on average well within safe limits for this location and pasture type, however 15 AE/km^2 exceeds the 20% threshold in over 60% of years (Table 14.1). Therefore although stockings rates between 10-15 AE km^2 may provide “safe” utilisation on average, heavy grazing pressure during dry periods could result in episodes of sub-optimal animal performance and pasture degradation.

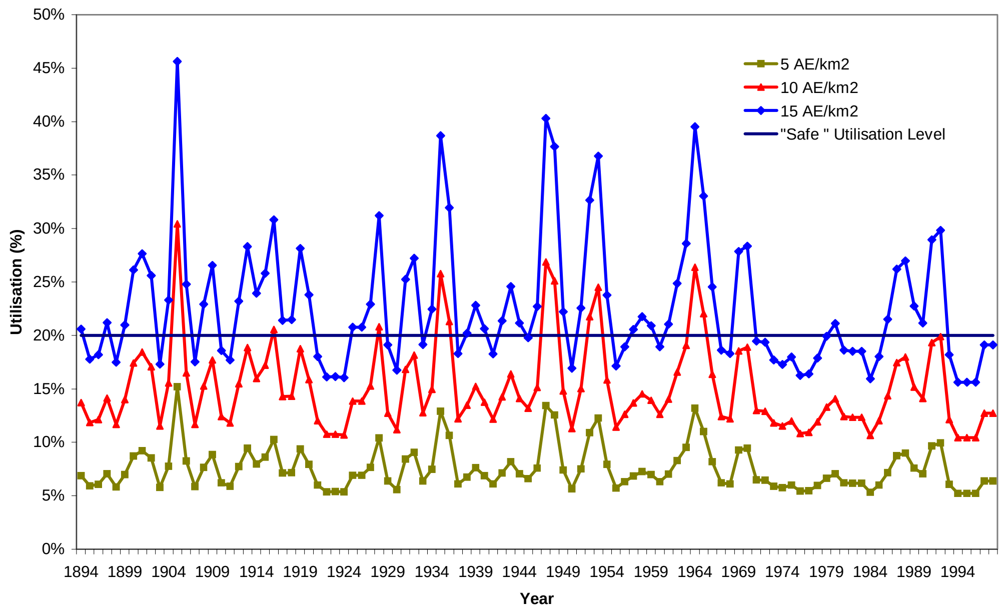

Figure 13.2: Estimated annual utilisation rates calculated from continuous stocking rates of 5, 10 and 15 AE/km^2 and predicted seasonal pasture growth over a period of 106 years at Victoria River Downs station.

Table 13.1: Predicted utilisation rates for fixed stocking rate scenarios over a period of 106 years from ribbon-blue grass pastures at Victoria River Downs station

Stocking rate (AE/km^2)	5	10	15
Average	8%	15%	23%
Min	5%	10%	16%
Max	15%	30%	46%

An indicator for flexible stocking decisions

The 3YMA stocking rate indicator and three threshold stocking levels are shown in Figure 14.3 (red line). The annual "safe" stocking rate is also shown as a comparison (blue line). In practice, stocking rates are maintained at one of three threshold levels (10, 12.5 or 15 AE/km^2), while the stocking rate indicator for each year is above that level. While the stocking indicator remains above the threshold level, utilisation rates are equal to or below safe values, which enables higher stocking in above average growth periods. Stock adjustments are usually made in a step-wise fashion, between the three levels.

The 3YMA stocking indicator is reasonably sensitive to the short-term fluctuations in seasonal conditions, but because it does not respond to one poor season amongst several good years, it reduces large stocking fluctuations and ensures utilisation levels rarely exceed unsafe levels. When seasonal conditions improve, the 3YMA indicator delays sudden and large increase in stocking rates as it takes into account the below-average conditions over the last three years and therefore allows opportunity for pasture recovery.

Actual stocking rate changes made each year using the seasonal stocking indicator were calculated and are shown in Figure 14.4. The flexible strategy results in an average stocking rate of 13 AE/km^2 and a utilisation rate of 19% (Table 14.2). An obvious question is whether the environmental or economic benefits of a flexible stocking, over a fixed strategy outweigh the additional complexity. At an equivalent average stocking rate (13 AE/km^2), a fixed stocking rate resulted in both average and minimum utilisation rates that were essentially the same as the flexible option. Each strategy exceeds the "safe" 20% utilisation rate 32 times over the one hundred and six-year period, however higher maximum utilisation rates (38%) from the fixed strategy may result in loss of desirable perennial grasses.

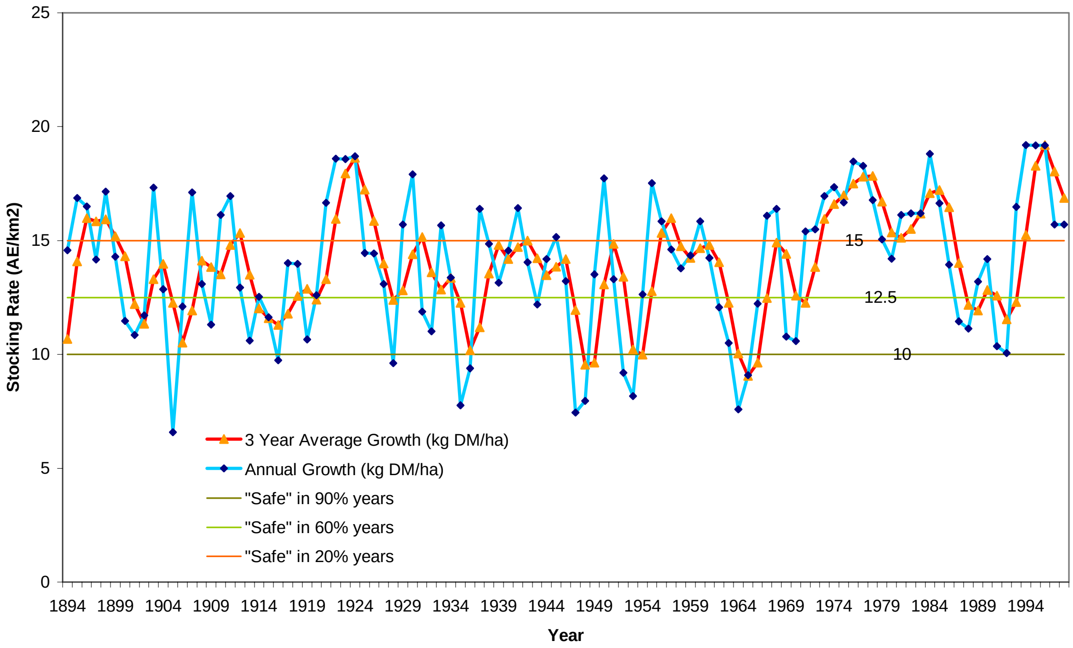

Figure 13.3: Changes in stocking rates based on 20% utilisation of annual and 3YMA modelled pasture growth for ribbon-blue grass pasture at Victoria River Downs over a period of 106 years.

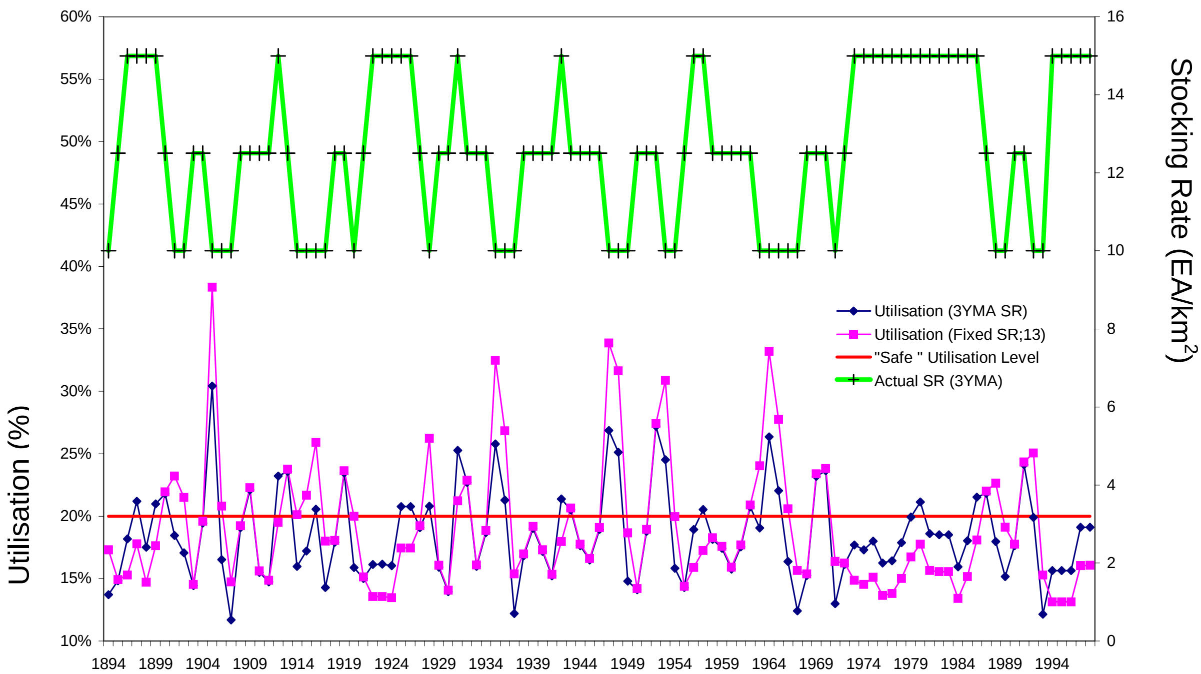

Figure 13.4: Changes in annual stocking rate using the 3YMA indicator (Actual SR (3YMA)). Comparison of annual utilisation rates between flexible (3YMA SR), continuous (Fixed SR; 13 AE/km^2) stocking strategies and the estimated “safe” utilisation level (20%).

Table 13.2: Comparison of stocking rates and utilisation levels between flexible (3YMA) and fixed (13 AE/km^2) stocking strategies over a period of 106 years at Victoria River Downs station.

	Flexible SR 3YMA		Fixed SR (13 AE/km^2)	
	SR (AE/km^2)	Utilisation (%)	SR (AE/km^2)	Utilisation (%)
Average	12.5	19%	12.5	19%
Min	10	12%	12.5	13%
Max	15	30%	12.5	38%

Conclusions

There are several difficulties with flexible stocking systems. Unless reliable seasonal forecasting is utilised these strategies tend to be reactive, based on the preceding seasons rainfall and forage production. Therefore pastures may be over-utilised or under-utilised for short periods unless adjustments are made. Large fluctuations in stock numbers may occur as attempts are made to match grazing pressure with forage production. In extensive systems, such large changes in livestock numbers are almost impossible in terms of logistics, ability to access and availability of appropriate stock. There is also the risk of buying when prices are high and selling when prices are low. These systems may be most appropriate for large pastoral companies that have a network of stations, who have the increased need and ability to transfer livestock between stations situated in different climate zones and pasture types. However until better seasonal forecasting tools are available for use in the VRD, stocking strategies will either have to remain fixed and conservative or remain reactive in nature.

If flexible stocking strategies enable increased utilisation rates, while maintaining pastures in good condition their adoption may be justified. However more intensive levels of management and monitoring would be required. The benefits of flexible stocking may arise from the ability to maintain higher utilisation levels without causing decline in pasture condition. Economic benefits arise from improved animal productivity over the long-term, due to maintenance of pasture condition (A. Ash *personal communication*).

It is questionable however whether the benefits of a flexible system out-way the increased level of management intensity and the additional costs and risk associated with adjusting animal numbers. These systems may be more appropriate where seasonal variability is more extreme or if higher threshold stocking rates were employed.

14. Appendix 3: Grazing Patterns and Fire

Table 14.1: Effect of soil type on yield in Wedgetail and Budgie Paddocks.

Kruskal-Wallis Anova. *** P<0.001, **P<0.01, * P<0.05. 1- August 1997 yield is uncalibrated.

Yield		All years	Aug-97[1]	Oct-97	Mar-98	Apr-98	Oct-98	Apr-99	Oct-99	Apr-00	Sep-00	May-01
Wedgie	P	***	***	ns	***	***	ns	**	***	***	***	***
	Black soil	1412	2250	1376	914	1777	1413	2473	1298	958	1605	2427
	Red Soil	1144	650	1376	914	1144	1051	2489	1107	251	825	1646
Budgie	P	***					ns	***	***	***	***	***
	Black soil	2142					1812	2892	1667	3992	1948	2492
	Red Soil	1079					1812	1270	996	1283	598	1247
	Hill	820					1152	203	904	587	723	759

Table 14.2: Effect of soil type on cover in Wedgetail and Budgie Paddocks.

Kruskal-Wallis Anova. *** P<0.001, **P<0.01, * P<0.05.

Cover		All years	Aug-97	Oct-97	Mar-98	Apr-98	Oct-98	Apr-99	Oct-99	Apr-00	Sep-00	May-01
Wedgie	P	ns	*	ns	**	ns	ns	ns	ns	***	ns	**
	Black soil	65	80	70	55	55	45	65	65	65	65	65
	Red Soil	65	80	70	35	55	45	65	65	65	55	65
Budgie	P	***					ns	***	***	***	***	***
	Black soil	75					55	75	65	75	65	75
	Red Soil	55					65	65	55	55	45	55
	Hill	55					55	25	55	45	45	45

Table 14.3: Effect of soil type on grazing in Wedgetail and Budgie Paddocks.

Kruskal-Wallis Anova.*** P<0.001, **P<0.01, * P<0.05.

Grazing		All years	Aug-97	Oct-97	Mar-98	Apr-98	Oct-98	Apr-99	Oct-99	Apr-00	Sep-00	May-01
Wedgie	P	***	ns	*	**	***	ns	***	***	***	**	***
	Black soil	2	2	3	1	2	3	1	3	3	3	2
	Red Soil	2	2	2	0	1	3	0	2	2	3	2
Budgie	P	**					ns	***	***	ns	***	ns
	Black soil	2					2	2	3	2	2	2
	Red Soil	2					3	1	3	2	3.5	2
	Hill	2					2	1	0	2	3	1

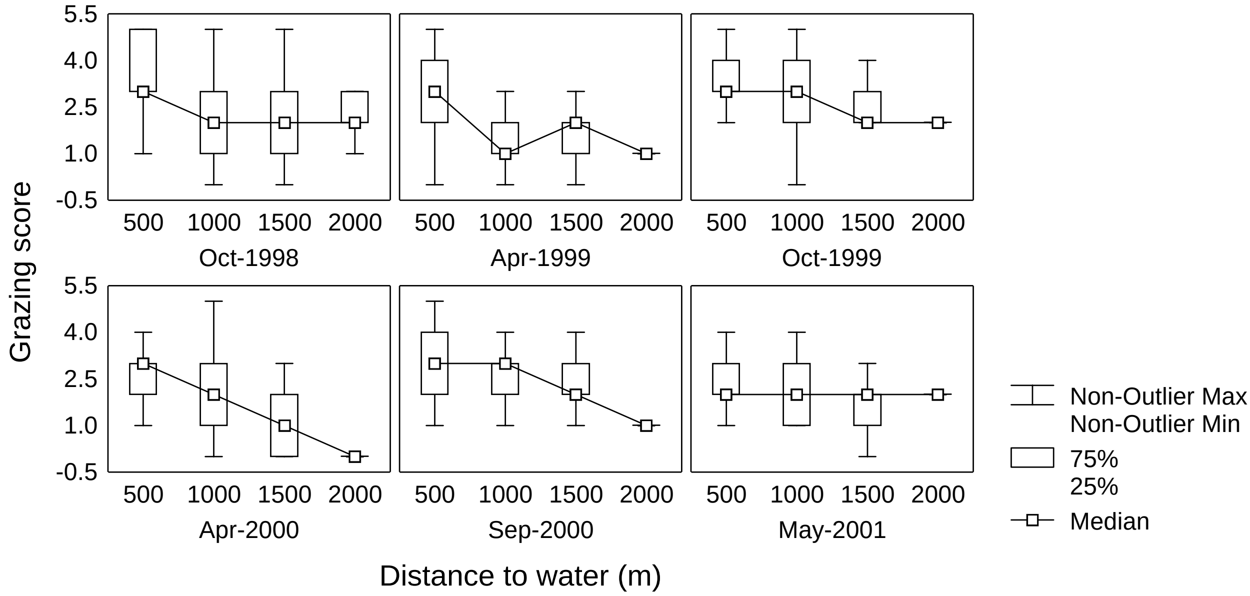

Figure 14.1: Effect of distance to water on grazing in Budgie Paddock through time.

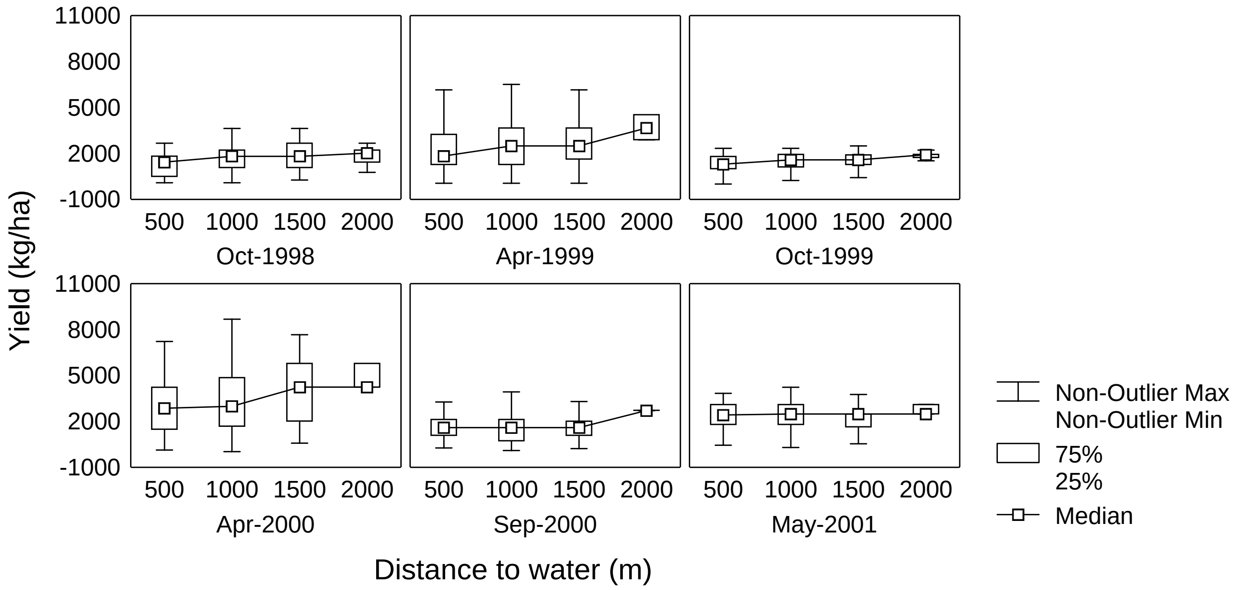

Figure 14.2: Effect of distance to water on yield in Budgie Paddock through time.

Table 14.4: Percentage composition of all species contributing ≥ 1% of the total yield in Budgie and Wedgetail Paddocks (average of all time sets).

Budgie		Wedgetail	
Species	% composition	Species	% composition
Astrebla spp.	33.0	Astrebla spp.	23.9
Chrysopogon fallax	18.4	Aristida latifolia	18.9
Aristida latifolia	13.9	Chrysopogon fallax	17.9
Dichanthium sericeum	9.3	Brachyachne convergens	5.7
Iseilema spp.	5.7	Dichanthium fecundum	4.7
Herbs	3.4	Enneapogon polyphyllus	4.4
Brachyachne convergens	3.4	Chionachne hubbardiana	4.1
Dichanthium fecundum	2.8	Herbs	3.6
Enneapogon polyphyllus	2.6	Dichanthium sericeum	3.1
Enneapogon purpurescens	1.5	Enneapogon purpurescens	2.3
Aristida spp. (annuals)	1.5	Sorghum sp. (annual)	2.3
Panicum decompositum	1.4	Aristida spp. (annuals)	1.9
		Iseilema spp.	1.6
		Panicum decompositum	1.4

Table 14.5: Correlation between vegetation and grazing variables and distance to fire in previous year.
Spearman's Rank Correlation. *** P<0.001, **P<0.01, * P<0.05

.	All Years	Aug 1997	Oct 1997	Mar 1998	April 1998	Oct 1998	April 1999	Oct 1999	Apr 2000	Sept 2000	May 2001
n	2413	191	237	265	352	407	na	na	508	440	418
Yield (kg dm/ha)	0.18***	na	0.64***	0.61***	ns	ns			0.32***	ns	0.14**
Cover (%)	0.25***	0.33***	0.41***	0.41***	0.19***	ns			0.13**	ns	0.36***
Grazing score	-0.09***	-0.30***	-0.59***	0.36***	0.14*	0.21***			ns	ns	-0.31***