Rangeland and Animal Performance Trends in Highland Sourveld

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Declaration

I, Alan Douglas Short, declare that this is my own work, except where otherwise acknowledged in the text.

Signed: Dated: 2 December 2010

Acknowledgments

My parents have always supported and encouraged me in this long journey and I thank them from the bottom of my heart.

Dr Shauna Costley, the wonderful woman who threatened to withhold my ticket to Splashy Fen this year unless I finally finished the work that had been dragging on for years: thank you for everything, especially your love and support.

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Abstract

Long-term trends in rangeland sward dynamics (species composition, structure, productivity) were examined on three trials established between 1989 and 1996 at Kokstad Research Station in the Highland Sourveld, while animal performance (average daily gain and gain per hectare) was examined on two of the trials. The region enjoys moderate rainfall of 782mm per annum, with hilly topography, and soil depths ranging from >1m to <20cm. The first trial was labelled the simulation trial, as it simulated a four-paddock rotational grazing system, in which animals spent two weeks in each of three paddocks while the fourth was rested for the entire season. The rested paddock was rotated each year. The trial tested two stocking rates (0.5 and 1.0 $AU.ha^{-1}$) at five ratios of cattle to sheep, ranging from cattle only to sheep only. The trial was unreplicated, and was established in 1989 on flat topography with deep soils. The second trial (labelled the flat two-paddock trial) was established in 1992 adjacent to the simulation trial. The trial examined two stocking rates of sheep weaners (0.5 and 1.0 $AU.ha^{-1}$ seasonally) in a continuous grazing two-paddock system, in which one paddock of each treatment was burned and grazed continuously while the second paddock was rested, to be burned and grazed in the following season. The trial was replicated twice. The third trial (labelled the steep two-paddock trial) mimicked the grazing system of the flat trial, but was located on a steep (c. 20%) West-facing slope with shallow soils. The trial incorporated two additional treatments: an intermediate stocking rate of 0.7 $AU.ha^{-1}$ and an ungrazed treatment.

Species composition of the sward was recorded biennially on all trials using the nearest plant-point technique with between 200 and 800 points per paddock. Sward standing crop was measured in the rested seasons of the simulation trial and at the beginning, middle and end of each season in one paddock of each two-paddock treatment of the two-paddock trials. In the two-paddock trials, sward standing crop was measured within and outside permanently placed exclosure cages. Animals were weighed fortnightly.

The response of species to grazing pressure or animal type was mediated by soil depth and slope, as well as the grazing system. *Tristachya leucothrix* declined on all grazed treatments. The ungrazed treatments remained relatively stable over ten years. On the low stocking rate treatments of the steep trial, unpalatable species increased, but so did *Themeda triandra*. The heavily grazed treatment of the steep trial was surprisingly stable, with little significant change in relative abundance of key species other than an increase in the unpalatable *Alloteropsis semialata* and decline in *T. leucothrix*. The medium stocking rate treatment on

the steep trial showed significant shifts in relative abundance of key species, with declines in *T. triandra* and *T. leucothrix* and increases in *A. semialata* and the unpalatable wiregrass *D. filifolius*. These trends were not repeated on the flat trial, however, with *T. triandra* and *A. semialata* increasing and all other key species declining or remaining stable. On the simulation trial, species responded largely unpredictably with species abundances often fluctuating considerably over time. *Microchloa caffra* and *A. semialata* increased substantially in both the low and high stocking rate sheep-only treatments, with a concurrent decline in *T. triandra* in the high stocking rate but not the low.

Changes in composition over time, as measured by Euclidean distance, showed that shallow soils, high stocking rates and a high proportion of sheep caused greater shifts in species composition over time than deep soils, low stocking rates or more cattle. Three treatments, the sheep-only treatments on the simulation trial and the high stocking rate on the steep trial, showed an initial rapid shift in composition over about 6 years, before stabilising in subsequent seasons. The flat trial showed no substantial shift in composition over time. This general pattern of change was confirmed by Non-Metric Multidimensional Scaling.

On the simulation trial, total standing crop was influenced by stocking rate and by the proportion of sheep in most seasons. On the two-paddock trials, increasing stocking rate significantly reduced sward vigour, and vigour declined over time.

Stocking rate reduced total standing crop on both trials at the end of the 2004/05 seasons and the crop of unpalatable species on the steep trial. Total palatable plants were unaffected by stocking rate on both trials.

The classic Jones-Sandland model of animal performance as influenced solely by stocking rate was not supported. Sheep performance was influenced by stocking rate and the interaction of stocking rate and seasonal rainfall. There was no difference in average daily gain between treatments over time, and hence cumulative animal production per hectare increased with increasing stocking rate. Animal performance was possibly influenced by many factors beyond the scope of this study, including the effect of predator attacks on surviving animals, and resource availability such as shade and shelter and high-production patches in some paddocks and not others. Scale effects on ecology are being increasingly investigated and a meta-analysis of this type shows that, even in one research farm, slight differences in management and environment can have significant effects on plant and animal responses to grazing.

Chapter 1 Introduction: Long-term grazing trials at Kokstad

Long term grazing trials at Kokstad Research Station

Long-term grazing trials offer crucial opportunities for examining trends in rangeland condition and animal performance that can be missed by modelling exercises or short-term research (Fuhlendorf and Smeins 1997). The influence of climatic variation on primary and secondary productivity or the presence of thresholds (Bestelmeyer 2006) can be observed directly, and gradual shifts in ecosystem variables such as species composition or primary productivity, which may be insignificant in the short term, may become substantial after many years.

Four long-term grazing trials were established at Kokstad Research Station between 1989 and 1995; one was discontinued after eight years and will not be discussed further in this report. The discontinued trial was discussed in detail by Hardy and Tainton (1995) and Hardy (1995). The other three trials continue to this day and are the subject of this dissertation. The trials were established at different times and for different purposes, but they all have the common feature that they examine the effect of grazing by livestock on rangeland productivity and composition, as well as animal performance in two of the trials, in one location in Highland Sourveld. The trials will be described in detail later, but they will be introduced briefly to the reader.

The first, unreplicated, trial examined the effect of different ratios of cattle to sheep, at different stocking rates, on veld condition. The trial is known as the Simulation trial, since the rotational grazing system was simulated. The experiment consisted of five ratios of cattle to sheep, ranging from cattle only to sheep only, at two stocking rates (0.5 ha/AU and 1.0 ha/AU). The grazing treatment simulated a four-paddock rotational grazing system, where one paddock was rested for an entire season while the animals were rotated around the other three paddocks. The rested paddock was rotated annually.

The second and third trials, although established separately and with slightly different experimental designs, are usually considered as one by the research staff since the grazing system is identical. The trials will be referred to as the flat two-paddock trial and the steep two-paddock trial after their topography on the farm. The trials examine the effect of a two-paddock "blaze and graze" (Zacharias 1994) system at different stocking rates on sheep performance, veld condition, runoff and soil loss. Each treatment consists of two small paddocks of between 0.5 and 1.1 ha. One of the paddocks is burnt early in the season, stocked soon thereafter with weaned merino lambs, and grazed continuously for the remainder of the season. The other paddock then receives the same treatment the following season.

The latitude and longitude of the three trials are: Simulation trial: 30°30'42" S 29°24'35 E; Flat two-paddock: 30°30'50" S 29°24'49 E; steep two-paddock: 30°30'24" S 29°25'54 E.

The steep trial, as the name implies, differs in one important aspect from the other two trials: it is situated on a steep (c. 20%), west-facing slope with shallow soils, while the other two trials are located on gentle slopes with deep soils (Figure 1.1). The soils are described in more detail in Table 1.2 and Table 1.3.

It is a core principle of the scientific method that if results are repeated they increase support for an hypothesis (Johnson 1999). The three trials described here provide an opportunity to test some of the fundamental principals of veld management: the effect of animal type, grazing system and stocking rate on veld condition.

Description of Kokstad Research Station

Kokstad Research Station is located just outside of the town of Kokstad in the East Griqualand region of the province of KwaZulu-Natal, South Africa. The station was established in 1962 from a combination of town commonage and State Forestry Reserve (Peard 1980), and is approximately 1200 ha in extent. The landscape is rolling, with steep mountains on the eastern and western boundaries of the farm. The vegetation of the farm falls within Gs12 – East Griqualand Grassland and Gs 10 – Drakensberg Foothill Moist Grassland of Mucina and Rutherford (2006), Dry Highland Sourveld of Camp (1999) or Highland Sourveld of Acocks (1988). The vegetation structure is described as a short, closed grassland according to Edwards (1983), consisting almost entirely of tufted species of <30cm tall. The sward is dominated by *Themeda triandra*, *Tristachya leucothrix*, *Diheteropogon filifolius*, *Elionurus muticus* and *Alloteropsis semialata,* with patches of shrubby *Leucosidea sericea* trees. Several alien invasive plants form prominent patches: *Acacia mearnsii*, *Eucalyptus* spp. and *Rubus cuneifolius*. *Senecio retrorsus* and several other *Senecio* species, forbs poisonous to livestock, form prominent patches during the summer, especially heavily-grazed areas such as firebreaks and some of the treatments of the trials.

On the gentle slopes, the soils are deep and well drained, dominated by Hutton and Clovelly forms, with some Westleigh forms in less well-drained areas (Soil Classification Working Group 1991). The steep slopes are dominated by shallow Glenrosa, Clovelly and Mispah soils (Figure 1.4).

The mean rainfall of the area is 782mm, with a CV% of 19.8; the annual rainfall of the farm from 1933 to 2007 is shown in Figure 1.5. Three trial seasons fell outside the standard deviation for the period: 1996/97, which was well above the mean rainfall at 1205mm, and 1992/93 and 2003/04, both of which were very dry seasons.

Soil forms and families, together with soil depth, texture of the soil and soil depth, can be grouped into a number of categories known as crop ecotopes (Smith 2006). Crop ecotopes are intended to describe the suitability of the soil for growing crops, by describing the most important attributes of the soil for an agronomist. For example, well drained soil forms such as Hutton and Clovelly are grouped into crop ecotope B (Table 1.1). The more than 70 soil forms can therefore be grouped into 11 categories to simplify the interpretation of soil maps. The proportion of the area of each camp occupied by an ecotope is described in Table 1.2 and Table 1.3.

Table 1.1 Crop ecotope codes and descriptions (Smith 2006) for soils found in the study

	Ecotope code	Description	Soil forms
Soil type	B	Well and moderately drained soils	Hutton, Clovelly
	D	Mottled and moderately drained soils	Avalon, Pinedene, Lichtenburg*
	E	Mottled and poorly drained soils	Westleigh
	H	Young soils	Mispah, Glenrosa
	J	Duplex soils	Sepane
Soil texture (clay %)	1	> 35%	
	2	15 - 35%	
	3	< 15 %	
Soil depth (mm)	1	>800	
	2	500-800	
	3	300-500	
	4	<300	

*Lichtenburg is a new soil form (J.O. Botha pers. comm.)

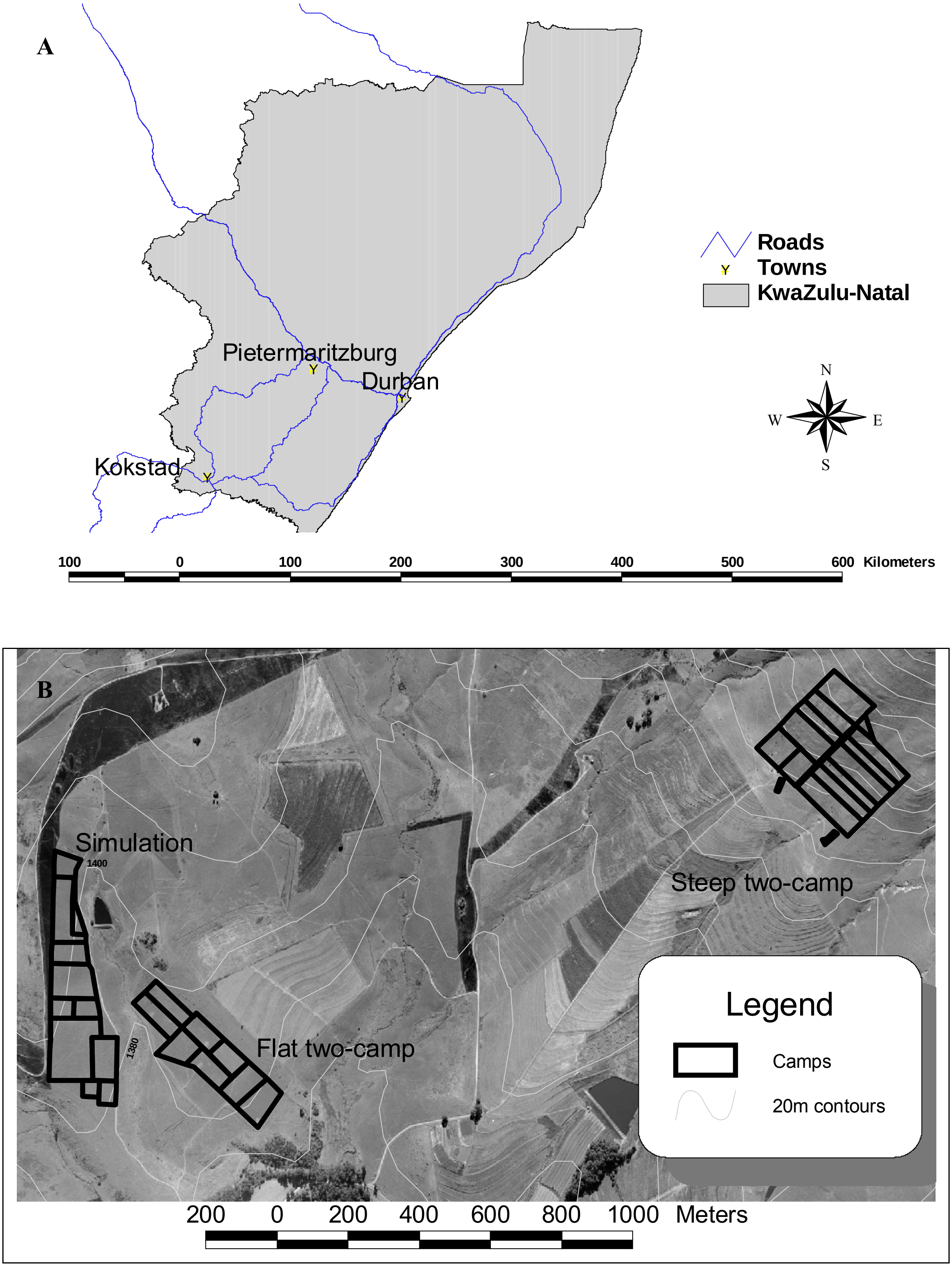


Figure 1.1: (A) Location of Kokstad in KwaZulu-Natal. (B) Location and layout of three long-term grazing trials at Kokstad Research Station.

Table 1.2: Description of soils and topography of the simulation trial. Paddocks are arranged from left to right by stocking rate (low and high) in order of increasing proportion of sheep. See Figure 1.2 for a map of the soil forms and families.

	Low stocking rate					High stocking rate				
Paddock number	10	3	9	4	5	1	6	8	7	2
Stocking rate ($AU.ha^{-1}$)	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0
Proportion sheep (AU)	0	0.25	0.5	0.75	1.0	0	0.25	0.5	0.75	1.0
Area (ha)	0.65	0.82	1.08	2.20	0.39	0.31	0.37	1.15	0.60	0.22
Soil form and family (proportion of paddock area occupied by each soil type)[1]										
Avalon 1100	0.14		0.07					0.25	0.01	
Clovelly 2100				0.35						
Hutton 2100	0.25	0.99	0.60	0.64	0.55	0.66	1.00	0.75	0.76	1.00
Lichtenberg 2100		0.01				0.34				
Pinedene 1100	0.61		0.34	0.01	0.45				0.23	
Ecotope (Proportion of each paddock occupied by each ecotope)[2]										
B.1.1				0.05			0.70	0.16	0.41	
B.2.1	0.25	0.99	0.60	0.82	0.55	0.66	0.30	0.59	0.35	0.50
B.2.2				0.12						0.50
D.2.1	0.75	0.01	0.40	0.01	0.45	0.34		0.25	0.24	
Effective rooting depth (mm)	1000	1000	1000	958	1000	1000	1000	1000	1000	824
Slope (%)	8.7	9.9	7.5	8.4	10.5	6.0	10.5	6.7	9.7	6.0
Clay (median % estimated in field)	25	25	25	26	25	25	39	28	33	25

[1] Soil Classification Working Group (1991); Lichtenberg is a new form (J.O. Botha pers. comm.)

[2] Crop ecotopes according to Smith (2006 p. 50)

Paddock layout

In all three trials, the main limiting factor in the trial design was the number of animals available for the studies. The paddocks were therefore planned to match the stocking rate of the treatment with the number of animals available. In addition, each trial was laid out in order to minimise topographic effects on treatments, and the treatments were randomised. The sizes of grazed paddocks ranged from 0.2 – 1.2 ha (Table 1.2 and Table 1.3). A more detailed description of each trial is given in Chapter 3.

Table 1.3: Description of the soils and topography of the two-paddock trials at Kokstad Research Station. Paddocks are arranged by trials, in order of increasing stocking density. See Figure 1.3 and Figure 1.4 for maps of the soil forms and families on each trial

	Steep trial																Flat trial							
	Ungrazed (0.0 $AU.ha^{-1}$)				Low (0.5 $AU.ha^{-1}$)				Medium (0.7 $AU.ha^{-1}$)				High (1.0 $AU.ha^{-1}$)				Low (0.5 $AU.ha^{-1}$)				High (1.0 $AU.ha^{-1}$)			
Paddock	Top (M)	Top (N)	Bot (O)	Bot (P)	5A	5B	10A	10B	7A	7B	9A	9B	6A	6B	8A	8B	3A	3B	4A	4B	1A	1B	2A	2B
Area (ha)	0.02	0.09	0.03	0.04	1.15	1.11	1.15	1.06	0.72	0.76	0.68	0.69	0.56	0.53	0.51	0.56	0.69	0.65	0.80	0.83	0.63	0.69	0.61	0.58
Soil form and family (proportion of paddock area occupied by each soil type)																								
Clovelly 2100				1.00	0.17	0.29	0.45	0.33		0.52	0.68	0.24		0.56	0.85	0.30	0.90	0.53				0.24		
Clovelly 2200	1.00					0.04	0.36	0.01		0.07	0.17			0.04	0.08	0.01								
Glenrosa 1111		1.00								0.10														
Glenrosa 2211					0.18							0.00												
Hutton 2100			1.00		0.38	0.24	0.19	0.04	0.99	0.21	0.15	0.57	1.00	0.18	0.08	0.50	0.10	0.31	0.97	1.00	1.00	0.76	1.00	1.00
Mispah 1100						0.33		0.62	0.01					0.06		0.06								
Sepane 1110					0.27							0.19				0.12								
Sepane 2110						0.10				0.12				0.16		0.02								
Westleigh 1000																		0.16	0.03					
Ecotope (Proportion of each paddock occupied by each ecotope)																								
B.2.1																	0.19	0.07	0.49	1.00	0.72	0.79	0.78	0.71
B.2.2	1.00				0.02	0.28	0.36	0.05	0.82	0.08	0.17	0.56	0.66	0.21	0.08	0.51	0.81	0.77	0.48		0.20	0.13	0.22	0.29
B.2.3			1.00	1.00	0.54	0.20	0.37	0.33	0.16	0.32	0.68	0.26	0.34	0.39	0.85	0.30								
B.2.4						0.09	0.27			0.40	0.15			0.17	0.08	0.00					0.09	0.07		
E.2.4																		0.16	0.03					
H.2.4		1.00			0.18	0.33		0.62	0.01	0.10		0.00		0.06		0.06								
J.2.3					0.27	0.10				0.12		0.19		0.16		0.13								
Rooting depth (mm)	650	250	400	400	352	388	449	285	603	345	419	539	565	419	408	509	718	609	811	1000	866	899	921	899
Slope (%)	25	40	14	25	15	22	25	25	14	26	25	17	14	23	25	18	6	6	6	7	13	12	8	6
Median Clay %	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

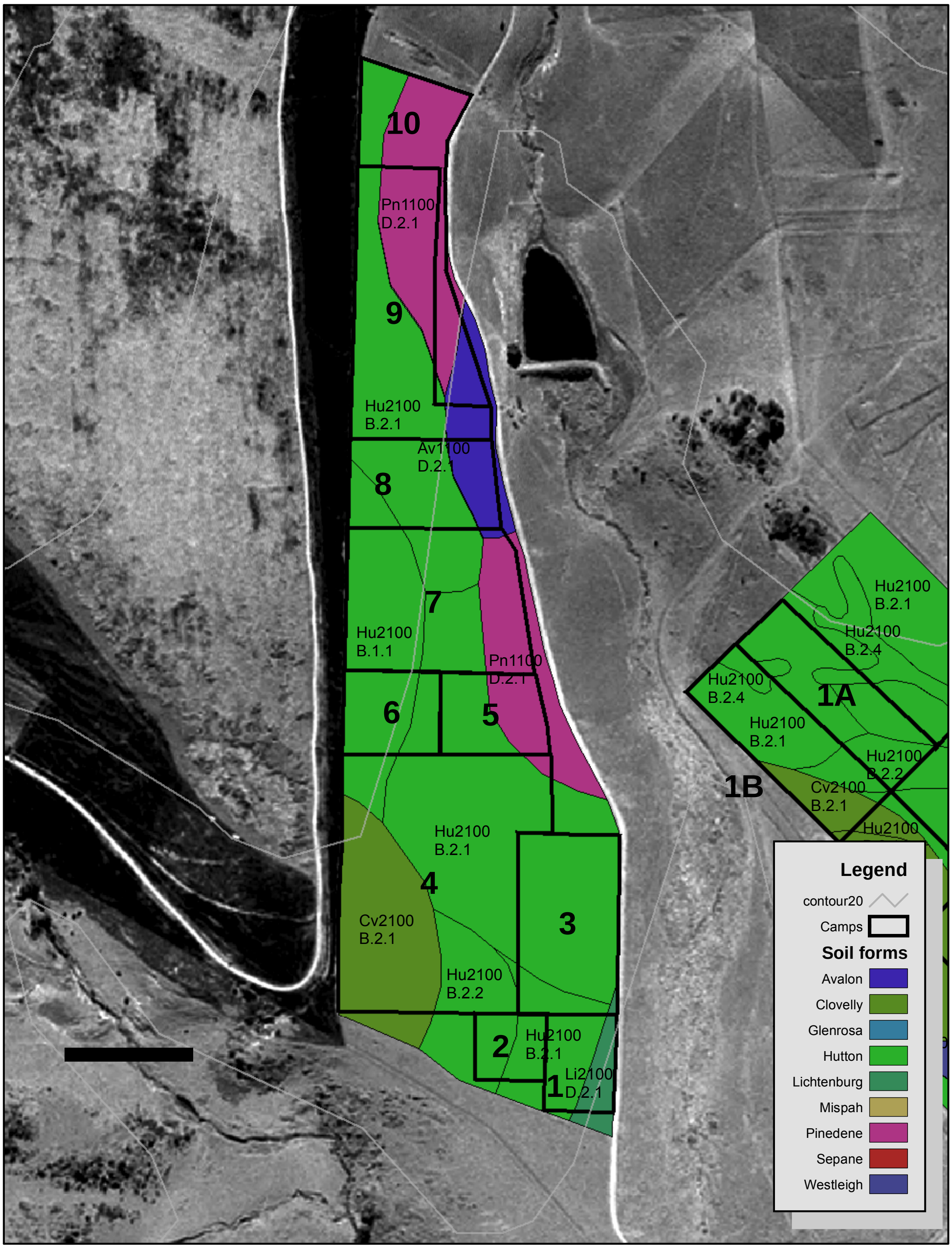


Figure 1.2: Soil forms and families of the simulation trial at Kokstad Research Station. Key: Bold letters refer to paddock numbers. Low stocking rate, increasing proportion of sheep from no sheep to only sheep: paddocks 10, 3, 9, 4 and 5 respectively. High stocking rate, increasing proportion of sheep: paddocks 1, 6, 8, 7 and 2 respectively. Soil families as per Soil Classification Working Group (1991). Alphanumeric code below each family refers to the ecotope code (sensu Smith 2006). Soil survey and mapping by A. Short and J.O. Botha.

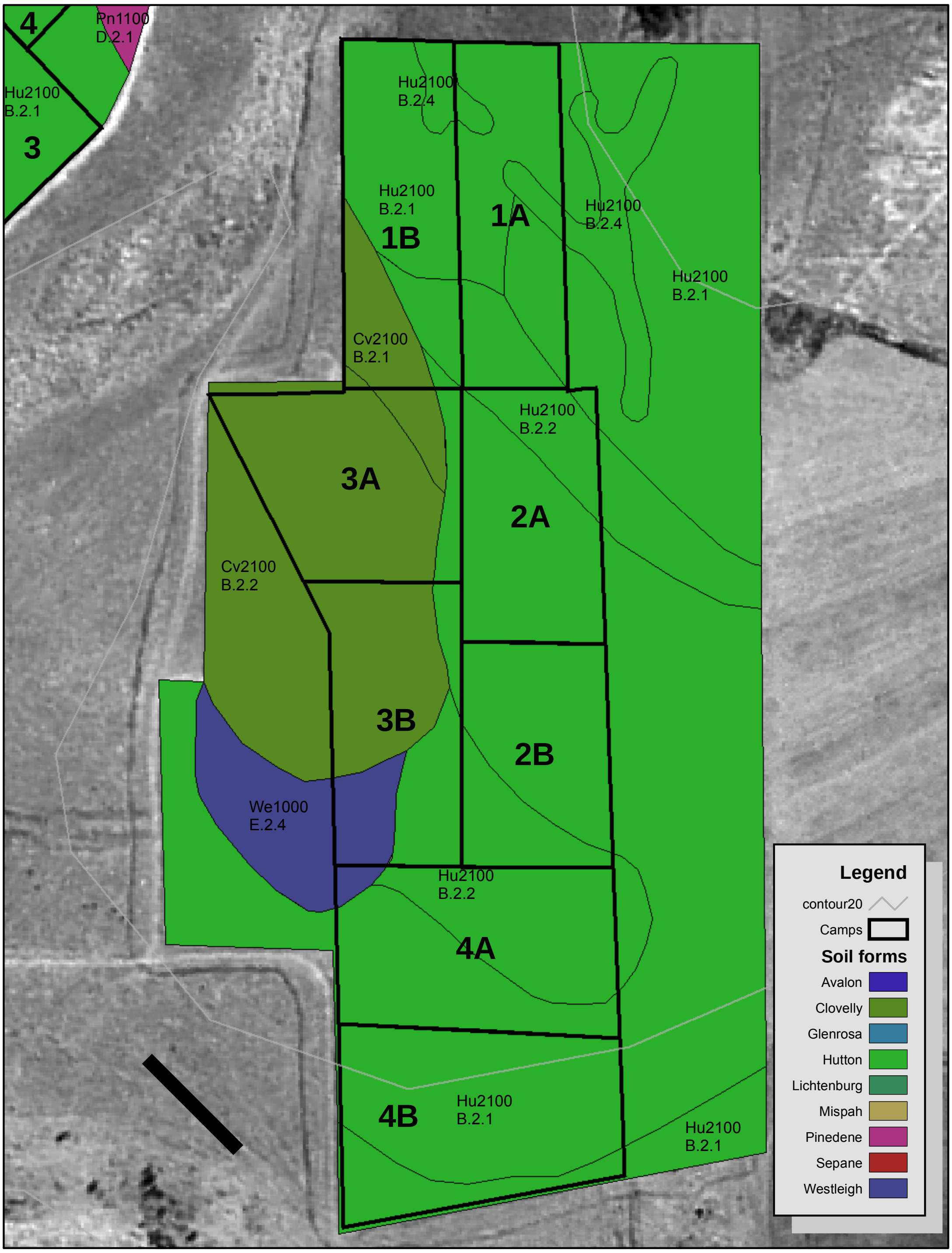


Figure 1.3: Soil forms and families of the flat two-paddock trial at Kokstad Research Station. Key: Bold letters and numerals refer to treatments and paddocks (low stocking rate: paddocks 3 and 4; high stocking rate: paddocks 1 and 2). Soil families as per Soil Classification Working Group (1991). Alphanumeric code below each family refers to the ecotope code (sensu Smith 2006). Soil survey and mapping by J.O Botha, B. Forbes and A. Short.

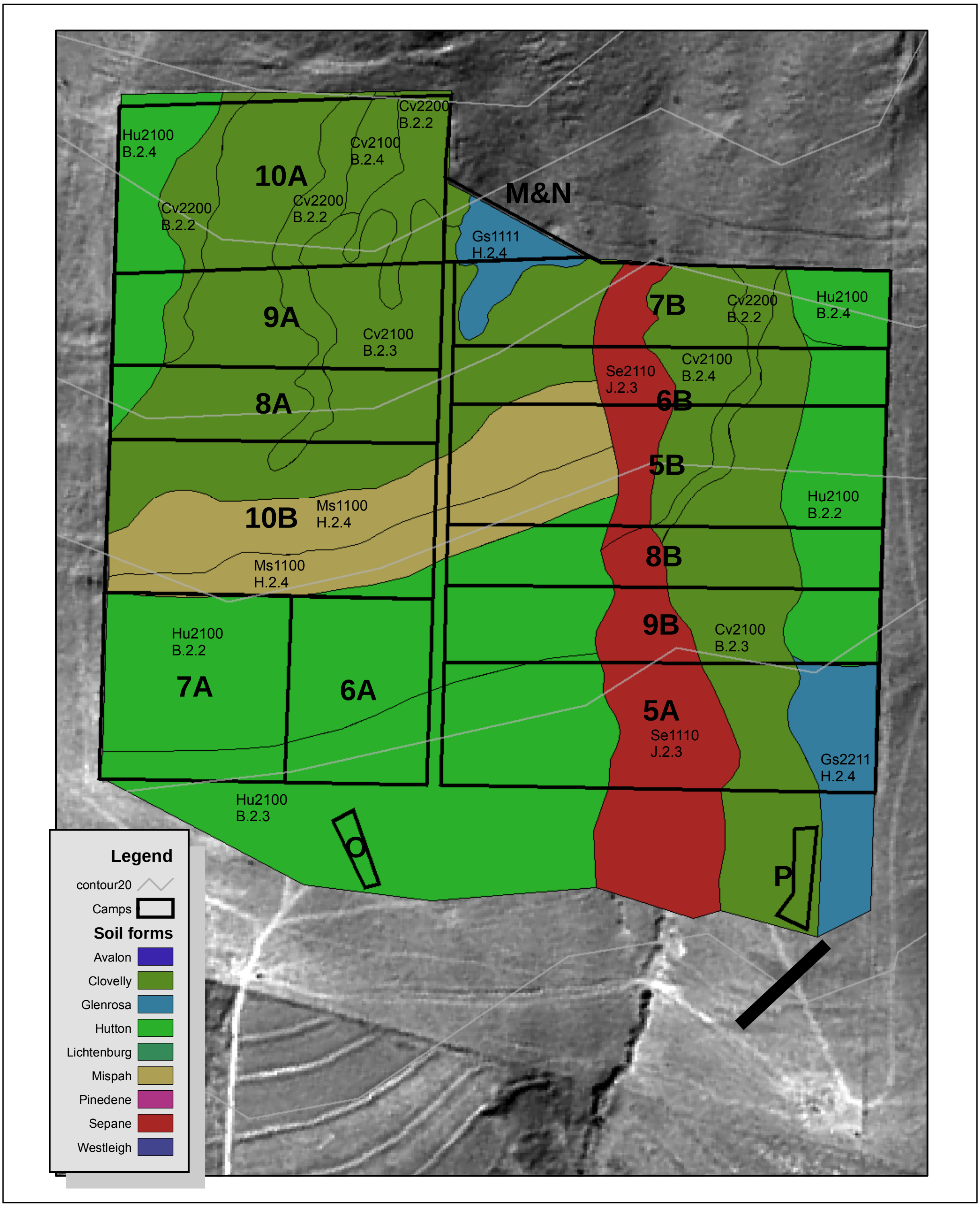


Figure 1.4: Soil forms and families of steep two-paddock trial at Kokstad Research Station. Key: Bold letters and numerals refer to treatments and paddocks (low stocking rate: paddocks 5 and 10; medium stocking rate: Paddocks 7 and 9; high stocking rate: paddocks 6 and 8; ungrazed plots: M, N, O and P). Soil families as per Soil Classification Working Group (1991). Alphanumeric code below each family refers to the ecotope code (sensu Smith 2006). Soil survey and mapping by J.O Botha, B. Forbes and A. Short.

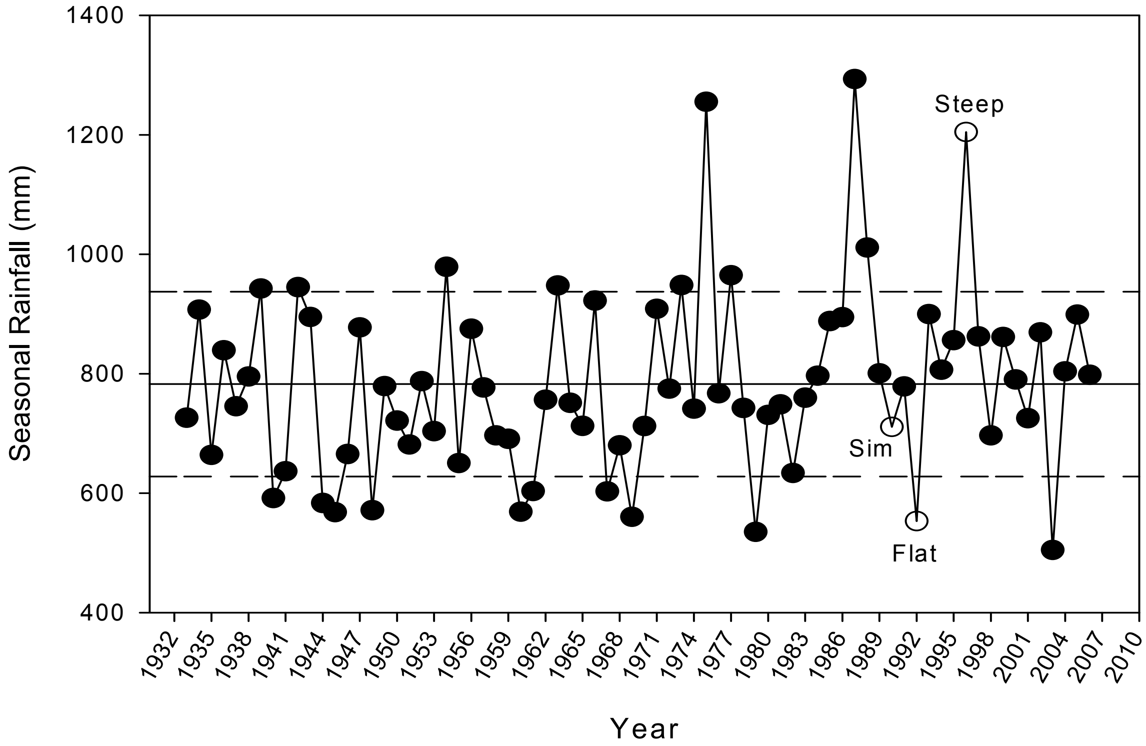


Figure 1.5: Seasonal rainfall (July-June) at Kokstad Research Station from July 1933 to June 2007. Horizontal line shows the mean for the period; dashed lines show the standard deviation. White symbols with labels indicate the start of the simulation trial, flat trial and steep trial respectively.

Objectives

The purpose of this work is to fully describe the long-term trends in vegetation composition and productivity across all three trials in relation to the grazing treatment and environmental factors such as soils and rainfall. Such a meta-analysis approach may well reveal patterns that would not be revealed by interpreting the results of each trial in isolation (Vesk *et al.* 2004). Secondly, the effect of stocking rate and environmental variables on sheep performance in the two paddock trials over a decade will be examined.

Specifically, the objectives of the study were to determine the effect of stocking rate and the influence of environmental factors on grass species composition; determine the effects of stocking rate and environmental factors on sheep performance in the two-paddock trials; determine the effect of stocking rate, rainfall and environmental factors on primary production; and to determine the influence of stocking rate, grazing system and environmental factors on trends in the above variables over the medium-to-long term.

Chapter 2 Literature review: Grazing in humid grasslands of southern Africa

Introduction

Grassland ecosystems can be influenced by a combination of "bottom-up" (e.g. geology, climate, soils) and "top-down" (e.g. fire, grazing) factors. For the grazier, management decisions that maintain or improve long-term rangeland productivity, especially secondary productivity, are important for sustaining livelihoods in the long-term (Danckwerts and King 1984a, Pope and McBryde 1984, Torrel *et al.* 1991). The relative contribution, and the direction of influence, of various top-down and bottom-up drivers on rangeland composition and ecosystem functioning has been a subject of research and debate for decades (O'Connor 1985, Milchunas *et al.* 1988, Mentis *et al.* 1989, Milchunas and Lauenroth 1993, Vetter 2005). The purpose of this review will be to examine the variables usually considered the most important in driving rangeland composition and functioning, namely fire, grazing, climate, and soils, and the variables usually considered most important response variables, namely primary productivity, species composition, and animal production.

Equilibrium versus non-equilibrium rangelands

Much debate has occurred in recent years about equilibrium versus non-equilibrium models of rangeland functioning (Briske *et al.* 2003, Vetter 2005). Rangelands are said to be equilibrial when the vegetation responds to disturbance (e.g. fire, drought, grazing) linearly, with the vegetation recovering to its former state when the disturbance is removed or reduced. Non-equilibrium systems, however, are driven by stochastic events with vegetation responding to rainfall and being de-coupled from animal numbers (Ellis and Swift 1988, Mentis *et al.* 1989, Westoby *et al.* 1989, Walker 1993). Recently, authors have integrated the equilibrium–non-equilibrium paradigm by proposing that rangelands occur along continuum from equilibrium to non-equilibrium, with the appropriate model depending on a range of factors including the temporal and spatial scale of the phenomenon in question (Briske *et al.* 2003, Vetter 2005, Gillson and Hoffman 2007). Higher-rainfall environments with a low CV%, such as Highland Sourveld, are more likely to fit the equilibrium model of rangeland dynamics (Ellis and Swift 1988, Fynn and O'Connor 2000, Vetter 2005, Campbell *et al.* 2006).

Most of the debate has taken place around arid and semi-arid rangelands. However, the non-equilibrium model is also related to the state-and-transition model introduced by Westoby *et al.* (1989). The state-and-transition model of rangeland functioning does not assume a simple, linear model of vegetation dynamics, but rather that any specific site can consist of a number of discontinuous states, with transitions between these states that may be gradual or sudden, depending on a trigger such as drought. Although the state-and-transition model is generally associated with the non-equilibrium paradigm of rangeland dynamics (Briske *et al.* 2003) there is no reason to assume that it cannot apply to more stable "equilibrium" rangelands. The Kokstad research station falls into a region of moderately high rainfall with a CV% of about 20 (Chapter 1), and therefore may fit the equilibrium model of rangeland dynamics more closely than the non-equilibrium model.

Interactive effects of ecological and management variables

Although the following discussion is broken into several influences, these factors cannot be viewed in isolation. The interactive effects of fire, grazing, landscape heterogeneity and climate can have significant effects on animal performance and veld condition (Ellis and Swift 1988, Zacharias 1994, Fuhlendorf and Smeins 1997, Illius and O'Connor 2000, Fuhlendorf and Engle 2004, Archibald 2008).

Landscape heterogeneity

Landscape heterogeneity and scale-dependant processes can have important influences on ecosystem functioning (Fuhlendorf and Smiens 1999, Illius and O'Connor 2000, Adler *et al.* 2001, Cromsigt and Olff 2008), even in controlled, relatively small-scale environments (Fynn and O'Connor 2000). Classical grazing trials have generally attempted to reduce environmental variation through replication and small-scale experiments, but some authors have argued that small-plot grazing trials have limited relevance to landscape-scale processes precisely because of the disproportionate influence of landscape heterogeneity on ecosystem functioning (Fuhlendorf and Smiens 1999, Teague and Foy 2004, Briske *et al.* 2008).

Specifically, at the landscape scale, variation in geology, soils, catenal position and slope can influence species composition and structure, primary production and nutritional quality of vegetation, and the movement of soils (Walker 1993, Tongway and Ludwig 1997, Fynn and O'Connor 2000). Site-specific research can have problems when scaling up to landscape or regional scale, but is important for defining models and testing hypotheses of ecosystem functioning. Site-specific research, together with broader ecological observation, will help to track and understand ecosystem changes (Milton *et al.* 2007).

Fire

Fire has long been known to be an important ecosystem driver in southern African rangelands, particularly in high-rainfall areas (Scott 1947). Fire removes moribund material and is used to stimulate new, nutritious growth in grass swards (Mentis *et al.* 1984, Morris *et al.* 1992, Kirkman and Morris 1999), which attracts grazers (Vermeire *et al.* 2004) and improves animal performance (Zacharias 1994). Humid grasslands are prone to frequent fires through a combination of frequent lightning strikes and anthropogenic ignitions (Edwards 1984) and the high fuel load (O'Connor 2008) of the ecosystem.

The high-rainfall grasslands of southern Africa are often referred to as fire-climax grasslands (Acocks 1988, Tainton and Walker 1993), as in the absence of fire (or other non-selective defoliation), the plant community will develop to a more woody state (Fynn 2003). *Themeda triandra* (hereafter *Themeda*) is a dominant grass species that is a fire-climax species in the high-rainfall grasslands of southern Africa, and considered an indicator of veld in good condition when it occurs in abundance (Foran *et al.* 1978, Turner 1988, Hardy and Hurt 1989, Vetter *et al.* 2006). Defoliation of moribund material will stimulate tillering (Mentis *et al.* 1984), and defoliation is most easily accomplished over large areas by fire. Vegetative regrowth in the first season after fire is more nutritious than in subsequent seasons without burning (Mentis *et al.* 1984, O'Reagain and Owen-Smith 1996). The production of fresh, green forage for animals is the main reason for graziers to burn veld over vast areas of the sub-continent.

The frequency of burning influences the species composition, cover and productivity of a grass sward (Everson *et al.* 1989, Short *et al.* 2003, Snyman 2003, Fynn *et al.* 2004, 2005a). Fire-climax grasses decline with decreasing fire frequency (Short *et al.* 2003, Fynn *et al.* 2005a), with productivity declining in the season after burning relative to unburnt veld (Tainton *et al.* 1977, Snyman 2003).

Grazing

Models of grazing dynamics in mesic grasslands tested stocking rate, grazing system and animal type as the main variables under the influence of the grazier (Mentis 1982, Hardy 1986, Hardy and Mentis 1986). Grazing system (continuous or rotational grazing) has been shown to have little influence on veld condition or animal performance in empirical studies

(Gammon 1977, O'Reagain and Turner 1992, Briske *et al.* 2008). Despite the lack of unambiguous evidence for the effectiveness of rotational grazing systems, rotational grazing, and particularly high-density grazing systems, remain popular (e.g. Snyman 1988, Phillips 2004). However, the evidence for the effectiveness of rotational grazing is mixed; while some reviews have pointed out little effect of rotational versus continuous grazing, those same reviews have also catalogued studies that did indeed show rotational grazing to be more effective, either in terms of animal production or veld condition, or both (O'Reagain and Turner 1992, Briske *et al.* 2003, Buntting 2003). While the effectiveness of rotational grazing is limited or possibly exaggerated in terms of sustainable grazing, multiple camp systems can give the grazier more control over his resources and manage other factors not considered by many grazing trials, such as breeding, disease, or theft.

Stocking rate is considered to be of primary importance in rangeland management (Vorster and Visagie 1980, O'Reagain and Turner 1992, Kirkman and Moore 1995a, Briske *et al.* 2003). Stocking rate has a greater effect on animal production than grazing system (Hardy and Mentis 1986, O'Reagain and Turner 1992, Briske *et al.* 2008). There are two possible effects of stocking rate on animal performance. The first is a reduction in animal performance caused by reduced herbage availability per animal with increasing stocking rate (Jones and Sandland 1974, Hardy and Mentis 1986), and the second is the long-term effect of high stocking rates on the palatable proportion of the veld (Morris *et al.* 1992, Hart and Ashby 1998). Milchunas and Lauenroth (1993), however, in a global analysis of grazing trials, found grazing pressure to be less influential than evolutionary history of grazing of the site and above-ground net primary production on the response of the vegetation to grazing.

The stocking rate for optimal cattle performance is considered to be slightly less than carrying capacity (Hardy 1994), but there are few objective methods for determining the optimum carrying capacity for a particular piece of veld (Mentis 1982, Hardy and Hurt 1989, Bosch and Booysen 1992). Recently, attempts at determining primary productivity and hence carrying capacity through remote sensing have been published, with mixed success (Palmer and Fortescue 2004, Grigera *et al.* 2007, Booth and Cox 2008, Hilker *et al.* 2008, Palmer *et al.* 2010). However, these remote sensing techniques are primarily aimed at regional (policy)-scale decision-making rather than farm (management)-scale decisions.

Resting

Resting of veld appears to the most important management factor, after stocking rate, which affects veld productivity in the long term (Scott 1947, O'Reagain and Turner 1992, Peddie *et al.* 1995). Rest appears to have contradictory influences on stability of the sward, with some experiments showing treatments without rest to be the most stable in composition (Morris *et al.* 1992, Kirkman 2002a). However, palatable plants after two or three consecutive seasons of grazing without rest have lost significant vigour, and require at least a season's rest to recover (Peddie *et al.* 1995). The frequency of rest in the Highland Sourveld, to maintain the vigour of palatable plants, appears to be no less than once in three years, with the common rotational rest of once in four years possibly being too infrequent for adequate recovery of palatable plants (Peddie *et al.* 1995).

Animal type

Most grazing research has used cattle, not sheep (Hardy 1994). Since cattle and sheep have different grazing habits (Malherbe 1971, Hardy *et al.* 1994, Hardy 1995, O'Reagain and Grau 1995, du Toit 2003) and different growth responses to grazing (Hardy and Tainton 1995), the response of veld grazed by cattle alone cannot necessarily be extrapolated to veld grazed by sheep or cattle and sheep.

Scott (1947) advocated cattle only in the Highland Sourveld, unless sweetveld or green feed was available to carry sheep through the winter. Cattle and sheep, stocked at equivalent $AU.ha^{-1}$, do not maintain equivalent stocking rates throughout the growing season (Hardy *et al.* 1994): the relative growth rates of cattle and sheep are confounded by stocking ratio. Sheep perform better when grazed together with cattle, especially as the ratio of cattle to sheep widens (Malherbe 1971, Hardy and Tainton 1995), as the less selective grazing habit of the cattle modifies the structure of the sward to be more suitable for sheep.

Sheep are usually thought to be more detrimental to veld condition than cattle because of their more selective grazing pattern (Kirkman 2002a). The effect of mixed stocking on veld depends on the stocking rate and the ratio of cattle to sheep. Narrow cattle to sheep ratios appear to be less detrimental to the veld than wide cattle to sheep ratios (Hardy *et al.* 1994). Stocking cattle and sheep together may also ameliorate the impact of sheep on the rangeland. Only one season of moderate stocking with sheep resulted in a severe decline in the vigour of palatable grasses (Hardy 1994). The effects of mixed stocking on the defoliation pattern of *Themeda triandra* and *Tristachya leucothrix* (both palatable species) and *Alloteropsis* *semialata* (an unpalatable species) varied with stocking rate and cattle:sheep ratio. Increasing stocking rate was associated with a decline in ungrazed plants of all three species.

Stocking cattle and sheep together does appear to improve overall secondary productivity, and the productivity of sheep, relative to grazing either cattle or sheep alone (Hardy and Tainton 1995).

Sward structure

Structure of sourveld has the largest short-term effect on diet quality and ingestive behaviour and hence performance of livestock (O'Reagain 1996, O'Reagain and Goetsch 1996, O'Reagain *et al.* 1996, O'Reagain and Owen-Smith 1996, Morris *et al.* 1999). Sward height has major influence on ingestive behaviour of ungulates grazing cultivated and natural pastures (O'Reagain *et al.* 1996, Morris *et al.* 1999, Hirata 2002). Cattle and sheep can engender and maintain distinct patterns of height variation within grass swards through selective grazing (Lütge *et al.* 1996, Morris *et al.* 1999, du Toit 2003). Herbivores concentrate on short leafy material and avoid tall stemmy material, resulting in tall patches being carried over into the next growing season if not burned or mown. More even sward use by grazers can be achieved by early grazing of swards at the start of the growing season, after a burn (Zacharias 1994, Kirkman 1999, Morris 2002). Maintenance of patches by herbivores grazing them ensures they have access to a pool of high-quality forage (Lütge *et al.* 1996, Archibald 2008, Cromsigt and Olff 2008).

Patch grazing is classically thought to be detrimental to veld condition in the long term as ungrazed patches gain vigour at the expense of selectively grazed patches (Lütge *et al.* 1996). However, scale-related research into ecosystem functioning has identified heterogeneity, including patch-selective grazing, as important processes in rangeland ecology (O'Connor 1992, Wilmshurst and Fryxell 1995, Freudenberger *et al.* 1997, Fuhlendorf and Smeins 1997, Fuhlendorf and Smiens 1999, Adler *et al.* 2001).

Effect of veld condition on animal performance

Reduced veld condition is assumed to result in reduced forage production, and hence reduced animal performance compared to equivalent veld in better condition. Most animal production or carrying capacity models explicitly include veld condition (Teague and Danckwerts 1984, Hardy and Mentis 1986, Turner 1988, 1990, Bosch and Gauch 1991, Smith *et al.* 1999). However, in some environments, veld condition and animal performance seem to be weakly correlated (O'Reagain 1996, O'Reagain *et al.* 1996, Ash and Corfield 1998). Even in the model of Hardy and Mentis (1986), species composition weakly affected animal performance, a result they initially attributed to a weakness in the model. Therefore, the relationship between veld condition and animal performance, and hence carrying capacity, appears to be poorly supported except at the extremes of veld condition [which may be considered, in some instances, to be alternate stable states *sensu* Westoby et al (1989)].

Conclusion

The factors influencing veld condition and animal performance on veld have been studied for decades, but with mixed results. Stocking rate influences animal performance, although the relationship between stocking rate and animal production is more complex than that of the classical Jones and Sandland (1974) relationship developed on pastures. The more variable the environment, the less predictable the response of the veld to disturbances such as drought, grazing, or fire, and managers need to take advantage of opportunities and avoid hazards. The environment at Kokstad is relatively stable (CV of rainfall = 20%), and therefore is likely to respond to grazing, fire and rainfall in the classical "equilibrium" fashion, meaning that veld condition (species composition, productivity, cover) will respond gradually to grazing, and that if grazing is removed the veld will recover in the direction of its climax or fire climax community.

Chapter 3 Long-term stability of rangeland under grazing in a humid grassland

Introduction

Rangelands are the most important source of forage for livestock and wildlife in southern Africa, and therefore the long-term maintenance of forage production is a key component of the sustainable utilisation of rangelands. In addition to producing forage, rangelands are an important reservoir of biodiversity (Blench and Sommer 1999), and the condition of rangelands influences the quality of runoff into the country's major river systems (Hoffman *et al.* 1999). Rangelands are also increasingly being recognised as important carbon reservoirs (Vågen *et al.* 2005). The capacity of the rangelands to produce these goods and services is usually referred to as the condition of the rangeland (Trollope *et al.* 1990).

Real changes in veld condition may be inferred from long-term trends in primary productivity and species composition, with associated changes in soil loss, water infiltration and other functional attributes of the system (Ludwig *et al.* 1997, Whitford *et al.* 1998).

Three long-term trials were established at Kokstad Research Station between 1989 and 1995 in order to test the sustainability of different grazing management systems under different topographical conditions on rangeland condition. The productivity and composition of each trial was regularly monitored in order to examine the effects of stocking rate, livestock species, rainfall and topography on veld condition. The purpose of this study is to examine the effects of different grazing systems and grazers (sheep or cattle) on long-term trends in species composition and primary productivity, and the influence of topographic and edaphic factors on those trends.

One attribute of rangelands commonly measured is the abundance of species. Veld condition is commonly inferred from the proportion of different species (Dyksterhuis 1949, Foran *et al.* 1978, Mentis 1983, Turner 1988, Hardy and Hurt 1989, Friedel 1991, Bosch and Booysen 1992). Certain species are thought to be "key" species, in that their abundance can be measured with some statistical confidence, and they respond predictably to management (Turner 1988, Hardy and Hurt 1989, Milchunas and Lauenroth 1993, Whitford *et al.* 1998, Lamb *et al.* 2009). The hypothesis that species respond predictably to management can be tested on the Kokstad trials by examining the effect of stocking rate, cattle to sheep ratio, and location on the relative abundances of key species over time.

The primary attribute of range condition of value to graziers is the productivity and nutritional value of the veld to their livestock. Productivity of veld can be affected by management and by edaphic factors (Kirkman 2002b, Pakeman 2004, Palmer and Ainslie 2006, Richardson *et al.* 2007). Increasing stocking rate is likely to reduce primary productivity, but the effect may be mitigated by edaphic factors (e.g more vs. less productive soils). Frequent, season-long resting of grazed paddocks has been proposed as a means to allow grazed plants to regain vigour, and therefore maintain productivity over the long term (O'Reagain and Turner 1992, Kirkman and Morris 1999). The Kokstad trials provided an opportunity to examine the effect of stocking rate on productivity, and to examine trends in productivity over time. If frequent, season-long rests of paddocks are sufficient to restore productivity, then there should be no measurable decline in productivity over time.

Sheep and cattle exhibit different grazing behaviour, with sheep being more selective than cattle (Malherbe 1971, Hardy 1994, Hardy *et al.* 1994, Peddie 1994). The selective behaviour of sheep has been reported to be detrimental to veld condition (Hardy *et al.* 1994), as they reduce the competiveness of palatable relative to unpalatable species (Morris and Tainton 1993). The different grazing behaviour of sheep and cattle should influence the response of species composition and productivity over time.

Primary productivity between seasons is directly influenced by seasonal rainfall (Bransby 1984, Snyman and Fouch, 1991, O'Connor 1993, Snyman and Fouch, 1993). The variation in seasonal rainfall is likely to temporarily affect primary productivity on the Kokstad trials but not trigger a more permanent effect as proposed for arid environments (Behnke et al. 1993, Vetter 2005).

Study site

The grazing trials are situated at Kokstad Research Station, located in the Highland Sourveld (Acocks 1988) or Gs 12 – East Griqualand Grassland and Gs 10 – Drakensberg Foothill Moist Grassland (Mucina and Rutherford 2006) (30° 31’ S, 29° 25’ E). The term “Highland Sourveld” is used throughout this thesis as descriptive of the broader area in which the trials fall. The station is located just outside of the town of Kokstad, in the region known as East Griqualand, on the southern KwaZulu-Natal border with the Eastern Cape. The mean annual rainfall is 782mm, most of which falls in the summer months (October-March). Frosts and occasional snowfalls occur in winter. The veld is a short, sour (i.e. losing nutritional value in winter), tufted grassland dominated by the grasses *Themeda triandra* and *Tristachya leucothrix*. *Diheteropogon filifolius*, *Elionurus muticus* and *Alloteropsis semialata* are also common in poorer condition veld.

The lithology is predominantly sandstone, with dolerite dykes in places. The soils are mesotrophic, and consist of deep Hutton, Clovelly, Westleigh and Pinedene soils on gentle slopes and shallow Hutton, Clovelly, Sepane, Mispah and Glenrosa soils on steep slopes (Soil Classification Working Group 1991).

Experimental design

Three long-term grazing trials were established at the station. For all experiments, stocking density was defined on a metabolic-mass basis, where one animal unit (AU) is defined as the metabolic equivalent of a 450kg steer gaining 0.5kg.d^{-1} and consuming 10kg.d^{-1} of dry matter (Meissner 1982). Animal health was managed according to the recommendations of the Animal Science section at Cedara research station and the State Veterinary Laboratory. All animals were either weaned merino sheep or Hereford or Nguni steers. The mean starting mass of merino sheep was 42.8±0.58 (s.e.) kg (n=500) and of steers (Ngunis and Herefords were not distinguished in the dataset) was 211.2±2.57 kg (n=119). Few Herefords were used over the course of the trial.

Flat 2-paddock

Established in 1992, the aim of this experiment was to determine how plant species composition, soil loss and animal production responded to stocking rate and slope. The experiment has two factors – slope and stocking rate – which are unreplicated. The slopes were ~5% and ~13%, and the seasonal stocking rates were low (1.0 AU.ha^{-1}) and high (2.0 AU.$^{-1}$) (one animal unit is equivalent to 6 sheep). The long-term stocking rates are half the short-term stocking rates. Soil loss, an additional factor the trials were designed to measure, was not considered in this study, and therefore the slopes were ignored to form two replicates of stocking rate. Each treatment consists of two paddocks, labelled A and B, and each of these paddocks is burnt alternately in early spring each year, stocked continuously for the next growing season with wethers (weaned male lambs) until autumn, and then rested the following season. The paddock sizes range from 0.5 – 0.8 ha.

Steep 2-paddock

Established in 1996, the aim of this trial is similar to the flat 2-paddock described above, but with some important design differences. The grazing and burning treatment is identical, except that gimmers (weaned female lambs) are used. The trial is on a steep slope (~20%), includes an additional medium stocking rate (1.5 $AU.ha^{-1}$) and small, ungrazed control plots. Each half (i.e. paddock) of each treatment is independently randomised, so that the paddocks for each paddock are not adjacent to one another as in the flat trial. The grazed paddocks range from 0.5 – 1.0 ha, and the ungrazed plots are small, standard runoff plots located in fenced enclosures.

Simulation trial

The simulation trial (also known as the “cattle-sheep trial”) was established in 1989 on flat ground, near to the site of the flat 2-paddock trial described above. The trial simulates a 4-paddock rotational grazing system with different ratios of cattle to sheep (1:0, 3:1, 1:1, 1:3 and 0:1 AU) at two stocking rates (1.0 $AU.ha^{-1}$ and 0.5 $AU.ha^{-1}$). The cattle:sheep ratios are hereafter described in terms of the proportion of sheep in the mix, ranging from 0 to 1. One of the four paddocks is rested for an entire year, while the animals are rotated around the other three paddocks on a fixed cycle of two weeks per paddock. The rested paddock is rotated each season, with the previously rested paddock being burnt at the beginning of the season to provide nutritious new forage for the livestock, while the rested paddock is also burnt at the beginning of the season to remove moribund material. Two steers are used in each of the 8 treatments requiring cattle, with the number of sheep and size of the paddocks adjusted accordingly. The trial is unreplicated, with paddocks of between 0.8 and 9 ha.

In order to simulate the grazing rotation, animals spent two weeks in the paddock and four weeks out; however, between 1998 and 2004 the animals spent two weeks in the paddock and three weeks out due to a misunderstanding – a substantial increase in grazing pressure. After 2004 the error was corrected. The scheduled rest cycle in the 1996/97 season was skipped, so that the paddock simulation paddocks received no rest for seven consecutive seasons.

The animals used were Hereford (occasionally Nguni) steers and two-tooth merino hamels.

The trial has been reported elsewhere by Hardy (1994), Hardy and Tainton (1995), Peddie *et. al* (1995), and Lütge *et. al* (1996).

The trials are summarised in Table 3.1.

Table 3.1: Summary descriptions of trials and treatments

Trial	Start year	Grazing cycle	Short-term stocking density	Burning cycle	Animals
Flat 2-paddock	1992	Continuous, biennial	1.0 $AU.ha^{-1}$ 2.0 $AU.ha^{-1}$	Biennial	Weaned merino wethers
Steep 2-paddock	1996	Continuous, biennial	0 $AU.ha^{-1}$ 1.0 $AU.ha^{-1}$ 1.5 $AU.ha^{-1}$ 2.0 $AU.ha^{-1}$	Biennial	Weaned merino hamels
Simulation	1989	Rotational grazing (2 weeks in, 4 weeks out). Rotational rest (once in 4 years)	0.5 $AU.ha^{-1}$ 1.0 $AU.ha^{-1}$ Each at five ratios of cattle to sheep	Twice in four years: beginning of rest year and beginning of following year	Two-tooth merino hamels and Hereford or Nguni steers

Materials and methods

Species composition

Relative abundance

Species composition was surveyed biennially in December, using a nearest plant-point technique with 200 points per plot. In the simulation trial, plots of 30 x 30m were permanently marked, ranging from one to four per paddock depending on the paddock size. In the 2-paddock trials, the entire paddock was treated as a plot. The simulation and 2-paddock trials were surveyed in alternate years, with varying operators. One operator (G. Peddie) was present in almost every season and the author was present from 2002 onwards.

At each point, the nearest grass was identified to species. If the nearest plant was not a grass, it was separately recorded as either a "forb" or "sedge" as appropriate. The exception to this rule was the poisonous forb *Senecio* [usually *Senecio retrorsus* but several other, similar, *Senecio* species occur in the trials (Martindale 2007)], which was recorded separately in most seasons.

Dry-weight-rank

In the 2004/05 season, dry-weight-rank assessments of standing crop and species composition (t'Mannetje and Haydock 1963, Jones and Hargreaves 1979, Barnes *et al.* 1982, Sandland *et al.* 1982, Reich *et al.* 1993) were conducted on the 2-paddock trials at the beginning, middle and end of the season. After a pilot survey, a quadrat size of 20x20cm was chosen, with 60 quadrats per paddock. On the steep trial, two plots of 30 quadrats each were laid inside and outside prominent drainage lines (particularly the Sepane soil form in Figure 1.4); while on the flat 2-paddock trial sampling was not stratified.

Basal cover

Basal cover was measured as part of the species composition assessment by recording the distance from each point to the nearest grass tuft and the diameter of the tuft in cm. The empirically derived formula of Hardy and Tainton (1993) was used to calculate percentage basal cover.

Sward productivity

Standing crop

In one of the paddocks of each treatment of the two-paddock trials, several 1m^2 circular exclosure cages were permanently placed. The cages were regularly spaced throughout the paddock, with 36 and 42 cages in the flat and steep trials respectively. The cages were randomly separated into three groups at the start of the trials, and the same groups were used thereafter. At the beginning, middle and end of each grazing season, the sward inside and adjacent to the cages of the relevant group was cut, by hand, in 50x50 cm quadrats to approximately 2cm above ground. The harvested material was oven-dried for 72 hours at 70°C, and weighed.

In four seasons in the simulation trial, 30 discmeter-sized quadrats were cut, dried and weighed in the same manner in each paddock, with the difference that grass and forbs were separated before drying and weighing. The seasons were 1998/99, 1999/2000, 2000/01, and 2004/05. The latter two seasons were rested seasons.

Fifty discmeter readings were taken in each paddock on the simulation trial whenever animals entered and exited the paddock. On the two-paddock trials, discmeter readings were taken irregularly in the grazed paddocks.

Statistical analysis

Unless otherwise stated, all statistical analyses were performed using Genstat 9.1 (Lawes Agricultural Trust 2006).

Species composition

Seven key grass species were identified for detailed examination: *Alloteropsis semialata*, *Diheteropogon filifolius*, *Heteropogon contortus*, *Microchloa caffra*, *Themeda triandra* and *Tristachya leucothrix*. On the simulation and flat two-paddock trials, *D. filifolius* was rare and was replaced by *Elionurus muticus*, a relatively common grass which is categorised similarly to *D. filifolius* by local veld management guidelines (Camp and Hardy 1999). The grasses are detailed in Table 3.2. In the 2-paddock trials, each of the four paddocks for each treatment (2 paddocks for each replicate) was treated as a separate datum.

The seven species were chosen as species that were dominant in the study area, and could therefore be used to study the response of individual species to management and environmental variables. *Themeda triandra*, *Tristachya leucothrix* and *Heteropogon contortus* were identified as key species in Highland Sourveld by Hurt and Hardy (1989), as species that show predictable responses to grazing and can be used to describe veld condition. The species also cover the whole spectrum of classical grazing response categories [i.e. Increaser 1, 2 and 3, and Decreaser (Foran *et al.* 1978)].

Table 3.2: Description of key grass species in Highland Sourveld identified in this study

Species name	Grazing value out of maximum of 10 (Camp and Hardy 1999)	Category* (Hardy and Hurt 1989, Camp and Hardy 1999)
Alloteropsis semialata	3	Increaser 1
Diheteropogon filifolius	0	Increaser 3
Elionurus muticus	0	Increaser 3
Heteropogon contortus	6	Increaser 2 (Camp and Hardy 1999)** Decreaser (Hardy and Hurt 1989)
Microchloa caffra	1	Increaser 2
Themeda triandra	10	Decreaser
Tristachya leucothrix	9	Increaser 1

* Increaser 1 increases with removal of grazing pressure; Increaser 2 increases with increasing grazing pressure; Increaser 3 increases with selective grazing; Decreaser declines under any of the previous management regimes but remains stable or increases under correct grazing pressure (Dyksterhuis 1949, Foran *et al.* 1978).

**The Increaser 2 category was used for this species in this study

The trends in relative abundance of each species over time was analysed by multiple linear regression, separately for each treatment, to determine if there was a change in abundance over time in that species. The variables used for the multiple regression on the two-camp trials were year (with year 0 being the first survey), stocking rate in AU.ha^{-1}, and the interaction of year and stocking rate, to test whether species responded differently to different stocking rates over time. On the simulation trial, the variables were year, treatment (i.e. the combination of stocking rate and proportion sheep), and the interaction of year and treatment.

The standing crop of each of the dominant species identified in the dry-weight-rank survey at the end of the 2004/05 season was analysed by two-way ANOVA, with grazing (grazed vs. rested paddocks), stocking rate, and their interaction as factors for each species on each trial separately. Species were grouped into three classes of palatability: palatable, intermediate and unpalatable, based on the work of Kirkman (1999) and the author's own experience. The total of each category of palatability was also analysed in the same way as each species, as was the total standing crop. The species *Eragrostis curvula, E. plana, Sporobolus africanus and S. pyramidalis* are commonly grouped as "Mtshiki" grasses due to their common response to management and similar palatability to livestock (Morris *et al.* 1992, Morris and Tainton 1996), and were grouped as such in this analysis. They are grasses which thrive under heavy grazing, nutrient-rich locations such as around watertroughs and licks, kraals, and heavily grazed communal areas in moist grasslands.

A separate regression was conducted on the simulation trial with the proportion of dry matter made up by forbs in each of the four seasons where standing crop was harvested. The proportion sheep was used as the explanatory variable with season and stocking rate as factors.

Multivariate analysis

The shift over time in the overall species composition of each paddock was measured by estimating the Euclidean distance of each paddock in 2005 (for the two-paddock trials) and 2004 (for the simulation trial) from the original composition of that paddock.

The effect of stocking rate and environmental variables on the amount of compositional change (Euclidean distance) was examined by regression analysis, combining the two two-paddock trials in order to provide a longer gradient of environmental effects. The influence of each parameter on the overall model was investigated using the Akaike Information Criterion to select important variables from the total set of measured parameters. The parameters included in the initial model were: stocking rate (included in all combinations of variables), slope, clay % (estimated in the field survey); altitude; effective rooting depth; and the proportions of each paddock consisting of each crop ecotope identified by the soil survey

(Table 1.1) Four crop ecotopes were identified: B (well drained soil profiles; Hutton and Clovelly soil forms); E (mottled and poorly drained soil profiles; Westleigh); H (young soil profiles; Mispah and Glenrosa) and J (duplex soil profiles; Sepane). Stocking rate, as the treatment applied to both trials, was forced into all analyses, while the remaining variables were chosen by their fit to the model.

One of the major objectives of long-term rangeland trials is to determine whether the treatments applied have any effect on species composition over time. However, species composition fluctuates naturally in response to a variety of factors, including sampling error and weather. Therefore a multivariate approach to define whether each treatment could be confidently described as having remained stable (i.e. fluctuated within certain defined bounds) or changed (i.e. crossed those bounds) was sought. This approach was inspired by the state-and-transition model of Westoby *et al.* (1989) and the "thresholds of potential concern" approach of South African National Parks (van Wilgen *et al.* 1998). However, in order to determine whether a treatment had remained stable within certain bounds or had crossed a bound, the bounds needed to be set.

An approach developed by Anderson and Thompson (2004), using the ControlChart software package (Anderson 2008) was used to determine the stability of each treatment on each trial. The procedure determines the multivariate distance of each site's composition at each survey to the centroid of a range of sites. In this case, a baseline data set consisting of the first two surveys for each site was considered as adequate for describing the baseline composition, and hence the bounds of "stable" composition. The Euclidean distance of each survey was calculated relative to the centroid of the baseline surveys. A bootstrapping technique was used to generate confidence limits for the calculated deviations, with 1000 repetitions. The software uses the bootstrapped distribution to generate 50th, 75th, 90th and 95th percentile confidence limits for the deviations. The deviations over time can then be graphed and any site crossing (and remaining across) the chosen confidence limit was described as having changed from the original (baseline) composition. The data for each paddock was used as the input for the programme, and the outputs were then grouped into treatments and expressed as the mean values for each treatment.

Productivity and vigour

Vigour was expressed by calculating the percentage of unprotected veld to veld protected by the exclosure cages on the two-paddock trials. The harvest from the end of each rested season was used for the calculation, in order to determine the recovery of the veld after a full season's rest. Multiple linear regression, with stocking rate and season as factors, was performed on each trial separately.

The standing crop on the simulation trial was analysed with a separate multiple linear regression for each season, with stocking rate and proportion sheep as factors.

The discmeter readings from midseason (January or February) of the two-paddock trials were analysed for each trial by multiple linear regression, with season and stocking rate as factors. For the simulation trial, midseason discmeter readings after a rest period in the grazing rotation were selected for analysis. All seasons were combined and stocking rate and proportion sheep were included as factors in a multiple linear regression. Stocking rate and cumulative seasonal rainfall to the date of the harvest was also examined by linear regression.

Basal cover

The influence of treatment over time on trends in basal cover were analysed for each trial separately, using multiple regression with season and treatment as explanatory variables.

Results

Changes in key species over time

Treatment significantly influenced the relative abundance of some grass species over time, while other grass species showed little predictable response to stocking rate over time. *Alloteropsis semialata* increased in the medium and high stocking rate treatments on the steep trial (Figure 3.1, Table 3.3), but showed no response to grazing on the flat trial (Figure 3.2, Table 3.4). On the simulation trial, *A. semialata* increased in both the sheep-only treatments (Figure 3.3, Figure 3.4, Table 3.5), and declined in the cattle-only treatment at the high stocking rate (Figure 3.3, Table 3.5).

Elionurus muticus showed no significant response to grazing on most of the simulation trial treatments (Table 3.5), or on the flat trial (Table 3.4). *Diheteropogon filifolius*, the wiregrass which replaced *Elionurus* in the analysis of the steep trial, increased substantially on the low and medium stocking rates, but not the ungrazed or high stocking rate treatments (Figure 3.1Figure 3.1: Trends in relative abundance of six key grass species on the steep two-paddock trial at Kokstad. Values are mean ± s.e. for four paddocks (grazed treatments) and two paddocks (ungrazed treatments). Species as in Table 3.2. Regression results are presented in Table 3.3., Table 3.3).

Heteropogon contortus increased on most of the high stocking rate treatments but not the low stocking rate treatments on the simulation trial (Table 3.5, but showed no significant response to grazing on the two-camp trials.

Microchloa caffra increased dramatically on both of the sheep-only treatments on the simulation trial, as well as in most of the high stocking rate treatments, but also showed no significant response to grazing on the two-camp trials (Table 3.3, Table 3.4).

Tristachya leucothrix declined on almost all the grazed treatments, with a much greater decline in the sheep-only treatments than in others of the simulation trial (Figure 3.3, Figure 3.4, Table 3.5). Treatments where *Tristachya* did not change significantly over time were several of the low stocking rate treatments (with a low proportion of sheep) and the cattle-only treatment on the simulation trial (Table 3.5). On the ungrazed treatments of the steep trial, *Tristachya* showed no trend over time, but decreased on all the grazed treatments of both two-paddock trials (Table 3.3, Table 3.4).

Themeda triandra, generally considered the key indicator species of Highland Sourveld, showed little consistent response to grazing, increasing significantly in some treatments while declining or showing no response in others. For example, sheep only at the high stocking rate caused *Themeda* to decline substantially (Figure 3.3, Table 3.5), while the reverse occurred with sheep only at the low stocking rate on the simulation trial (Figure 3.4, Table 3.5). However, on the adjacent, flat, two-camp trial (grazed only with sheep), *Themeda* showed no significant response to grazing (Table 3.4) and in some individual camps actually increased at the high stocking rate (individual camp results not shown).

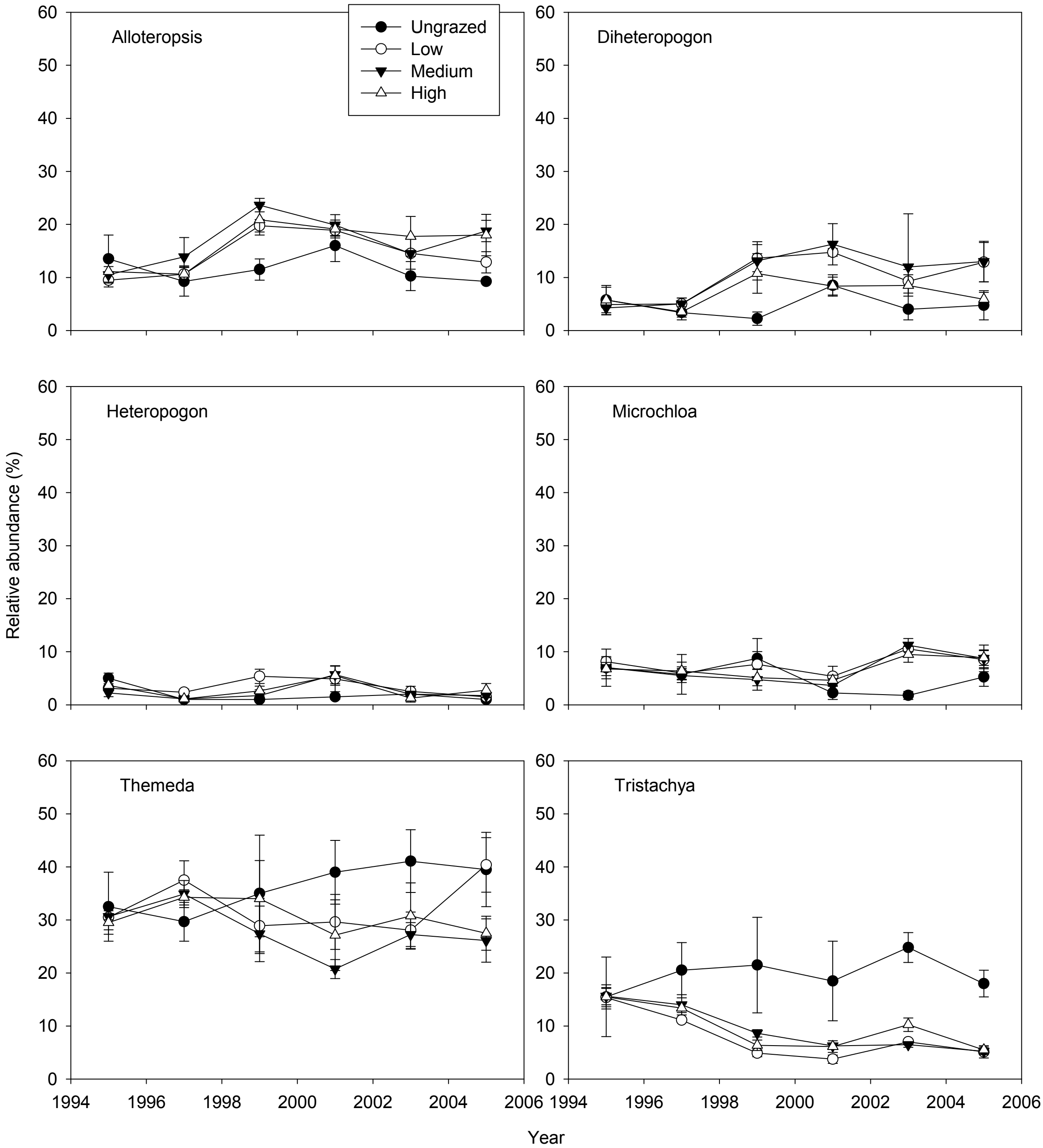


Figure 3.1: Trends in relative abundance of six key grass species on the steep two-paddock trial at Kokstad. Values are mean ± s.e. for four paddocks (grazed treatments) and two paddocks (ungrazed treatments). Species as in Table 3.2. Regression results are presented in Table 3.3.

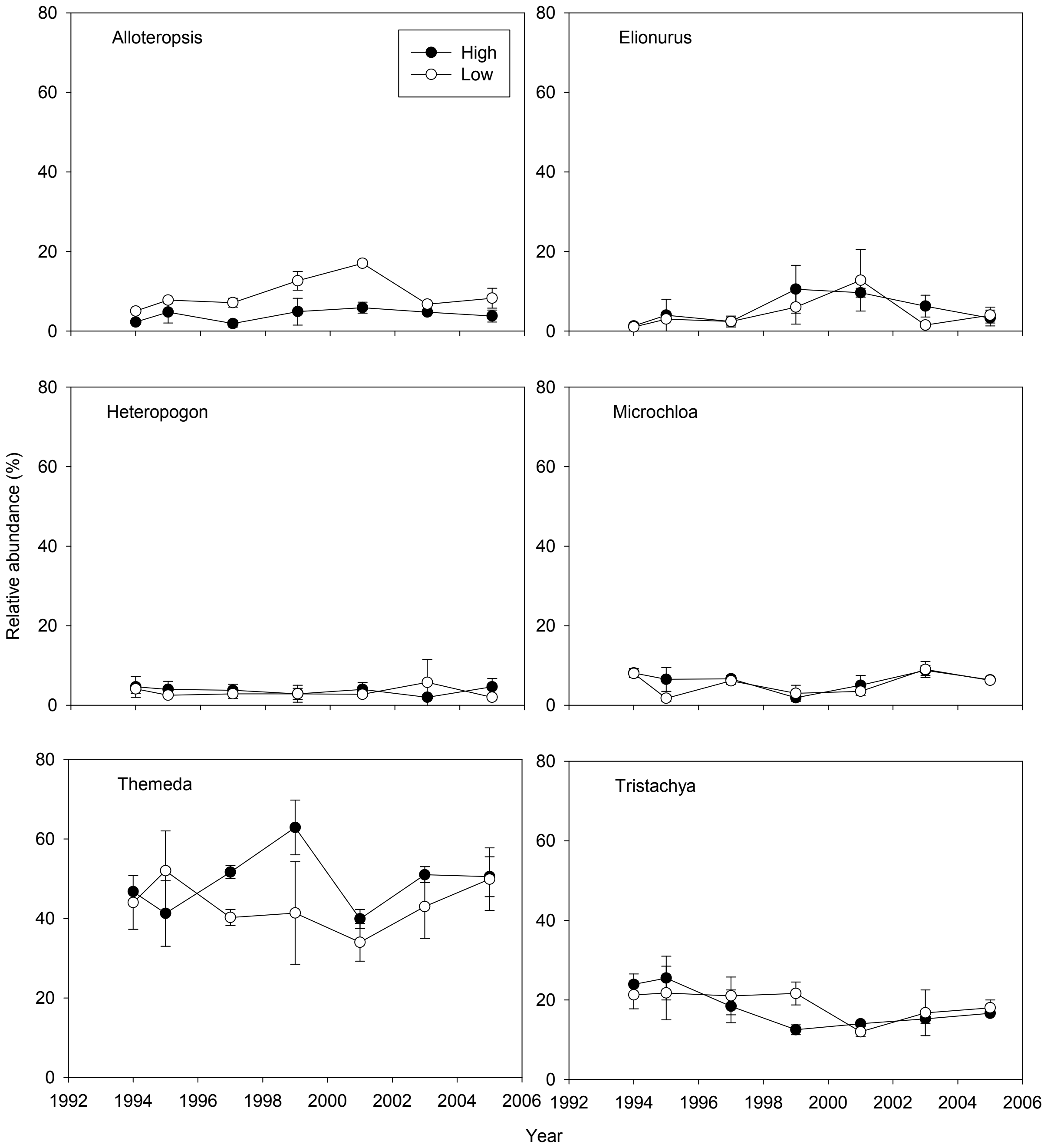


Figure 3.2: Trends in relative abundance of six key grass species on the flat two-paddock trial at Kokstad. Values are means ± s.e. for four paddocks. Species as in Table 3.2. Regression results are presented in Table 3.4.

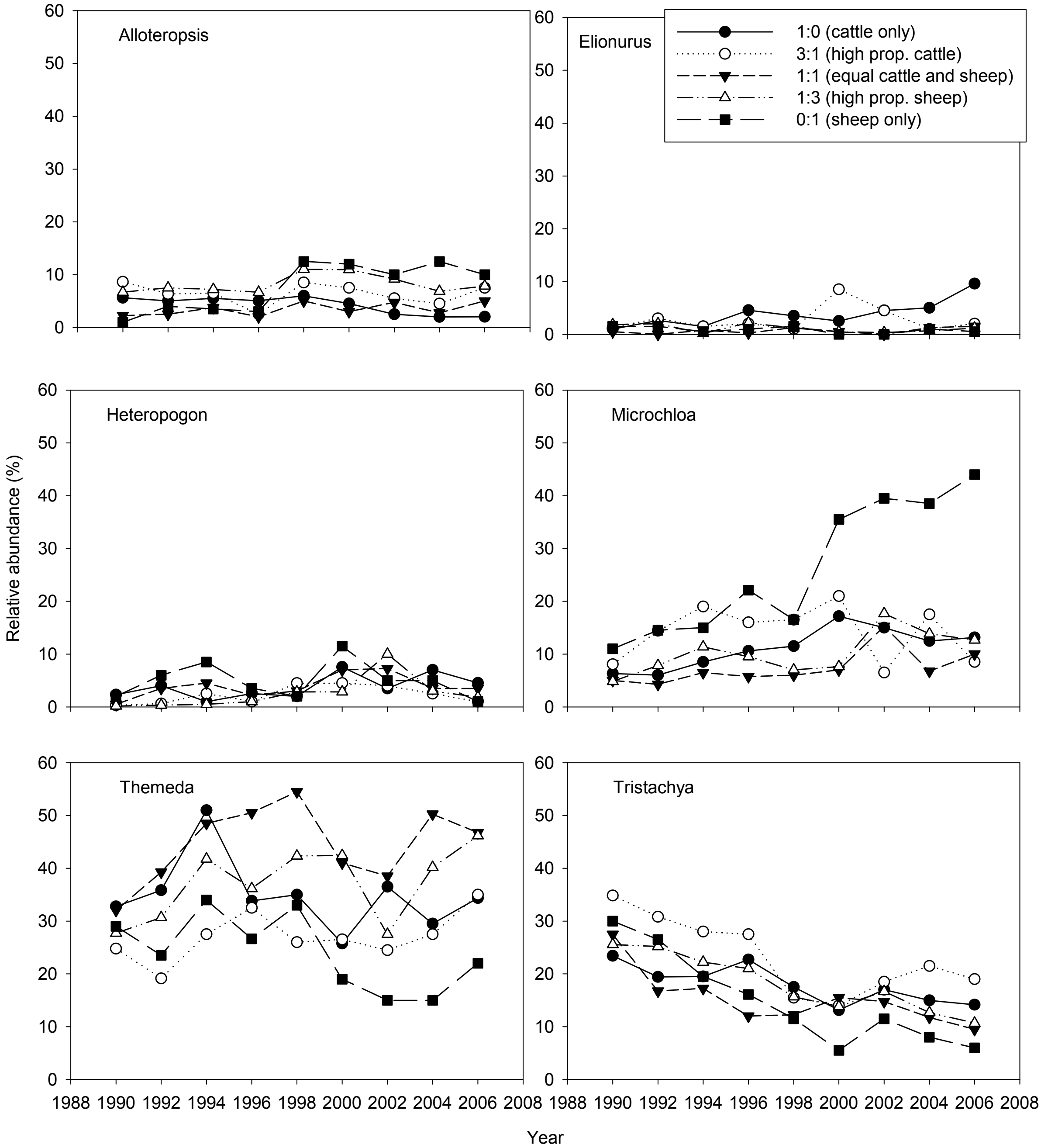


Figure 3.3: Trends in relative abundance of six key grass species in the high stocking rate treatments of the simulation trial at Kokstad. Treatments are unreplicated. Species as in Table 3.2. Regression results are presented in Table 3.4.

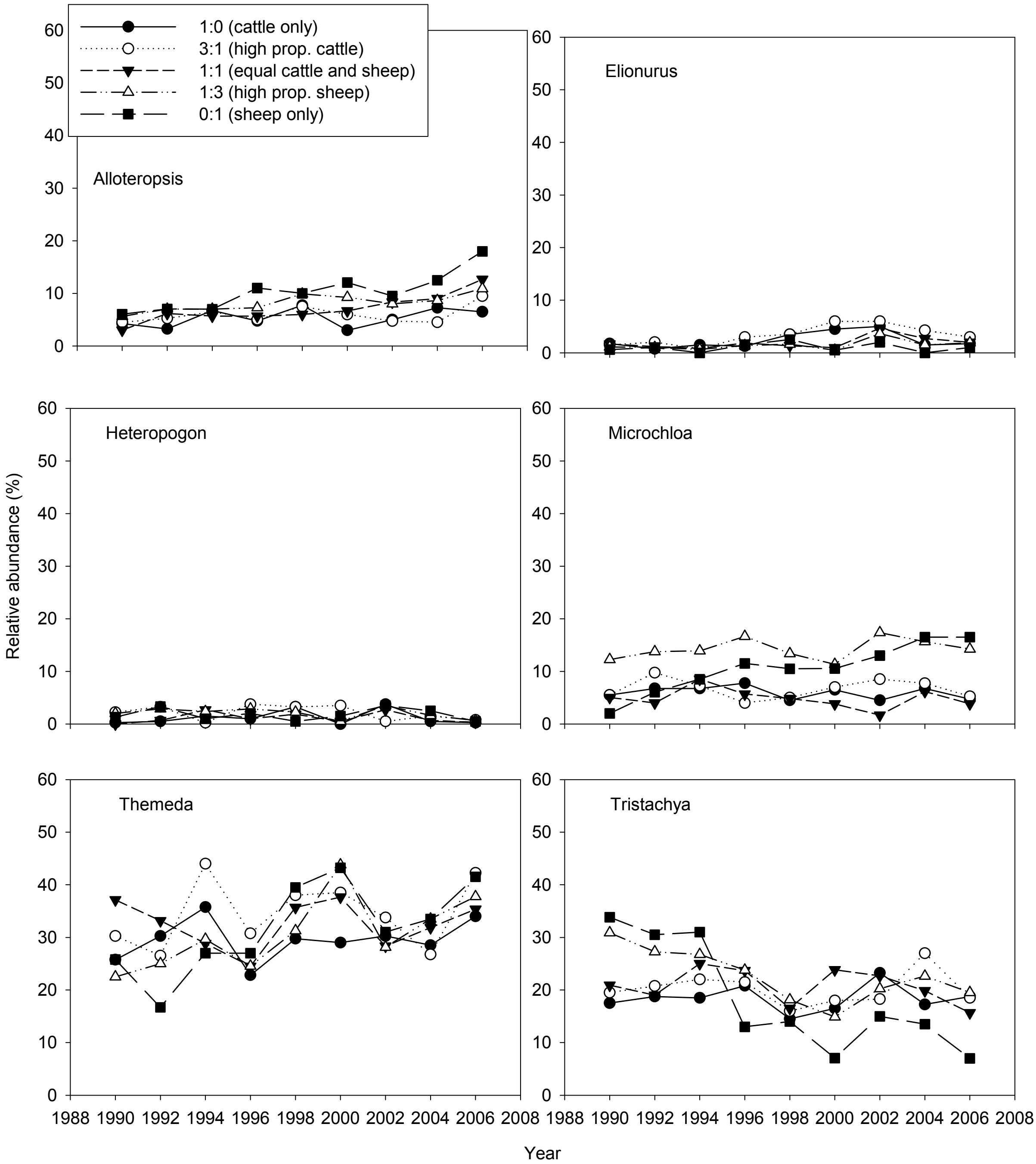


Figure 3.4: Trends in relative abundance of six key grass species in the low stocking rate treatments of the simulation trial at Kokstad. Treatments are unreplicated. Species as in Table 3.2. Regression results are presented in Table 3.4.

Table 3.3: Effect of stocking rate over time on the relative abundance of key species on a steep trial grazed by sheep at Kokstad Research Station. Species are as in Table 3.2. Significant P-values are highlighted in bold. "Year" indicates the combined datasets for all treatments over time

Species	Parameter	Slope	s.e	P-value	Difference with high stocking rate (P-value)
Alloteropsis semialata	Year	0.488	0.179	**0.008**	
	Ungrazed	-0.196	0.436	0.655	0.072
	Low Stocking rate (SR)	0.421	0.320	0.192	0.416
	Medium SR	0.664	0.320	**0.042**	0.778
	High SR	0.792	0.320	**0.016**	
Diheteropogon filifolius	Year	0.565	0.188	**0.004**	
	Ungrazed	0.045	0.445	0.920	0.823
	Low SR	0.849	0.327	**0.011**	0.146
	Medium SR	1.008	0.327	**0.003**	0.074
	High SR	0.169	0.327	0.606	
Heteropogon contortus	Year	-0.031	0.081	0.701	
	Ungrazed	-0.255	0.206	0.220	0.276
	Low SR	-0.031	0.166	0.853	0.812
	Medium SR	0.057	0.146	0.699	0.867
	High SR	0.022	0.146	0.880	
Microchloa caffra	Year	0.115	0.116	0.321	
	Ungrazed	-0.389	0.294	0.190	0.092
	Low SR	0.132	0.216	0.543	0.739
	Medium SR	0.271	0.216	0.214	0.904
	High SR	0.234	0.216	0.282	
Tristachya leucothrix	Year	- 0.770	0.194	**<.001**	
	Ungrazed	0.319	0.343	0.356	**0.004**
	Low SR	-0.972	0.251	**<.001**	0.915
	Medium SR	-1.107	0.251	**<.001**	0.629
	High SR	-0.934	0.251	**<.001**	
Themeda triandra	Year	-0.040	0.289	0.891	
	Ungrazed	1.046	0.701	0.140	0.095
	Low SR	0.446	0.514	0.388	0.234
	Medium SR	-0.784	0.514	0.132	0.624
	High SR	-0.426	0.514	0.410	

Table 3.4: Effect of stocking rate over time on the relative abundance of key species on a flat trial grazed by sheep at Kokstad Research Station. Species are as in Table 3.2. Significant P-values are highlighted in bold. "Year" indicates the combined datasets for all treatments over time

Species	Parameter	Slope	s.e	P-value	Difference with high stocking rate (P-value)
Alloteropsis semialata	Year	0.100	0.107	0.354	
	Low stocking rate (SR)	0.379	0.196	0.059	0.316
	High SR	0.148	0.192	0.445	
Elionurus muticus	Year	0.097	0.156	0.534	
	Low SR	0.288	0.371	0.442	0.411
	High SR	0.188	0.361	0.607	
Heteropogon contortus	Year	0.059	0.086	0.499	
	Low SR	0.021	0.187	0.911	0.663
	High SR	-0.055	0.171	0.751	
Microchloa caffra	Year	-0.015	0.124	0.903	
	Low SR	0.048	0.164	0.772	0.766
	High SR	-0.086	0.160	0.596	
Tristachya leucothrix	Year	-0.747	0.206	**<.001**	
	Low SR	-0.615	0.297	**0.044**	0.529
	High SR	-0.879	0.291	**0.004**	
Themeda triandra	Year	0.195	0.389	0.619	
	Low SR	0.076	0.541	0.889	0.727
	High SR	0.342	0.529	0.520	

Table 3.5: Effect of stocking rate and proportion sheep in veld grazed by mixed cattle and sheep on the relative abundance over time of key grass species. Species are as in Table 3.2. P-values ≤ 0.05 are highlighted in bold

Species	Stocking rate	Proportion sheep	Slope	s.e	P-value	Difference with high stocking rate, no sheep (P-value)
Alloteropsis semialata	High	0.0	-0.228	0.123	**0.069**	
		0.25	-0.145	0.123	0.243	0.637
		0.5	0.091	0.123	0.464	0.072
		0.75	0.153	0.123	0.219	**0.033**
		1.0	0.842	0.123	**<.001**	**<.001**
	Low	0.0	0.124	0.123	0.320	**0.048**
		0.25	0.051	0.123	0.683	0.115
		0.5	0.332	0.123	**0.009**	**0.002**
		0.75	0.211	0.123	0.093	**0.015**
		1.0	0.429	0.123	**<.001**	**<.001**
Elionurus muticus	High	0.0	-0.020	0.105	0.852	
		0.25	0.018	0.105	0.866	0.802
		0.5	-0.001	0.109	0.993	0.902
		0.75	0.070	0.105	0.509	0.549
		1.0	-0.030	0.109	0.784	0.946
	Low	0.0	0.170	0.105	0.111	0.207
		0.25	0.300	0.105	**0.006**	**0.036**
		0.5	0.183	0.105	0.088	0.179
		0.75	0.093	0.105	0.378	0.450
		1.0	0.093	0.163	0.571	0.564
Heteropogon contortus	High	0.0	0.294	0.140	**0.040**	
		0.25	0.249	0.140	0.080	0.823
		0.5	0.287	0.140	**0.045**	0.971
		0.75	0.459	0.140	**0.002**	0.409
		1.0	0.131	0.140	0.354	0.414
	Low	0.0	0.250	0.154	0.109	0.835
		0.25	0.111	0.140	0.433	0.359
		0.5	-0.011	0.172	0.950	0.174
		0.75	-0.035	0.140	0.802	0.102
		1.0	0.056	0.140	0.691	0.234
Microchloa caffra	High	0.0	0.683	0.285	**0.020**	
		0.25	0.195	0.285	0.497	0.230
		0.5	0.410	0.285	0.155	0.501
		0.75	0.584	0.285	**0.045**	0.806
		1.0	2.222	0.285	**<.001**	**<.001**
	Low	0.0	-0.041	0.285	0.885	0.077
		0.25	0.541	0.285	0.062	0.725
		0.5	-0.113	0.285	0.692	**0.053**
		0.75	0.184	0.285	0.521	0.220
		1.0	0.842	0.285	**0.004**	0.695

Table 3.5 cont.

Species	Stocking rate	Proportion sheep	Slope	s.e	P-value	Difference with high stocking rate (P-value)
Tristachya leucothrix	High	0.0	-0.560	0.306	0.073	
		0.25	-1.255	0.306	**<.001**	0.114
		0.5	-0.743	0.306	**0.018**	0.674
		0.75	-0.965	0.306	**0.003**	0.353
		1.0	-1.641	0.306	**<.001**	**0.015**
	Low	0.0	0.050	0.306	0.870	0.164
		0.25	-0.060	0.306	0.845	0.253
		0.5	-0.007	0.306	0.982	0.207
		0.75	-0.803	0.306	**0.011**	0.576
		1.0	-1.730	0.306	**<.001**	**0.009**
Themeda triandra	High	0.0	-0.568	0.481	0.242	
		0.25	0.211	0.481	0.662	0.256
		0.5	0.621	0.481	0.202	0.085
		0.75	0.471	0.481	0.331	0.132
		1.0	-1.067	0.481	**0.030**	0.465
	Low	0.0	0.033	0.481	0.946	0.380
		0.25	-0.316	0.481	0.513	0.713
		0.5	-0.154	0.481	0.750	0.545
		0.75	0.840	0.481	0.085	**0.043**
		1.0	1.107	0.481	**0.025**	**0.017**

The detailed beginning initial and final species composition for each treatment is shown in Table 3.6, Table 3.7 and Table 3.8.

Basal cover

Basal cover increased slightly over time on all two-camp treatments ($p<0.001$ on steep and $p=0.003$ on flat), with no difference between treatments on either of the trials ($p>0.2$), from c. 16% at the start of the trials to c. 18% in 2005. The relationship for the flat trial was:

Basal cover (%) = 0.19(years grazed) + 16.6;*

and for the steep trial:

Basal cover (%) = 0.20(years grazed) + 16.4.*

On the simulation trial, there were no basal cover data for the first eight years of the trial. There was a significant difference between stocking rates ($p<0.001$), with the low stocking rate treatments having lower basal cover than the high stocking rate treatments, but no influence of time ($p=0.228$). Low stocking rates remained constant at c. 18% basal cover, while high stocking rates declined slightly from c. 21% to c. 20%.

Multivariate analysis

The ControlChart outputs showed that the majority of treatments were stable – that is, they did not cross the 90th percentile of the variation in Euclidean distance for all surveys (Figure 3.5). The two paddock trials remained relatively stable, with some treatments crossing the 90th percentile boundary but returning to within the normal range of variation. The medium stocking rate, however, remained very close to the 90th percentile line.

The simulation trial, on the other hand, showed two treatments – the two sheep-only treatments – change dramatically and consistently over time, while at the high stocking rate two other treatments showed less dramatic but steady change (the 1:3 and 3:1 cattle to sheep ratio treatments).

Euclidean distance was negatively correlated with rooting depth on the two-paddock trials, but stocking rate had very little influence on Euclidean distance, even when forced into the regression analysis (Figure 3.6). The regression model constant + soil depth + stocking rate resulted in a significant fit for soil depth (t=-2.77, 19 df, p=0.012), but no effect of stocking rate when comparing the three grazed treatments with the ungrazed treatment ($p \geq 0.297$). Soil depth alone correlated significantly with Euclidean distance (t=-2.79, 22 df, p=0.011), with the relationship

$$ED = -0.013\, d + 24.97$$

where *ED* is Euclidean Distance and *d* is soil depth in mm.

Other variables had very little influence on Euclidean distance, and the significance of their effect declined as more variables were included in the models. Two other variables with strong effects on Euclidean distance were altitude and slope, both of which were correlated with one another and with soil depth. The altitudinal range was relatively small (150m).

On the simulation trial, proportion sheep and stocking rate influenced Euclidean distance (Figure 3.7). Euclidean distance increased as the proportion of sheep on the treatment increased (t=5.28, 7 df, p=0.001), and as the stocking rate increased (t=4.02, df=7, p=0.005).

The non-metric multidimensional scaling results showed a wide variation in trends of species composition over time, depending on trial location and treatment. The initial composition of the two two-paddock trials differed substantially at the start of the trials, and the steep trial showed far greater variation in composition and a much greater shift in composition over time than the flat trial (Figure 3.8). The NMMDS showed a classical successional gradient along the first axis of the ordination, with *Themeda triandra* and *Tristachya leucothrix* on one extreme and a number of increaser species on the opposite end of the axis. Exceptions to the rule were species that were unique to specific locations, such as *Elionurus muticus* which occurred predominantly on the flat site, and *Panicum aequinerve*, *P. ecklonii*, and *Poa binata* on the steep trial.

On the simulation trial (Figure 3.9) the most obvious result was the distinctive change in composition of the heavily stocked, sheep-only treatment, which was characterised by *Microchloa caffra* (Table 3.8). Other treatments remained relatively stable, and the low stocking rate treatments showed less variation in their final composition than the high stocking rate treatments.

Comparing the simulation trial to the adjacent flat two-paddock trial (Figure 3.10) confirmed that the simulation trial had shifted more in composition and showed greater variation after 16 years than the flat two-paddock trial after 12 years, although once again the variation was dominated by the sheep-only, high stocking rate treatment.

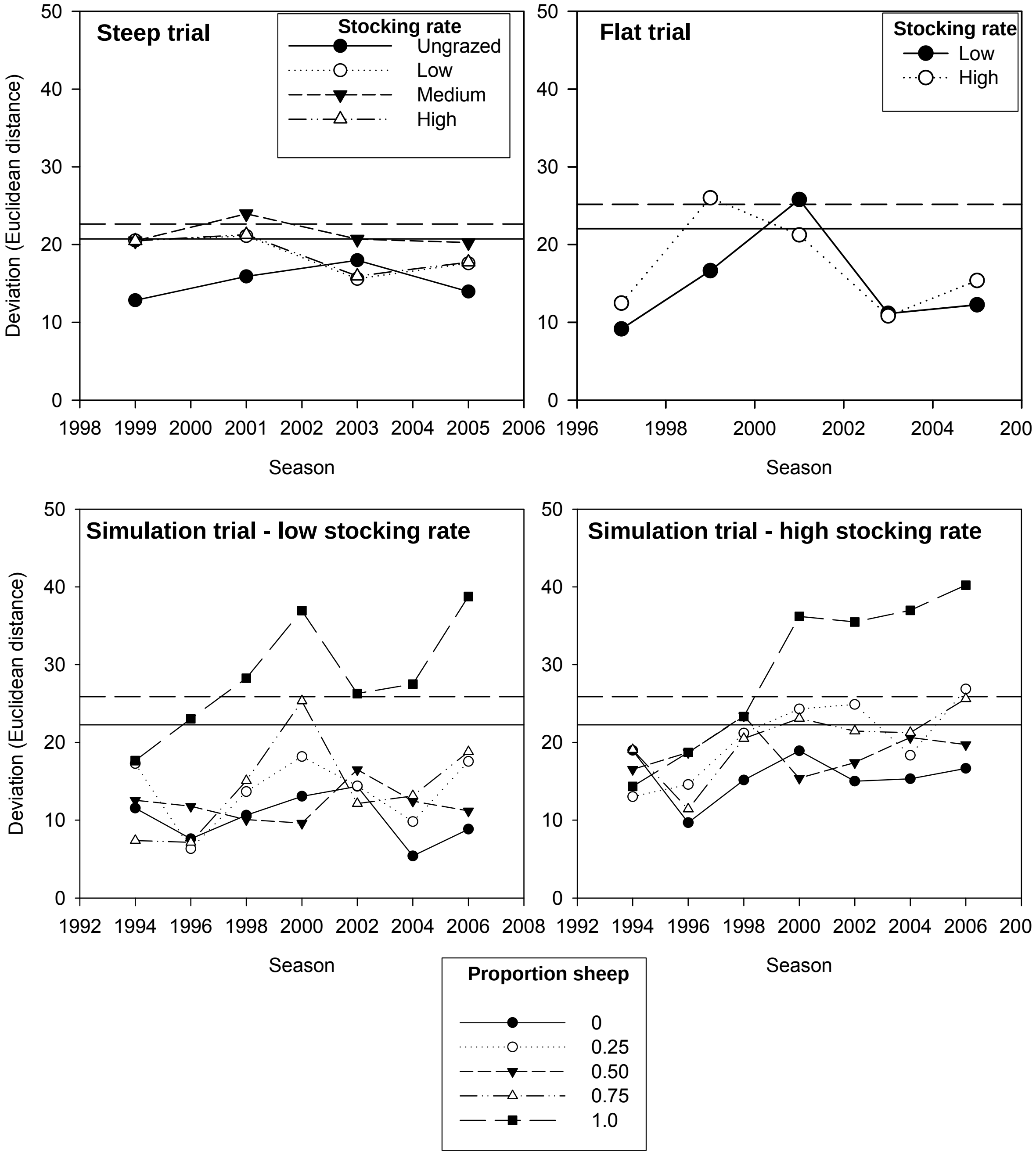


Figure 3.5: Deviations of Euclidean distance from baseline composition of three trials, with the 90th (solid horizontal line) and 95th (dashed horizontal line) percentiles of variation in Euclidean distances calculated from bootstrapped samples of all surveys. The proportion sheep in the simulation trial reflects the proportion of the metabolic mass of cattle and sheep herds that is made up of sheep.

Table 3.6: Initial and final species composition (mean relative abundance ± s.e.) of grass species in each treatment of the flat two-paddock trial, with grazing values (out of a maximum of 10) and categories from Camp and Hardy (1999). Occurrences of species at abundances ≥ 5% are highlighted in bold.

				Low stocking rate		High stocking rate	
Category	Species and abbreviation		Grazing value	1994/95	2005/06	1994/95	2005/06
Increaser 1	*Alloteropsis semialata*	ASE	3	**5.0 ± 0.5**	**8.3 ± 2.0**	2.3 ± 0.4	3.8 ± 1.3
	Digitaria diagonalis	DDI	2	0.1 ± 0.1		0.1 ± 0.1	
	Digitaria setifolia	DSE	2	0.8 ± 0.8		0.1 ± 0.1	
	Digitaria sp	DSP	2		0.3 ± 0.3		
	Digitaria tricholaenoides	DTR	6	0.3 ± 0.3			
	Eulalia villosa	EVI	3	3.5 ± 0.7	0.5 ± 0.2	0.5 ± 0.4	0.1 ± 0.1
	Helictotrichon turgidulum	HTU	1		0.1 ± 0.1		0.4 ± 0.2
	Koeleria capensis	KCA	1	3.4 ± 0.7	3.9 ± 1.2	3.3 ± 0.8	3.4 ± 0.2
	Setaria nigrirostris	SNI	5	1.3 ± 0.4	1.1 ± 0.5	3.1 ± 1.0	4.6 ± 1.8
	Trachypogon spicatus	TSP	3	2.6 ± 1.1	3.3 ± 1.1	1.1 ± 0.7	2.8 ± 0.4
	Tristachya leucothrix	TLE	9	**21.3 ± 2.4**	**18.0 ± 1.7**	**23.9 ± 2.5**	**16.6 ± 2.4**
Increaser 1 Total				***38.1 ± 4.6***	***35.4 ± 2.7***	***34.4 ± 3.0***	***31.6 ± 4.5***
Decreaser	*Andropogon appendiculatus*	AAP	5				0.1 ± 0.1
	Brachiaria serrata	BSE	4	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
	Diheteropogon amplectens	DAM	8	0.5 ± 0.2		0.4 ± 0.2	
	Monocymbium ceresiiforme	MCE	6		0.4 ± 0.2		
	Panicum ecklonii	PEC	1	0.3 ± 0.1			
	Themeda triandra	TTR	10	**44.0 ± 3.9**	**49.9 ± 5.1**	**46.8 ± 4.4**	**50.5 ± 3.5**
Decreaser Total				***44.9 ± 4.0***	***50.4 ± 5.4***	***47.3 ± 4.4***	***50.8 ± 3.7***
Increaser 2	*Eragrostis capensis*	ECA	2	0.6 ± 0.2	0.1 ± 0.1	1.1 ± 0.6	0.8 ± 0.6
	Eragrostis curvula	ECU	5	1.1 ± 0.7	0.3 ± 0.1	1.0 ± 0.3	0.9 ± 0.3
	Eragrostis plana	EPL	3	0.8 ± 0.6	0.1 ± 0.1	0.5 ± 0.4	0.1 ± 0.1
	Eragrostis racemosa	ERA	2	1.3 ± 0.6	0.9 ± 0.4	1.8 ± 1.0	0.4 ± 0.4
	Harpochloa falx	HFA	3	0.4 ± 0.2	0.6 ± 0.6	0.3 ± 0.1	0.1 ± 0.1
	Heteropogon contortus	HCO	6	4.1 ± 1.1	1.6 ± 0.9	4.6 ± 2.5	4.6 ± 2.7
	Microchloa caffra	MCA	1	**8.0 ± 2.0**	**6.3 ± 0.3**	**8.1 ± 1.0**	**6.4 ± 1.0**
	Sporobolus africanus	SAF	3		0.4 ± 0.4	0.1 ± 0.1	0.9 ± 0.6
	Sporobolus centrifugus	SCE	3	0.1 ± 0.1			
Increaser 2 Total				***16.4 ± 3.3***	***10.3 ± 2.0***	***17.5 ± 3.3***	***14.1 ± 4.1***
Increaser 3	*Diheteropogon filifolius*	DFI	0			0.1 ± 0.1	0.3 ± 0.3
	Elionurus muticus	EMU	0	0.5 ± 0.3	4.0 ± 2.5	0.8 ± 0.4	3.3 ± 1.2
Increaser 3 Total				***0.5 ± 0.3***	***4.0 ± 2.5***	***0.9 ± 0.4***	***3.5 ± 1.0***
Grand Total				**100**	**100**	**100**	**100**

Table 3.7: Initial and final species composition (mean relative abundance ± s.e.) of grass species in each treatment of the steep two-paddock trial, with grazing values (out of a maximum of 10) and categories from Camp and Hardy (1999). Occurrences of species at abundances ≥ 5% are highlighted in bold

Category	Species and abbreviation		Grazing value	Ungrazed 1995/96	Ungrazed 2005/06	Low 1995/96	Low 2005/06	Medium 1995/96	Medium 2005/06	High 1995/96	High 2005/06
Increaser 1	*Alloteropsis semialata*	ASE	3	**13.5 ± 3.1**	**9.3 ± 0.6**	**9.5 ± 1.3**	**12.9 ± 2.0**	**10.5 ± 1.6**	**18.8 ± 2.0**	**11.1 ± 2.0**	**18.0 ± 3.9**
	Eulalia villosa	EVI	3	0.3 ± 0.3	2.0 ± 1.2	0.9 ± 0.4	0.6 ± 0.6	0.6 ± 0.3		1.0 ± 0.5	
	Festuca spp.	FSP	1	0.5 ± 0.3	0.3 ± 0.3	0.1 ± 0.1		0.5 ± 0.5		0.1 ± 0.1	
	Koeleria capensis	KCA	1	2.3 ± 0.9	3.5 ± 1.9	**5.9 ± 1.7**	3.6 ± 0.9	4.6 ± 0.4	3.6 ± 0.7	4.8 ± 0.5	2.8 ± 0.7
	Setaria nigrirostris	SNI	5	1.0 ± 0.7	2.0 ± 0.9	0.4 ± 0.2	2.1 ± 1.0	1.0 ± 0.6	2.6 ± 1.0	0.6 ± 0.6	3.1 ± 0.6
	Trachypogon spicatus	TSP	3	0.5 ± 0.3	**5.3 ± 3.0**	1.4 ± 0.1	1.9 ± 0.7	0.4 ± 0.1	1.5 ± 0.4	1.3 ± 0.9	1.3 ± 0.3
	Tristachya leucothrix	TLE	9	**15.5 ± 5.0**	**18.0 ± 2.1**	**15.4 ± 1.7**	**5.1 ± 1.1**	**15.6 ± 1.6**	**5.3 ± 0.7**	**15.5 ± 2.3**	**5.5 ± 0.7**
	Other			1.3 ± 0.3	1.0 ± 0.4	0.3 ± 0.1	0.9 ± 0.6	0.3 ± 0.1	0.6 ± 0.1	1.1 ± 0.5	0.4 ± 0.2
Increaser 1 Total				***34.8 ± 3.7***	***41.3 ± 3.4***	***33.8 ± 1.7***	***27.1 ± 2.3***	***33.5 ± 2.9***	***32.4 ± 1.3***	***35.5 ± 2.8***	***31.0 ± 3.8***
Decreaser	*Diheteropogon amplectens*	DAM	8	0.8 ± 0.5		1.9 ± 0.8		0.8 ± 0.4		0.9 ± 0.5	
	Panicum ecklonii	PEC	1	1.5 ± 0.6	2.3 ± 1.9	2.4 ± 0.7	1.3 ± 0.6	3.5 ± 1.0	0.8 ± 0.3	2.9 ± 0.9	0.6 ± 0.2
	Themeda triandra	TTR	10	**32.5 ± 4.5**	**39.5 ± 4.8**	**30.5 ± 2.4**	**40.4 ± 5.1**	**30.6 ± 0.6**	**26.1 ± 4.1**	**29.5 ± 2.2**	**27.5 ± 3.2**
	Other			0.8 ± 0.3	0.3 ± 0.3	0.6 ± 0.2		0.1 ± 0.1		0.1 ± 0.1	
Decreaser Total				***35.5 ± 4.6***	***42.0 ± 5.0***	***35.4 ± 2.6***	***41.6 ± 5.6***	***35.0 ± 0.9***	***26.9 ± 4.0***	***33.4 ± 2.3***	***28.1 ± 3.0***
Increaser 2	*Eragrostis capensis*	ECA	2	1.0 ± 0.7		0.3 ± 0.3	0.1 ± 0.1	0.5 ± 0.5	0.9 ± 0.3		0.4 ± 0.2
	Eragrostis curvula	ECU	5	3.3 ± 1.5		2.9 ± 1.1	2.8 ± 0.6	4.8 ± 2.1	3.5 ± 1.2	4.1 ± 1.6	4.4 ± 0.9
	Eragrostis plana	EPL	3	2.0 ± 0.4		2.9 ± 0.8	0.8 ± 0.5	3.0 ± 0.8	3.0 ± 0.2	2.9 ± 0.6	3.5 ± 0.5
	Eragrostis racemosa	ERA	2	0.5 ± 0.5		1.0 ± 0.8	0.1 ± 0.1	1.3 ± 0.9	1.0 ± 0.2	0.6 ± 0.3	
	Harpochloa falx	HFA	3	2.0 ± 1.4	2.3 ± 0.9	2.4 ± 0.6	1.4 ± 0.6	1.9 ± 0.2	0.4 ± 0.2	1.4 ± 0.7	1.3 ± 0.8
	Heteropogon contortus	HCO	6	2.5 ± 1.5	0.5 ± 0.3	3.1 ± 0.3	0.8 ± 0.5	2.3 ± 0.7	1.8 ± 0.4	3.6 ± 0.7	2.8 ± 1.3
	Microchloa caffra	MCA	1	**7.0 ± 2.1**	**5.3 ± 1.6**	**8.1 ± 0.7**	**8.5 ± 1.7**	**7.0 ± 2.1**	**8.8 ± 2.5**	**6.8 ± 1.2**	**8.9 ± 1.5**
	Poa binata	PBI	4	3.5 ± 1.3	3.3 ± 1.3	1.8 ± 1.3	1.8 ± 0.5	0.9 ± 0.5	2.5 ± 0.9	1.0 ± 0.5	1.3 ± 0.8
	Sporobolus africanus	SAF	3	1.0 ± 0.4		2.9 ± 1.2	1.8 ± 1.0	4.6 ± 2.1	**5.3 ± 0.7**	3.6 ± 1.5	**12.4 ± 2.0**
	Sporobolus spp.	SSP				0.6 ± 0.5				0.1 ± 0.1	
Increaser 2 Total				***22.8 ± 2.7***	***11.3 ± 0.9***	***25.9 ± 3.7***	***17.9 ± 2.1***	***26.5 ± 5.2***	***27.0 ± 1.6***	***24.3 ± 2.7***	***34.8 ± 2.8***
Increaser 3	*Diheteropogon filifolius*	DFI		**5.8 ± 2.4**	4.8 ± 2.1	4.9 ± 0.5	**12.9 ± 3.7**	4.3 ± 1.3	**13.0 ± 3.8**	**5.8 ± 2.4**	**5.9 ± 1.3**
	Rendlia altera	RAL			0.3 ± 0.3			0.3 ± 0.1		0.1 ± 0.1	
Increaser 3 Total				***5.8 ± 2.4***	***5.0 ± 2.0***	***4.9 ± 0.5***	***12.9 ± 3.7***	***4.5 ± 1.4***	***13.0 ± 3.8***	***5.9 ± 2.4***	***5.9 ± 1.3***
Unknown	Other			1.3 ± 0.8	0.5 ± 0.5	0.1 ± 0.1	0.5 ± 0.2	0.5 ± 0.4	0.8 ± 0.1	1.0 ± 1.0	0.3 ± 0.1
Grand Total				**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 3.8: Initial and final species composition (mean relative abundance ± s.e.) of grass species in each treatment of the simulation trial. Grazing values and categories as in Table 3.6. Cattle:sheep ratios are expressed in terms of metabolic mass. Occurrences of species at abundances ≥ 5% are highlighted in bold

			Low stocking rate										High stocking rate									
	Cattle:Sheep ratio		1:0		3:1		1:1		1:3		0:1		1:0		3:1		1:1		1:3		0:1	
Category	Species and grazing value		90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05	90/91	04/05
Increaser 1	*Alloteropsis semialata*	3	4.3	**7.3**	4.5	4.5	3.0	**9.0**	**5.6**	**8.6**	**6.0**	**12.5**	**5.6**	2.0	**8.7**	4.5	2.3	2.8	**6.7**	**6.8**	1.0	**12.5**
	Digitaria spp.	2	1.8	0.3	2.0		1.5		1.1	0.6	2.0	1.0			1.6		0.3		0.6		0.5	
	Digitaria tricholaenoides	6				0.3	0.5	0.5				0.5	2.0	1.5			1.5	3.0				0.5
	Eulalia villosa	3	**7.3**	**6.0**	2.0	2.3	4.7	**6.3**	4.3	1.8	2.6	1.0			1.3	0.5	**5.0**	0.5	3.2	0.2	3.0	
	Helictotrichon turgidulum	1	0.3	1.0		1.3	0.2	1.0		0.6	0.3			1.5				0.3	0.3	0.5		
	Koeleria capensis	1	**5.0**	**7.3**	1.0	3.0	1.3	**6.2**	1.4	3.3	0.3	3.0	2.3	2.5	1.6	1.5	1.3	4.8	1.0	3.8	0.5	1.5
	Setaria nigrirostris	5	**12.8**	**11.0**	**9.8**	**11.3**	**13.2**	3.3	4.3	2.1	**15.7**	**7.5**	**9.0**	**6.0**	**7.7**	4.5	**11.0**	3.8	**16.7**	**6.7**	**6.0**	2.5
	Trachypogon spicatus	3	**10.8**	**7.0**	**12.8**	4.8	**7.1**	3.8	**9.1**	3.6	**6.6**	3.5	**8.0**	2.0	**6.7**	1.5	**8.5**	0.5	**6.9**	1.0	**9.0**	0.5
	Tristachya leucothrix	9	**17.5**	**17.3**	**19.5**	**27.0**	**21.1**	**19.8**	**30.9**	**22.6**	**33.8**	**13.5**	**23.4**	**15.0**	**35.1**	**21.5**	**27.5**	**11.8**	**25.4**	**12.7**	**30.0**	**8.0**
Increaser 1 Total			***60.1***	***57***	***51.6***	***54.3***	***52.6***	***50.0***	***56.7***	***43.3***	***67.3***	***42.5***	***50.3***	***30.5***	***62.7***	***34***	***57.4***	***27.25***	***60.8***	***31.7***	***50***	***25.5***
Decreaser	*Brachiaria serrata*	4	1.5	0.8	0.5	1.3	0.5	0.5	0.4	0.1	0.3		1.0	0.5	0.3	1.0	0.8	0.3	0.8	0.8		0.5
	Diheteropogon amplectens	8	2.3	1.8	3.8	1.8	1.3	1.0	1.4				1.6		0.3	0.5	0.8	0.3	0.7		2.0	
	Monocymbium ceresiiforme	6				0.3				0.1												
	Panicum ecklonii	1								0.4										0.2		
	Themeda triandra	10	**25.8**	**28.5**	**30.3**	**26.8**	**37.4**	**31.8**	**22.5**	**33.5**	**25.8**	**33.5**	**32.8**	**29.5**	**24.9**	**27.5**	**32.0**	**50.3**	**27.7**	**40.2**	**29.0**	**15.0**
Decreaser Total			***29.6***	***31***	***34.6***	***30***	***39.2***	***33.3***	***24.3***	***34.1***	***26.1***	***33.5***	***35.4***	***30.5***	***25.5***	***29***	***33.6***	***50.75***	***29.2***	***41.3***	***31***	***15.5***
Increaser 2	*Eragrostis capensis*	2	0.5	0.3	0.3	0.8	0.2	0.5		0.6	0.3	3.0	0.3	0.5	1.0		1.3		0.3		1.5	1.5
	Eragrostis curvula	5	0.5		0.3	0.3		0.2	1.1	1.5	0.6	1.5	1.3	3.5		**7.5**	0.5	1.0	0.5	0.8	1.5	**7.5**
	Eragrostis plana	3			2.3		0.3	0.8	0.4	0.4	0.6		0.3	2.0	0.3		0.5	0.3	0.3	0.2	0.5	0.5
	Eragrostis racemosa	2	1.5	1.0	0.5	0.5	0.7	0.3	0.3	0.1							0.3	3.8	0.5	1.0		0.5
	Harpochloa falx	3							1.1	0.4												1.0
	Heteropogon contortus	6	0.3	0.5	2.3	1.5		0.7	2.0	1.6	1.3	2.5	2.3	**7.0**	0.3	2.5	0.5	3.5	0.2	3.0	2.0	**5.0**
	Microchloa caffra	1	**5.5**	**6.8**	**5.5**	**7.8**	**5.1**	**6.2**	**12.3**	**15.6**	2.0	**16.5**	**6.3**	**12.5**	**8.1**	**17.5**	**5.0**	**6.8**	4.9	**13.8**	**11.0**	**38.5**
	Setaria sphacelata	6		1.3				4.3										3.3		2.7		
	Sporobolus africanus	3	0.5	0.8	1.0	0.8	1.0	1.0	0.9	0.6	1.0	0.5		**8.5**	0.6	**8.5**	0.3	2.3	1.3	4.8	0.5	3.5
Increaser 2 Total			***8.8***	***10.5***	***12.2***	***11.5***	***7.3***	***14.0***	***18.1***	***20.9***	***5.8***	***24***	***10.5***	***34***	***10.3***	***36***	***8.4***	***20.8***	***8***	***26.3***	***17***	***58***
Increaser 3	*Elionurus muticus*	0	1.8	1.5	1.5	4.3	0.8	2.7	1.1	1.5	0.6		1.0	**5.0**	1.3	1.0	0.5	1.3	1.8	0.7	1.5	1.0
Increaser 3 Total			***1.8***	***1.5***	***1.5***	***4.3***	***0.8***	***2.7***	***1.1***	***1.8***	***0.6***		***1***	***5***	***1.3***	***1***	***0.5***	***1.25***	***1.8***	***0.7***	***1.5***	***1***

Grand Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**97***	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

* Some data appear to be missing from this season

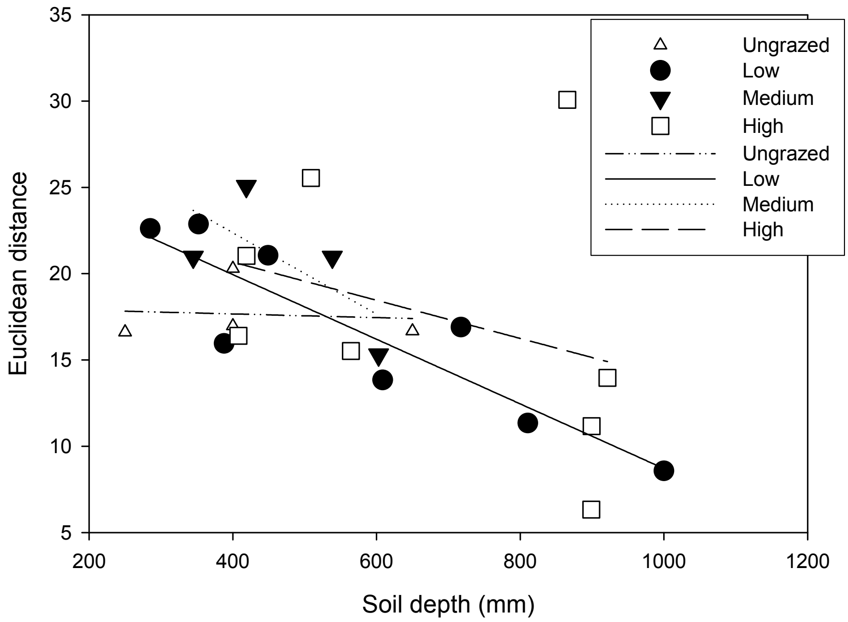


Figure 3.6: Relationship between Euclidean distance and soil depth and stocking rate on two two-paddock trials on Kokstad Research Station. Euclidean distance is the distance of the 2005 grass species survey from the initial survey (1994 and 1995 for the flat and steep trials, respectively).

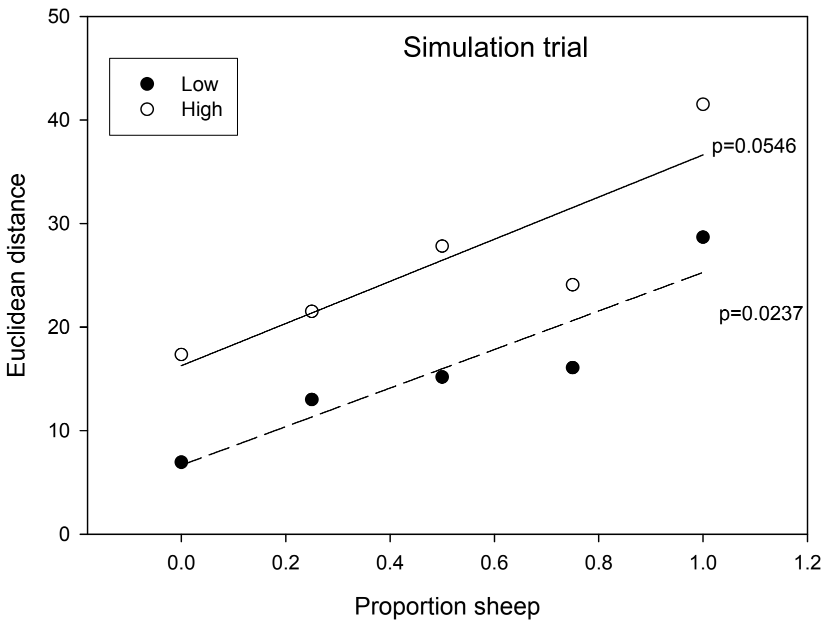


Figure 3.7: Influence of stocking rate and proportion sheep on Euclidean distance of 2006 grass species composition from 1990 composition on the simulation trial.

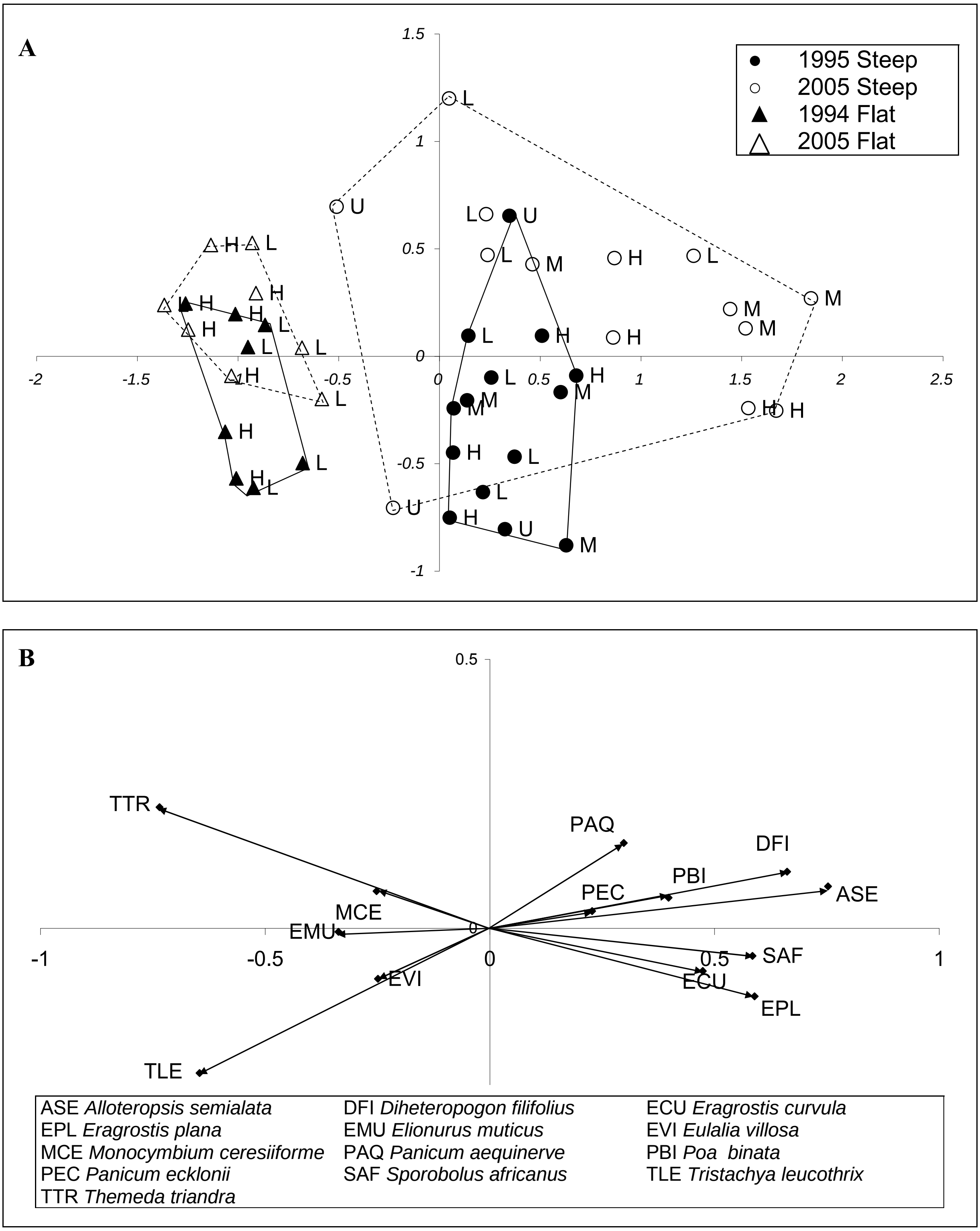
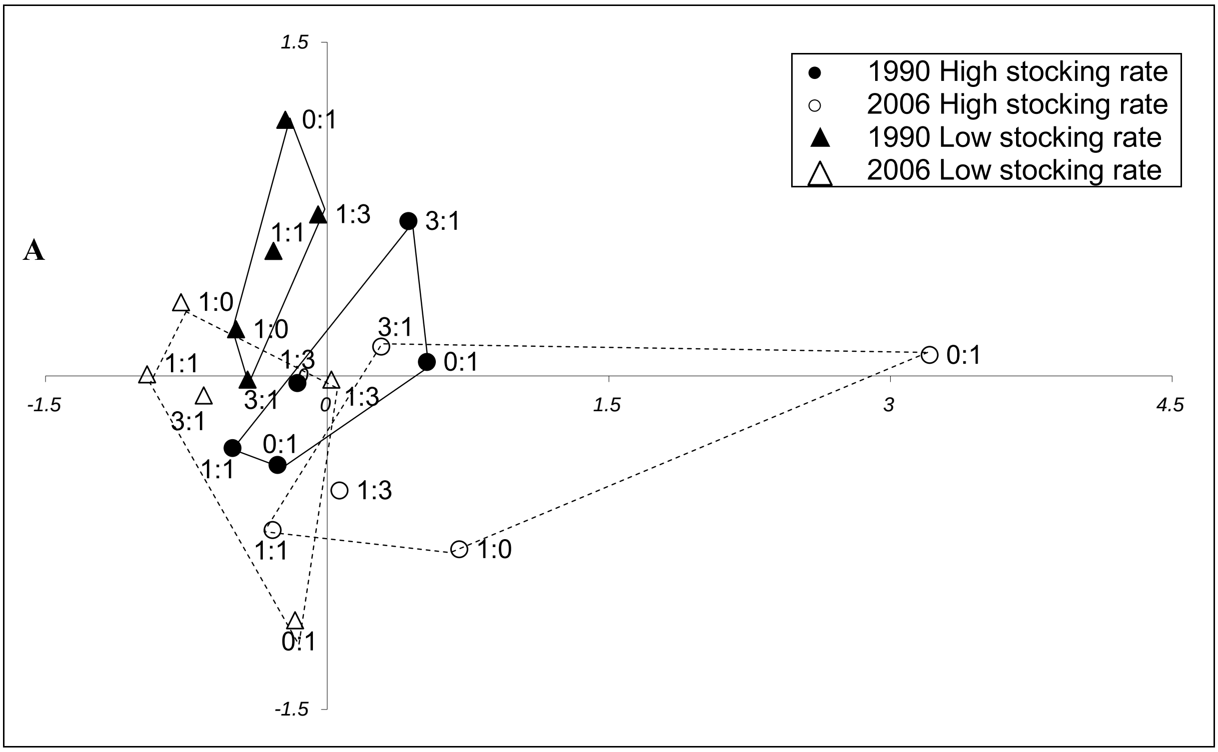


Figure 3.8: Non-metric multi-dimensional scaling of two two-paddock trials at Kokstad (stress for 2-dimensional projection = 0.1393). (A): site ordination. Each point represents an individual paddock. Key: U: ungrazed treatments; L: Low stocking rate; M: Medium stocking rate; H: High stocking rate. Polygons highlight the pattern of site distribution on the NMMDS plot. (B): Species ordination. Only species with correlation ≥0.3 are included in the ordination.



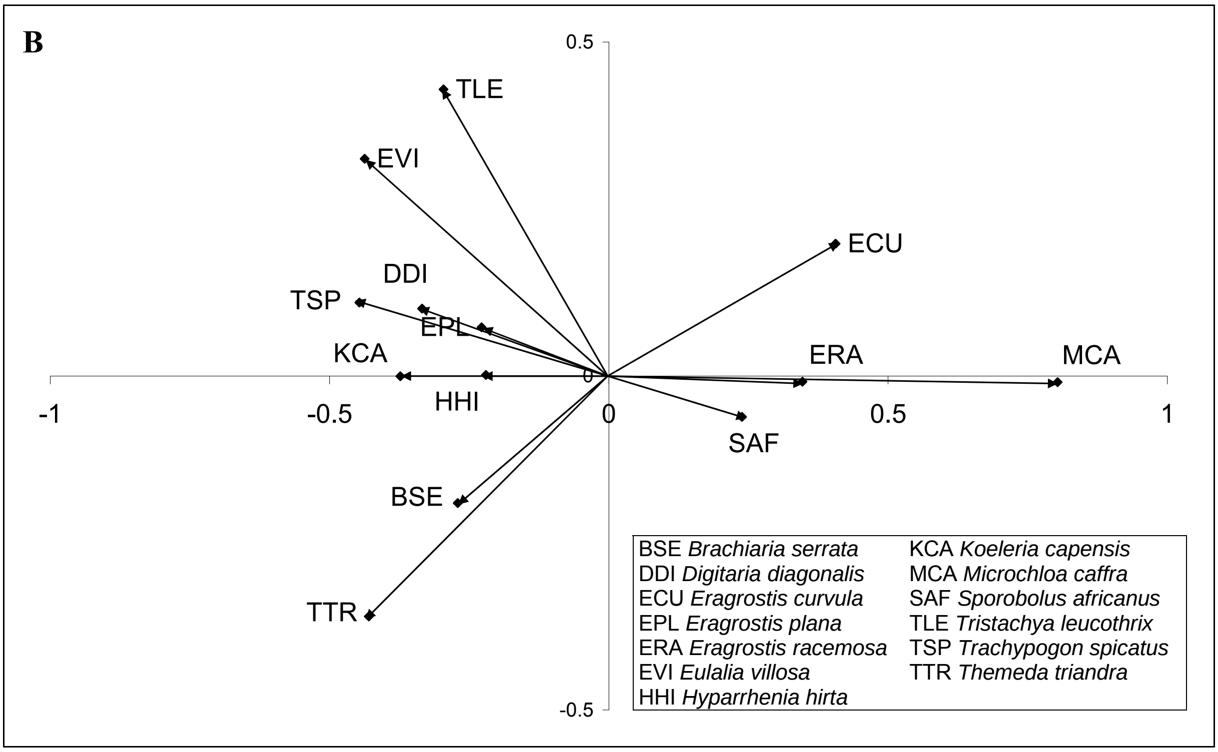


Figure 3.9: Non-metric multidimensional scaling of the grass species composition on the Simulation trial at Kokstad Research Station (stress for 2-dimensional projection: 0.1397). (A): Initial (1990) and final (2006) site ordinations. Labels adjacent to symbols refer to the metabolic ratio of cattle to sheep on each treatment. Polygons highlight the dispersion of each group of sites. (B): Grass species ordination. Only species with correlation ≥0.3 are included in the ordination.

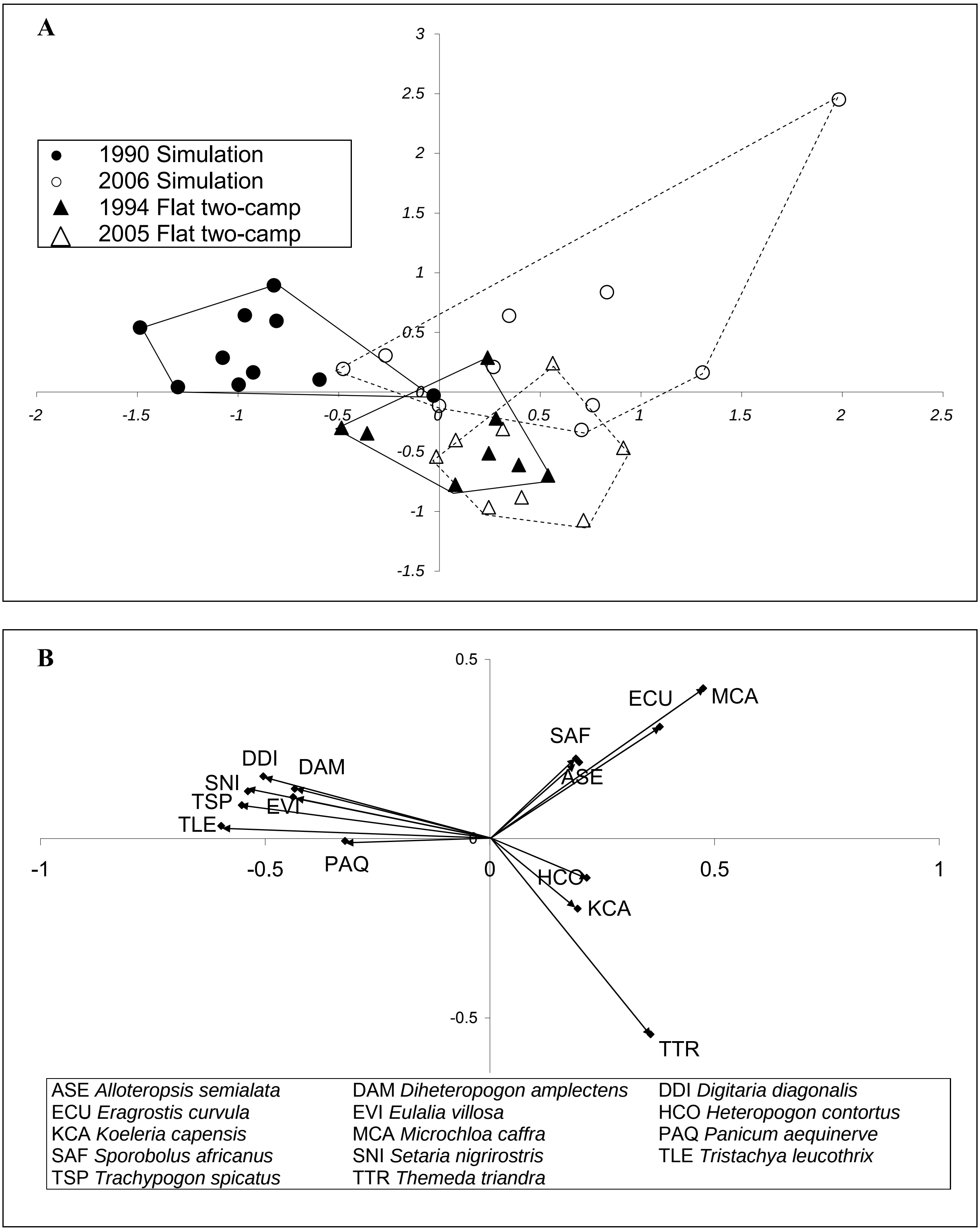


Figure 3.10: Non-metric multidimensional scaling of grass species composition on the flat trial and the adjacent simulation trial (stress = 0.1499). (A) Site ordinations of initial and final composition of each paddock on the two trials. Polygons highlight the dispersion of each group of sites on the ordination plot. (B) Species ordination. Only species with correlation ≥0.3 are included in the ordination.

Dry-weight-rank

Dry-weight-rank survey conducted in March 2005 showed significant effects of grazing vs. resting on total standing crop (Table 3.9 and Table 3.10), with total standing crop being significantly influenced by stocking rate, grazing vs. resting, and their interaction. Total standing crop was higher in rested than grazed paddocks. On the steep trial, grazing reduced the standing crop of palatable, intermediate and unpalatable species. Stocking rate reduced total standing crop and the standing crop of two species of intermediate palatability (Table 3.9). On the flat trial, palatable species were unaffected by treatment, while intermediate and unpalatable species were reduced by increasing stocking rate and by grazing (Table 3.10). Of the individual species, *Themeda triandra* and forbs were reduced by grazing on the steep trial and forbs by grazing on the flat trial.

Table 3.9: Standing crop (kg.ha^{-1}) of species on the steep trial in March 2005, with the results of the ANOVA of stocking rate (SR), Grazing (Gr) (grazed or rested), and the stocking rate by treatment interaction. P-values of ≤0.1 are highlighted in bold

Palatability	Species	Grazed			Rested			SR	Gr	SRx Gr
		Low	Med	High	Low	Med	High	P	P	P
Palatable	*Eulalia villosa*	0.0	0.0	0.0	77.8	0.0	0.0	0.431	0.363	0.431
	Heteropogon contortus	4.9	6.3	19.1	18.0	27.8	30.1	0.652	0.232	0.921
	Setaria nigrirostris	0.4	7.3	0.4	0.9	2.4	0.0	0.330	0.552	0.662
	Themeda triandra	423.0	255.5	251.5	1167.8	520.6	829.3	0.113	**0.009**	0.370
	Tristachya leucothrix	27.0	17.7	6.4	20.4	26.5	36.1	0.982	0.358	0.433
	Other	0.0	4.1	4.0	0.9	45.4	15.6			
Palatable Total		455.2	291.0	281.5	1285.8	622.7	911.1	0.212	**0.016**	0.514
Intermediate	*Alloteropsis semialata*	884.7	861.9	252.8	2018.9	1088.8	1339.8	**0.060**	**0.005**	0.143
	Microchloa caffra	47.0	37.9	9.6	40.2	23.5	15.3	0.428	0.786	0.901
	Mtshiki	52.3	65.4	325.9	62.0	71.7	136.9	**0.033**	0.226	0.180
	Harpochloa falx	42.8	0.0	0.3	129.1	26.3	1.3	0.166	0.300	0.586
	Other	4.7	49.6	18.2	73.5	20.9	67.8			
Intermediate Total		1031.5	1014.9	606.7	2323.8	1231.2	1561.1	0.136	**0.013**	0.218
Unpalatable	*Diheteropogon filifolius*	999.0	528.4	12.1	936.5	744.3	591.4	0.303	0.468	0.716
	Elionurus muticus	1.3	0.0	0.7	16.5	0.0	0.0	0.395	0.418	0.466
	Forbs	187.3	78.2	38.4	648.9	321.8	329.8	0.152	**0.014**	0.613
	Senecio spp.	3.4	1.6	0.0	1.3	14.7	14.6	0.678	0.189	0.461
	Other	72.5	21.4	6.3	26.3	65.1	68.9			
Unpalatable Total		1263.5	629.6	57.5	1629.5	1145.8	1004.6	0.107	**0.081**	0.698
Grand Total		2750.2	1935.4	945.6	5239.1	2999.8	3476.9	**0.002**	**<.001**	**0.061**

*Mtshiki is the combination of *Sporobolus africanus*, *S. pyramidalis*, *Eragrostis curvula* and *E. capensis*.

Table 3.10: Standing crop (kg.ha^{-1}) of species on the flat trial in March 2005, with the results of the ANOVA of stocking rate (SR), Grazing (Gr) - grazed or rested, and the stocking rate by treatment interaction. P-values of ≤0.1 are highlighted in bold

Palatability	Species	Grazed		Rested		SR	Gr	SRxGr
		Low	High	Low	High	P	P	P
Palatable	*Eulalia villosa*	11.1	0.0	8.2	1.7	0.194	0.917	0.699
	Heteropogon contortus	6.5	136.4	58.4	54.0	0.447	0.846	0.420
	Setaria nigrirostris	0.4	6.1	0.0	71.4	**0.074**	**0.107**	**0.105**
	Themeda triandra	751.7	521.8	673.3	873.1	0.950	0.582	0.582
	Tristachya leucothrix	81.7	63.4	102.7	107.3	0.751	0.198	0.601
	Other	1.1	4.8	4.2	18.1			
Palatable Total		852.6	732.3	846.8	1125.5	0.738	0.435	0.423
Intermediate	*Alloteropsis semialata*	762.2	426.4	1129.6	687.6	**0.072**	0.115	0.735
	Microchloa caffra	40.2	35.2	24.6	26.3	0.926	0.516	0.852
	Mtshiki*	9.0	99.6	12.3	8.1	**0.013**	**0.012**	**0.010**
	Harpochloa falx	0.5	0.0	10.0	28.8	0.546	0.250	0.525
	Other	31.5	11.8	72.3	37.6			
Intermediate Total		843.5	572.9	1248.8	788.3	**0.046**	**0.069**	0.457
Unpalatable	*Diheteropogon filifolius*	0.0	81.9	0.0	0.0	0.391	0.391	0.391
	Elionurus muticus	236.0	65.7	44.4	168.2	0.870	0.755	0.341
	Forbs	88.2	44.2	313.4	269.5	0.601	**0.058**	1.000
	Senecio spp.	18.3	13.5	15.1	36.4	0.426	0.351	0.240
	Other	22.2	29.0	55.2	67.6			
Unpalatable Total		364.7	234.2	428.1	541.7	0.940	0.170	0.322
Grand Total		2060.9	1539.5	2523.7	2455.6	**0.075**	**0.008**	0.131

*Mtshiki is the combination of *Sporobolus africanus*, *S. pyramidalis*, *Eragrostis curvula* and *E. capensis*.

Vigour and productivity

Vigour, expressed as the crop of unprotected veld as a proportion of protected veld at the end of a rested season, was significantly influenced by stocking rate (Figure 3.11). The flat trial showed a significant treatment effect on vigour with the high stocking rate showing significantly lower vigour than the low stocking rate (t=3.47, 17 df, p=0.003) but little influence of season (coefficient for season: -0.019±0.011, p=0.112). The response of vigour on the steep trial over time was also significantly influenced by treatment, and also declined over time (coefficient for season: -0.018±0.009, t=-2.07, 26 df, p=0.048). There was no interaction of season and treatment in either trial.

Standing crop on the simulation trial increased significantly with proportion sheep, and declined with stocking rate, in all seasons (Multiple regression: p<0.04) except the 2004/05 season, where proportion sheep had no effect and stocking rate only a weak effect on standing crop (Figure 3.12). In only one out of four seasons was the proportion of the total crop made up by forbs influenced by treatment, with the proportion of forbs increasing with increasing proportion sheep and with stocking rate in the 1997/98 season (Multiple regression: p=0.001).

On the simulation trial, the mid-season disc pasture meter readings declined with increasing stocking rate ($t=-7.87$, 57 df, $p<0.001$) but were not influenced by proportion sheep (over all seasons combined) ($p=0.52$) or the interaction of proportion sheep and stocking rate ($p=0.927$). Disc height increased with cumulative seasonal rainfall to mid-season ($p=0.042$), but there was no interaction of rainfall and stocking rate ($p=0.801$).

On the two-paddock trials, mid-season disc height declined with increasing stocking rate in all seasons except the 2002/03 and 2003/04 seasons on the flat trial ($p=0.321$ and 0.521 respectively).

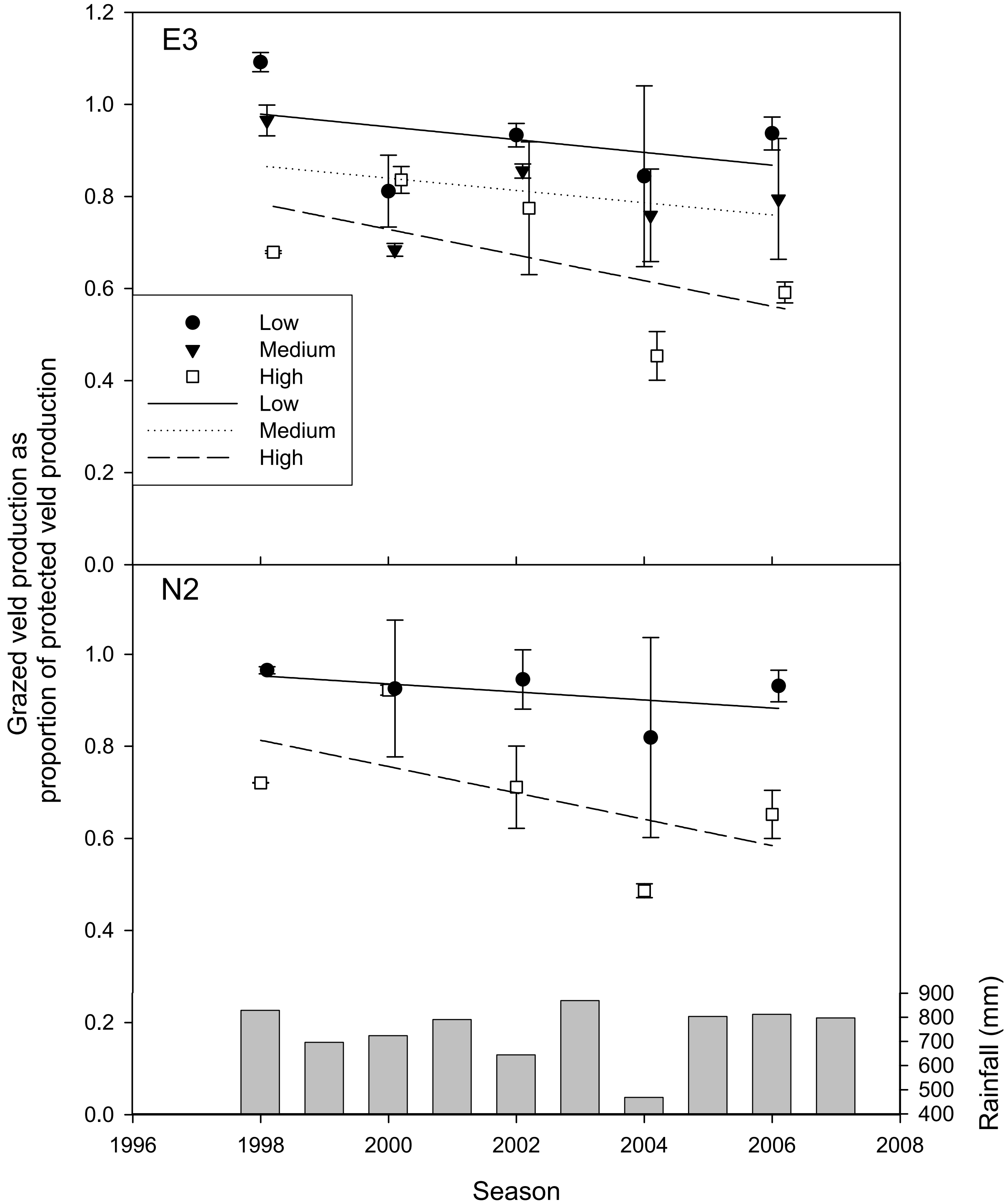


Figure 3.11: Vigour of veld (mean of two reps ± s.e.) grazed in alternate years by sheep at different stocking rates on two trials at Kokstad, and seasonal rainfall from July to the month of the cut; total seasonal rainfall is shown for the intervening seasons. The proportion of above-ground production of unprotected veld to adjacent veld protected by exclosure cages, at the end of each rested season, is shown.

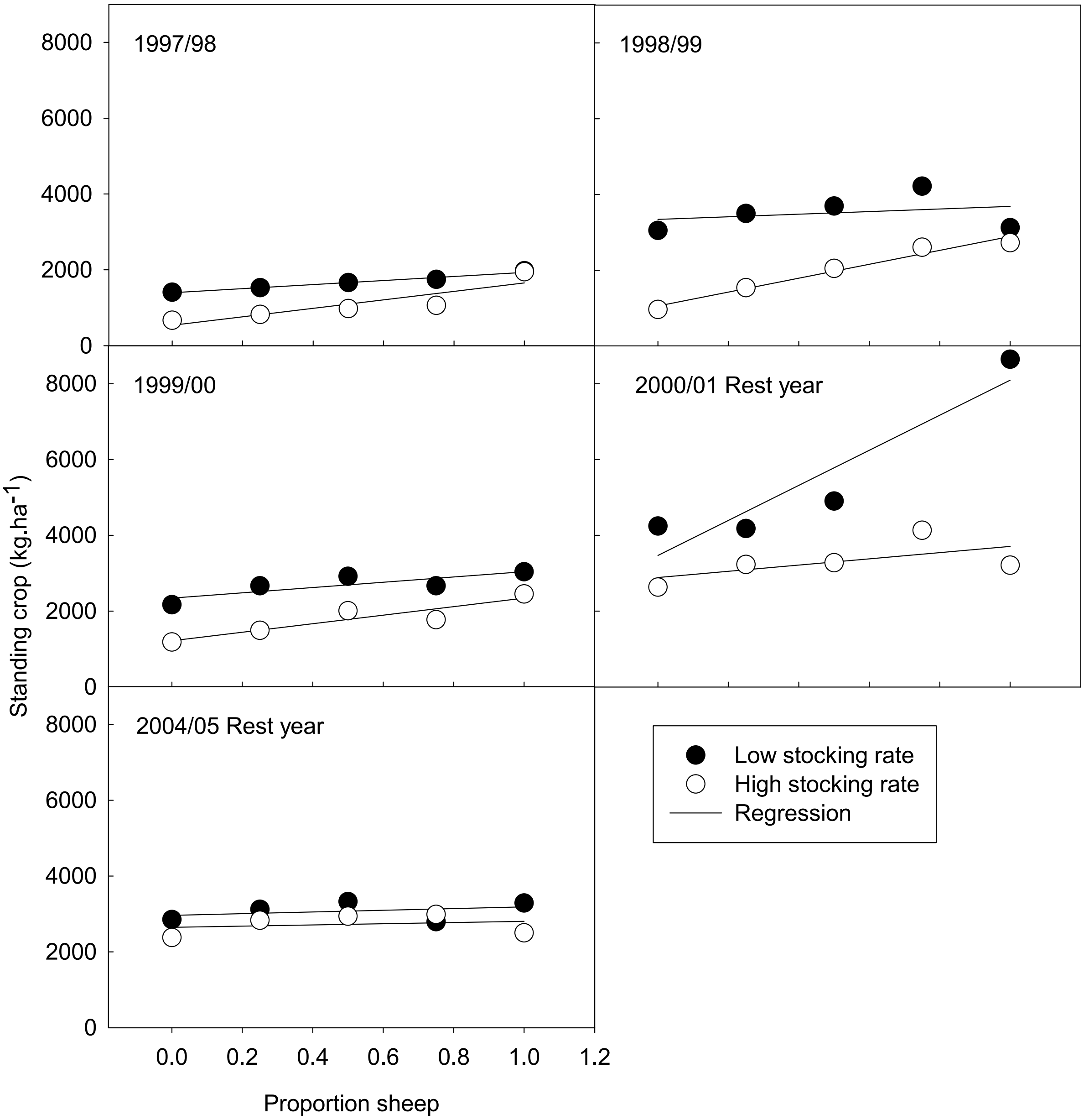


Figure 3.12: Influence of proportion sheep (in a sheep-cattle mixture) and stocking rate on total standing crop in 3 grazed seasons and two rested seasons of a grazing trial at Kokstad Research Station. Proportion sheep is calculated in terms of animal units.

Discussion

Species responses to management and environmental factors

Classical grazing theory classifies all plant species as increasers or decreasers, depending on their response to management (Dyksterhuis 1949, Foran *et al.* 1978), with the proportion of species and their response to grazing being assumed to be consistent within a veld type. However, species respond to multiple factors in addition to grazing or fire, such as soil moisture and fertility, soil depth, or competition from other plants (Keddy *et al.* 2002, Fynn 2003, Fynn *et al.* 2005b). Previous meta-analyses have shown that many species do not respond consistently to grazing (Vesk and Westoby 2001, Pakeman 2004).

In this study, *Tristachya leucothrix* was the species most sensitive to grazing, declining across all three trials except in the ungrazed treatments of the steep trial, in common with results from previous studies in moist grasslands (Morris *et al.* 1992, Peddie 1994). *Alloteropsis semialata* increased with increasing proportion sheep and with declining stocking rate. This is probably as a result of the grass being avoided by sheep at low stocking rates, but grazed at high stocking rates, and being grazed by less-selective cattle (pers. obs.). Although *Alloteropsis* is usually classed as an increaser 1 species (i.e. increases with under-utilisation of the veld), it appears that *Alloteropsis* increases with selective grazing (i.e. selective avoidance). *Diheteropogon filifolius* responded to grazing as predicted by its increaser 3 classification – it increased at low and moderate stocking densities but not in ungrazed veld or heavily-grazed veld. Sheep would be forced to graze *Diheteropogon* at heavy stocking densities only when all other available fodder was removed; this observation was supported by the results of the dry-weight-rank survey, where *Diheteropogon* was almost absent from the high stocking rate treatments at the end of the season (Table 3.9). *Microchloa caffra*, a low-growing grass, responded dramatically to increasing proportion sheep on the simulation trial, as well as to stocking rate, increasing as both factors increased. On the two-paddock trials, *Microchloa* increased with grazing but showed no response to stocking rate.

Themeda triandra, the dominant grass of this veld type and used as an indicator of veld condition (Foran *et al.* 1978, Turner 1988, Hardy and Hurt 1989), showed little consistent pattern in its response to grazing. The relative abundance of *Themeda* fluctuated dramatically within paddocks from season to season, and in fact, on only one treatment of the two-paddock trials did *Themeda* decline – on all other treatments *Themeda* was unaffected or even increased over time (Figure 3.2). *Themeda* is more tolerant of heavy grazing in Highland

Sourveld than common wisdom would predict. Fynn *et al.* (2005b) demonstrated that *Themeda* was a highly competitive grass in conditions of infertile soils and frequent defoliation.

The amount and rate of change of all species was moderated by soil depth and stocking rate, with greater change in relative abundance at higher stocking rates and on shallower soils.

The changes in species composition of most species, although they were analysed using linear regression, could be characterised as logistic responses – that is, the change in abundance slowed in the latter years of the trials. This shape of the response curves was most obvious in the simulation trial, after nearly twenty years of treatment effects, and it is possible that some species on the two-paddock trials may still be adjusting to the treatments.

The overall community response of each treatment on each trial was significantly influenced by stocking rate and by proportion sheep on the simulation trial after 15 years of grazing. However, although stocking rate influenced community change on the two-paddock trials, the overall change was heavily influenced by soil depth. Shallower soils on steeper slopes were more sensitive to grazing and showed greater compositional change.

The compositional response to grazing was more pronounced on the simulation trial than on the neighbouring flat two-paddock trial, despite similar stocking densities and a small difference in the age of the trials. On one of the heavily grazed paddocks in the two-paddock trial, *Themeda* actually increased over time (results for the individual paddocks are obscured by the means shown in Figure 3.2). The results of the simulation trial and the neighbouring flat 2-paddock trial appear at first glance to be contradictory, since the amount of compositional change on the simulation trial increased linearly as the proportion of sheep in increased, and with increasing stocking rate (Figure 3.7), while the ControlChart results showed the flat 2-paddock trial to be apparently more stable than the sheep-only treatments of the simulation trial (Figure 3.5).

The stability of the flat 2-paddock trial under sheep-only grazing, at both high and low stocking rates, relative to the sheep-only treatments of the neighbouring simulation trial, may be further corroboration of the importance of frequent rests in maintaining the vigour and health of veld. The two-paddock trials are rested biennially, while the simulation trial is only rested every four years. However, this explanation is confounded by the increased grazing intensity of the simulation trial during the late 1990s, which may have contributed significantly to the shift in composition during the same period.

The ControlChart technique appears to be promising in estimating whether or not a "threshold" has been crossed when monitoring complex plant communities over many years. By the method proposed here, two treatments appear to have either crossed a threshold from one state into a new (possibly stable) state (Figure 3.5): both low and high stocking rate sheep-only treatments on the simulation trial crossed and remained above the 95% confidence line.

Indeed, the trajectory of the sheep-only treatment of the simulation trial [corroborated by the veld condition scores of the same treatments (Booi *et al.* 2009)] appears to strongly support the multiple-stable state hypothesis of rangeland dynamics (Westoby *et al.* 1989, Laycock 1991). The sheep-only treatments were in a *Themeda*-dominated state when the trial began; over a relatively short time (approximately 10 years) the sheep-only treatments entered a transition phase where they rapidly became dominated by *Microchloa caffra*, after which the treatments entered a new, stable phase.

The effect slope and stocking rate on species composition

The locations of the trials had significant effect on the direction and magnitude of change in species composition. The deeper, well-drained soils on the gentle slopes of the flat trial were far more stable in composition than the shallow soils of the steep trial. The two-camp trials were never stratified for surveying in the same way that the simulation trial was, so testing of the hypothesis that deeper soils may have influenced the trends in species composition (by comparing the trends within and outside the major drainage lines running through the steep trial) were not possible over time.

However, the neighbouring simulation trial, also situated on deep soils on gentle slopes, suffered a dramatic decline in veld condition on the heavily stocked, sheep-only treatment. The substantial unplanned increase in stocking rate between 1998 and 2005 (where the veld was rested for only three weeks rather than four between grazing periods) certainly contributed to this change, but some of the change in species composition occurred before 1998 (Figure 3.5).

The selective nature of sheep grazing versus cattle grazing was well illustrated by the results of the simulation trial, especially at the high stocking rate. The sheep-only treatment was dominated by *Alloteropsis semialata* and *Microchloa caffra*, with *Themeda triandra* a distant third in the species rankings (Table 3.8). On the cattle-only treatment, the sward was less patchy (Figure 3.13.) with species such as *Eragrostis* and *Sporobolus* spp. and a high proportion of *Themeda* (Table 3.8).

The heavily grazed treatments in some particularly dry seasons were grazed almost bare (Figure 3.14, right and Figure 3.15, right). On the medium and low stocking rates, however, sheep selectively avoided unpalatable grasses (Figure 3.14, left). This phenomenon was most notable with *Diheteropogon filifolius* in the steep two-camp trial (Table 3.3). The reduction in vigour caused by the heavy stocking densities (Figure 3.11) was therefore balanced by the maintenance of a relatively high proportion of palatable species in the heavily stocked treatments.

The patchy nature of the sheep-only sward on the high stocking rate (pers. obs.) contradicts one of the objectives of rotational grazing, which is to achieve more efficient utilisation of the sward (Briske *et al.* 2008). However, other workers have found that rotational grazing systems can be as patchy, or patchier, than continuous grazing systems (Short 2003, du Toit *et al.* 2007). The structure of the sward was not investigated in this study, but was often obvious near the end of a season (Figure 3.13, Figure 3.14, Figure 3.16).

Dry-weight rank

The standing crop of palatable, intermediate or unpalatable plants in the two-paddock trials at the end of one season was predominantly influenced by whether the paddocks had been grazed or rested (Table 3.9 and Table 3.10), and less so by the stocking rates of the paddocks. However, the total standing crop was significantly influenced by the stocking rates, with standing crop declining with increasing stocking rate. Interestingly, *Alloteropsis semialata* was reduced by heavy stocking at the high stocking rate and unaffected by low or intermediate stocking, indicating that at high stocking rates sheep will graze unpalatable plants that are normally avoided. The ANOVA of *Diheteropogon filifolius* on the steep trial showed no treatment effect; however, the conspicuous reduction in the standing crop of *Diheteropogon* in the heavily-grazed paddocks (12.1 $kg.ha^{-1}$ in the high stocking rate, grazed paddocks, versus 500-1000 $kg.ha^{-1}$ for the medium and low stocking rate grazed paddocks - Table 3.9) cannot be ignored. Once again, the unpalatable plants were intensively grazed by sheep on the heavy stocking rate paddocks.

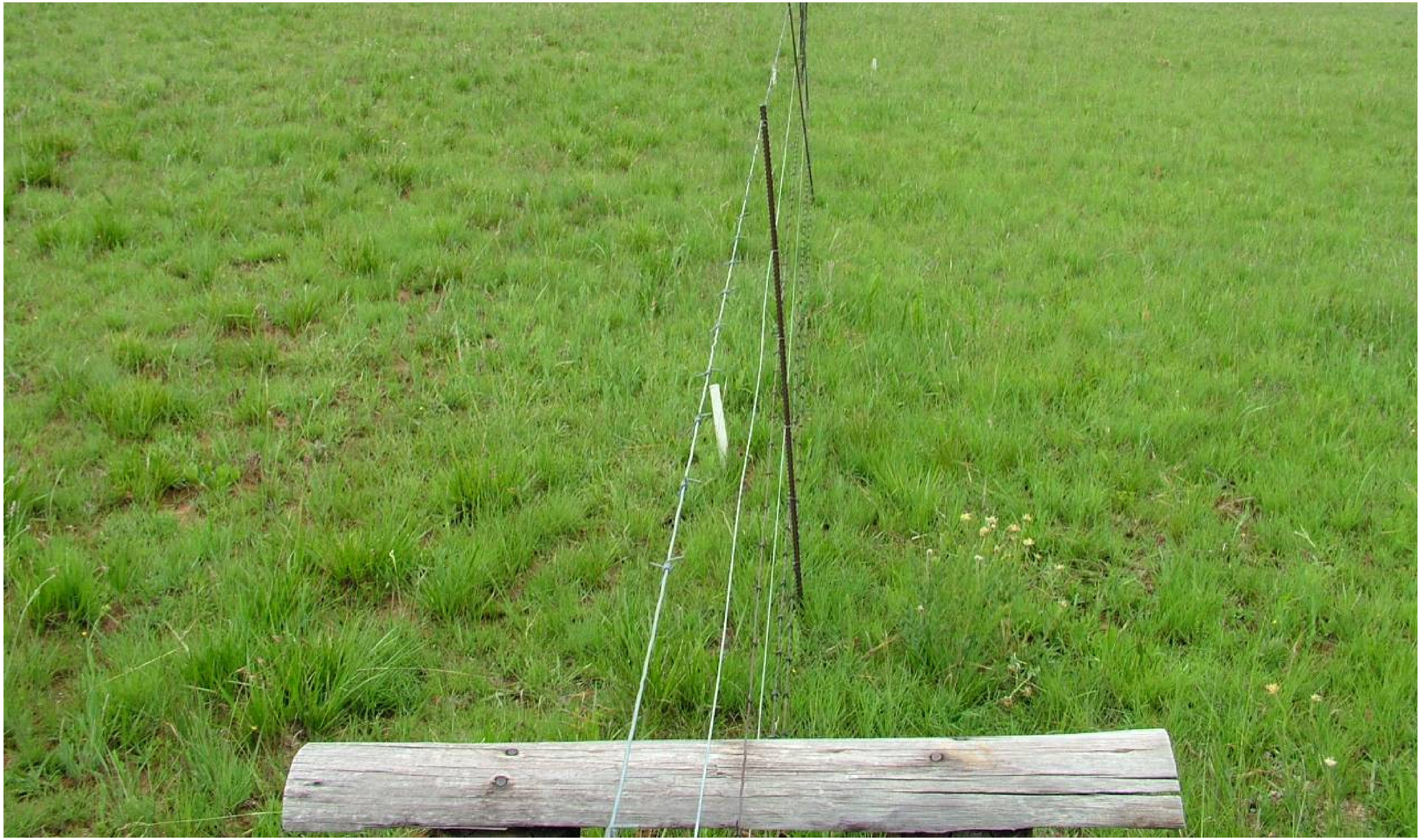


Figure 3.13: Contrast between cattle stocked heavily (right) and sheep stocked heavily on the simulation trial in May 2005. Tufts of *Alloteropsis semialata* are conspicuous on the left (sheep-only) side of the fence

Figure 3.14: Contrast between high stocking rate (right) and medium stocking rate on the steep trial in February 2008

Figure 3.15: Contrast between heavily grazed paddock (right) and rested paddock (left) on the flat trial in February 2008

Figure 3.16: High stocking rate on the flat trial, March 2005.

Vigour

Vigour (measured by standing crop at the end of a rest year) declined with increasing stocking rate on all trials, and declined over time more steeply on heavily-grazed treatments, as shown by other workers (Peddie *et al.* 1995, Kirkman 2002b). Although the regression analyses that were conducted on the two-paddock trials were linear (Figure 3.11), there is a possibility that the heavily grazed treatments may be entering a new stable state of productivity; however, there is insufficient evidence to support or refute this hypothesis.

Variations in rainfall did indeed influence productivity temporarily, but productivity was primarily influenced by stocking rate in the long term.

Rangeland dynamics in Kokstad

The non-equilibrium model (Behnke *et al.* 1993) generated fierce debate in rangeland science. Disequilibrium systems are those where animal numbers are not density-dependant but are regulated by stochastic events such as drought. However, key resources can play a hugely important role in buffering animals from the effects of drought (or other events influencing forage production), thereby minimizing the disequilibrial dynamics of rangelands (Gillson and Hoffman 2007). Gillson and Hoffman (2007) proposed a synthesis of equilibrium and non-equilibrium models, where non-equilibrium processes occur to cause fluctuations in primary production, but where density-dependant effects can occur at specific scales or times (e.g. in high production patches).

Most of the debate around rangeland dynamics in the last two decades has been based around arid and semi-arid systems. Kokstad is a cool, mesic (sourveld) system, and appears to be stable over the long term, with responses of vegetation production and composition strongly coupled to management. Sourveld grasslands appear to follow a more traditional, stable, successional approach, but state-and-transition model can still be appropriate as a management model (Westoby *et al.* 1989, Walker 1993, Vetter 2005). The response of the grass composition to management on the simulation trial (Figure 3.5) certainly seemed to fit a state-and-transition model – the two sheep-only treatments on the simulation trial have shifted to a new stable state dominated by *Microchloa caffra* and *Alloteropsis semialata*. The grazed treatments on the steep trial appear to also be on a "threshold" of change to a state dominated by less palatable plants, while the flat trial has remained relatively stable over the twelve years reported in this work.

Conclusion

The effects of grazing on grass species composition and vigour have been investigated many times before. Most of the results of these trials corroborated previous findings; that is, heavy grazing reduces sward vigour relative to lenient grazing; that palatable species decline with increasing stocking density; that frequent rests are important to maintain the vigour and condition of the veld; that heavy grazing will force livestock to graze unpalatable plants. Environmental effects (especially slope and soil depth) moderated the response of species and sward vigour significantly, as reported previously by Fynn and O'Connor (2000).

However, the meta-analysis approach used in this report also revealed several apparent contradictions, most notably the different responses of species in the adjacent simulation and flat 2-paddock trials. The two-paddock treatment remained stable in composition, despite the sheep-only treatment, compared to the sheep-only treatments in the simulation trial. The more frequent rests and burns in the two-paddock trial (biennial versus four-yearly for the simulation) trial, may explain the apparent differences in sward response.

The Highland Sourveld appears to be an ecosystem resilient to heavy grazing over decades. The two-paddock “blaze and graze” approach to veld management appears to be sustainable when practiced on deep, stable soils, and apparently more sustainable than a rotational grazing approach in near-identical conditions.

Chapter 4 The effect of rainfall and stocking rate on sheep performance in Highland Sourveld

Introduction

In southern Africa, rangelands are the most important source of forage for livestock (Hurt 1998). Animal performance on rangelands is controlled by multiple factors, including genetic and environmental factors. Environmental factors can influence animal performance directly, (e.g. heat, cold, disease) or indirectly by influencing factors such as forage production and quality (Chapter 3, Fynn and O'Connor 2000).

Forage production is determined by rainfall and edaphic factors such as soil depth, slope, fertility and water holding capacity, as well as the long-term vigour of desirable forage species under grazing and burning. Although stocking rate is often used as a proxy for forage availability per animal, forage availability per animal is a combination of seasonal forage production and stocking rate applied.

A frequently-cited model by Jones and Sandland (1974) relates animal production (kg per animal or kg per hectare) to stocking rate, assuming constant production (they based their work on cultivated pastures). The model highlights that, above a critical stocking rate, individual animal performance declines because of increasing resource limitation, until animal performance reaches zero at the maximum stocking rate. Animal production per hectare follows a bell-shaped curve, peaking at one-half maximum stocking rate.

Mentis and Tainton (1981) criticised the frequent use of the model in complex rangeland systems, for which the model was never proposed. In semi-arid systems, seasonal rainfall interacts with stocking rate to determine animal performance (Fynn and O'Connor 2000). Indeed, animal performance in arid and semi-arid systems may not be strongly coupled to stocking rate at all (Behnke *et al.* 1993). In humid systems, stocking rate and animal performance appear to be more strongly coupled (Peterson *et al.* 1965, Kirkman 1999). Kokstad may be regarded as an "equilibrium" system, as a result of the relatively high rainfall and stable biomass production from year to year (Palmer *et al.* 2010) in contrast with "non-equilibrium" systems where biomass production is strongly coupled to rainfall. Nonetheless, Bransby (1984) proposed a model to predict animal performance based on both rainfall and stocking rate, developed in the higher-rainfall region of South Africa. Ash and Smith (1996) reviewed pasture and rangeland experiments and concluded that rangelands are far less sensitive to increases in stocking rates than pastures. They explained the differences between the response of pastures and rangelands to the much greater spatial and temporal variability in rangelands, and proposed dynamic simulation models for rangelands instead.

Productivity of the veld is influenced in the short term by rainfall, but a central tenet of veld management is that veld productivity will decline in the long term if the veld is overgrazed or otherwise poorly managed (Mentis and Tainton 1981).

Based on the above models of animal performance, stocking rate and rainfall, the following relationships should be predicted: within a season, individual animal performance will decline with increasing stocking rate (Jones and Sandland 1974); between seasons animal performance will decline with decreasing rainfall (Bransby 1984); and between seasons, animal performance will decline if veld condition declines (Mentis 1982).

Materials and methods

Trial design

The two trials are described in detail as the two-paddock trials in Chapter 3. The design and layout are briefly reiterated here for convenience.

The trials are referred to henceforth as the flat trial and the steep trial, owing to their locations on a flat (c. 5-12% slope) and a steep (c. 20% slope) respectively. Both trials consist of stocking rate treatments (low and high on the flat trial, low, medium and high on the steep trial). The grazing system for each treatment is identical, consisting of two paddocks; one paddock is burned in early spring and grazed continuously for the growing season by weaned merino sheep (males on the flat trial and females on the steep trial), while the other paddock is rested. In the following season, the paddocks are swapped. The long-term stocking densities for a treatment are therefore half of the seasonal stocking densities, as only half the veld is grazed in any season.

Stocking densities are calculated in terms of animal units (AU) per hectare (Meissner *et al.* 1983), and are described as seasonal (not long-term) stocking densities.

The flat trial was established in 1992, and animal numbers per treatment varied from 5 to 10, depending on the size of the paddock. The steep trial was established in 1995, and each paddock was stocked with 8 animals. The paddock sizes varied according to the intended stocking rate for that paddock, from 0.5 to 1.2 ha.

Animal health

Sheep were treated according to the recommendations of the Animal Science section and the Allerton Veterinary Institute of the KwaZulu-Natal Department of Agriculture and Environmental Affairs. Every year before being put onto the trial, weaners were dosed with activated charcoal to minimise risk of poisoning from *Senecio* species. Animals were supplemented *ad lib.* with a phosphate and salt lick throughout the season.

Experimental procedure

Animals were stocked on the burned paddocks soon (generally within 4 weeks) after the spring burn had been applied. Animals were weighed and randomly assigned to each treatment, after which animals were weighed every two weeks. Towards the end of a season, weighing was increased to weekly.

The dates that animals were placed on the trials and removed varied between seasons according to the seasonal conditions and the judgment of the technical staff. In addition, the actual stocking densities often varied substantially from the intended stocking densities (Table 4.1).

Animals lost due to death, illness or injury were replaced with equivalent animals, but only animals that had been on the trial from the beginning to the end of each season were regarded as "tester" animals for the purposes of determining animal performance. In some seasons, predator attacks were a serious problem (Table 4.2).

Table 4.1: Actual and planned seasonal stocking rates (AU.ha^{-1}) on two long-term trials (named steep and flat) in Kokstad

Trial	Paddock no.	Planned AU.ha^{-1}	Planned animals. ha^{-1}	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/05	04/05
Steep	5	1.0	7			1.0	0.9	0.9	1.0	1.1	1.1	1.1	1.1	1.0	1.0
	10	1.0	7			0.9	0.9	0.9	1.0	1.2	1.2	1.1	1.0	1.1	1.0
	7	1.5	11			1.5	1.4	1.4	1.5	1.7	1.8	1.7	1.6	1.6	1.6
	9	1.5	11			1.5	1.2	1.5	1.5	1.8	1.7	1.6	1.5	1.6	1.4
	6	2.0	15			2.1	1.9	1.9	2.0	2.4	2.3	2.2	2.0	2.1	2.1
	8	2.0	15			2.1	1.9	1.8	2.1	2.4	2.4	2.2	2.1	2.2	2.1
Flat	3	1.0	9	1.2	1.2	1.1	1.1	1.2	1.2	1.3	1.2	1.2	1.2	1.3	1.2
	4	1.0	9	1.1	1.2	0.9	0.9	1.0	1.0	1.1	1.1	1.0	1.0	1.0	0.9
	1	2.0	13	1.8	1.9	1.5	1.6	1.7	1.8	1.9	2.0	2.0	1.8	1.9	1.7
	2	2.0	13	1.6	1.7	1.8	1.8	1.9	1.8	2.1	2.1	2.0	1.9	1.9	1.8

Table 4.2: Number of animals killed or injured by predators on two sheep grazing trials at Kokstad

Trial	Season	Number of animal injured or killed by predators
Steep	1995/96	1
	1997/98	4
	1999/00	2
	2001/02	1
	2004/05	5
Flat	1994/95	1*
	1995/96	2
	2000/01	1
	2001/02	5
	2004/05	6

*Trial had to be ended early because of dog attacks.

Analysis

All analyses described below were performed separately for the flat and steep trials, as two different classes of sheep were used on the trials (males and females).

Animal performance

The start and end dates varied considerably between seasons, and no consistent rules appeared to be followed to determine when to remove animals. As a result, animal performance towards the end of each season varied considerably, with animals in some seasons staying on the trial until they had lost most of the weight gains made during the growing season, while in other seasons animals were removed from the trials at the peak of their condition.

Therefore, for the purposes of comparison of animal performance, each season was truncated at the point where animal performance began to decline (i.e. at the peak of animal performance). The following procedure was used to decide where, or if, a season's data needed to be truncated: working backwards from the end of the season, if more than half of the paddocks showed a decline in the mean livemass of testers, that weighing date was removed. Six out of 12 seasons were truncated on the flat trial, and two out of ten seasons on the steep trial. Most truncated seasons only had the final weighing date removed, which was usually two weeks after the penultimate date. The notable exceptions were 1997/98 and 1999/2000 on the flat, and 2004/05 on the steep trials, where over 4 weeks were removed from the end of the season (Table 4.3).

Following the procedure of Kreuter (1985), an exponential curve of the form $W = a - be^{-c.t_i}$ was fitted to the mean mass of animals over time in each treatment to calculate mass gain, where W = livemass in kg; a, b and c are constants; e is the base of the natural logarithm; and t_i = time from commencement of grazing (days). Average daily gain (ADG) for the season was calculated from the difference between initial and final predicted mass, and production per hectare was therefore the product of ADG, stocking density (animals.ha^{-1}) and number of grazing days.

Animal performance as a function of veld condition

In Chapter 3, the species composition trends were reported. The species composition data were used to calculate a veld condition score for each paddock in each season, by summing the relative abundances of *Themeda triandra*, *Tristachya leucothrix* and *Heteropogon contortus* (*sensu* Turner 1990). These three grasses were chosen because they were dominant grasses with a subjective grazing value of at least 6 out of ten (Camp and Hardy 1999). These same species were also identified as key species across a grazing gradient in Highland Sourveld by Hardy and Hurt (1989). Since the species composition assessments were only carried out every second year, the mean of two seasons' data was used to calculate the values for the intervening seasons.

Animal performance as a function of stocking rate

Stocking rate was expressed as actual stocking rate in AU.ha^{-1}, rather than planned stocking rate, since there were often great variations between seasons (Table 4.1). The actual stocking rate was taken as the stocking rate at the mid-point of every season. The start and end dates and seasonal rainfall are shown in Table 4.3. Seasonal rainfall was the rainfall from 1 July to the month when animals were removed.

Animal performance model

A forward stepwise multiple regression procedure was followed, using Genstat 9.1 (Lawes Agricultural Trust 2006), separately for the steep and flat trials, and for ADG and production.ha^{-1}. The following variables were included in the regression: stocking rate, seasonal rainfall, stocking rate by rainfall interaction, veld condition score, accumulated animal unit grazing days per hectare (to test whether the stocking rate effect accumulated over time (Fynn and O'Connor 2000)). Rainfall was replaced by mean end-of-season exclosure cage production of each trial in a separate analysis, as biomass production is a function of rainfall (Fynn and O'Connor 2000). For production per hectare, a second, quadratic model of the form derived by Jones and Sandland (1974) was also run, to test the relationship between stocking rate and production per hectare, with all seasons combined.

Cumulative animal performance over several seasons was used to test whether slight differences between treatments became greater over time. Cumulative production per hectare may be understood as the kilogrammes of live weight gain a grazier can expect over several years from his land. Cumulative production (kg.ha^{-1}) was regressed over seasons, and the slopes of the regressions compared between treatments over the duration of the trial. This was similar to the approach adopted by Turner (1990).

Table 4.3: Seasonal rainfall (August-July), burning and grazing dates for sheep grazing veld on two trials (steep and flat) in Kokstad. In some seasons, analyses of animal performance were limited to periods of weight gain (see Materials and Methods); the final dates and number of grazing days for each trial are shown, with the actual dates that animals were removed from the trial and number of grazing days in parentheses

	Season											
	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05
Seasonal Rainfall (mm) (1 Aug – 30 Jul)	899.7	582.4	856	1204.5	862.2	696.3	861.3	790.2	725.2	869	504.7	803.5
Burning date	17 Aug	*	*	*	*	*	8 Sep	7 Sep	12 Aug	15 Aug	*	*
No. days post-burn	30						54	6	66	26		
Start grazing	16 Sep	19 Sep	16 Oct	25 Sep	25 Sep	17 Sep	1 Nov	13 Sep	17 Oct	10 Sep	6 Oct	6 Oct
End grazing	Flat: 4 May (Actual: 18 May)	20 Mar	Flat: 3 Apr (Actual: 17 Apr)	20 Mar	Flat: 3 Apr Steep: 24 Apr (Actual: 11 May)	30 Apr	Flat: 10 Apr (Actual: 16 May)	Flat: 27 Mar (Actual: 9 Apr)	Flat: 22 Apr (Actual: 7 May)	24 Feb	23 Mar	Flat: 15 Apr Steep: 1 Apr (Actual : 29 Apr)
No. of grazing days	Flat: 230 (Actual: 244)	182	Flat: 170 (Actual: 184)	176	Flat: 190 Steep: 211 (Actual: 228)	225	Flat: 161 (Actual: 197)	Flat: 195 (Actual: 208)	187 (Actual: 202)	167	169	Flat: 191 Steep: 177 (Actual: 205)

*No record of burning date could be found

Results

Rainfall and stocking rate

The stepwise multiple regression showed that animal performance was significantly influenced by seasonal rainfall and by the interaction of rainfall and stocking pressure (expressed either as stocking rate or as the product of stocking rate and number of grazing days). On the steep trial, the final regression chosen for ADG included all variables except veld condition score, and accounted for 41.6% of variance (Table 4.4). The flat trial, on the other hand, showed only a weak relationship between average daily gain and seasonal rainfall.

Table 4.4: Results of stepwise multiple regression of average daily gain of sheep grazing veld on two trials at Kokstad Research Station

Trial	Percentage variance	Parameter	Estimate	s.e.	P-value
Steep	41.6	Constant	203.3	31.7	<.001
		Seasonal Rainfall	-0.125	0.033	<.001
		Stocking rate	-80.8	19.7	<.001
		Stocking rate x Seasonal Rainfall	0.076	0.022	0.001
		End of season phytomass	-0.012	0.004	0.004
		Accumulated AU grazing days.ha^{-1}	0.018	0.006	0.005
Flat	13.8	Constant	65.9	12.6	<.001
		Seasonal Rainfall	-0.036	0.015	0.021

There was a simple linear positive relationship between stocking rate and production per hectare on both trials (all seasons combined) accounting for 34.6% and 41.5% of variance on the steep and flat trials respectively, but no quadratic relationship.

On the flat trial, ADG ranged from 11 to 67 g.day^{-1} (Figure 4.1), and on the steep trial from 16 to 95 g.day^{-1} (Figure 4.2). Production per hectare on the flat trial ranged from 11 to 151 kg.ha^{-1}, and on the steep trial from 21 to 166 kg.ha^{-1} (Figure 4.1 and Figure 4.2). On the steep trial the correlation between stocking rate and animal performance was poor in most seasons, with wide variation in animal performance between the two replicates of a treatment. The slopes of the ADG vs. stocking rate regression were relatively flat on both trials, indicating that stocking rate alone had little effect on animal performance. Production per ha was more influenced by stocking rate, but in opposite directions on the two trials. On the flat trial, production.ha^{-1} increased with increasing stocking rate, while the opposite appeared to be the case on the steep trial.

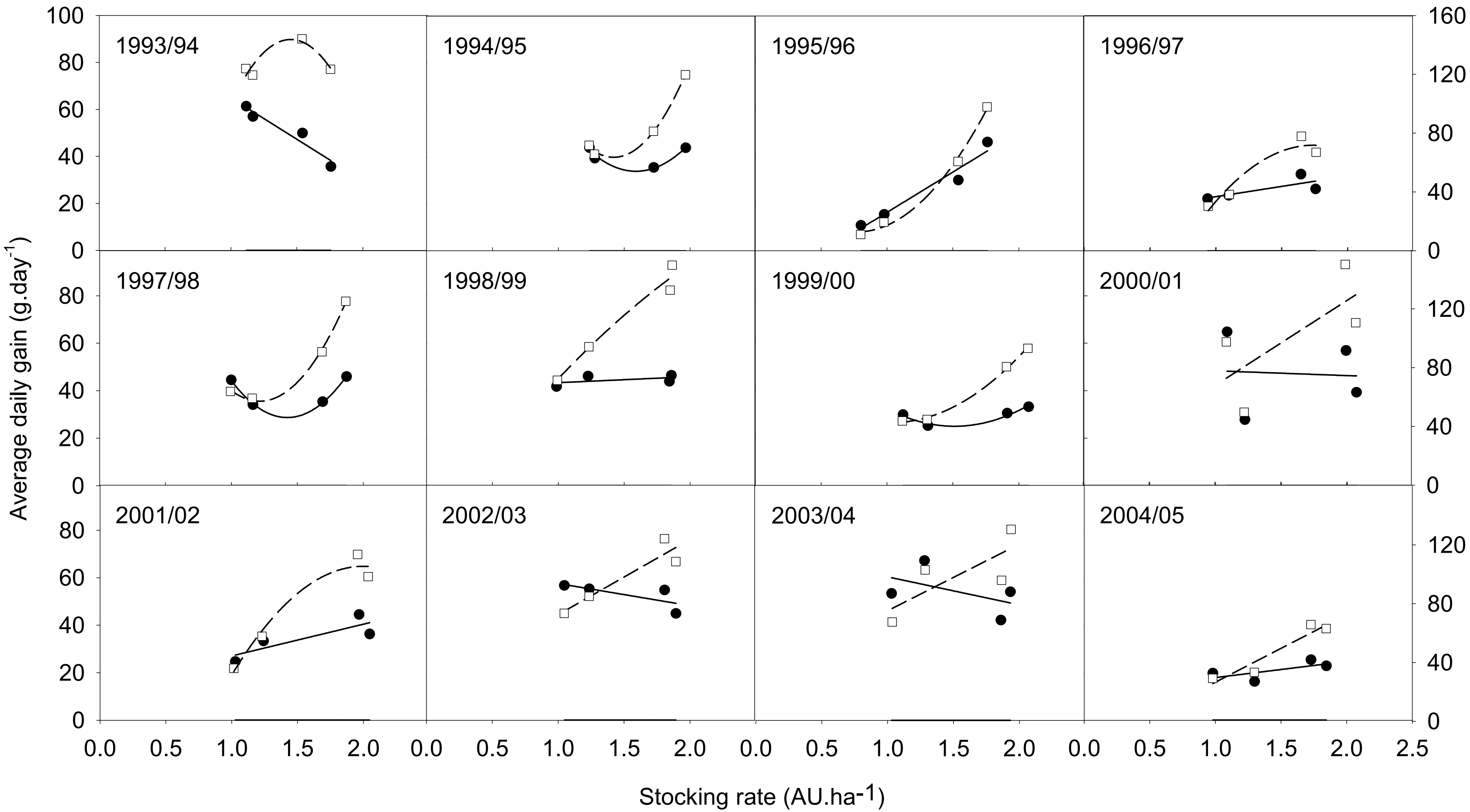


Figure 4.1: Relationship between stocking rate and average daily gain (circles and solid lines) and stocking rate and production per ha (squares and dashed lines) of merino weaners grazing veld on a flat slope at Kokstad over 12 seasons. Lines are best fit (linear or quadratic) of stocking rate against animal production.

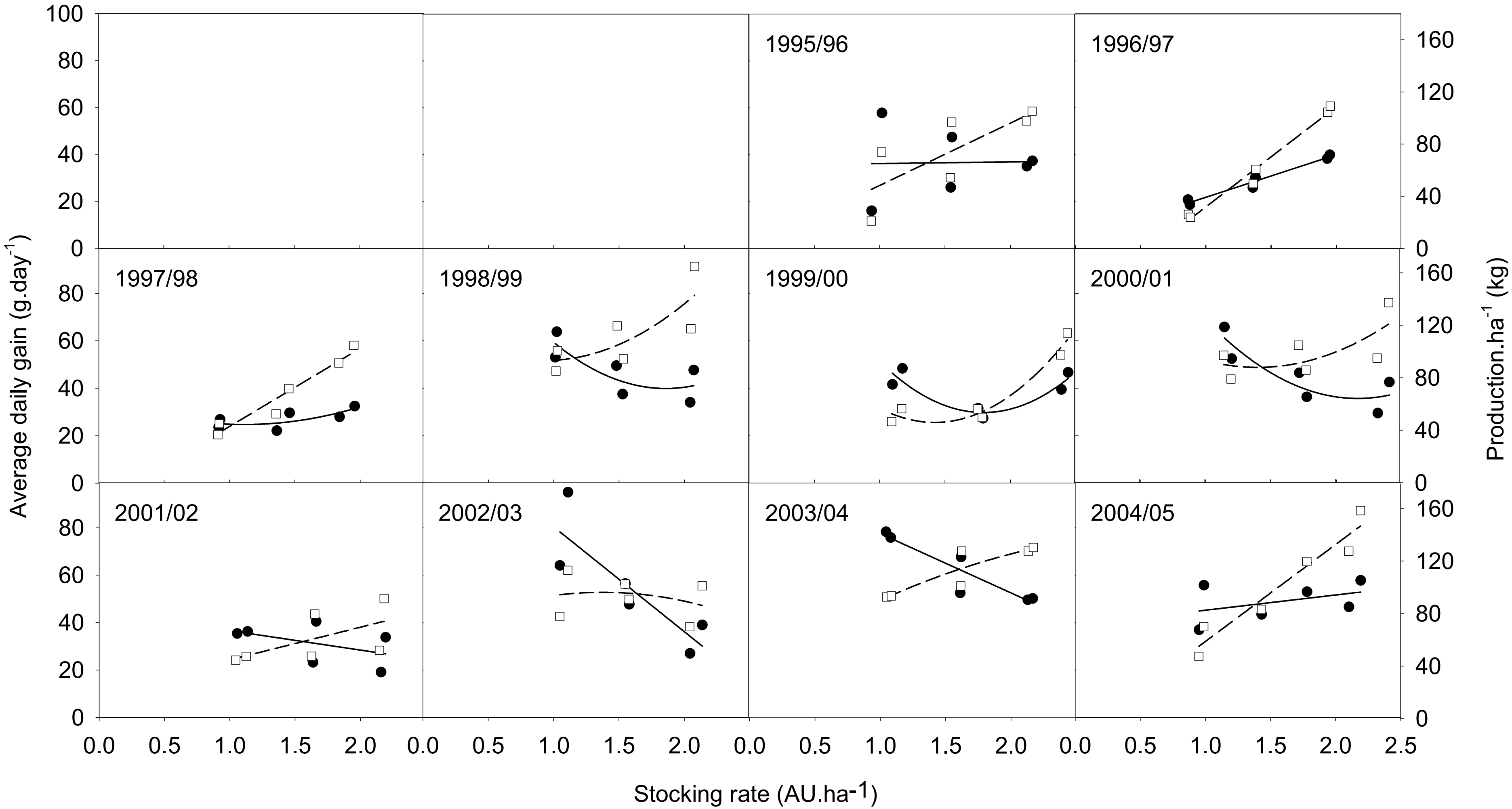


Figure 4.2: Relationship between stocking rate and average daily gain (circles and solid lines) and production per ha (squares and dashed lines) of merino weaners grazing veld at Kokstad on steep veld over 10 seasons. Lines are best fit (linear or quadratic) of stocking rate against animal production.

Animal performance as a function of stocking pressure per kilogramme biomass

The relationship between stocking pressure expressed as AU kg biomass^{-1} ha^{-1} and ADG was non-significant, either within or between seasons.

Animal performance over time

Cumulative gain, used in this study, means the total animal production over all seasons; in other words, the total production a farmer can expect from his land over many years. Cumulative production per ha differed significantly between treatments (Figure 4.3), with the cumulative production per ha increasing with increasing stocking rate on both trials ($p<0.001$). Table 4.5 gives the slopes of the cumulative production regressions over time for each trial

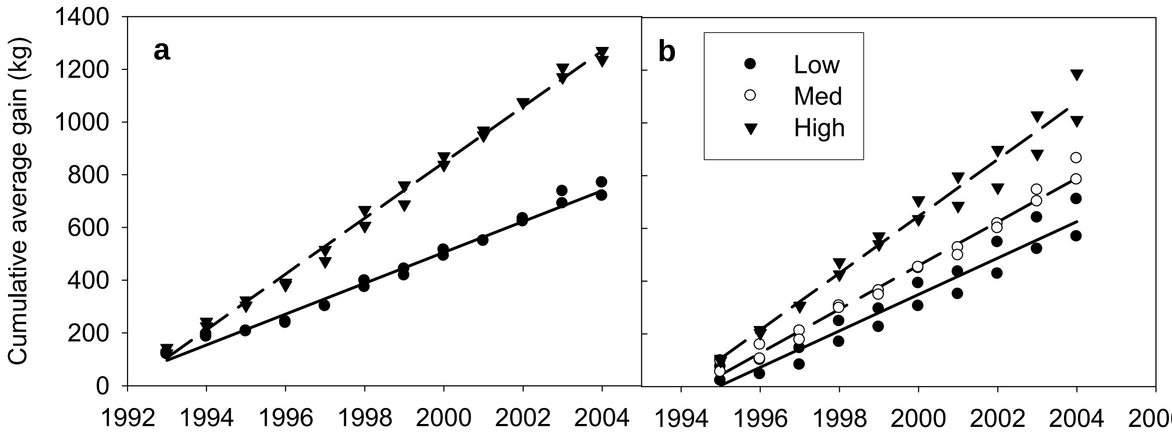


Figure 4.3: Cumulative production per hectare over several seasons of sheep grazing veld on two trials at Kokstad. Results of regression analyses are given in Table 4.5.

Table 4.5: Cumulative production per hectare of sheep at different stocking rates on two trials at Kokstad Research Station. Significant P-values are highlighted in bold

Trial	Variable	Stocking rate	Slope	P-value	Difference from high stocking rate (P-value)
Flat	Production per ha (kg.ha^{-1}.a^{-1})	Low	58.4	**<.001**	**<.001**
		High	105.8	**<.001**	
Steep	Production per ha (kg.ha^{-1}.a^{-1})	Low	69.0	**<.001**	**<.001**
		Medium	82.9	**<.001**	**<.001**
		High	107.9	**<.001**	

Discussion and conclusions

The stocking rate/rainfall interaction was most clearly demonstrated in the 1996/97 grazing season, which experienced the highest rainfall of the trial period (1206mm). On the steep trial, animal performance increased with increasing stocking rate, probably because the animals on the high stocking rate treatments were able to utilise the increased herbage effectively. Sheep require short, leafy material for good production, and if the stem to leaf ratio declines, their performance will suffer (Hardy and Tainton 1995). Conversely, in low rainfall years, the animals stocked at the low density could be expected to perform better than animals stocked at higher densities. In 2003/04, the driest season, an inverse linear relationship between animal performance and stocking rate was indeed evident on the steep trial. However, other seasons with higher rainfall showed similar trends on the steep trial (Figure 4.2). The interaction of stocking rate and rainfall on the steep trial indicates that at high stocking rates, animals perform better in high-rainfall seasons than at low stocking rates; hence, the second hypothesis was not supported.

The significant effect that the interaction of rainfall and stocking rate had on animal performance over time shows the importance of rainfall even in a relatively mesic environment (mean rainfall of 782mm). Rainfall has been shown to significantly affect animal performance in a semi-arid savanna (Fynn and O'Connor 2000), but in moist grasslands, stocking rate is usually seen as the primary determinant of animal performance (Kirkman 1999, Kirkman and Morris 1999).

The influence of rainfall was largely observed because the trials experienced extremes of dry and wet seasons (from 505mm to 1203mm between 1993 and 2005). The range of rainfall variation illustrates the importance of long-term trials for elucidating trends in animal performance. Had the trials only been conducted for three or four seasons, the interaction of rainfall and stocking rate would not have been clear.

We hypothesised that the interaction of stocking rate and veld production would influence animal performance. The results of this trial indicated that veld production as measured directly had a very weak effect on animal performance, but that rainfall did influence animal performance. Rainfall presumably influences veld production, although rainfall may have other effects on animal performance, such as the incidence of diseases and parasites, which were not measured.

Additionally, veld production alone does not describe the availability of palatable forage. In some seasons the above-ground production was dominated by unpalatable species (Table 3.9 and Table 3.10).

Veld condition, as calculated in this study by the sum of *Themeda*, *Tristachya* and *Heteropogon*, had no measurable influence on animal performance. This was somewhat surprising, as species composition is used as to calculate carrying capacity in many different models. However, it appears that, within the range of veld conditions experienced in the current trials, veld condition had far less effect on animal performance than stocking rate, rainfall and other management factors.

The predator attacks experienced during the course of the trials may have profoundly affected the performance of the surviving animals. In many seasons, there were paddocks in which most animals lost weight in mid-season (data not shown), which may be attributed to predator attacks. The exponential function used to calculate animal performance smoothed out many of the weight fluctuations experienced by the sheep. A review by Howery and DeLiberto (2004) of the indirect effects of predators on livestock showed that livestock performance could decline substantially from the mere threat of predators.

The variation in animal performance in the two replicates of each treatment on the steep trial is instructive (Figure 4.2). The exact location of the paddock in which the animals were grazing may have significantly influenced their performance in any given season. Some paddocks had large drainage lines running through them, which may have served as key grazing resources (Figure 1.4). Other paddocks had medium-sized *Leucosidea sericea* (ouhout) trees located in them (unpublished data), which may have provided shelter and shade for animals. Both of these physical features may have influenced animal performance, but any influence was difficult to isolate with the data available.

The effect of stocking rate on animal performance, as well as the difference in response of animals grazing on the two trials, was clearly illustrated by the cumulative animal performance (Figure 4.3, Table 4.5). On both trials there were significant differences between treatments in both cumulative production per hectare and cumulative individual animal production. However, the results were somewhat counterintuitive. On the steep trial, individual animal performance declined with increasing stocking rate, but production per hectare was still greater after 10 years at the high stocking rate. On the flat trial, the high stocking rate treatment showed better animal performance than the low stocking rate treatment, with a substantially greater annual production per hectare after twelve years.

The two trials also clearly illustrated that results from one site should be interpreted with caution. Even though the two trials were less than a kilometre apart, the difference in results was marked. The two trials cannot be directly compared, as the effect of site was confounded with the class of animals used (ewes vs. hamels). Nonetheless, average daily gain of animals on the flat trial was far less influenced by stocking rate than the animals on the steep trial. The veld of the flat trial was located on deeper soils, and was far more stable in composition than the veld of the steep trial (Chapter 3), indicating that the stability and productivity of the veld markedly influenced animal performance.

Field research trials are classically designed to minimised variation in factors other than the variables of interest to the researcher. However, the results of these two trials demonstrate that small-plot trials must be interpreted with caution before extrapolation to a landscape scale. There is some criticism of small-plot trials in understanding ecosystem processes which operate at the landscape scale, such as fire (Freckleton 2004) or grazing (Teague and Foy 2004). The results from the two trials reported in this work should not be viewed in isolation; indeed, much of the value of the work is from the contrast between the two sites despite the nearly identical location and trial designs.

Management implications

Farmers are generally encouraged to stock veld conservatively (below the estimated grazing capacity of the area) in order to maintain the condition and productivity of the rangeland (Mentis and Tainton 1981, Danckwerts and King 1984b). The Jones and Sandland (1974) model is usually used to demonstrate to farmers that they can achieve better profitability by stocking conservatively. The results of the trials reported here, and others (Campbell *et al.* 2006), show that this approach is simplistic. Animal performance was not consistently depressed by increasing stocking rate, and production per hectare, especially cumulative production per hectare over many years, was clearly greater at higher stocking rates.

A number of workers have proposed grazing management systems that take into account seasonal variation in forage production (Venter and Drewes 1969, Daines 1980, Buntting 2003). The two-block grazing management system tested in these trials was inspired by the observation that stocking rate, rather than grazing management system, is the most important management factor influencing both animal performance and veld condition (O'Reagain and Turner 1992, Briske *et al.* 2008), and that periodic season-long rests are required to restore the vigour of the veld (Tainton *et al.* 1977, Kirkman and Moore 1995b, Peddie *et al.* 1995, Kirkman 1999). However, managers will need to be able to respond to variable rainfall in order to take advantage of increased herbage production in high-rainfall seasons and destock, if necessary, in low-rainfall seasons.

Chapter 5 Conclusions

Veld condition

Species composition was influenced over time by stocking rate, soil depth, and the proportion of sheep, with species composition shifting to a state dominated by grazing-tolerant, unpalatable species such as *Microchloa caffra*, *Diheteropogon filifolius* and *Alloteropsis semialata* at higher stocking rates, at a higher proportion of sheep, and on shallower soils. However, species composition did not respond consistently to proportion of sheep, with the flat, two-camp, sheep-only trial remaining stable over time in contrast to the sheep-only treatments on the adjacent simulation trial. The two sheep-only treatments appeared to shift fairly rapidly in the first decade of the simulation trial to a new stable state, where they remained stable for the second decade of the trial.

The response of *Themeda triandra*, generally considered the most important grazing grass in Highland Sourveld and an indicator of the condition of veld, did not respond consistently to grazing pressure, even within one trial. *Tristachya leucothrix* declined with grazing across all the trials. *Diheteropogon filifolius*, a wiregrass associated with selective grazing, remained stable or declined at high stocking rates and under no grazing, and increased at intermediate stocking rates, supporting the “selective grazing” response model.

The dry-weight-rank survey showed few significant responses of individual species to grazing treatment.

Veld productivity

Veld productivity declined significantly with increasing stocking rate, despite frequent season-long rests, on both two-camp trials. Standing crop also increased with increasing proportion sheep on the simulation trial, consistent with the selective grazing behaviour of sheep which left quantities of ungrazed material in each camp.

The dry-weight-rank survey showed few significant responses of individual species to stocking rate, but total standing crop did decline with increasing stocking rate, even in rested camps at the end of the growing season. However, the apparent lack of significant response to treatment may have been more a result of the statistical design (only two replicates). For example, the mean crop of *Themeda triandra* in the low stocking rate on the steep trial at the end of the season was nearly double that of the high stocking rate, in both grazed and rested camps.

Animal performance

Sheep performance declined with increasing rainfall. The decline was probably caused by the increasing grass production in high rainfall seasons, which resulted in large quantities of fibrous material. Sheep require short, green, leafy material, and therefore in seasons of high primary production their performance declined.

Sheep performance declined with increasing stocking rate on the steep trial, but there was also a stocking rate by rainfall interaction, where sheep performed better at high stocking rates in years of high rainfall.

Over a decade, the relatively small effect of stocking rate on sheep performance resulted in significantly higher total production per hectare at high stocking rates. There would be little economic justification for farmers in Highland Sourveld to stock sheep at low stocking rates over the medium term.

Research and management implications

The results of these trials show that veld in Highland Sourveld is resilient to heavy grazing pressure over twenty years. There appear to be inconsistent responses to sheep grazing on the three trials. On the two two-camp trials, the difference in responses of the veld to sheep grazing can be attributed to edaphic effects, with veld on gentle slopes with deep soils being more resilient to grazing than veld on steep slopes with shallow soils. However, the difference in response of the veld between the flat two-camp trial and the adjacent simulation trial is less easily explained. One possible explanation is that the continuous grazing system of the flat trial is better for the veld than the fixed rotational grazing system of the simulation trial. The increase in stocking rate caused by the reduced absent period of the simulation trial must have also contributed to the increased change in composition; however, much of the compositional shift had already occurred before 1998, when the error in trial procedure was introduced.

Much of the Highland Sourveld is mountainous country, with topography similar to that of the steep two-camp trial, and is therefore far more prone to degradation than bottomlands. The steep trial has certainly declined in veld condition over ten years. The conventional wisdom, supported by the results of this research and previous research in sourveld, that sheep should be grazed with cattle, is supported by this trial. However, the continuous grazing system with frequent season-long rests appears to be better for the veld than a fixed rotational system. This option could be explored further with cattle and mixed cattle and sheep.

Future research into some of the issues explored by these grazing experiments should consider working directly with farmers on much larger scales. Grazing effects on species composition and productivity are mitigated by environmental factors, especially soil. However, the effects of scale are important to rangeland dynamics, and are often not addressed by classical small-plot grazing trials with few animals. Most grazing experiments rely on unvarying routines, while farmers adapt their management to changing circumstances, both within the season and over years.

The future of the classical grazing trial needs to be seriously questioned before new trials are established. There are many questions, new and old, that can be examined by conducting research on existing long-term trials or on farms. However, long-term trials, properly conducted, are valuable sources of reliable, regular data than can be examined using techniques not considered by the original designers of the trials. Extrapolating from short-term results to long-term trends can be misleading, as shown by the non-linear species composition change on the sheep-only treatments of the simulation trial – a trend that was only revealed with two decades of data.

The state-and-transition model of Westoby *et al* (1989) appears to be useful approach to managing cool, moist grasslands, and probably more useful to farmers than the one-dimensional successional model. The successional model was partly supported by the research, in that some species (e.g. *Tristachya leucothrix* and *Diheteropogon filifolius*) responded as predicted by the model to grazing pressure. The successional model could be used in conjunction with multiple stable state approach to describe transitions between states. At least two, and possibly three, stable states were identified by the multivariate analysis of the Kokstad species data.

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