SUSTAINABLE AND PROFITABLE NATIVE GRASS-LEGUME PASTURES FOR SOUTHERN SPEARGRASS LANDS

MEAT RESEARCH CORPORATION PROJECT CS195

FINAL REPORT

SUSTAINABLE AND PROFITABLE NATIVE GRASS-LEGUME PASTURES FOR SOUTHERN SPEARGRASS LANDS

Final report to the Meat Research Corporation

Project CS195

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CSIRO Division of Tropical Crops and Pastures
in collaboration with
Queensland Department of Primary Industries

CSIRO AUSTRALIA

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LAND & WATER RESOURCES

Meat Research Corporation

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PART A. ABSTRACT

A grazing trial was conducted to identify environmental and management factors affecting the stability, productivity and profitability of grazing in the southern speargrass lands. The project assessed the effects of four stocking rate regimes (very low, low, medium, high), and legume bandseeding, on the composition and stability of pastures in three land classes, representing the variation occurring in commercial paddocks. Increased grazing pressure led to the replacement of large, productive perennial grasses (notably *Heteropogon contortus*) by smaller, short-lived grasses and forbs, perennial forbs, and ultimately by drought-resistant perennials such as *Fimbristylis dichotoma* and *Chrysopogon fallax*. Soil changes were associated with the pasture changes, leading to increased rainfall runoff and lowered potential plant productivity. The mid slope land class was relatively resistant to degradation. Other land classes were adversely affected by grazing pressure, but upper and lower slopes were modified by different processes.

Five pasture states were described in relation to grazing pressure. Legume sown paddocks were also prone to loss of perennial grasses, particularly on the upper and lower slopes, and there was little evidence that oversowing of legumes was able to offset the effects of higher stocking rates. Even though legume sowing increased animal productivity, there were considerable financial and ecological risks.

The cattle were able to buffer the wide range of pasture conditions; liveweight gain and health was maintained in all treatments during the growing seasons. However, in the high and medium stocking rate paddocks, there were forage shortages in the dry season associated with pasture states of low potential plant productivity. Of the four stocking rate regimes, the highest provided neither economic advantage nor good pasture condition. Lightest stocking favoured pasture condition but was insufficient to generate a profit at the whole enterprise level when property debt had to be serviced. The medium stocking rate resulted in the highest gross margins and return on equity, but there are several indications that this stocking rate could be associated with loss of pasture condition. The low stocking rate regime represented a compromise between economic profitability and pasture condition. At this stocking rate, *H. contortus* populations persisted and soil losses were relatively low.

A number of management principles have been developed from the outcomes of the trial. These are linked to the more general issues of ecological and economic risk. In the broadest terms, management options that carried the greatest potential for economic return (i.e. legume sowing and elevated stocking rates) have a higher probability of ecological damage in terms of losses of pasture productivity, increased rainfall runoff and soil erosion. A second general consideration is the importance of monitoring pasture condition, irrespective of the condition of the livestock, as cattle are able to buffer the effects of deteriorating pasture condition.

Amongst a range of communication activities conducted, two were chosen for particular emphasis as the best methods for communication of research results:

1) Field walks for producers involving information exchange and contextual interpretation. Six of these exercises were conducted in the last two years of the trial.

2) The use of pasture managment planning workshops. We developed, completed and field tested a Property Planning Management Module in collaboration with Queensland Department of Primary Industries specialist staff. The module addressed ecological and economic risk associated with land resource management in the southern black speargrass region and incorporated results of the trial.

PART B. EXECUTIVE SUMMARY

BACKGROUND

The dominant land use in the sub-tropical woodlands region of eastern Australia is the extensive grazing of pastures by beef cattle. These woodland pastures represent an important natural and economic asset but their status is under threat. A significant proportion of the grazed pastures are considered to have already been seriously degraded or are under threat of degradation. The major causes of the degradation have been attributed to overgrazing and generally poor land management practices. This project addressed these issues through a grazing trial conducted in black speargrass (*Heteropogon contortus*) pasture from 1989-1996. The project assessed the effects of stocking rate and legume augmentation on the composition and stability of pastures in different land classes that represented the variation occurring in commercial paddocks. The multi-disciplinary approach integrated studies of pasture composition and community ecology, plant population biology, plant and animal production, soil hydrology and economics. The results were used to synthesize a picture of pasture dynamics under drought and heavy grazing pressure, with consideration given to their implications for the financial and ecological sustainability of grazing enterprises.

PROJECT OBJECTIVE 1. IDENTIFY ENVIRONMENTAL AND MANAGEMENT FACTORS AFFECTING THE STABILITY, PRODUCTIVITY AND PROFITABILITY OF GRAZING THE SOUTHERN SPEARGRASS LANDS.

Decline of *H. contortus* through high grazing pressure was linked with pasture and soil degradation in black speargrass pastures. The degradation is manifested as the replacement of large, productive perennial grasses (States 2 and 3, Table i) by smaller, short-lived species, forbs and drought resistant perennials such as *Fimbristylis dichotoma* and *Chrysopogon fallax* (States 4 and 5). Soil changes are linked to the processes of decline - the effects of trampling and shifts to less productive plant species are likely to influence soil characteristics and increased runoff has been measured as a result of increased stocking rates and grazing pressures. Periods of drought are able to accelerate these processes by reducing plant growth and increasing grazing pressure. The soil changes associated with high stocking rates are not likely to be reversible in the short-term, or possibly even in the long-term.

A second type of decline of *H. contortus* has also been associated with very low grazing pressures and stocking rates. Under these circumstances, *H. contortus* tended to be replaced by equally robust perennial tussock grasses (State 1, see Table i). However, the changes were not associated with decline in soil condition and increased rainfall runoff.

The presence of extensive areas of State 1 was associated with degradation of other parts of the paddocks as a result of cattle focussing grazing pressure away from State 1 areas, to those containing preferred plant species. Areas of increased grazing pressure were converted to States 4 and 5, leading to a divergence of pasture condition within the paddock. State 1 species are often unpalatable (e.g. coarse-leaved *Aristida* spp., *Cymbopogon refractus* and *Arundinella nepalensis*) and have been generally associated with lowered animal productivity. However, we were unable to find such a link and the potential productivity of State 1 species was high.

Land classes were associated with differences in resistance to grazing-induced degradation. Mid slopes were highly resistant to degradation, maintaining both high water infiltration rates and populations of *H. contortus*. Upper and lower slopes were both vulnerable to degradation, but two different processes led to this degradation. Lower slopes tended to have significant amounts of State 1 species leading to declines in *H. contortus* as described above. A second process was observed on the upper slopes where lowered plant productivity resulted from the soils being shallower and drier. Total grazing pressure on the vegetation of the upper slopes was relatively higher and this led to degradation.

The ecological effects of legume sowing were similar to those of increased grazing pressure - decline of *H. contortus* populations and increases in annual species. These processes were most evident on the more vulnerable land classes (upper and lower slopes). We could not conclude from the trial that legumes were able to offset the effects of grazing pressure.

Increased stocking rates resulted in increasing levels of water runoff and soil loss. Losses of water and soil were also greater for upper slopes compared to mid slopes. There is a major problem if soil is washed into surface waters and is lost to the system. With this in mind, it becomes evident that the condition of the lower slopes, which are adjacent to watercourses, is critical. The presence of State 1 and 2 pastures on the lower slopes may be most critical to the long-term condition of the pastures.

The cattle were able to buffer the effects of pasture condition and maintained weight gain and health during the growing season over the range of conditions. However, in the high and medium stocking rate paddocks, there were forage shortages in the dry season, requiring the use of feeding supplementation to maintain stocking rates. This management further obscured the effects that differences in pasture condition may have had.

PROJECT OBJECTIVE 2. INTEGRATE THE INFORMATION INTO A MANAGEMENT FRAMEWORK THAT HIGHLIGHTS DIFFERENT PRODUCTION STATES AND TRANSITION PATHS.

A state and transition model has been developed to summarize the effects of increasing grazing pressure on the composition of black speargrass pastures, and is summarized in Table i. Associated features relating to productivity, soil condition and probability of transitions have been linked to each state.

A second model has been developed to describe the effects of legume sowing on different land classes and stocking rates. Legume establishment varied with stocking rate and land class, with different legume species being associated with the various combinations of these two factors. The pasture states described in Table i were used to characterize the legume sown treatments. Compared to equivalently stocked native pasture, legume sown paddocks contained higher frequencies of States 4 and 5 species, indicating that, overall, they did not have improved pasture condition.

Table i. Summary of a state and transition model developed to describe the effects of increased grazing pressure on speargrass (*Heteropogon contortus*) dominated pastures

	State 1	State 2	State 3	State 4	State 5
Grazing pressure	Lowest	→	→	→	Highest
General features	Perennial grasses of low palatability	Perennial grasses; *Heteropogon* dominant	Perennial grasses; *Heteropogon* declining	Annual and short-lived grasses and forbs	Short perennial grasses and sedges
Indicator species	*Arundinella* *Cymbopogon* *Aristida ramosa* *A. calycina*	*Digitaria brownii* Siratro *Cyperus fulvus*	*Bothriochloa decipiens*	*Indigofera* *Sida* sp. *Tragus* *Eragrostis* spp.	*Fimbristylis* *Chrysopogon* *Richardia* *Zornia*
			Associated features of states		
Rainfall runoff	Very low	Low	Low	High	High
Potential plant productivity	High	High	Moderate	Moderate /Low	Low
Plant palatability	Low	Moderate	Moderate	High	High
Animal productivity in growing season	High	High	High	High	High
Forage deficit in winter	Low	Low	Low	High	High
Heteropogon adult population density	Moderate	High	Moderate	Moderate /Low	Low
Heteropogon recruitment	Moderate	High	High	Low	Low
Potential for transition to lower numbered state	Not applicable	High	High	Moderate	Low

PROJECT OBJECTIVE 3. CHARACTERIZE OPTIONS RELEVANT TO THESE STATES AND TRANSITIONS IN TERMS OF POSSIBLE TRADE-OFFS BETWEEN PRODUCTION BENEFITS AND RESOURCE DEGRADATION.

Attempts to relate animal production to specific pasture states were not successful. Production data are collected on a paddock basis and cannot account for grazing preferences within a paddock. However, **there was a clear link between the low potential plant productivity of States 4 and 5 and the appearance of feed deficits in the dry season.**

Of the four stocking rate regimes, the highest provided neither economic advantage nor good pasture condition. Lightest stocking favoured pasture condition but was insufficient to generate a profit at the whole enterprise level when property debt had to be serviced. The medium stocking rate resulted in the highest gross margins and return on equity, but there are several indications that this stocking rate could be associated with the loss of pasture condition - evidenced by a decline in *Heteropogon* and, by extrapolation, water runoff and soil movement **The low stocking rate regime represented a compromise between economic profitability and pasture condition**. At this stocking rate, *H. contortus* populations persisted and soil losses were relatively low.

A liveweight gain advantage of approximately 22 kg per steer was obtained from legume sowing. However, the projected economic return from legume sowing was heavily influenced by the establishment success of the initial sowing and whether it is in fact possible to increase and sustain stocking rates at a higher level than those for the previously untreated native pasture. Return is substantially higher when the stocking rate is doubled regardless of whether the initial establishment is successful or not. Given that the ecological effects of legume sowing are similar to the effects of higher grazing pressure at the same stocking rate (reductions of perennial grasses and increases in annuals and forbs), it is clear that elevated stocking of legume sown paddocks can lead to pasture degradation. **A general conclusion is that while the economic advantage of legume sowing may be positive under some circumstances, the option carries considerable financial and ecological risk.**

PROJECT OBJECTIVE 4. DEVELOP GUIDELINES TO ASSIST BEEF PRODUCERS TO USE THESE FRAMEWORKS TO MAINTAIN OR IMPROVE LAND CONDITION.

A number of management principles have been developed from the outcomes of the trial. These fall under the general rubric of ecological and economic risk. In the broadest terms, **management options that carry the greatest potential for economic return (legume sowing and elevated stocking rates) have a higher probability of ecological damage in terms of losses of pasture productivity and soil condition**. A second general consideration is the importance of monitoring pasture condition, irrespective of the condition of the livestock, as cattle are able to buffer the effects of deteriorating pasture condition. However, there seem to be unquantified risks of lowered productivity due to losses of soil and productive plants in the long-term, that were beyond the scope of this study.

The management principles are not prescriptive and depend on the delivery of detailed information on ecosystem processes in a form that producers can apply intelligently to their own situation. We have used the detailed results of the grazing trial to illustrate the following recommendations:

- That stocking rates be adjusted to ensure the maintenance of *H. contortus* populations (or perennial grasses of equivalent utility) in pastures.
- That managers take into account the ecological and economic risks associated with increasing stocking rates.
- That the ecological and financial risks of legume sowing be incorporated into management decisions relating to legume augmentation.
- That monitoring of pasture condition be adopted as a priority tool in property management.
- That monitoring take into account the fact that some parts of the landscape are more vulnerable to ecological change.

- That plant identification skills be provided to enable pasture monitoring to be conducted by producers.
- That fire be considered as a tool to effect a transition from State 1 to State 2, where an abundance of State 1 is putting severe grazing pressure on other parts of the paddock.
- That strategies to rehabilitate degraded pastures be adjusted to current pasture condition and climatic conditions .

Amongst a range of communication activities conducted, two were chosen for particular emphasis as the best method of communicating these management principles:

1) Field walks for producers involving information exchange and contextual interpretation. Six exercises were conducted in the last two years of the trial.

2) Property planning management workshops. A Property Planning Management Module was developed, completed and field tested in collaboration with specialist PMP staff from the Queensland Department of Primary Industries. The module addressed ecological and economic risk associated with grazing management in the southern black speargrass region and is the first of its kind in Queensland.

FUTURE RECOMMENDATIONS ARISING FROM THE RESEARCH

A number of recommendations regarding future research and communication activities are suggested. These relate to the further development of state and transition models, the need to increase the generality of research results and to collect data at a scale that increases their relevance to producers. Communication activities need to take into account the particular difficulties of delivering messages relating to sustainability. This will involve more intensive communication, with the inclusion of educational components that address ecological concepts and plant identification. These are essential to provide producers with the appropriate tools for pasture monitoring.

1. INTRODUCTION

1.1. Background

The dominant land use in the sub-tropical woodlands region of eastern Australia is the extensive grazing of pastures by beef cattle (Mott and Tothill 1984). In the main, these grazed woodlands comprise native pastures with limited management input beyond timber control, fencing, and provision of water supplies. To a lesser extent, some exotic plant species, notably legumes, have been introduced to these pastures with an aim to raising the production potential via improved liveweight gain and increased stocking rates. Fire, applied episodically to remove dry material and promote new growth, has been a feature of pasture management over many years, but is now in decline.

These extensive woodland pastures represent an important natural and economic asset. They can provide a variety of production and other environmental services now and, potentially, well into the future. However, their status is under threat. A significant proportion of the grazed pastures are argued to have already been seriously degraded or are under threat of degradation (Tothill and Gillies 1992). The major causes of the degradation have been attributed to overgrazing and generally poor land management practices (e.g. MacLeod and Taylor 1995).

The principal production systems employed on pastoral holdings centre on continuous year-around grazing at a range of notional stocking rates. These rates are for most purposes fixed (Partridge 1993), although there is necessarily some variation in these rates both between and within seasons in response to climatic factors, herd dynamics and individual animal growth patterns. While there is a growing interest in alternative grazing systems that involve spelling intervals and rotations of varying length, these remain limited in practice (Jones 1993).

In all grazed rangeland contexts, the effective stocking rate applied at any given time has the most influence on animal production and longer-term pasture resource stability (Wilson and Harrington 1984). Fire management can also play an important role in promoting rangeland health for most grassy ecosystems (Hodgkinson *et al.* 1984). Therefore, decisions concerning the most appropriate stocking rate and whether to include fire regimes into management systems are the main ones confronting livestock managers. A key issue regarding the introduction of exotic species is their persistence and whether the stability of the native grass component can be maintained in legume augmented pastures.

Given the projected importance of both stocking rates and fire regimes on animal production and the sustainable longer-term use of grazing lands, the value of stocking rate and burning trials to determine optimum stocking rates and fire regimes has received some attention in the rangeland literature (e.g. Riewe 1961; Hart 1978; Hodgkinson *et al.* 1984; Wilson 1984; Bransby *et al.* 1988; Bransby 1989). Two issues of particular interest are the projected differences between ecological and economic optima (Workman and Fowler 1986) and quantification of feedback mechanisms between stocking rate, fire, pasture resource status and animal performance (Wilson and MacLeod 1991; Ash and Stafford-Smith 1996).

Despite a significant body of pasture and animal research in the region to date, there remains limited empirical evidence to support decision-making on appropriate stocking rates, fire regimes and the management of legume augmented pastures. This would particularly apply to key management information needs relating to the nature and extent of tradeoffs between animal production and profit in the short term, as well as to tradeoffs between animal production, resource condition and enterprise viability over the longer term. Project CS195, in part, addresses these issues.

1.2. Project objectives

The broad project objectives of CS195 are to:

1. Identify environment and management factors affecting the stability, productivity and profitability of grazing the southern speargrass lands.

2. Integrate these into a management framework that highlights different production states and transition paths.

3. Characterize options relevant to these states and transitions in terms of possible trade-offs between production benefits and resource degradation.

4. Develop guidelines to assist beef producers to use these frameworks to maintain or improve land condition.

The specific experimental objectives are:

a) Measure the establishment of, and short-term stability of the legume component.

b) Assess the stability and productivity of the complex of native grasses, with and without legumes and at a range of stocking rates.

c) Assess the stability and production of the legume component at a range of stocking rates.

d) Measure the liveweight gain of beef cattle on the different classes of native grass pastures and native grass pastures oversown with a mixture of legumes.

e) Measure the effect of pasture condition and a low-cost legume mixture on:
   i) The stability of the native grass component in each of the land classes
   ii) The liveweight gain of cattle

f) Assess the effect of fire, combined with strategic grazing, on botanical composition and productivity of the complex of native grasses.

1.3. Project team

Principal investigator:	Dr John Taylor (CSIRO Division of Tropical Crops and Pastures[1])
Project leaders:	Dr Sue McIntyre (CSIRO DTCP[1]) Mr Neil MacLeod (CSIRO DTCP[1])
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Keith Gould	Art Schulman
Frank Hochmuth	Bevin Smith
Richard Jones	Peter Van Beek
Peter Jones	Peter Vance
Peter Kerridge	Rollo Waite
Lel Wallace	Peter Wandera

1.4. Research activities

This report covers five major research activities based on experiments or data collection conducted at the experimental site. Each research area is focussed on one or more of the three major treatments applied in the field experiment. These are **1) legume augmentation** (presence or absence of band-sown legume mixtures); **2) stocking rate** (up to four levels of stocking in some treatments) and **3) land class** (paddocks located on upper, middle or lower slopes).

1.4.1. Pasture composition

(S. McIntyre, J. Hodgkinson and J. Ogden)
The effects on pasture composition of the three major treatments was monitored over the six-year experimental period. The major focus was on recording data on the legume and perennial grass species but seventy other pasture species were also included in assessments at the beginning and end of the experiment. Woody regrowth was also monitored. The data were used to define pasture states relating to increasing grazing pressure and legume sowing.

1.4.2. Animal production

(N. MacLeod, J. Hodgkinson, J. Ogden)
Animal production was recorded throughout the experiment for all treatments. Liveweight gain data were also used in economic studies of legume sowing and stocking rates and were linked to pasture states.

1.4.3 Soil hydrology

(M. Sallaway and D. Waters)
An associated LWRRDC-funded project (No. QPI2) examined soil movement and water runoff though the application of various techniques, including the use of a rainfall simulator and disc permeameter. These data were collected under different stocking rates, as well as in different land classes and pasture states, to obtain an overall picture of water and soil movement across the landscape. In addition to the use of run-off plots, measurements of underground water flow (using piezometers) and soil moisture (using gypsum blocks) were taken.

1.4.4. Population dynamics of *Heteropogon contortus* and *Aristida*

(D. Orr and C. Paton)
Individual plants of *Heteropogon contortus* and *Aristida* were monitored to assess population changes, plant size and seed production. The status of these populations was measured for two land classes, three stocking rates and in paddocks that were burnt annually and lightly grazed. This study provided information on the mechanisms of population change.

1.4.5. Economic studies

(N. MacLeod)
The economic studies had two thrusts, firstly to highlight the economic impact of the treatment effects in terms of per animal and per hectare performance. For the stocking rate treatments this work was further extended to a whole enterprise analysis, and an assessment of economic risk made on the basis of returns to capital and equity. The second activity was to assess the economic performance of pastures bandseeded with legumes relative to that of native pastures.

1.5. Structure of this report

The structure of the report reflects the interrelated nature of the research activities and the meeting of project objectives. The major Sections 3-6 cover the main treatment variables and the subsections within each section develop the findings and issues of importance that emerged from the different research activities. Thus the results of individuals' research appear in one or more major sections. The findings of each major section is summarized and contributes to the development of synthesized themes. These are incorporated into Section 7 which presents the state and transition models and the overall synthesis of results.

Sections in which the objectives are addressed are summarized below:
Objective 1. Sections 3-6 describe how environment (climatic conditions and land class) and management factors (legume sowing, stocking rate and fire) affect the stability, productivity and profitability of the pastures.
Objective 2. State and transition models are presented in Section 7.
Objective 3. The possible trade-offs between production benefits and resource degradation of different states are presented in Section 7.
Objective 4. Guidelines to assist beef producers to use these frameworks are developed in Sections 7 and 9 while Section 8 describes how these guidelines have been packaged and presented to beef producers.

1.6. Acknowledgments

We would like to thank the McIver family of 'Glenwood', and the CSIRO Narayen Research Station staff for providing numerous forms of support; the Land and Water Resources Research and Development Corporation supported the hydrological studies (Project No. QPI2); Monsanto provided herbicide; Incitec provided fertilizer and Mr Jim Robertson of 'Dykehead' (via Mundubbera) contributed legume seed for the trial.

2. METHODS

2.1. The experimental site

The trial was established on the property 'Glenwood', near Mundubbera, (25°41'S, 150°52'E) with a history of about 100 years of stock grazing and periodic timber control. The site was selected on the basis that pasture condition at the beginning of the experiment was considered to be typical for a commercial property in the district. A 400 ha portion of 'Glenwood' was leased for the experiment and managed by CSIRO staff located on the neighbouring field station, 'Narayen'.

The original vegetation at 'Glenwood' before European settlement was probably eucalypt woodland of unknown density, but which is likely to have been burnt regularly, maintaining an open savanna structure. The understorey would have been grass dominated and historical records for this vegetation type suggest that kangaroo grass (*Themeda triandra*) is likely to have been a major species. The vegetation is still a grassy woodland although now dominated by black speargrass (*Heteropogon contortus*, hereafter referred to as *Heteropogon*). In the past, regular burning by indigenous people probably controlled tree density. Currently, eucalypt regrowth tends to be prolific and is now typically controlled by chemical means.

In addition to the 'Glenwood' site, two trial paddocks were set up in similar country on 'Narayen' to include *Heteropogon* grassland that had a history of more lenient grazing. Four paddocks were also set up at 'Narayen' on ridges that had supported spotted gum (*Eucalyptus maculata*) forest with a shrubby understorey. This vegetation type is quite distinct from the grassy woodlands as it tends to have a shrubby rather than a herbaceous ground layer and is on relatively unproductive soil. For ecological and statistical reasons, these ridge (spotted gum) treatments did not form part of the core experimental design and are not systematically discussed in the report. The sites are ecologically marginal, difficult to keep clear of shrub regrowth (see Sect. 4.4) and of questionable value for pasture production.

Average annual rainfall in the area is 708 mm (1888-1995), 70% of which falls between October and March (Cook and Russell 1983). Soils are granite-derived, mainly yellow podzolics with a coarse textured surface.

Twelve months prior to the imposition of treatments the site was burnt and then left unstocked while fences were erected. Treatments commenced in December 1989 and continued until 1995/6. All young trees (diameter <50 mm) were killed between 1989 and 1990 (see Sect. 4.4) and the larger trees were thinned in 1989.

2.2. Climatic conditions

The overriding climatic condition between 1989 and 1995 was drought. This site has an historical annual long term rainfall average of 708 mm (as at 1996). Over the experimental period, the site experienced moderate drought conditions for 39 months (Fig. 2.2a) and severe drought conditions prevailed for 21 months, as determined by the QDPI Rainman software package. A moderate drought is when 395 to 441 mm is received in 12 months (second driest 5% of calendar years). A severe drought is where less than 395 mm falls in 12 months (driest 5% of calendar years).

After good spring rains, the first legumes were sown in Nov./Dec. 1989. This sowing was followed by the second driest summer on record (over 100 years of records). The 1990-91 year was the seventh driest on record. The run of poor growing seasons at this stage had been exceeded only twice on record. This second consecutive dry year forced reductions in stocking rates across the entire experiment to protect legumes from heavy grazing. By 1992, the 'Glenwood' site had been exposed to 21 months of continuous drought. The site was then classified as experiencing severe drought for 80% of this time.

By 1993, the previous four consecutive growing seasons had been the driest in recorded history. It was this succession of recent dry years which had more impact, than the severity of the individual years. The 1993-1994 year was also dry, although the February and March 1994 were above average rainfall months. The 5 year total to June 1994 was the lowest since rainfall records began in the district in 1887. Rainfall received in 1994/1995 was 438 mm. This is well below the 108 year average of 708 mm. This gave six consecutive years of below average rainfall at 'Glenwood' and over the experimental time-frame of 79 months, the site was in a state of drought for 60 months. It is in the context of these ongoing dry conditions that the results of the experimental work have to be viewed.

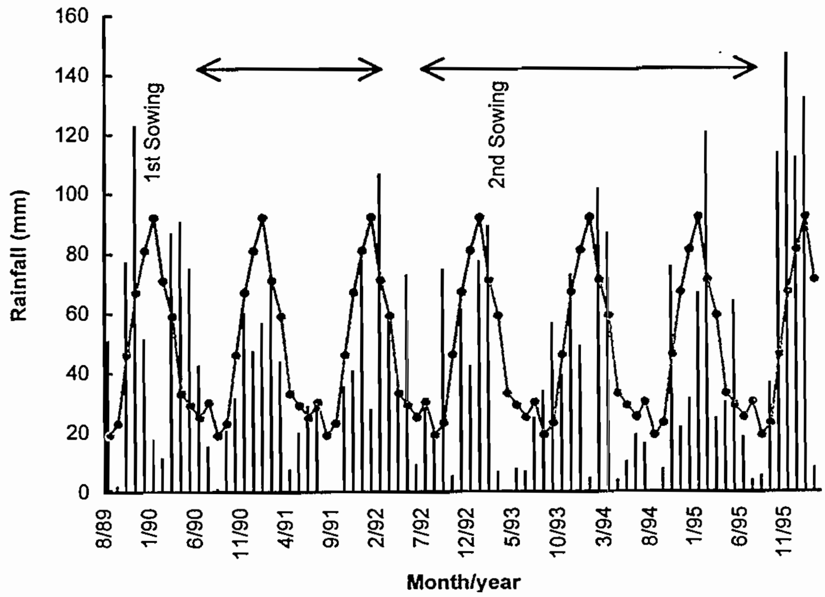


Fig. 2.2a. Monthly rainfall recorded at 'Glenwood' (bars) compared with decile 5 average rainfall (•—•) . Arrows(↔) indicate times of drought during the experimental period as defined by the QDPI Rainman computer software. The two legume sowings were in Nov.-Dec. 1989 and Feb. 1993.

Individual rainfall events during this time have also been below average, although some events have produced intensities which approach the two year Average Recurrence Interval (ARI). ARI is the average number of years within which an event will be equalled or exceeded. For any location, there is a general relationship between the duration and intensity of rainfall events. Longer events usually have greater rainfall totals, but are of lower average intensity than shorter events (Table 2.2a). For example, the event of 21/11/1995 recorded 8.6 mm of rain falling at 103 mm /hour in five minutes but 15.6 mm at 94 mm /hr in the 10 minute period. Those long events may also contain short bursts of rain with high intensities. Events with high average intensities occur less often than those with low average intensities.

Frequency distributions can be fitted to long-term rainfall/duration data to give an estimate of the probability of any intensity/duration combination occurring. The resultant distributions are termed intensity-frequency-duration (IFD) curves (Fig. 2.2b). By comparing the recorded data in Table 2.2a with the long term distribution of the site, an indication of the probability of an event can be achieved. For example, half the ten minute rainfall periods approximated or exceeded the two year ARI (95 mm/hr), but only one exceeded the ten year ARI (140 mm/hr). The high intensity events that did occur, produced little runoff due to the dry antecedent moisture conditions.

Table 2.2a. Rainfall intensities (mm hr^{-1}) for 5, 6 or 10 minute periods recorded for major runoff producing events 1992-95 at 'Glenwood'.

Rain period	Event date							
	9 Feb 1992	29 Mar 1992	5 Feb 1993	6 Feb 1993	21 Nov 1993	18 Feb 1995	20 Nov 1995	21 Nov 1995
5 min	98	77	110	86	139	178	122	103
6 min	98	64	102	80	134	178	116	100
10 min	74	55	85	70	114	158	97	94

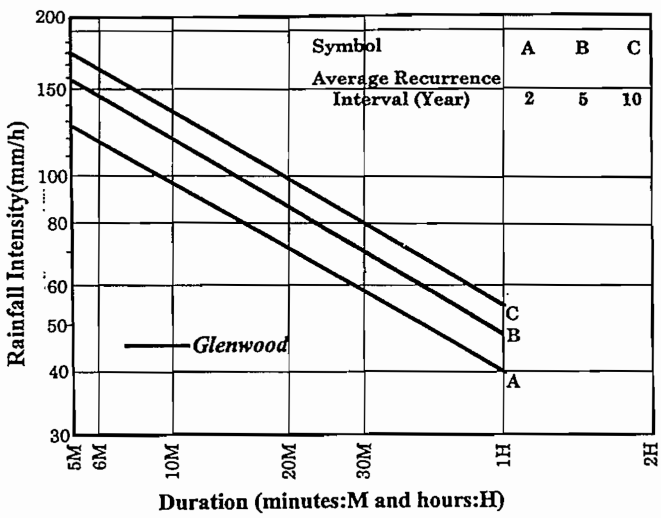


Fig. 2.2b. Relationship between rainfall intensity, frequency and duration at the 'Glenwood' site at three levels of probability (A, B, C) derived from long-term data.

2.3. Grazing trial - core design

2.3.1. Experimental design

Three main experimental treatments were incorporated into the core design of the grazing trial established at 'Glenwood'. Their inclusion in the overall design is outlined here and details of the treatments themselves are described in Sect. 2.4 (stocking rate), Sect. 2.5 (legume sowing) and Sect. 3.1 (land class). The trial was based on an incomplete factorial design (not all possible treatment combinations were provided). Each treatment combination in the trial described in this report had two replicate paddocks.

Land class paddocks These formed the main part of the experimental design and consisted of paddocks in which fences were positioned so that cattle were confined to one of the three major land classes (upper, mid and lower slopes). The three land classes represented three treatment levels. Two other treatments, stocking rate (four levels) and legume sowing (two levels, sown and native pasture) were applied over the land class treatments. There were a total of 32 land class paddocks which varied from 2.2 - 6.6 ha depending on stocking rate.

Landscape paddocks These differed from the land class paddocks in that cattle had access to three land classes within the paddock rather than being confined to a single land class. Landscape paddocks were 13.3 ha and were used to compare two 'Narayen' native pasture (lighter grazing history) with two at 'Glenwood'. These four paddocks were not legume sown and were grazed at the medium stocking rate. A stocking rate (low and medium stocking within legume sown treatment) and a legume comparison (sown and unsown within the medium stocking rate) were also possible between the six landscape paddocks at 'Glenwood'.

2.3.2. Statistical analysis

The floristic and animal liveweight gain data (see Sect. 2.6, 2.7.1) were analysed using Analysis of Variance on 38 paddocks. As the overall design was not fully factorial, six analyses were required to fully explore the treatment effects and these are summarized in Table 2.3.2a. Here the limits of the treatment combinations are apparent e.g. all four stocking rates can be compared on legume sown paddocks only and all three land classes can be compared across two stocking rates.

As some of the ANOVA designs are more powerful than others in the comparison of a particular treatment, it is possible to get a significant effect for a treatment in one analysis and not in another. It is also possible to obtain different averages for a particular treatment (e.g. three estimates of any particular measure can be obtained for the medium stocking rate, using ANOVA 2, 3, or 4). For clarification it will often be necessary to relate particular results to one or more of the ANOVA designs described in Table 2.3.2a.

For some treatment combinations that were represented in both land class and landscape paddocks, a comparison was possible between land classes fenced separately and those within landscapes (ANOVA 6).

Table 2.3.2a. Six analyses of variance (ANOVA) used to examine all treatment combinations in 38 paddocks at 'Glenwood' and 'Narayen' sites. Some paddocks were included in more than one analysis. All treatments had two replicates, accounting for twice the number of paddocks as the number of treatment combinations in each ANOVA.

	Treatment	Level
ANOVA 1 (landscape paddocks)	Grazing history	Commercial ('Glenwood')
(Total 2 x 2 = 4 paddocks)		Light ('Narayen')
ANOVA 2-5 (these involved land class paddocks only)		
ANOVA 2	Land class	Upper slope
All paddocks legume sown		Mid slope
(Total of		Lower slope
3 x 2 x 2 = 12 paddocks)	Stocking rate	Low
		Medium
ANOVA 3	Stocking rate	Very low
All paddocks legume sown		Low
		Medium
(Total of		High
4 x 2 x 2 =16 paddocks)	Land class	Upper slope
		Mid-slope
ANOVA 4	Stocking rate	Low
		Medium
(Total of	Land class	Upper slope
2 x 2 x 2 x 2 =16 paddocks)		Mid slope
	Legume sowing	Legumes sown
		Native pasture
ANOVA 5	Land class	Upper slope
All paddocks at medium stocking rate		Mid slope
		Lower slope
(Total of 3 x 2 x 2 =12 paddocks)	Legume sowing	Legumes sown
		Native pasture
ANOVA 6 (land class paddocks compared with land classes within landscapes)		
All paddocks at medium stocking rate	Land class vs landscape	Landclass fenced separately
		Land class within landscape
(Total of 3 x 2 x 2 x 2 =24 paddocks or landscape portions)	Legume sowing	Legumes sown
		Native pasture
	Land class	Upper slope
		Mid slope
		Lower slope

2.4. Definition and description of stocking rates

All paddocks were grazed continuously by Belmont Red steers, which were introduced as weaners and retained on the site for two years, with an annual change-over of half the animals. Differential stocking rates were initially created by the use of experimental plots of different sizes (2.2, 3.3 and 6.6 ha) with two steers per plot. Prior to June 1993 there were three notional stocking rates: 0.3 steers/ha, 0.6 steers/ha, and 0.9 steers/ha. There were more replicates of the 0.6 steers/ha paddocks which had been reserved for additional treatments. Owing to the dry conditions and the need to establish legume populations, the notional stocking rates were halved in all paddocks over four periods, for a total of 27 months of the 50 month experimental period.

In August 1993 a fourth stocking regime ('very low') was created by permanently removing half of the animals from the 0.3 steers/ha legume paddocks (final stocking rate of 0.15 steers/ha). A new set of 0.3 steer/ha paddocks was created by removing half of the animals from the set of 0.6 steers/ha legume paddocks that had been reserved for additional treatments within the GLASS trial. The native pasture paddocks that were notionally stocked at 0.3 steers/ha prior to 1993, stayed at this level and these two sets of paddocks formed the 'low' stocking rate regime. From that time the actual stocking rates were held at their relative levels, giving four stocking rate regimes: **very low** (0.3/0.15), **low** (0.6/0.3 or 0.3/0.3 steers/ha), **medium** (0.6/0.6 steers/ha) and **high** (0.9/0.9 steers/ha). The first and second of these stocking levels listed in brackets identify the notional stocking rates prior to, and after, August 1993 respectively. The stocking history of the four regimes are detailed in Table 2.4.a. The mixed stocking rates in the paddocks forming the low stocking regime apply to the first four years but not the last three years. Only the comparison of the legume treatment of ANOVA 4 involves the possible confounding effect of mixed stocking rates (see Table 2.3.2a)

Table 2.4.a. Actual stocking rates for the four stocking rate regimes over the study period 1989-1995. In the 'Low' regime, two rates are listed: sown paddocks, native paddocks. The longest period of sustained stocking rates is indicated in bold.

Dates	Stocking rate regime (steers/ha)			
(month/year)	Very low	Low	Medium	High
7/89 - 9/89	0.3	0.6, 0.3	0.6	0.9
9/89 -11/89	0	0	0	0
11/89 - 3/90	0.3	0.6, 0.3	0.6	0.9
3/90 - 7/90	0.15	0.3, 0.15	0.3	0.45
7/90 - 1/91	0.3	0.6, 0.3	0.6	0.9
1/91 - 6/91	0.15	0.3, 0.15	0.3	0.45
6/91 - 8/91	0.3	0.6, 0.3	0.6	0.9
8/91 - 7/92	0.15	0.3, 0.15	0.3	0.45
7/92 - 12/92	0.3	0.6, 0.3	0.6	0.9
12/92 - 2/93	0.15	0.3, 0.15	0.3	0.45
2/93 - 4/93	0	0	0	0
4/93 - 6/93	0.15	0.3, 0.15	0.3	0.45
6/93 - 8/93	0.3	0.6, 0.3	0.6	0.9
8/93 - 3/96	**0.15**	**0.3**	**0.6**	**0.9**

2.5. Legume sowing

A mixture of six legumes was oversown into the pasture by bandseeding (Cook *et al.* 1993). This technique simultaneously drills seed, places fertilizer and sprays a 50 cm wide band of herbicide (glyphosate in this trial). One third of the sown area was herbicide treated in bands across the paddock. Fertilizer (molybdenized superphosphate; 0.02% Mo; 8.8% P) was applied at 45 kg ha^{-1}. Legumes were sown in November 1989, immediately after the first collection of floristic data. Because of poor establishment under the dry conditions, a second sowing was made in February 1993. Legumes sown (by seed weight, total = 3 kg ha^{-1}) were 50% siratro (*Macroptilium atropurpureum*), 17% wynn cassia (*Chamaecrista rotundifolia*), 12% fine-stem stylo (*Stylosanthes guianensis* var. *intermedia*), 12% seca stylo (*Stylosanthes scabra*), 5% bargoo joint-vetch (*Aeschynomene falcata*) and 4% lotononis (*Lotononis bainesii*).

2.6. Floristic data collection

Floristic data were recorded in quadrats approximately located on grid points across the entire site. Thus the density of quadrats was the same for all paddocks but total number of quadrats varied according to the size of the paddock. The main data collected were the relative rank (according to biomass) of selected species, together with an estimated % contribution to total biomass of the top four species ranked. Total % cover and biomass of the vegetation was also estimated visually. The Botanal package (Tothill *et al.* 1992) was used to process data and convert biomass estimates to kg/ha. This involves the use of reference standards which are harvested and calibrated against yield estimates. As well as the biomass data, the frequency of species was used as a measure of abundance. Frequency was calculated as the percentage of quadrats in which a species was either present (frequency) or ranked as a dominant (frequency of dominance).

1989 and 1995 data sets: Two detailed assessments of pasture composition were made, the first in March 1989, before the imposition of experimental treatments, and the second in March 1995 towards the end of the trial. Eighty species or species groups were recorded in $1m^2$ quadrats located on a 25 x 50 m grid. Cover, biomass and rank estimates were made on a 0.25 x 0.25 area within the larger quadrats. These species and their recorded frequencies are listed in Appendix 2. Additional species that were recorded in the quadrats but which were not included in the analysis due to rarity are listed in Appendix 3.

Abbreviated data sets for 1990-1994: An abbreviated species list was used to record Botanal data annually in 1990-94 as well as spring 1989 and 1993. The main species of interest were: *Heteropogon contortus* , all sown legume species, *Aristida* spp. (all species), *Arundinella nepalensis* and *Chrysopogon fallax*. Other categories recorded were forbs, native legumes, perennial grasses and sedges.

2.7. Cattle weighing and management

2.7.1. Liveweight gain data

Animals were weighed on a six-weekly basis following an overnight fasting (water was available). Prior to 1993, when various spelling/destocking strategies were necessarily invoked, liveweight gain data was only collected for the animal(s) which remained in the paddock for the full season. Two data sets were analysed - liveweight gain per head and per hectare. ANOVAs 2-5 (Table 2.3.2a) were used to analyse the data.

2.7.2. Feeding strategies

Continuing dry conditions were experienced throughout the life of the trial and a severe feed deficit occurred in all of the high stocking rate paddocks, and a proportion of the medium stocking rate paddocks in the late winter season of 1994 . This led to a decision to supplement the affected animals with a ration of pasture hay (1 x 15 kg bale/animal/week Rhodes grass and *Setaria*) or pasture hay and protein blocks (Rumevite green 30% crude protein). The supplementation regime imposed was based on a set of trigger points relating to cumulative weight losses for individual animals in each of the treatment paddocks and was applied differentially according to the age group of the affected animals. When the relevant threshold was reached by at least one animal, all animals in the affected paddocks were supplemented (Table 2.7.2a).

Table 2.7.2a. Thresholds used to determine supplementary feeding regimes imposed after July 1993. Weight loss was determined from the peak weight of animals at the end of the previous wet season (all weight losses occurred during the dry season). Year-1 and -2 animals were those in their respective first and second years on the trial.

Feeding regime	Weight loss of year-1 animals	Weight loss of year-2 animals
No supplement	less than 10%	less than 15%
Pasture hay	10 - 15%	15 - 20%
Hay + protein block	in excess of 15%	in excess of 20%

2.8. Economic analyses

2.8.1 Stocking rate and land class treatments

Economic interpretation of the field experiment results relating to stocking rate and land class treatments involved the construction and comparison of gross margin budgets (Rickards and McConnell 1967). The modelled enterprise was a hypothetical trading steer property in which purchased weaner steers were assumed to be fattened on the treatment pastures and sold direct to meatworks after two years of grazing. Liveweight gain was assessed as the relevant treatment average. A whole enterprise assessment of profitability was made for the stocking rate treatments only by subtracting the overhead costs for a median sized beef cattle enterprise obtained from a MRC-funded survey (Taylor Byrne 1993) from the total enterprise gross margin. Risk is assessed by comparing return to equity for a range of equity ratios. Results are presented in Sect. 4.7.2.

2.8.2 Legume treatment

A static assessment of the economic value of the legume treatment (Sect. 5.3) was made using a comparative gross margin analysis identical to that for the stocking rate and land class treatments, described above. However, pasture "improvement" investments are typically long-lived with benefits and costs accruing at different points of time over the life of the investment. A second, more detailed assessment was made using a multi-period partial budgeting and discounted cash flow analysis (MacLeod *et al.* 1993) (Sect. 5.4). Animal performance was assessed using mean treatment liveweight gain difference between legume and native pasture treatments. Treatment profitability was assessed against conventional capital budgeting appraisal criteria of net present value, benefit-cost ratio, internal rate of return, and pay-back period. Risk assessments were conducted by comparing scenarios in which a second legume sowing was assumed.

2.9. Hydrology

2.9.1 Rainfall runoff plots

The stocking rate treatments monitored for runoff were an exclosure (no cattle) and the low and high stocking rates (Table 2.4a). Measurements commenced in July 1989, on two land classes - upper slopes and mid slopes, and plots covered two types of herbaceous vegetation - patches dominated by *Heteropogon* and by *Aristida* spp. The main soil type was a yellow podzolic with a gritty loamy coarse sand surface texture.

For each stocking rate, plots were installed to measure paddock runoff. These consisted of one large landscape plot and four smaller land class plots per stocking rate. The landscape plots ran from the top of the slope (the narrow-leaved ironbark land class) to the toe of the slope where the mid slopes (silver-leaved ironbark) intergraded with the lower slope (blue gum) land class (Fig. 2.9.1a). Plot length varied slightly depending on the site ranging between 120 and 180 m. Plots were approximately rectangular with a slope of 5%. The large plots were 20 m in width and bounded on all sides so that surface runoff was contained within the plot. Two small plots were established in each of two land classes (upper slope and mid slope) for each of the stocking rates (Fig. 2.9.1a). These were 10 m wide and 7 to 9 m deep, and each was located so as to cover a patch of *Heteropogon* as well as an *Aristida* patch. They represented the smallest hydrologic unit that was recognised in the field.

The landscape and small plots were equipped to measure runoff and sediment movement. Runoff from the small plots was measured via a logged 4 litre tipping bucket, logging at one minute intervals, while runoff from the large plots was measured using a 150 mm Parshall flume. Depth of flow in the flume was measured using a

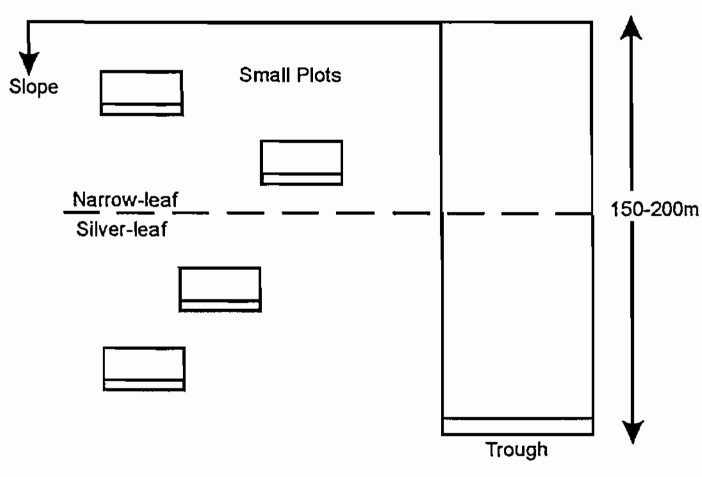


Fig. 2.9.1a. Plot layout installed in each of three stocking rates to measure rainfall runoff at 'Glenwood'. Broken line represents the boundary between two land classes:
upper slopes (= narrow-leaf) and mid slopes (= silver-leaf).

capacitance water height measuring device which was logged at two minute intervals. Rainfall was recorded by replicated tipping bucket rain gauges recording at one minute intervals.

2.9.2 Runoff and infiltration parameters

Runoff and infiltration parameters were determined using a rotating disc rainfall simulator (Grierson and Oades 1977). Parameters for a modified Green and Ampt infiltration model were derived (Connolly *et al.* 1991). Rain was applied to a one square metre plot at an intensity of 86 mm hr^{-1} until a steady rate of runoff occurred (approximately 20 minutes). Plots were replicated three times on each of the two patch types for each of the land classes on each stocking rate.

The pore size characteristics of the soil surface have a major effect on the infiltration characteristics of a site. Pore size was determined using a disc permeameter (Perroux and White 1988) applied at tensions of -1 and -3 cm of water, which allowed separation of the 3 mm and 1 mm pores. The measurements were replicated five times. Pore size measurements were taken on each of the patch types (*Heteropogon, Aristida* spp.) for each of the land classes (upper and mid slopes) at each of the stocking rates.

Subsurface lateral water movement was monitored in conjunction with surface runoff measurements. Piezometers were installed to measure lateral movement in the sandy A horizon, the clay B horizon, and the underlying granitic parent material (Fig. 2.9.2a). Depth of flow within each horizon was measured using a capacitance water height measuring device which was logged at two minute intervals. The piezometers were located at the upper, mid and lower slopes for the high and low stocking rates.

Antecedent soil moisture conditions can significantly affect the measured runoff response. Soil moisture was measured using gypsum blocks at depths of 10, 20 cm and on top of the impervious B horizon (approximately 40 cm). Monitoring of the entire profile was required to establish the wetting front depth and the wetting and drying cycle of the soil. Soil moisture potential was measured at 6 minute intervals using rectangular gypsum blocks. Blocks were installed at the upper, mid and lower slopes for the high and low stocking rates.

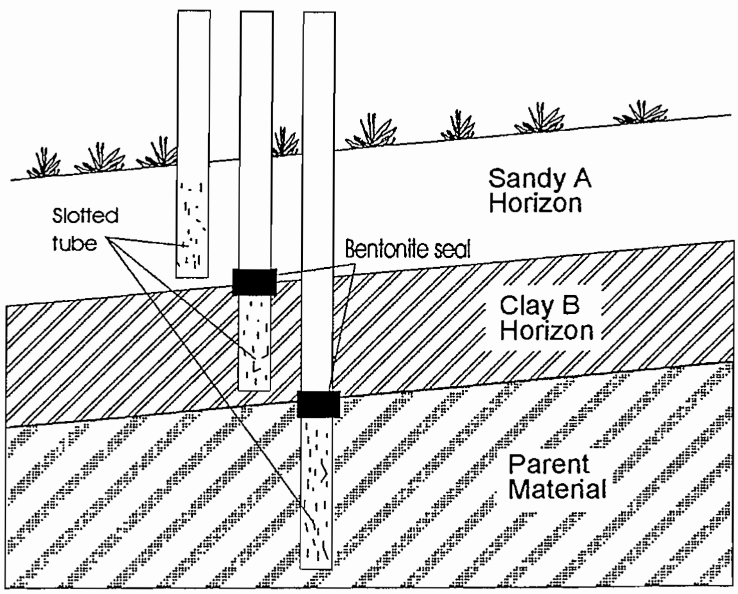


Fig. 2.9.2a Vertical section of soil profile showing the piezometer installation for a single landscape position at three depths.

2.10. Fire treatment

In 1992, the Meat Research Corporation requested the addition of a fire treatment at 'Glenwood'. This request followed a large recruitment of *Aristida* spp. seedlings measured in autumn 1991 at the 'Glenwood' site and research at Brian Pastures Research Station indicating that *Aristida* spp. could be controlled using fire in spring combined with reduced grazing pressure (Orr et al. 1991). Consequently, during winter 1992, two paddocks, each 6 ha in size, were fenced at 'Glenwood' so as to be grazed by one steer (0.15 steers/ha) between autumn 1992 and autumn 1995 (while the paddocks were burnt for the three successive springs). In autumn 1995 these two paddocks were stocked with two steers. These two paddocks were located in a mixed upper and mid slope landscape position. They were burnt each spring between 1992 and 1994 following the first fall of > 25 mm or more of rain between August and November. For the purpose of comparison, results from this burning treatment will be compared with the very low (Table 2.4a) native pasture treatments in the upper and mid slope land classes.

In autumn 1992, pasture composition and yield were estimated using the Botanal technique (Tothill et al. 1992) while permanent quadrats were located and charted (see Section 2.11) to monitor the dynamics of populations of *Heteropogon* and *Aristida* spp. These measurements have been repeated each autumn between 1993 and 1996.

2.11. Population dynamics

The grass tussock was considered the appropriate experimental unit for study and tussocks were delineated in permanently marked quadrats. These permanent quadrats were positioned on the boundaries between *Heteropogon* and *Aristida* spp. patches Wandera (1993) so that the fate of individual tussocks could be monitored through time. Previous attempts to follow individual plants (J. C. Tothill, personal communication) indicated that tussocks break-up with increasing age and it was decided for the current study that the integrity of individual plants could best be monitored in quadrats located in this "interzone" area.

Treatments chosen for the study were two land class positions (mid and upper slope), two pasture types (native pasture and legume sown) and three stocking rates (very low/ low, low/ medium and high). The two lowest stocking rate treatments were each a mixture of paddocks from two of the three lightest stocking rate regimes described in Table 2.4a Twenty permanent quadrats, each 0.5 x 0.5 m, were established in autumn 1990 in two nests each of ten quadrats and were representative of each paddock. Quadrats were selected to contain a minimum of 60 *Heteropogon* plants and the variable number of *Aristida* spp. plants that occurred within these quadrats. Starting in autumn 1990, the position of each *Heteropogon* and *Aristida* spp. tussock in each quadrat was charted using a pantograph and the diameter of each tussock was measured in two perpendicular directions. At this initial 1990 recording, plants of both *Heteropogon* and *Aristida* spp. were classified into mature and seedling plants (plants < 1 cm diameter) so that two age groups of plants were identified for 1990. Subsequent recordings were made annually in autumn when the survival of existing tussocks and the appearance of new seedlings was recorded. At each recording, the level of defoliation on each tussock was recorded using a scale of ungrazed, light, medium or heavy grazing (based on methodology reported in Orr 1980).

Annual seed production of *Heteropogon* was estimated each year between 1991 and 1996 as the product of inflorescence density and seeds per inflorescence. The main flowering/seed production period for *Heteropogon* occurs during mid March so that inflorescence density was measured in the permanent quadrats during late March. The number of seeds per inflorescence was determined from 5 random inflorescences in each paddock in each year. (Plants flowered in late January 1966 so that data on seeds per inflorescence are unavailable, consequently, a figure for seeds per inflorescence was calculated as the mean for each paddock between 1991 and 1995). Inflorescence density was the major component contributing to variation in seed production because there was little variation between years in the number of seeds per inflorescence.

The germinability of the seed produced annually was tested following twelve months laboratory storage because seed of *Heteropogon* is dormant when fresh and requires up to twelve months to overcomes this dormancy. The germinability of seed from each year was tested by germinating three replicates of (25 seeds per replicate) for seven days. Germinability after these storage conditions was considered to reflect seed viability.

The soil seed bank of *Heteropogon* was estimated in spring each year between 1990 and 1995 by germinating soil cores collected from the area adjacent to the permanent quadrats. Each soil core was 5 cm diameter and 5 cm deep and four of these cores were bulked into one sample and there were 15 samples (ie. 60 cores) from each paddock. In the subsequent summer (after seed dormancy had been overcome), seed in these soil samples was germinated on a column of sand in 15 cm diameter pots by watering with an overhead sprinkler for 30 minutes per day in a glasshouse. After six weeks of watering, seedlings of *Heteropogon* were identified, counted and removed (Orr *et al.* 1996).

It is acknowledged that the results obtained from the permanent quadrats do not necessarily reflect overall trends in the larger paddocks. The results are representative only of the behaviour of the population within the permanent quadrats. However, the results from the permanent quadrats do tend to reflect similar trends to that in the larger paddocks, as determined by measurements of botanical composition.

Complete statistical analyses have not yet been conducted on these data. For the purposes of this report, treatment means and their standard errors are presented in order to identify trends in the data.

3. SPATIAL VARIATION IN PASTURES - LAND CLASSES

3.1. What are land classes and why are they important?

3.1.1. Topography

At the site, the land classes are represented by a toposequence of three landscape positions: lower slopes, mid slopes and upper slopes. The land classes are also associated with particular eucalypt species: blue gum (*Eucalyptus tereticornis*) on the lower slopes, silver-leaved ironbark (*E. melanophloia*) on mid-slopes and narrow-leaved ironbark (*E. crebra*) on the upper slopes. The land class boundaries in the experiment were determined from a combination of topography and tree species. In commercial paddocks, more than one land class is usually present and producers in southern speargrass regions tend to recognize the different types of 'country' (land classes) by the tree species that grow on the undulating or hilly landscape.

The significance of land classes lies in the different growing conditions that they provide for pasture plants. This is due to variations in microclimate, soil and drainage conditions that are associated with position on the slope. Because of this variation, it is possible that the same form of management (e.g. stocking rate) will produce quite different responses on different land classes. This is the first grazing trial in Queensland that has attempted to study the different responses of land classes to management. This information is needed to identify which parts of the landscape are most likely to indicate grazing-induced changes and which are most vulnerable to degradation.

3.1.2. How microclimate varied with land class

Grass minimum temperatures and soil water potential were monitored at 'Glenwood' in the different land classes. The results show that minimum temperatures were higher on the upper slopes where there were fewer frosts. Although the number of frosts is similar on the mid and lower slopes, frosts are more prolonged on the lower slopes. Soil water measurements indicated that during dry conditions, the lower slopes had more favourable soil water conditions, with water potential decreasing upslope (Taylor and Cook 1993). Lower slopes could potentially become waterlogged during wet conditions, but monitoring only occurred under relatively dry conditions.

3.1.3. How cattle use the different land classes

The extent to which cattle preferred to graze one land class over another was assessed by comparing the total biomass (an indication of grazing pressure) of fenced land classes with that of land classes within landscape paddocks (ANOVA 6, Table 2.3.1). This was done for two years' data: 1993 when pasture had relatively low grazing pressure (overall standing biomass 1800 kg/ha) and 1994, when grazing pressure had been high (1300 kg/ha).

The results show that in both years, biomass (or grazing pressure) was similar when the same land classes were compared between landscapes (where cattle could choose freely between land classes) and land classes (where they could not). In other words, there was no evidence that cattle chose to graze more heavily on one of the three land classes when they had the option (i.e. in landscape paddocks).

It is possible that within different land classes, regardless of choices of other land classes available, cattle graze more, or less, heavily. This is suggested by the significant difference in remaining biomass (lower slopes>mid slopes>upper slopes) between land classes, regardless of whether they were in landscapes or separately fenced. However, a more likely suggestion is that the plant productivity and quality differ between land class. This could be due to different species being present and/or quality and productivity of the same species varying with land class. Grazing preference for the different species represented would also play a role in influencing the quantities of plants that were left ungrazed. These issues are further explored in the following sections.

3.2. How soil and vegetation differed between land classes

3.2.1. Soil patterns

The geomorphology and soils of the 'Glenwood' site have been described in detail in Barton (1991). Essentially the landscape consists of gently undulating rises formed due to the erosion of much of the deeply weathered adamellite parent material. Parent material and landscape position appear to be the most dominant factors influencing soil profile development. A brief summary of the main soil types that correspond with the land classes is given below.

Upper slopes - Jacabar soils

These soils are found on gently sloping convex crests and short slopes of higher rises. They are hard setting mildly acid, red or brown to yellow. Jacabar are texture contrast soils with a cobble of silcrete and ferricrete in the course surface horizon and pebbles of quartz and ironstone throughout. The soils overlay ferruginous sandstone or highly weathered adamellite.

Mid slopes - Cheltenham/Narayen soils

These soils are found on the crests and convex upper slopes of the lower rises and overlie freshly weathering adamellite. Cheltenham are hard setting, mildly acid to neutral, red-brown gritty texture contrast soils. Angular adamellite pebbles are found on the surface and ant holes commonly occur. Narayen soils are closely associated with the Cheltenham soils but are generally found lower down the landscape. Both soils exhibit a similar coarse sandy surface with a lag of fine angular adamellite pebbles and numerous ant holes. The difference between the two is due to the deposition of course material lower in the landscape associated with water shedding from the upper slopes. This results in the leaching of clay and iron particles in the Narayen soil giving it a mottled appearance. Narayen soils tend to have a thicker surface A horizon than the Cheltenham soils, with a bleached course gravel layer above the clay subsoil.

Lower slopes - Hogarth soils

Hogarth are texture contrast soils that are hard setting, acid to alkaline, grey or yellow brown sodic and gritty. Local alluvium and colluvium overlays an impermeable, mottled clay horizon. These areas accumulate runoff and sediment from the upper slopes. With a concentration of sodium, the clay horizon has become much more impermeable creating a perched water table during prolonged rainfall.

3.2.2. Vegetation patterns

As land classes vary in their soil and microclimatic conditions, it is not surprising that plants vary in their ability to grow on different land classes. This may simply reflect their physiological ability to grow under specific conditions. However, this expression of growth may be suppressed by competitive effects of other species. A third layer of complexity relates to the effects of grazing animals and other herbivores which may remove plants that could potentially grow at a site. To minimise the effects of the latter, land class patterns in plant abundance were looked for in the 1989 data, when the pastures had been rested from grazing for 12 months. These patterns are summarized in Table 3.2.2a, which lists species that has significantly greater frequencies in one or more land classes. Many, but not all of these patterns persisted into 1995. Others were affected by the experimental treatments.

Table 3.2.2a. Common species (>5% frequency) that showed land class preferences in 1989 before the imposition of treatments ($p < 0.05$). Preference is expressed as a greater frequency on particular land class(es), indicated by a '+'. Brackets indicate a gradient of response, with the bracketed land class having a frequency intermediate between the adjoining two.

Species/ species group	Upper slopes	Mid and upper	Mid slopes	Lower and mid	Lower slopes
Aristida § Streptachne			+		
Aristida § Calycinae	+				
Arundinella nepalensis					+
Boerhavia dominii			+		
Bothriochloa decipiens	+				
Desmodium varians		+			
Glycine tabacina			+		
*Gomphrena celosioides**	+				
Goodenia glabra	+	(+)			
Heteropogon contortus			+		
Indigofera linnaei			+		
Murdannia graminea					+
*Richardia brasiliensis**					+
Sida subspicata	+				
Tricoryne elatior				(+)	+
Vernonia cinerea				+	
Wahlenbergia sp.					+
Zornia dyctiocarpa	+				
Zornia muriculata	+				

Approximately one third of the species analysed showed significant patterns, and it is likely that a proportion of the remaining species also has land class patterns that were not detected in the study. The land class patterns of some species, notably *Heteropogon* and *Arundinella nepalensis* have important implications for processes of pasture change under grazing. These are discussed in the next section.

3.3. Vegetation dynamics varied between land classes

3.3.1. Degradation processes on the upper and lower slopes

The decline in *Heteropogon* populations is considered to indicate pasture degradation from the perspective of perennial grass loss. At the site, a range of species replaced *Heteropogon*, including forbs, annuals and perennial grasses. However, the replacement perennial grasses were generally smaller in size than *Heteropogon*. The issue of species change is considered in more detail in Sect. 7; in this section we will examine different change processes in relation to land class. The data presented are the proportion of quadrats (i.e. frequency) in which *Heteropogon* was ranked highest in term of biomass i.e. frequency of dominance. This enables the data to be compared over each of the six years of the trial, and focuses on the dominance aspect i.e. presence of large, mature plants or many smaller plants.

Initially, there was a significantly higher frequency of *Heteropogon* on the mid slopes compared to the upper and lower slopes (Fig. 3.3.1a). This relativity persisted throughout most of the trial, although there were shifts in the frequency of *Heteropogon* dominance when the cattle were introduced after the 1989 assessment, resulting in no significant differences between land classes. Twelve months prior to Dec. 1989, the site had remained ungrazed and short-term (but not long-term) grazing effects would have been less in the 1989 and 1990 data. *Heteropogon* increased in all paddocks in 1990-91 (Fig. 3.3.1a) but from 1991 the trial saw a decline in all land classes; this was when grazing pressures really increased in the medium stocked (ANOVA 3) paddocks (see Fig 4.1a).

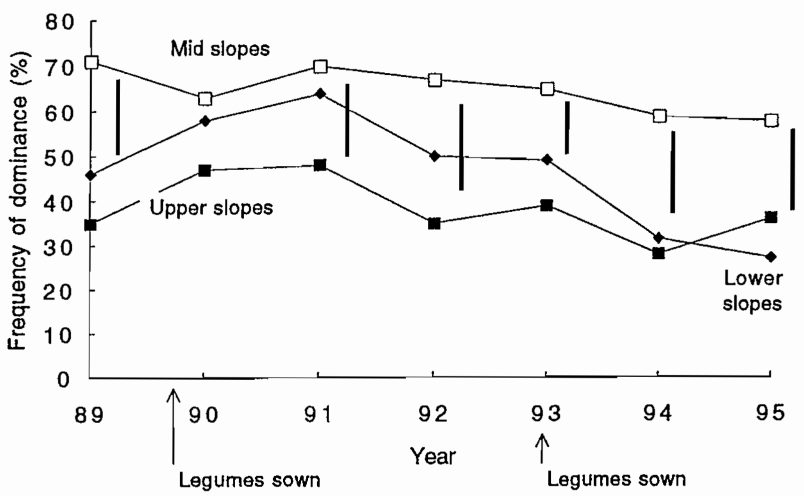


Fig. 3.3.1a. Change in frequency of dominance of *Heteropogon* (proportion of quadrats in which it was ranked highest in biomass terms) in three land classes recorded in autumn from 1989-95. Bars are l.s.d. $p < 0.05$, comparisons within years only. In 1990, means were not significantly different. Data are from ANOVA 5 and all paddocks were medium stocked. Upper slopes = ■ ; mid slopes = □ ; lower slopes = ◆.

Of interest, is that the rate of decline differed between land classes, with populations on mid slopes being more persistent (see also McIntyre, MacLeod and Taylor 1995 for presentation of frequency data). For the last three assessments, frequency of dominance on upper and lower slopes was significantly less than mid slopes. Decline in *Heteropogon* also seemed to be more pronounced on the lower slopes. It appears that there may be different processes of degradation on different land classes.

Upper slopes are drier and water deficits may make populations less resistant to grazing. Grazing pressure on this land class was also highest for much of the trial (compare total biomass values in Table 3.3.1a) and may have been related to the lower potential productivity related to soil and moisture conditions.

Table 3.3.1a. Shoot biomass in three land classes in autumn 1990-1995. Data are from ANOVA 2 and all paddocks were legume sown, and averaged over medium and low stocking rates. Paddocks were sampled more intensively in 1990-94.

Shoot biomass (kg ha^{-1})	1989	1990	1991	1992	1993	1994	1995
Upper slopes							
Heteropogon	800	1290	530	430	500	320	460
A. nepalensis	0	0	10	10	0	0	0
Other species	940	960	610	850	900	610	670
Total	1740	2250	1150	1290	1400	930	1130
Mid slopes							
Heteropogon	1110	1170	610	1010	1040	690	970
A. nepalensis	0	20	5	0	20	30	20
Other species	790	590	440	660	820	450	850
Total	1900	1780	1055	1670	1880	1070	1840
Lower slopes							
Heteropogon	1020	1150	640	700	640	380	140
A. nepalensis	380	950	420	650	780	1080	180
Other species	1020	810	370	620	700	440	810
Total	2420	2910	1430	2170	2120	1900	1130

Soil moisture on the lower slopes is higher than mid or upper slopes and moisture deficits cannot explain the lack of persistence on this land class. Also total biomass was generally higher than on the mid slopes and total grazing pressure was therefore lower. We suggest that another perennial grass, *Arundinella nepalensis*, may have contributed to the decline of *Heteropogon* on lower slopes. This species is mainly confined to the lower slopes (Table 3.2.2a). On lower slopes, average frequency of *A. nepalensis* increased only slightly, by less than 3% (ANOVA 5). However, shoot biomass was maintained at high levels due to the unpalatability of this grass and it became an increasingly important component of the sward (Table 3.3.1a). *Heteropogon* is grazed in preference to mature *A. nepalensis* (Milestone Report 9, 1994). We hypothesize that the resulting higher grazing pressure on *Heteropogon* and other species may have contributed to the decline of *Heteropogon* on the lower slopes. By 1994, grazing pressures became severe in the moderate to high stocking rates and cattle began actively grazing *A. nepalensis* in preference to wynn cassia for most of the year (personal observation). In 1995, a decline in *A. nepalensis* biomass was apparent (Table 3.3.1a). These processes were highly visible in the field and led to dramatic changes in pasture appearance and composition in some paddocks.

3.3.2. *Heteropogon* population processes

Large differences in seed production occurred between land classes with the mid slope consistently producing more seed than the upper slope (Fig. 3.3.2a). Large differences in seed production occurred between years in response to variation in rainfall.

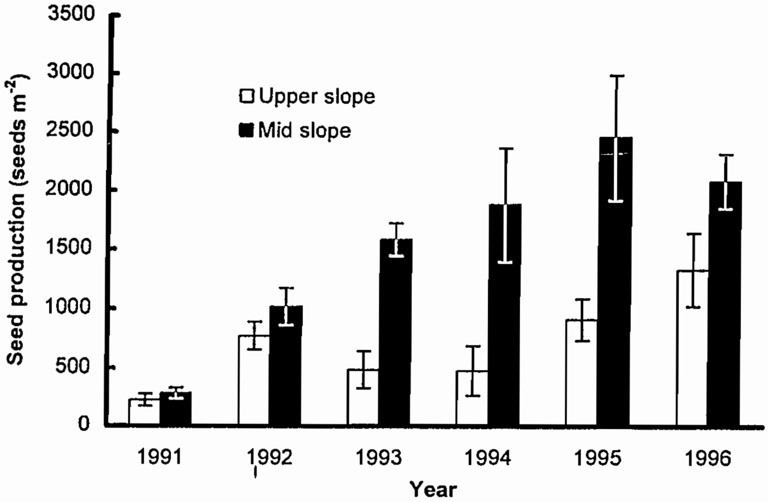


Fig. 3.3.2a. Seed production (seeds m^{-2}) of *Heteropogon* in two land classes from autumn 1991 to 1996. (Bars are ± standard errors).

Because of large differences in seed production between years, large differences occurred in the germinable seed banks with consistently more seed in the mid slope compared with the upper slope. These differences in germinable seed bank measured in spring reflected the pattern of seed production in the previous autumn. However, the size of the germinable seed bank was consistently smaller than the seed production measured in the previous autumn even after allowing for the annual variation in seed viability.

Seedling recruitment differed between land classes and between years because of variation in the size of the soil seed bank together with large variation in summer rainfall. Consistently more seedlings were recruited on the mid slopes compared to upper slopes, and this was consistent with more seed in the soil seed bank. Despite this trend of higher seedling recruitment in the mid slopes, an exceptional recruitment of 43 seedlings m^{-2} was recorded in one upper slope paddock compared with the highest recruitment in a mid slope paddock of 18 seedlings m^{-2}. Both of these densities were measured in 1995.

Plant density declined in both land classes between 1990 and 1993, and increased between 1993 and 1995. The decline from 1990 was mainly associated with low recruitment and high levels of mortality in the 1990 and 1991 seedlings, together with poor survival of the originally marked plants (Fig. 3.3.2b). In contrast, the increase after 1993 was associated with increased seedling recruitment and establishment together with decreased rates of mortality in the original plants. Plant abundance was generally higher in the mid slope than in the upper slope (see Table 3.2.2a, 3.3.1a; Fig. 3.3.1a).

Survival of the original 1990 plants was higher in the mid slopes compared with the upper slopes (Fig. 3.3.2b). There was a marked reduction in plant survival in both land classes due to drought between 1991 and 1992. Plants from each of the annual seedling cohorts identified, displayed differing survival between years with no consistent differences between the two land classes.

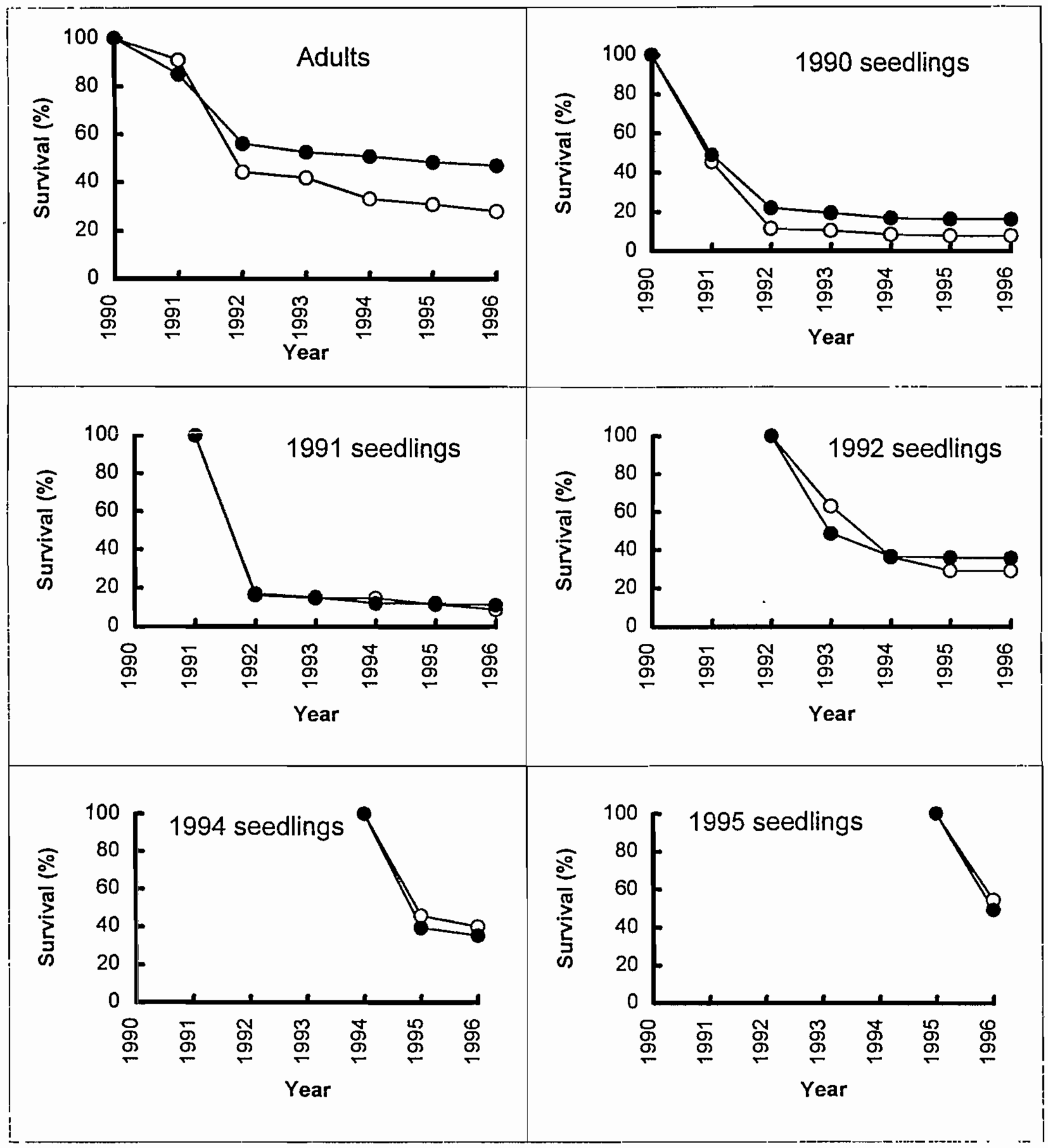


Fig. 3.3.2b. Percentage survival of six cohorts of *Heteropogon* on two land classes (O = upper slope; ● = mid slope) between 1990 and 1996. Adults = original plants marked in 1990, and seedlings marked in 1990, 1991, 1992, 1994 and 1995.

Basal area of *Heteropogon* declined in both land classes between 1990 and 1992 and increased between 1992 and 1996. The decline between 1990 and 1992 was associated with relatively poor survival (see Fig. 3.3.2b) and reduced size of the original plants together with low seedling recruitment and limited growth of these few seedlings (Fig. 3.3.2c). In contrast, basal area increased after 1992 and this increase was associated with increased seedling recruitment and growth as well as an increase in the size of established plants.

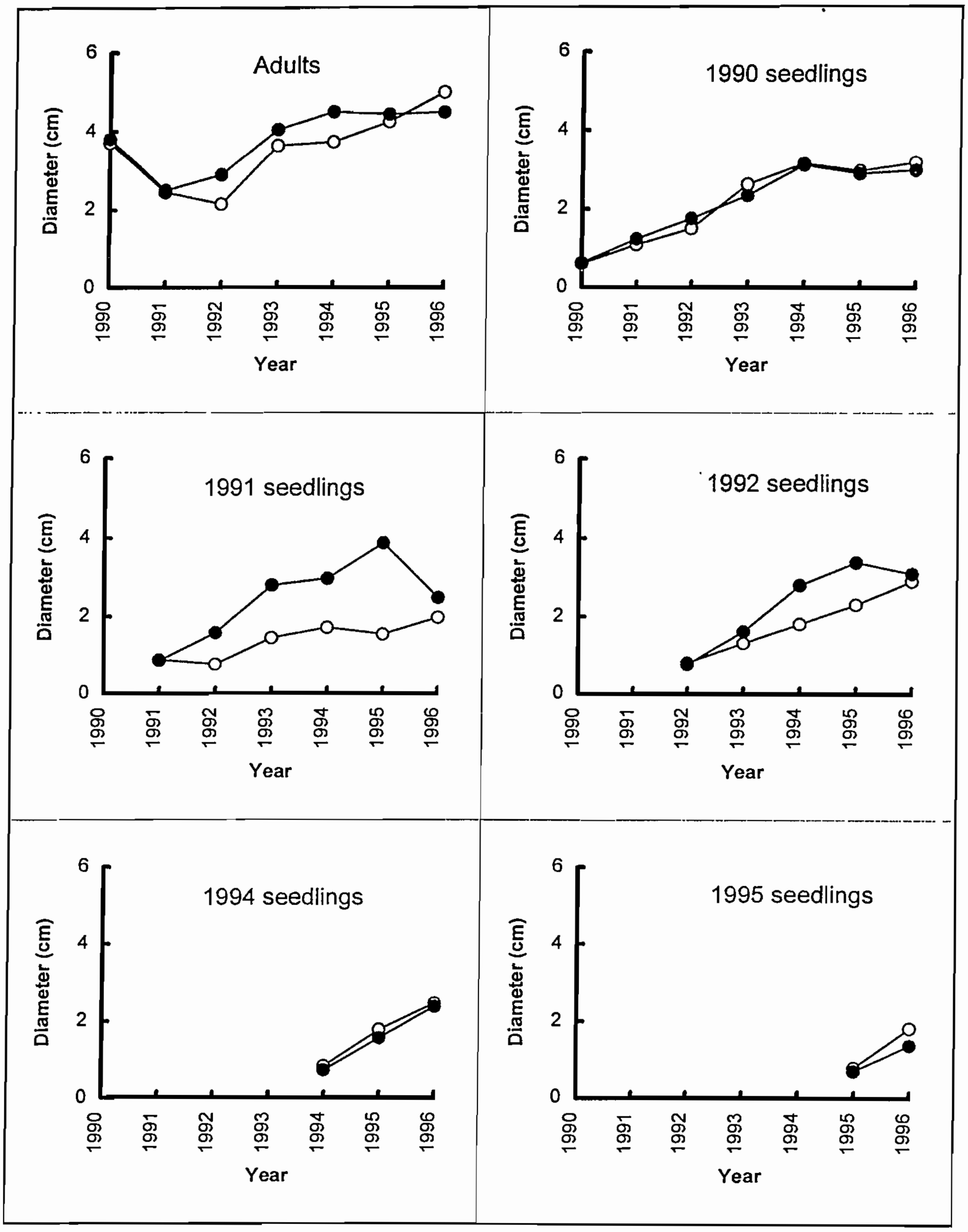


Fig. 3.3.2c. Average diameter (± standard errors) of *Heteropogon* plants in two land classes (O = upper slope; ● = mid slope) between 1990 and 1996. Adults = original plants marked in 1990, and seedlings marked in 1990, 1991, 1992, 1994 and 1995.

The original 1990 plants declined in size between 1990 and 1991 and then increased in a similar pattern in both land classes although there was a trend between 1992 and 1994 for plants in the mid slope to be larger than plants in the upper slope land class (Fig. 3.3.2c). Plants from each of the annual seedling cohorts tended to increase in size in a similar pattern although there was a trend, particularly for the 1991 plants, to increase more in the mid slope compared with the upper slope land class.

3.3.3 *Aristida* spp. population processes

Recruitment of *Aristida* spp. varied between years but not between land classes within years. A large recruitment occurred over the 1990-91 summer but was less than 1 seedling m^{-2} for all other years. Accordingly, plant density increased between 1990 and 1991 reflecting this seedling recruitment over the 1990-91 summer. Since 1991, *Aristida* spp. density declined and there have been no differences between the two land classes. Survival of the original 1990 plants has been similar in both land classes (Fig. 3.3.3a) but survival of plants from the 1991 recruitment has been higher in the upper than in the mid slope

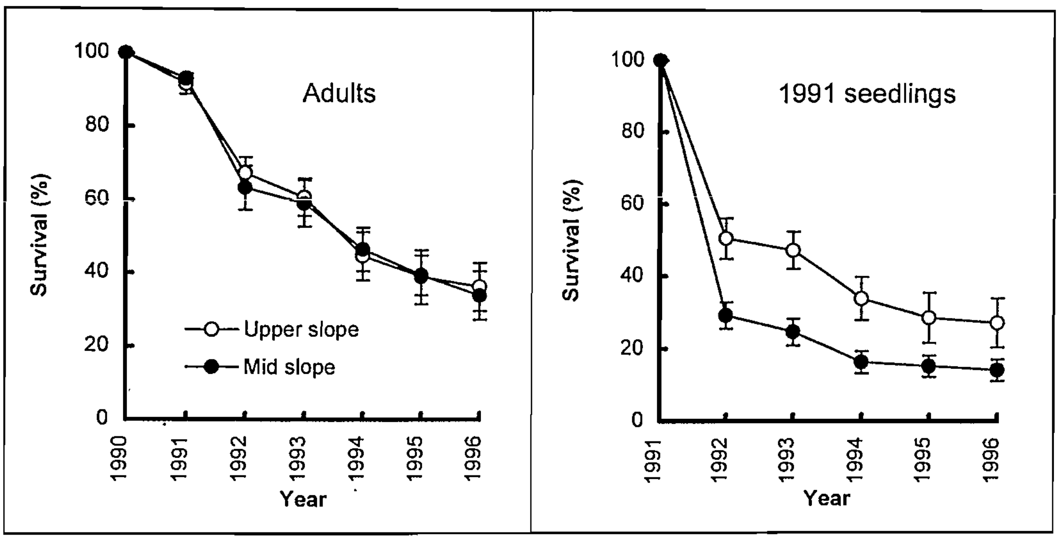


Fig. 3.3.3a. Percentage survival of *Aristida* spp. plants on two land classes between 1990 and 1996. Adults = original plants marked in 1990; 1991 seedlings = seedlings marked in 1991. (Bars are ± standard errors).

Basal area of *Aristida* spp. declined between 1990 and 1996 and this decline was similar in both the upper and mid slopes. The size of the original 1990 plants generally declined between 1990 and 1996 with no difference between the two land classes. Plants from the 1991 recruitment increased in size at a similar rate for each land class (Fig. 3.3.3b).

Overall, differences in the population processes of both *Heteropogon* and *Aristida* spp. have been influenced less by land class than by seasonal rainfall. However, there was a general trend for seed production, recruitment and plant size of *Heteropogon* to have been greater on the mid slopes than on the upper slopes.

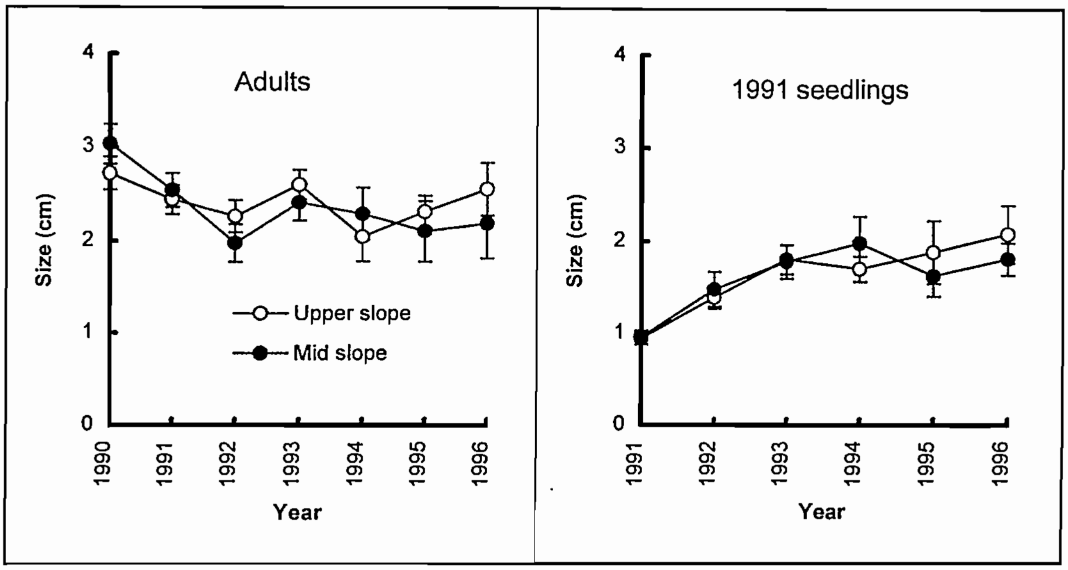


Fig. 3.3.3b. Diameter of *Aristida* spp. plants on two land classes between 1990 and 1996 Adults = original plants marked in 1990, 1991 seedlings = seedlings marked in 1991. (Bars are ± standard errors).

3.4. Soil hydrology and soil movement

3.4.1 Pore Size Characteristics.

Mean hydraulic conductivity values for patch type and land class are shown in Table 3.4.1a. Values at -1 and -3 cm of water of applied suction are given. These tensions represent the contribution that pores, of less than 3 and 1 mm in diameter respectively, contribute to the hydraulic conductivity.

Table 3.4.1a. Hydraulic conductivity (mm hr^{-1}) on two patch types and two land classes, at two levels of applied suction using a disk permeameter. Means followed by the same letter are not significantly different ($p<0.05$) between treatments for the same head.

Treatment	Head (cm H_2O) - 1	Head (cm H_2O) - 3
	Pore diameter (mm) <3.0	Pore diameter (mm) <1.0
Patch type		
Heteropogon	77 a	41 a
Aristida spp.	59 b	34 a
Land class treatment		
Upper slope	44 a	28 a
Mid slope	93 b	47 b

Patch type had a major effect on the contribution to hydraulic conductivity of the 1 to 3 mm pores. There was no significant difference in the contribution to the hydraulic conductivity of the pores less than 1 mm. However there was a significant increase in the contribution to hydraulic conductivity that pores up to 3 mm made, between the *Aristida* spp. patch and the *Heteropogon* patch (59 - 77 mm hr^{-1}).

There was a significant difference in the hydraulic conductivity at -1 and -3 cm water suction between the mid-slope and upper-slope areas. The mid-slope land class had a much higher hydraulic conductivity at both suction heads.

3.4.2 Rainfall Simulator

The results obtained using the disk permeameter were reflected in the peak rate of runoff and total runoff found using a rainfall simulator (Table 3.4.2a). The *Heteropogon* patches had significantly lower total runoff (2%), and peak runoff rates (3%), compared with the corresponding *Aristida* spp. grass patches (8%, 14%). The land classes showed a similar trend, with the mid-slope areas having significantly lower total (2%) and peak runoff (4%) than the upper-slope areas (8%,12%).

Table 3.4.2a. Mean peak runoff rate (Qp^a) and total runoff (%), derived using a rainfall simulator. Means followed by the same letter are not significantly ($p<0.05$) different between treatments.

$$\text{Peak runoff rate} = \frac{\text{rate of runoff}}{\text{rate of applied rainfall}} \times \frac{100}{1}$$

	Qp^a (%)	Total runoff (%)
Patch type		
Heteropogon	3 a	2 a
Aristida spp.	14 b	8 b
Land class		
Upper slope	12 a	8 a
Mid slope	4 b	2 b

3.4.3 Plot Runoff

On the small plots only eight major runoff events occurred during the six years of recording, due to the dry conditions. However, minor runoff frequently occurred when significant rainfall fell on a dry catchment. It was also noticeable that the significant runoff events from the small plots did not translate into significant runoff in the landscape plots, ie runoff was localised within the catchments.

Land class had a noticeable effect on annual cumulative runoff with the upper slopes producing more runoff (Fig. 3.4.3a). However, the difference between land classes was only significant when the cumulative runoff for all six seasons was compared. The land class difference is consistent with the findings from the disk permeameter and rainfall simulator. There were only a limited number of individual runoff events for which hydrographs can be analysed. Further detailed analysis of these hydrographs will allow finer definition of the runoff-producing processes.

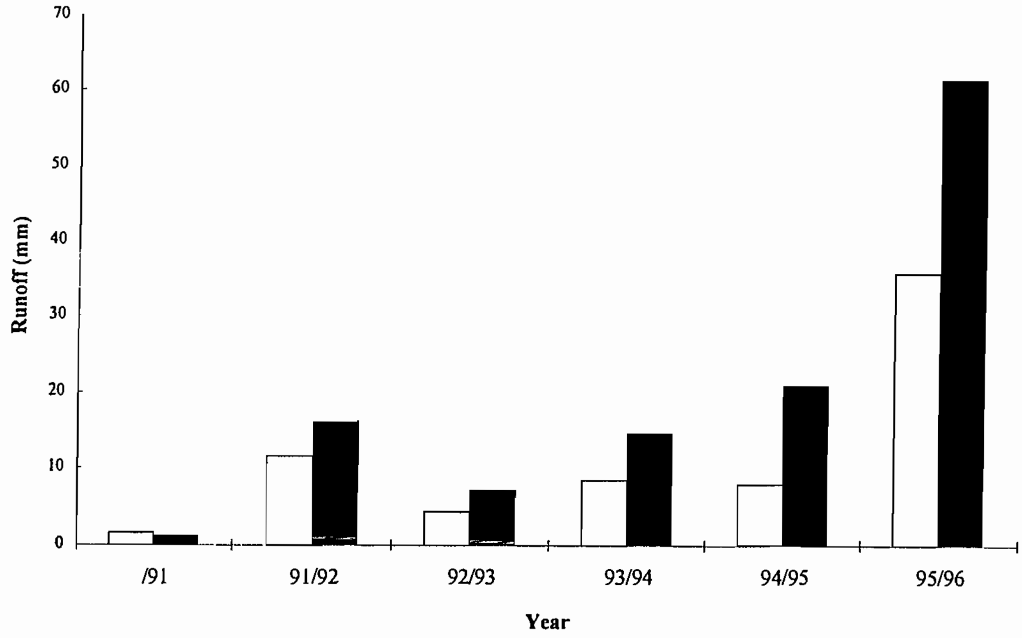


Fig 3.4.3a. Average annual cumulative small plot runoff (mm) over 6 seasons on two land classes, mid slope (◻) and upper slope (■), averaged over stocking rates.

3.4.4 Soil Movement.

Despite the below average seasonal conditions a number of runoff events occurred, particularly on the heavier stocking rate sites and in the small plots sampling individual land classes. A number of these runoff events were associated with the transport of soil in the water. The effect of land class is evident with the upper slopes producing more soil movement than the mid slopes (Fig. 3.4.4a).

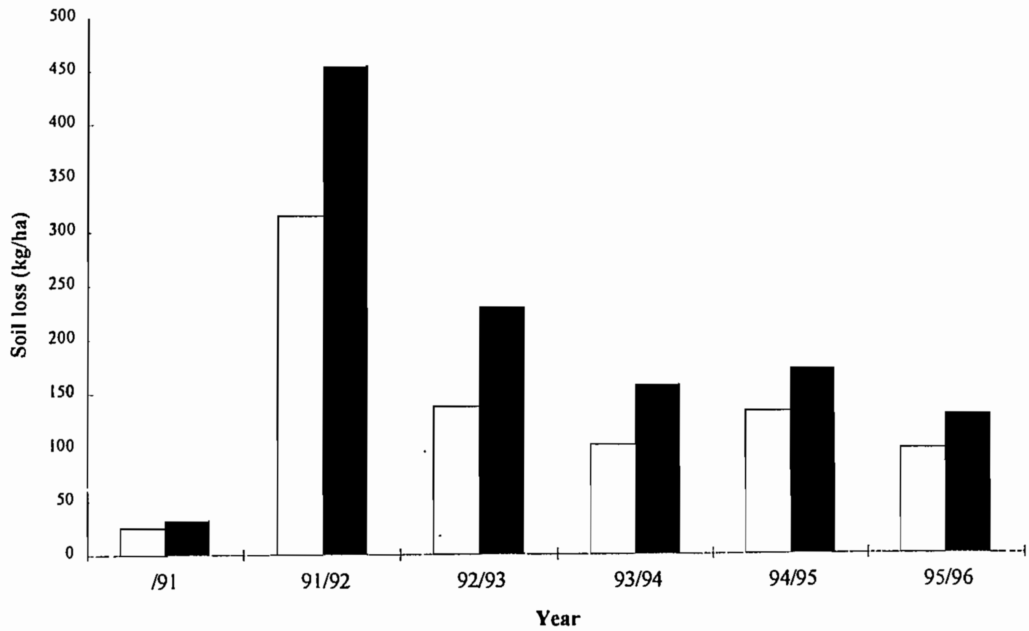


Fig 3.4.4a. Average annual cumulative soil loss (kg/ha) in small plots over 6 seasons for two land classes, mid slope (◻) and upper slope (■), averaged over stocking rates.

It is noticeable in Figs 3.4.3a and 3.4.4a, that the sediment production for the 1995/96 summer period was not significantly greater than the earlier summer periods, despite the fact the increased rainfall resulted in much higher runoff. The 1995/96 summer period which promoted greater growth, produced significantly less sediment per mm of runoff than occurred during the drought period when grass growth was greatly reduced. It is evident that even during drought periods, significant runoff producing events can occur from isolated high intensity rainfall events. These rainfall events can result in significant soil movement due to the poor protective surface conditions.

Runoff and soil movement at the landscape scale was variable between seasons. For the 'Glenwood' site with a low average rainfall (708 mm) and a permeable surface soil (coarse grained yellow podzolic), no significant runoff events were recorded at the landscape scale during the drought period, and it was only in the last summer period with a return to 'average' rainfall that the landscape produced runoff. No significant soil movement was recorded.

3.4.5 Subsurface water movement.

Due to the impervious nature of the clay B horizon, lateral water movement was restricted to the A horizon (see Fig. 2.9.2a). Subsurface flow occurred when the soil profile was in a saturated state i.e. after long periods of low intensity rainfall (approximately 100 mm). Seven subsurface events were recorded over the trial period. Four of these occurred in the 1995/96 summer. Similar short duration flows were found on the upper and mid slope positions while the lower slope integrated all the water moving down from the upper slopes as shown in Fig. 3.4.5a.

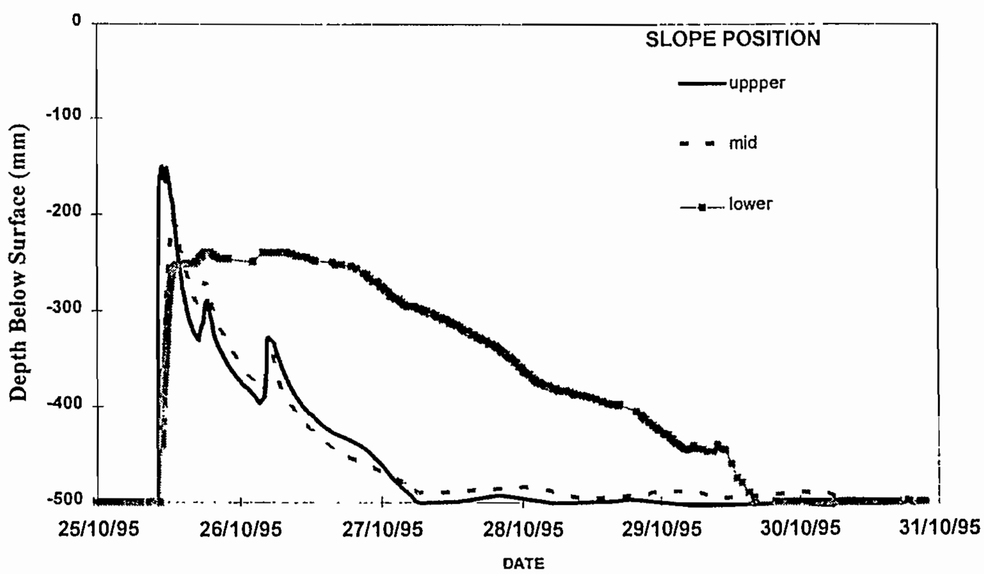


Fig 3.4.5a. Subsurface flow depths below the ground surface over six days at three landscape positions.

3.5. Animal production

There was no significant land class treatment effect observed on animal production in any of the years between 1990-91 and 1994-95 (Table 3.5a). This may reflect the substantial variability within the land class paddocks. However, a trend is apparent for the mid slope treatment paddocks to be generally more productive than the lower and upper slope paddocks. It is possible that the lower liveweight gain in the lower slope paddocks may be influenced by the presence of relatively unpalatable species (eg. *Arundinella*) and forage quality differences attributed to microclimatic factors (eg. frosting frequency and severity) in the more critical winter period. Liveweight gain for the spotted gum treatment paddocks on 'Narayen' (not shown) was significantly lower than that of the other land class treatments in each year of the trial except 1993-94.

Table 3.5a. Annual liveweight gain (kg head^{-1}) of steers in three land classes 1990-95, averaged over native and legume sown treatments. Data are from ANOVA 2. All paddocks were medium stocked.

Land Class	1990-91	1991-92	1992-93	1993-94	1994-95
Lower slope	128	124	125	154	136
Mid slope	173	167	140	166	166
Upper slope	163	150	127	160	141
l.s.d (p<0.05)	n.s.	n.s.	n.s.	n.s.	n.s.

3.6. Summary

- Land classes integrate a number of environmental variables that flow from the effects of topography. Higher landscape positions (upper slopes) drain water and cold air more effectively, and are therefore warmer, and have shallower soils with comparatively lower moisture levels. Lower slopes collect cold air and sediment from higher areas and are therefore more frosted, with more soil moisture, greater waterlogging potential and deeper soils. Mid slopes are intermediate in terms of intensity of frosts, soil moisture and soil depth.

- A number native plants were found to be significantly more abundant on one or more land classes. This was considered to reflect the ecological tolerances of the species. The distribution of several groups was considered to have important implications for pasture management and condition. *Heteropogon* was most frequent on the mid-slopes and *Arundinella* most abundant on the lower slopes. Groups within *Aristida* (Sections) displayed different land class preferences. Two sections were equally abundant on all land classes. Section Streptachne (represented by the fine-leaved *A. spuria*) was more abundant on mid-slopes. Section Calycinae, (represented by the coarse-leaved *A. calycina*) was more abundant on upper slopes. When observed collectively (all *Aristida* spp. grouped), no differences in recruitment or survival of *Aristida* was observed between mid and upper slopes.

- Mid slopes appeared most resistant to degradation, *Heteropogon* populations were more resilient and resistant to decline, due to higher levels of seed production, recruitment and survivorship. Compared to lower slopes, mid slope soils were more permeable to rainfall due to better pore structure. As a result of better infiltration, there was less runoff and soil loss on the mid slopes compared to the upper slopes.

- Although soil hydrological characteristics were not observed on the lower slopes, it is apparent that pasture changes were also occurring there in the form of reduced frequency and proportion of *Heteropogon*. *Arundinella*, which is generally avoided by cattle in the mature state, was abundant in the lower slopes, forming up to 45% of the total biomass. The decline in *Heteropogon* is attributed to the increased grazing pressure placed on it as a result of cattle avoiding large quantities of *Arundinella* that occurred on the lower slopes.

4. STOCKING RATE

4.1. How did stocking rate and seasonal variation affect grazing pressure?

The actual amount of plant material in the experimental paddocks was affected by the seasonal conditions (which determined the amount of growth) and the stocking rate. At a given stocking rate, the overall grazing pressure will increase as the total biomass in the paddock declines. In this section we explore the effects of stocking rate at the paddock level. This information is important in that it is directly comparable with the animal liveweight gain data, which was also collected on a paddock basis.

The grazing pressure may not be uniform within a paddock, and varies according to the behaviour of the cattle (e.g. variation due to species preference described in Sect. 3.3.1). Although the cattle tended to graze the different land classes at similar levels overall (Sect. 3.1.3) within the land classes there was strong visual evidence of patchy grazing. Analysis of the data at the patch scale can thus reveal variation and dynamics that may not be detected at the paddock scale and will be described further in Sect. 7.

The effects of stocking rate on the total shoot biomass of the paddocks from 1989-95 is shown in Fig. 4.1a. Up until August 1993, there were effectively only three stocking rate treatments (Table 2.4a) - the intermediate treatment was split into medium and very low rates, and post-1993, these effects on biomass are evident (Fig. 4.1a). Biomass in all paddocks were very similar in 1989 and 1993 as the paddocks had been spelled prior to the assessments, in preparation for legume sowing. A real separation of biomass corresponding to stocking rate treatments was, therefore, not evident until 1994/95. This is why many of the stocking rate effects on data (e.g. cattle weight gain) were only evident in the last few years of the trial.

The variation in biomass from year to year resulted from changes to stocking rates (such as described for 1993 onwards), seasonal conditions and the effects of the legume treatments. It is not possible to unravel these as separate effects, however, it is likely that the big reduction in biomass in 1991 was related to low rainfall in the months prior to the May 1991 sampling (Fig. 2.2a).

4.2. Species composition and stocking rate

4.2.1 Effects of stocking rate on *Heteropogon*

Overall, *Heteropogon* declined in frequency and frequency of dominance in all stocking rates over the duration of the trial, although there were seasonal fluctuations (Fig. 4.2.1a & b). Low stocking rate paddocks maintained the highest frequencies and very low stocking supported the lowest frequency of dominance (Fig. 4.2.1a). The development of significant differences between low and very low stocking rates

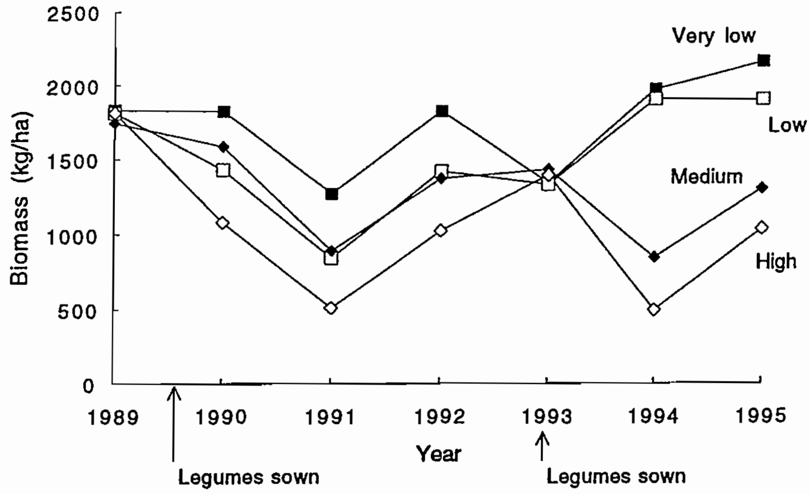


Fig. 4.1a. Change in total shoot biomass over four stocking rates from 1989 - 1995. Data are from ANOVA 3, all paddocks are legume sown and from upper and mid slopes. The effects of stocking rate were significant ($p < 0.05$) in all years except 1989 and 1993.

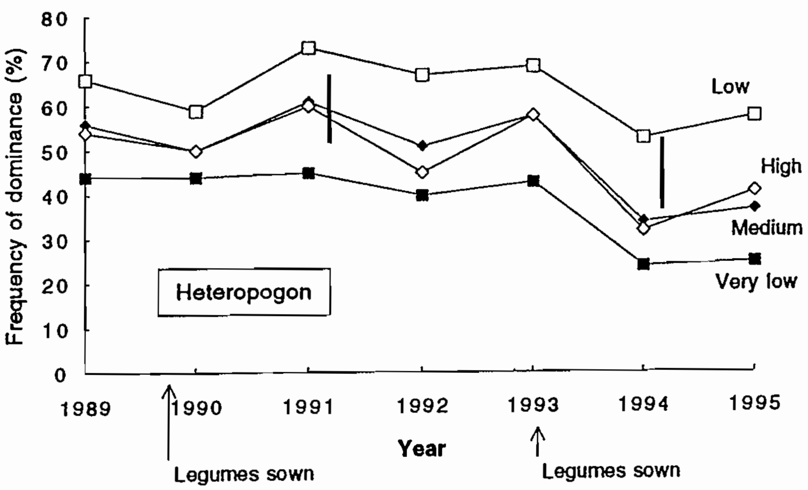


Fig. 4.2.1a. Change in the frequency of dominance of *Heteropogon* (proportion of quadrats in which it was ranked highest in biomass terms) in four stocking rates recorded in autumn from 1989-95. Bars are l.s.d. $p < 0.05$, comparisons between stocking rates within years 1991 and 1994 only. In other years, means were not significantly different. Data are from ANOVA 5 and all paddocks were legume sown and on upper and mid slopes.

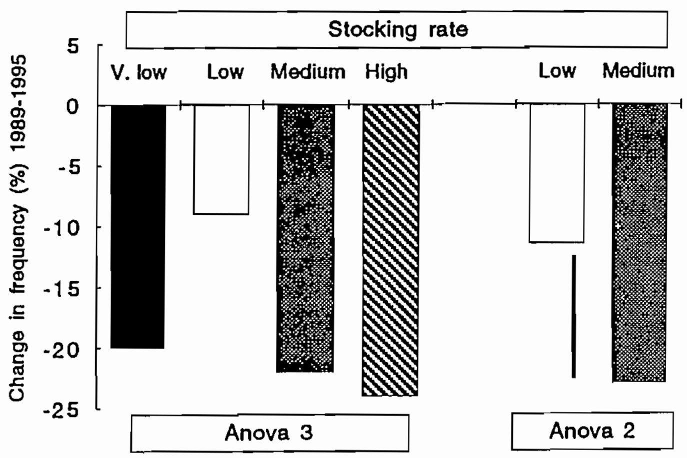


Fig. 4.2.1b. Difference in frequency of *Heteropogon* (proportion of quadrats in which it was present) between 1989 and 1995 in four stocking rates (ANOVA 3) and two stocking rates (ANOVA 2). Bars are l.s.d. $p < 0.05$, comparisons between stocking rates for ANOVA 2 only. In ANOVA 3, means were not significantly different.

occurred in 1991 and between low stocking and the remainder of treatments in 1994. However, the initial population levels were quite variable (actually reflecting the final results) and the fluctuations in treatment effects (significant in some years and not others) make the patterns suggestive but not convincing. Fig. 4.2.1b tends to confirm the suggestion that *Heteropogon* populations were most persistent under low stocking and declined under very low, medium and high levels. The decline in frequency of *Heteropogon* over the experimental period was around 10% at low stocking and 20-25% in the other treatments. In ANOVA 2 (a more powerful comparison of the middle two stocking rates than ANOVA 3), the difference between low and medium stocking was significant. This result tends to strengthen the likelihood of actual differences between low and high, and low and very low treatments - the magnitude of the decline in very low, medium and high treatments was very similar.

The humped response curve of *Heteropogon* to grazing intensity (ie more persistent under intermediate grazing) is quite consistent with that observed by Howden (1988) after experimental defoliation of *Heteropogon*. It also may explain why comparisons of published stocking rate trial results (reviewed by Grice & McIntyre 1995) reveal inconsistent responses of *Heteropogon* to increased stocking rates. Depending on which part of the response curve the treatments related to (i.e. the actual defoliation and growth conditions), *Heteropogon* may decrease, remain stable or increase under increased stocking.

4.2.1 Effects of stocking rate on other species in the pasture

Appendix 2 summarizes the stocking rate response of the major species. Only a minority of species had significant changes in frequency that related to stocking rate. It is likely that there were many more stocking rate responses that were not detected due to the variation in paddocks and the low level of replication in the design. In Section 7, the analysis of individual quadrats provides a more detailed examination of the effects of grazing pressure. Sown legume response is discussed in Sect. 5.

Nine species were significantly more frequent at higher stocking rates. The annual grass *Tragus* and the annual herb *Portulaca pilosa* were the most abundant species and increased the most over the trial period. Other plants responding to high stocking were perennial forbs, including four species of native legume. Species which responded negatively to stocking rates were *Melinus repens*, *Aristida* (Sections *Aristida*, *Calycinae* and *Arthratherum*) and *Cymbopogon refractus*.

4.3. Population processes and stocking rate

4.3.1 Heteropogon population processes

Large differences in seed production occurred between years, but numbers were generally similar in the two lower stocking rates and was reduced at high stocking. Similarly, large differences occurred in the germinable seed banks between years; seed banks were generally similar at very low and low stocking rates but were reduced at high stocking rate. These differences in germinable seed banks measured in spring reflected the pattern of seed production in the previous autumn. However, the size of the germinable seed banks were considerably and consistently smaller than the seed production measured in the previous autumn even after allowing for variation in seed viability.

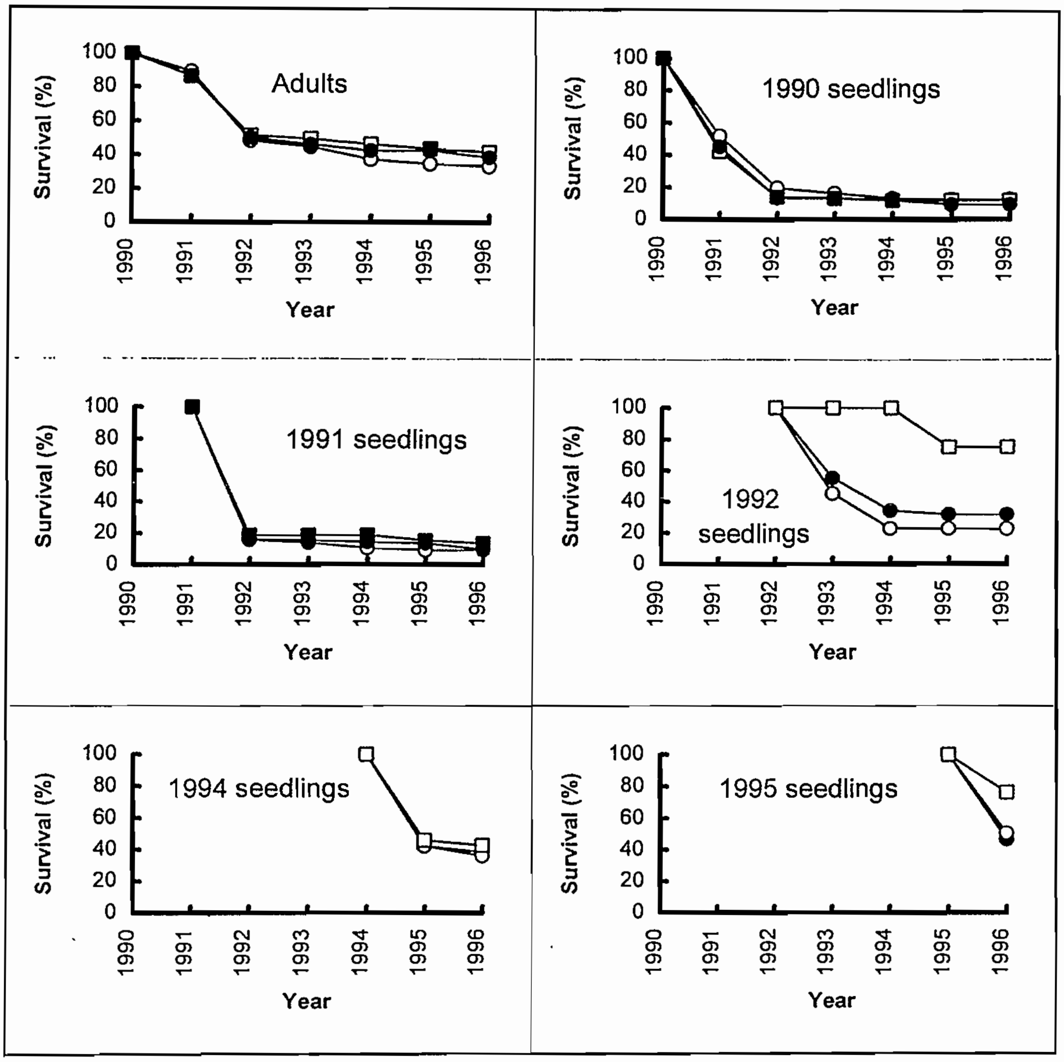


Fig. 4.3.1a. Percentage survival of six cohorts of *Heteropogon* at three stocking rates (O = very low/low; ● = low/medium; ❑ = high) between 1990 and 1996. Adults = original plants marked in 1990, and seedlings marked in 1990, 1991, 1992, 1994 and 1995.

Seedling recruitment varied with stocking rate and years due to variation in size of the soil seed bank together with large variation in summer rainfall. Seedling recruitment in 1991 was highest at the high stocking rate but this effect was reversed in subsequent years. Large variation in recruitment at the highest stocking rate occurred in 1994 and 1996 and was caused by large variation between the two land classes. Seedling recruitment in 1995 and 1996 was higher at the low/medium compared with the very low/low stocking rate.

Plant density declined at all three stocking rates between 1990 and 1993 and increased between 1993 and 1995 with a trend for density to be highest at the medium/low compared to the very low/ low and high stocking rate treatments. The decline from

1990 was associated with low seedling recruitment and establishment together with poor survival of existing plants (see Fig. 4.3.1a). In contrast, the increase after 1993 was associated with increased recruitment establishment and increased survival of existing plants.

Survival of the original 1990 plants was similar for all three stocking rates (Fig. 4.3.1 a) and the effect of drought on survival was evident with an increased rate of plant death between 1991 and 1992. Plants from each of the annual seedling cohorts displayed different survival between years with few consistent differences between the three stocking rates (Fig. 4.3.1a). An exception to this generalisation was apparent in the high stocking rate treatment for the 1992 seedling cohort, but this anomaly was probably the result of a limited number of seedlings.

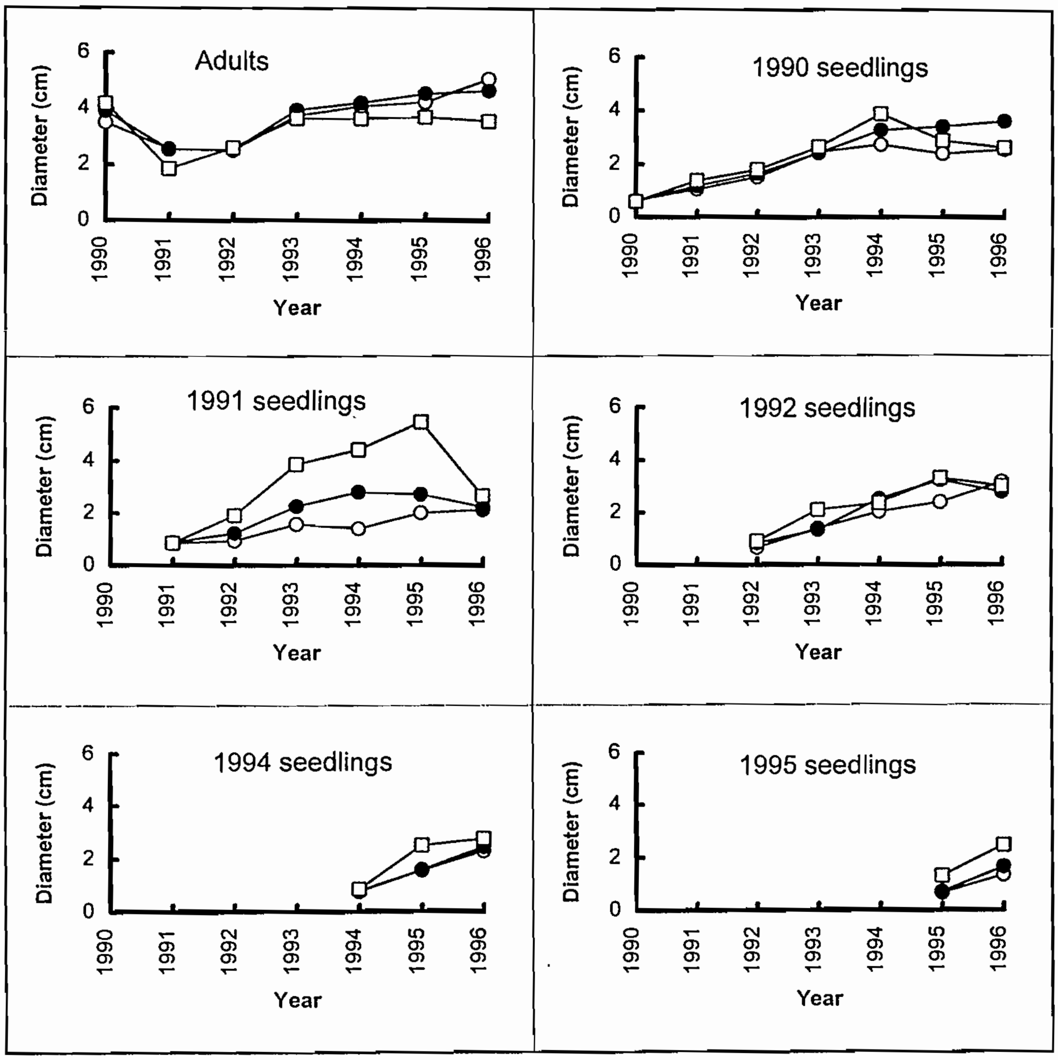


Fig. 4.3.1b. Average basal diameter of six cohorts of *Heteropogon* at three stocking rates (O = very low/low; ● = low/medium; ❑ = high) between 1990 and 1996. Adults = original plants marked in 1990, and seedlings marked in 1990, 1991, 1992, 1994 and 1995.

Basal area of *Heteropogon* declined at all three stocking rates between 1990 and 1992 and increased between 1992 and 1996. The decline between 1990 and 1992 was associated with relatively poor survival (Fig. 4.3.1a) and reduced size of existing plants together with limited seedling recruitment and limited growth of these few seedlings (see Fig. 4.3.1b). In contrast, the increased basal area after 1992 resulted from a combination of increased seedling recruitment and growth as well as an increase in the size of established plants.

The original 1990 plants declined in size at all three stocking rates between 1990 and 1991 and, after 1992, increased in a similar pattern at the two lowest stocking rates. However, by 1996, plants at the high stocking rate had been reduced in size compared with those at the other two stocking rates (Fig. 4.3.1b). Plants from each of the annual seedling cohorts at the two lowest stocking rates tended to increase in size in a similar pattern. Annual seedling cohorts at the high stocking rate tended to increase in size more than cohorts at the two lowest stocking rates.

4.3.2 *Aristida* spp. population processes

Recruitment of *Aristida* spp. varied between years but not between stocking rates within years. A large recruitment occurred over the 1990-91 summer but was less than 1 seedling/m^2 for all other years. Accordingly, plant density increased between 1990 and 1991 reflecting this relatively large seedling recruitment over the 1990-91 summer. Plant density declined after 1991 and there was a trend for density to be reduced more as the stocking rate increased.

Survival of the original 1990 plants tended to decrease as the stocking rate increased. A similar pattern of decreased survival as stocking rate increased was apparent for plants from the 1991 recruitment (Fig. 4.3.2a).

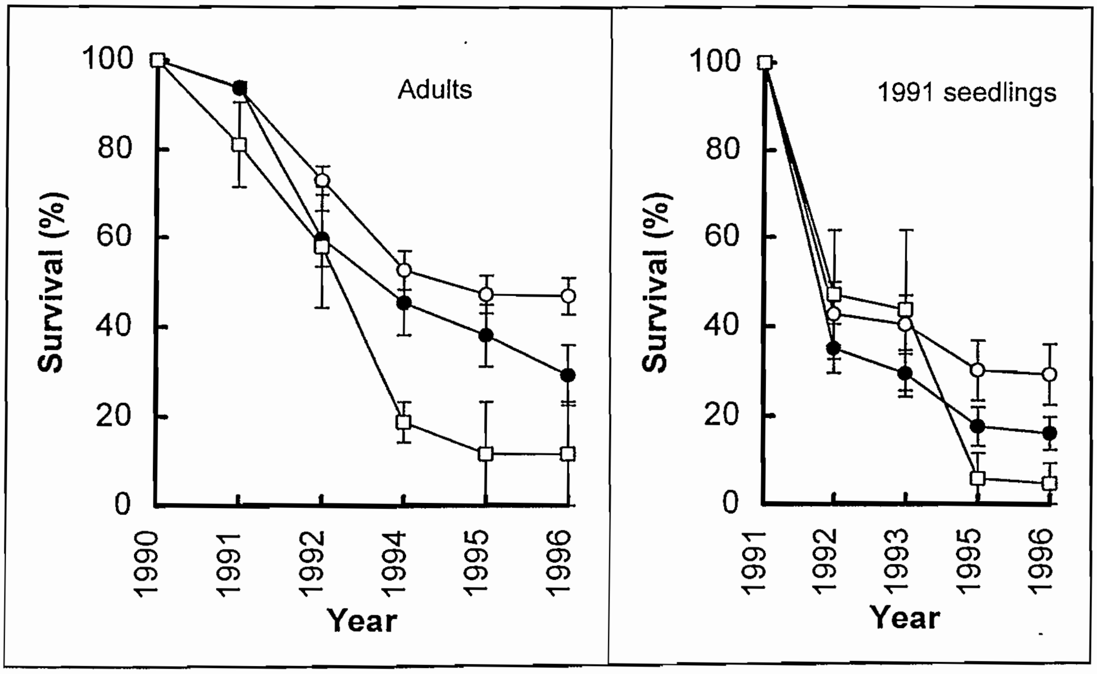


Fig. 4.3.2a. Percentage survival of two cohorts of *Aristida* spp. at three stocking rates (O = very low/low; ● = low/medium; ❑ = high) between 1990 and 1996. Adults = original plants marked in 1990, and 1991 seedlings = seedlings marked in 1991. (Bars are ± standard errors).

Basal area decreased between 1990 and 1996 at all stocking rates and this decrease was accentuated with increasing stocking rate. This reduction in basal area with increasing stocking resulted from reduced survival (see Fig. 4.3.2a) and size (see Fig. 4.3.2b) of individual plants.

The size of the original 1990 plants at the very low/ low stocking rate remained relatively stable (Fig. 4.3.2b). However, the size of the original 1990 plants at the low/ medium and high stocking rates was reduced, particularly at the high stocking rate, between 1990 and 1996. Plants from the 1991 recruitment increased in size at a similar rate at the very low and low stocking rates (Fig. 4.3.2b). Results for the high stocking rate treatment after 1993 probably reflect the effect of limited seedling numbers.

Overall, differences in the population processes of both *Heteropogon* and *Aristida* spp. have been influenced less by stocking rate than by seasonal rainfall. However, there was a clear trend for seed production, recruitment and plant density of *Heteropogon* to be reduced at heavy grazing. There was also a clear trend for *Aristida* spp. to be adversely affected more at high than at very low and low stocking rates.

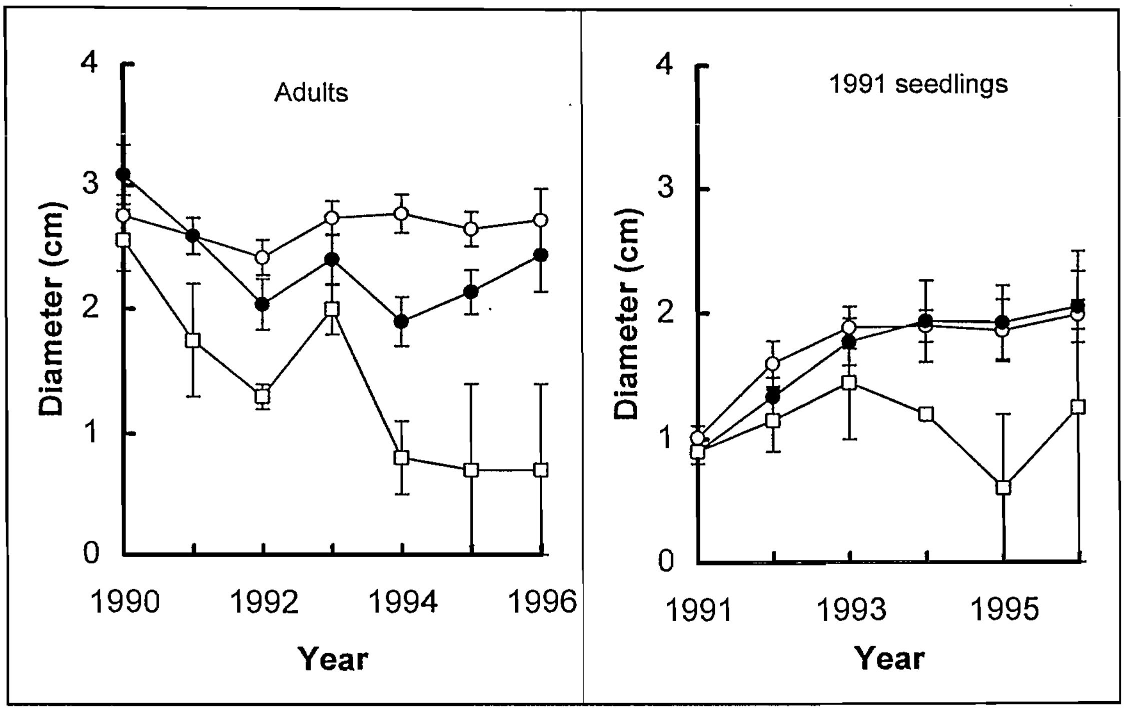


Fig. 4.3.2b. Average basal diameter of two cohorts of *Aristida* spp. at three stocking rates (O = very low/low; ● = low/medium; ❑ = high) between 1990 and 1996. Adults = original plants marked in 1990, and 1991 seedlings = seedlings marked in 1991. (Bars are ± standard errors).

4.4. Tree regrowth and stocking rate

Tree regrowth is an important factor in management of native pastures and its control can be a major cost in grazing operations. The effect of the experimental treatments on rates of tree regrowth is therefore of interest. Initially, (1989/1990), all trees in the experimental paddocks that were < 50 mm in diameter were treated with Garlon® 600 herbicide and diesel. This was applied as a low pressure spray to the stems, near their base. After this single treatment, subsequent regeneration was then allowed to grow over the next 5 years. Monitoring of this regrowth commenced in September 1991 and was restricted to land class paddocks.

The ridge (spotted gum) land class paddocks on 'Narayen' were monitored for a two year period but because of the amount of regenerating *Acacia*, they had to be re-treated with Garlon® 600 herbicide and diesel at two year intervals for the rest of the trial.

The tree and shrub regeneration (either seed or sucker derived) was recorded in 32 paddocks, consisting of 4 stocking rates, 3 land classes and 2 legume treatments enabling ANOVA 2, 3, 4 and 5 to be performed and examine the effects of stocking rate, land class and legume augmentation. The data was collected annually in spring over a five-year period.

The data were recorded along strips 2 m wide and arranged in parallel across each paddock spaced at 50 m intervals. Two data types were recorded:
i) Frequency of each species - Each strip was divided into 25 m adjoining segments and the presence of all tree and shrub species was recorded. Frequency of each species (and for all species as a group) was calculated as the percentage of segments in which that species (or any species) occurred.
ii) Height - Height of all regenerating trees and shrubs was recorded in every second segment.

The woody species recorded were :- narrow-leaved ironbark (*Eucalyptus crebra*), silver-leaved ironbark (*E. melanophloia*), blue gum (*E. tereticornis*), spotted gum (*E. maculata*), Moreton Bay ash (*E. tessellaris*), bloodwood (*E. polycarpa*), kurrajong (*Brachychiton populneus*), smooth-barked apple (*Angophora costata*), wattle (*Acacia* spp.), gumtop box (*E. moluccana*), poplar box (*E. populnea*).

After 5 years, in spring 1995, the frequency of regrowth (all species) was six times higher on the upper slopes (20%) than on the mid (3.5%) or lower (2.5%) slopes, but the differences were not significantly different. Similarly, the legume treatment had no significant effect on the frequency of regrowth, being 15% in native pasture and 11% in the legume augmented pastures.

After 5 years there was a trend towards overall increase in frequency of regrowth as the stocking rate was reduced (see Fig. 4.4a). Although the differences were large, the treatment averages were not significantly different. However, the height of the regrowth in the very low stocking rate was significantly higher than any other stocking rate. This result suggests that tree control with very low stocking may be more critical, in terms of the extent of regrowth and potential competitive effects of trees and shrubs on the herbaceous layer. However, at low stocking rates the availability of fuel is greater, providing more opportunities for the use of fire to control regrowth.

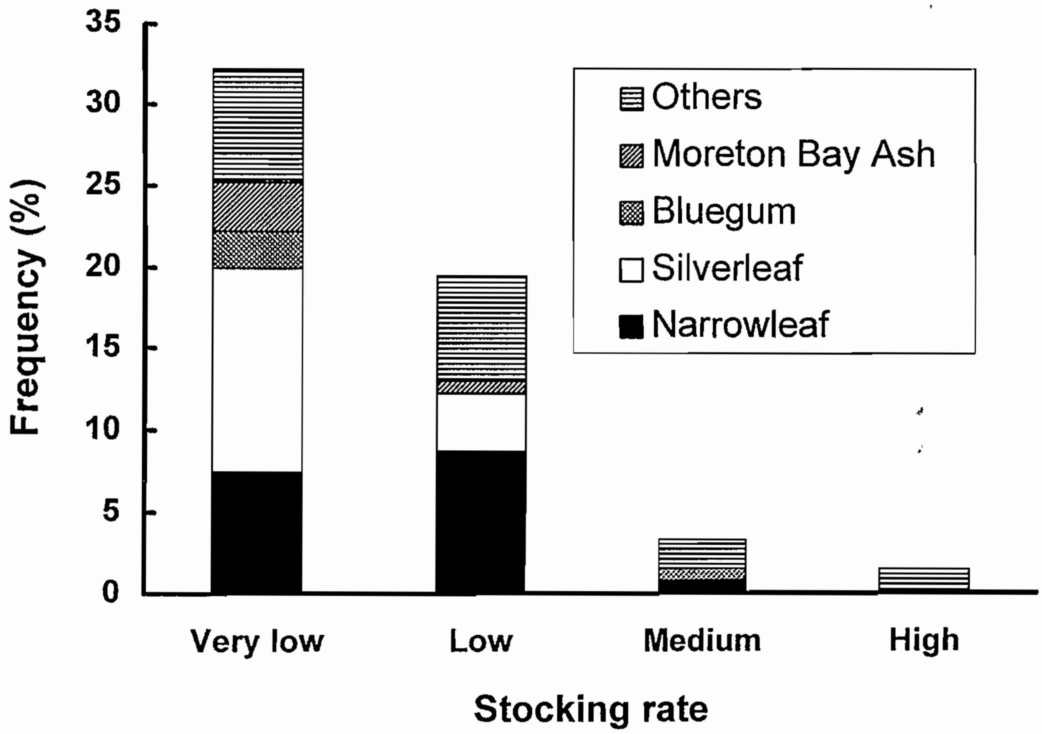


Fig. 4.4a. Percent frequency of tree and shrub regrowth under four stocking rates in 1995, five years after an initial control treatment of all trees and shrubs with a stem diameter of <50 mm. Data are form ANOVA 3 and means were not significantly different.

4.5. How does high stocking affect soil condition?

4.5.1 Pore size characteristics.

Stocking rate can affect the soil hydrologic characteristics, and hence runoff and soil movement. At 'Glenwood', there was no clear stocking rate effect, with the exclosure having the highest hydraulic conductivity at both suctions, and the low stocking rate having the lowest hydraulic conductivity at both suctions (Table 4.5.1a). The contribution of the pores between 1 mm and 3 mm to water conductivity was the same for the exclosure and the high stocking rate (40 mm/hr), while the low stocking rate is significantly reduced (13 mm/hr).

Table 4.5.1a. Hydraulic conductivity (mm hr^{-1}) at three levels of stocking and two levels of applied suction using a disk permeameter for 'Glenwood'. Means followed by the same letter are not significantly (P<0.05) different between treatments for the same head.

Treatment	Head (cm H_2O) -1	Head (cm H_2O) -3
	Pore diameter (mm)	
Stocking rate treatment	<3.0	<1.0
Exclosure (no stock)	99a	59a
Low	30c	17c
High	76b	36b

Parallel observations made at the Galloway Plains grazing trial (MRC Project DAQ080) showed a large reduction in hydraulic conductivity under heavy stocking. It is possible that the differences between low and high stocked runoff plots at 'Glenwood' reflect the effects of past grazing patterns rather than those more recently imposed in the experimental design.

4.5.2 Rainfall simulator

The results obtained using the disk permeameter were not reflected in the peak rate of runoff and total runoff found using a rainfall simulator (Table 4.5.2a). The stocking rate effect is not clear, with the plots showing an increase in total (2, 5, 9%) and peak runoff (3, 7, 15%) with stocking rate, but these values are not significantly different.

Table 4.5.2a. Mean peak runoff rate (Qp^a) and total runoff (%) on three stocking rate treatments, derived using a rainfall simulator. Means followed by the same letter are not significantly ($p<0.05$) different between treatments.

$$\text{Peak runoff rate} = \frac{\text{rate of runoff}}{\text{rate of applied rainfall}} \times \frac{100}{1}$$

	Qp^a (%)	Total runoff (%)
Stocking rate treatment		
Exclosure (no stock)	3a	2a
Low	7ab	5a
High	15b	9a

4.5.3 Plot runoff and soil movement

Stocking rate had a marked effect on runoff in the small plots; the higher the stocking rate the higher the runoff (Fig. 4.5.3a). Grass cover does not appear to be well correlated with runoff at the intensity of rainfall experienced. Due to the dry conditions experienced, cover levels in the grazed plots have generally been low (<40%) and there is no significant difference in cover between the low and high stocking rates. The cover in the exclosure has been consistently higher, ranging between 80 and 100 percent.

There appears to be an additive effect of land class and grazing pressure, with the upper slope, high stocking rate plots producing the maximum runoff (205 mm). The above average rainfall for the 1995/96 season maintained the soil profile at field capacity for a high proportion of the summer. This resulted in exceptionally large runoff volumes across all stocking rates for the 1995/96 summer compared to previous seasons. There have been only a limited numbers of individual runoff events for which hydrographs can be analysed.

Associated with the runoff events recorded for the small plots, a number of soil loss events were measured (Fig. 4.5.3b). The effect of stocking rate is clearly visible, with the heavier stocking rate producing a cumulative soil movement of up to 3092 kg/ha for the higher stocking rate plots. For the exclosure areas, only 79 kg/ha were recorded.

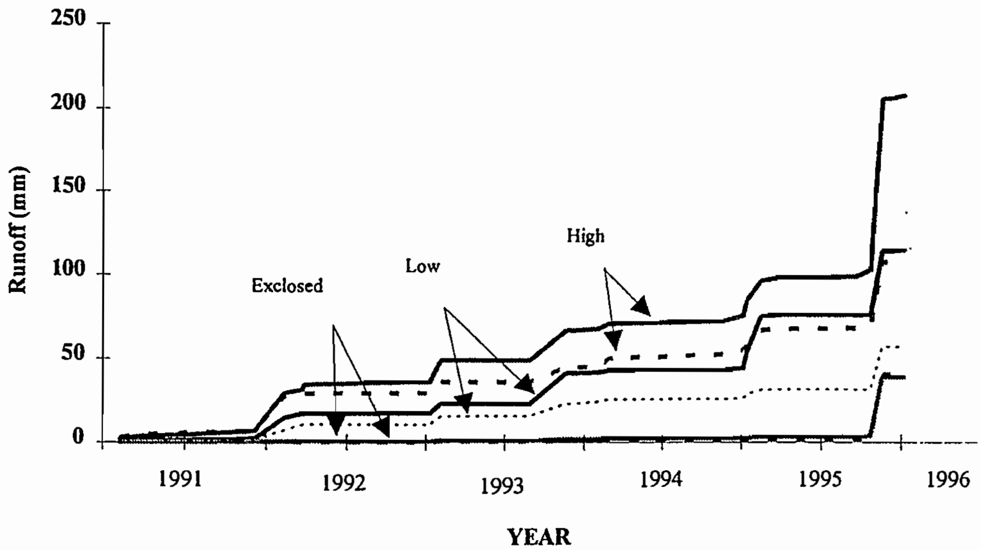


Fig. 4.5.3a. Average cumulative runoff in small plots over six seasons for two land classes, upper slope (solid lines) and mid slope (broken lines); and three stocking rates: exclosed (no stock), low and high.

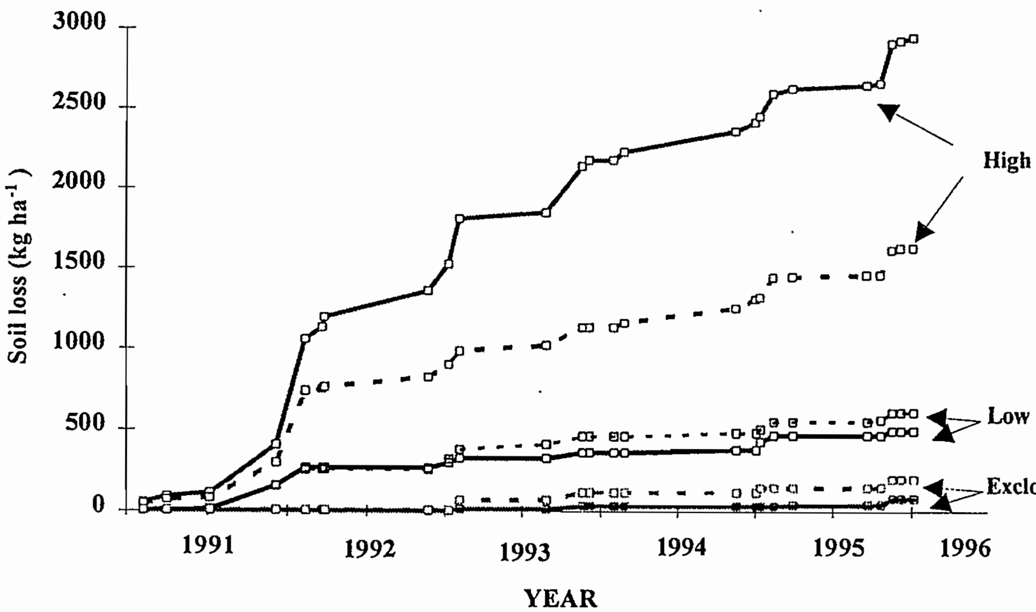


Fig. 4.5.3b. Average cumulative loss of soil in small plots over six seasons for two land classes, upper slope (solid lines) and mid slope (broken lines); and three stocking rates: exclosed (no stock), low and high.

4.6. Animal production and stocking rate

Although there were four stocking rate regimes included in the trial (very low, low, medium and high), the design was not fully factorial and only three of the stocking rate treatments were imposed on the native pasture (ie. very low, low and medium) and two on the lower slope land class (low and medium). The following production results are for the mid and upper land classes paddocks within the legume sown treatment only (ANOVA 3).

In the first three years of the trial there was no significant difference in liveweight gain per steer observed for the different stocking rate treatments (Table 4.6a). In these years, any animal production differences could only be attributed to the presence or absence of the legume sown treatment (Sect. 5.3.). This lack of a stocking rate effect might be partly explained by the removal of grazing pressure at critical times to establish legumes (Sect. 2.4). Coinciding with the decision to maintain stocking rates at their nominal levels from August 1993 onwards, the pattern of earlier seasons changed. In both 1993-94 and 1994-95, there was a significant difference in liveweight gain per steer between the high treatment and the other three treatments. However, despite the continued poor seasonal conditions over these two years, the average liveweight gain per steer was higher than that in 1992-93 when the paddocks were fully or partially spelled for approximately 50% of the season. This result may be partly explained by the supplementary feeding regime introduced in 1994 (Sect. 2.7.2.) to maintain full stocking rates for the entire season (1993-94) whereby some animals were fed through the winter of 1994 commencing in May (affecting both 1993-94 and 1994-95 seasons).

Table 4.6a. Liveweight gain (kg head^{-1}) for four stocking rate treatments 1990-95. The 'very low' treatment commenced in 1993-94. Statistical comparisons are not available for the 'high' treatment prior to 1993-94. Data are from ANOVA 3.

Stocking rate treatment	1990-91	1991-92	1992-93	1993-94	1994-95
Very low	176	178	143	187	158
Low	155	155	137	169	163
Medium	173	155	149	156	144
High	160	142	122	111	100
l.s.d ($p < 0.05$)	n.s.	n.s.	n.s.	23	27

A typical focus for extensive livestock management is the paddock rather than the animal and, while related by the common factor of stocking rate, per animal and per unit area production relationships can be substantially different. This is evident for the present trial results. For example, while there was only a limited difference between per steer productivity (Table 4.6a) for each treatment when the stocking rate treatments were fully applied, the liveweight gain per hectare (Table 4.6b) was significantly different across all but the two highest stocking rates. This is consistent with an observation for many stocking rate trials (Wilson and MacLeod 1991) whereby, for a feasible range of stocking rates (ie. within the limits of commercial practice) higher stocking rates are commonly consistent with increasing productivity per unit area. In the context of the present trial, it must be recognised that all of the animals in the high stocking rate treatment and a proportion of the animals (60%) in the medium stocking rate treatment were fed a supplementary hay ration for a period of 24 and 12 weeks, respectively, to prevent excessive weight loss. However, despite this supplementation, the liveweight gain per animal (Table 4.6a) was significantly less than that for the other three stocking rates. Moreover, it is obvious from the extent of the feeding, that without this management intervention, it would not have been feasible to hold stock in the higher stocked paddocks without severe mortality. The lack of significant difference between the low and medium stocking rate treatments prior to 1993-94 may largely reflect their near-equal stocking rates status prior to that season.

Table 4.6b. Liveweight gain (kg hectare^{-1}) for four stocking rate treatments 1990-95. Data are from ANOVA 3.

Stocking rate treatment	1990-91	1991-92	1992-93	1993-94	1994-95
Very low	53	54	43	28	24
Low	93	93	82	51	49
Medium	104	93	89	94	86
High	144	128	110	100	90
l.s.d (p<0.05)	17	14	21	15	18

4.7. The economics of stocking rate

4.7.1. Gross Margin Analysis

Comparative gross margin analyses are commonly applied to experimental data from stocking rate trials in order to make an assessment of the relative profitability of the respective stocking rate treatments (eg. Bransby 1989, Wilson & MacLeod 1991). Because gross margins are a useful indicator of farm business performance and are widely used by farm business advisers and producers to assess the economic value of different management options, we have adopted the approach for the present trial with economic performance presented in terms of gross margin per steer and per hectare. Similar to animal performance (Sect. 4.6.), results are presented for each of the five years of the trial with most emphasis placed on the last two seasons in which the full stocking rates applied .

Gross margins are derived by calculating gross animal revenue, which is the product of steer sale weights (kg/steer /year) and the price of beef (cents /kg liveweight basis), and then subtracting direct husbandry and marketing costs ($/steer / year). The beef price used is the mean value for 'over the hooks' price quotations from export meatworks (AMLC National Livestock Report) for the relevant classes of finished stock (Japanese Steer and Korean Steer trading categories) that have applied from January 1996 to May 1996. Husbandry and marketing costs have been derived from local sources including the QDPI, CSIRO Narayen Research Station trading accounts, and agribusiness firms in the Burnett region.

The gross margin per steer estimate is converted to a gross margin per hectare by multiplying by the relevant stocking rate.

Gross margin per steer

Estimates of gross margin per steer for the four stocking rates for 1990/91 to 1994/95 are presented in Fig. 4.7.1a. While the mean value of liveweight gain per steer (Table 4.6a) has been used to derive these estimates, not all of the treatment liveweight gains were significantly different and the individual values are presented for all treatments for illustrative purposes. Sale values and husbandry costs (including extraordinary items such as drought feeding costs) also affect this measure. For example, market specifications are placing increasing emphasis on the liveweight performance of individual steers and substantive premiums and penalties apply for different weight for age classes of finished stock. In 1992-93 the projected sale weight of steers from all four stocking rate treatments was such as to downgrade them from Japanese Steer (500 kg liveweight plus) to Korean Steer market category, incurring a 2 cents per kilogram liveweight penalty (pre-1996 the penalty would be closer to 6 cents /kg). In the other years, with the exception of 1990/91 when all treatment steers would have attained the minimum Japanese Steer market sale weights, the steers from the high stocking rate treatment would have incurred the 2 cent/kg penalty, as did the medium treatment steers in 1994/95. Supplementation of all of the high stocking rate steers and a significant proportion (Sect. 2.4.2 and 4.6.) of the medium treatment steers in the winter-spring period of 1994/95 incurred an expected cost per steer of $15 and $48 per steer respectively for these two treatments.

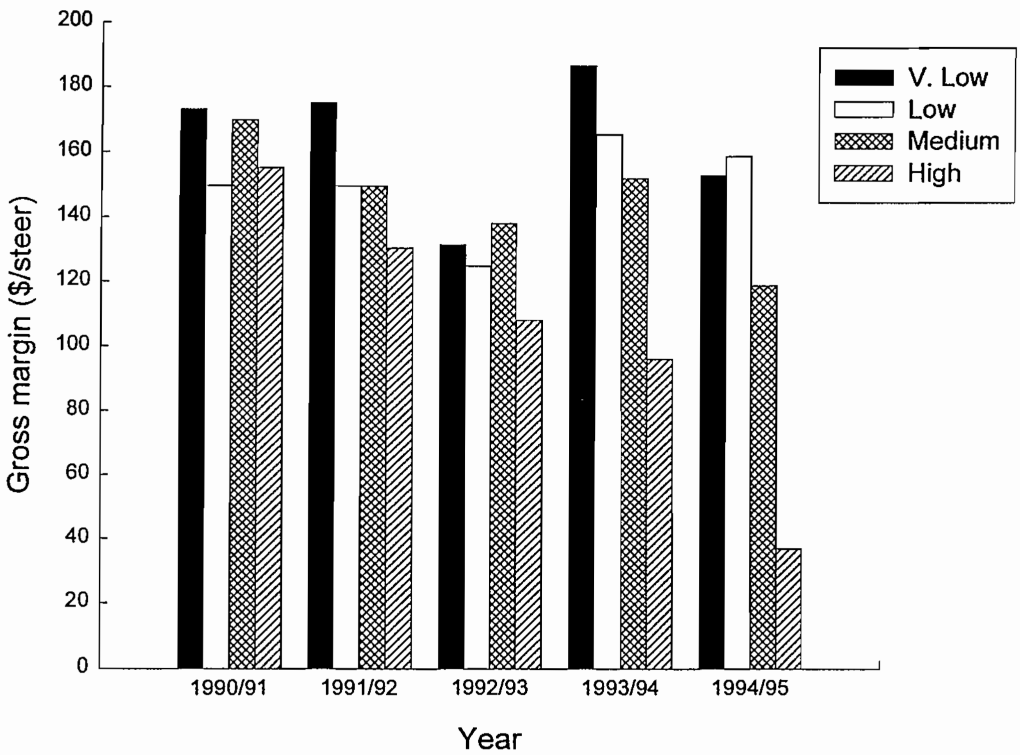


Fig. 4.7.1a. Gross margin per steer for the four stocking rate treatments 1990/91 to 1994/95.

Gross margin per hectare

Gross margin per hectare estimates are presented in Fig. 4.7.1b. Like the gross margin per head estimates, the per hectare values largely mirror the corresponding liveweight gain estimates (Table 4.6b). For example, in the first three seasons the estimated gross margin per hectare values generally increased with increasing stocking rates and the corresponding increases in liveweight gain per hectare. The spelling and destocking that occurred during these seasons, and the return to full stocking after August 1993 are reflected in the absolute magnitudes of the estimates. However, unlike the liveweight gain per hectare estimates (Table 4.6b), the high stocking rate treatment is not universally consistent with the highest economic return. In 1993/94, the market penalty was sufficient to reduce the gross margin per hectare for the high stocking rate below that of the medium stocking rate treatment. By 1994/95, the combined effect of market penalties and supplementary feeding costs incurred for the two highest stocking rates had further reduced the estimated gross margin values. The largest impact occurred in the high stocking rate treatment which incurred the more substantial feeding penalty resulting from supplementation (see feeding rules, Table 2.7.2a). This generated a lower gross margin compared with the low stocking rate treatment.

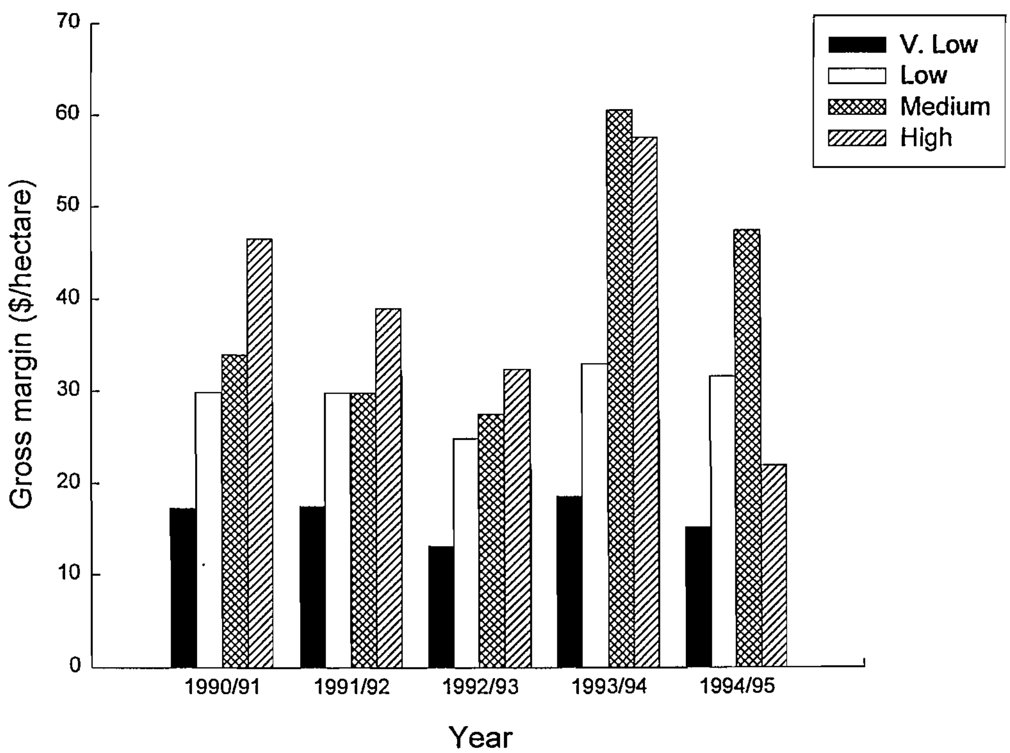


Fig. 4.7.1b. Gross margin per hectare for the four stocking rate treatments 1990/91 to 1994/95.

4.7.2 Whole enterprise analysis

The effects of the treatments are projected to a whole enterprise (property) basis by calculating the total gross margin, operating (net) profit, return to capital, and return to equity for each stocking rate treatment. For this exercise, the liveweight gain results (Sect. 4.7.1., 4.7.2.) are projected for a hypothetical bullock trading herd for a 4000 hectare property located in the Burnett region. Weaner steers enter the herd at 200 kg liveweight and are sold after two seasons. Husbandry practices are consistent with local practice and feeding and supplement costs estimated for the medium and high stocking rate treatments are based on the pasture hay feeding regime imposed for the trial (Sect. 2.7.2.). Enterprise overhead cost and capital structures are derived from a survey of properties in the southern black speargrass region of sub-coastal Queensland (Taylor Byrne 1993).

Operating profit is derived by subtracting overhead costs from the estimated total gross margin (gross margin per hectare by 4000 hectares). Return to capital is the ratio of net profit to total capital (including. land, plant and improvements and livestock) and risk is assessed by examining return to equity (debt-adjusted return to capital) calculated for a range of assumed debt levels. The analysis is only conducted for the 1994-95 data.

Operating profit and return to capital

Operating profit and return to capital (full equity) estimates for 1994/95 are presented in Table 4.7.2a.

Table 4.7.2a. Operating profit and return to capital (full equity) by stocking rate treatment 1994/95.

	Stocking rate			
	Very low	Low	Medium	High
Net profit	$13713	$79418	$138979	$36202
Return to capital	1.4%	6.6%	9.3%	2.2%

The net profit and return to capital does not necessarily reflect the gross margin per hectare estimates (Fig. 4.7.1b). The highest net profit was derived for the medium stocking rate which was over 50% higher than that of the next most profitable stocking rate. The high stocking rate treatment yielded a net profit less than one half that of the low stocking rate, and almost one quarter of the medium stocking rate. The poor profit result for the very low stocking rate treatment is due to the limited saleable beef turnoff and gross income (Table 4.6.b and Fig. 4.7.1b) available to contribute towards meeting the overhead costs.

Equity and Risk

The return to capital estimates relate to enterprises that are 'debt free'. However, there will always be a proportion of enterprises carrying various levels of debt which must be serviced from existing cash flows. Return to equity adjusts both the net profit estimate to allow for interest due on outstanding debt and the enterprise capital to reflect the actual equity held by the managers. Risk arises in the context of low rates of return on capital because, in the face of a continuing cost-price squeeze, variable markets and seasonal conditions, low rates of return on full equity usually translate to a worse picture when debt is carried as illustrated for the four stocking rate treatments in Table 4.7.2b.

As the level of equity declines, the rate of return on that equity also declines across all of the four stocking rate treatments.

By the nature of the definition of gross margins which underpin the preceding analysis, all of the economic performance measures are sensitive to price and cost assumptions. The respective effects of a 5% and 10% decrease in beef prices and increase in the production costs assumed for the analysis are illustrated in Table 4.7.2c.

Table 4.7.2b. Return on equity by stocking rate treatment for a range of equity levels 1994/95.

	Stocking Rate Treatment			
Equity level	Very low	Low	Medium	High
50%	-11.1%	-0.6%	4.7%	-9.4%
60%	-7.0%	1.8%	6.3%	-5.6%
70%	-4.0%	3.5%	7.3%	-2.8%
80%	-1.8%	4.8%	8.1%	-0.7%
90%	Nil	5.8%	8.8%	0.9%
100%	1.4%	6.6%	9.3%	2.2%

Table 4.7.2c. Effect on operating profit and return to full equity of changing beef prices and production costs 1994/95.

Parameter change		Stocking rate			
		Very low	Low	Medium	High
Beef price:					
- 5%	Operating profit	$7917	$67602	$12177	$61814
	Return to equity	0.8%	5.7%	8.2%	0.9%
-10%	Operating profit	$2121	$55786	$99627	($12182)
	Return to equity	0.2%	4.8%	6.9%	(0.8%)
Production cost:					
+ 5%	Operating profit	$11103	$76573	$138313	$31355
	Return to equity	1.1%	6.4%	9.2%	1.9%
+ 10%	Operating profit	$8492	$73728	$133900	$74149
	Return to equity	0.8%	6.2%	8.9%	1.3%

4.8. Summary

- Despite drought conditions, the effects of stocking rate were not strongly evident until the last two years of the experiment. This was due to periodic episodes of half-stocking and resting (over all treatments), which were strategically applied to assist sown legumes to establish.

- The dominant grass *Heteropogon*, fluctuated in abundance from year to year but declined overall (1989-95) in all stocking rates. Decline in frequency at the low stocking rate was half that in the very low, medium and high rates. There were no clear patterns in the population dynamics to explain these differences in overall decline. Seed production was reduced under the high stocking rate, but the mixing of stocking rate regime paddocks across the two lower stocking rate treatments may have obscured patterns in the last two years of the trial.

- Plant species composition of pastures varied with stocking rate; different species increased under different levels. Annuals and forbs, including native legumes were relatively more abundant under higher stocking rates. The perennial grasses *Melinus repens* and *Cymbopogon refractus*, and *Aristida* (Sections *Aristida*, *Calycinae* and *Arthratherum*), were negatively affected by higher stocking rates. In the measurements of *Aristida* population dynamics, these results were reflected in higher mortality and reduced plant size at higher stocking rates.

- Tree and shrub regeneration was monitored and was found to be very high on the spotted gum (ridge) land class at 'Narayen', such that control of *Acacia* regrowth was necessary every two years. At 'Glenwood', none of the treatment effects (land class, stocking rate or legume) had significant effects on regrowth frequency, although there was a trend for regrowth to be more abundant on the upper slopes and to increase with reduced stocking rate. Height of regrowth trees was significantly greater with lighter stocking.

- In livestock exclosures, water conductivity and runoff was highest and soil loss was lowest. Comparisons between low and high stocking rates were not so clear, but water runoff and soil loss from small plots on high-stocked sites was greater, particularly on the upper slopes.

- Consistent with the results of other stocking rate trials in rangelands, the highest levels of liveweight gain per hectare corresponded to the highest stocking rates. However, gain per head was significantly lower under the high stocking regime in the closing years of the trial - despite the fact that the animals were supplemented.

- In early years of the trial, economic performance (gross margins) mirrored the liveweight gain results with the highest gross margin occurring under the high stocking rate. However, after 1993/94, when full stocking recommenced, the combined effect of market penalties and supplementary feeding costs reduced the gross margin of the high stocking rate, to the point that it fell below medium and low regimes. The whole enterprise analysis reflected this gross margin results and further highlighted the viability risk associated with high stocking rates.

- Of the four stocking rate regimes, the highest provided neither economic advantage or good pasture management - *Heteropogon* declined and substantial soil losses occurred when it rained on the high stocking rate paddocks. The lowest stocking regime favoured perennial grasses (although not *Heteropogon*) but was insufficient to generate a profit at the whole enterprise level when property debt had to be serviced. The medium stocking rate resulted in the highest gross margins and return on equity, but there are several indications that this stocking rate could be associated with deterioration of pasture condition - evidenced by a decline in *Heteropogon* and, by extrapolation, water runoff and soil movement The low stocking rate regime represented a compromise in economic profitability and pasture condition. At this stocking rate, *Heteropogon* populations persisted and soil losses were relatively low.

5. LEGUMES

5.1. Background

The bandseeding technology was designed to provide more reliable establishment of legumes into existing native pastures by reducing the competition from existing plants. Establishment is facilitated by spraying the pasture sward along the legume rows and placing fertilizer in close proximity to the legume seed. In some unreplicated treatment paddocks at medium stocking, it was found that early establishment of legumes was less in i) a paddock that was broadcast sown and ii) a paddock that had disced strips (Milestone No. 5 report) compared to a similarly stocked bandseeded paddock.

There is ample evidence to predict greater animal liveweight gains in bandseeded paddocks and the major questions posed in the trial related to the role, if any, that bandseeding may have had on the overall stability of native pasture under high grazing pressure. On one hand, the enhanced nutrient status of legume paddocks may make grass populations more resistant to grazing pressure. Alternatively, the bandseeding itself may directly or indirectly disadvantage some components of the native pasture. The following sections describe the results of legume sowing and explore the questions of pasture stability.

5.2. The ecology of legume establishment

5.2.1. Overall establishment of different legumes

Three legumes established successfully, wynn cassia, seca stylo and siratro (Table 5.2.1a). The spread of fine stem stylo was about half that of these species, while lotononis and bargoo joint vetch barely established at all, being present in only very small quantities and not represented in the sampled vegetation. After the first sowing, seca stylo established very poorly compared to wynn cassia and siratro (Fig. 5.2.1a). This was not due to lack of seedling emergence, but high plant mortality. Over 90% of seca stylo plants died in winter/spring of 1990, over twice the mortality of siratro and wynn cassia (see Milestone No. 5 Report). However, rapid spread and growth of seca stylo followed the second sowing and its biomass eventually outstripped the other established legumes.

5.2.2. Effects of land class on legume establishment

Establishment varied across land classes, with legumes showing individual patterns summarized for 1995 in Fig. 5.2.2a. Wynn cassia showed a clear preference for lower slopes and similar comparisons of data from earlier years shows this pattern present in 1991, two years after initial sowing. Siratro showed no difference in spread across land classes, although in earlier years abundance was lower on the upper slopes. By 1995, frequency had increased to similar levels as those found on mid and lower slopes. Seca stylo established equally well on upper and lower slopes and although this pattern was evident in previous years, the differences were only significant in 1995.

No legume performed better on the mid slope land class. This could be because this environment was not optimal, but may have also been related to more effective competition from *Heteropogon* which grew better on this land class.

Table 5.2.1a. Overall establishment success of the six legumes sown in November 1989 and February 1993. Frequency and shoot biomass estimates are grand means of the twelve ANOVA 2 paddocks in March 1995. Frequency indicates the degree of spread of legumes across paddocks while shoot biomass indicates overall bulk of the species.

	Amount sown	Abundance in 1995	
	(kg/ha)	% Frequency	Biomass (kg/ha)
Seca stylo	0.4	43	140
Siratro	1.5	43	67
Wynn cassia	0.5	41	75
Fine-stem stylo	0.4	18	2
Lotononis	0.12	0	0
Bargoo joint vetch	0.15	0	0

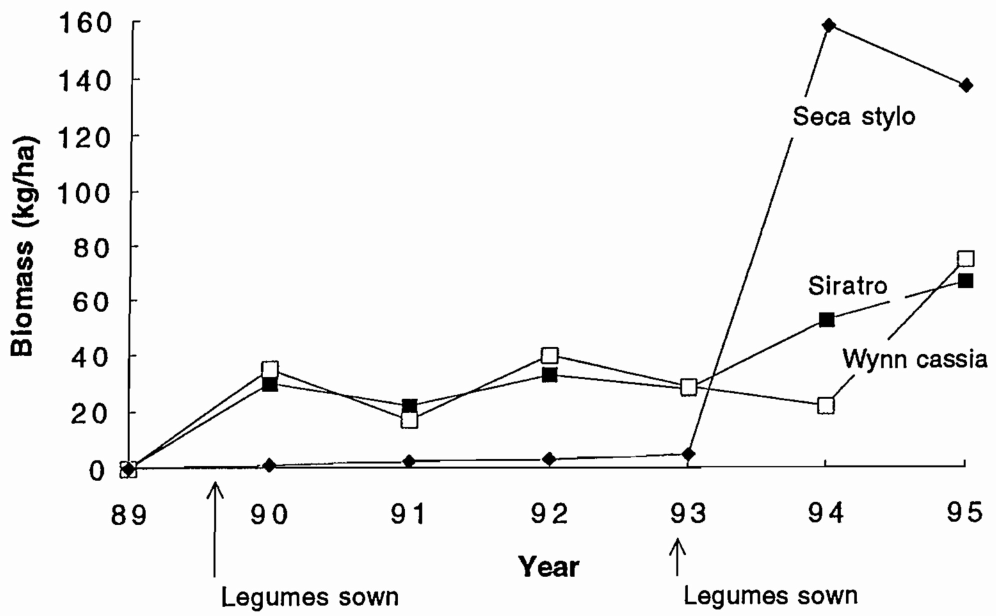


Fig. 5.2.1a. Changes in biomass of three legumes from 1989 to 1995. Estimates were made in autumn of each year. Values are grand means of the 12 ANOVA 2 paddocks.

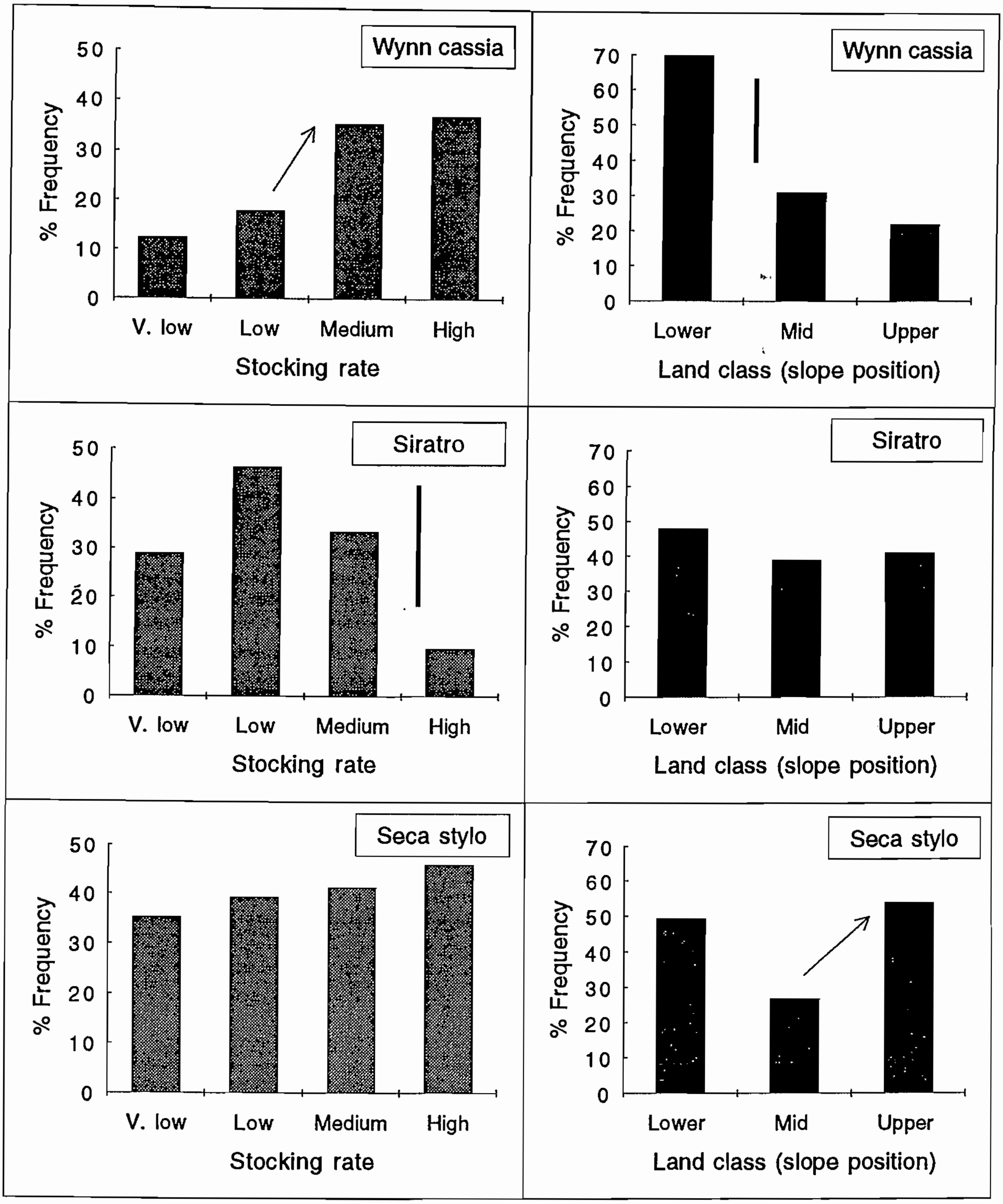


Fig. 5.2.2a. Percent frequency of three most common legumes (measured in 1m^2 quadrats) recorded in March 1995. Comparisons are for stocking rate (ANOVA 3) and land class (ANOVA 2). Bars are l.s.d. ($p<0.05$) and indicate significant differences between stocking rate (for siratro) and land class (for wynn cassia). Arrows indicate where two treatment levels were significantly different in ANOVA comparisons other than those represented in the plots (ANOVA 2, wynn cassia and stocking rate; ANOVA 3 seca stylo and land class).

5.2.3. Effects of stocking rate on legume establishment

As full stocking rates were not imposed continuously until 1993 (to assist legume establishment), no treatment effects were evident until after this time. However, by 1995 two legumes showed significant differences between stocking levels (Fig. 5.2.2a). Wynn cassia was more abundant in the medium and high rates while siratro did not establish well under the high stocking rate. Seca stylo showed a slight trend towards better establishment under higher stocking although the differences were not significant.

Stocking was halved immediately after legume sowing on both occasions and it is not possible to determine whether the application of full stocking treatments during establishment would have led to a different outcome. An early observation is that heavier grazing increased seedling emergence while lighter grazing permitted better growth and seed set in the twelve months after the first sowing (Milestone No. 4 Report).

5.2.4. Effects of bandseeding on overall composition

There are multiple possible effects of the legume sowing treatment on pasture species other than legumes. These are:

a) The direct effects of herbicide spraying;
b) The effects of fertilizer addition;
c) The effects of the legumes themselves, both through direct competition and possible indirect effects of nitrogen addition to the soil;
d) Changes in overall grazing pressure resulting from a);
e) Changes in grazing preference resulting from b) and c).

These possible factors were not specifically investigated but the changes in composition point to some of the factors being more influential than others. Of the 25 most common non-legume species, only five showed significant responses to legume sowing in terms of their frequency (Table 5.2.4a). The most important of these is *Heteropogon* which declined significantly more in the legume treatments (Fig. 5.2.4a). The only plants that increased were three annual species and *Eragrostis* a genus of annual and short-lived perennial grasses.

Table 5.2.4a. Species showing significant response in frequency (ANOVA 4 or 5) to the legume sowing treatment amongst the fifteen most abundant species in 1989 and 1995 (a total of 25 species).

Species with positive response to legume sowing		Species with negative response to legume sowing	
Portulaca pilosa	Annual forb	*Heteropogon contortus*	Perennial grass
Tragus australianus	Annual grass	*Evolvulus alsinoides*	Perennial forb
Eragrostis spp.	Short-lived grasses		
Gomphrena celosoides	Annual forb		

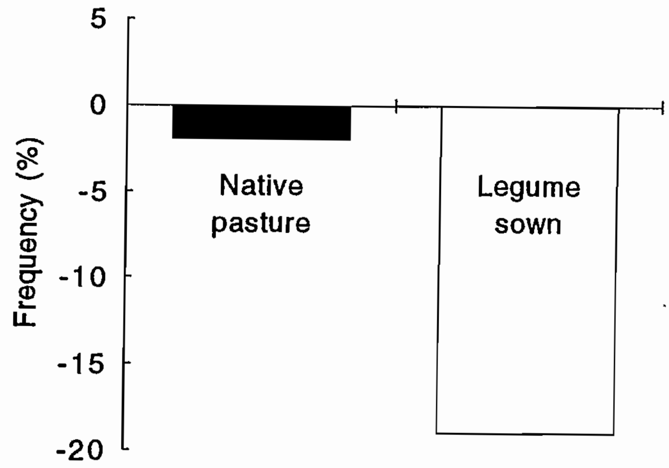


Fig 5.2.4a. Change in frequency of *Heteropogon* between 1989 and 1995 in native pasture paddocks and in paddocks bandseeded with a legume mixture (ANOVA 5). Means are significantly different at p = 0.003.

When the biomass contribution in native and sown paddocks were compared for 1995 the decrease in *Heteropogon* and increase in annual species is also apparent (Fig. 5.2.4b.). The biomass reduction of *Heteropogon* and other perennial grass species in the sown pastures is roughly equivalent to the amount of annual species and sown legumes, indicating a substitution by these species.

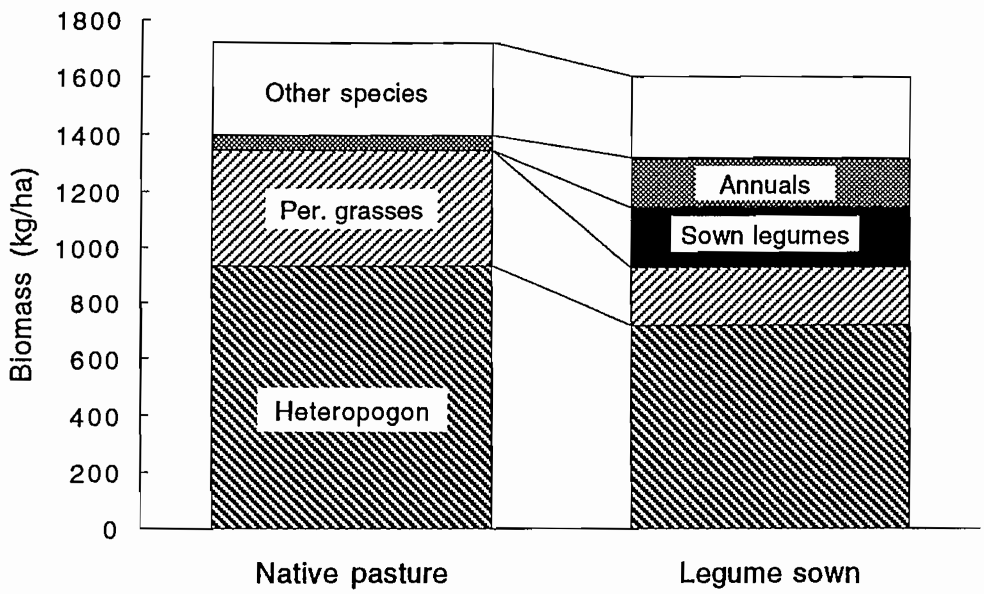


Fig. 5.2.4b. Composition of native and legume sown pastures (ANOVA 4) in 1995. The perennial grass category represents the combined biomass of perennial grasses characterizing states 1-3 (see Sect. 7): *Arundinella nepalensis, Cymbopogon refractus, Digitaria brownii, D. divaricatissima, Bothriochloa decipiens, Aristida* spp. and *Melinus repens*. The 'annual' category represents the biomass of the three most frequent annual species (*Portulaca pilosa, Tragus australianus* and *Gomphrena celosoides*).

The spraying of one third of the pasture for bandseeding resulted in the death of plants and hence a direct reduction of existing biomass. Annuals are generally good colonizers from seed and were probably advantaged by the bare ground created by the herbicide sprayed rows. Observations of the pasture on- and off-row 18 months after the first sowing suggested that populations of grasses such as *Digitaria*, *Heteropogon* and *Melinus* had recolonized the rows successfully while *Cymbopogon*, *Bothriochloa decipiens*, *Aristida* and *Arundinella* were present in the sprayed rows but in lesser quantities than in the unsprayed areas. The longer-term suppression of *Heteropogon* up to 1995 is therefore likely to have been related to greater grazing pressure in sown paddocks compared to native pasture at the same stocking rate. From 1990 to 1994, biomass in the native paddocks was significantly greater than the legume paddocks (ANOVA 5). Although there was still a difference in 1995 it was no longer significant ($p = 0.07$). In summary, it seems that the direct effect of spraying and the subsequent grazing pressure in the legume sown paddocks combined to result in the decline of perennial grasses, (most notably *Heteropogon*) and increases of annual species.

The presence of the legumes themselves may have also affected grazing pressures. Fig. 5.2.4c summarizes a number of changes that were apparent in the sown pasture composition that'related to both stocking rate and land class. The lower amounts of *Heteropogon* in the medium compared to low stocking rate are apparent, as are the reduced quantities on the lower slopes. In the analyses these effects were additive and the least *Heteropogon* occurred on legume sown paddocks on the lower slopes that were grazed at medium and high (see Sect. 4) stocking rates. Comparing stocking rates on the lower slopes, it is evident that wynn cassia has increased while *Arundinella* has

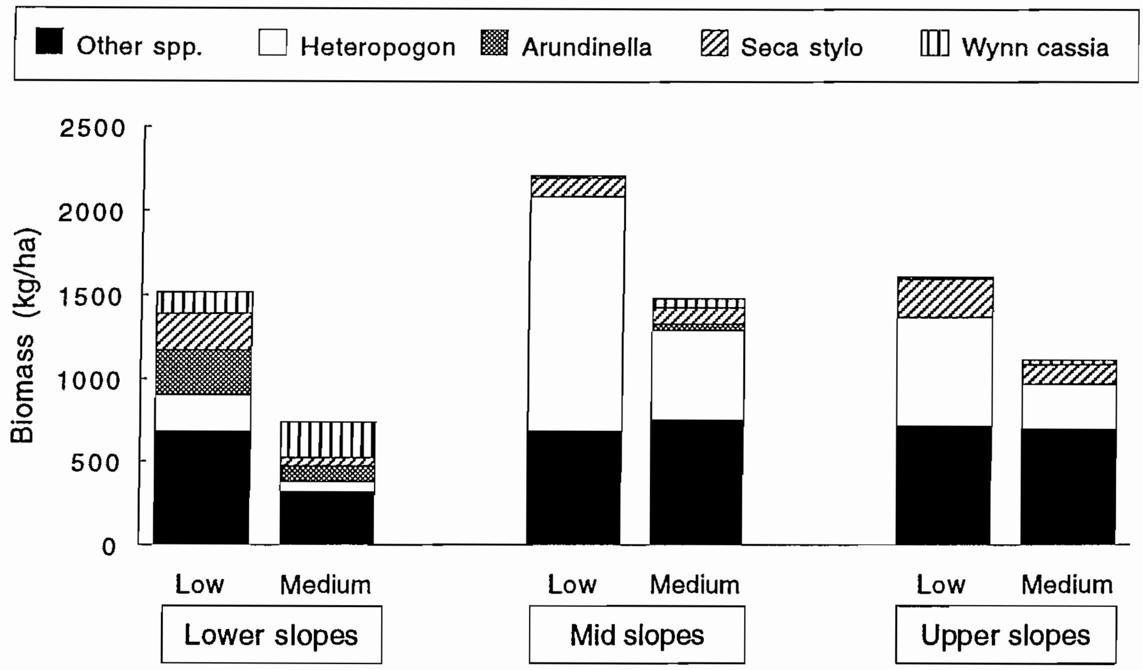


Fig. 5.2.4c. Average composition of pastures in three land classes and two stocking rates (low and medium) in March 1995. Data are from ANOVA 2 paddocks.

declined at the higher level. Although *Arundinella* is a grass of very low grazing preference (see Milestone no. 9 report), it appears to be preferred over wynn cassia. *Heteropogon* decline in the paddocks is likely to be related to it being grazed preferentially to both these species for most of the year. Visually, the shift to wynn cassia dominance was even more apparent on the lower slopes after the 1995 survey.

The loss of *Heteropogon* dominance in legume-sown paddocks is of significance to sustainable pasture management, as replacement of the perennial grass matrix with a short-lived species such as wynn cassia may have the following outcomes:

- Loss of pasture stability as populations of short-lived species are likely to fluctuate due to seasonal effects and the replacement species are more likely to be short-lived plants than perennial grasses;
- Increased likelihood of forage deficits during the dry season due to losses of large perennial species which tend to carry forage into the dry season;
- Increased likelihood of exposure of bare ground and consequent soil erosion during the late dry and early wet season when grazing pressures are highest.

It was apparent that these problems are most likely on the upper and lower slopes where medium and high stocking occurred. Appropriate grass-legume balances occurred under low stocking on mid and upper slopes. There was no evidence that legume sowing ameliorated the effects of grazing pressure on *Heteropogon* populations. However, in the longer term perennial grasses may recover either through active management over a series of favourable seasons or a shift in the nutrient balance, whereby the legumes may fix sufficient nitrogen to competitively favour grasses.

5.3. Animal production and legume treatments

With the exception of 1993/94, which spans the period of the second sowing of the legume treatment paddocks, there was a significant difference between the native pasture and legume-augmented treatments in each year of the trial (Table 5.3.a). Steers are weighed on a 6 weekly basis and, until the late autumn-early winter period, generally show no direct liveweight advantage from access to the legume component of the legume sowing treatment. As feed quality and availability generally decline with the onset of the colder dry season, the steers from the legume treatment then show a production advantage as their condition is held longer and/or weight losses are avoided.

Table 5.3.a. Annual liveweight gain (kg head^{-1}) of steers for native pasture and legume sown treatments 1990-95. Data are from ANOVA 5. All paddocks were medium stocked.

Treatment level	1990-91	1991-92	1992-93	1993-94	1994-95
Native pasture	135	120	121	140	114
Legume sown	160	153	141	153	135
l.s.d (p<0.05)	22	25	16	n.s.	12

5.4. Economic analysis of legume sowing

Pasture "improvement" strategies, where feasible and successful, have the potential to offer production and financial gains for beef producers. Included in such strategies is the augmentation of native grass pastures with legume and exotic grass species, as represented by the sown legume treatment of the present trial, to raise both the quantity and quality of feed on offer, particularly at times of year when the native pastures lack these attributes.

A positive effect of legume-augmentation on liveweight gain performance was evident in each year of the trial (with the exception of 1993-94), with an average gain difference of approximately 22 kgs per steer over the period (Sect. 5.3). However, whether this actually does translate to a positive economic advantage depends on:

- The size and timing of the production gains relative to the values for the finished product;
- The extent to which stocking rates can be increased and sustained;
- The cost of the "improvement" strategy;
- The effectiveness of the strategy in terms of seedling establishment and ongoing survival (MacLeod *et al.* 1993).

Before the legume establishment results were available from the trial, a number of *ex-ante* analyses were conducted for bandseeding technology which relied on a combination of experimental and heuristic data and which pointed to definite economic advantages (eg. MacLeod, Cook and Walsh 1991, MacLeod, Cook and Walsh 1993). However, subsequent analyses also highlighted the potentially adverse effects of establishment failures and the implications of resowing on the economics of such strategies (eg. Milestone No. 4 Report - July 1993, Milestone No. 10 Report - July 1994).

It is now possible to re-evaluate the economic performance of the legume sowing treatment using the actual data from the trial to update and refine the earlier analyses which were based on a multiperiod partial budgeting technique and discounted cash flow analysis (see MacLeod, Cook and Walsh 1993 for a detailed description of the procedure). For this purpose four scenarios are developed:

Scenario 1. Establishment is successful on the first sowing, stocking rates are held constant at 0.3 steers /ha, liveweight gain advantage is 22 kgs /steer /year.

Scenario 2. Establishment is successful on the first sowing, stocking rates are increased to 0.6 steers /ha, liveweight gain advantage is 22 kgs /steer /year.

Scenario 3. Establishment is not successful on the first sowing, pastures are resown in the second year, stocking rates are held constant at 0.3 steers /ha, liveweight gain advantage is 22 kgs /steer /year.

Scenario 4. Establishment is not successful on the first sowing, pastures are resown in the second year, stocking rates are increased to 0.6 steers /ha, liveweight gain advantage is 22 kgs /steer /year.

These basically relate to whether or not the legumes establish successfully on first sowing (Scenarios 1 and 3) and if it is possible to raise and sustain stocking rates after the pastures are treated (Scenarios 2 and 4). Output and input prices were set at the same levels as those in the earlier economic section of this report (Sect. 4.7). A projected pasture life of 15 years and a real discount rate of 5% was used to calculate net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR) and pay-back period (PBP) for each scenario. The direct cost of bandseeding the legume mixture used in the trial (described in Sect. 5.2.1) was estimated to be approximately $60 per hectare (MacLeod *et al.* 1993). The results can be interpreted as follows:

A project is usually considered to be worthwhile if:

(a) NPV of the net benefit stream is positive - ie. in present dollar terms the projected benefit flow exceeds the cost incurred.

(b) BCR exceeds 1.0 - as per (a) the present value of the costs are less than the present value of the benefits.

(c) IRR exceeds the discount rate. IRR is the rate of return on the invested funds and is a measure of how large the discount rate would have to be to make the NPV equate to zero. In the present context an IRR above 5% is worthwhile.

(d) PBP is reasonable. This is a subjective decision, but investments that quickly recoup the outlaid costs are usually preferred, especially when project risks are high.

The PBP is a measure of "risk exposure". Results are summarised in Table 5.4a.

Table 5.4a. Economic results for 4 scenarios of legume establishment success and subsequent animal productivity. NPV= net present value; BCR= benefit-cost ratio; IRR= internal rate of return; PBP= pay-back period.

Performance Criterion	Scenario 1	Scenario 2	Scenario 3	Scenario 4
NPV*	$37/ha	$380/ha	- $28/ha	$281/ha
BCR*	1.5	3.1	0.8	2.2
IRR	10%	28%	3%	18%
PBP	13 years	5 years	15 years	8 years

* Calculated using 5% real discount rate

The projected economic return from the legume sowing option was heavily influenced by the establishment success of the initial sowing <u>and</u> whether it is in fact possible to increase and sustain stocking rates at a higher level than those for the previously untreated native pasture. In fact, the latter consideration dominated the calculation as the return measured by all four performance criteria was substantially higher (Scenarios 2 and 4) when the stocking rate is doubled, regardless of whether the initial establishment is successful or not (Scenario 4).

If the initial establishment fails (requiring a resowing) and stocking rates are maintained at the pre-treatment level (Scenario 3) the outcome is a clear economic failure with a projected net present cost of $28 and a benefit-cost ratio below 1.0. This scenario/outcome is probably the one that is most analogous to the trial outcome as the treatments were sown twice (Sect. 2.5., 5.1.) and, under the conditions that prevailed for much of the trial, a doubling of stocking rate would seem to be unwarranted. A general conclusion to be drawn is that while there is *a priori* reason to suggest that the economic advantage of legume sowing may be positive under some circumstances, the option carries considerable risk of financial failure. It may also carry risks of pasture degradation (Sect. 5.2.4.). However, an important caveat is that, while these results may be disappointing and would represent a significant loss to an individual producer sharing a similar experience to that of the trial, they should also be seen in context. Few producers would have undertaken a legume second planting until seasonal prospects looked better than those prevailing in 1992-93. The trial paddocks were resown to meet an experimental rather than a commercial imperative.

5.5. Summary

- The decision to sow the experimental paddocks a second time implies failure of the bandseeding technique under difficult seasonal conditions. Indeed, there is an important element of risk associated with any method used to establish plants from seed, as the seedling is the most vulnerable part of the plant life cycle. Retrospectively it may not have been necessary to resow in order to establish siratro and wynn cassia. Regardless of any re-sowing requirement, it is still notable that three of the six legumes sown established successfully during a period of record drought which is testimony to both the hardiness of the legumes and the overall effectiveness of the bandseeding technique.

- Two of the legumes sown demonstrated land class preferences : wynn cassia established best on the lower slopes while seca stylo was most abundant on upper and lower slopes. However, these land classes were not associated with significantly higher animal weight gains. In fact the trend was for mid slopes, which had a smaller legume component, to have greater animal production (Sect. 3.5. It appears that while legumes can give significantly higher liveweight gains compared to native pasture, more legumes are not necessarily better.

- A legume/ grass balance seems appropriate to meet a suitable forage quantity/quality balance. Perennial grasses such as *Heteropogon* provide forage bulk during the dry season and complements the higher quality, but lower quantity, of legumes. The tendency for dominance of seca stylo on upper slopes and wynn cassia on lower slopes are warning signs that careful management is required to achieve this balance. Within commercial paddocks these two land classes need to be watched most carefully for signs of legume imbalance.

- In the short-term at least, legume sowing did not ameliorate the effects of grazing on the native pasture. The opposite effect was more apparent, with the legume treatment producing changes that were similar to the effects of the higher stocking rates viz. declines in *Heteropogon,* other perennial grasses and increases in annual species. This is not surprising as the bandseeding treatment effectively increased grazing pressure. There are ecological risks associated with these changes. Decline of *Heteropogon* has been equated to pasture and soil degradation in the region (Tothill and Gillies 1992). The degradation is essentially associated with the large size and productive capacity of some perennial grasses. Robust tussocks provide physical protection of the soil from water erosion. The accumulation of litter and the presence of a substantial leaf canopy protects soil from the impact of rainfall, while the basal cover provided by the tussock bases is an obstruction to overland water flow (Tongway 1994). The greater biomass produced by large perennial tussocks, compared to forbs and annual species, provide a carry-over of fodder for cattle during the dry season, as well as a contribution of organic matter for the continuation of soil processes. Thus the ecological risks associated with legume sowing may translate to reduced plant and animal productivity in the longer term without active management. While it is not clear how reversible these changes are, it is evident that the stability of native pasture may be reduced by legume sowing.

- Legume-augmentation, where feasible and successful, can offer production and financial gains for beef producers. A liveweight gain advantage was evident in each year of the trial (with the exception of 1993-94) of approximately 22 kgs per steer over all of the years. However, the projected economic return from the legume sowing option is heavily influenced by the establishment success of the initial sowing and whether it is, in fact, possible to increase and sustain stocking rates at a higher level than those for the previously untreated native pasture. The latter consideration dominates overall profitability as the return from four modelled scenarios (covering combinations of stocking rate increases and establishment success) is substantially higher when the stocking rate is doubled regardless of whether the initial establishment is successful or not. A general conclusion, therefore, to be drawn is that while there is *a priori* reason to suggest that the economic advantage of legume sowing may be positive under some circumstances, the option carries considerable risk of financial failure.

6. FIRE

6.1. Pasture composition

There were no consistent differences between the burnt and unburnt paddocks in either the yields or frequencies of *Heteropogon*, fine-leaved *Aristida* spp. (includes *A. spuria*, *A holathera*) or coarse-leaved *Aristida* spp.(includes *A. ramosa*, *A. calycina*) between 1992 and 1996. However, some patterns were observed. Yields of *Heteropogon* increased after 1993 and this increase was consistent with the overall improvement in summer rainfall after the 1993-94 summer. There was also a gradual decline in the frequency of coarse-leaved *Aristida* spp. over the three years of burning between 1992 and 1995, compared to unburnt paddocks. Over this period, frequency declined from 13 to 1%, while the frequencies of coarse-leaved *Aristida* in the two unburnt paddocks were maintained (upper slope 22% in 1992 to 30% in 1995, mid slope 8% to 12%).

6.2 Plant processes

6.2.1 *Heteropogon* population processes

Seed production of *Heteropogon* was generally higher in the burning treatment and in the mid slopes than in the upper slopes. More seed was produced in the burning treatment than on the mid slopes in 1994 and 1996, however the stocking rate was lighter in the burning treatment between 1992 and 1995. Accordingly, large differences occurred in the soil seed bank between years, but there was no consistent pattern between treatments except that the seed bank in the mid slope and burning treatments was generally higher than in upper slope.

The pattern of seedling recruitment varied between years with generally more seedlings in the mid slope and the burning treatment than in the upper slope. In 1994, recruitment in the mid slope was higher than that in the burning treatment but this situation was reversed in 1996. Plant density increased between 1993 and 1995 particularly in the mid slope and burning treatments and this increase reflected the pattern of seedling recruitment.

Basal area increased in all treatments between 1992 and 1996 and was consistently higher in the mid slope and burning treatment than in the upper slope. The increase in basal area was associated with increased seedling recruitment and an increase in the size of the original plants (see Fig. 6.2.1a)

The original plants increased in size in all treatment between 1992 and 1996 and plants in the burning treatment tended to be larger than in the upper and mid slopes (Fig. 6.2.1a). Plants from the 1994 seedling cohort were of similar size in all treatments

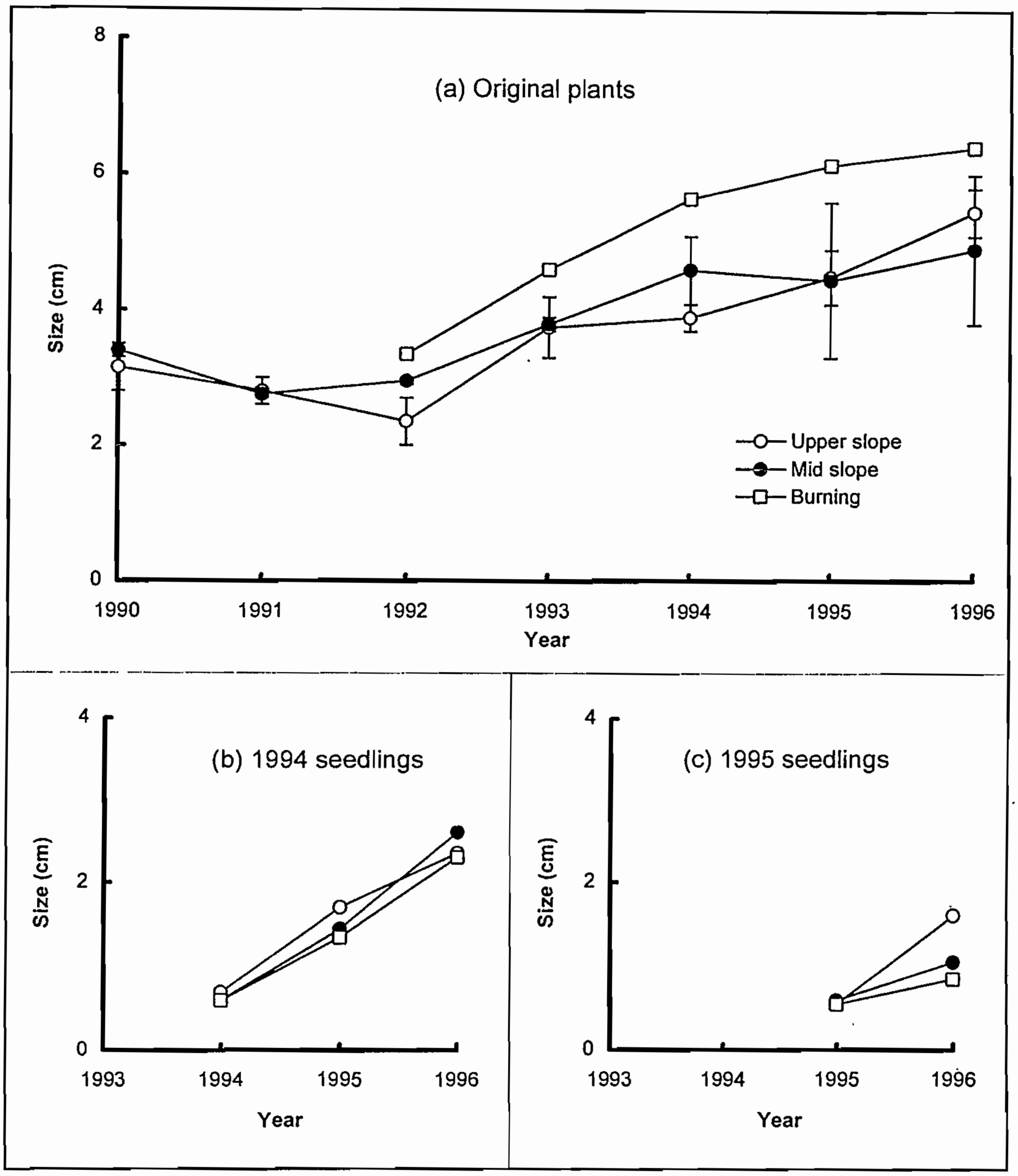


Fig. 6.2.1a, b & c. Comparison of the effect of burning with unburnt paddocks on two land classes on the diameter of *Heteropogon* plants between 1990 and 1996. a) original plants marked in 1990; b) 1994 seedlings and c) 1995 seedlings. (Bars are ± standard errors).

while seedling plants from the 1995 recruitment grew larger in the upper slope than in the mid slope and burning treatments (Fig. 6.2.1 b, c).

The failure to record an increase in recruitment and consequently, frequency of *Heteropogon* probably resulted from the pattern of summer rainfall. Rainfall over the 1992-93 summer was well below average and few seedlings were recorded in any treatment. After above average rainfall in October 1994, a preliminary seedling count in early December revealed significantly higher seedling recruitment in the burnt compared with the unburnt native pasture treatments. However, below average rainfall between November 1994 and February 1995 resulted in the death of many of these seedlings. This finding is consistent with results from Brian Pastures (Orr and Paton, unpublished data) indicating that the seasonal pattern of rainfall over the summer period has a substantial effect on seedling survival.

6.2.2 *Aristida* spp. population processes

Burning at Brian Pastures resulted in a reduction in both density and basal area of *Aristida* spp. and an increase in recruitment of *Heteropogon* (Orr and Paton 1993) but these results were not repeated in this study at 'Glenwood'. Seedling recruitment of *Aristida* spp. was less than 1 seedling m^{-2} between 1993 and 1996. Consequently, plant density and basal area of *Aristida* spp. changed little between 1992 and 1996.

One reason for these differences appears to be the apparently different responses to burning between the species of *Aristida* spp. The dominant *Aristida* at Brian Pastures is a coarse-leaved species, *A. ramosa* var. *speciosa* (D. Orr pers. comm.). At 'Glenwood' there are two common coarse-leaved taxa (Sections *Calycinae* and *Aristida*) and two common fine-leaved taxa (Sections *Arthratherum* and *Streptachne*; see Table ii in Appendix 4). In 1995 the average frequency of these four groups over all treatments was 17, 12, 18 and 9% respectively. The ecological characteristics of these groups differs and their grazing tolerance varies (see Section 7 and Appendix 4).

In the burning treatment, the fine-leaved *Aristida* spp were more common and this group did not decline with repeated fires (Fig. 6.2.2a & b). The population of coarse-leaved *Aristida* spp. in the same paddock showed a slight decline but numbers overall were too low for this to be of much significance.

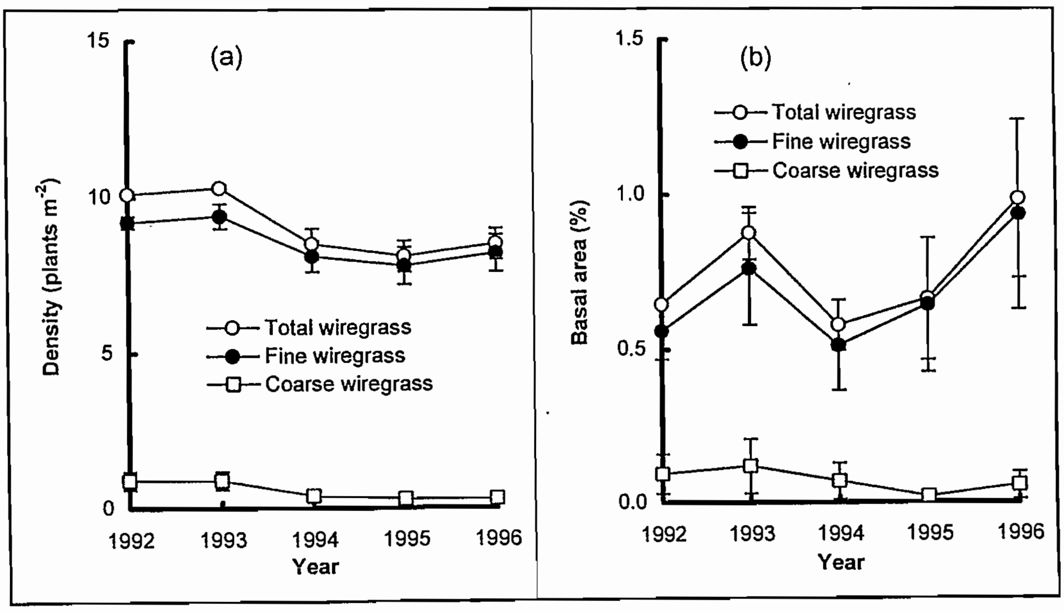


Fig. 6.2.2a & b. A comparison of the contribution of fine-leaved and coarse-leaved *Aristida* spp. to total (a) density (plants/m^2) and (b) basal area (%) between 1992 and 1996 in the burning treatment. (Bars are ± standard errors).

7. STATE AND TRANSITION MODELS

7.1. Background - uses of state and transition models

State-and-transition models have become generally accepted as a format to depict vegetation change, pasture condition and other relevant attributes. Their advantage is that the format of state-and-transition models can potentially incorporate a wide range of dynamic patterns and mechanisms, including climax-terminated successional patterns which (as suggested by Joyce 1993) do occur in many regions. Thus the state-and-transition format presents a more flexible approach to summarizing knowledge about a variable set of ecosystems.

It is notable that most published state-and transition models represent conceptual summaries of current knowledge or perceptions rather than a quantified measurement of vegetation change. The original proponents envisaged the models as "a system of concepts, generalizations or assumptions" which are used to guide what data are collected (Westoby et al. 1989), and presumably, how it is analysed. With this proposal, the models should form a tool in an iterative process in which they are used to summarize the information base concerning a particular rangeland ecosystem (however inadequate). The models would also assist in the formulation of new questions and experimental observations (Bellamy and Brown 1994). Only when adequate data are incorporated into the model (in a number of stages) would it be possible to present the model as a true generalization of the behaviour of an ecosystem. If the models are going to have an ongoing role in the development of theory and the building of knowledge, explicit and objective methods of model building will need to be developed.

As in many other rangelands, the development of state-and-transition models for Australian sub-tropical savannas dominated by black speargrass (*Heteropogon contortus*) is at the preliminary stage of conceptualization of current understanding, and rests on a slim base of published information (Orr, Paton and McIntyre 1994; Grice and McIntyre 1995). In the following sections we present two models, the first (Sect. 7.2 - 7.3) takes a more formal approach to the identification of states through an analysis of plant species response to a gradient of increasing pressure by grazing animals. The analysis presented takes into account within-pasture variation in grazing intensity and uses multivariate analysis to classify species into response groups. The advantage of this approach over one that focuses only on paddock scale data is that it is able to document patch grazing within paddocks and thus describe pasture changes under grazing intensities higher than those observed as paddock averages.

The second model (Sect. 7.4) summarizes the changes observed in speargrass pasture (with, and without, legume sowing) in terms of paddock-level observations of: 1) establishment of different legumes, and 2) the representation in paddocks of the grazing states previously identified. Legume establishment is described in relation to spatial variation in pastures (land classes) and stocking rates. In the case of both models, our information is still incomplete, particularly in relation to transitions. Nonetheless, the models represent a significant advance in our knowledge of the grazing system. We have also developed methods whereby floristic data can be objectively incorporated into a conceptual framework and then synthesized with a broader range of traits associated with pasture condition, sustainability and productivity.

7.2. Grazing model

7.2.1. Identification of floristic states

Approach and assumptions made

A more conventional way to approach the analysis would be to describe species response at the paddock scale and describe the response to stocking rate treatments. However, because of patch grazing by the cattle, the variation in grazing pressure within paddocks was high. Although paddock averages of total biomass did vary significantly with stocking rates, it was thought that the use of paddock averages alone would lead to much lost information. For this reason, estimates of biomass of individual quadrats taken in one point in time, were used to indicate grazing pressure and related directly to the floristic information associated with that quadrat. These visual biomass estimates were recorded at the same time as the floristic data using the Botanal technique. The entire data set must be collected as the same time in order to control for seasonal variation in biomass. While biomass can vary widely within and between years, at any one point in time, the relative in difference biomass across the trial paddocks was considered to reflect variation in grazing pressure. Areas that had been closely grazed over a long period were assumed to be in the sample of low biomass quadrats. At the same time it is recognized that some recently closely grazed areas will also fall into this sample and may not contain grazing tolerant species. Variation of this type would be expected in any floristic data set collected for ecological study.

A second assumption was that species associations were individualistic and species were grouped by their common response to grazing pressure rather than particular associations with other species. The means by which species were classified and allocated to states is summarized in Appendix 5. The basic principle used was that plant species that had similar responses to the grazing pressure gradient (as expressed by amount of standing biomass) were grouped together and allocated to one or more states depending on the shape of the response curve. Dominant species (ranked 1 or 2 in ≥2% of quadrats) were analysed separately from minor species and the results were merged.

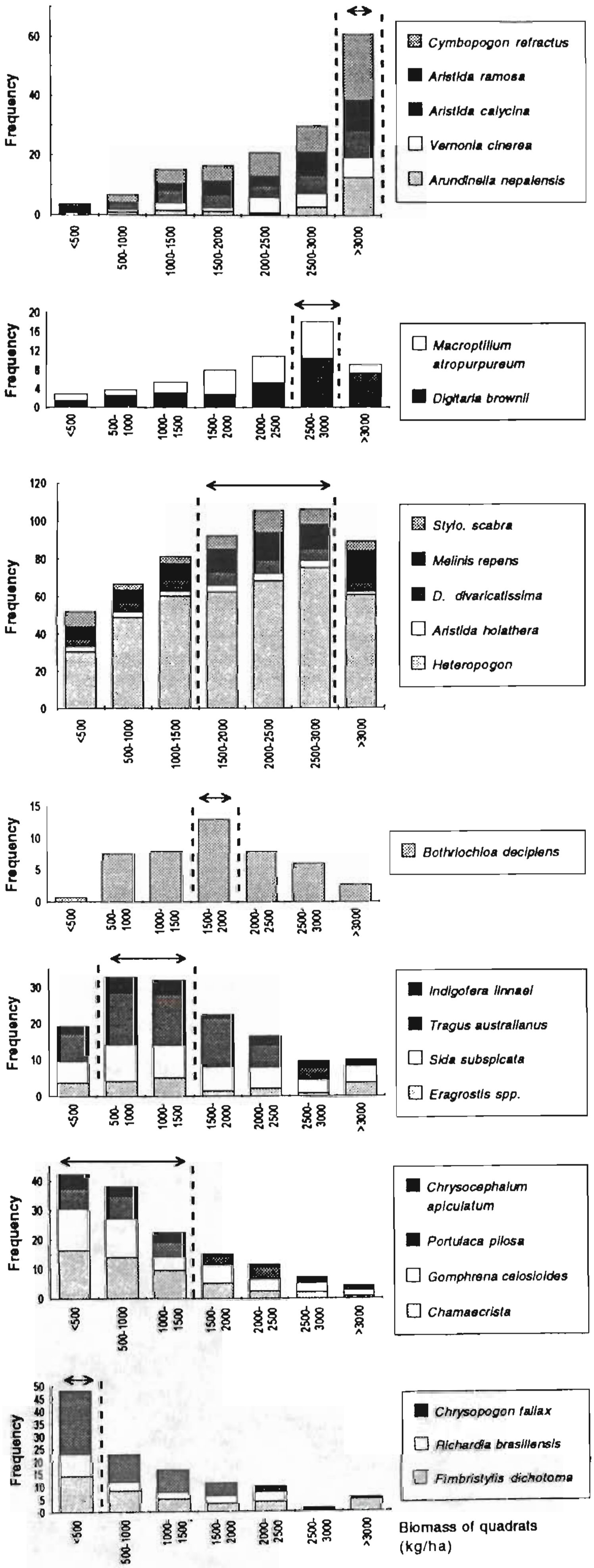


Fig. 7.2.2a. Dominant species classified into groups based on response to grazing.

State 1
Indicator species

State 2
Indicator species

States 2 & 3
Characteristic species

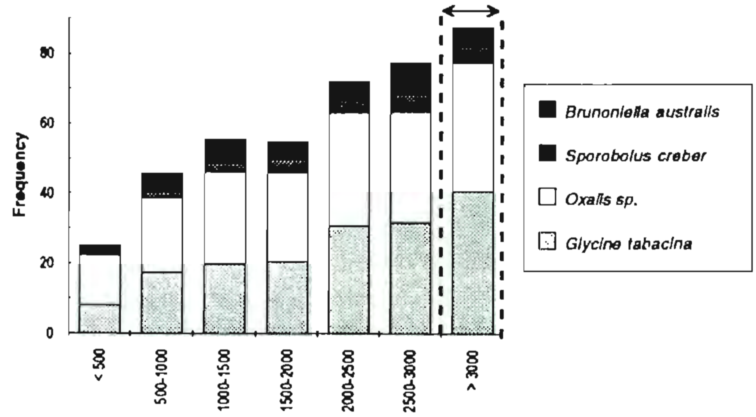
State 3
Indicator species

State 4
Indicator species

States 4 & 5
Characteristic species

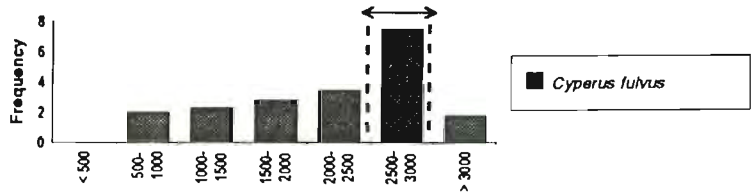
State 5
Indicator species

Fig. 7.2.2b.
Minor species classified into groups based on response to grazing



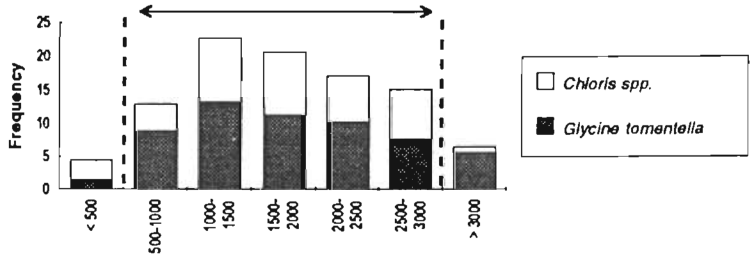
State 1

Characteristic species



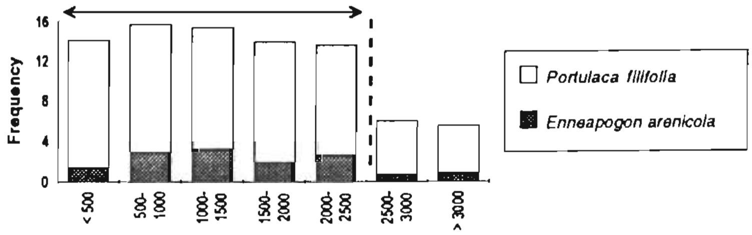
State 2

Indicator species



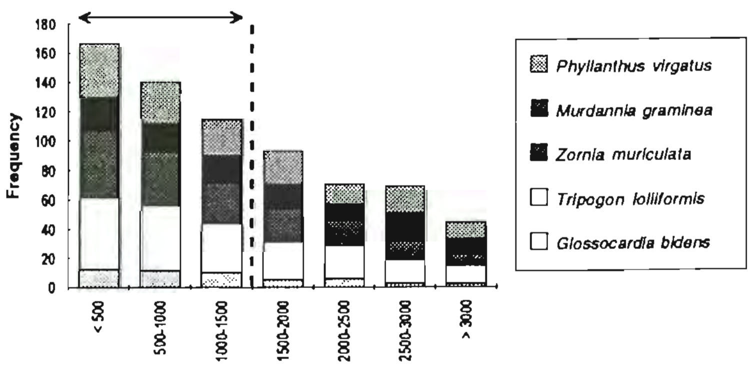
States 2, 3 & 4

Characteristic species



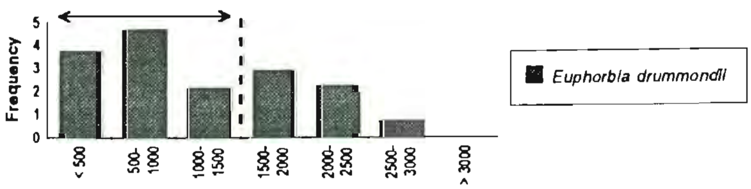
States 3, 4 & 5

Characteristic species



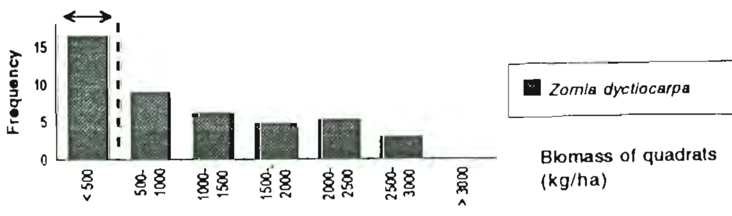
States 4 & 5

Characteristic species



States 4 & 5

Characteristic species



State 5

Indicator species

7.2.2. Description of states on the grazing gradient

The response curves of the dominant and minor species that were classified into states are presented in terms of percent frequency (Figs 7.2.2a & b). Of the 59 species analysed, nineteen minor species could not be allocated to particular states due to their flat or fluctuating response curve. These species were, therefore, not used to characterize the states, although further studies might reveal some of this group to have more distinctive responses to grazing. Of the 24 dominant species analysed, all were allocated to states and could be used to characterize them. The synthesis of the classification results is summarized in Fig. 7.2.2c. The species groups identified in Fig. 7.2.2c are those that had peaks of abundance in the same part of the grazing pressure gradient (illustrated in Figs 7.2.2a & b).

State 1 is indicated by the dominance of a group of perennial grasses that are generally of low grazing preference (Fig. 7.2.2c). Although this state is linked to the lowest grazing pressure and therefore low stocking rates, it can occur at high levels in medium stocked paddocks e.g. on the lower slopes where *Arundinella* was abundant. Where highly unpalatable State 1 grasses are common, grazing pressure is likely to increase around them substantially before they are eaten themselves. This was highly evident in the medium stocked, lower slope paddocks where above average levels of States 1, 4 and 5 occurred. State 1 exemplifies the important point that the states described reflect the actual grazing pressure at specific locations in the paddock, not necessarily the average grazing pressure for the entire paddock. Where grazing preferences for plants in the paddock differ widely, there is greater likelihood of divergence in the range of states represented.

State 2 is characterized by the highest level of dominance of *Heteropogon*, but the indicator species are the grazing sensitive siratro (*M. atropurpureum*, see Sect. 5.2) and the perennial grass *Digitaria brownii*.

State 3 is also characterized by *Heteropogon,* but the degree of dominance of this species is declining and the indicator species is *Bothriochloa decipiens*, a perennial grass that is also of low grazing preference. States 2 and 3 share a suite of characteristic species (in addition to *Heteropogon*) that are mainly perennial grasses of moderate-high attractiveness to cattle.

State 4 indicators are two forbs, the native legume *Indigofera*, and *Sida* as well as two annual/short-lived grasses, *Tragus* and *Eragrostis*. Forbs and annuals are also prominent amongst the characteristic species, and perennial tussock grasses are reduced in importance, although it is worth noting that while *Heteropogon* dominance is declining, it is still abundant relative to other species where grazing pressure is heavier (i.e. lower biomass, Fig. 7.2.2a).

State 5 is also characterized by annuals and forbs, but differs significantly from State 4 in the presence of a perennial grass (*Chrysopogon*) and a perennial sedge (*Fimbristylis*) as indicator species. These species, particularly *Chrysopogon* form conspicuous patches in the pastures, when subjected to very heavy grazing pressure. *Chrysopogon* is notable in its tendency to exclude other species where it dominates presumably due to competition created by its dense system of clonal underground rhizomes (Wandera 1993).

Indicator species (indicate a particular state)

State no. 1	State no. 2	State no. 3	State no. 4	State no. 5
Arundinella nepalensis	**Digitaria brownii**	**Bothriochloa decipiens**	**Indigofera linnaei**	**Fimbristylis dichotoma**
Aristida calycina	**Macroptilium atropurpureum***		**Sida subspicata**	**Chrysopogon fallax**
Cymbopogon refractus	Cyperus fulvus		**Tragus australianus**	**Richardia brasiliensis***
Aristida ramosa			**Eragrostis spp.**	Zornia dyctiocarpa
Vernonia cinerea				

Characteristic species (characterize more than one state)

State no. 1	State no. 2	State no. 3	State no. 4	State no. 5
Glycine tabacina	THESE SPECIES DECLINE GRADUALLY WITH INCREASING UTILIZATION →			
Sporobolus creber				
Oxalis sp.				
Brunoniella australis				
	Stylosanthes scabra*	**Stylosanthes scabra***		
	Heteropogon contortus	**Heteropogon contortus**		
	Digitaria divaricatissima	**Digitaria divaricatissima**		
	Melinis repens*	**Melinis repens***		
	Aristida holathera	**Aristida holathera**		
	Chloris spp.	Chloris spp.	Chloris spp.	
	Glycine tomentella	Glycine tomentella	Glycine tomentella	
		Portulaca filifolia	**Portulaca filifolia**	**Portulaca filifolia**
		Enneapogon arenicola	Enneapogon arenicola	Enneapogon arenicola
			Gomphrena celosioides*	**Gomphrena celosioides***
			Chrysocephalum apiculatum	**Chrysocephalum apiculatum**
			Chamaecrista rotundifolia*	**Chamaecrista rotundifolia***
			Portulaca pilosa*	**Portulaca pilosa***
			Glossocardia bidens	Glossocardia bidens
			Euphorbia drummondii	Euphorbia drummondii
			Zornia muriculata	Zornia muriculata
			Tripogon loliiformis	Tripogon loliiformis
			Phyllanthus virgatus	Phyllanthus virgatus
			Murdannia graminea	Murdannia graminea

Fig. 7.2.2c. Indicator and characteristic species associated with different pasture states in pasture under increasing grazing pressure.
* denotes exotic species
Bold indicates species that were dominant (rank 1 or 2) in ≥2% of quadrats

In summary, the trend in plant composition, moving from State 1 to 5, is for perennial tussock grasses to decline, species of low grazing preference to decline, annuals and forbs to increase and for two distinctive patch-forming species, the grass *Chrysopogon* and a perennial sedge *Fimbristylis* as indicators of the most heavily-grazed parts of the paddock.

It is important to emphasize that the states represent points on a continuum of floristic variability - all states may be present to varying degrees in a paddock and the boundaries between states is not clear cut. The analysis of floristic variation at 'Glenwood' by Wandera (1993) demonstrated that, although patches in the paddocks were clearly visible due to different levels of grazing utilization and the appearance of the dominant species, the differences were due to the dominance rather than the presence or absence of groups of species. In other words, most species could potentially be found in any patch. It is the amount of a species in a patch that is important in determining what state it might represent.

7.2.3. Transitions

Transitions are the process of change from one state to another and are generally described in terms of the underlying causes of the changes. They are also often described in terms of the probability of a change occurring. There is a high degree of consistency between the species patterns described by the grazing states, and the stocking rate effects on different species (Appendix 2). Thus although the states are not described from temporal sequences, there is reason to be confident that the transitions are grazing-induced. The legume sown paddocks were included in the analysis, and although paddocks were sampled three years after sowing, there may still have been some effects of herbicide use on floristic composition. Of the four species that responded positively to legume sowing (Table 5.2.4a), three also responded positively to higher stocking rates and the fourth (*Gomphrena*) had a very strong trend in the same direction. This supports the idea that increased grazing pressure resulted from legume sowing and that both factors, therefore, could increase the extent of States 4 and 5 in paddocks.

While the effects of increased grazing pressure is linked to transitions in a general way, the details of the transitions and their reversals have not been explicitly studied. In Fig. 7.2.3a, transitions are summarized and all transitions to higher numbered states are listed under the rubric of higher grazing pressure, possibly accelerated by drought. It is possible, even probable that non-sequential transitions (e.g. T1-4 or T4-2) occur, but the complexity of this scheme far exceeds our inadequate knowledge of the transitions.

At the patch scale, State 1 persists or develops when the constituent species are avoided by stock. At the paddock scale, this state increased under medium stocking where grazing was selective and declined where grazing was non-selective. Thus T1-2 will be described differently depending on whether it is being considered at the patch or paddock scale. This scale dependence may also apply to other transitions, but it was only apparent in relation to State 1 where the difference in grazing preference of State 1 species was most pronounced.

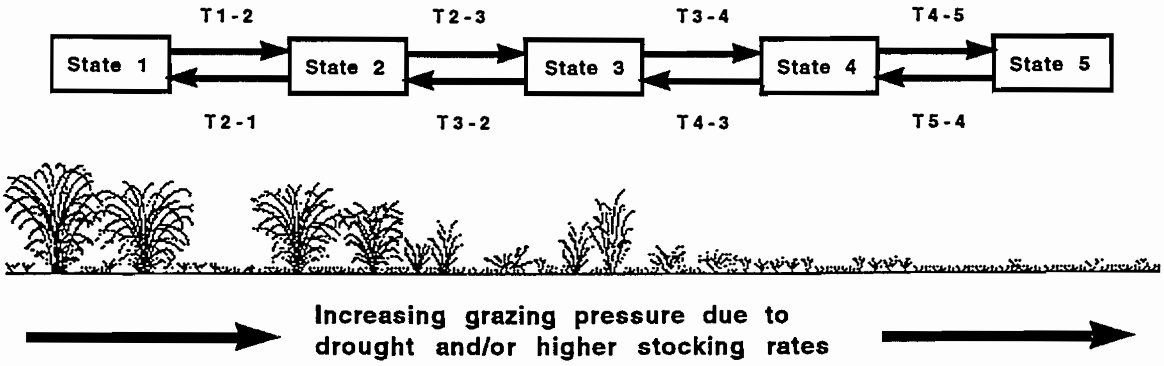


Fig. 7.2.3a. Notation for states and their transitions.

Reversals - transitions from higher to lower numbered states

The baseline assumption is that reversals (e.g. T3-2, T5-4) come about through resting the pasture - lighter grazing or complete removal of stock. This generalization is based on the assumption that there is a trade-off between grazing tolerance and competitive ability under non-grazed conditions, whereby grazing intolerant species eventually out compete tolerant ones when grazing is removed. Intuitively, we would expect that any grazing-sensitive species could recolonize a previously heavily grazed site, although these transitions have not been well documented in the CS195 research. This is not surprising given the climatic conditions and grazing regimes during the experimental period. More evident, have been observations that the rate of reversal, or its likelihood, could be reduced by a range of factors. These factors are summarized in Table 7.2.3a. It is also apparent from our own, and other observations, that the reversal T2-T1, and the T1-T2 transition is a more complex issue due to various factors including grazing preference and possible fire effects.

The role of fire in effecting transitions

Experimental work attempting to effect a T1-T2 transition (where T1 is characterized by the coarse-leaved *Aristida ramosa* var. *speciosa*) at Brian Pastures demonstrated that this could be achieved with the use of fire (Orr and Paton 1993; D. Orr pers. comm.). There is indirect evidence that fire may also facilitate a T1-T2 transition when *Arundinella* is dominant, as the palatability of fresh growth of this species is substantially higher than of mature plants (Milestone Report No. 9). The fire trial at 'Glenwood' applied the same management technique as used at Brian Pastures, however, the dominant *Aristida* species were *A. holathera* (characteristic of States 2 and 3) and *A. spuria* (not characteristic of any state). In this trial, fire did not facilitate a T3-T2 transition, i.e. it did not increase the dominance of *Heteropogon*. Nor was *Aristida* reduced by burning. As grazing pressure increases, and pastures undergo transition to higher-numbered states, it is likely that fire becomes a less frequently used tool, due to the reductions in fuel by grazing animals, but it may still have an important role.

Table 7.2.3a. Factors that may affect the reversal of states (e.g. T4-3, T3-2, T2-1) under conditions of reduced grazing pressure or complete resting.

Factor	Transition affected	Evidence
Drought	Delay or prevention of T5-4, T4-3, T3-2, T2-1	Lack of seedling establishment is clearly more likely in the absence of adequate water; Little change occurred in permanent quadrats observing a range of states over two years of complete resting in droughted conditions; *Heteropogon* recruitment fluctuated widely in permanent quadrats from year to year (Sect. 7.3.4).
Soil changes	Delay or prevention of T5-4, 3 or 2	Failure to establish *Heteropogon* seedlings in *Chrysopogon* dominated patches despite watering and fertilization due to competitive effects and soil changes (Wandera 1993; see also Sect. 7.3.1).
Absence of seed for recolonization	Delay or prevention of potentially all transitions	If species are to re-establish, there must be adequate seed (or vegetative propagules) within dispersing distance of the area in question. The greater the area of local extinction, the less likely the species in question are able to effect the transition. The near absence of *Themeda triandra* from the 'Glenwood' site is an example of a state for which a transition is unlikely to be effected.
Absence of fire with selective grazing	Facilitate T2-T1	*Heteropogon* responds positively to fire (Orr and Paton 1993; Grice and McIntyre 1995) and some species of *Aristida* are reduced by fire.

Rainfall as a factor affecting transitions

Rainfall can influence all transitions by affecting the survival of plants of all ages, as well as seedling recruitment. In the trial, overall seed production and seedling recruitment have been influenced more by year to year variation than by land class, stocking rate, legume oversowing or burning treatments. Although much of this variation is presumably related to rainfall events, seasonal rainfall totals are not always reflected directly in terms of recruitment or death. This is because the timing and distribution of rainfall across the season is as critical to plant survival as the total rainfall amount. Some of the effects of rainfall are illustrated in Fig. 7.3.2a in which the germinability of 12 month laboratory-stored *Heteropogon* seed is related to the rainfall occurring in March of the year that the seed was collected. It appears that the viability, or at least the dormancy, of the seed produced may be related to rainfall, and so influences the amount of seed entering the soil seed bank and becoming available for the recruitment of seedlings in the following summer.

Another factor that is likely to be influencing transitions is drought. The increased grazing pressure due to drought effects are likely to have accelerated transitions over all paddocks, at least in terms of plant mortality and relative performance of different species. Shifts to new states through seedling establishment are less likely to have occurred during the drought, although it was observed for some species.

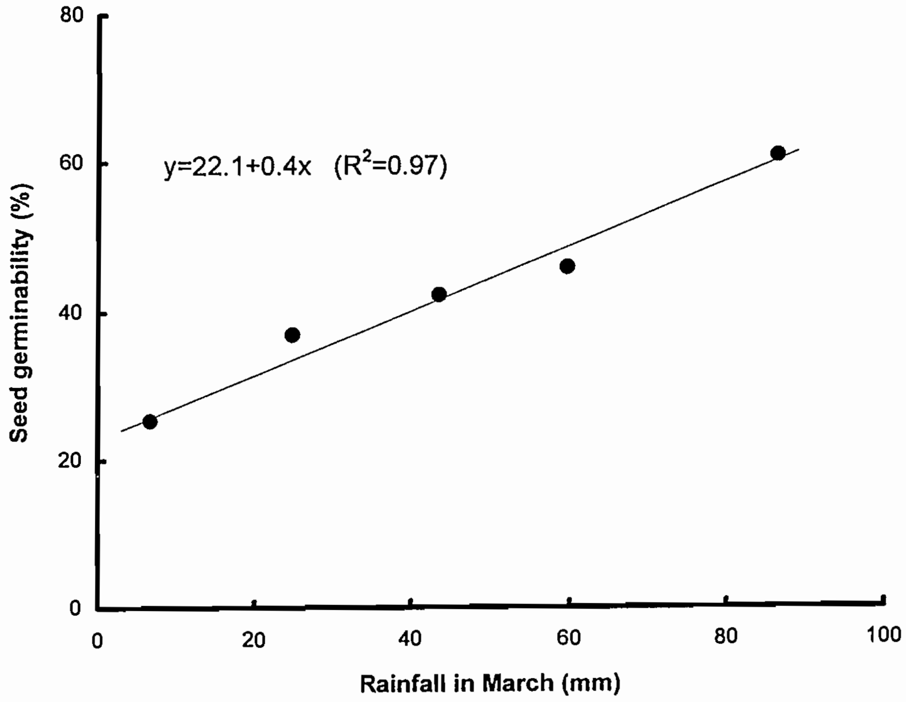


Fig. 7.2.3b. Variation in *Heteropogon* seed germinability between 1991 and 1995 in relation to rainfall in March.

In terms of transitions, we would predict that rainfall deficits could facilitate transitions from lower- to higher-numbered states in two ways:

1) the direct effect of dry conditions on plant health and mortality;

2) The increased grazing pressure under fixed stocking rates due to the reduced amount of plant growth.

It was not possible to separate these effects in the trial. Point 1 assumes that species typifying higher-numbered states are more drought tolerant. Indeed, *Fimbristylis* and *Tripogon* are known to be resurrection species (able to desiccate and rehydrate) and *Chrysopogon* has a dense underground root system. Annual species are not necessarily drought tolerators, but are able to utilize small rainfall events opportunistically. As outlined in Table 7.2.3a, drought is likely to reduce the probability of transitions from higher- to lower-numbered states, particularly where species from lower-numbered states have become locally extinct, rather than less dominant.

7.3. Integrating soil condition and productivity indicators into the grazing model

7.3.1. Soil condition

Pasture composition can have a major effect on the hydrological characteristics of a landscape. The infiltration characteristics of the different states, identified from the dominant pasture species were determined using a rainfall simulator. Results indicate that the progression to higher-numbered states is associated with a gradient of increasing runoff volume and runoff rate. For example, in moving from a speargrass dominant state to the annual/short-lived grass state, runoff rate (25 - 48 %) and runoff volume (17 - 35 %) approximately doubled.

Table 7.3.1a. Mean peak runoff rate (%) and Total runoff volume (%), derived using a rainfall simulator for the 5 pasture states.

State	Characteristics of dominant species	Runoff Rate[1] (%)	Runoff Volume[2] (%)
1	Tall perennial grasses of low grazing preference.	11	7
2	*Heteropogon* dominant; various perennial grasses, sown legumes.	25	17
3	*Heteropogon* abundant but declining; Bothriochloa decipiens, various perennial grasses.	40	30
4	Annual and short lived grasses and forbs	48	35
5	Short perennial grasses and sedges (*Chrysopogon* and *Fimbristylis*); forbs.	46	40

1. Runoff rate = (Peak runoff rate/Rainfall Intensity) x 100
2. Runoff volume. = (Total runoff volume /Total rainfall volume) x 100

7.3.2. Potential plant production

The primary productivity of pasture states could not be assessed from the quadrat surveys as the samples had been grazed differentially. We therefore compared growth of pasture of different states (defined by the dominant species) in ungrazed areas. Plots were protected from grazing in January 1995 and clipped to a height of 3 cm. In March 1995, the plots were clipped again to 3 cm. The plant material from each plot was dried and weighed after sorting into the following three categories:

a) The indicator or characteristic species that were dominant in the states sampled (we selected plots that were strongly dominated by *Heteropogon*, *Arundinella*, *Aristida* spp., *Bothriochloa decipiens*, *Digitaria* spp., *Chrysopogon*, *Fimbristylis*.)

b) Other grasses and sedges and

c) Other forbs

This gave us an indication of plant productivity that is potentially available to cattle over 12 weeks of the growing season.

There were up to ten-fold differences in the average productivity between different dominant species. *Heteropogon*, *Arundinella* and *Aristida ramosa* produced the most biomass and *Fimbristylis* the least (Fig. 7.3.2a). In some cases, other species partially compensated for the low productivity, but mostly the total productivity of the state reflected that of the dominant species. This would not necessarily be the case over the entire pasture, as the patches we selected represented the highest levels of dominance achieved by the species sampled. There was a clear trend in the data that suggested that the potential productivity of the states declined with increasing state number i.e. heavily grazed patches will eventually be dominated by species of lower productivity.

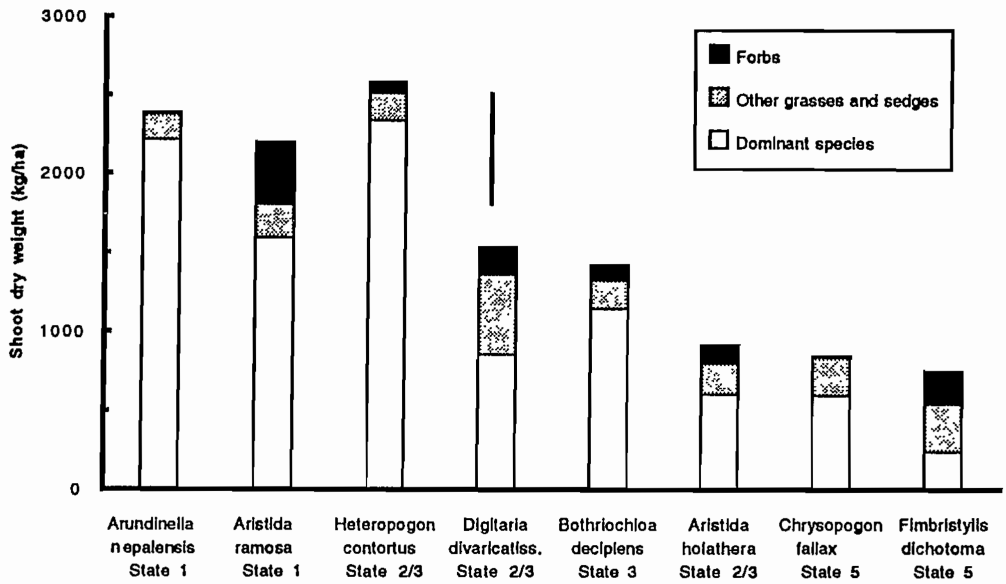


Fig. 7.3.2a. Shoot productivity of plots (0.25 m^2) harvested to a height of 3 cm after 12 weeks growth between January and March 1995. Plots were located on patches considered to represent different states in the pastures (state numbers are indicated) as indicated by the dominant species.

A parallel trend is that grazing preference of the higher state species tends to be higher, with less preferred species being more characteristic of States 1-3 (Milestone No. 9, 1994). It is also worth noting that, at around 1000 kg/ha, the total potential productivity of State 5 was higher than the total biomass of the quadrats samples that were used to characterize this state (Fig. 7.3.2a cf. Fig. 7.2.2a). These samples were less than 500 kg. This does confirm that these quadrats were grazed very closely, not simply that they were dominated by plants of small stature.

7.3.3. Animal production

Despite the primary productivity differences observed for clipped exclosures representing the different defined states, no significant animal production potential differences could be reliably determined for the states from the available trial data. This is largely due to non-availability of selection preference data for the larger trial and herbage quality data from the detailed exclosure work (Section 7.4.2). Many proxy measures were attempted using the paddock liveweight gain and herbage yield and composition data with assistance from Dr Peter Jones (CSIRO IPPP Biometrics Unit) with limited success. Techniques attempted for this purpose included simple and multiple regression, frontier regression and principal components analysis applied to the paddock liveweight gain data and aggregated pasture yield and composition data from individual quadrats within the paddocks. The most likely explanation for the inability to detect significant relationships was that the animals were able to effectively buffer against herbage presentation deficiencies associated with the different states through selective grazing over the whole paddock. This would be further compounded by the use of supplements forced under the winter feeding rules for the two highest stocking rates in the last year (Sect. 2.7.2.).

Some indicators of potential differences were, nonetheless, observed from the botanical studies. For example, primary plant productivity declines across the continuum of states from lower to higher state numbers. There is, however, a potential offsetting feed/diet quality effect observable in changes in certain well-recognised quality attributes across the same continuum. For example, species palatability and leaf to stem ratios tend to improve with the shift towards annual species. Forbs which increasingly contribute to higher numbered states are among the highest quality components of most rangeland pastures. Similarly, fresh shoot and leaf regrowth from grazed patches is commonly selected by animals, further reinforcing the patch effect that promotes it in the first place.

One important animal performance effect that carries real economic significance is the increased probability that paddocks characterised by high proportions of high-numbered states will be depleted of standing feed, particularly in the winter to early spring period. To avoid severe production losses, including deaths, this typically invokes a need for supplementary feeding or destocking, both of which are expensive and time-consuming. An indication of the potential impact of this can be seen in terms of the actual supplementary feeding regime that was triggered in 1994-95 under the feeding rules laid down for the trial (Section 2.7.2.). Data showing the proportion of paddocks in which steers were fed a supplementary hay ration is presented in Fig. 7.3.3a.

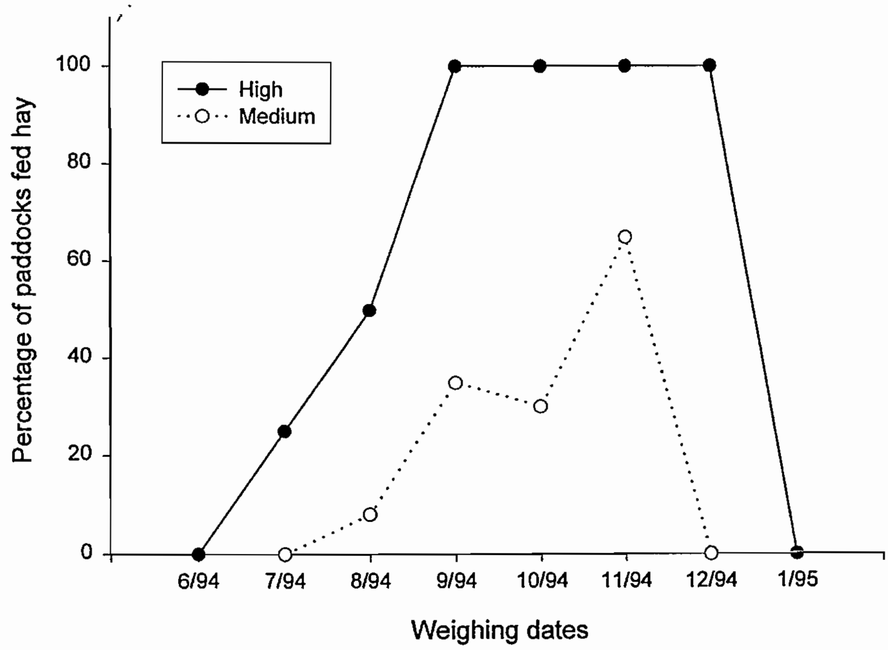


Fig. 7.3.3a. Proportion of paddocks fed hay supplement in the 1994/95 season.

Only the animals that were in the medium and high stocked paddocks, were affected by the feeding criteria. All of the steers in the high stocking rate treatment were fed during the winter period with the peak (100% of the animals) duration lasting 12 weeks. The feeding commenced a full 4 weeks before it was necessary to commence feeding some of the steers in the medium stocking rate treatment. It was also carried on for 4 weeks beyond that necessary for the medium stocking rate treatment. The proportion of affected animals in the latter treatment was 65% and the peak feeding duration only one half (6 weeks) that of the high stocking rate treatment. The total feeding duration for the medium and high stocking rates was 16 and 24 weeks respectively.

7.3.4 Age structure of *Heteropogon* populations

The age distribution of plants in 1996 was dominated by those plants originally present in 1990 and strongly reflects the influence of seasonal rainfall conditions. The drought between 1991 and 1993 is reflected by the low representation of plants aged 3 to 5 years, while improving rainfall from 1994 is reflected in the higher representation of plants aged 2 years and less which, in turn, reflects the improved soil seed banks and seedling recruitment between 1994 and 1996 (Fig. 7.3.4a). A higher density of plants aged 1 and <1 year was recorded in the low /medium stocking rate compared with the very low /low and high stocking rates.

These results illustrate some of the processes that might operate during transitions from State 2 to higher-numbered states, when populations of *Heteropogon* are declining. Because of the ability of adults plants to live for five or more years, changes can be occurring in the populations without a substantial visual impact in the pastures. In the case of this trial, recruitment virtually stopped between 1991-93 while existing adults plants maintained a presence. It is also evident that at high and very low stocking, recruitment has been suppressed between 1995-96. The implication of these data is that processes of decline can be set in place before the decline is necessarily apparent, due to the persistence of mature plants. While adult plants are present, there is always the possibility that populations can recover under favourable seasonal conditions. However, the failure of recruitment over a prolonged period does signal a period of vulnerability, and could be considered an indication that the fate of adult plants has become critical for the maintenance of *Heteropogon* populations.

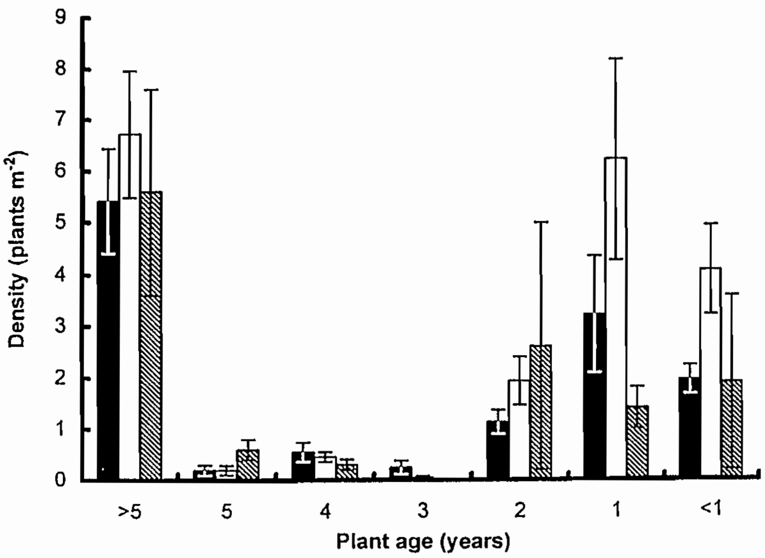


Fig. 7.3.4a. Density (plants/m^2) of *Heteropogon* plants of different ages in autumn 1996 at three stocking rates:
■ = very low /low;
☐ = low /medium;
shaded = high.

7.3.5 Relating states to treatments

The proportion of paddocks represented by the different states demonstrates the variation in grazing pressure occurring within paddocks, but at the same time reflects the treatment effects that have been identified in previous sections. The vulnerability of the lower slopes and upper slopes to pasture degradation is well illustrated, with above average amounts of State 4 present on the upper slopes and the previously discussed divergence of lower slopes into States 1 and 5, resulting from heavy grazing of parts of the paddock not dominated by State 1 species. States 1 - 3 are strongly represented in the low stocking rate regimes compared to the larger proportion of States 4 - 5 associated with high and medium stocking. Overall, medium stocking was still selective enough to allow the persistence of State 1.

Table 7.3.5a. Proportion of paddocks represented by each state. Values are derived from classification of quadrats sampled in 1995, using the dominant species (Rank 1) to determine states. Values are derived from a sample of 18 paddocks, representing nine treatments (three land classes, three stocking rates), two replicates per treatments. All paddocks were legume sown. Shaded cells indicate above-average levels of a state in a particular treatment.

% area in each state	State 1	State 2	State 3	State 4	State 5
Land class					
Upper slopes	1	26	30	31	12
Mid slopes	2	37	39	18	4
Lower slopes	8	19	21	21	31
Stocking rate					
Low	5	38	37	12	8
Medium	4	20	25	26	24
High	1	24	27	32	17
Mean (all paddocks)	3	27	30	23	16

7.3.6 The integrated grazing model

The various indicators of pasture condition and productivity have been linked with the floristic states and summarized in Table 7.3.6a. Where direct measurement of the indicators relating to states was not possible (e.g. animal production which was measured only at paddock scale), they are linked through Table 7.3.5a which relates paddocks to states and treatments. The floristic states themselves and some of their transitions are summarized in Fig. 7.3.6a. The transitions are described in terms of paddock-scale, rather than the patch-scale grazing, pressures that were used to circumscribe the individual states. Thus, selective grazing at the paddock scale is considered to increase the representation of State 1 through a T2-1 transition.

In terms of pasture condition, States 1 and 2 are optimal. They maximize rainfall infiltration (and, therefore, plant growth). The growth of productive perennial grasses in these states is likely to contribute to general levels of fertility and soil condition through the support of soil microfauna. However, the presence of large amounts of State 1 may increase grazing pressure in other parts of the pasture with resulting loss of condition. States 4 and 5 show clear signs of degradation in the form of increased rainfall runoff and possible soil losses. State 3 is intermediate in pasture condition.

Animal productivity did not neatly reflect pasture condition. Degraded States 4 and 5 supported good liveweight gains in the growth season, but production rapidly collapsed in winter when forage was depleted. Even when full growth potential is reached by species in these states, forage deficits are still likely due to their limited growth potential. The coarse-leaved *Aristida* species, which indicate State 1, are generally recognized as unproductive from an animal production perspective. However, we could not link lowered liveweight gain with this state.

Table 7.3.6a. Indicators of pasture condition and productivity relating to different floristic states developing under increasing grazing pressure. Assessment of *Heteropogon* recruitment are rough estimates only, based on extrapolations from population data.

	State 1	State 2	State 3	State 4	State 5
Rainfall runoff	Very low	Low	Low	High	High
Potential plant productivity	High	High	Moderate	Moderate /Low	Low
Plant palatability	Low	Moderate	Moderate	High	High
Animal productivity in growing season	High	High	High	High	High
Forage deficit in winter	Low	Low	Low	High	High
Heteropogon adult population density	Moderate	High	Moderate	Moderate /low	Low
Heteropogon recruitment	Moderate	High	High	Low	Low
Potential for transition to lower numbered state	n.a.	High	High	Moderate	Low

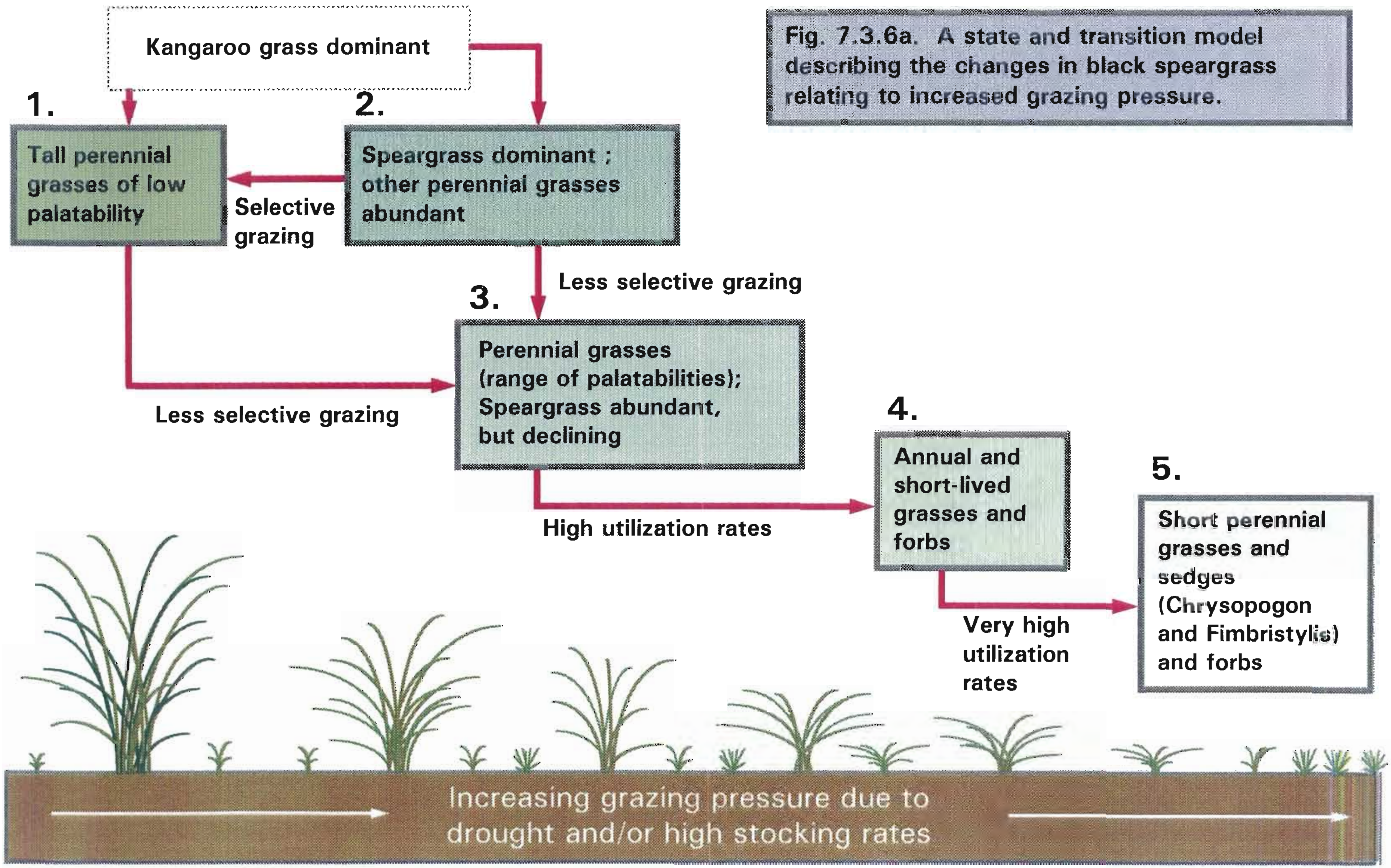


Fig. 7.3.6a. A state and transition model describing the changes in black speargrass relating to increased grazing pressure.

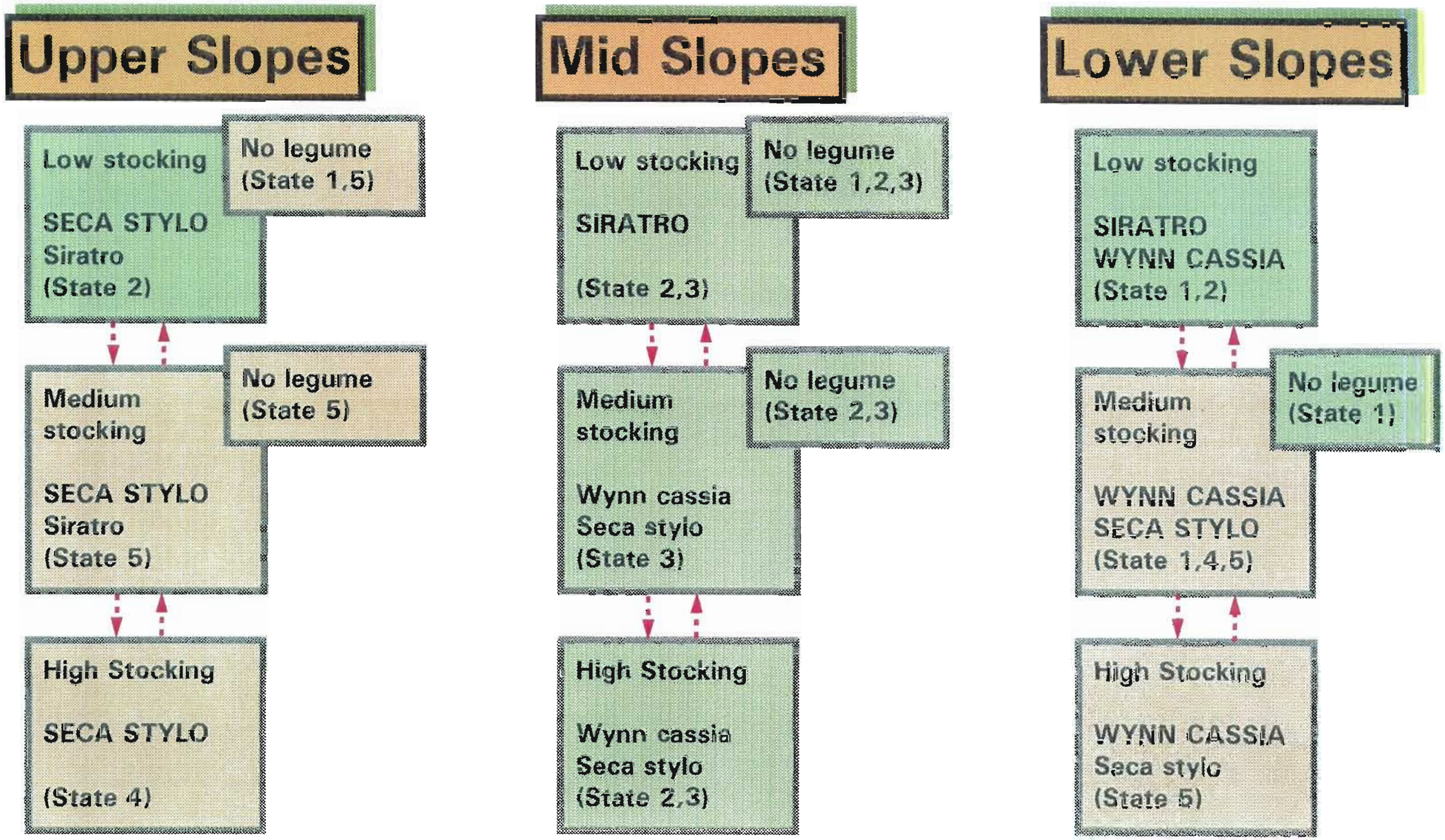


Fig. 7.4a. A state and transition model describing the changes in black speargrass resulting from legume bandseeding at different stocking rates and on different parts of the landscape.

7.4 The legume model

The change in pasture condition as represented by floristic states, and the nature of the legume populations are summarized in Fig. 7.4a. The figure describes legume establishment on three land classes and under three levels of stocking. High levels of frequency of the different legumes are indicated by upper case lettering. Unsown native pastures, of equivalent land class and stocking rate, are depicted as smaller boxes overlapping their sown pasture counterparts. Apart from legume representation, the states are described in terms of the relative amounts of the different grazing states (1-5) that occurred in the paddocks. Where states were at above-average levels (averaged over all treatments) for a particular treatment combination, the state is listed. Brown-shaded states have above-average levels of States 4 and/or 5, as these are associated with the highest levels of soil deterioration.

Of the three legumes that established effectively, there was one or more species that were able to colonize all parts of the landscape at a range of stocking rates. The resistance of mid slopes to loss of pasture condition is very evident in the model. On the upper slopes, there is some indication that legume sowing may reduce the incidence of States 1 and 5 with low stocking rates. On the lower slopes, the opposite was observed. At medium stocking, above average levels of States 4 and 5 were observed where legumes were sown, but not in native pasture paddocks.

A general reduction in *Heteropogon* frequency occurred in legume paddocks relative to native pasture (Sect. 5.4.2). These effects of decline are additive with the effects of land class on condition, so that decline in condition is least apparent on the mid slopes.

7.5. Summary

- Floristic states were identified by analysing pasture composition at the quadrat scale. States that were associated with increased grazing pressure at the quadrat scale where characterized by decreases in perennial tussock grasses and increases in short-lived species, forbs and species of low potential productivity and high palatability.

- Sequential transitions along the gradient were generally related to increased grazing in one direction, and lighter grazing, or resting, in the other. A number of factors were considered to affect the probability of a transition, including rainfall, changes to soil condition associated with heavy grazing, availability of seed sources and fire. The species and soil changes associated with State 5 (highest grazing pressure) appear to be associated with the lowest probability of transition to another state. The soil changes and the competitive growth form of *Chrysopogon* (a State 5 indicator species) probably reduces the chances of *Heteropogon* seedling establishment in State 5 patches.

- The state and transition model associated with increasing grazing was linked to a number of attributes relating to pasture condition and productivity. With increasing grazing pressure, the associated states were correlated with soil changes leading to increased water runoff and with lower potential plant productivity.

Other trends were towards reduced populations of *Heteropogon* and reduced potential for *Heteropogon* populations to recover. Although animal production during the growing season did not appear to be related to state composition, forage deficits in the dry season are linked to the states of low potential productivity that result from heavy grazing pressure.

- Although States 4 and 5 could be considered to indicate pasture degradation, it is the degree of representation of different states in paddocks that is important for pasture monitoring. Most states are represented in all paddocks, but the proportion of States 4 and 5 were higher with the highest stocking rate. The more degradation-prone land classes (lower and upper slopes) also had higher proportions of these states.

- Because grazing pressure is variable within paddocks, the profile of states in a paddock is not always a reflection of the linear effects of increased grazing pressure. For example, State 1 is avoided by grazing cattle and while its representation did not decline under medium stocking, it did decline under high stocking rate, when overall grazing pressure was sufficiently high for it to be grazed. Meanwhile, other parts of the paddock were converted to States 4 and 5 under medium stocking.

- A state and transition model for legume sowing linked land class, and stocking rate to legume establishment and the five grazing states. Legume sowing appeared to even out grazing pressure at low stocking on upper slopes but led to degradation of pastures on lower slopes at medium stocking. Overall, there was no strong evidence that legume sowing prevented degradation. In fact, *Heteropogon* populations were adversely affected by bandseeding.

- A <u>predictor</u> of imminent pasture degradation in black speargrass pastures is the sustained suppression of *Heteropogon* regeneration. <u>Indicators</u> of decline in pasture condition include losses of *Heteropogon* and increases in annuals, forbs and short-lived grasses, including dominance by *Indigofera linnaei*, *Fimbristylis dichotoma*, *Sida subspicata*, *Chrysopogon fallax*, *Tragus australianus*, *Richardia brasiliensis*, *Eragrostis* spp., *Portulaca filifolia*, *Enneapogon arenicola*, *Gomphrena celosioides*, *Chrysocephalum apiculatum*, *Chamaecrista rotundifolia* (wynn cassia), *Portulaca pilosa*.

8. COMMUNICATION

8.1 Introduction

In this section 'communication' is used in the broadest sense to include various activities associated with promoting technology transfer ideals; including the establishment, consolidation and maintenance of networks with other R&D teams and stakeholders to the CS195 research, transferring and sharing knowledge and management principles, and general public relations initiatives. The general approach followed has been to undertake an integrated set of activities which combine to promote and reinforce the main extension goal of CS195 - ie. the widespread adoption of its outputs. To this end, and despite obvious set-backs due to the sequence of adverse seasons (Sect. 2.2.), the project team has been both innovative and active in its extension outlook. For example, it actively sought to engage the interests of stakeholders through a targeted series of producer and technical field days, small group discussion meetings across the region, trade displays (eg. Beef '94, AgShow, Farmfest etc), media reports, and development of a PMP module covering the management of ecological risks.

8.1.1 Communication prior to May 1995

For much of the early life of CS195, the main focus of communication was on general field days for local beef producers, extension interests and researchers. There was emphasis on promoting the project objectives and explaining the nature of the various field experimental activities that were then being established on the 'Glenwood' site. As this period coincided with the commercialisation of the Bandseeder, a substantial emphasis was also placed on the bandseeding technology and perceived value of legumes as a potential source of productivity gains (MacLeod *et al.* 1991, Cook *et al.* 1993). Less emphasis was placed on species recognition, native pasture management and the dynamics of grazed and modified native pasture ecosystems.

From the period mid-1992 to early 1994, communication activities for CS195 were largely centred on a concurrent "communication" research initiative, LWRRDC-RIRDC-GRDC Project CTC2. Activities involved with CTC2 which have been reported in previous milestone reports (eg. Milestone No. 11 Report pp 24-26, Milestone No. 20 Report p 31) included a series of six focus group meetings and a series of paddock meetings with beef producers in the South Burnett region in 1993. However, in the face of somewhat disappointing operational performance for this project as well as a decision by CSIRO to restructure its commitment to CS195, a decision was taken in June 1994 to terminate the project (MacLeod 1995). Only limited extension activities took place in the following 6 months while these issues were being resolved. Despite this set-back, the CTC2 project established a valuable network of producer, agribusiness, research and extension support that became central to the communication focus for the project in its final phase.

8.2 Communication activities after May 1995.

In late February 1995 the project team conducted a major review and redirection of the central communication strategy for CS195. A revised action plan was drafted and submitted to the NAP2 Management Committee in May 1995 (Milestone No. 22 Report). Activities and key stakeholders are summarised in Table 8.2a.

Table 8.2a. CS195 communication activities and the stakeholders targeted for those activities. **M** = major stakeholders targeted by the activity; m = minor or incidental stakeholders

	Farm walks	Technical field days	PMP workshops	Static displays	Popular articles	Television segment
1. Producers in the southern speargrass region with speargrass pasture on granitic soils	**M**		**M**	**M**	m	m
2. Producers in the southern speargrass region with other native or semi-improved pastures	**M**		**M**	**M**	m	m
3. Beef cattle producers generally			m	**M**	**M**	**M**
4. DPI extension staff in southern black speargrass region	**M**	m		m	m	m
5 DPI land conservation staff associated with PMP		m	**M**	m	m	m
6. Agribusiness and financial agencies in the southern speargrass region				m	m	m
7. R&D staff on projects sponsored by NAP2		**M**		m		m
8. Other R&D project staff				m		m
9. The general public				**M**	**M**	**M**

The plan essentially encompassed four major thrusts, viz:

1) *Adult education, information exchange and contextual interpretation* .

This was achieved through site walks and focussed discussion forums for producers and technical exchanges with other R&D professionals and extension specialists. There were 6 such exercises conducted which replaced the more traditional open field days that were held in the early years of the project. Open field days were seen to represent a major commitment of time and resources to promoting the project. However, while these exercises were popular with local producers and other stakeholders (eg. bank staff, DPI research and extension, and local agribusiness interests), their longer-term effectiveness in exchanging technology and changing management thinking was judged to be doubtful. A more targeted and interactive format was introduced to provide a more effective dialogue between the R&D team and stakeholders. This took the form of a structured site walk for smaller groups (20-30 people) with various opportunities for discussion and debriefing during the exercise. Groups were based on natural groupings (eg. LandCare or family groups) and participation was invited through co-operating DPI extension staff in targeted districts.

Activities: The first technical meeting was held at 'Glenwood' in April 1995 involving university academics, CSIRO and DPI R&D staff, and other staff from state land management agencies. The first producer site walk was held at that time involving producers from the Auburn River district. This test exercise was rated a significant advancement in knowledge exchange by both the producer participants and the DPI extension officer who chaired the sessions (John Day, pers comm.). Further rounds of both types of field meeting were held in November 1995 (Crows Nest/Kingaroy/Durong and Eidsvold/Monto producers) and April 1996 (Gayndah/Mundubbera producers). This gave the project direct coverage with producers drawn from regions extending roughly from Monto to Esk in the Brisbane Valley District.

2) Improved land management in practice

This has been approached through a close and effective working relationship with DPI land conservation staff producing and managing the Property Management Planning (PMP) process in south-central Queensland, and the regional extension staff who assist in its delivery and reinforcement. PMP is seen to be a particularly cost-effective vehicle for delivering technical information that may be put into practice. It also taps into an existing and significant investment in personnel and educational resources associated with PMP, thereby offering substantial leverage.

Activities: An agreement was reached in April 1995 for CS195 project staff to assist PMP specialist staff to produce a specialised module covering ecological and economic risk associated with land resource management in the southern black speargrass region. A project officer was employed on a casual basis for 6 months to co-ordinate the production of the module. The module was completed on schedule and field tested with producers from the Mt Perry district at Brian Pastures in April 1996. Feedback from both the participants and the course convenors was extremely positive (Craig Woods, DNR Mundubbera, pers comm.). Input from CS195 will also be made to other modules for animal production, native vegetation management, improved pasture management and paddock planning that are presently being developed by DPI in the Burnett region.. A major two day field training workshop was held in April 1996 at Narayen Research Station for DPI extension staff involved with PMP delivery and other land management technical advice.

3) Issue awareness and project identity

General awareness of the project was obtained through wider scale and more diffuse public relations and education processes. This includes the more traditional uses of media (eg. ABC radio, print and television) and participation in trade exhibitions and conference/workshops via a major static display.

Activities: A major static display highlighting key messages from the individual CS195 experiments was prepared for AgShow in Toowoomba in 1994. This display was upgraded and used at Agrotrend (Bundaberg) in May 1995 and 1996, and will also feature at the Australian Rangeland Society Conference (Port Augusta September 1996). Contacts were made with ABC rural reporting staff to promote an awareness of CS195 and its findings. The project featured on the national television show `Cross Country' in October 1995 and again on `Totally Wild' in March 1996. Project staff addressed a number of field days and LandCare meetings in the South Burnett region during 1994 and 1995. A feature story on CS195 was also carried in the CSIRO publication *ECOS* in April 1996 and a further feature is to be included in *Rural Research* in the later part of 1996.

4) Synthesis of R&D effort

Synthesis of R&D effort was achieved through closer interaction with other NAP2-sponsored R&D teams working in the area of sustainable land resource management.

Activities: The CS195 team participated in a field meeting organised by the Aristida-Bothriochloa R&D project team at Injune in April 1995. The project team hosted a two day meeting at Narayen Research Station and 'Glenwood' in November 1995. This exercise centred on a focussed workshop and field inspection format to more strongly draw out principles and key messages for land resource management from the suite of NAP2 projects.

As the individual experiments associated with CS195 were being completed, a greater emphasis was placed on the integration of the data and synthesis of the scientific knowledge into communicable management principles. A central vehicle for this communication effort is the state and transition vegetation model that has been developed and refined by the project team (Sect. 7).

8.3 Learnings

The potential effectiveness of findings from R&D notwithstanding, the ultimate benefit from a major research investment such as that committed to CS195 will be determined by the success of its technology transfer strategy. Key factors here are the extent and rate of adoption which have a substantial impact on the projected benefit stream (MacLeod 1993). However, the main products of CS195 are largely centred on information and insights into managing complex grazed ecosystems which, as part of the genre of `environmental' or `systems' research issues, have a poor track record of adoption and industry impact despite the scale of problems on which they focus (eg. Pampel and Van Es 1977, Chamala *et al.* 1982). For this reason, the CS195 team leaders spent a considerable amount of time considering options for increasing the exposure of the project and its findings to various stakeholder groups.

The LWRRDC-RIRDC-GRDC Project CTC2 was established to meet this ideal. This project which was centred on accepted best practice in extension systems methods (MacLeod and Van Beek 1993) essentially aimed to maximise the interaction between the R&D team and different stakeholder groups. Through a continuing dialogue in which perspectives were shared, it was believed that both the "messages" and "mediums" of their delivery would be tailored and packaged in such a way as to promote more extensive and rapid uptake of the project outputs. In this regard, the exercise was of limited immediate success and it was terminated (Sect. 8.1.). The performance of this project to the time of its termination and some major implications for future R, D & E into grazing land management are critically reviewed elsewhere (MacLeod 1995). However, many valuable insights into technology transfer came from CTC2 and it acted as a catalyst for the team to critically question what it could or should aim to achieve. This experience and the associated learnings had a major influence on the subsequent design and implementation of the CS195 communication strategy.

Key learnings include:

(a) Targeting messages to a limited but influential range of key stakeholders. The available time and resources available to small R&D teams is such that anything else will be of limited value and inevitably executed in a less than optimal manner.

(b) Clarity of purpose is essential to ensure that the message is appropriate to the stakeholders and medium. That is, the message, medium and target audience have to be matched to be effective. Blanket communication has limited value beyond general PR.

(c) Contracting members to take responsibility for and/or perform the agreed communication tasks. The team must be prepared to "sign on" to the proposed communication activities and be clear about its purpose. It also shares the task load and raises internal ownership of the communication plan.

(d) Champion(s) have to be identified to oversee and drive the process, otherwise it will not get done, or will be done poorly. Communication is time consuming and expensive, and under present reward systems largely competitive with conducting the scientific tasks needed to generate the communicable messages. Without a champion for the life of the project, communication will almost invariably lapse and/or opportunities to be effective are foregone.

(e) Interaction between the R&D team, extension conduits and stakeholders is effective but must be managed. Participation in R, D & E *per se* will not guarantee successful outcomes and, based on some aspects of CTC2, can lead to less effective outcomes or frustrated expectations on the part of some stakeholders. Small group exercises which combine adult learning principles, hands-on experience, and mutual opportunities for exchanging experience and knowledge are more effective than large group exercises centred on one-way information flows as typified by open field days.

(f) Context and local application credibility is everything in getting management principles accepted as potentially useful for implementation into land management practice. Practical managers largely wish to see how something works and be convinced that it suits their application context before deciding on adoption (MacLeod and Taylor 1995). The closer the message can be pitched to their situation the more effectively it can be screened by them, and the less likely it will be ignored.

(g) Land and pasture degradation is an issue concerning many beef producers and the desire for knowledge about processes and management responses is reasonably widespread. However, the technical skill base available to monitor degradation processes is limited and a real desire for aids (including species identification and monitoring guidelines) is evident within both the grazing community and the extension providers.

8.4 Future directions.

On the basis of the experience obtained with executing the CS195 communication strategy and the learnings in Sect. 8.3, a new approach has been proposed for future R&D initiatives following on from CS195. This involves the use of a limited set of property case studies that would act as a platform for both the land resource R&D and its associated communication effort. By adopting a focus for the R&D that is set at the whole enterprise level, the requirements for context, interaction, and credibility are better accommodated than may be the case for smaller scales such as the experimental site. This captures some of the advantage of PDS but addresses a more appropriate scale for management decision making. Interaction is promoted if the case study properties act as both a technical and social focal point for the stakeholders and researchers. To this end, a one page proposal was forwarded for consideration for within NAP3.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions from the research

i) Pasture states recognized in the trial

Grazing pressure was found to alter pasture composition, and a series of five states were identified that represented a sequential change resulting from a gradient of very low (State 1) to very high (State 5) grazing pressure. State 2 is characterized by the highest levels of dominance of *Heteropogon*. However, because the grazing pressure within a paddock is highly variable, the status of the pasture needs to be described in terms of the relative amounts of States 1-5 occurring in an area.

ii) Processes of degradation that were observed in the trial

In the trial, decline of *Heteropogon* through high grazing pressure was linked to degradation in black speargrass pastures. The degradation is manifested as the replacement of large, productive perennial grasses by smaller, short-lived species, forbs and drought resistant perennials such as *Fimbristylis* and *Chrysopogon* (States 4 and 5). Robust tussocks provide physical protection of the soil from water erosion. The accumulation of litter protects soil from the impact of rainfall, while the basal cover of the tussocks provides an obstruction to overland water flow. The greater biomass produced by large perennial tussocks, compared to forbs and annual species, provides a carry-over of fodder for cattle during the dry season as well as a contribution of organic matter for the continuation of soil processes, such as nutrient recycling. These advantages were progressively lost with the conversion of pasture to States 3, 4 and 5.

iii) Two causes of decline in Heteropogon populations

Decline of *Heteropogon* was associated with the highest grazing pressures. Soil changes are associated to the processes of decline - the effects of trampling and shifts to less productive plant species are likely to influence soil characteristics, and increased runoff has been measured as a result of increased stocking rates and grazing pressures. These soil changes are likely to positively feed back into the species changes, making it more difficult for degraded pasture to recover. Periods of drought are thought to accelerate these processes by reducing plant growth and increasing grazing pressure.

A second type of decline of *Heteropogon* was observed at very low stocking rates. Under these circumstances, it tended to be replaced by equally robust perennial tussock grasses, but the changes were not associated with a decline in soil condition and increased rainfall runoff.

Although vulnerable to extremes of grazing pressure, *Heteropogon* proved to be a productive and persistent grass, able to tolerate extremes of drought and effectively recolonize bare ground. It combined ecological resistance (ability to resist degradation processes) and resilience (ability to recover from drought and grazing) with moderate palatability and high productivity. This combination of characteristics makes it an extremely valuable resource for producers.

iv) The role of State 1 species in pasture dynamics

State 1 species are often unpalatable (e.g. *Aristida* Sections *Aristida* and *Calycinae*; *Cymbopogon refractus* and *Arundinella*). A conventional view is that these species are associated with lowered animal productivity, but we were unable to find such a link. Instead, the presence of large amounts of these species was associated with degradation of other parts of the paddocks as a result of the cattle shifting their grazing activity from State 1 areas to more palatable species. This was evident in medium-stocked paddocks which had above average levels of States 1, 4 and 5. However, this phenomenon may not occur in commercial paddocks unless State 1 species form a substantial proportion of the paddock. A feature of State 1 areas is that the soil is well protected by the large tussocks, and the water runoff measured on State 1 was the lowest of the five pasture states.

Although the burning treatment in this trial did not create a clear picture of the role of fire, previous research results suggest that the use of fire may be a factor in the transition from State 1 to 2. Similarly, while not demonstrated in this trial, fire, combined with spelling, may also have a role in facilitating State 5-4, 4-3 and 3-2 transitions, at least in terms of *Heteropogon* recovery.

v) The importance of spatial variation - land classes

The research has established the importance of spatial variation in paddocks and the role of land class in pasture changes. Land classes were associated with variation in both native and exotic species abundance, but more importantly with differences in resistance to degradation through grazing. Mid slopes were highly resistant to losses of *Heteropogon,* and to other species changes associated with degradation. Soil condition was also maintained on the mid slopes. Upper and lower slopes were both vulnerable to degradation, but different processes occurred. Lower slopes tended to have significant amounts of State 1 species and there was a divergence of grazing pressure within the paddocks (described in iv) leading to declines in *Heteropogon.* Similar declines in *Heteropogon* were observed on the upper slopes where total grazing pressure was higher. The shallower soils and lower moisture status of the upper slopes constrain plant growth. This renders the grazing pressure from a particular stocking rate on upper slopes to be higher than the grazing pressure from the same stocking rate on mid slopes. Losses of water and soil via runoff were also greater for upper slopes compared to mid slopes; this is likely to be both a cause of, and the result of, lowered plant productivity.

vi) Ecological effects of legume sowing

The ecological effects of bandseeding legumes were similar to those of increased grazing pressure - decline of *Heteropogon* populations and increases in annual species. A number of factors could potentially contribute to this process;

a) the increased grazing pressure resulting from herbicide applied during bandseeding;
b) addition of fertilizer increasing the competitiveness of legumes over *Heteropogon*;
c) the direct competitive effects of the legumes;

d) the grazing preference of cattle for grasses over some legumes (notably wynn cassia and seca stylo) for at least a portion of the year.

These processes were most evident on the more vulnerable land classes - upper and lower slopes. We could not conclude from the trial that legumes were able to offset the effects of grazing pressure. Rates of legume establishment were lowest on the mid slopes, the land class that was most resistant to loss of pasture condition.

vii) Effects of stocking rate on soil condition

Rainfall runoff was used as an indicator of soil condition. It reflects the extent to which rainfall is captured in the soil profile and the availability of water for plant growth (and consequently animal liveweight gain). Compared to sites where livestock were excluded, increased stocking rates resulted in increasing levels of water runoff and soil loss. Losses of water and soil were also greater for upper slopes compared to mid slopes. Soil deposition from higher parts of the landscape onto the mid and lower slopes may contribute to productivity in these areas so that total production is not necessarily lost. However, there is a major problem if this soil enters surface waters and is lost to the system. With this in mind, it becomes evident that the condition of the lower slopes, which are adjacent to watercourses, is critical. The presence of State 1 and 2 pastures on the lower slopes may be most critical to the long-term condition of the pastures.

viii) Animal production and stocking rate

Attempts to relate animal production to specific pasture states were not successful. Production data are collected on a paddock basis and cannot account for grazing preferences within a paddock. It is also apparent that cattle are able to buffer a wide range of herbage states in terms of weight gain and health. However, there was a clear link between the low potential plant productivity of States 4 and 5 and the appearance of feed deficits in the dry season. This necessitated the use of feeding supplementation to maintain stocking rates, and further obscured the effects that differences in pasture condition may have had.

In the trial, the highest levels of liveweight gain per hectare corresponded to the highest stocking rates. However, gain per head was significantly lower under the high stocking regime in the closing years of the trial - despite the fact that the animals were supplemented. In early years of the trial, economic performance (gross margins) mirrored the liveweight gain results with the highest gross margin occurring under the high stocking rate. However, after 1993/94, when full stocking recommenced, the combined effect of market penalties and supplementary feeding costs reduced the gross margin of the high stocking rate, to the point that it fell below the medium and low regimes. The whole enterprise analysis reflected this gross margin result and further highlighted the risk to viability associated with high stocking rates.

Of the four stocking rate regimes, the highest provided neither economic advantage nor good pasture condition. The lowest stocking regime favoured pasture condition but was insufficient to generate a profit at the whole enterprise level when property debt had to be serviced. The medium stocking rate resulted in the highest gross margins and return on equity, but there are several indications that this stocking rate could be associated with deterioration of pasture condition - evidenced by a decline in *Heteropogon* and, by extrapolation, water runoff and soil movement. The low stocking rate regime represented a compromise between economic profitability and pasture condition. At this stocking rate, *Heteropogon* populations persisted and soil losses were relatively low.

ix) Animal production and legume sowing

A liveweight gain advantage from legume-augmentation was evident in each year of the trial (with the exception of 1993-94) of approximately 22 kg per steer over all of the years. However, the projected economic return from legume sowing was heavily influenced by the establishment success of the initial sowing and whether it is, in fact, possible to increase and sustain stocking rates at a higher level than those for the previously untreated native pasture. The latter consideration dominates overall profitability as the return from four modelled scenarios (covering combinations of stocking rate increases and establishment success) is substantially higher when the stocking rate is doubled regardless of whether the initial establishment is successful or not. Consequently, the general conclusion is that while there is *a priori* reason to suggest that the economic advantage of legume sowing may be positive under some circumstances, the option carries considerable risk of financial failure.

x) Communication of research results

Messages relating to sustainable pasture management can be reduced to simple management principles, but producers require an understanding of the functioning of complex ecological systems in order to be able to apply them appropriately to their own enterprise. They often also need to be convinced of the importance of sustainability, as it may require a substantial shift in perceptions and values. We found a trade-off between the number of people that could be communicated with and the effectiveness of that communication. Small group exercises which combined adult learning principles, hands-on experience, and mutual opportunities for exchanging experience and knowledge, were more effective than large group exercises centred on one-way information flows, as typified by open field days.

9.2 Management recommendations

Recommendation: That stocking rates be adjusted to ensure the maintenance of *Heteropogon* (or ecologically equivalent perennial tussock grass) populations in pastures.

Heteropogon is a valuable pasture resource on granite soils, due to its productivity and ecological characteristics. However, stocking rates that are sufficiently high to cause an overall decline of *Heteropogon* in pastures are likely to also result in degradation. This will be manifested as reductions in potential pasture productivity through a shift to smaller sized plants and less effective infiltration of incident rainfall into the soil profile. Rainfall not intercepted will run off, and can potentially result in losses of soil from the pasture system. This degradation process is also likely to be associated with the loss of other perennial grass species. For example, Partridge (1993) has classified *Bothriochloa bladhii*, *Dichanthium sericeum* and *Capillipedium spicegerum,* together with *Heteropogon,* as grasses considered to decrease under heavy grazing.

Recommendation: That producers take into account the ecological and economic risks associated with increasing stocking rates.

Liveweight gain per hectare increased directly with stocking rate. However, liveweight gain per head declined at high stocking rates. When weight-for-age market premiums and the cost of supplementary feeding were accounted for, the highest gross margins and return on equity occurred with the medium stocking rate. Optimizing economic return was not associated with optimization of pasture condition. Medium stocking led to a decline in *Heteropogon* populations and an increase in water runoff. While there may be financial incentives to maintain stocking rates for maximum profit, there are ecological risks that may lead to longer-term losses of productivity.

Recommendation: That the ecological and financial risks of legume sowing be incorporated into management decisions relating to legume augmentation.

It is possible to establish legume populations using the bandseeding technique, even during episodes of drought. While successful legume-augmentation can substantially increase animal production, it is a risky investment when intensive establishment methods are used. Dry seasons may lead to establishment failure or prevent established populations expressing their full productive potential. If establishment is achieved, the grass component of the oversown pasture needs to be monitored for over-grazing and consequent reductions in *Heteropogon* populations

Recommendation: That monitoring of pasture condition be adopted as a tool in property management.

Livestock performance is not a sensitive indicator of pasture change and cannot be used to monitor deterioration of pasture condition. Effective pasture monitoring could be achieved using predictors of imminent change (e.g. monitoring *Heteropogon* seedlings) or indicators of pasture condition (e.g. the increase of plants that are associated with different states and/or observing evidence of water runoff and soil erosion).

Recommendation: That monitoring take into account the fact that some parts of the landscape are more vulnerable to ecological change.

Some parts of the landscape are more vulnerable to grazing-induced changes (e.g. upper and lower slopes). If this variation is not considered in pasture monitoring, large areas of degradation may be unrecognized. In some cases, particular parts of the landscape may be seen as more critical for monitoring, regardless of their vulnerability (e.g. areas adjacent to watercourses).

Recommendation: That plant identification skills be gained to enable pasture monitoring to be conducted.

Research has identified pasture states and transitions relating to the effects of grazing pressure and changes in the productive potential of pastures. If producers are going to use this type of information, they require a knowledge of the indicator species on their own properties. This issue is further discussed in Section 9.3.

Recommendation: That fire be considered as a tool to effect a transition from State 2 to 1, where an abundance of State 1 is putting severe grazing pressure on other parts of the paddock.

Although the fire treatments did not appear to reduce all *Aristida* spp. in pastures, there is still evidence that fire could be effective in evening up grazing pressure and preventing degradation of heavily grazed patches. This is particularly relevant in paddocks where State 1 species are abundant.

Recommendation: That strategies to rehabilitate degraded pastures be adjusted to current pasture condition and climatic conditions.

Spelling, or reduced grazing pressures, are considered to be necessary conditions for the rehabilitation of degraded pastures (i.e. to effect transitions from States 3, 4 and 5 to State 2, at least in terms of their relative amounts in the paddock). However, extensive areas of State 5 may not be very responsive to spelling, owing to changed soil conditions. In addition, if drought conditions are co-incident with spelling, this may reduce, or prevent, establishment of new species. These are the ecological risks attendant on heavy stocking rates - the pastures may not be resilient enough to rapidly recover. Thus rehabilitation management may need to be strategically implemented to take advantage of rainfall events. The time frame for rehabilitation may also need to lengthened in the case of severely degraded pastures. The cost/benefits of higher input, active interventions to achieve rehabilitation have not been assessed either ecologically or economically, although conventionally managed bandseeded legumes do not appear to offer a solution.

9.3 Communication recommendations

Recommendation: That communication activities take into account the special nature of sustainability research and focus on formats featuring sustained and intensive communication.

Because of the relative newness of the issues relating to sustainable pasture management, and their complexity, communication activities needs to be intensive and ongoing. Unfamiliar concepts and ways of thinking should be introduced and visual demonstrations of the processes be provided and reinforced. Communication will inevitably need to incorporate an educational component, to provide the tools for action. Property Management Planning workshops are one example of an appropriate form of communication activity.

Recommendation: That skills in plant identification form an important part of the educational component that is essential to communication of sustainability concepts.

The fundamental language of pasture sustainability and monitoring is that of plant names. Basic identification and the use of plant names is a pre-requisite for communication of this topic. This activity is often considered too difficult for producers and therefore, discounted in importance. While it is undoubtedly a challenging area, without a knowledge of the main plants in their pastures, producers will never be able to articulate or communicate their observations, or fully appreciate the results of pasture research. Plant identification exercises need to be provided, and can be a valuable exercise in involving producers in the observation of their own pastures.

Recommendation: That the use of state and transition models as a communication tool be refined and continued.

The use of the state and transition format to describe processes of pasture changes can be a successful tool for researchers trying to communicate complex processes to producers. Continued refinement of their uses and format would be valuable. Other formats for communication should also be explored as part of the process of improvement and refinement.

Recommendation: That efforts be made to improve the generality of research results to address the variety of ecological and management circumstances encountered by producers.

Although field trials and experiments provide good visual foci for communication events, they tend to focus the researcher on the specifics of that site. They do not equip researchers to deal with the range of observations and experiences that producers will bring to a meeting. Putting field experiments in a regional context, through the collection of complementary data will better equip researchers to interpret and communicate their experimental results.

9.4 Research recommendations

Recommendation: That state and transition models continue to be developed for sub-tropical pastures with the aim of improving their generality and refining the indicators of sustainability associated with them.

Although a substantial advance in the documentation of pasture dynamics, the state and transition model presented in this report still represents incomplete knowledge. The states need to be placed in a broader regional context and the transitions refined. Identification of the biological traits of the plants characterizing the states could be lead to a robust model suitable for general use in grasslands, and reduce the dependency of producers on advanced plant identification skills to understand the models. The range of indicators of sustainability could be increased to include more indicators of soil condition and biodiversity status. Models also need improvement in their capacity to describe spatial variation in paddocks, both in terms of variation in land types and the variation attributable to grazing behaviour. It is unsatisfactory to describe paddocks simply in terms of a single state or even a single dominant state.

Recommendation: That the generality of pasture management information be improved through the incorporation of regional/district scale observations and employing sampling designs that create 'natural' experiments involving longer time-scales.

Although single site plot experiments will still be necessary to identify details of ecological processes, their limitations lie in the difficulty of extrapolating the results to generalizations that apply to a wider range of circumstances. However, it is possible to complement experimental results by collecting data at larger spatial scales. This puts the detailed experimental work into a broader context and gives the researcher a more authoritative grasp of the general and specific issues relating to pasture management

Recommendation: That research address economic and pasture management issues at the paddock and enterprise scale.

Paddocks and whole enterprises represent the pasture management and economic decision making units. For complex issues relating to sustainable management, it is necessary to include these levels of organization within a research portfolio. Our demonstration of the importance of landscape variation and variation of grazing pressure within paddocks underscores the importance of paddock scale investigations, although there are still methodological difficulties associated with this.

Recommendation: That appropriate levels of taxonomic discrimination be used in pasture research.

Pasture research in Queensland has not traditionally emphasized fine taxonomic discrimination, particularly in relation to native pastures. However, increasing interest in pasture sustainability and plant diversity necessitates a rigorous approach to this issue. Our results have shown that closely related species can have vastly different ecological characteristics and the differences have important implications for management. For example, *Aristida* includes fire tolerant and intolerant species and a single set of management recommendations will not be adequate for the group as a whole. Taxonomic accuracy is necessary to place research data in the broader geographic context, as there may be substantial differences between regions in their floristics, although not necessarily the functioning of their vegetation.

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11. APPENDICES PART I

Appendix 1. Publications arising from work related to CS195 research activities. Appendices Part II is a separate volume of these listed papers and reports.

(a) Journal Publications

Cook, S. J., Clem, R. L., MacLeod, N. D. and Walsh, P. A. (1993) Tropical pasture establishment. 7. Sowing methods for pasture establishment in northern Australia. *Tropical Grasslands* **27**, 335-343.

Cook, S.J., Gilbert, M.A. and Shelton, H.M. (1993) Tropical pasture establishment. 3. Impact of plant competition on seedling growth and survival. *Tropical Grasslands* **27**, 291-301.

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1992-1993 - Nos. 2-5. CS195
1993-1994 - Nos. 8-11. CS195
1994-1995 - Nos. 17-21. CS195

CSIRO Divisional Biennial Reports
1988-1990 pp. 62-69
1991-1993 pp. 48-59
1992-1994 pp. 41-55

(d) Other Publications

Anon (1996) Ecological Risk in Native Pasture Systems: a Workshop for Beef Producers. Property Management PlanningWorkshop Notes. Queensland Department of Primary Industries, Bundaberg.

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Appendix 2. Overall change in the frequency (percentage of quadrats in which the species occurred) of plants between 1989 and 1995. Quadrats (n = 1619) were recorded in both autumn 1989 and autumn 1989 in 38 paddocks representing the range of land class, stocking rate and legume sowing treatments. Chi-squared tests were performed on the differences in count for each species between the two years. Significance was set at p< 0.001.
Stocking rate response is based on results of ANOVA 2, 3 and 4. Analyses were not performed on species with a frequency of ≤2% in 1995 and 'other' categories. Responses may be relative e.g. a positive response may be less decline at a higher stocking rate.
ns = no significant effect at p < 0.05; ←↑→ = most abundant at intermediate stocking rates. ↓ = negative response to higher stocking rate; ↑ = positive response to higher stocking rate; - = test not relevant or species too infrequent for statistical testing.
1. PG = perennial grass; AG = annual grass; PF = perennial forb; AF = annual forb; NL = native legume; SL = sown legume; PS = perennial sedge.

Type of plant[1]	Species/ species group	% Frequency 1989	1995	Change 95-89	Stocking rate response
	INCREASE SIGNIFICANT AT P<0.001				
AF	*Portulaca pilosa**	16	67	51	↑
AG	*Tragus australianus*	7	49	42	↑
PG	*Digitaria brownii*	5	30	25	ns
PG	*Tripogon loliiformis*	9	32	23	ns
SL	*Chamaecrista rotundifolia**	0	21	21	↑
SL	*Stylosanthes scabra**	0	20	20	ns
AF	*Gomphrena celosioides**	10	28	18	ns
PG	*Melinis repens**	8	26	18	↓
PF	*Sida subspicata*	9	27	18	ns
PF	*Evolvulus alsinoides*	16	33	17	ns
SL	*Macroptilium atropurpureum**	0	16	16	←↑→
PS	*Fimbristylis dichotoma*	69	83	14	ns
PG	*Digitaria ammophila*	2	13	11	ns
NL	*Indigofera linnaei*	18	29	11	↑
PF	*Oxalis* sp.	15	26	11	ns
AF	*Portulaca filifolia*	0	11	11	ns
PF	*Boerhavia dominii*	18	28	10	←↑→
SL	*Stylosanthes guianensis**	0	8	8	ns
PG	*Aristida* - Section *Aristida*	5	12	7	↓
AF	*Portulaca oleracea*	1	8	7	ns
PG	*Digitaria divaricatissima*	37	43	6	ns
PF	*Glossocardia bidens*	2	8	6	ns
AG	*Perotis rara*	3	9	6	ns
PF	*Phyllanthus virgatus sens lat.*	17	23	6	↑
PG	*Chloris divaricata / C. truncata*	1	6	5	ns
NL	*Glycine clandestina*	6	11	5	ns
PF	*Murdannia graminea*	12	17	5	ns
PF	*Vittadenia pustulata*	3	7	4	↑
PF	*Alternanthera nana*	5	8	3	ns
AF	*Chenopodium cristatum*	0	3	3	ns

	CHANGE NOT SIGNIFICANT AT P<0.001				
PF	*Tricoryne elatior*	14	18	4	ns
PF	*Richardia brasiliensis**	9	12	3	ns
PG	*Chrysopogon fallax*	17	19	2	ns
PG	*Bothriochloa decipiens*	17	18	1	ns
PS	*Cyperus fulvus*	1	2	1	-
PF	*Euphorbia drummondii*	1	2	1	-
SL	*Lotononis bainesii**	0	0.7	0.7	-
PG	*Aristida* - Sect. *Macrocladae*	0.4	0.1	0.4	-
PG	Other stoloniferous grasses	2	2	0.4	-
SL	*Aeschynomene falcata**	0	0.3	0.3	-
PF	*Calotis lappulacea*	1	1	0.2	-
PF	*Brunoniella australis*	5	5	0.1	ns
PF	*Crotalaria mitchellii*	0.2	0.2	0.1	-
PG	Other tussock grasses	15	15	0.1	-
PF	*Epaltes australis*	5	5	-0.3	ns
PG	*Themeda triandra*	0.1	0	-0.1	-
PF	*Rostellularia adscendens*	2	2	-0.6	-
PF	*Verbena officinalis**	0.2	0.5	-0.3	-
PG	*Arundinella nepalensis*	4	3	-1	ns
PG	*Panicum effusum*	20	19	-1	ns
PG	*Enneapogon arenicola*	4	2	-2	-
PF	*Chrysocephalum apiculatum*	26	22	-4	ns
PF	*Vernonia cinerea*	28	24	-4	ns
NL	*Glycine tomentella*	12	9	-3	ns
	DECREASE SIGNIFICANT AT P<0.001				
PG	*Bothriochloa bladhii*	3	0	-3	-
PG	*Capillipedium parviflorum*	3	0	-3	-
AF	*Lepidium bonariense**	4	1	-3	-
NL	*Zornia muriculata*	30	26	-4	↑
fern	*Cheilanthes tenuifolia*	8	3	-5	ns
PG	*Sporobolus creber / S. elongatus*	8	3	-5	ns
NL	*Zornia dyctiocarpa*	12	6	-6	↑
PG	*Aristida* - Section *Calycinae*	24	17	-7	↓
NL	*Desmodium varians*	19	12	-7	↑
AF/PF	Other forbs	30	22	-8	-
NL	Other native legumess	18	9	-9	-
PG	*Cymbopogon refractus*	25	15	-10	↓
NL	*Glycine tabacina/ Galactia tenuiflora*	32	22	-10	ns
PG	*Heteropogon contortus*	89	79	-10	←↑→
PF	*Aster subulatus**	11	0	-11	-
PG	*Aristida* - Section *Streptachne*	21	9	-12	ns
PF	*Conyza sumatrensis**	12	0	-12	-
PG	*Aristida* - Sect. *Arthratherum*	31	18	-13	↓
PS	Other sedges and rushes	16	1	-15	-
PF	*Oenothera indecora**	18	1	-17	-
PF	*Goodenia glabra*	38	20	-18	ns
PF	*Wahlenbergia* sp.	24	6	-18	ns
AG/PG	*Eragrostis* spp.	65	38	-27	↑

Appendix 3. Frequency of species in 38 paddocks totalling1619 quadrats (0.5 x 0.5 m) in March 1989. These are species that were recorded in 1989 but that were not individually listed in Appendix 1 because of their inclusion in multi-species or 'other' categories. Nomenclature follows Anon (1994).

Species	Frequency (%)	Species	Frequency (%)
Eragrostis sororia	45.3	*Sida cordifolia**	0.3
Aristida calycina var. *calycina*	14.9	*Tribulus terrestris*	0.3
Eragrostis brownii	12.3	*Aristida leptopoda*	0.2
Aristida calycina var. praealta	8.8	*Cheilanthes sieberi*	0.2
Indigofera colutea	4.8	*Chloris virgata*	0.2
Eragrostis parviflora	4.0	*Fimbristylis microcarya*	0.2
Bothriochloa bladhii	3.7	*Fuirena ciliaris*	0.2
Indigofera hirsuta	3.6	*Portulaca filifolia*	0.2
Cyperus squarrosus	3.5	*Pterocaulon redolens*	0.2
Eriachne rara	3.4	*Scleria mackaviensis*	0.2
Commelina lanceolata	3.3	*Aristida vagans*	0.2
Podolepis arachnoidea	3.3	*Chloris truncata*	0.2
Crotalaria linifolia	3.1	*Crotalaria mitchellii*	0.2
Eragrostis leptostachya	2.9	*Cyperus cuspidatus*	0.2
Haloragis heterophylla	2.8	*Cyperus polystachyos*	0.2
Aristida ramosa	2.6	*Drosera indica*	0.2
Tephrosia filipes / T. bidwillii	2.3	*Eriochloa pseudoacrotricha*	0.2
Polygala linariifolia	2.3	*Macroptilium atropurpureum*	0.2
Alloteropsis semialata	2.2	*Oldenlandia mitrasacmoides*	0.2
Aristida gracilipes	2.0	*Solanum nigrum*	0.2
Digitaria ciliaris	1.9	*Vittadinia triloba sens lat.*	0.2
Sauropus trachyspermus	1.9	*Brachiaria sp.*	0.1
Brachyscome microcarpa	1.8	*Calotis dentex*	0.1
Polycarpaea corymbosa	1.8	*Chloris gayana*	0.1
Rumex brownii	1.8	*Cyperus concinnus*	0.1
Cymbopogon obtectus	1.7	*Cyperus difformis*	0.1
Tephrosia purpurea	1.7	*Drosera spatulata*	0.1
Dichanthium sericeum	1.7	*Eremophila debilis*	0.1
Cyperus nervulosus	1.6	*Eriochloa procera*	0.1
Fimbristylis depauperata	1.5	*Euphorbia hirta*	0.1
Bulbostylis barbata	1.5	*Lomandra leucocephala*	0.1
Chloris divaricata	1.4	*Rotala tripartita*	0.1
Lipocarpha microcephala	1.4	*Sida rhombifolia*	0.1
Cyperus gracilis	1.4	*Solanum densevestitum*	0.1
Hypoxis hygrometrica	1.4	*Spermacoce laevigata*	0.1
Brachiaria subquadripara	1.2	*Stylosanthes scabra*	0.1
Chamaecrista mimosoides	1.1	*Triraphis mollis*	0.1
Aristida benthamii	1.0	*Alternanthera denticulata*	0.1
Cyperus betchei	1.0	*Alternanthera pungens*	0.1
Dianella longifolia	0.9	*Ammannia multiflora*	0.1
Cyperus cyperoides	0.9	*Aristida queenslandica*	0.1
Sehima nervosum	0.8	*Asperula conferta*	0.1
Hybanthus enneaspermus	0.7	*Conyza bonariensis*	0.1
Paspalidium gracile	0.7	*Conyza canadensis*	0.1
Cyperus conicus	0.7	*Cucumis myriocarpus**	0.1
Cyperus sanguinolentus	0.7	*Cynodon dactylon*	0.1

Digitaria longiflora	0.6	*Cyperus brevifolius*	0.1
Einadia nutans	0.6	*Cyperus leiocaulon*	0.1
Indigofera linifolia	0.6	*Dactyloctenium aegyptium*	0.1
Vetiveria filipes	0.6	*Dactyloctenium radulans*	0.1
Crinum angustifolium	0.6	*Dianella revoluta*	0.1
Hypericum gramineum	0.6	*Dichanthium aristatum*	0.1
Mentha satureioides	0.6	*Dichopogon strictus*	0.1
Cyperus flaccidus	0.5	*Einadia trigonos*	0.1
*Verbena officinalis**	0.5	*Eleocharis atricha*	0.1
Ajuga australis	0.4	*Eleocharis atropurpurea*	0.1
Aristida warburgii	0.4	*Entolasia stricta*	0.1
Cyperus bifax	0.4	*Eragrostis molybdea*	0.1
Eragrostis cilianensis	0.4	*Euchiton involucratus*	0.1
Eragrostis elongata	0.4	*Goodenia rotundifolia*	0.1
Rhynchosia minima	0.4	*Heteropogon triticeus*	0.1
Chloris inflata	0.4	*Hydrocotyle acutiloba*	0.1
Fimbristylis nuda	0.4	*Hypochaeris glabra*	0.1
Juncus polyanthemus	0.4	*Lomandra longifolia*	0.1
Lomandra multiflora	0.4	*Malvastrum americanum*	0.1
Paspalum dilatatum	0.4	*Physalis minima*	0.1
Swainsona phacoides	0.4	*Plantago debilis*	0.1
Verbena rigida	0.4	*Schizachyrium fragile*	0.1
Vigna lanceolata	0.4	*Setaria surgens*	0.1
Brachiaria piligera	0.3	*Sida fibulifera*	0.1
Cenchrus ciliaris	0.3	*Solenogyne bellioides*	0.1
Eragrostis pilosa	0.3	*Spermacoce brachystema*	0.1
Fimbristylis brownii	0.3	*Themeda avenacea*	0.1
Opuntia stricta	0.3	*Velleia paradoxa*	0.1

Appendix 4. Aristida - ecology and taxonomy

Due to the large number of species and their apparent similarity, the identification of *Aristida* in field surveys presents problems. Flowering material is necessary for identification and species differences are not always apparent, particularly with grazed plants. In the 1995 Botanal assessment, plants were identified to Section (a taxon between genus and species) to achieve an appropriate degree of accuracy and differentiation of the group, which is heterogeneous. Table i) lists the features of the sections; these are simple and amenable to rapid field assessment. The *Aristida* species names used in the report (for simplicity) represent most abundant species in each section, and are identified in Table ii). Table iii) summarizes the treatment responses of the different sections, illustrating the variation of ecological characteristics displayed by this group. Future work with *Aristida* will need to take this variation into account.

Table i). Characters identified by Simon (1992) to be diagnostic within the genus *Aristida* and descriptions of the six sections containing Australian species.

Section name	Description
§ *Streptachne*	Lateral awns extremely short or absent
§ *Arthratherum*	Lemma convolute and with a column with a distinct or indistinct articulation
§ *Pernicoisae*	Lemma involute and with a column without an articulation
§ *Calycinae*	Lemma involute and without a column
§ *Aristida*	Lemma convolute and without a column
§ *Macrocladae*	Lemma convolute and with a distinct or poorly devloped column without an articulation

Table ii). Frequency of species of *Aristida* recorded at the Glenwood site in 1989 before commencement of experimental treatments. The number of quadrats (from a total of 2,050) in which the species was recorded is given in brackets. Bold indicates the species names used in the report.

Section	Species	% Frequency (number of quadrats species present)	
§ *Streptachne*	***A. spuria***	20	(408)
§ *Arthratherum*	***A. holathera***	31	(640)
§ *Calycinae*	*A. benthamii*	1.0	(21)
	A. calycina var. *calycina*	17	(352)
	A. calycina var. *praealta*	8.6	(176)
	A. queenslandica	0.1	(1)
§ *Aristida*	*A. gracilipes*	1.9	(39)
	A. leptopoda	0.6	(13)
	A. ramosa	2.5	(52)
	A. vagans	0.1	(3)
§ *Macrocladae*	*A. warburghii*	0.3	(7)

Table iii). Changes in overall frequency and summary of responses of *Aristida* to stocking rate, land class and legume treatments in 38 treatment paddocks at Glenwood between 1989 and 1995. Responses are summaries of the range of ANOVA's performed these paddocks. Section *Macrocladae* was rare at the site overall and was not recorded in these treatment paddocks.

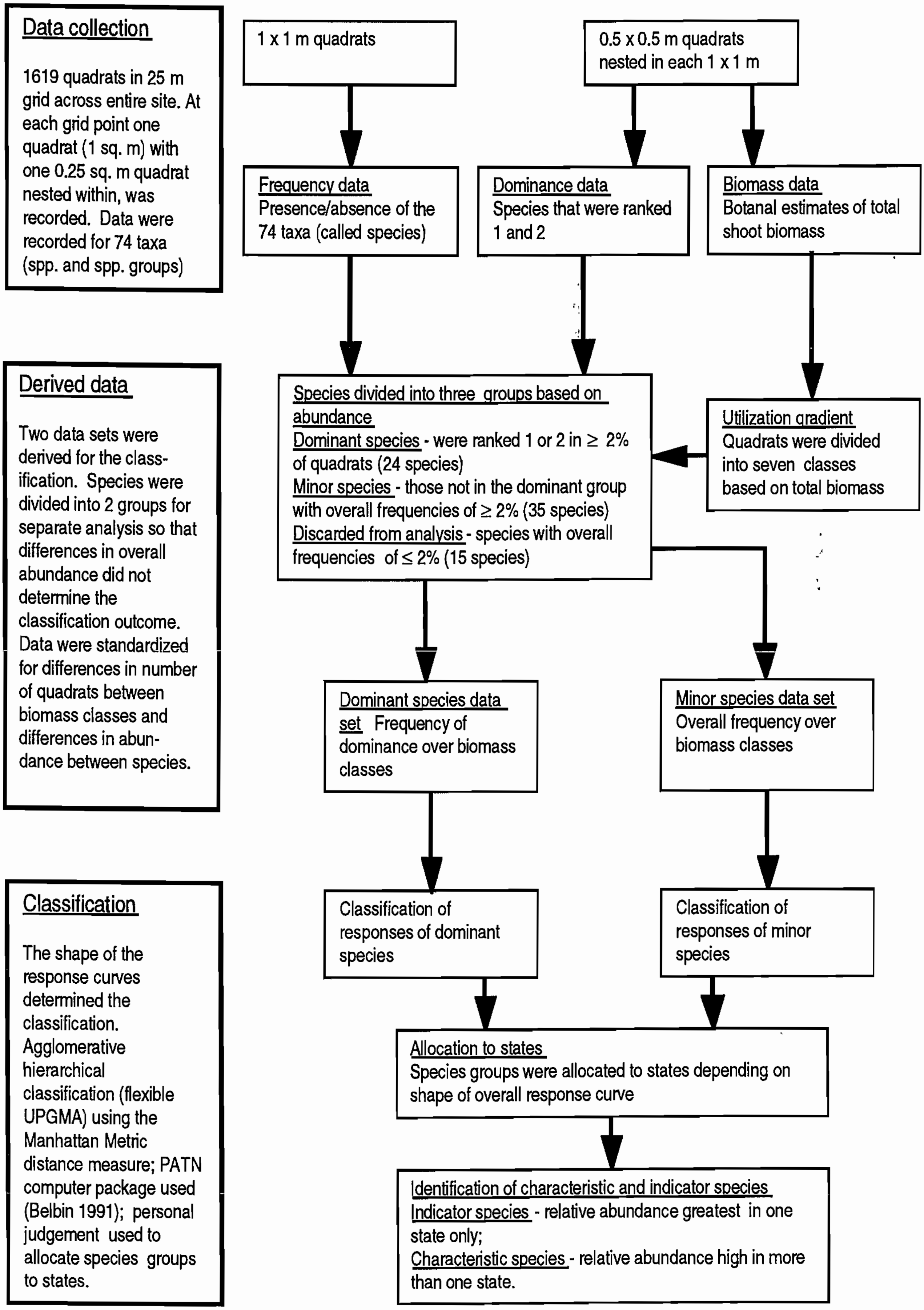
Section	% Frequency		Treatment response summary		
	1989	1995	Preferred land class	Stocking rate (SR)	Legume treatment
§ *Streptachne*	21	9	Mid slopes in 1989 but no difference in 1995	No SR response	Decline where legumes were sown
§ *Arthratherum*	31	18	Better resistance to grazing on mid slopes	Greatest decline at medium and high SR on upper slopes only	Lower levels in 1995 where legumes were sown
§ *Calycinae*	24	17	Upper slopes	Greatest decline at medium to high SR	No response
§ *Aristida*	5	12	No preference	Eliminated from high SR; progressively large increase in lower SR's	No response

Appendix 5. Description of methods used to determine the composition of states describing plant response to grazing.

A description of the data sets and process of analysis used to identify indicator and characteristic species of states that occur along a gradient of grazing pressure at 'Glenwood' is described in the following flow diagram.

The choice of plant species used in the analyses was a two stage process. Initially data were collected for 74 taxa (not including 'other' categories). The list included species that were abundant in 1989 and species which appeared to be of some importance in 1995. The average frequency of these 74 taxa in 1995 was 16% compared to the 0.4% average frequency of the 'other' species (latter figure based on 1989 species numbers which were comprehensive). This list was further reduced to 59 by the exclusion of species with an overall frequency of ≥ 2% in 1995.

In the classifications, more groups were specified than were actually used. Final number of groups was accepted based on the interpretability of the results. Not all the groups defined in the classification were used to define states as the species in them did not have appropriate response patterns e.g. species with a flat or irregular response curve. These species may be tolerators of the spectrum of grazing intensity, or they may have gradients that were not picked up.


Data collection
1619 quadrats in 25 m grid across entire site. At each grid point one quadrat (1 sq. m) with one 0.25 sq. m quadrat nested within, was recorded. Data were recorded for 74 taxa (spp. and spp. groups)
1 x 1 m quadrats
0.5 x 0.5 m quadrats nested in each 1 x 1 m
Frequency data Presence/absence of the 74 taxa (called species)
Dominance data Species that were ranked 1 and 2
Biomass data Botanal estimates of total shoot biomass
Derived data
Two data sets were derived for the classification. Species were divided into 2 groups for separate analysis so that differences in overall abundance did not determine the classification outcome. Data were standardized for differences in number of quadrats between biomass classes and differences in abundance between species.
Species divided into three groups based on abundance
Dominant species - were ranked 1 or 2 in ≥ 2% of quadrats (24 species)
Minor species - those not in the dominant group with overall frequencies of ≥ 2% (35 species)
Discarded from analysis - species with overall frequencies of ≤ 2% (15 species)
Utilization gradient Quadrats were divided into seven classes based on total biomass
Dominant species data set Frequency of dominance over biomass classes
Minor species data set Overall frequency over biomass classes
Classification
The shape of the response curves determined the classification. Agglomerative hierarchical classification (flexible UPGMA) using the Manhattan Metric distance measure; PATN computer package used (Belbin 1991); personal judgement used to allocate species groups to states.
Classification of responses of dominant species
Classification of responses of minor species
Allocation to states Species groups were allocated to states depending on shape of overall response curve
Identification of characteristic and indicator species
Indicator species - relative abundance greatest in one state only;
Characteristic species - relative abundance high in more than one state.