CAUSES AND CONSEQUENCES OF FENCELINE CONTRASTS IN NAMIBIAN RANGELAND

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ABSTRACT

Key words: biodiversity; bush encroachment; fenceline contrasts; fire; Namibia; rangeland condition; rangeland management; rest; savanna; stocking rate.

This study made use of the opportunity provided by fenceline contrasts in Namibia to measure differences in rangeland and learn from farmers about the inputs and outputs of management on each side of the fence. The 34 measured contrasts were mostly clustered within the Camelthorn and Thornbush Savannas, with three in the Highland and Dwarf shrub Savannas of Namibia. Mean annual rainfall ranges from 235 to 475 mm.

Rangeland measurements focussed on well established perennial vegetation to avoid the fluctuating effect of ephemerals. Eight characteristics were measured and significant ($P<0.05$) differences occurred in at least one of these at each contrast. Two characteristics (distance from sample point to the nearest perennial grass and the species) were combined to determine a rangeland condition index. At 22 of the 34 contrasts the condition index was significantly ($P<0.05$) higher on one side of the fence.

There was no clear method to distinguish between the influences of different management inputs that may have caused the fenceline contrasts. Therefore, subjective judgment was relied upon to identify bush control as the most likely single causative factor at ten contrasts, stocking rate and period of rest at five contrasts each, and stocking density at two contrasts. Management contributed to both causes and consequences of fenceline contrasts. The negative correlation between stocking rate and rangeland condition index was weak ($r = -0.2575$, $P = 0.04$, $n = 64$), suggesting that there may have been more farms where a higher stocking rate was the cause of poorer rangeland than farms where the higher stocking rate was the consequence of better rangeland raising the carrying capacity. The stronger correlation between profit and income ($r = 0.9288$, $P < 0.001$, $n = 25$) than between profit and expenditure ($r = 0.0267$, $P = 0.899$, $n = 25$), suggests that farmers should focus on reducing non-essential expenditure to increase profitability. Game farming can earn high income, but continuous selective grazing by gregarious game animals may lead to poorer rangeland condition.

Useful lessons were learnt from the case study of an innovative farmer who adapted his management based upon his keen observations of rangeland dynamics. Many of his interventions were strategically timed in relation to rainfall events. There is much that can be learnt by both scientists and other farmers from the management strategies applied by successful farmers who earn a good profit while sustaining the rangeland.

UITTREKSEL

Sleutelwoorde: biodiversiteit; bosverdigting; veldtoestand; grensdraad kontraste; Namibië; rus; savanna; veldbestuur; weidingkapasiteit; vuur.

Hierdie studie het die geleentheid wat deur grensdraad kontraste in Namibië moontlik gemaak is gebruik om veranderinge in plantegroei beide kante van die grensdraad te meet en om kennis in te win van boere omtrent die bestuursinsette- en uitsette aan beide kante van die grensdaad. Die 34 gemete kontraste was meestal binne die kameeldoring en doringbos savanna van Namibië geleë, met drie in die Hoogland savanna en dwerg bossie savanna. Gemiddelde jaarlikse reënval het gewissel van 235 – 475 mm.

Plantegroei metings het gefokus op gevestigde meerjarige plante ten einde die wisselvalligheid van eenjarige plante te vermy. Agt veranderlikes is gemeet en betekenisvolle (P<0.05) verskille in ten minste een veranderlike is by elke kontras gevind. Twee veranderlikes (afstand vanaf metingspunt na die naaste meerjarige gras, asook die spesie) is gekombineer om ‘n veldtoestands indeks te bereken. By 22 van die 34 kontraste was die veldtoestand betekenisvol (P< 0.05) hoër aan die een kant van die grensdraad in vergelyking met die ander kant.

Daar was geen geskikte metode om tussen die bydraes van verskillende bestuursinsette wat moontlike tot die grensdraad kontraste aanleiding gee het, te onderskei nie. Om hierdie rede was dit nodig om op subjektiewe beoordeling te vertrou waarvolgens ontbossing geidentifiseer is as die mees waarskynlike veranderlike wat by 10 kontraste tot die meeste verskille bygedra het. By ‘n verdere vyf kontraste is veelading en rus as die belangrikste veranderlikes geïdentifiseer en veedigtheid by nog twee kontraste. Bestuur het bygedra tot beide die oorsake en gevolge van die grensdraad kontraste. Die negatiewe korrelasie tussen veelading en veldtoestands indeks was swak (r = −0.2575, P = 0.04, n = 64). Hieruit wil dit voorkom of daar meer plase was waar ‘n hoë veelading die oorsaak van swak weiding was teenoor plase waar die hoër veelading die gevolg was van beter weiding wat die weidingkapasiteit verhoog het.

Die sterker korrelasie tussen wins en inkomste (r = 0.9288, P<0.001, n = 25) as tussen wins en uitgawes (r = 0.0267, P = 0.8999) n = 25), is ‘n aanduiding dat boere op die vermindering van nie noodsaaklike uitgawes moet konsentreer ten einde winsgewendheid te verhoog. Wildboere kan ‘n hoër inkomste verdien, maar aanhoudende, selektiewe beweiding deur wildtroppe mag tot swakker weidingtoestande lei.

Uit die gevallestudie van ‘n innoverende boer wat sy bestuur op fyn waarnemings van weiveld dinamika gebaseer het, is waardevolle lesse geleer. Talle van sy bestuursintervensies was met strategiese tydsberekening ten opsigte van reënval toestande geneem. Daar is baie wat deur beide navorsers en mede boere van die bestuurstrategië van suksesvolle boere wat ‘n redelike wins toon en wie hul weiding in ‘n goeie toestand hou, geleer kan word.

DECLARATION

I declare that the dissertation hereby submitted by me for the partial fulfilment of the requirement for the degree of Doctor of Philosophy (Grassland Science) at the University of the Free State is my own independent work, and has not been submitted by me to any other university/faculty. I further cede copyright of the dissertation in favour of the University of the Free State.

Ibo Zimmermann

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CHAPTER 1

INTRODUCTION

1.1 NAMIBIA'S RANGELANDS

Rangelands are broadly defined as all uncultivated land with the potential to support grazing by domestic animals (Thurow, 2008). They occupy most of Namibia's land surface of 823 988 km^2, of which 69% is regarded as semi-arid and 16% as arid (Barnard, 1998). The hyper-arid part of the Namib Desert, occupying 12% of Namibia along the coast in the west, is normally too dry to be regarded as rangeland. The remaining 3% of Namibia in the north east is tropical semi-humid rangeland. An alternative classification system used by De Klerk (2004) defines Namibia's land surface proportions as 37% semi-arid, 33% arid, 22% desert and 8% semi-humid and sub-tropical.

The renewable resources on Namibia's rangelands support numerous livelihoods through production of extensive livestock, game, ecotourism, wood and a wide variety of other veld products. Figures from Namibia's Ministry of Agriculture, Water and Forestry (MAWF, 2005) indicate that in 2004 the production from cattle, sheep and goats contributed just under N$ 1.0 billion to the national economy, while Brown (2006) stated that indigenous biodiversity production systems (dominated by tourism and trophy hunting) in the commercial sector alone contributed N$ 3.2 billion. Of course not all tourism is based upon rangelands, as the Namib Desert and coast also attract tourists. According to Reid *et al*. (2007) the main objective of tourism to Namibia is nature and landscape touring as well as game viewing. Although impossible to accurately quantify, rangelands obviously contribute significantly to the valuable tourism industry. Of the approximately 4 400 freehold farms in Namibia, 667 (15%) were registered for trophy hunting in 2005 (Mendelsohn, 2006). Trophy hunting in the conservancies on communal land is popular, generating N$ 3.6 million for those conservancies in 2005 (NACSO, 2006).

Mendelsohn (2006) identified four major farming systems in Namibia covering 78% of the country. According to this classification, "cattle ranching" dominates in 38% of the country, primarily in the semi-arid rangelands, while "extensive small-stock" dominates in 33 % of the country, primarily in the arid rangelands. The farming system of "small-scale cereals and livestock" covers almost 7% of the country, while "intensive agriculture" occupies only 0.05%. According to figures provided by Mendelsohn (2006), there are about 2 180 000 cattle, 2 400 000 goats and 2 444 000 sheep on Namibia's rangelands.

About 14% of Namibia is covered by national protected areas (Barnard, 1998), including most of the hyper-arid portion of the Namib Desert.

Fencing of rangeland for commercial farming was started in the mid 1920's, although subdivision to allow rotational grazing only progressed beyond 10% of the farms after 1952 through the provision of loans and subsidies (Bester, 1995).

Apart from supporting livelihoods, rangelands also provide essential ecological services, such as carbon sequestration and the control of wind and water. Water is the greatest limiting factor in Namibian rangelands and their condition has an enormous influence on the water use efficiency (Snyman, 1999). The plant taxa that are specialized for coping with Namibia's harsh environment have great potential for use in other places affected by climate change and rangeland degradation (Maggs *et al*., 1994).

Over the past decades most of Namibia's rangelands have degraded, as evidenced by symptoms such as lowered animal production and bush encroachment (De Klerk, 2004). Ward & Ngairorue (2000) measured the herbage standing crop on Namibian commercial farms along a rainfall gradient ranging in mean annual rainfall from 140 to 450 mm. They found that the herbage yield was approximately half that of 50 years previously, which they attribute to long-term heavy grazing. In addition, a large amount of soil and water has been lost, fertility of the remaining soil has declined and plant species composition has worsened. In a systematic vegetation survey by Strohbach (2000), 93% of the 824 plots sampled across a significant part of Namibia's rangelands showed signs of soil erosion.

The dominant erosion processes in Namibian rangelands tend to be wind driven in the flatter rangelands on sands and water driven in the more sloping rangelands on harder textured soils. In the sand plains, a downward spiral of degradation develops when bare patches of soil expand and link up to the extent that the soil and organic debris are blown out of the landscape instead of being trapped by surrounding vegetated patches. This has the potential to turn local degradation into regional desertification (Pringle, 2008a). In the sloping rangelands, gully incision and lowered base levels, often initiated by animal tracks, result in a downward spiral of desiccation and lowered fertility as water, organic debris and soil flow out of the landscape (Pringle & Tinley, 2003).

Strohbach (2001) lamented the lack of baseline data on rangeland condition in Namibia, but he was able to roughly re-locate and survey two sites, one of which had been surveyed by Volk (undated) during 1956 and the other that had been surveyed in 1985 by

Kellner (1986). His follow-up surveys indicated a great reduction in perennial grass cover at both sites and an increase in encroacher species of bush with a corresponding decrease in palatable bushes and dwarf shrubs at the site measured previously in 1956. However, not all of Namibia's rangelands are degraded to the same extent, with some being more degraded than others, and a few remaining in good condition. This diversity of rangeland condition provides learning opportunities, if the causes of their different conditions can be determined by research.

1.2 FENCELINE CONTRASTS

Contrasts between sides of a fenceline usually reflect differences in amount and type of vegetation cover, which may reflect the condition of the rangeland. Rangeland condition is defined by Trollope *et al*. (1990) as "the condition of vegetation in relation to some functional characteristic, normally maximum forage production and resistance to soil erosion". Teague *et al*. (2009) state that rangeland condition "represents the productivity, health and composition of the herbaceous vegetation to provide an index of ecological functional integrity".

Research to determine the impacts of human use on rangeland condition is confounded by the spatial heterogeneity of landscape pattern and climate. Since climate is the major driving force in rangeland ecosystems (Friedel *et al*., 1988), and since rainfall distribution is extremely patchy, the contrast between sites cannot be attributed solely to different treatments unless the sites are sufficiently close together to receive similar rainfall. Furthermore, topography and soil also play a major role in influencing rangeland condition. Their distribution in the landscape similarly confounds research on rangeland impacts, unless the sites being compared are sufficiently close together to occupy the same soil and topography.

Fencelines provide artificial barriers that may divide areas with similar soil and climate into portions between which any difference in rangeland condition is the result of differences in the management treatment applied. The resulting fenceline contrasts assist in dispelling the frequent claim that declining rainfall is responsible for land degradation where long-term rainfall records show no decline (Ward *et al.*, 2000). Fenceline contrasts have been used to study differences in seedling abundance and key processes that influence water and organic carbon fluxes (Sigwela *et al*., 2003), soil quality (Mills & Fey, 2004a), landscape function (Palmer *et al.*, 2001), birds and small mammals (Joubert & Ryan, 1999) and arthropods (Rivers-Moore & Samways, 1996). Fencelines can provide a convenient research tool if they do indeed cut across similar land units. However, this is not always the case because one of the principles of dividing grazing land is to fence off units that are as homogeneous as possible, to ensure their optimal, individual grazing management (Du Toit, 1998). Nevertheless, since fencelines are usually straight, while land unit boundaries are not, it is often possible to find fencelines that do cut across homogenous land units. In addition, the boundaries between farms were often drawn as straight lines on maps, without much regard for land unit boundaries.

Research on secondary determinants of rangeland can either be experimental or incidental. The experimental approach applies different treatments to the rangeland and subsequently measures the resulting differences in rangeland condition (Gammon, 1978). The application of clearly defined treatments, combined with records kept over the duration of the experiment, may allow the causes of any observed differences in rangeland condition to be determined. However, it may take several decades before the results become apparent and heterogeneity in landscape distribution may confound the results (Kruger, 1998). The incidental approach looks for contrasts in rangeland condition, and tries to relate these to the differences in management being applied on each side of the fence. It is obviously quicker than experimental research and largely avoids the main problems of heterogeneity in landscape and climate. However, the main difficulties with this incidental approach are to obtain reliable information on the past and present management applied and to determine when the transitions in state of the rangeland took place.

Care needs to be taken when interpreting fenceline contrasts. Temporary contrasts may occur as a result of ongoing management. For example, one side of the fence may be in the process of being grazed, and therefore short on grass, while across the fence there may be abundant grass, waiting to be grazed (Figure 1.1).

The latter area being grazed a few weeks afterwards may appear identical to the previously grazed area on the other side of the fence. Therefore, it is necessary to determine whether longer-term conditions are really different, by controlling whether the difference has persisted over time. Furthermore, even if the effect of a fenceline has been determined to be persistent, it might just be due to a difference in position along a spatial degradation gradient. For example, one side of the fence might be near a water point, so it may appear to be overgrazed in comparison to the other side of the fence, which is further from water, and yet the management might be identical on both sides of the fence (Figure 1.2).

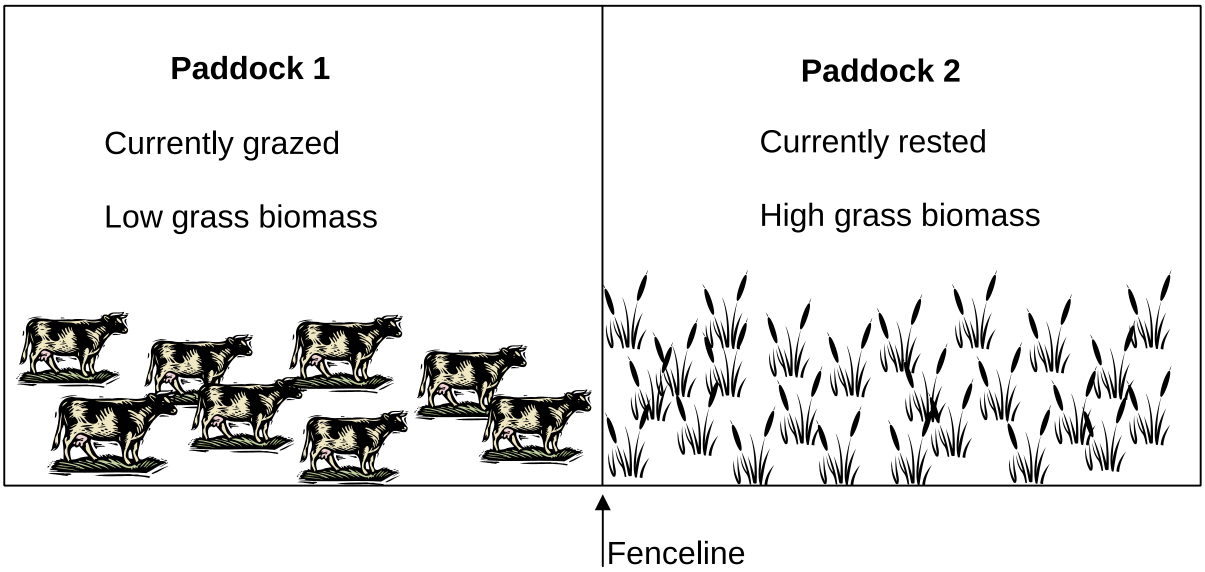


Figure 1.1 Illustration of a temporary fenceline contrast that could result from different stages in a grazing rotation, despite similar management applied to both paddocks.

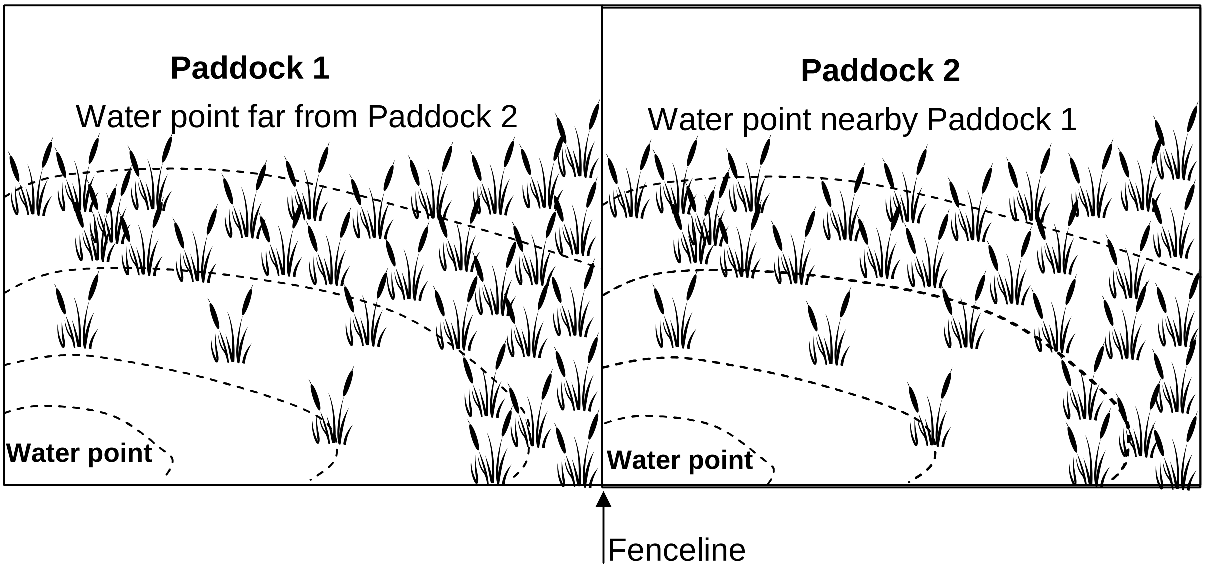


Figure 1.2 Illustration of a fenceline contrast that could result from different piospheres (separated by stippled lines) at the fenceline, despite similar management applied to both paddocks. Although the overall paddocks appear identical, there is a large difference near the fenceline separating them, due to differing distance from the water point.

Therefore it is also necessary to explore potential causes of spatial degradation, such as locating positions of water points and determining whether fires might have stopped at the fenceline shortly before the fenceline contrast was detected.

There are numerous fenceline contrasts in Namibia, which are clearly evident when flying over the rangelands. The contrasts that were brought about by different management practices are a potentially valuable source of information. However, the information about the causes of these contrasts, and their consequences, is rapidly being lost as resettlement brings about changing ownership of the land. Existing knowledge needs to be urgently captured, processed and made available to the land users so that they can make wiser decisions on how to manage the land. This may also be invaluable to the scientific community in order to better understand similar contrasts in other geographical regions.

1.3 OBJECTIVES OF THE STUDY

This study forms part of the Biodiversity Transect Analysis in Africa (BIOTA) programme of which the main focus was "sustainable management of biodiversity in the continent, integrated in a long-term observation system" Krug (2006). Observatories are scattered along transects that follow environmental gradients. The main transect of BIOTA Southern Africa extends from near Cape Town in the Fynbos biome and high winter rainfall zone of South Africa through the low winter rainfall Succulent Karoo biome into the low summer rainfall Nama Karoo biome of southern Namibia, through the Savanna biome of central Namibia, ending in the Woodland biome of northern Namibia with higher summer rainfall. There is also a shorter transect following a rainfall gradient that runs perpendicular to the main transect from the coast and Namib Desert in the west across central Namibia into the Camelthorn Savanna of the Kalahari. Another characteristic of the BIOTA programme is the reliance on para-ecologists, who are members of the nearby communities trained in very basic ecology and research methodology, to assist the BIOTA researchers and provide a link between the researchers and the communities (Araya *et al*., 2009).

The ultimate objective of this study is to achieve improved management of rangeland in Namibian savannas to support livelihoods and maintain ecological support services. In order to achieve this objective, it is necessary to acquire a clearer scientific understanding of management impacts on both the rangelands and people's livelihoods, while participation by land users is imperative to ensure that management is improved by applying the acquired information. The research addresses the following issues:
Which management actions have caused the persistent contrasts across fencelines?
What are the ecological and socio-economic consequences of the differences in management?
How can the acquired information be applied to improve management?

The specific objectives of the study are therefore:
1. To assess various methods of measuring rangeland condition.
2. To compare rangeland condition on both sides of fenceline contrasts.

3. To determine the management inputs that caused the contrasts.
4. To determine the ecological and socio-economic consequences of the contrasts.
5. To publicise the acquired information to encourage improved rangeland management.

1.4 TERMINOLOGY

The terminology used is based on Trollope *et al*. (1990) unless stated otherwise. A notable exception is the way of expressing stocking rate in terms of liveweight of animals per unit area (Van Wyk, 1988). This has become popular in Namibia and is useful to compare with production rates expressed in the same units of kg liveweight ha^{-1} a^{-1}. Since animals normally graze on Namibian rangeland throughout the year, the "a^{-1}" is often omitted from the units used for expressing the stocking rate.

Although neither "mulch" nor "litter" are defined by Trollope *et al*. (1990), they are used interchangeably for loose and dead organic matter on the soil surface. In this study the term "mulch" was used. Similarly, the term "paddock" was used in preference to "camp" for a portion of rangeland that is fenced for animals to periodically or continuously graze in.

CHAPTER 2

STUDY AREA

2.1 INTRODUCTION

Thirty-four fenceline contrasts and six experimental plots were measured in this study. Most of the contrasts were between two farms or two paddocks on the same farm, but five of them were between three farms or paddocks, where boundary fences formed a "T-junction".

The terminology used to describe the different levels of the areas under investigation, is presented in Table 2.1. "Study area" refers to the large portion of central Namibia within which the whole study was conducted. The study focussed on several "clusters" of farms within the study area. A "contrast" comprised a strip along the boundary of neighbouring farms or paddocks, while a "site" was the sample area measured on each side of the contrast. The measurements were taken at or around "sample points" located within each site. Since measurements were also taken at experimental plots at one of the contrasts, these are also presented in Table 2.1, in brackets.

Table 2.3 The hierarchy of names used to describe different levels of areas studied, together with an approximation of their sizes and numbers.

Name of location	Order of magnitude	Number
Study area	10 000 000 ha	1
Cluster of nearby contrasts	100 000 ha	9
Contrast (or group of experimental plots)	10 ha	34 (1)
Site (or single experimental plot)	4 ha	73 (6)
Sample point	0.008 ha	7 300 (600)

Numbers in brackets apply to experimental plots.

2.2 GEOGRAPHICAL LOCATION

The contrasts and plots were clustered in three different directions from Windhoek, occurring in different vegetation types as described by Giess (1971). Contrasts 1-16, to the north of Windhoek, were located in the Thornbush Savanna. Contrasts 17-31, to the east, were located in the Camelthorn Savanna. Contrasts 32 and 33, both between three farms, were located in the Dwarf shrub Savanna to the south-west. Contrast 34, also between three farms, was in the southern extreme of the Highland Savanna of Namibia

(Giess, 1971) but rather resembled the Dwarf shrub Savanna than typical Highland Savanna. Two exclosures and two experimental grazing plots were also located at the latter contrast, on each side of the boundary fence between two of the farms.

A map with approximate locations of studied contrasts in relation to savanna types is presented in Figure 2.1. The locations are only approximate, in order to respect anonymity.

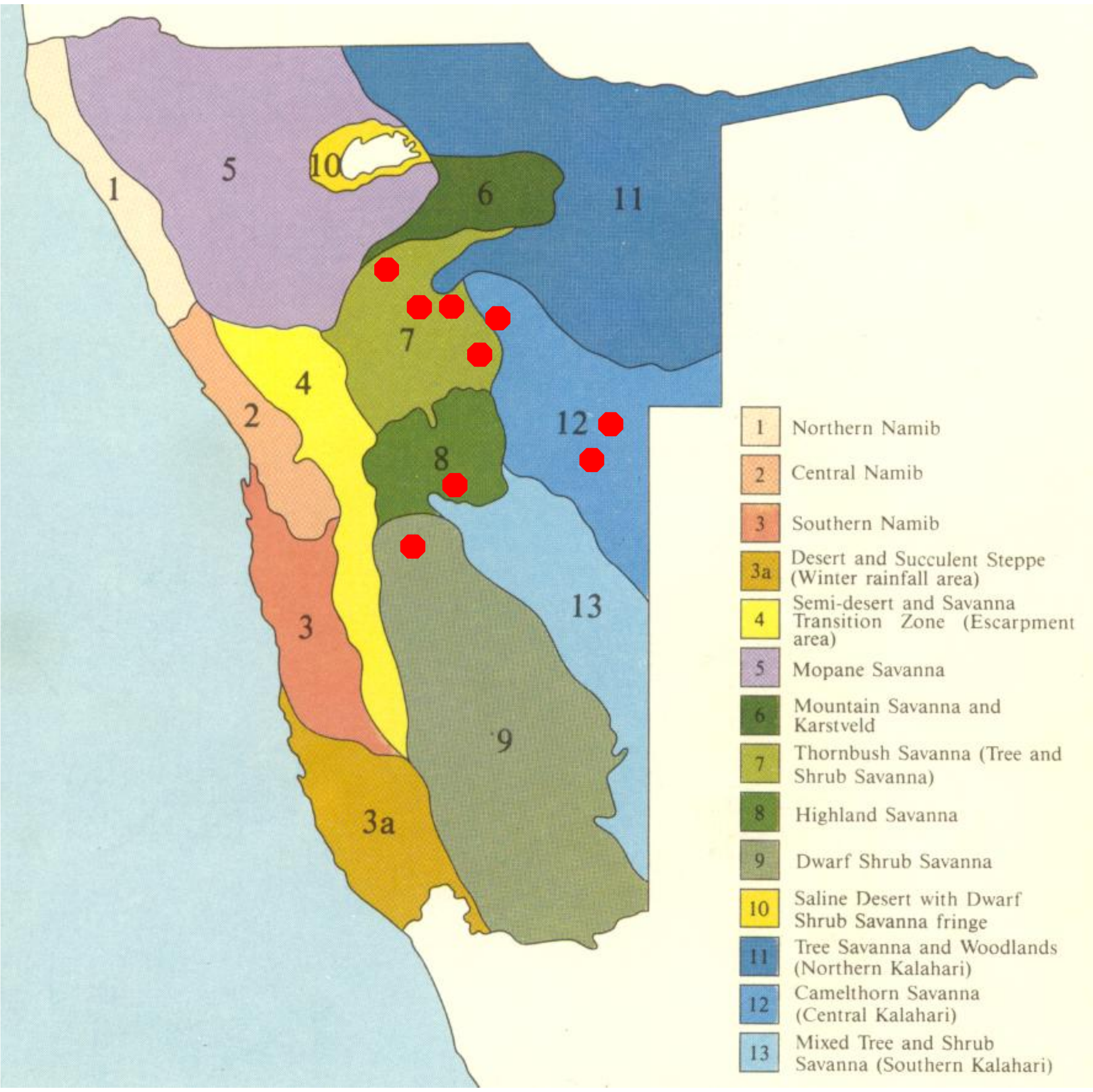


Figure 2.1 Map of savanna types identified by Giess (1971), sourced from Müller (1986), on which approximate locations of clusters of study sites have been marked by red dots.

2.3 GEOLOGY

The geology of the study sites in the Camelthorn Savanna includes limestone and sandstones of the Witvlei Group of the Damara Supergroup; sandstones and conglomerates of the Kuibis and Schwarzrand Subgroup of the Nama Group; and primarily Kalahari sands that suppress the influence of old rock formations lying deep below (Mendelsohn *et al*., 2002). The general lithography of contrasts 1-12 is described by MAWF (2003) as unconsolidated aeolian material, while of contrasts 13-16 it is organic sedimentary rock.

Geology of the study sites in the Thornbush Savanna includes schists of the Swakop and Khomas Groups of the Damara Supergroup, as well as Kalahari sands that suppress the influence of old rock formations lying deep below (Mendelsohn *et al*., 2002). The general lithography of contrasts 17-12 is described by MAWF (2003) as unconsolidated aeolian material, of contrasts 19-28 it is acid metamorphic rock, while of contrasts 29-31 it is organic sedimentary rock.

The geology of the study sites in the Dwarf shrub and Highland Savannas includes limestone and sandstones of the Witvlei Group of the Damara Supergroup; granites of the Gamsberg; associated granites of the Namaqua Metamorphic Complex and related rocks; and complexes of the Rehoboth Group and associated rocks (Mendelsohn *et al*., 2002). The general lithography of contrasts 32-34 is described by MAWF (2003) as acid metamorphic rock.

2.4 LANDSCAPE TYPES

The study sites in the Camelthorn Savanna fall within the landscape classified by De Pauw *et al*. (1999) as Kalahari Sands Plateau, with Contrasts 1-10 and 13-16 furthermore having stabilised sand drift with few pans, while Contrasts 11-12 have stabilised NW-SE dunes with common pans. The plateau is fairly flat, with a regional slope of less than 2% and slightly dissected (MAWF, 2003). The altitude of Contrasts 1-12 varies between 900 and 1 300 m above sea level, while contrasts 13-16 lie between 1 400 and 1 600 m above sea level (Mendelsohn *et al*., 2002).

The study sites in the Thornbush Savanna are also flat and slightly dissected at an altitude of between 900 and 1 300 m above sea level. However, they are classified by De Pauw *et al*. (1999) as Central Plateau, with sub-classifications of southern Omatako plain at Contrast 17; fringe plains at Contrasts 18-28; and red kalkveld at Contrasts 29-31.

Contrast 32 is classified by De Pauw *et al*. (1999) as Escarpment, high plateau on Basement Complex rocks, while Contrasts 33-34 are Central Plateau, strongly dissected inselberg plains of altitudes varying between 1 400 and 1 600 m above sea level. The area of Contrasts 32-33 is dissected and gently undulating with a regional slope of 2-5%, while the area of Contrast 34 is strongly dissected with rock outcrops and undulating, with a regional slope of 5-8% (MAWF, 2003).

2.5 SOIL TYPES

The soil types occurring in the mapping units where the fenceline contrasts were located are presented in Table 2.2. The predominance of sands, along with the dominance of Ferralic Arenosol, is apparent in the Camelthorn Savanna.

Table 2.4 Percentage soil types occurring within the soil mapping units according to the Namibian Agricultural Resources Information System (NARIS) of the Ministry of Agriculture, Water and Forestry, in relation to the fenceline contrasts represented by their numbers in the left hand column.

Fence contrast number	Soil type (FAO classification)								
	Ferralic Arenosol	Petric Calcisol	Arenic-leptic Regosol	Leptic-chromic Cambisols complex	Chromic Cambisol	Haplic Leptosol	Mollic Leptosol	Leptic-mollic Cambisol	Leptic skeletic Regosol
Camelthorn Savanna									
1 - 8	90%	10%							
9 - 10	85%		15%						
11 - 12	90%	10%							
13 - 16		60%		40%					
Thornbush Savanna									
17 - 18	90%	10%							
19 - 28		10%		15%	75%				
29 - 31		20%					40%	40%	
Dwarf shrub Savanna									
32-34		10%				60%			30%

2.6 SOIL CHARACTERISTICS

To help characterise the study sites, topsoil samples to a depth of approximately 17 cm were collected by auger at 10 positions spaced approximately 10 m apart. After thoroughly mixing the 10 samples, a subsample was taken and sent to the laboratory of the Ministry of Agriculture, Water and Forestry (MAWF) for a standard analysis.

The results of the soil analyses are presented in Table 2.3. Due to limited funds it was not possible to analyse the soil of all the sites. The low phosphorous content of these soils limits animal production in Namibia (Grant *et al*., 1996), resulting in low liveweight gains and poor body condition. As a result, most farmers provide phosphate lick to their livestock.

Table 2.3 Results of soil sample analyses carried out by the laboratory of the Ministry of Agriculture, Water and Forestry.

No.[1]	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm	pHw	ECw µS/cm	OM %	$CaCO_3$ % Min	$CaCO_3$ % Max	Texture (% of) Sand	Clay	Silt
Camelthorn Savanna													
1a	0.73	98	276	46	0	6.9	29	0.26	0	0	88.9	3.5	7.5
1b	0.71	68	252	46	0	6.5	27	0.26	0	0	81.5	2.9	15.6
2a	0.90	64	432	32	0	7.3	50	0.52	0	0	90.7	4.3	4.9
2b	1.04	91	368	42	0	7.1	36	0.29	0	0	85.1	6.4	8.6
3b	0.56	116	176	32	12	6.9	137	0.26	0	0	85.7	3.4	10.9
6a	0.70	89	354	40	0	7.1	28	0.50	0	0	89.0	5.0	6.0
7a	0.03	50	262	28	0	6.7	12	0.37	0	0	83.2	9.0	7.7
8a	0.20	70	498	34	0	7.0	51	0.48	0	0	75.3	4.7	20.0
8b	0.27	169	426	36	0	7.1	32	0.39	0	0	80.2	4.1	15.7
10a	1.40	68	158	40	0	6.1	19	0.40	0	0	81.7	4.5	13.8
10a	0.82	47	156	24	0	5.8	16	0.25	0	0	87.9	4.4	7.7
10b	0.75	46	148	38	0	5.6	16	0.36	0	0	80.9	5.3	13.9
10b	0.53	53	152	30	0	5.9	30	0.38	0	0	85.4	5.8	8.8
11a	0.40	51	210	22	1	8.3	20	0.25	0	0	90.4	3.4	6.2
11b	0.18	40	160	18	2	6.1	13	0.29	0	0	92.9	6.1	1.1
11c	0.69	51	212	22	0	7.0	24	0.41	0	0	92.0	2.9	5.0
12a	1.83	47	112	22	2	5.6	14	0.24	0	0	87.0	4.8	8.2
12b	3.32	89	164	30	0	5.7	35	0.36	0	0	85.6	5.5	8.9
13a	3.03	202	212	48	0	6.1	63	0.40	0	0	83.9	9.8	6.4
13b	1.51	165	316	62	0	5.9	25	0.50	0	0	78.4	10.9	10.7
Thornbush Savanna													
17a	1.64	131	172	78	0	6.0	22	0.47	0	0	83.5	8.5	8.0
17b	0.99	118	124	76	0	5.7	24	1.01	0	0	71.4	13.1	15.6
17c	1.67	139	172	114	0	6.1	25	0.59	0	0	63.1	8.0	28.9
18a	1.26	80	134	32	0	5.5	16	0.60	0	0	77.2	8.0	14.8
18b	1.53	123	198	48	0	5.8	19	0.63	0	0	83.9	9.8	6.4
29a	2.10	110	2396	64	0	7.8	115	1.05	0	0	69.4	8.7	21.9
29b	1.70	114	968	50	3	7.6	48	0.68	0	0	78.7	5.2	16.2
30a	1.03	137	1070	62	0	7.7	59	1.24	0	0	76.1	15.1	8.8
30b	0.52	167	1384	86	0	8.1	74	1.13	0	0	77.1	7.4	15.5
31a	4.41	192	3966	152	5	8.1	141	1.59	2	5	59.8	26.5	13.6
31b	6.82	196	2074	106	1	8.2	92	1.40	0	0	74.6	11.8	13.7
Dwarf shrub and Highland Savannas													
32a	2.47	165	286	106	0	6.3	20	0.66	0	0	70.3	8.1	21.6
32b	17.05	199	308	136	0	6.2	38	1.28	0	0	70.4	8.5	21.1
32c	24.48	172	280	120	0	6.3	39	0.71	0	0	73.3	8.4	18.4
33a	1.54	256	502	152	0	7.2	65	1.02	0	0	79.5	4.3	16.2
33b	1.20	181	318	200	0	7.3	33	0.88	0	0	75.7	5.2	19.0
33c	1.44	173	328	192	0	7.2	35	1.11	0	0	76.4	6.3	17.3
34a	0.93	55	2978	28	0	8.4	93	1.22	2	5	66.2	8.5	25.3
34b	0.63	101	1506	40	0	8.7	71	1.05	1	2	72.7	4.1	23.2
34c	0.84	56	2558	30	0	8.4	106	1.32	2	5	65.6	32.5	1.9
RG	0.82	62	3170	22	0	8.6	98	0.35	2	5	66.3	19.4	14.4
CG	0.75	41	2694	30	0	8.6	83	0.28	2	5	80.8	4.4	14.9

[1] The sample number refers to the fenceline contrast and the letter refers to the side of the fence, while capital letters in the last two rows refer to experimental grazing plots.

Although Contrasts 13-16 occurred in a mapping unit dominated by Petric Calcisol (Table 2.2), the collected soil samples did not have any calcium carbonate, while the soil of Contrasts 31 and 34 had, despite the low occurrence of Petric Calcisol in their mapping units.

The texture classes of the soils sampled in each savanna type are summarised in Figure 2.2, with sandy loam dominating samples of both Thornbush and Dwarf shrub Savanna soils, while loamy sand featured in more samples of the Camelthorn Savanna soils.

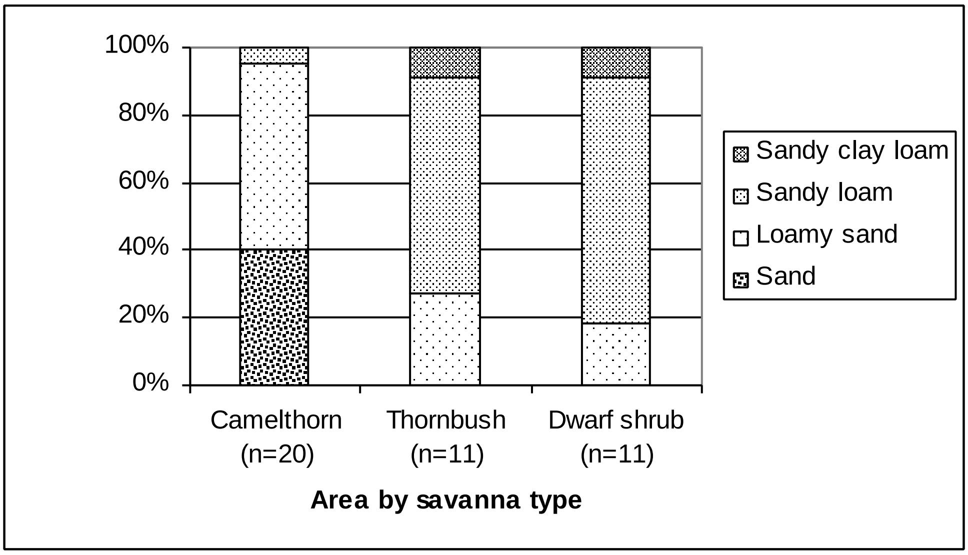


Figure 2.2: Proportion of soil texture classes of soil samples collected in the three different savanna types.

2.7 CLIMATE

2.7.1 Rainfall

All study sites fall within the summer rainfall area, usually receiving most of their rain in the months of January and February. According to maps of Mendelsohn *et al*. (2002) the mean annual rainfall varies from approximately 235 mm at the most southerly sites in the Dwarf shrub Savanna and Camelthorn Savanna, with a coefficient of variation of 60-70%, to approximately 475 mm at the most northerly sites in the Thornbush Savanna, with a coefficient of variation of 30-40%. The mean annual evaporation varies from approximately 2 100 mm at the most southerly site to approximately 1 900 mm at the most northerly site. The long-term mean annual rainfall for clusters of fenceline contrasts is presented in Table 2.4.

Table 2.4 Long-term mean annual rainfall for clusters of fenceline contrasts.

Vegetation type	Fenceline contrast numbers	Mean annual rainfall
Camelthorn Savanna	1-8	320 mm
	9-10	350 mm
	11-12	250 mm
Thornbush Savanna	17	420 mm
	18	400 mm
	19-28	380 mm
	29-31	475 mm
Dwarf Shrub and Highland Savannas	23-33	235 mm
	34	250 mm

Du Pisani (2001) analysed rainfall data collected since 1950 by 286 stations over the whole of Namibia and found a negative trend in the data of 201 stations, a positive trend in the data of 80 stations and a zero trend in data of the remaining five stations. However, these trends are minor, with most less than 10% of the median value per decade (Du Pisani, 2003).

2.7.2 Temperature

According to maps of Mendelsohn *et al*. (2002) the mean maximum temperature during the hottest month is fairly similar for all study sites, at about 32^{o}C, while the mean minimum temperature during the coldest month is about 2 ^{o}C with a mean of roughly 10 days of frost per year. Namibia has experienced an increasing trend in diurnal temperature range and the proportion of hot days since 1960 (New *et al*., 2006).

2.8 VEGETATION

Since vegetation was measured in this study and details will be presented in the Chapters 4-6, only very brief descriptions are given here.

2.8.1 Camelthorn Savanna

Most of the study sites in the Camelthorn Savanna fall within the zone of which the vegetation structure is described as Shrubland-woodland mosaic, except the most southerly which is in Kalahari shrubland (Mendelsohn *et al.*, 2002). Areas with red sands are generally dominated by *Acacia* species, while the less fertile whitish-grey soils are dominated by macrophyllous Combretacae, such as *Terminalia sericea* (Rothauge, 2006).

The free draining Kalahari sands do not hold much capillary water, but where pan layers occur below the soil surface, the extra water trapped there can support different vegetation. According to Tinley (1982), pan layers are made conspicuous by denser and/or taller woody cover in comparison to the surrounding deep horizonless sands. For example, patches of *Acacia erioloba* woodland occur on the crests of convexities that are surrounded by scrub savanna on deep sand.

2.8.2 Thornbush Savanna

All the study sites in the Thornbush Savanna fall within the zone of which the vegetation structure is described as Dense shrubland (Mendelsohn *et al.*, 2002). *Acacia* species predominate and the most common genus of broad-leaf shrub is *Grewia*.

2.8.3 Dwarf shrub and Highland Savannas

The study sites to the south-west of Windhoek fall within the zone of which the vegetation structure is described as Sparse shrubland (Mendelsohn *et al.*, 2002).

CHAPTER 3

PROCEDURE

3.1 INTRODUCTION

The approach to the research was opportunistic, because it depended on the availability of appropriate circumstances, such as the occurrence of fenceline contrasts that were easily accessible and the willingness of the farmers on each side of the fence to be interviewed and have measurements taken of their rangeland. Most of the fieldwork was done with the assistance of students from the Polytechnic of Namibia as part of their training, therefore these study sites had to be in fairly close proximity to a camping site.

3.2 SELECTION OF STUDY SITES

The fenceline contrast in the southern extreme of the Highland Savanna had already been identified by BIOTA and selected for location of two standardised observatories of 1 km^2 each. Identification of fenceline contrasts in the Thornbush and Dwarf shrub Savannas was done by the remote sensing team (S01) of BIOTA, which provided Tagged Image File Format (tiff) files of Landsat images of Namibia, taken on 17 May 2000. Each image had been superimposed with farm boundaries and names, and had clear fenceline contrasts marked on them in red by an automated function in GIS software. The images of portions of the Thornbush Savanna where study sites occurred, are presented in Appendix 1, whereas those for the Highland and Dwarf shrub Savannas are presented in Appendix 2. The images did not cover most of the Camelthorn Savanna, as they had been purchased to cover only the BIOTA observatories at the time. Therefore the identification of fenceline contrasts in the Camelthorn Savanna was based on consultation with farmers met previously and knowledge of the area acquired during previous practical exercises done in the area with students of the Polytechnic of Namibia. Since many of the farmers in the latter area did not have telephones, their farms were visited and permission obtained to proceed with the measurements.

In the Thornbush and Dwarf shrub Savannas, fenceline contrasts suitable for the purpose of the study were identified from the tiff images. Thereafter the names of farmers on both sides were obtained from the data base of the Namibian Agricultural Resources Information System (NARIS) of the Ministry of Agriculture, Water and Forestry (MAWF, 2003). A telephone directory was then consulted in an effort to find the contact numbers of these farmers. Where contact numbers could be established, these farmers were phoned to enquire whether they would be willing to be interviewed and have measurements taken on their land. The farmers willing to participate were asked to provide contact details of their neighbours on the other side of the contrasts. When neighbours were also willing to participate, their details for that contrast were added to a list of potential sites. Thereafter the final selection of fenceline contrasts to be measured was made, also taking into account factors such as accessibility and proximity to a camping site, to ensure a manageable number that would cover a spectrum of management differences.

The most striking contrasts were those where the symptoms of bush encroachment had recently been controlled. Management aimed at controlling the causes of rangeland degradation, such as herbivore and fire management, is likely to provide more useful information, although their fenceline contrasts may not be so striking. Therefore in the final selection of fenceline contrasts to measure, it was attempted to strike a balance between different types of contrast, within the limits of the logistical constraints.

3.3 ESTABLISHMENT OF EXPERIMENTAL PLOTS

Six plots were established as demonstration sites. They were unreplicated due to budgetary limitations and because their main purpose was for demonstration rather than scientific rigour. At the fenceline that separated two of BIOTA's observatories, a plot of 120 x 120 m was fenced on each farm in January 2005 to completely exclude all large herbivores, as part of BIOTA's long-term monitoring programme. Alongside each of these exclosures, a similar sized plot was also fenced, but with a gate to allow grazing by livestock once in the growing season and once in the dry season. The plot was supposed to be grazed by the same animals that graze in the surrounding paddock and at the same overall stocking rate in terms of AU-grazing days ha^{-1}, with the only difference being the provision of a much longer rest. However, since the plot on one farm is about 0.5% of the size of the surrounding paddock, and on the other farm about 0.25% of the surrounding paddock, this would mean the plots would be stocked for only a few hours each season. The livestock herded into the plot for such a short time, did not settle down and graze to the extent that represented their grazing in the surrounding paddock. Therefore instead of basing the stocking on a fixed time period, the BIOTA para-ecologist was asked to keep the animals grazing in the plot until the grass had been grazed down to roughly the same height as that in the surrounding paddock, as subjectively assessed by the para-ecologist. A similar sized plot remained unfenced in the paddock surrounding the exclosure and grazing plot on each farm, to act as the control that received the treatment normally applied by the farmer.

3.4 MEASUREMENTS TO INDICATE RANGELAND CONDITION

3.4.1 Introduction

Methods for on-farm monitoring of indicators of rangeland condition have been proposed by Zimmermann *et al*. (2001a). The methods included fixed point photographs, as a quick and simple method of noting changes over time, and some quantifiable measurements of perennial grasses and bushes. These formed the basis of the measurements of indicators of rangeland condition used in the study of fenceline contrasts. Annual plants were considered less useful as indicators of rangeland condition, due to their tendency to change too rapidly from year to year in response to timing of rainfall events.

3.4.2 Season and year of measurements

Measurements of indicators of rangeland condition were made towards the end of the growing season, in March and April, when perennial grass species could be more easily identified. Some fenceline contrasts were measured in 2004, others in 2005 and yet others in 2006. Shortly after establishment in February 2005, the six experimental plots were measured for baseline data and were subsequently re-measured in 2007 and 2008.

3.4.3 Involvement of students

As part of their training, students of the Polytechnic of Namibia are routinely involved in taking measurements of indicators of rangeland condition (Zimmermann *et al*., 2001b; Zimmermann, 2003). The study of fenceline contrasts also involved students, who measured 24 of the contrasts under the supervision of the researcher. The remaining 10 contrasts and six experimental plots were measured by the researcher and his temporary assistant, who was also a student.

Classes of students who had to take the measurements of rangeland condition, were first provided with training, which started in the classroom to outline the procedure and theory. Later in the field students were taught to identify the plant species occurring there and were taken through some exercises on the measuring procedures. They were then tested on both plant species identification and measurement procedures and their test results were used to allocate the students to groups, in an effort to ensure sufficient competence in each group.

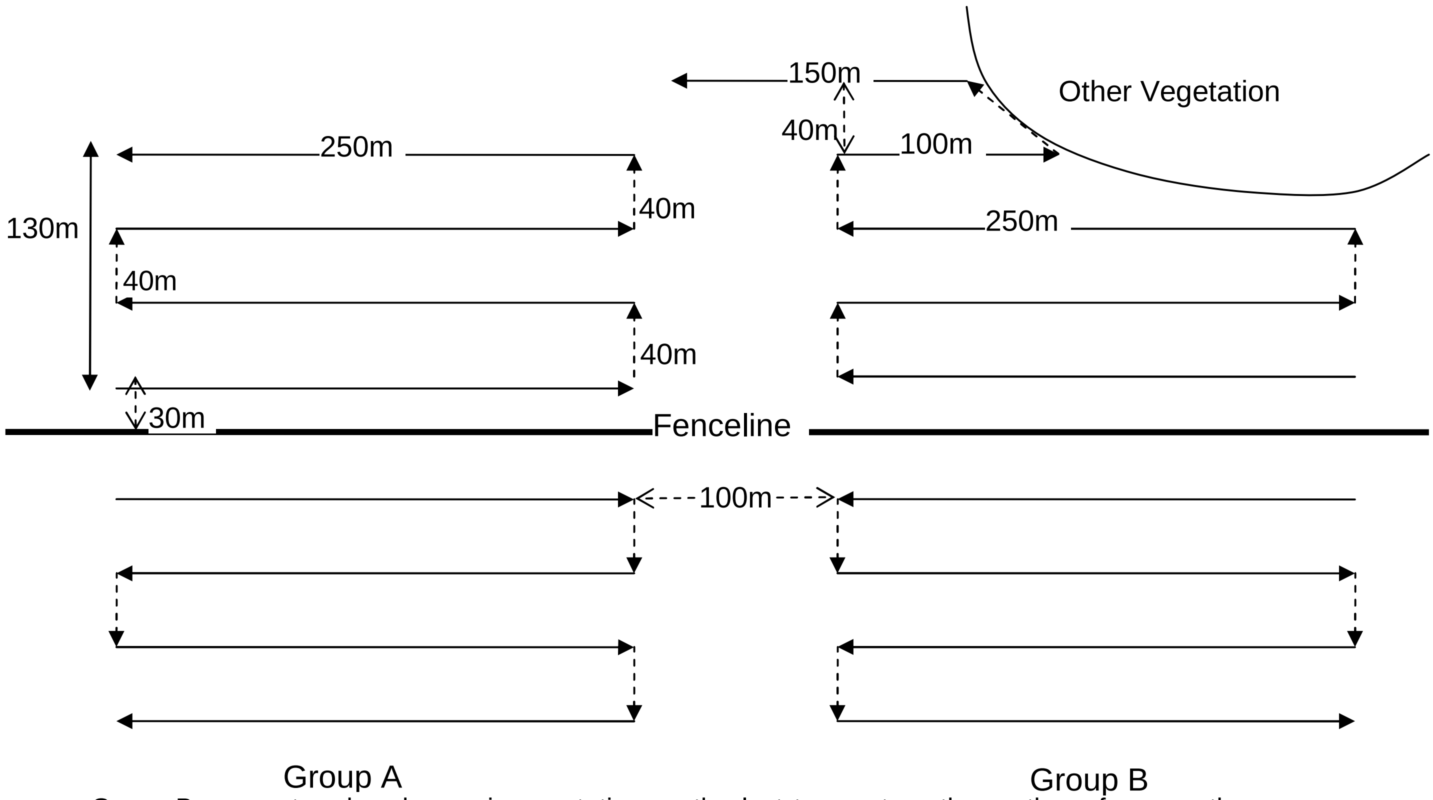
3.4.4 Location of sites and sample points

Measurements of most of the variables used to indicate rangeland characteristics were made at 100 sample points located within a site of approximately 250 x 130 m on each side of the fenceline contrast. Where classes of students assisted, the students were assigned to groups and each group was allocated a site on each side of the fenceline. The sample points were located by roughly uniform pacing along transects combined with a dart thrown over the shoulder, in the same direction as the transect, to provide some randomness. There were 25 dart points per transect and four transects per sample site.

To locate the starting position along the fenceline, a fixed direction and distance in paces were decided beforehand. The distance was paced out, usually from a corner of one of the paddocks, and a mark was made at the fence. The rangeland in the following 250 m along the fenceline, and as far as could be seen each side of the fenceline, was subjectively evaluated for uniformity. In the few instances where the vegetation altered within the 250 m, another distance was decided upon and paced out to mark a new starting position along the fenceline.

A distance of approximately 30 m was then paced out at a right angle to the fence, to locate the starting point of the first transect. When a geographical positioning system (GPS) was available, the coordinates of that position in decimal degrees in WGS84 were recorded. The dart was then thrown over the shoulder to a distance of approximately 2 m, in the same direction as the transect, to add a degree of randomness to the sampling. The position where the dart landed was the first sample point, at which several measurements were taken, as described in section 3.4.6.

The dart was then removed from the ground and a distance of approximately 8 m was paced along the transect, whereafter the body was turned 180^0 to face the direction of the first sample point. The dart was then again thrown over the shoulder to a distance of approximately 2 m in the direction of the transect, to locate the second sample point. The GPS coordinates of the position from where the dart was thrown were recorded, and measurements were taken. This procedure was repeated until the 25th point along the transect, after which a distance of approximately 40 m was paced at right angles to the transect and away from the fenceline, to locate the start of the second transect. The position of the second transect was thus opposite the first transect, so that the 50th point was approximately adjacent to the starting point of the first transect. The same procedure was followed along the third and fourth transects until the 100th point ended up also roughly adjacent to the start of the first transect. Hence there were 25 dart points spaced approximately 10 m apart along four parallel transects spaced approximately 40 m apart as indicated in Figure 3.1.



Group B encountered a change in vegetation on the last transect on the northern farm, so they moved away from it along a new transect to complete the same total length of 1 000 m of transects per site within a relatively homogenous area.

Figure 3.1 Illustration of the positioning of transects (solid arrows) along which measurements were taken by two groups of students in relation to the fenceline and another type of vegetation.

After measuring at 100 points on one side, the fenceline was crossed and measurements were made on the other side in a similar fashion but with the transects appearing more or less as a mirror image of the transects already measured on the first side. Since sampling took place within a 5 m radius of each point, the site covered an area of approximately 250 m x 130 m on each side of the fenceline. When another area was to be sampled on the same side of the fenceline, the starting point of its first transect was spaced approximately 100 m from the previous site, as indicated in Figure 3.1. Groups of students were therefore spaced approximately 350 m apart when taking measurements along the same fenceline.

Whenever a change in vegetation was encountered, a deviation was made to a new transect away from it (Figure 3.1). In the few instances where three farms were measured near to the T-junction of their fences, two transects of 500 m were measured on the farm at the top of the "T", to sample an area opposite each of the sites on the other two farms.

Since the exclosures and grazing plots of 120 x 120 m were too small to be sampled according to the layouts described above, each plot was instead divided into 10 equally spaced transects, approximately 10 m apart, with 10 points sampled per transect. Since measurements were to be repeated at these plots, the direction of each transect was noted and the GPS coordinates in decimal degrees in WGS84 recorded at each position from where the dart was thrown. During follow-up measurements in 2007 and 2008, the GPS was used to relocate the positions from where the dart was to be thrown. As soon as the correct coordinates appeared on the screen of the GPS, the back was turned to the direction of the transect and the dart thrown over the shoulder to a distance of approximately 2 m.

3.4.5 Fixed point photographs

Photographs were taken within each site on each side of the fenceline, with a student standing 10 m from the camera for scale. The GPS coordinates were taken at both the point of the camera and the point where the student was standing. The same longitude coordinate was established for both points, to ensure that the camera was facing south for the central photo, with the student located in the centre. A second photo was taken to the left and a third to the right of the central photo, so that they could be joined for a panoramic view of the sampled area. A fourth photo was then taken of the ground, with the camera tilted about 45^{o} facing south.

3.4.6 Rangeland measurements

The data sheets used for recording measurements are presented in Appendices 3-5. Since annual plants vary significantly from year to year, as do young perennial plants, the measurements focussed on well-established perennial plants that contribute more to stable rangeland conditions. All but one of the measurements were taken at 100 points on each side of the fence, a sufficient number to smooth the running mean for most of the variables (Zimmermann *et al*., 2001a). Measurements were taken of soil cover; canopy cover of woody plants; height class distribution of woody plants; and species composition and density indices of perennial grasses and woody plants taller and shorter than 0.5 m (Table 3.1).

Table 3.1 Summary of the ten rangeland variables that were measured on each side of fencelines.

Variable	Meaning	Units
Hit	Whether dart landed on bare soil, biological soil crust, stone, mulch or base of live perennial grass.	% Frequency
Canop	Species of the tallest woody plant canopy covering the point.	% Frequency
NP	Species of nearest perennial grass of >5 cm basal diameter within 75 cm of sample point.	% Frequency
DistP	Distance from sample point to nearest perennial grass of >5 cm basal diameter within 5m of sample point.	cm
NB	Species of nearest woody plant taller than 0.5 m within 5 m of sample point.	% Frequency
Height class	Height class of the woody plant recorded in NB.	% Frequency
DistB	Distance from sample point to nearest woody plant taller than 0.5 m within 5 m of sample point.	cm
No P	Number of perennial grasses of >5 cm basal diameter within 75 cm of point.	Density (number per unit area, regardless of species)
Woodies	Count of woody plants shorter than 0.5 m within 75 cm of sample point.	Density (number per unit area, separated by species)
Bitterlich	Canopy cover by species of woody plants taller than 0.5 m.	% of ground covered, as calculated from counts per species

The names given to the first eight variables correspond with the column headings of the data sheet in Appendix 3, while Woodies (woody plants shorter than 0.5 m) were recorded on the data sheet in Appendix 4 and Bitterlich (canopy cover of woody plants taller than 0.5 m) was recorded on the data sheet in Appendix 5.

3.4.6.1 Soil cover

The variable of soil cover is abbreviated as “Hit”. Although this may not be a very precise indicator from only 100 points, it is so simple and quick to measure that it was considered worthwhile to include in the measurements. The procedure was as follows:

- At the point where the dart has landed, it was determined whether it struck a stone or rock (R), exposed bare soil (S), soil that was capped with a biological soil crust (C), mulch (M) or the base of a live perennial grass (B). A biological soil crust is usually formed by cyanobacteria and indicated by a dark green or almost black colour. Mulch was considered as any dead organic matter on the surface of the soil, including leaves, stems, bark, seeds, bases of dead grasses and dung.

- The symbol R , S, C, M or B was recorded under the “Hit” column of the data sheet in Appendix 3.
- The numbers of “S”s, “C”s, “M”s, “B”s and “R”s were added to determine the % of each.

Because the basal cover is so low, even in rangeland of good condition, recording of basal hits (B) at 100 points are insufficient and thus not considered to be a reliable estimate of the basal cover. However, basal cover values (B) added to mulch cover values (M) are considered a more reliable estimate of the % soil covered by organic matter.

3.4.6.2 Canopy cover of woody plants taller than 0.5 m

The variable of canopy cover is abbreviated as “Canop” in the point method described below and as “Bitterlich” in the more precise method described later.

To obtain a quick and rough indication of canopy cover, the procedure was as follows:

- At each sample point it was determined whether there was a woody canopy directly above it.
- When there was no canopy directly above the point, “X” was recorded in the “Canop” column of the data sheet in Appendix 3.
- When there was a live canopy directly above the point, then the abbreviation for the species was recorded in the column “Canop” of the point data sheet. Where canopies of two or more bush or tree species covered the point, only the tallest was recorded.
- When there was only a canopy of a dead woody plant over the point, then it was recorded as “DEAD”.
- This procedure was repeated at all 100 points.
- The number of times each species was recorded as canopy, was added up to obtain its approximate % canopy cover estimate.
- The number of canopies recorded of all species was added to obtain the total % canopy cover estimate.

To obtain a more precise measure of canopy cover of woody plants, a Bitterlich gauge was used (Friedel & Chewings, 1988). This is a simple device that represents nothing more than a triangle to provide an angle, as indicated in Figure 3.2. The gauge is held horizontally with the tip of the handle held just below the eye. The gauge is pointed in the direction of a woody canopy, to determine whether the sighting pins extend beyond the canopy, in which case the canopy is ignored, or whether the canopy extends beyond the sighting pins, in which case the canopy is counted.

The method is described by Friedel & Chewings (1988) for various half angles. In this case a half angle of 12º 55' was used. The clumped distribution of some bushes made it difficult to determine where the canopy of one plant ended and another began. Therefore, in cases where canopies in a clump overlapped to form an approximate circle, the whole clump was counted as one individual, even if the canopy of each individual bush did not extend beyond the sighting pins of the Bitterlich gauge. Such a clump was therefore treated as if it were one large canopy instead of several smaller canopies. Hence the final result gives an estimate of the % soil area covered by woody canopy, rather than of the absolute canopy cover, which could in theory be more than 100%.

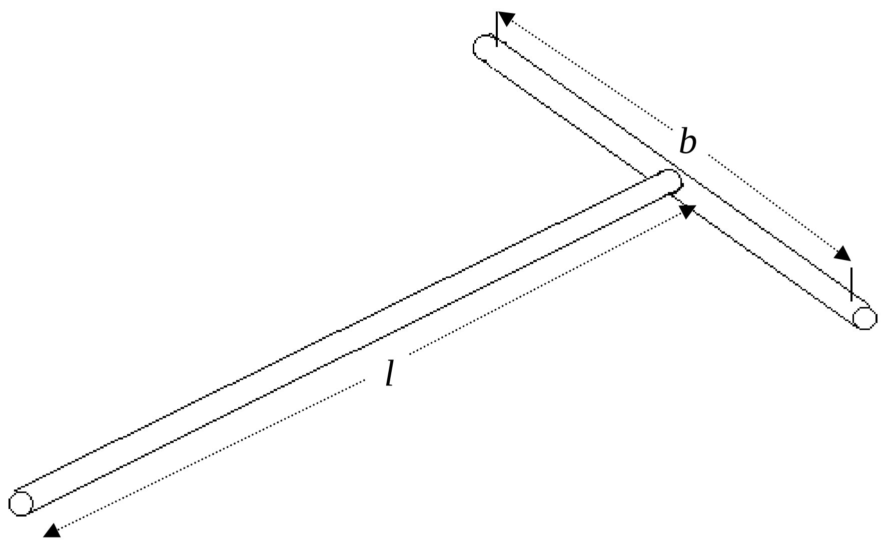


Figure 3.2 Illustration of the Bitterlich gauge, with length of handle l = 75 cm and breadth between the two sighting pins on the cross piece b = 33.54 cm.

The Bitterlich gauge was used at every fourth point along the transects, giving a total of 25 points per site, a sufficient number to dampen the running mean (Zimmermann *et al*., 2001a). The points were identified by shading the numbers on the data sheet presented in Appendix 3. The procedure was as follows:

- At the sample point the direction of the transect was faced and the Bitterlich gauge was held up to the eye.
- The gauge was pointed at any woody canopy along the transect, as presented in Figure 3.4 on page 32.

- When the canopy extended beyond the two sighting pins of the cross piece, it was recorded on the data sheet (Appendix 5). If it was living, the abbreviation of its species was recorded in the column labelled "Species" and a small vertical mark was made in the cell along the row of that species and under the column of that point. When the canopy was dead, while the bush was still standing upright, it was recorded under the "Species" column as "DEAD". When the dead canopy was of a bush that had fallen over, it was regarded as mulch and ignored as canopy. If the canopy was mostly dead, but belonged to a bush that was still alive, it was recorded under its species, as a live bush. When the canopy consisted of overlapping plants of different species, only the dominant species for that canopy was recorded.
- A clockwise turn was made to find the next canopy that extended beyond the sighting pins of the gauge, and it too was recorded. Should this canopy be of the same species, a second mark was made next to the first mark in the same cell. If it was of a different species, the abbreviation of the species was recorded under the "Species" column in the next row, and a mark made in the cell of that point number along that row.
- This procedure was repeated until completing a full turn of 360^o. The mark for the fifth canopy count of the same species at the same point, was made horizontally across the four vertical marks, to ease later tallying in groups of five.
- The percentage canopy cover around that point was estimated by multiplying the number of canopies by five. This is a consequence of the angle of the gauge.
- This procedure was repeated at every fourth sample point, thus rendering 25 points per site.
- To calculate the median canopy cover, the median count was multiplied by 5.
- To calculate the mean canopy cover, the total count of all 25 points was divided by 5, which was used to estimate the canopy cover of the site.
- Species composition of canopy cover was also estimated as described in section 3.4.6.5.

3.4.6.3 Perennial grass species composition

The variable of perennial grass species composition is abbreviated as "NP". Only live perennial grasses that were well established, with a basal diameter of at least 5 cm, were measured. This provides a more stable indication of rangeland condition as it avoids the interference caused by short-lived perennial and annual plants of which the abundance changes dramatically from year to year (Friedel *et al.*, 2000). This might discriminate against some perennial grass species that have smaller tussock diameters, but a more stable indication of rangeland condition is considered preferable to a more accurate measure of perennial grass species. The procedure was as follows:

- The live perennial grass, at least 5 cm in basal diameter and closest to the sample point, was identified.
- When a recently established perennial grass less than 5 cm at the base occurred closer to the point, it was ignored.
- The species of the nearest live perennial grass at least 5 cm in basal diameter, was recorded in the column marked “NP/A” on the data sheet (Appendix 3). An abbreviation was used, made up of the first letter of the genus name, followed by the first three letters of the species name.
- After the species at all 100 points had been recorded, the number of points per species were added to estimate the percentage contribution of that species to the perennial grass species composition of the site. Where no perennial grass of at least 5 cm basal diameter within 5 m of the point was recorded, the percentage contribution to species composition was calculated by dividing the species count by the total number of points that had a perennial grass recorded, and the answer multiplied by 100.

In order to combine perennial grass density with species composition, a pseudo-species called “Bare” was used for points with no perennial grass of at least 5 cm basal diameter within a given distance of the point. The procedure was as follows:

- A cut-off distance was determined between the dart point and the nearest live perennial grass of at least 5 cm basal diameter, beyond which the species name was changed to a pseudo-species called “Bare”. In this study, cut-off distances of 100 cm and 30 cm were used, but since the distance was in any case measured up to a maximum of 5 m, the data could easily be re-analysed, using a different cut-off distance.
- After the species had been recorded at all 100 points, the number of points of each species was added to estimate the percentage contribution of that species to the perennial grass species composition of the site, including the pseudo-species “Bare”.

3.4.6.4 Distance to nearest perennial grass

The variable of distance to nearest perennial grass is abbreviated as “DistP”. Measurements of distance were used both as a direct index, for comparison to the other side of the fence, and as a converted density index. The procedure was as follows:

- A 5 m tape was used to measure the distance from the point to the base of the grass that was recorded as the nearest perennial grass (column “NP/A” in the data sheet in

Appendix 3). The distance was rounded off to the nearest cm and recorded in column "DistP" on the data sheet.

- When there was no live perennial grass of at least 5 cm basal diameter within 5 m of the sample point, ">5m" was entered under "DistP", and the abbreviation of the nearest annual grass or perennial grass less than 5 cm basal diameter was recorded under "NP/A". When there was no grass whatsoever within 5 m of the point, "X" was entered under "NP/A".
- After recording all 100 points, the median distance was determined when there were more than 50 that had live perennial grass at least 5 cm in basal diameter within 5 m of the point.
- The median distance was converted to an index of density, using Formula A below:

Formula A: Density index, in plants m^{-2} $= \frac{10\ 000}{2\pi \times d^2}$

where π = Pi, and d = the median distance in cm from the sample point to the nearest live perennial grass of at least 5 cm basal diameter.

- Where 50 or more points under "DistP" had been recorded as ">5m", the remaining points were used to determine the median distance that was applied to Formula A to obtain an inaccurate density estimate. It was then converted to an improved estimate by using Formula B below:

Formula B: Density index in plants m^{-2} = Answer from Formula A x $\frac{(100 - b)}{100}$

where b = the percentage of bare points, with no perennial grass within 5 m.

Formula A is an adaptation of a formula by Mueller-Dombois & Ellenberg (1974), using median distance instead of mean distance, because: (i) the distribution of distances is skewed; and (ii) the mean could not be calculated whenever there had been no perennial grasses within 5 m of any sample point. The adaptation assumed that the median distance represents the radius which, when converted to area, represents half of the area available per plant, since there is an equal probability of the dart landing within this radius to the nearest plant and landing beyond this radius. Formula B above assumes that the density was zero at points where there was no perennial grass within 5 m radius.

The density measure obtained by these formulae is still only an index, because it does not account for the degree of clumping amongst the plants (McNeill *et al*., 1997), and therefore underestimates the true density. It could, however, be useful for comparative purposes, especially between sites that have more or less the same degree of clumping.

The inclusion of distance measurements from points to nearest plants allows not only the determination of a density index, but also the characterization of bare patch size frequencies (Friedel *et al*., 2000). A visual impression was obtained by plotting frequencies of distance to nearest perennial grass (DistP) classes on bar charts, where distances exceeded one metre.

3.4.6.5 Bush and tree species composition

Only live bushes or trees of at least 0.5 m in height were measured. The procedure was similar to that for perennial grass species composition, as follows:

- The live tree or bush of at least 0.5 m, occurring closest to the sample point, was identified.
- The species was recorded in the column marked “NB” on the data sheet (Appendix 3). An abbreviation was used, composed of the first letter of the genus name, followed by the first three letters of the species name.
- If there were no woody plants at least 0.5 m in height within 5 m of the point, “X” was recorded under NB.
- After recording at all 100 points, the number of points of each species were added to estimate the percent contribution of that species to the woody plant species composition of the site. This included a pseudo-species “Bare” for points with no woody plants at least 0.5 m in height within 5 m of the point.

Since the Bitterlich data collected by the method described in section 3.4.6.2 usually provided more than the 100 counts that nearest bush (NB) provided, it could give a more precise indication of bush and tree species composition, although by canopy cover rather than by number of plants. To calculate the percentage contribution of a species to canopy cover, the count of that species was divided by the total count of all species at that site and the answer was multiplied by 100.

3.4.6.6 Distance to nearest tree or bush taller than 0.5 m

As already mentioned for perennial grasses in section 3.4.6.4 above, measurements of distance were used both as a direct index, for comparison to the other side of the fence, and as a converted density index. The procedure was similar to that for grasses, but the units and formula for the density index, differed as follows:

- A tape measure was used to measure at ground level the distance from the point to the stem of the nearest bush (recorded under column “NB” in the data sheet presented in Appendix 3). The distance was rounded off to the nearest cm and recorded under "DistB" in the data sheet (Appendix 3).

- When there were no woody plants of >0.5m in height within 5m of the point, ">5 m" was recorded under "DistB".
- After recording at all 100 points, the median distance was determined when fewer than 50 points were recorded as ">5m" under "DistB".
- The median distance measurement was converted to an index of density, using Formula C below:

<u>Formula C</u>: Density index, in plants/ha = $\frac{100\,000\,000}{2\pi \times d^2}$

where π = Pi, and d = the median distance in cm from the sample point to the nearest live perennial grass of at least 5 cm basal diameter.

- Where 50 or more points had been recorded under "DistB" as ">5m", the median distance was determined using the remaining points and was applied to Formula C to obtain an inaccurate estimate that was then converted to an improved estimate by using Formula D below:

<u>Formula D</u>: Density index in plants/ha = Answer from Formula C x $\frac{(100 - b)}{100}$

where b = the percentage of bare points, with no perennial grass within 5 m.

3.4.6.7 Height classes of bushes and trees

The height class of each live bush or tree of 0.5 m or taller, sampled for the species composition and distance measurements, was also determined. The eight height classes were: 0.5-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m, 5-6 m, 6-8 m and >8 m. The procedure used to record the height class, was as follows:

- The height from ground level to the highest living part of the bush or tree was determined.
- If the bush or tree clearly fell within a particular height class, as determined by subjective judgment based on experience, no measurement was needed.
- In borderline cases of bushes, the height was determined directly with a tape measure.
- In the case of borderline trees, the height was estimated by asking a student to stand against the tree trunk, holding the 2 m mark on the tape measure, which was held vertically with 0 m at ground level. Then, from a distance of at least 10 m, the length of a pen held in an outstretched arm, was marked to represent that 2 m, with the top of the pen at the 2 m height of the tree and a thumb marking the ground level. The pen was then moved upward so that the thumb rested level with the 2 m height on the tree and the top of the pen then represented approximately 4 m.

- The relevant cell was ticked on the data sheet in the row for that point and the column representing the height class.
- After recording at all 100 points, the percentage of each height class was determined for all bushes and trees together or for dominant species only. When the percentage of each height class was required for all bushes and trees, and when 100 bushes and trees were counted (indicated by no "X" column NB in the data sheet) the percentage of any height class was simply the number counted in that height class (frequency).
- When fewer than 100 bushes and trees had been sampled, if there had been no bush within 5 m of any point, the percentage of each height class (either of all species or a particular dominant species, whichever information was required) was calculated by dividing the frequency of that height class by the number of bushes and trees sampled and multiplying it by 100.

3.4.6.8 Density counts of certain types of plants

The density of certain types of plants was estimated by counting them in sample plots. These plants included perennial grasses of at least 5 cm basal diameter, bush and tree seedlings and saplings lower than 0.5 m, as well as designated forbs and dwarf shrubs that were considered to be important. At one location a new contrast resulted from a recent management intervention on one side of the fence. All perennial grass plants were then counted, regardless their basal diameter, to determine the short-term effect of the recent management. At all sites all perennial grass species were grouped together, but the other types of plants were separated according to species.

A circular plot was selected in preference to a square or rectangular plot, because it is convenient to determine whether a plant near the boundary is actually in the plot or not, without having to mark out the boundary. The Bitterlich gauge handle was used as the 75 cm radius of the circle, rendering a plot size of 1.766 m^2.

A difficulty with this method is differentiating between individual plants, without having to dig to find out whether two plants that appear separated above ground, are connected underground. Therefore a rule was established beforehand to consider any stems or tussocks that emerged from the ground at least 5 cm apart, as separate plants, and conversely, to consider any stems or tussocks that emerged from the ground less than 5 cm apart as the same plant. Perennial grasses of at least 5 cm basal diameter are indicated in the hypothetical example (Figure 3.3).

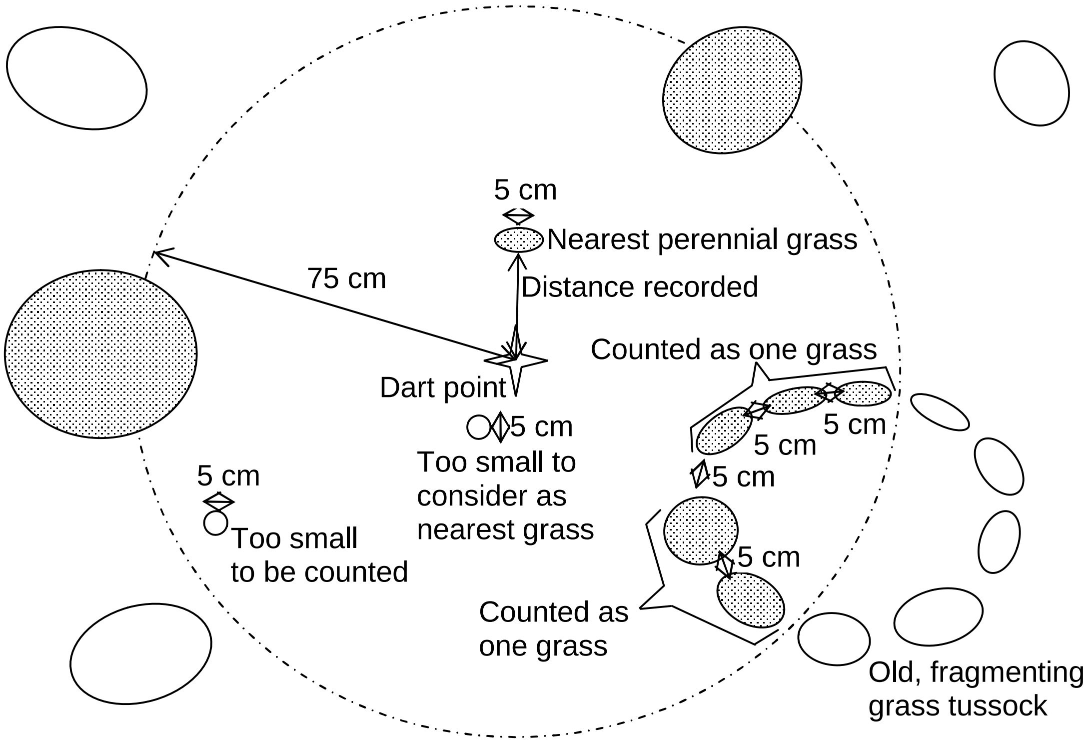


Figure 3.3 Hypothetical view of perennial grass bases surrounding the dart point to illustrate: (i) the plant that is recorded as the nearest perennial grass with a basal diameter of at least 5 cm; (ii) how the distance is measured from the dart point to the base of a plant; and (iii) which grasses (shaded) are counted within 75 cm of the dart point, according to the rule set beforehand (in this case giving a count of five).

The procedure used for the density count was as follows:

- One tip of the cross piece of the Bitterlich gauge was placed at the dart point, while holding it above, at the other tip, as presented in Figure 3.5.
- A type of plant to be counted was selected if noted to grow within 75 cm of the point.
- The long handle of the Bitterlich gauge was pointed in the direction of the transect and then twirled around clockwise, while looking down from above and counting all plants of the selected type that it crossed, until completing 360^0 and ending up facing the transect again.
- The number of selected plants counted, was recorded on the relevant data sheet.
- In the case of perennial grasses, the number counted was recorded under “No P” in the points data sheet (Appendix 3).
- In the case of small woody plants and designated forbs, the number of the point was recorded at the top of the column on the data sheet for short woody plants (Appendix 4). If not already known, the number was found by looking at the points data sheet (Appendix 3).
- When the species name already appeared on the left of the data sheet, the row for age of plant was selected, according to whether it was a seedling that germinated during the current season(s), or an older plant (o).

- That selected row was followed towards the right until meeting the column with that point number, and in that cell the number of plants of the same species and age category were recorded.
- If the species name did not already appear on the data sheet, then it was recorded in the next row down from where the previous species was recorded.
- When there was no perennial grass of at least 5 cm basal diameter within 75 cm of the point, then zero was recorded under “No P” on the data sheet (Appendix 3).
- If there was no small woody plant or designated forb within 75 cm of the point, nothing was recorded on the data sheet of Appendix 4.
- This procedure was repeated for any other species of the selected type of plant (if not a grass) and other types of plants to be counted by this method, if they occurred within 75 cm of the dart point.
- This procedure was repeated at all 100 sample points of the site.
- The density was estimated from the mean by using Formula E for grasses or Formula F for the other plants:

Formula E:

$$\text{Number of plants per ha} = \frac{\text{Total number of plants counted in all 100 plots}}{176.6}$$

Formula F:

$$\text{Number of plants per ha} = \frac{\text{Number of plants counted in all 100 plots}}{0.01766}$$

Figure 3.4 The Bitterlich gauge being used for its original purpose, to estimate the canopy cover of bushes and trees. In this case the canopies to the right of the observer, which were counted because their canopies extended beyond the pins of the gauge, were the *Acacia mellifera* tree in the background, the *Grewia retinervis* bush in between, and the young *Terminalia sericea* to the right.

Figure 3.5 The Bitterlich gauge being used for its supplementary role of twirling around 360^{o} while counting the perennial grasses that were crossed by the handle, in order to estimate the density of perennial grasses. In this case three grasses were counted inside the circular plot of 1.776 m^{2}.

3.4.6.9 Soil water content

The soil water content was measured only at Contrast 12, to determine whether soil water could be conserved by strategically applied trampling that had been applied on one side of the fence. The water content was measured once at the end of the rainy season in April and once in the middle of the dry season in July. It was only measured at two sample points on each side of the fence, using an auger to collect soil from different depths down to approximately 1 m. Each sample was placed in a strong plastic bag that was tied and subsequently weighed before and after drying to constant weight in an oven at 60^{o}C. The mass of the empty bag was subtracted from both moist and dry weights.

3.4.6.10 Soil compaction

Soil compaction was measured only at another contrast, Contrast 22, with sandy clay loam. It was measured to determine whether the long-term use of the rangeland for hay production had altered the soil compaction in comparison to the natural rangeland on the other side of the fence. A crude penetrometer was used, consisting of a steel soil probe that was made of a 12 mm round bar sharpened at one end and bent to form a handle at the other end. It was pressed at a right angle into the dry ground, 20 paces away from the fence, and the weight of the same student was applied to it as a single jump on top of it, while holding the handle with both hands (Figure 3.6). The probe was subsequently pulled from the soil and the depth that it penetrated the soil was measured to the nearest 0.5 cm. This procedure was repeated at 50 points spaced two paces apart along the transect parallel to the fence on each side of the contrast. Three such transects were measured, approximately 200 m apart.

Figure 3.6 Jumping on the top of a soil probe to press it into the ground at Site 22b to determine compaction of the soil by measuring how deep it penetrated.

3.5 DATA PROCESSING

3.5.1 Entering data onto spreadsheet

Field data were entered onto an Excel spreadsheet (Microsoft Corporation, 2003), mostly in a similar way as the data sheets had been filled in. One exception was the height class data. On the data sheet the appropriate cell had been ticked, but in the spreadsheet the letter "H" was entered, followed immediately by a number between "0" and "8", with zero indicating that there was no bush taller than 0.5 m within 5 m of the point, represented by "H0". If the nearest bush was between 0.5 m and 1 m tall, "H1" was entered, and if between 1 m and 2 m "H2" was entered up to "H7" for trees between 6 m and 8 m tall, and "H8" for trees beyond 8 m in height. The letter was placed in front of the number to ensure that it would be recognised as categorical data instead of numerical data when performing the pivot table analysis. Another exception was made when the distance to nearest perennial grass (DistP) or distance to nearest bush (DistB) was recorded as ">5m" on the data sheet, in which case the number "1 000" was typed into the relevant cell on the spreadsheet. This was done to ensure that when median distances were calculated, these cases would be included in the formulae, instead of being ignored as non-numerical data.

3.5.2 Controlling reliability of data

Some formulae were added to the spreadsheet in order to identify cases of data errors, where the conditions for recording the data had clearly not been met. When the following were found, the row of the spreadsheet was marked to indicate that it was suspect and likely to contain some incorrect data.

- If "No P" was more than zero and "DistP" was more than 75 cm.
- If "Hit" was "B" for base of perennial grass and "DistP" was not zero.
- If "NB" was "X" for nearest bush and "DistB" was not 1000.
- If "Height class" was "H0" and "DistB" was not 1000.
- If "Canop" was "X" and "DistB" was less than 50 cm, unless "Height class" was less than 1 m since it could theoretically be possible for a small bush to have a canopy narrower than 50 cm from the stem of a small bush.
- If "Canop" was not "X" or "DEAD" and "DistB" was more than 200 cm, unless "Height class" was bigger than "H4", since it is theoretically possible to have a canopy stretching more than 200 cm from a tree trunk with no other woody plant of less than 50 cm in height being closer.

The data in marked rows were then compared with the data of the corresponding rows on the data sheet and errors corrected on the spreadsheet. In the few cases where many rows were marked in the spreadsheet, the data from that group of students were treated as unreliable and discarded.

Another control was implemented by comparing the woody canopy cover estimated by points to that estimated by Bitterlich gauge on the same site. A significantly higher cover by Bitterlich gauge suggested that the students had been avoiding bushes when pacing their transects, while a significantly higher cover by points identified those who may have sought shade when taking their measurements. It became clear that a few groups of students had not understood the method of counting by Bitterlich gauge and hence their data were discarded.

There were several groups of students who had mistakenly recorded an annual grass species as nearest perennial grass (NP), distance to nearest perennial grass (DistP) and count of perennial grasses (No P), so their data, for at least these three variables, were also discarded.

Out of the 76 surveys undertaken by students, seven (9%) were discarded for such reasons of unreliability.

3.5.3 Summarising the data

Pivot tables were used to obtain frequency estimates of the different variables measured as a single category per sample point. Since 100 points were sampled per site, the frequencies were equivalent to percentages. The variables on which the pivot table analyses were performed directly are soil cover (Hit), canopy cover by points (Canop) and height class of bushes and trees. In the case of the nearest perennial grass (NP), two extra columns were inserted to the right of the NP column, for formulae that converted species abbreviations of plants more than 100 cm and 30 cm from the point, to the pseudo-species “Bare”. In the case of the nearest bush (NB), one extra column was inserted to the right of each of the NB column, for a formula that converted species abbreviations of bushes more than 500 cm, to the pseudo-species “Bare”. The pivot table analyses were then performed on the data in these inserted columns.

The median was calculated in the case of distance to nearest perennial grass (DistP) and distance to nearest bush or tree (DistB). Both the median and the mean were calculated for: (i) count of perennial grasses (No P); (ii) count of woody plants shorter than 0.5 m

(Woodies); and (iii) canopy cover by Bitterlich gauge of woody plants at least 0.5 m in height (Bitterlich). The median was used to indicate dispersion of the data, while the mean was used to estimate the density of perennial grasses (No P); density of woody plants shorter than 0.5 m (Woodies); and canopy cover by Bitterlich gauge of woody plants at least 0.5 m in height (Bitterlich).

3.5.4 Composite variables

Data of some variables were combined to form composite variables. To obtain the density index of a particular species of bush or tree, the overall density index of the site, as calculated from distance to nearest bush or tree (DistB), was multiplied by the proportion of that species in the nearest bush data (NB). Similar combinations were applied to estimate densities of mesophytic grasses, encroacher bushes and palatable dwarf shrubs. Another composite variable was an estimated index of rangeland condition, discussed in section 3.5.5. A few further combinations of variables were applied to ordination analysis, as described in section 3.5.6.11.

3.5.5 Calculation of rangeland condition index

An estimated index of rangeland condition was calculated for each site by adapting the ecological index method that was, according to Pienaar (2006), developed by Vorster (1982) and revised by Heard *et al.* (1986). This makes use of the perennial grass species composition and a relative index value for each species according to its ecological status. The method assigns a relative index value of 10 to Decreaser species, 7 to Ia and IIa species, 4 to Increaser IIb species and 1 to Increaser IIc (Vorster, 1982, as cited by Pienaar, 2006). Since this method has been applied to South African conditions (Pienaar, 2006), the relative index values are unlikely to be the same for the same species under Namibian conditions.

Namibian grass species were described by Müller (2007), who did not assign ecological status of Decreasers and different types of Increasers to the Namibian grass species. Therefore an alternative method of assigning relative index values to Namibian species was adopted by using two criteria given by Müller (2007). These were the rangeland trend associated with the species and the grazing value of the species, both of which Müller (2007) divided into three categories. The relative index values assigned subjectively to different criteria combinations are presented in Table 3.2. Slightly more weight was accorded to rangeland trend than to grazing value when subjectively assigning the relative index values for the species listed in Table 3.3.

The Namibian species found in this study were assigned relative index values of 10, 8, 5, 3 and 1, which differ slightly from the values of 10, 7, 4 and 1 assigned by Pienaar (2006). In addition, the pseudo-species “Bare” was assigned a relative index value of zero in this adapted method. This applied to all points where there was no perennial grass at least 5 cm in basal diameter within 30 cm of the point, as used by Zimmermann *et al*. (2001a) in the Camelthorn Savanna and by Smit & Rethman (1999) in South Africa. The adaptations are justified by the need to: (i) include both the criteria of rangeland trend as well as gazing value in the relative index value, and (ii) differentiate between a patch of rangeland that has at least a poor quality and status of perennial grass within a radius of 30 cm (assigned a relative index value of one) and a similar size patch that has no perennial grass (assigned a relative index value of zero).

Each sample point was allocated its relative index value according to the species of perennial grass recorded at the point, including the pseudo-species “Bare”. The relative index values were then added to obtain the rangeland condition index of the site.

Table 3.2 Relative index values assigned subjectively to grass species according to combinations of the criteria of grazing value and rangeland trend assigned by Müller (2007).

	Rangeland trend the species is associated with		
Grazing value	Improvement	Transition	Deterioration
High	10	7	3
Average	8	5	2
Low	7	3	1

Shaded cells are the only criteria combinations assigned to the grass species in this study

The rangeland condition indices obtained by this method may be useful to compare sites on each side of fenceline contrasts, but less useful for comparison between contrasts spaced far apart because it was not related to the condition of benchmark sites for the different areas.

Table 3.3 Relative index values assigned subjectively to the grass species in this study, as derived from the grazing value and rangeland trend assigned by Müller (2007).

Genus	species	Code	Grazing value	Rangeland trend	Relative index value
Andropogon	*chinensis*	ACHI	High	Improvement	10
Anthephora	*pubescens*	APUB	High	Improvement	10
Aristida	*congesta*	ACON	Low	Deterioration	1
Aristida	*meridionalis*	AMER	Average	Transition	5
Aristida	*stipitata*	ASTI	Low	Deterioration	1
Bothriochloa	*radicans*	BRAD	Low	Deterioration	1
Brachiaria	*nigropedata*	BNIG	High	Improvement	10
Cenchrus	*ciliaris*	CCIL	High	Improvement	10
Enneapogon	*scoparius*	ESCO	High	Improvement	10
Eragrostis	*bicolor*	EBIC	Low	Transition	3
Eragrostis	*echinochloidea*	EECH	Average	Transition	5
Eragrostis	*lehmanniana*	ELEH	Average	Transition	5
Eragrostis	*nindensis*	ENIN	Average	Transition	5
Eragrostis	*pallens*	EPAL	Low	Transition	3
Eragrostis	*rigidior*	ERIG	Average	Transition	5
Eragrostis	*rotifer*	EROT	Average	Transition	5
Eragrostis	*tricophora*	ETRI	Average	Improvement	8
Eragrostis	*truncata*	ETRU	Average	Transition	5
Fingerhuthia	*africana*	FAFR	Average	Improvement	8
Heteropogon	*contortus*	HCON	Average	Improvement	8
Melinis	*repens*	MREP	Average	Transition	5
Microchloa	*caffra*	MCAF	Low	Transition	3
Panicum	*coloratum*	PCOL	High	Improvement	10
Panicum	*maximum*	PMAX	High	Improvement	10
Pogonarthria	*squarrosum*	PSQU	Low	Transition	3
Schmidtia	*pappophoroides*	SPAP	High	Improvement	10
Sporobolus	*ioclados*	SIOC	Average	Improvement	8
Stipagrostis	*ciliata*	SCIL	Average	Improvement	8
Stipagrostis	*hochstetteriana*	SHOC	Low	Transition	3
Stipagrostis	*obtusa*	SOBT	High	Improvement	10
Stipagrostis	*uniplumis*	SUNI	Average	Transition	5
Tricholaena	*monachne*	TMON	Low	Transition	3
Triraphis	*ramosissima*	TRAM	High	Improvement	10
Urochloa	*oligotricha*	UOLI	High	Improvement	10
Pseudo-species for points with no perennial grass within 30 cm		Bare	N/A	N/A	0

3.5.6 Statistical analyses

3.5.6.1 Selection of data for analysis

In cases where more than one group of students had measured a fenceline contrast, the data of the most reliable group was selected to represent that contrast. This is because after discarding the unreliable data, the number of groups remaining was usually too low to measure the variation among groups. If no mistakes were encountered in the data of more than one group, the data of the group with the lowest proportional difference between canopy cover by points (Canop) and canopy cover by Bitterlich gauge (Bitterlich) was chosen for the analysis. In one case mistakes were found in the data of all groups that measured at the same fenceline contrast. The data of the group with mistakes in only one variable were therefore selected for analysis of all the variables without mistakes, while the data for the variable with mistakes was selected from the next-best group that did not make a mistake in that variable. In another case all the data of one group appeared to be reliable, except for the Canop : Bitterlich ratio, but there was no other group that obtained reliable data from the same contrast. Therefore, all the data of the most reliable group was retained for further analysis.

The data of the reliable groups of students gathered at the same contrast were not combined for the purpose of increasing sample size. This was partly to ensure sufficient reliability in the data that were retained for further analysis. Another reason for not combining the data was that there were some differences in how each group interpreted the instructions for taking measurements of some of the variables. For example, some groups considered a tiny fragment of leaf to represent mulch, while other groups only recorded mulch if the dart landed on fairly large pieces of organic matter. When deciding whether a perennial grass had a basal diameter of at least 5 cm, some groups measured it exactly at ground level while other groups measured at a few cm above ground level and therefore the latter counted more perennial grasses in their measurements and obtained slightly shorter distances to the nearest perennial grass. Since the method used by each group was the same on each side of the fence, the results of reliable groups are useful to contrast the differences on each side, even if the absolute estimates are not strictly comparable between groups of students who measured the same fenceline contrast. Out of the 69 student surveys that remained after discarding the seven with clearly unreliable data, 24 (35%) were selected to represent the fenceline contrast data analysed in this study.

In all cases, 100 points were therefore contrasted on each side of each fenceline for most of the variables measured, but only 25 of the measurements with the Bitterlich angle gauge. The points were treated as independent samples, rather than being paired, because the distance between points on one side of the fence was shorter than the distance to the paired point on the other side of the fence.

3.5.6.2 Continuous data versus categorical data

Variables that were estimated by counting of categories provided frequency data, which underwent a Chi-Square test (Zar, 1999). They were soil cover (Hit), canopy cover by points (Canop), nearest perennial grass (NP), nearest bush or tree (NB), and height class of bush or tree (Height). Variables for which numerical data appeared in groups, also underwent a Chi-square test. This applied to the composite variable “rangeland condition index” and to counts of plants, namely the canopy cover by Bitterlich gauge (Bitterlich); the count of woody plants shorter than 0.5 m (Woodies); and the number of perennial grasses (No P). At high perennial grass densities the latter variable behaved like continuous data and was sometimes treated as such. It underwent different tests depending on normality of data distribution and whether two or three sides of a contrast were being compared. The same tests were carried out on other continuous numerical variables, namely distance to nearest perennial grass (DistP) and distance to nearest bush or tree (DistB).

3.5.6.3 Quick test for individual category of a frequency variable

A Chi-Square test (Zar, 1999) was applied in Excel (Microsoft Corporation, 2003) to generate the values in Table 3.4, which was then referred to as a rapid test of whether the percentage frequency for any individual category of a variable differed significantly ($P<0.05$) across the fenceline.

An example of how Table 3.4 could be useful is when seven of the 100 dart throws landed on mulch on one side of the fence and 14 landed on mulch on the other side of the fence. Then the apparent doubling of mulch cover would not be significant ($P>0.05$). Table 3.4 indicates that the lower value of seven requires a higher value of at least 17 to be significantly ($P<0.05$) different for 100 points sampled. On the other hand, if ten of the 100 dart throws landed on mulch on one side of the fence and 20 landed on mulch on the other side of the fence, then the apparent doubling of mulch would be significantly ($P<0.05$) different. Table 3.4 indicates that the lower value of ten requires a higher value of at least 20 to be significantly ($P<0.05$) different for 100 points sampled.

Table 3.4 would not be valid for use in cases where a category could not be recorded at all 100 points on each side of the fence, such as where there was no bush within 5 m of the point from which to record for species and height class. In such cases a contingency table was set up as described below.

Table 3.4 Data generated by Chi-Square tests to indicate the lower and upper percentages required to obtain a significant (P<0.05) difference between two observations from point sampling.

	Upper % required for P<0.05				
	Number of points sampled				
Lower %	50	100	200	500	1000
0	(20) ~~8~~	(10) ~~4~~	(5) ~~2.0~~	(2) ~~0.8~~	(1) ~~0.4~~
1		(9) ~~7~~	4.5	2.8	2.1
2	(18) ~~14~~	9	6.0	4.2	3.5
3		10	7.5	5.6	4.7
4	16	12	9.0	7.0	6.0
5		13	10.5	8.2	7.1
6	20	15	12.0	9.4	8.3
7		17	13.0	10.6	9.5
8	22	18	14.5	11.8	10.6
9		19	15.5	13.0	11.7
10	26	20	17.0	14.2	12.8
15		27	23.0	19.8	18.3
20	38	33	28.5	25.2	23.7
25		38	34.0	30.6	28.9
30	50	44	39.5	36.0	34.1
35		49	45.0	41.2	39.3
40	60	54	50.0	46.2	44.4
45		59	55.0	51.2	49.5
50	70	64	60.0	56.2	54.4
60	80	74	69.5	66.0	64.3
70	88	82	79	75.6	74.0
80	94	90	87.5	84.8	83.4
90	100	97	95.5	93.6	92.5

The first column indicates the % value of the observation with the lowest value, while the other columns indicate the % that would be required in the other observation to be at least 95% sure that it differs significantly (P<0.05) from the lower value, for the different sample sizes appearing across the top of the table. Those with low values at the top of the table that are struck through would not be valid, due to having expected frequencies of less than five. The required values to meet this requirement appear in brackets.

3.5.6.4 Test for variables measured by frequency

To test whether a group of categories within a variable differed significantly (P<0.05) across the fenceline, a contingency table was set up in Excel (Microsoft Corporation, 2003) for performing a Chi-Square test (Zar, 1999). In the case of the soil cover (Hit) variable, one category had always been recorded at each point, and in the cases of nearest perennial grass (NP) and nearest bush or tree (NB), a category of “Bare” was assigned when no plant category could be recorded. In these cases the expected values for each category were calculated as the mean between the two sides of the fence. However, in the case of the height variable, no category was assigned when no bush was found within 5 m of the point. Therefore, when testing for differences in height class, the data were treated the same way as data from variables with numbers of plants counted at each point, namely count of perennial grasses (No P), canopy cover by Bitterlich gauge (Bitterlich) and count of woody plants shorter than 0.5 m (Woodies). For these the expected frequency of any category on any side of the fence was calculated from the total counts of the category of both (or all three) sides, multiplied by the proportion of overall counts (of all categories) on that side of the fence.

If any category indicated an expected frequency of less than five (Zar, 1999) in the contingency table, it was grouped with the category most similar to it in terms of functionality. If the expected frequency was still less than five, then the next most similar category was added, until rendering an expected frequency of five or greater. A Chi-Square test was performed on the resulting contingency table to show whether there was a significant ($P<0.05$) overall difference. This limited the number of species that could be tested, which were therefore grouped into categories such as encroacher and non-encroacher bushes, or xerophytic and mesophytic grasses, to which there is no clear dividing line.

Species had not been recorded in the case of count of perennial grasses (No P), so the categories consisted only of numbers of plants. Although species had been recorded in the variable of canopy cover by points (Canop), there were insufficient recordings to warrant analysis for differences in species. The Chi-Square test (Zar, 1999) was therefore applied only on the categories of hit and miss of canopies, while data from canopy cover measurements by Bitterlich gauge (Bitterlich) and species of nearest bush (NB) were used to analyse composition of groups of bush species.

3.5.6.5 Test for normality of data from numerical variables

Numerical data were tested for normality of distribution by the Kolmogorov-Smirnov test (Zar, 1999) using Statistica 7.1 software (StatSoft, 2005). The data were considered sufficiently close to normal distribution for application of parametric statistical analyses when the Kolmogorov-Smirnov test indicated a P-value greater than 0.05. Only the Bitterlich data were found to be normally distributed for the vast majority of sites. Concerning the count of woody plants shorter than 0.5 m (Woodies), none were normally distributed because of the large number of points where zero was recorded. At sites with low perennial grass density, the count of perennial grasses (No P) data faced a similar problem. All these variables had categories to which the Chi-Square test (Zar, 1999) was therefore applied. Although data for the distance measurements were found to be normally distributed at some sites, there were some that were not normally distributed. Therefore, for the sake of consistency, non-parametric statistical analyses were applied to all of the distance-to-nearest-plant measurements.

3.5.6.6 Non-parametric test for continuous numerical variables

Although distances to the nearest plants were recorded to the nearest cm, they were far enough to behave as continuous data. Therefore to determine whether differences in distance to nearest perennial grass (DistP) and distance to nearest bush or tree (DistB) across paired fencelines were significant ($P<0.05$), a Mann-Whitney U test (Dytham, 2003) was performed using Statistica 7.1 (StatSoft, 2005). Where fenceline contrasts were measured between three sites, a Kruskal-Wallis test (Dytham, 2003) was applied instead. Measurements of soil compaction, taken at Contrast 22, underwent a Mann-Whitney U test.

3.5.6.7 Parametric test for grass count at one contrast

In the case of one contrast, where all perennial grasses were counted instead of only those with a basal diameter of at least 5 cm, the data were normally distributed so a t-test (Dytham, 2003) was performed, using Excel (Microsoft Corporation, 2003).

3.5.6.8 Dispersion for numerical variables

As a measure of dispersion for the nearest plant distances and soil compaction, the upper and lower quartiles were calculated around the median, using the descriptive statistics in Statistica 7.1 (StatSoft, 2005). These were then indicated by error bars in charts, using Excel (Microsoft Corporation, 2003).

Only in the case of the single contrast where all perennial grasses were counted instead of only those with a basal diameter of at least 5 cm, the 95% confidence limits were presented around the mean, since the data were normally distributed. These were calculated using the "Descriptive statistics" function in Excel (Microsoft Corporation, 2003), giving an upper confidence interval that was equal to the lower interval.

3.5.6.9 Dispersion of frequency variables

For most of the frequency variables there was no way to show dispersion, because the estimate was just a percentage. However, in the case of count of perennial grasses (No P) and canopy cover by Bitterlich (Bitterlich), the count data were used to indicate upper and lower quartiles around the medians.

3.5.6.10 Testing of relationships

Relationships between variables were tested at different scales: (i) within a site; (ii) across sites within a savanna type; and (iii) across all sites in all savanna types, but in most cases grouped according to farmer.

To test the relationship between a numerical variable and groups of another variable within the same site, such as whether the median distance to nearest perennial grass obtained from points under canopies differed significantly ($P<0.05$) from those in the open, a Mann-Whitney U Test (Dytham, 2003) was applied.

To test the relationship between a numerical variable and groups of another variable within the same site, a Chi-Square test (Zar, 1999) was performed. For example, to test whether biological soil crust cover was associated with canopies of bushes, the numbers of points that fell on biological soil crust were separated in a contingency table according to whether they occurred under bush canopies or not. The expected values were then calculated from the percentage of points that fell under canopies at that site.

Relationships between pairs of variables, such as between bush and grass variables, were tested using means or medians from each site within the same savanna type. This was done by first examining scatter plots in Excel (Microsoft Corporation, 2003) and determining normality of distribution using a Kolmogorov-Smirnov test (Zar, 1999). When data were not distributed normally, transformations were applied, in most cases by log transformation. Relationships using transformed data were examined by scatter plot to determine whether linearity in the relationship had improved, and by Kolmogorov-Smirnov test to determine whether transformed data became normally distributed. Correlation analyses were applied to relevant data using Statistica 7.1 (StatSoft, 2005). Product-moment correlations were applied when both variables were distributed normally, while Spearman rank-order correlation was applied when either of the variables did not follow a normal distribution (Dytham, 2003). For variables that may have predictive value, a trend line was added to the scatter plot in Excel (Microsoft Corporation, 2003) to obtain a regression, while the P-value was obtained from Statistica 7.1 (StatSoft, 2005).

The rangeland condition indices were correlated with the current stocking rate applied to the farms where those sites were located, across all savanna types. They were also correlated with socio-economic data obtained from farmers. The methods used for the analyses were similar to those described above.

3.5.6.11 Ordination analysis

Although the vegetation data were from rangeland that appeared to differ on each side of the fencelines, when taken together, they did not provide a degradation gradient within a relatively homogenous area. The data of the Highland and Dwarf shrub Savannas was unsuited to ordination, containing only nine fenceline contrast sites and six experimental plots. However, an attempt was made at ordination of the data of each of the Camelthorn and Thornbush Savannas to gain insight into possible relationships. The data were entered into the Canonical Community Ordination (CANOCO) software (Ter Braak & Smilauer, 2002). A Detrended Correspondence Analysis (DCA) ordination was performed to examine the pattern that emerged and whether the sites were ordered more or less according to their state of degradation, as described by Bosch and Gauch (1991). The length of the first axis was used as a guide to determine the most appropriate ordination to perform subsequently (Ter Braak & Smilauer, 2002).

The sample data that provided the input for the ordination analyses comprised a combination of nearest perennial grass species (NP) and count of perennial grasses (No P), expressed as densities of the nearest perennial grass species. Eight environmental variables were included during direct analysis. For rainfall data the long-term mean annual rainfall was used. Soil data could unfortunately not be included as samples been analysed from only few of the contrasts. Therefore, soil was treated as a nominal variable by assigning each contrast to one of three categories: (i) loose sand (also indicated by dominance of *Terminalia sericea* among woody plants); (ii) loamy sand (also indicated by dominance of *Acacia erioloba*), and (iii) the occurrence of calcrete on or close to the soil surface (also sometimes indicated by dominance of *Catophractes alexandrii*). Another nominal environmental variable was included arbitrarily for each contrast, to indicate the relative effects of management and location of contrast. Environmental variables derived from measurements at the sites were: (i) bush density index; (ii) bush canopy cover; and (iii) mulch and basal cover. Management variables that served as environmental variables were: (i) current stocking rate applied to the whole farm; (ii) period of absence provided during or over the growing season.

After performing the direct ordination with the eight environmental variables described above, a ninth variable was added and the ordination repeated. It was the rangeland condition index, which auto-correlates with the species data used as samples in the ordination. The reason for including it was to determine where any degradation gradient may lie in relation to the first and second axes.

3.6 GATHERING INFORMATION FROM FARMERS

The farmers were interviewed with the help of a formal questionnaire, appearing in Appendix 6. Questions included those aimed at understanding the management that was previously and is currently applied to the farms and those aimed at quantifying the production levels achieved. Certain answers were followed up during and after the interviews if deemed necessary. The majority of farmers provided all the answers from memory, without referring to records, therefore some information may be inaccurate.

Farmers responded to questions on quantities in different ways and in different units. For example, some farmers gave stocking rates and production levels in terms of ha AU^{-1}, some in terms of kg liveweight ha^{-1}, some in terms of numbers of animals and others as a percentage of liveweight or animals. Therefore the units were standardised by appropriate conversions. The conversions were based on estimates, some of which may be inaccurate, but the inaccuracy in the farmers' answers is likely to have been greater. This applied especially to the estimates of game animals, which were taken into account when determining stocking rates.

Most farmers answered all of the questions, but there were some farmers who had insufficient time to answer all questions and some who did not wish to give answers to particular questions, most notably those asking about income and expenditures. One farmer could not be traced and his foreman was not willing to be interviewed.

Many of the figures given by farmers are rough estimates. Often the response to a question was "It is not fixed and keeps changing in response to circumstances experienced". A follow-up question then requested the estimation of a rough average.

The areas in which most farmers responded were usually their whole farms, but farmers who owned or rented additional farms, were asked to answer for the area they treated as a whole management unit, whether it was an individual farm or a group of farms over which animals were occasionally moved. Despite this request, some multiple farm owners / renters responded to some questions for the farm where measurements had been made but to other questions their response applied to all farms combined.

In the case of an innovative adaptive farmer, more details were obtained to understand his successful management better as a case study. The farmer made a drawing of his conceptual model, which was then copied. Visits were made with the farmer to various sites on the farm, where he showed the effects of different management and described his observations that had led to him trying out various strategies.

Data from the filled questionnaires were transferred to Excel spreadsheets (Microsoft Corporation, 2003) for analyses to illustrate the proportion of different categories of responses. These categories will become clear when the results are presented in Chapter 7. In a few cases, analysis of the relationship between type of response and type of farmer was also carried out. However, the small sample size for some categories usually resulted in expected frequencies of less than five, thus the Chi-square test would not strictly be valid (Zar, 1999). This occurred despite grouping of some similar categories. Therefore, only those results that appeared highly significant ($P<0.0001$) are reported on when there were expected frequencies of less than five.

Relationships between some of the numerical data obtained from farmers were tested by correlations, as described in section 3.5.6.10 for vegetation data. The only link tested between the socio-economic data and vegetation data was with rangeland condition indices. Since the socio-economic data were obtained from each farmer, and some farmers owned more than one site, the mean rangeland condition index was calculated from all measured sites owned by the same farmer.

3.7 INFORMATION FEEDBACK TO FARMERS

3.7.1 Workshops

Workshops were held in each of the three study areas. Participants of the workshops included owners of the farms where measurements were made; other farmers in those areas; agricultural extension officers and other researchers. Some of the fenceline contrast results were presented and discussed at the workshops. Towards the end of the workshops, participants elected from the groups of commercial farmers, communal farmers and affirmative action farmers the one they considered to have applied best practice in management of the rangeland. Each winner was awarded a prize, comprising a book on grasses.

3.7.2 Problem trees as diagnostic tools

The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse the sequence of events that eventually lead to a problem (Fussel, 1995). Problem trees, explaining a variety of environmental problems, were constructed as teaching exercises for students as well as environmental awareness workshops. Students routinely included problem trees during their action research with communities of farmers (Zimmermann, 1998). The trees were built upside down, with the roots representing the root causes, at the top. A problem tree was started by writing down a symptom of rangeland degradation at the bottom of a page. These symptoms included bush encroachment, erosion gullies, coppice dunes and outbreaks intestinal worms. After writing the symptom and drawing a short arrow pointing down towards the symptom, the possible causes were addressed. The proximate cause that came to mind was written above the arrow and the procedure repeated to identify intermediate causes until the root cause was reached towards the top of the page. Since ecological interactions tend to be complex, with multiple determinants, the arrows in an ecological problem tree tend to grow out into branches. This was done by going back to the proximate cause in the trunk of the tree and investigating alternative reasons for that cause. If another reason came to mind, an arrow was branched down to that proximate cause and the new reason written above it. Another arrow was pointed down to the new reason and the reason thereof investigated. This was repeated until a new root cause was reached, whereupon the intermediate causes were then questioned. Occasionally a positive feedback loop would appear, resulting in a vicious circle.

The basic problem trees drafted during workshops were developed further through informal discussion with farmers and researchers. The problem trees were generalised by considering all possible causes, and not only those applying to a particular circumstances such as a particular bush encroached area or a particular species of bush. Diverse views on the causes of the symptoms were considered, including those well established, some speculative, some controversial and some anecdotal.

Diagnosis through drawing a problem tree is useful in guiding decisions on management of the problem. Of course not all branches of a problem tree will be relevant to every situation, so farmers first need to identify which of the branches are of relevance to them. Management that addresses causes higher up a problem tree, closer to the root causes, if feasible, is likely to be more effective in the long run than management that addresses the proximate causes or symptoms at the bottom of a tree.

CHAPTER 4

RESULTS: CAMELTHORN SAVANNA

4.1 INTRODUCTION

Results from alternative methods of measuring the same vegetation characteristic in the Camelthorn Savanna are presented first. The contrasts between the alternative methods will be used in Chapter 7 to evaluate measuring methods. Thereafter the plants species recorded at the contrasts are listed according to groups and some explanations on abbreviations are given. An overview of all contrasts in the Camelthorn Savanna is then presented, before describing the results from the 16 individual fenceline contrasts measured in this savanna type. To ease identification of sites, the order of their presentation in charts and photographs is always Site a followed by Site b (and then Site c where three sites were measured at a contrast). Finally, results are presented of the relationships between some variables, including the ordination analyses.

4.2 COMPARISON BETWEEN METHODS OF MEASURING

4.2.1 Woody canopy cover by points and by Bitterlich gauge

When comparing the estimates of canopy cover obtained by Bitterlich gauge (Bitterlich) and by points (Canop), the relationship was rather poor (Figure 4.1). Analysis by product moment correlation (Dytham, 2003) resulted in $r = 0.572$ and $P = 0.0002$ ($n = 33$). There may be several reasons for this poor correlation. Examination of the two outliers that underestimated canopy cover by points revealed that they had been measured by the same group of students, at the same contrast, so it is likely that they avoided bush clumps when pacing their transects. The outlier that overestimated canopy cover by points was at the site with the highest canopy cover, and since many bushes were overlapping at this site, it is likely that the Bitterlich count underestimated their canopy cover. A group of overlapping bushes was counted as a single large canopy instead of many small canopies. If both methods were performed correctly it is likely that the relationship would be linear for lower canopy covers and then start to curve downwards as more bushes overlapped. It is also likely that the Bitterlich method would give the more precise measurement, because of the greater number of canopies counted. However, if a group of students performed one of the methods incorrectly while pacing transects correctly, it would more likely be the Bitterlich method, since it is more complicated than the simple point method.

The implication of such inaccuracies for this study is that when comparing variables among contrasts measured by different groups, the results need to be treated with caution. However, this is not the main objective of this study. Rather, the main objective of comparing sides of fenceline contrasts can still be achieved, since each contrasting site was been measured by the same observers. Any inaccuracy in applying the method would have affected the results from either side of the contrast in the same way, whether over or under estimated.

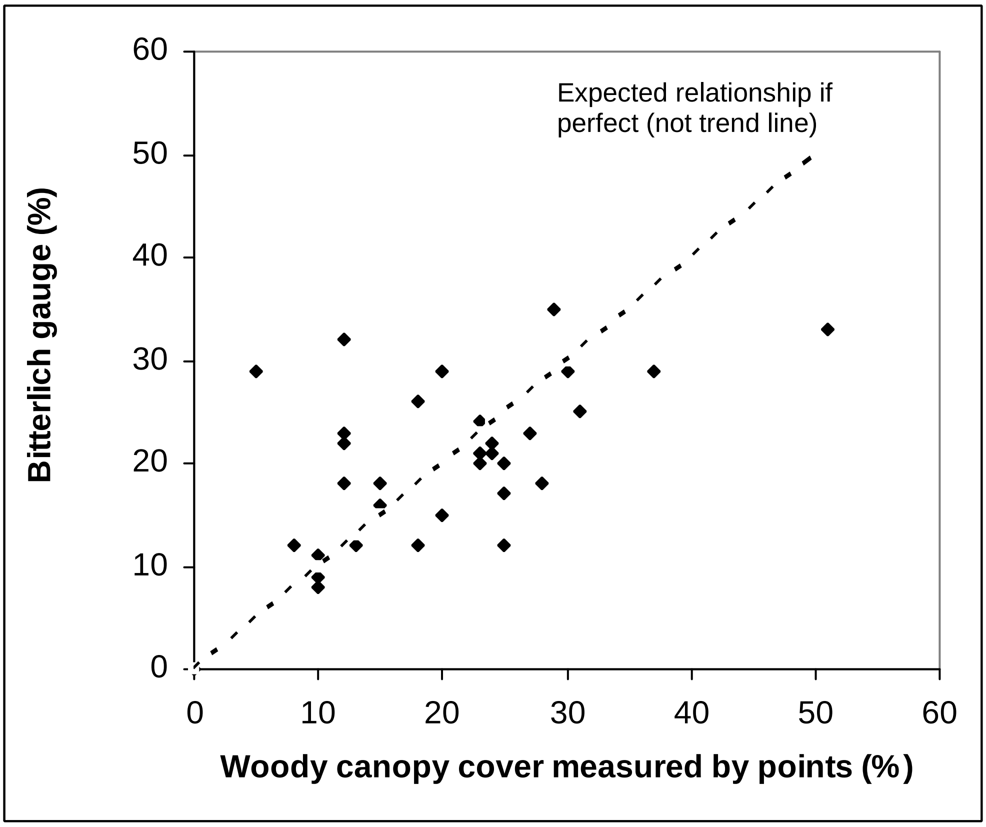


Figure 4.1 Relationship between the woody canopy cover measured by points and by Bitterlich gauge at 33 sites in the Camelthorn Savanna.

4.2.2 Distance to nearest perennial grass and count of density

The factor that influences the relationship between distance to nearest perennial grass (DistP) and density of perennial grasses (No P) is the degree of clumping among the perennial grasses. DistP only followed a normal distribution after square-root or log transformation, while No P followed a normal distribution before transformation, but the fit improved after transformation. Therefore a linear regression was applied to the log transformed data of both variables to obtain the P-value, while a power regression was applied to the untransformed data for a visual impression of the relationship and to provide the regression equation (Density index = 203.57*DistP$^{-1.3315}$, r^2 = 0.9063, P<0.0001, n = 33) (Figure 4.2). The relationship may therefore provide a useful predictor of perennial grass density in the Camelthorn Savanna. The advantages of using distance to nearest perennial grass (DistP) over the count of perennial grasses within 75 cm (No P) are that DistP is a much faster measurement to take and it avoids the confusion that occurs when deciding whether nearby tussocks should be counted as the same or different plants.

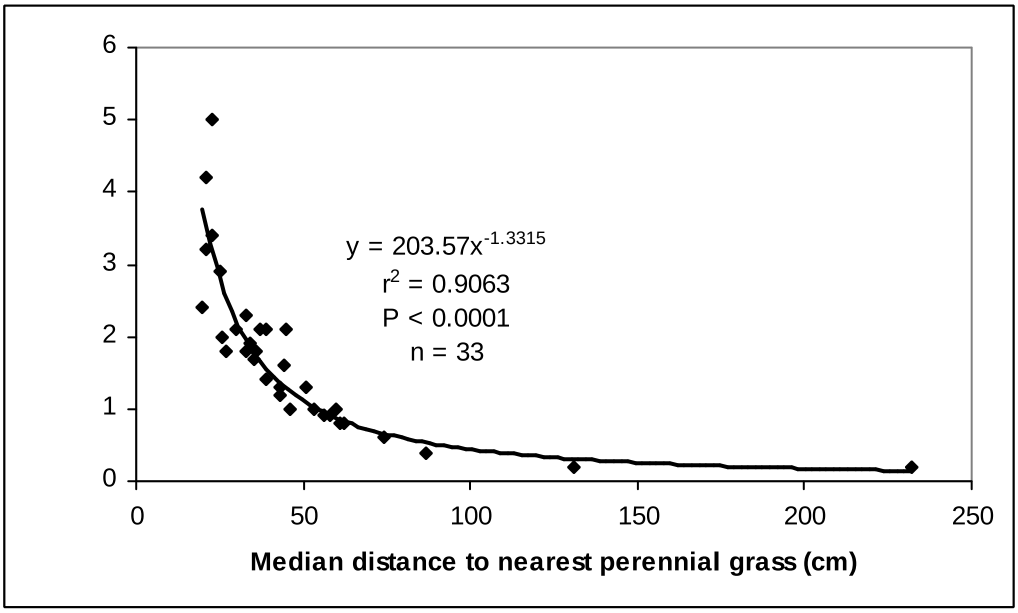


Figure 4.2 Relationship between the median distance to the nearest perennial grass and the mean grass density counted within 75 cm of points, at all 33 sites in the Camelthorn Savanna, with the resulting power regression.

The density index was calculated from the median distance to nearest perennial grass (DistP) using Formula A or Formula B (section 3.4.5.4). This is compared with the mean counted perennial grass density in Figure 4.3. The relationship suggests a greater degree of clumping when the density is very low, such as below 1 grass m^{-2}, as would be expected from larger bare patches.

The degree of clumping can be indicated by the extent to which the density index overestimates the counted grass density. The change in degree of clumping with grass density is presented in Figure 4.4. It represents an alternative way of illustrating the relationship, which detects differences not evident in Figure 4.3, such as the high very high degree of clumping for the site with the lowest perennial grass density. At most of the sites with densities above 1.5 grasses m^{-2}, the degree of clumping appeared to be quite low.

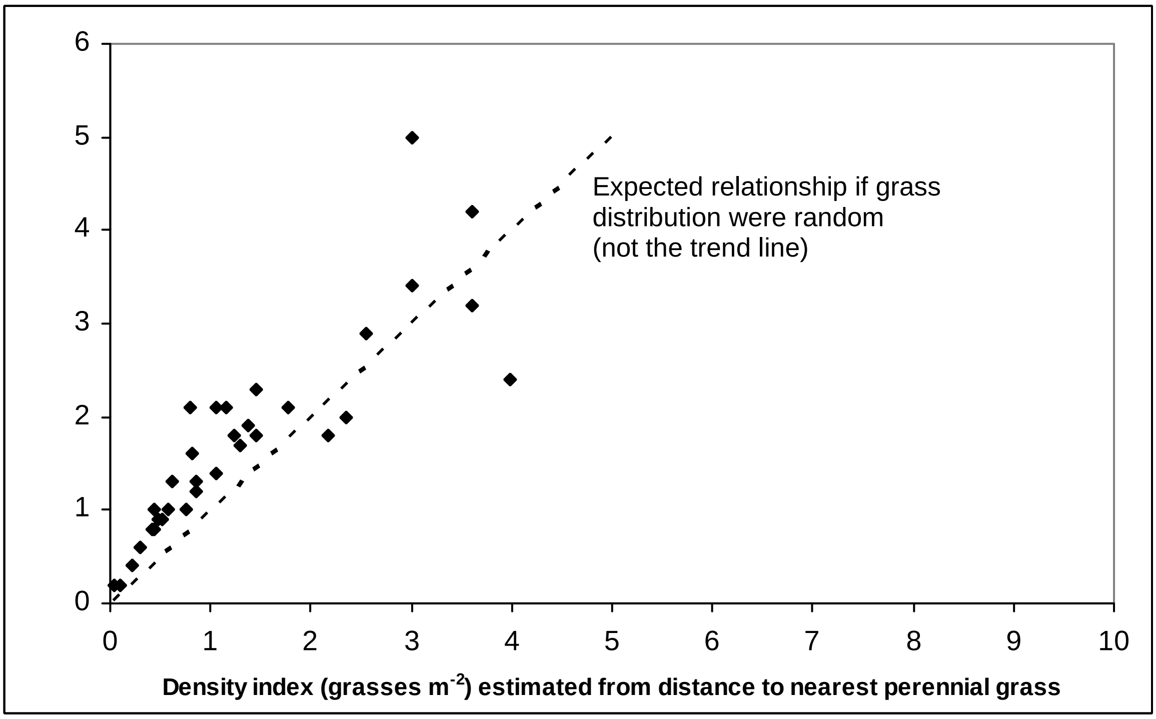
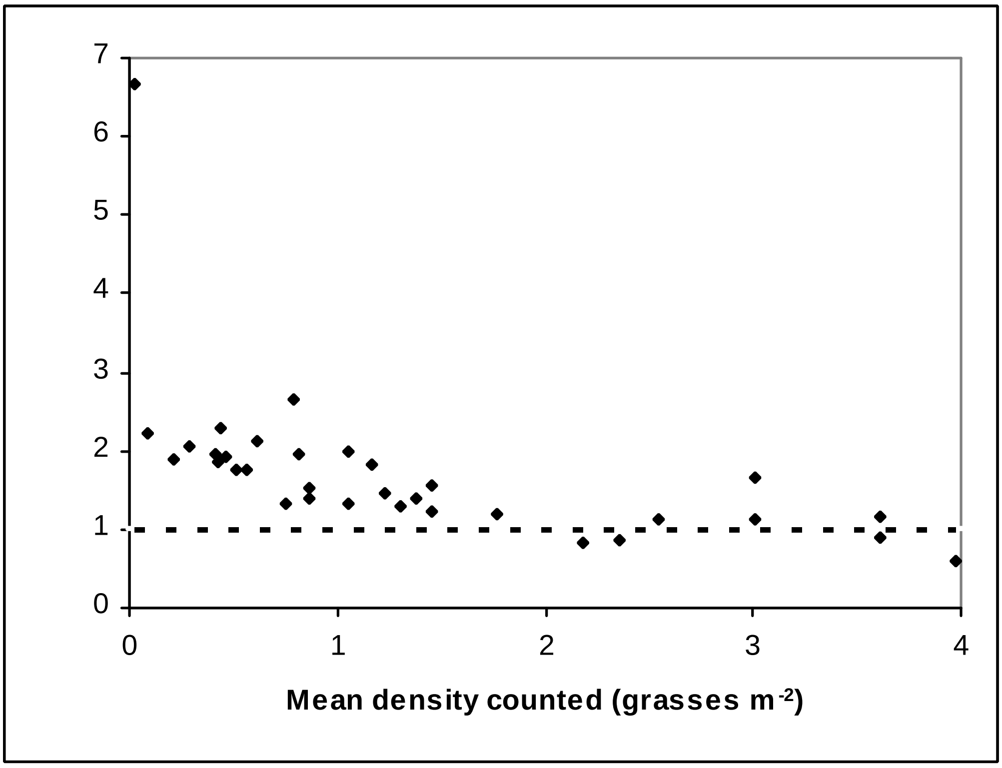


Figure 4.3 Relationship between the perennial grass density index - estimated from the median distance to nearest perennial grass - and the mean grass density counted at all 33 sites in the Camelthorn Savanna.



The stippled line represents the expected relationship if the distribution of grass plants were random, with no clumping.

Figure 4.4 Relationship between the mean perennial grass density and the degree of grass clumping at all 33 sites in the Camelthorn Savanna.

4.3 PLANT SPECIES RECORDED

Since abbreviations were used in tables for species names, and since species were subjectively grouped for analysis, the abbreviations and groups are presented in Table 4.1 for perennial grasses and in Table 4.2 for bush and tree species. The abbreviations use the first letter of the genus name followed by the first three letters of the species name, unless the species from the same genus were combined, in which case the first four letters of the genus name were used for the abbreviation.

Table 4.1 Species of perennial grasses assigned subjectively to broad categories of xerophytic and mesophytic species.

Xerophytic species	Mespohytic species
Aristida congesta (ACON)	*Aristida meridionalis* (AMER)
A. stipitata (ASTI)	*Cenchrus ciliaris* (CCIL)
Stipagrostis obtusa (SOBT)	*Eragrostis lehmanniana* (ELEH)
S. uniplumis (SUNI)	*E. nindensis* (ENIN)
	E. pallens (EPAL)
	E. rigidior (ERIG)
	E. tricophora (ETRI)
	Melinis repens var. *repens* (MREP)
	Panicum coloratum (PCOL)
	P. maximum (PMAX)
	Pogonarthria squarrosum (PSQU)
	Schmidtia pappophoroides (SPAP)
	Tricholaena monachne (TMON)
	Triraphis schinzii (TSCH)
	Urochloa oligotricha (UOLI)

The abbreviated names used in other tables and charts for these species appear in brackets.

Table 4.2 Species of bushes assigned subjectively to broad categories of encroacher and non-encroacher species.

Encroacher species	Non-encroacher species
Acacia fleckii (AFLE)	*Albizia anthelmintica* (AANT)
A. hebeclada (AHEB)	*Acacia erioloba* (AERI)
A. karoo (AKAR)	*A. hereroensis* (AHER)
A. luederitzii (ALUE)	*Boscia albitrunca* (BALB)
A. mellifera (AMEL)	*B. foetida* (BFOE)
Catophractes alexandrii (CALE)	*Commiphora* spp. (COMM)
Dichrostachys cinerea (DCIN)	*Combretum collinum* (CCOL)
Gymnosporia senegalensis (GSEN)	*C. hereroensis* (CHER)
Rhigozum brevispinosum (RBRE)	*Diospyros lycioides* (DLYC)
	Ehretia rigida (ERIG)
	Grewia bicolor (GBIC)
	G. flava (GFLA)
	G. retinervis (GRET)
	Lycium bosciifolium (LBOS)
	L. eenii (LEEN)
	Ozoroa paniculosa (OPAN)
	Phaeoptilum spinosum (PSPI)
	Phylenoptera nelsii (PNEL)
	Rhus tenuinervis (RTEN)
	Tarchonanthus camphoratus (TCAM)
	Terminalia sericea (TSER)
	Ziziphus mucronata (ZMUC)

The abbreviated names used in other tables and charts for these species appear in brackets.

4.4 OVERVIEW OF ALL CONTRASTS

The overview tables that follow use one row per survey site. The contrasts are numbered 1 to 16 and are followed by a lower case letter to denote the side of the fence. Letter "a" is used for the side to the west or north, while letter "b" is used for the eastern or southern side of the fence. Where three farms were contrasted, letter "c" is used for the third farm in a clockwise rotation.

In order to provide background information on the 16 contrasts measured, a few words are used in Table 4.3 to describe the main difference in management applied each side of the fence, and the land tenure where applicable. Where the same farm provided more than one site, its data are repeated in the relevant row(s). Where possible, an indication is given of the differences between sites in the same farm. More details of individual contrasts are presented in section 4.5.

Many of the figures given in Table 4.3 are rough estimates. The stocking rates and production rates in most cases apply to the whole farm. They were estimated as rates over the year previous to the measurements, although likely to have changed over the years. Where the stocking rate was known to be very different at the survey site in comparison with the whole farm, an attempt was made to indicate this in Table 4.3. However, in many cases this was a very rough estimate, as suggested by the farmer, or simply an unquantified description, since farmers were unable to give precise figures. This separation of survey site from the rest of the farm was not attempted in the case of the production figures, which were derived from the whole farm.

Table 4.4 summarises the rangeland data, with results for the main variables presented alongside each other. Significant ($P<0.05$) differences were found at all contrasts, although not in all variables. These are presented in section 4.5. The soil cover refers to organic material, whether living, from bases of perennial grasses, or dead, from mulch. It ranged from 1% to 38%. For distance to nearest perennial grass (DistP) the medians are presented, ranging from 20 cm to 232 cm. The same applied to distance to nearest bush or tree (DistB), with the median ranging from 92 cm to >500 cm. On the other hand, means were used to calculate the density of perennial grasses, ranging from 0.2 to 5.0 grasses m^{-2}, and canopy cover by Bitterlich angle gauge, which ranged from 0% to 35%. Mesophytic grass species and encroacher bushes are presented as the percentages they make up out of total nearest perennial grasses (NP) and Bitterlich gauge counts respectively. The mesophytic grass species ranged from 0% to 90%, while the encroacher bush cover ranged between 0% and 72%.

Results from the count of woody plants shorter than 0.5 m (Woodies) are not presented in Table 4.4 because they only showed few significant ($P<0.05$) differences for bush and tree species. The method used was not sensitive enough to detect actual differences, because the small sample area of only 1.766 m^2 resulted in zero counts in most of them, so median values were always zero and often there were insufficient points with counts for performing a Chi-Square test on. The few significant ($P<0.05$) differences were for all bush species combined rather than for individual species and they will be mentioned when the individual contrasts are described in section 4.5. However there were significant ($P<0.05$) differences in other, more abundant, non-bush species recorded under count of woody plants shorter than 0.5 m (Woodies) and these too will be mentioned when the individual contrasts are described.

Table 4.5 presents the percentage perennial grass species composition obtained from NP. Shaded pairs of cells (or group of three) show the species for which the difference was significant ($P<0.05$) across the fenceline. Significant differences were found at all fenceline contrasts except for Contrast 12. *Schmidtia pappophoroides* was the most common species for which the difference in species composition occurred.

Table 4.5 also indicates that the most common xerophytic grass species was *Stipagrostis uniplumis*, which made up more than half of the perennial grass plants at 22 of the 33 sites. *Aristida stipitata* was common on some of the sites with loose sand and *A. congesta* tended to occur more on slightly harder textured soil. The most common mesophytic species was *Schmidtia pappophoroides* on the farms to the east, while to the west the mesophytes tended to be dominated by *Eragrostis rigidior* on sandier soil and by *Cenchrus ciliaris* on harder textured soil.

The densities of the different perennial grass species, calculated from the nearest perennial grass (NP) and mean density of perennial grasses (No P), are presented in Table 4.6. The highest density recorded for a single species was 4.4 plants m^{-2} for *Schmidtia pappophoroides*.

The percentage species composition for bushes and trees is presented in Table 4.7 as related to density (obtained from species of nearest bush (NB)), and in Table 4.8 as related to canopy cover (obtained by Bitterlich gauge). The density index for the bush and tree species, calculated from distance to nearest bush or tree (DistB), appears in Table 4.9. It has to be borne in mind that this index is likely to be an underestimation of true density, due to the tendency for bushes and trees to clump. Since there was insufficient space for all the species in these three tables, the rarest species were excluded while other rare species were combined with similar species of the same genus, such as *Acacia fleckii* with *A. luederitzii, A. karoo with A. mellifera, Grewia bicolor* with *G. retinervis, Boscia foetida* with *B. albitrunca.* Of these rare species, the most abundant was *G. bicolor* that made up only 0.5% of all recorded bushes. Furthermore, the combination was done only for presentation in the table and not for the analyses. The two *Commiphora* species had been recorded as *C. pyracanthoides* and *C. africana* but they were combined for all analyses because the exact species had not been confirmed. Two plants from different genera were also combined, namely *Phaeoptilum spinosum* with *Lycium bosciifolium*, as they are similar in appearance and in distribution (Curtis & Mannheimer, 2005).

In Table 4.7 the shaded pairs of cells (or groups of three) show the species for which the difference in species composition was significant ($P<0.05$) across the fenceline. Significant differences were found at all fenceline contrasts except for Contrasts 5 and 12, while at Contrast 10 it could not be determined due to the lack of bushes in the hayfield. *Acacia erioloba* was the most common species for which the difference in species composition occurred.

The differences between the results in Tables 4.7 and 4.8 are not only due to size and shape of plants, with some species comprised more of bigger plants with wider canopies, but also due to the association between some plants. When under or near a tree canopy it was very rare for nearest bush (NB) to be the same as the plant providing the canopy because of understory bushes that were usually closer to the point. Nevertheless both Tables 4.7 and 4.8 indicate that the most common bush and tree species were *Grewia flava, Acacia erioloba, A. mellifera, Terminalia sericea* and *Catophractes alexandrii*.

Table 4.3 Overview of management data for sites at the fenceline contrasts in the Camelthorn Savanna.

Contrast number	Main management or tenure difference between sides of fence	Paddocks per herd	Growing season rest (weeks)	Type of animals (sheep + goats = shoats)	Farm size (ha)	Stocking rate		Animal production kg ha^{-1} a^{-1}
						ha AU^{-1}	kg ha^{-1} a^{-1}	
1a	Absentee leasehold	Unknown	Unknown	Cattle, shoats, equines	±800		Unknown	Unknown
1b	Mass resettled	1.5	4	Cattle, shoats, equines	425	5	98	10
2a	Commercial beef	14	14	Cattle	6 200	11	42	8
2b	Leasehold mixed	3	26	Cattle, shoats, equines	460	8	56	10
3a	Commercial beef (same farm as 2a)	14	14	Cattle	6 200	11	42	8
3b	Leasehold mixed	3	4	Cattle, shoats, equines	400	4	105	8
4a	Absentee game paddock of 2 000 ha	1	0	Game	2 975	8	58	6
4b	Leasehold mixed	2	4	Cattle, shoats, equines	425	5	96	16
5a	Small dairy herd on 975 ha (same farm as 4a)	7	8	Dairy cattle	2 975	38	12	NA
5b	Leasehold mixed	1	0	Cattle, goats, equines	600	6	79	7
6a	Moderate continuous stocking	1	0	Cattle, goats, equines	375	17	26	3
6b	High continuous stocking	1.5	0	Cattle, shoats, equines	±450		Locally high	9
7a	Moderate continuous stocking	1	0	Cattle, shoats, equines	800	19	24	5
7b	High stocking (same paddock as 6b)	1.5	0	Cattle, shoats, equines	±450		Locally high	9
8a	Paddock with water (paddock of 6b & 7b)	1.5	0	Cattle, shoats, equines	±450		High	9
8b	Paddock without water (farm of 6b, 7b & 8a)	1.5	0	Cattle, shoats, equines	±450		Low	9
9a	Commercial beef breeding	6	6	Cattle, horses	4 600	8	53	11
9b	Speculation oxen on part of stud farm	1	0 when stocked	Cattle	4 500	8	60	4
10a	Hay production (same farm as 9b)	NA	26	Cattle after hay harvest	4 500		Very low	NA
10b	Holding of equines(same farm as 9b)	1	0	Horses & donkeys	4 500	8	60	NA
11a	Paddock of 6 ha	5	6	Cattle, sheep & goats	3 000	7	67	12
11b	Paddock of 120 ha (same farm as 11a)	5	5	Cattle, sheep & goats	3 000	7	67	12
11c	Paddock of 340 ha (same farm as 11a)	5	3	Cattle, sheep & goats	3 000	7	67	12
12a	Slow fixed rotation	4	26	Cattle	3 100	14	33	7
12b	Strategic rotation (same farm as 11a, b & c)	6	5	Cattle, sheep & goats	3 000	7	67	12
13a	No bush control	8	9	Cattle	5 000	13	34	7
13b	Selective bush control in past	4	8	Cattle	6 450	10	47	6
14a	Selective bush control (same farm as 13b)	4	8	Cattle	6 450	10	47	6
14b	Speculation oxen grazed continuously	1	0 when stocked	Cattle	3 300	8	56	13
15a	Moderately slow rotation	6	13	Cattle	12 400	9	51	13
15b	Speculation oxen (same paddock as 14b)	1	0 when stocked	Cattle	3 300	8	56	13
16a	Lower stocking, faster rotation (pdk of 13a)	8	9	Cattle	5 000	13	34	7
16b	Higher stocking, slower rotation (pdk of 15a)	6	13	Cattle	12 400	9	51	13

Table 4.4 Overview of vegetation survey results for sites at the fenceline contrasts in the Camelthorn Savanna.

Contrast number	% soil cover [1]	Perennial grasses over 5 cm base				Bushes over 0.5 m in height			% Bush height class		
		DistP [2] (cm)	Grasses m^{-2}	Condition index	% Mesophytes [3]	DistB [4] (cm)	% Canopy [5]	% Encroacher [6]	0.5-1 m	1-2 m	>2 m
1a	27	20	2.4	344	26	287	12	8	20	41	39
1b	14	27	1.8	295	19	155	18	12	48	39	13
2a	24	25	2.9	397	69	203	20	13	36	55	9
2b	24	21	3.2	367	36	286	18	9	35	52	13
3a	16	23	5.0	650	90	142	32	23	15	52	34
3b	31	39	2.1	202	8	271	29	3	29	38	32
4a	5	61	0.8	82	16	328	9	9	78	21	1
4b	24	35	1.7	266	25	266	12	0	51	39	10
5a	9	30	2.1	322	47	250	11	9	37	47	16
5b	9	26	2.0	309	33	>500	8	13	30	50	20
6a	23	37	2.1	347	58	300	12	0	63	28	10
6b	35	60	1.0	156	30	238	12	0	46	44	10
7a	38	45	2.1	214	56	295	16	2	23	68	10
7b	27	44	1.6	188	32	225	29	5	30	60	10
8a	13	39	1.4	186	22	283	22	2	21	49	30
8b	38	36	1.8	274	72	259	23	6	22	44	34
9a	9	23	3.4	416	51	171	26	25	16	60	24
9b	7	46	1.0	111	30	121	35	41	16	62	22
10a	18	21	4.2	371	50	>500	0	NA	NA	NA	NA
10b	25	56	0.9	86	27	145	29	19	15	34	51
11a	13	33	2.3	225	1	262	15	72	36	40	24
11b	13	51	1.3	120	0	272	17	52	52	41	8
11c	14	43	1.3	123	1	213	22	71	35	49	17
12a	8	87	0.4	40	2	92	33	70	25	73	2
12b	9	33	1.8	225	5	148	20	66	29	70	1
13a	21	43	1.2	157	10	134	25	15	27	69	4
13b	23	34	1.9	225	2	159	21	16	30	68	2
14a	3	74	0.6	80	12	117	18	24	65	34	1
14b	6	131	0.2	65	29	114	23	47	44	51	5
15a	19	53	1.0	150	42	118	21	39	30	64	6
15b	21	62	0.8	115	22	119	24	33	25	70	5
16a	1	232	0.2	20	18	101	29	46	20	78	2
16b	3	58	0.9	120	1	177	21	38	6	91	3

Shaded pairs (or groups of three) numbers differ significantly ($P<0.05$); [1] % soil cover = % of soil covered by mulch plus grass base; [2] DistP=Median distance from point to nearest perennial grass; [3] % Mesophytes = % of mesophytic species among recorded grasses; [4] DistB = Median distance from point to nearest bush or tree; [5] % Canopy = % of mesophytic species among recorded grasses; [6] % Encroacher = % of encroacher species among recorded bushes.

Table 4.5 Perennial grass species composition recorded at the fenceline contrasts sites in the Camelthorn Savanna.

Contrast number	Number of points at which the species abbreviated in the row below appeared as nearest perennial grass of at least 5 cm basal diameter																		
	ACON	AMER	ASTI	CCIL	ELEH	ENIN	EPAL	ERIG	ETRI	MREP	PCOL	PMAX	PSQU	SPAP	SOBT	SUNI	TMON	TSCH	UOLI
1a			5		1			5		3				5		69	12		
1b			3		5			3		7				3		78	1		
2a			4		2			12		21				30		27	4		
2b	1		12					7		11				17		51			
3a					1			1		1				87		10			
3b	1		4							1				7		87			
4a	13			1	3			5						6		71		1	
4b	2			1	9			2						13		73			
5a			12		10			1		2				34		41			
5b			11		1			7		11				14		56			
6a	2			1	4									52		40	1		
6b	17				4		1	2		1				22		53			
7a			12		5		1	2		3				43		32	2		
7b			36		1			4						27		32			
8a			25		4					3				15		53			
8b	2		15		1			6		2				61		11	2		
9a	2		23		4		1	4		9			1	32		24			
9b			26	1	8			10		2				8		44			
10a	4		26		7		10	1		3			2	25		20	2		
10b	7		31		14		1	10		2						34			
11a			1	1												98			
11b			6													94			
11c			11					1							1	87			
12a								2								98			
12b					3			1			1					95			
13a	5			4					2			3				86			1
13b	2			1				1								96			
14a				11			1									88			
14b				27		1	1									71			
15a				11				31								58			
15b		1		1				20								78			
16a				18												82			
16b				1												99			

Shaded pairs (or groups of three) numbers differ significantly (P<0.05).

The names for species abbreviations are: ACON = *Aristida congesta*; AMER = *Aristida meridionalis*; ASTI = *Aristida stipitata*; CCIL=*Cenchrus ciliaris*; ELEH = *Eragrostis lehmanniana*; ENIN = *E. nindensis*; EPAL = *E. pallens*; ERIG = *E. rigidior*; ETRI = *E. tricophora*; MREP = *Melinis repens* var. *repens*; PCOL = *Panicum coloratum*; PMAX = *Panicum maximum*; PSQU = *Pogonarthria squarrosum*; SPAP = *Schmidtia pappophoroides*; SOBT = *Stipagrostis obtusa*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*; TSCH = *Triraphis schinzii*; UOLI = *Urochloa oligotricha*.

Table 4.6 Perennial grass species densities calculated from the surveys at the fenceline contrasts sites in the Camelthorn Savanna.

Contrast number	Densities in plants per 100 m^2 of the species of perennial grass of at least 5 cm basal diameter abbreviated in the row below																			Total
	ACON	AMER	ASTI	CCIL	ELEH	ENIN	EPAL	ERIG	ETRI	MREP	PCOL	PMAX	PSQU	SPAP	SOBT	SUNI	TMON	TSCH	UOLI	
1a			12		2			12		7				12		163	28			236
1b			6		9			6		13				6		140	2			180
2a			12		6			35		61				87		78	12			290
2b	3		40					23		36				56		165				324
3a					5			5		5				438		50				503
3b	2		8							2				15		182				209
4a	11			1	2			4						5		59		1		83
4b	3			2	16			3						23		127				174
5a			25		21			2		4				72		87				212
5b			22		2			14		22				28		111				198
6a	4			2	8									107		82	2			206
6b	17				4		1	2		1				22		52				98
7a			25		11		2	4		6				91		68	4			211
7b			58		2			6						44		52				161
8a			35		6					4				21		74				139
8b	4		27		2			11		4				109		20	4			179
9a	7		77		13		3	13		30			3	108		81				336
9b	0		26	1	8			10		2				8		43				98
10a	17		110		30		42	4		13			8	106		85	8			425
10b	6		28		13		1	9		2						31				89
11a			2	2												222				227
11b			8													119				127
11c			15					1							1	116				134
12a								1								35				36
12b					5			2			2					169				178
13a	6			5					2			4				103			1	120
13b	4			2				2								182				189
14a				6			1									50				57
14b				5		0.2										14				19
15a				11				32								59				102
15b		1		1				15								60				77
16a				3												14				17
16b				1												87				88

The names for species abbreviations are: ACON = *Aristida congesta*; AMER = *Aristida meridionalis*; ASTI = *Aristida stipitata*; CCIL=*Cenchrus ciliaris*; ELEH = *Eragrostis lehmanniana*; ENIN = *E. nindensis*; EPAL = *E. pallens*; ERIG = *E. rigidior*; ETRI = *E. tricophora*; MREP = *Melinis repens* var. *repens*; PCOL = *Panicum coloratum*; PMAX = *Panicum maximum*; PSQU = *Pogonarthria squarrosum*; SPAP = *Schmidtia pappophoroides*; SOBT = *Stipagrostis obtusa*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*; TSCH = *Triraphis schinzii*; UOLI = *Urochloa oligotricha*.

Table 4.7 Species composition of nearest bush recorded at the fenceline contrasts sites in the Camelthorn Savanna.

Contrast number	Percent of points at which the species abbreviated in the row below appeared as nearest bush of at least 0.5 m height, excluding rare species																		
	AANT	AERI	AHEB	ALUE	AMEL	BALB	CALE	COMM	DCIN	ERIG	GFLA	GRET	GYMN	LBOS	LEEN	RBRE	TCAM	TSER	ZMUC
1a		94	2		1						2								
1b		68	4		2						24								1
2a		22	2		2				5		56							13	
2b		27	3								64							5	1
3a		29	3	1	1				38		26						1		1
3b		48	1		1						48								1
4a		10			10				13		54						13		
4b		39			1				2		46						11		
5a		31	3	3							35						26		1
5b		32	5		5						34						20		5
6a		35	3								40						23		
6b		58	9		3				1		12						13		3
7a		59	1						3		26						3		9
7b		37	2		1				1		48						6		6
8a		45	2		1						30						20		1
8b		38	4		4						27						25		3
9a		4	4	1	6				8		28	3					2	41	
9b		3	2	1	16				7		27	1			1		3	38	
10a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10b		5	6	1					9	0	21						2	55	1
11a		18	32		49						0								1
11b		33	10		40						15								2
11c		17	9		58						14								2
12a		2	1		64		3		1	1	16			7	2	3			
12b		1			71						19			6	1	2			
13a		1	1	1	4	3	2	34	3	5	24	17	2	3					
13b	4	2		1	2	1	11	20	3	5	22	27		1					
14a						3	26	18	3		18	18	12			1		1	
14b	2				3	3	24	6	2		27	8	22			3			
15a	2			2	4	2	9				64	8		3	5				
15b	3		2		2		23	2	1		37	19		8	2				
16a	1			3	5	7	35	7	3	1	20	17							
16b	3			2	5	3	1	2	6		28	7	37		1	1			2

Shaded pairs (or groups of three) numbers differ significantly (P<0.05); NA = Not applicable due to limited number of bushes in hayfield; AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; ALUE = *A. luederitzii*; AHEB=*A. hebeclada*; AMEL=*A. mellifera*; BALB = *Boscia albitrunca*; CALE=*Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GFLA = *Grewia retinervis*; GSEN = *Gymnosporia senegalansis*; LDEC = *Laggera decurrens*; LBOS = *Lycium bosciifolium* + *Phaeoptilum spinosum*; LEEN= *Lycium eenii*; RBRE = *Rhigozum brevispinosum*, TCAM = *Tarchonanthus camphoratus*; TSER = *Terminalia sericea*; ZMUC = *Ziziphus mucronata*.

Table 4.8 Species composition of bush canopy cover recorded at the fenceline contrast sites in the Camelthorn Savanna.

Contrast number	% of bush canopy cover contributed by each of the species abbreviated in the row below, based on measurements with the Bitterlich gauge																		
	AANT	AERI	AHEB	ALUE	AMEL	BALB	CALE	COMM	DCIN	ERIG	GFLA	GRET	GSEN	LBOS	LEEN	RBRE	TCAM	TSER	ZMUC
1a		83	7		2						8								
1b		54		2	10						23								11
2a	1	5	5		3				5		38							40	2
2b		4	3		4				1		55							28	3
3a		18	2		1				20		58								1
3b		17	3		1						74								5
4a		43		2	7						46						2		
4b		30									43						23		5
5a		89		2	7														2
5b		88		10	3														
6a		53									33						10		3
6b		53									33						10		3
7a		45			2						33						13		6
7b		33	2		3						40						5		17
8a		62	1		1						16						17		3
8b		55	3		3						17						17		5
9a		2	4	1	14				7		24						5	44	1
9b		1	3	1	31				5		25						3	29	1
10a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10b		3	5	1	10				3		15						5	56	1
11a		24	31		41										1				3
11b		36	14		37						7								5
11c		15	23		48						7			1					6
12a		4	1		67	1	2				14			9	1	1			
12b		6	1		64	2					21			5	1	1			
13a				2	3	10	10	18	1	1	30	25		1					
13b					4	8	10	10	2	1	43	19		2					
14a				1	1	8	16	7	1		29	33	4						
14b	8	1	2		4	11	21				21	12	19			1			
15a	4		1	6	10		16		7		32	8		3	12				
15b	8		4	1	9		19	4			30	17		6	3				
16a	11			1	7	23	38	9			7	4							
16b	20		3	1	16	21		3	3		10	8	16						

NA = Not applicable due to limited number of bushes in hayfield; The names for species abbreviations are: AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; ALUE = *A. luederitzii*; AHEB=*A. hebeclada*; AMEL=*A. mellifera*; BALB = *Boscia albitrunca*; CALE=*Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GFLA = *Grewia retinervis*; GSEN = *Gymnosporia senegalansis*; LDEC= *Laggera decurrens*; LBOS = *Lycium bosciifolium* + *Phaeoptilum spinosum*; LEEN = *Lycium eenii*; RBRE = *Rhigozum brevispinosum*, TCAM = *Tarchonanthus camphoratus*; TSER = *Terminalia sericea*; ZMUC = *Ziziphus mucronata*.

Table 4.9 Density index (plants ha^{-1}) of bushes of at least 0.5 m in height at the fenceline contrasts sites in the Camelthorn Savanna.

Contrast number	Density index (plants ha^{-1}) for the species abbreviated in the row below as estimated from NB and DistB, excluding rare species																			
	AANT	AERI	AHEB	ALUE	AMEL	BALB	CALE	COMM	DCIN	ERIG	GFLA	GRET	GYMN	LBOS	LEEN	RBRE	TCAM	TSER	ZMUC	Total
1a		363	9		5						9									387
1b		906	54		27						325								14	1326
2a		172	18		18				36		433							99		777
2b		107	10		0						249							20	5	391
3a		461	49	16	16				592		411						16		16	1579
3b		211	5		5						211								5	435
4a		29			29				40		159						40		0	296
4b		176			5				11		209						49		0	450
5a		158	15	15	0						181						135		8	512
5b		48	7		7						51						31		7	151
6a		124	9		0						142						80		0	354
6b		326	50		19				6		69						75		19	565
7a		216	5		0				9		96						9		32	367
7b		232	14		7				7		302						35		35	632
8a		181	9		5						121						79		5	399
8b		180	18		18						126						120		12	475
9a		44	44	11	66				88		308	33					22	451		1067
9b		66	44	22	351				154		592	22			22		66	833		2171
10a																				0
10b		76	92	15					137		320						31	839	15	1525
11a		84	149		227						0								6	466
11b		142	44		172						64								10	432
11c		121	61		410						99								15	705
12a		76	38		2434		114		38	38	609			266	76	114				3804
12b		15			1039						278			88	15	29				1464
13a		18	18	18	71	54	36	608	54	89	429	304	36	54		0				1787
13b	51	25		13	25	13	140	254	38	64	280	344		13		0				1260
14a						70	610	422	70	0	422	422	282			23		23		2346
14b	49				74	74	593	148	49	0	667	198	544			74				2472
15a	46			46	92	46	208	0	0	0	1476	185		69	115					2284
15b	68		45		45	0	522	45	23	0	839	431		181	45					2245
16a	32			96	159	223	1115	223	96	32	637	541								3153
16b	32			21	54	32	11	21	64	0	289	75	375		11	11			21	1017

AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; ALUE = *A. luederitzii*; AHEB=*A. hebeclada*; AMEL=*A. mellifera*; BALB = *Boscia albitrunca*; CALE =*Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GFLA = *Grewia retinervis*; GSEN = *Gymnosporia senegalansis*; LDEC = *Laggera decurrens*; LBOS = *Lycium bosciifolium* + *Phaeoptilum spinosum*; LEEN= *Lycium eenii*; PSPI = *Phaeoptilum spinosum*; RBRE = *Rhigozum brevispinosum*, TCAM = *Tarchonanthus camphoratus*; TSER = *Terminalia sericea*; ZMUC = *Ziziphus mucronata*

Dispersion around the median values for numerical variables are presented for: (i) distance to nearest perennial grass (DistP) in Figure 4.5; (ii) count of perennial grasses (No P) in Figure 4.6; (iii) distance to nearest bush or tree (DistB) in Figure 4.7; and (iv) canopy cover by Bitterlich gauge (Bitterlich) in Figure 4.8. No chart was plotted for count of bushes shorter than 0.5 m (Woodies), since all medians were zero.

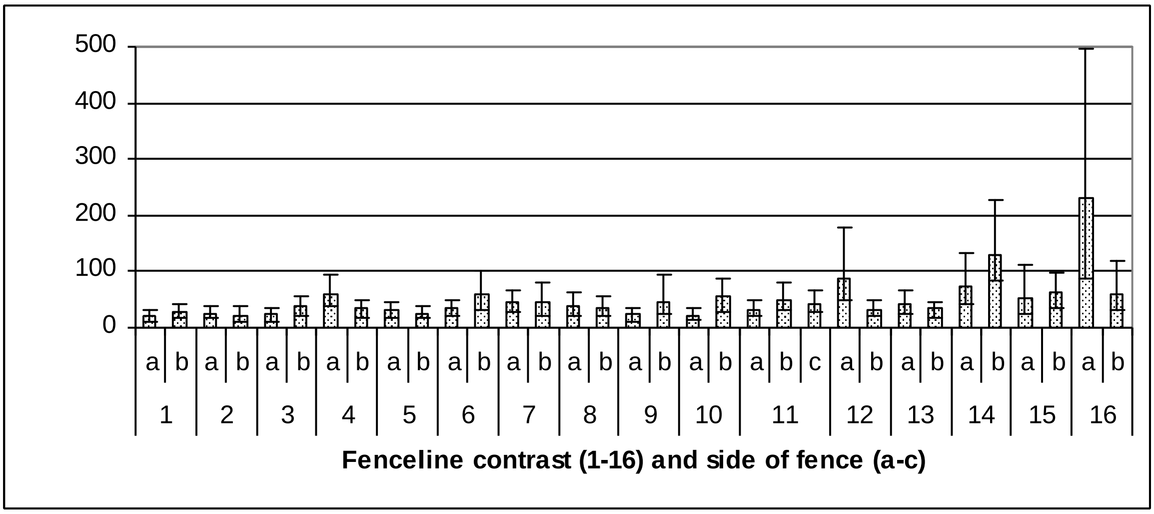


Figure 4.5 Median values and quartiles for the distance from sample point to nearest perennial grass of at least 5 cm basal diameter, for each of the sites measured at fenceline contrasts in the Camelthorn Savanna.

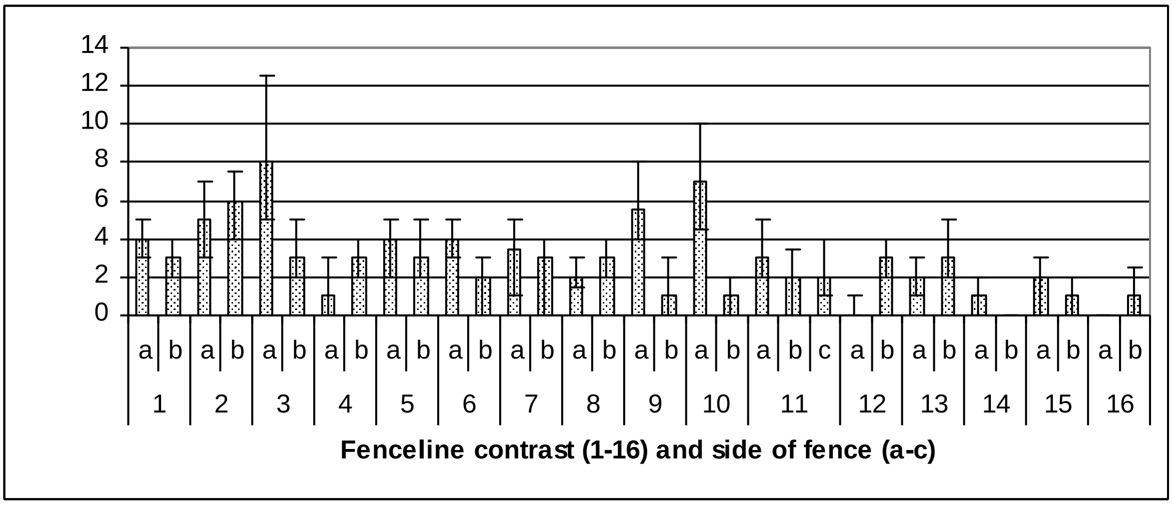
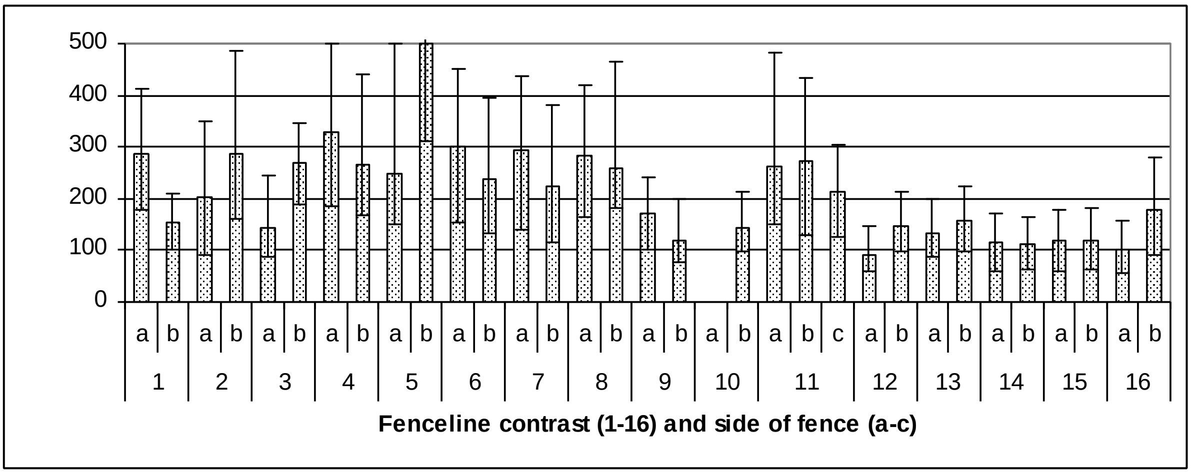


Figure 4.6 Median values and quartiles for the number of perennial grasses of at least 5 cm basal diameter counted in each of fenceline contrast sites in the Camelthorn Savanna.



The upper quartiles of 5a and 5b, and the median of 5b, were more than 500 cm and were therefore not measured. 10a was a hayfield with no bushes to measure.

Figure 4.7 Median values and quartiles for the distance from sample point to nearest bush or tree of at least 0.5 m in height, for each of the sites measured at fenceline contrasts in the Camelthorn Savanna.

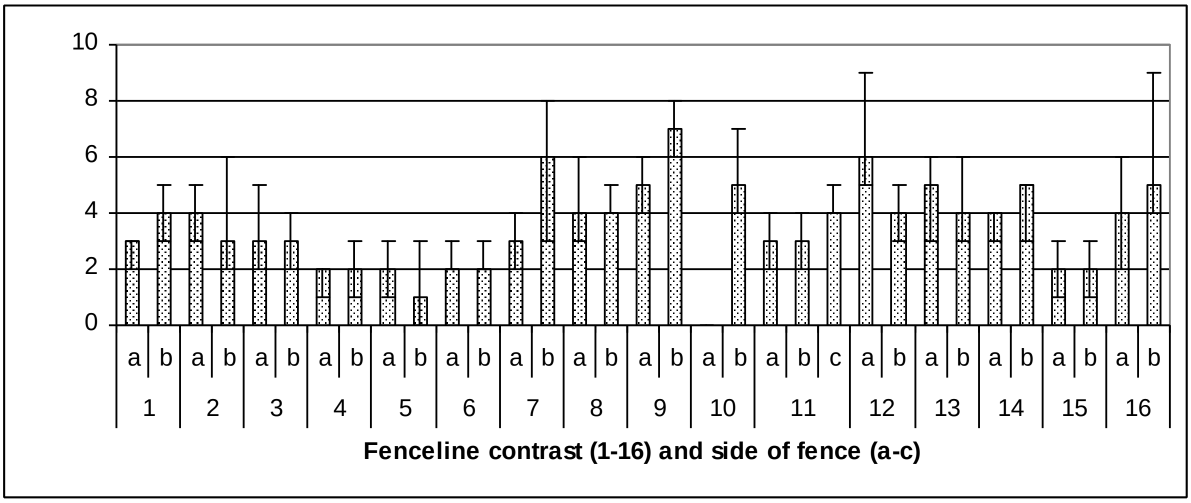


Figure 4.8 Median values and quartiles for the number of canopies of trees and bushes of at least 0.5 m in height counted by Bitterlich gauge in each of fenceline contrasts sites in the Camelthorn Savanna.

Results from Soil cover (Hit) measurements appear in Figure 4.9. Stones and rock were only encountered in the northwest of the Camelthorn Savanna, nearby the Thornbush Savanna.

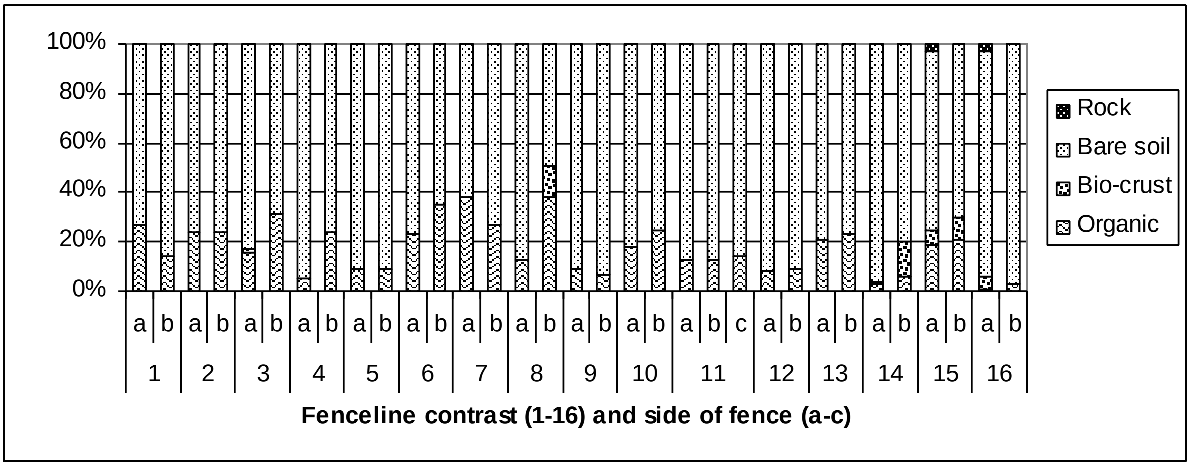


Figure 4.9 Proportions of organic cover over the soil (from mulch and bases of perennial grasses), biological soil crust, bare soil and rock found in each of fenceline contrasts sites in the Camelthorn Savanna.

4.5 INDIVIDUAL CONTRASTS

4.5.1 Contrast 1, between absentee leasehold farm and group resettled farm

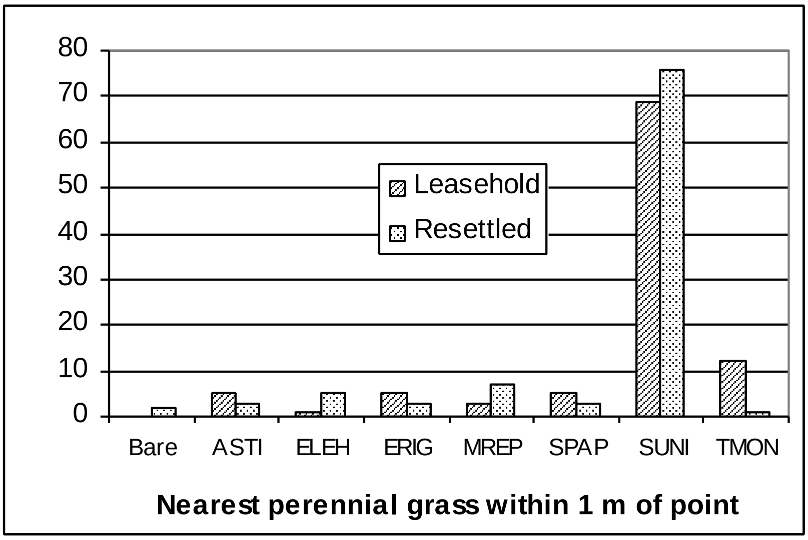
Site 1a on the northern side of Contrast 1 was on the only farm for which the farmer was not interviewed. Therefore the information on its management is not available. However it is likely to have been similar to that received by Site 7a adjoining it, which was estimated to be stocked at 24 kg liveweight ha^{-1} (19 ha AU^{-1}), They were both leasehold land on portions of the same former commercial farm that had been allocated to different families in 1989 by the Tswana Traditional Authority through long-term leases, where cattle, sheep, goats, horses and donkeys were kept. In the case of Site 1a the farmer was employed in northern Namibia and rarely visited the farm, with the foreman complaining of lack of farming inputs. The land was divided into a few paddocks, although they were more likely to be used continuously by different herds rotating through them and therefore probably did not receive much rest.

The contrasting site had also been a commercial farm where many sheep had been kept before 1996 when it was allocated to 48 families under the resettlement programme. It was not viable and the families were struggling to survive off the insufficient land allocated to them. Several families had been settled around each of the water points to share portions of the former farm. It was stocked heavily, estimated at 98 kg liveweight ha^{-1} (5 ha AU^{-1}), and the farmers felt powerless to apply proper management.

Photographs of the fenceline contrast are presented in Figure 4.10.

Figure 4.10 Fenceline contrast between leasehold land (1a, left) and resettled land (1b, right). The photographs were taken in March 2005.

The resettled farm had a lower organic cover over the soil and a lower perennial grass density (Table 4.2). Further differences in perennial grass are presented in Figure 4.11, with more *Tricholaena monachne* appearing on the leasehold side, although there was no significant (P>0.05) difference in proportions of mesophytic and xerophytic species. The rangeland condition index was slightly but not significantly (P>0.05) higher on the leasehold farm (344 versus 295). Despite quite a lot of perennial grasses surviving on the resettled farm, it is likely that they were still in the process of declining, since the heavy stocking had occurred for less than a decade.



Bare = no perennial grass within 1 m; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

Figure 4.11 Perennial grass species composition at Contrast 1 in the Camelthorn Savanna.

The resettled farm also had a higher bush density, as evidenced by the shorter distance to nearest bush. The proportion of short bushes between 0.5 and 1 m was also higher on the resettled farm (Figure 4.12).

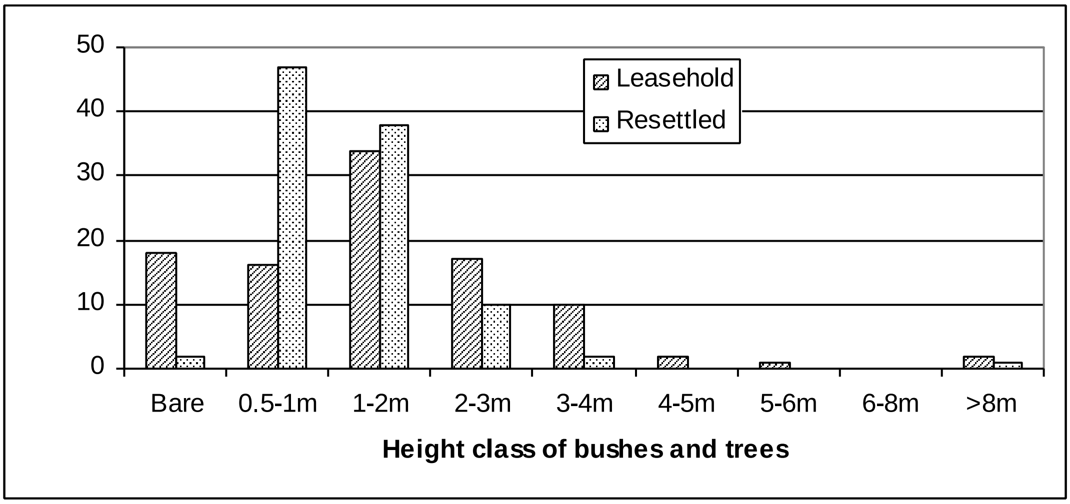


Figure 4.12 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 1 in the Camelthorn Savanna.

Three times as many plants of the geophyte, *Senna italica*, often abundant on degraded land, were found on the resettled side, giving a mean density estimate of 2 320 plants ha^{-1} compared to 790 on the leasehold side. However this was not significantly (P=0.15) different by Chi-Square test, due to the low number of points at which it was counted, as a consequence of the small sample area.

4.5.2 Contrast 2, between commercial beef farm and absentee leasehold farm

Contrast 2 was between a large commercial beef farm, 2a, which was divided into many paddocks, and leasehold land, 2b, comprising a three paddock portion of a former commercial farm. The stocking rate was about 14% higher on the leasehold land where the absentee farmer rotated his 40 cattle systematically every three months through the three paddocks to which his 60 sheep, 30 goats and 2 donkeys had continuous access. Although the six months of rest from cattle on the leasehold farm was about twice as long as on the commercial farm during the growing season, the period of grazing was about 13 times longer. The commercial farm also had goats and horses, but they were not taken to the boundary paddocks through fear of stock theft.

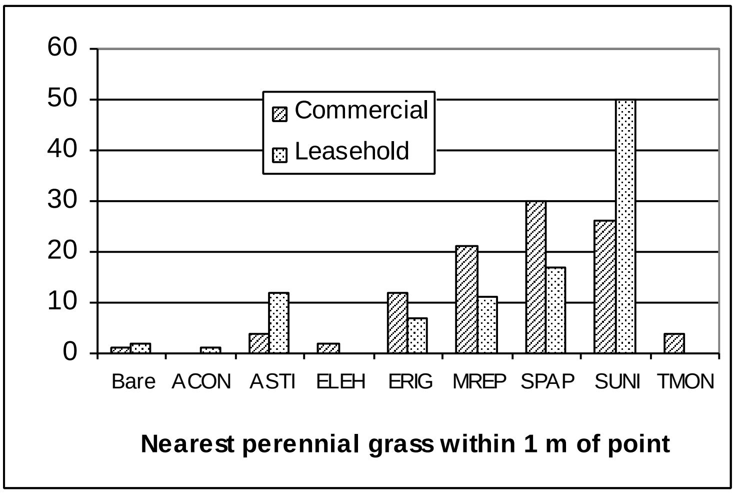
The farm at Site 2a had only four paddocks and one water point until the early 1980's when additional boreholes were drilled and paddocks were subdivided. The farm at Site 2b had been occupied by three families for a year after conversion to leasehold in 1989. The current leaseholder claimed that the farm had been heavily overstocked during that year, when the contrast with Site 2a developed, and that many trees had been chopped. The grass apparently improved after he took over the farm from those families.

Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.13.

Figure 4.13 Both sides of fenceline contrast between commercial land (2a, top) and leasehold land (2b, bottom). The photographs were taken in March 2005.

Although the perennial grass density was not significantly different (P>0.05), the proportion of mesophytes amongst them was greater on the commercial farm. The most common mesophyte species were *Schmidtia pappophoroides* and *Melinis repens*, (Figure 4.14). The rangeland condition index was only slightly and not significantly (P>0.05) higher on the commercial farm (397 versus 367).

The bush density was higher on the commercial farm, as evidenced by the lower distance to nearest bush or tree (DistB), although the canopy cover and height class did not differ significantly (P>0.05). Almost twice as many stems of the woody geophyte, *Elephantorrhiza elephantina*, often abundant on degraded land, were found on the leasehold side, giving a mean density estimate of 7 470 plants ha^{-1} compared to 4 360 plants ha^{-1} on the commercial side. This difference was significant (P<0.05).



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

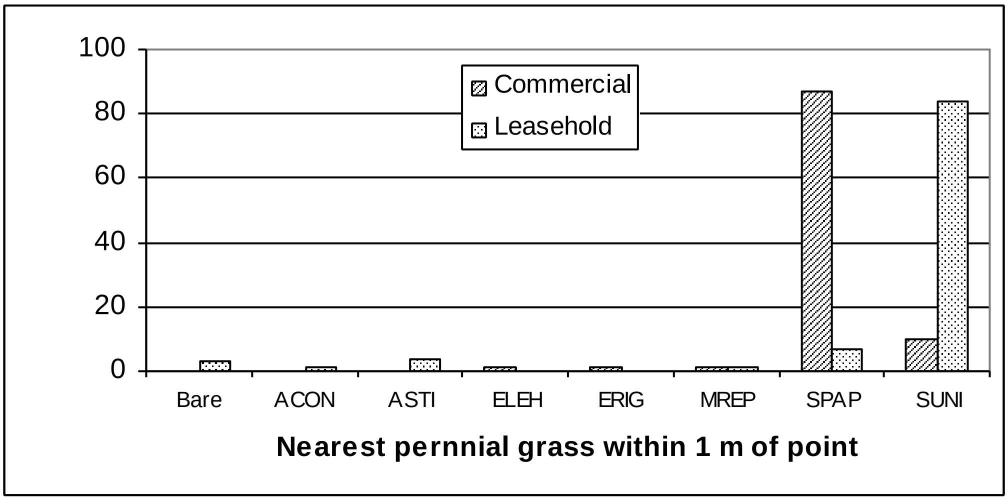
Figure 4.14 Perennial grass species composition at Contrast 2 in the Camelthorn Savanna.

4.5.3 Contrast 3, between commercial beef farm and group leasehold farm

Site 3a was on the same commercial beef farm as 2a. The contrasting site, 3b, was another portion of leasehold land comprising a three paddock portion of a former commercial farm and roughly of similar size at about 400 ha. However the main difference between it and Site 2b was that it had been allocated to four families who all lived permanently on the farm, depending primarily on their livestock, compared to the single absentee leaseholder on 2b. Site 3b had the highest stocking rates of all the sites measured in the Camelthorn Savanna, estimated to be 105 kg liveweight ha^{-1} (4 ha AU^{-1}). Only occasionally was permission given by the headman of a nearby community for the cattle to be grazed in one of the communal paddocks to relieve the pressure from the leased farmland. The contrast was believed to have developed soon after conversion of Site 3b to leasehold in 1989. Photographs of the fenceline contrast, taken in March 2005, are presented in Figure 4.15.

Figure 4.15 Fenceline contrast between a commercial farm (3a, right, in the distance) and leasehold land (3b, left, in the distance) in the Camelthorn Savanna.

Site 3a on the commercial farm had the highest perennial grass density out of all sites recorded in the Camelthorn Savanna, with a mean of 5 grasses m^{-2}. In addition, it had the highest proportion of mesophytic grasses amongst the perennial grasses recorded, at 90%, contrasting with 8% on the leasehold side of the fence. The cover of *Schmidtia pappoporoides* was particularly high on the commercial farm (Figure 4.16). The rangeland condition index was significantly ($P<0.0001$) higher on the commercial farm (650 versus 202).



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 4.16 Perennial grass species composition at Contrast 3 in the Camelthorn Savanna.

Surprisingly the mulch cover was more than twice as high on the leasehold farm, at 21% compared to 11 % on the commercial farm. The types of mulch had not been differentiated, but the leasehold site had numerous dead perennial grasses mostly grazed down to about 15 cm by horses and donkeys. It is likely that these dead grasses and the loose thatch dislodged from them by trampling contributed to the high mulch, together with lots of dry dung and masses of hoof marks that trapped dicotyledonous leaves and grass seeds.

The bush density was higher on the commercial farm, with a median distance to nearest bush or tree (DistB) of 142 cm compared to 271 cm on the leasehold farm. This translates to a difference in density index of 1 579 compared to 435 plants ha^{-1} (Table 4.6). A greater proportion of bushes on the commercial farm was in the 1-2 m height class (Figure 4.17), with a smaller proportion in the 0.5-1 m height class. The commercial farm had a high proportion of *Dichrostachys cinerea* amongst the bushes (Figure 4.18).

However, in the case of the woody geophyte, *Elephantorrhiza elephantina*, a significantly (P<0.05) higher number of stems were found on the leasehold side, giving a mean density estimate of 3 230 plants ha^{-1} compared to 170 on the commercial side.

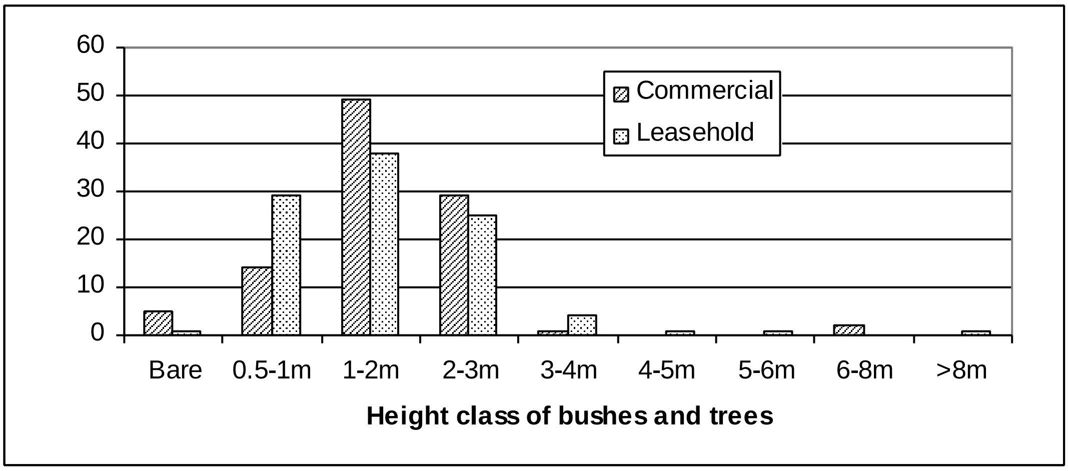
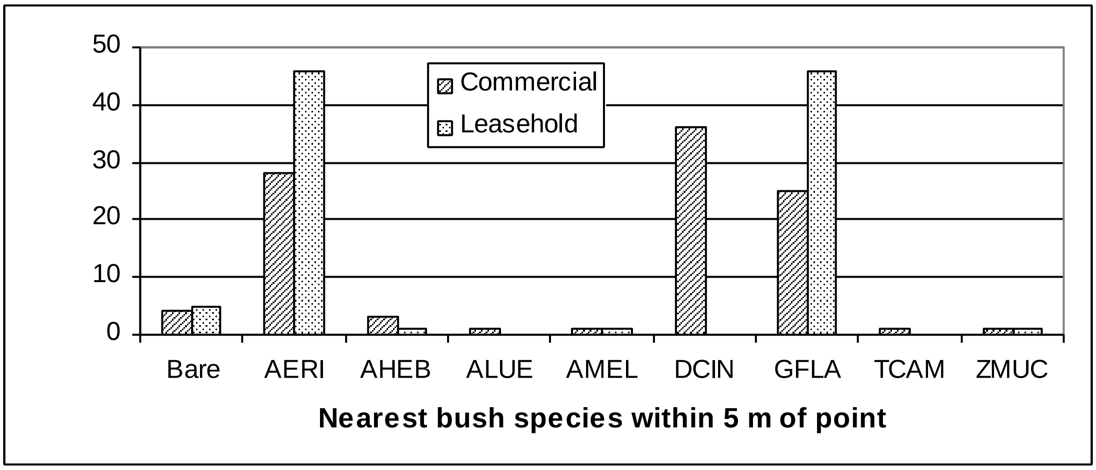


Figure 4.17 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 3 in the Camelthorn Savanna.



Bare = no bush within 5 m; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; AMEL = *A. mellifera*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 4.18 Bush species composition at Contrast 3 in the Camelthorn Savanna.

4.5.4 Contrast 4, between game farm and individual leasehold farm

Site 4a was located in a large game paddock stocked continuously with a variety of game species for the previous five years. Before then it had been a smaller paddock for cattle to rotate through. The game species were dominated by both blue and black wildebeest and blesbok. The overall stocking rate was estimated at 58 kg liveweight ha^{-1} (8 ha AU^{-1}), although the game animals appeared to prefer the southern portion of the paddock. The contrasting site to the south, 4b, was leasehold land on a portion of a former commercial farm. The cattle were moved through two paddocks per herd, but as this was done regularly every month the grasses hardly received any rest. Although the overall stocking rate was higher on the leasehold land, estimated at 96 kg liveweight ha^{-1} (5 ha AU^{-1}), the grazing pressure from the cattle, small stock and equines was less at the fence with the contrast, while the game animals concentrated in the south of the game paddock, along this fence. In each case the water point was near the centre of the grazing area, so the animals seemed to prefer grazing in a southerly direction, a tendency also observed at some of the other sites nearby.

The absentee game farmer believed that the contrast developed in 1999 when he removed cattle and dismantled internal fencing, allowing better grass to establish. On the other hand, the resident farmer of Site 4b believed that the contrast developed during drought in 1992 and intensified during the following drought in 1996, reducing the grass more on Site 4b.

Photographs of the fenceline contrast are presented in Figure 4.19.

Figure 4.19 Fenceline contrast between leasehold land (4b, left) and a game paddock (4a, right) in the Camelthorn Savanna. The photographs were taken in March 2005.

The findings differed from the perceptions of both farmers. The leasehold farm had significantly ($P<0.05$) higher organic cover of 25% over the soil compared to 5% for the game paddock. The perennial grass density was also significantly ($P<0.05$) higher with a mean density of 1.7 grasses m^{-2} compared to 0.8 on Site 4a. The proportions of mesophytes and xerophytes did not differ significantly ($P>0.05$), since *Stipagrostis uniplumis* dominated both sides, but *Aristida congesta* made up 13% of the perennial grasses found on the game paddock compared to 2% on 4b. There were more bare patches on the game paddock (Figure 4.20), often associated with sites where game animals concentrate. The rangeland condition index was significantly ($P<0.001$) lower on the game farm (82 versus 266).

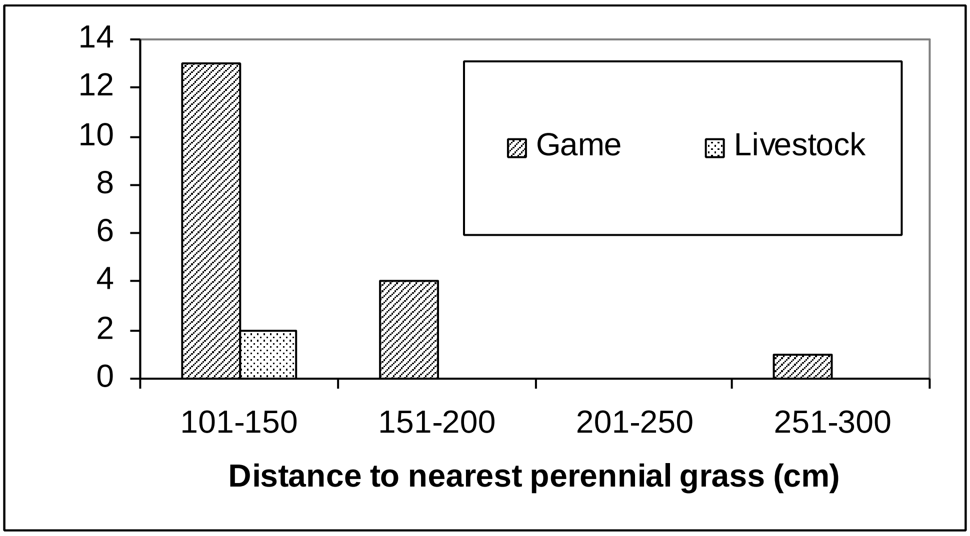


Figure 4.20 Bare patch size frequencies at Contrast 4 in the Camelthorn Savanna.

The bush density did not differ significantly (P>0.05), but there were more small bushes of 0.5-1 m height class in the game paddock (Figure 4.21). They made up 78% of the bushes, which was the greatest proportion found amongst all sites measured in the Camelthorn Savanna. The game paddock had 9% of encroacher species among the bushes, compared to none on the leasehold farm.   Figure 4.22 presents the composition of bush species, with a greater proportion of *Acacia erioloba* on the leasehold farm and a greater proportion of *Acacia mellifera* and *Dichrostachys cinerea* on the game paddock, while *Grewia flava* dominated both farms.

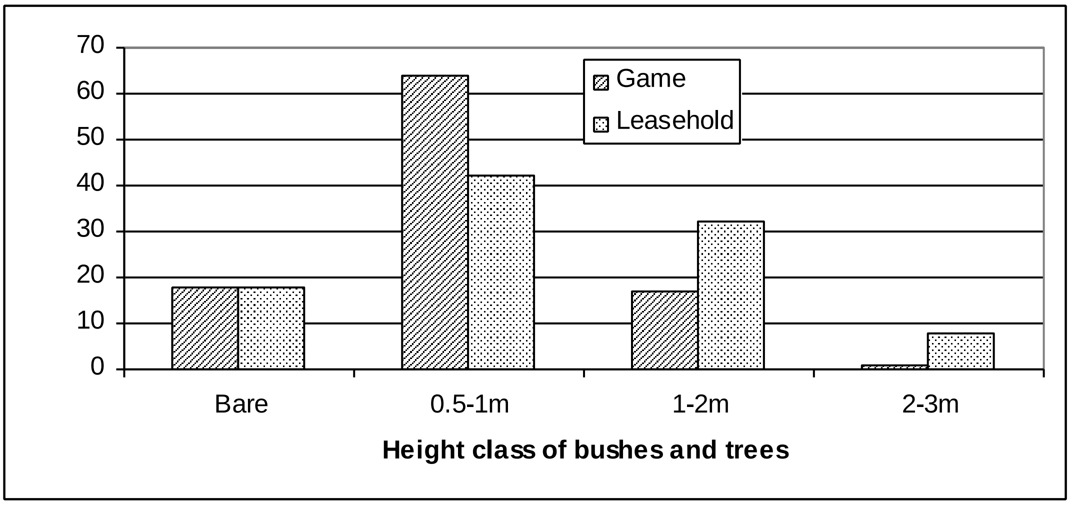
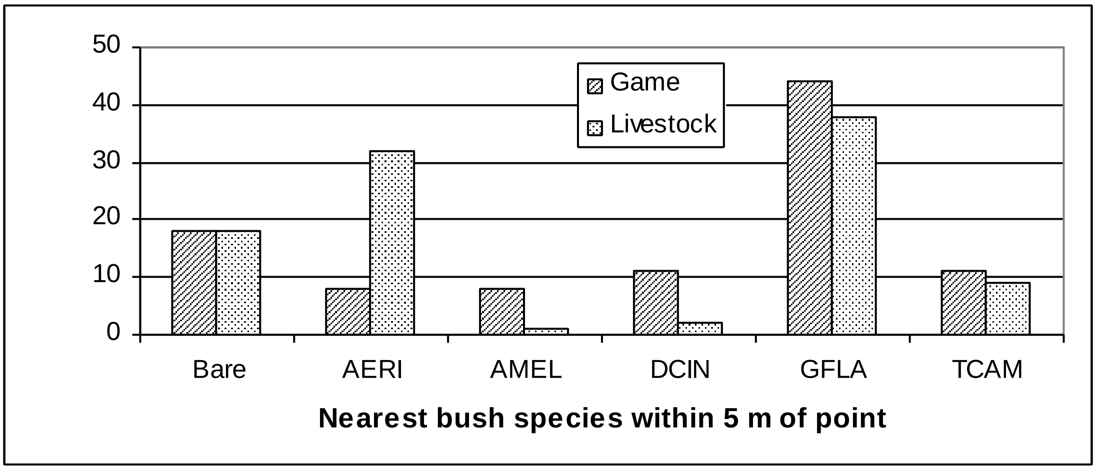


Figure 4.21 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 4 in the Camelthorn Savanna.



Bare = no bush within 5 m; AERI = *Acacia erioloba*; AMEL = *Acacia mellifera*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; TCAM = *Tarchonanthus camphoratus*.

Figure 4.22 Bush species composition at Contrast 4 in the Camelthorn Savanna.

A significantly ($P<0.05$) higher number of stems of *Elephantorrhiza elephantina* were found on the game paddock, giving a mean density estimate of 5 440 plants ha^{-1} compared to 850 plants ha^{-1} on the leasehold side.

4.5.5 Contrast 5, between dairy paddock and individual leasehold farm

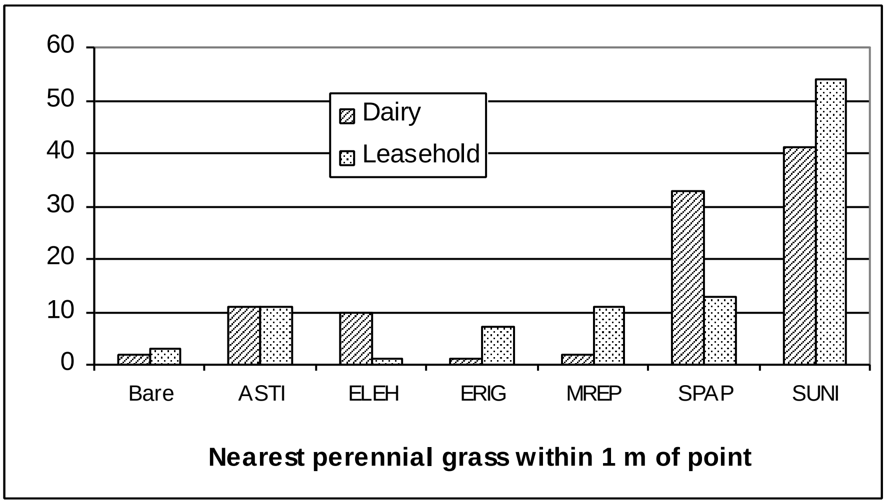
Site 5a was on the same farm as the game paddock of 4a, but it was stocked with a small herd of dairy cattle that rotated through six other paddocks, estimated at 12 kg liveweight ha^{-1} (38 ha AU^{-1}). Five years previously it had been stocked at a higher rate by beef cattle. The contrasting site, 5b, was on leasehold land that was divided into two paddocks, although each was grazed continuously by cattle, small stock and equines. The grazing pressure appeared to be higher than on the neighbouring leasehold farm of Site 4b, although the reported stocking rate was slightly lower, estimated at 79 kg liveweight ha^{-1} (6 ha AU^{-1}). The appearance of higher grazing pressure on Site 5b may have resulted from the longer period during which it had been heavily stocked than Site 4b. Nevertheless the grazing pressure on 5b was higher than on Site 5a at the time of the measurements.

The contrast was believed to have developed a few years after Site 5b was converted from commercial farm to leasehold in 1989.

Photographs of the fenceline contrast are presented in Figure 4.23.

Figure 4.23 Fenceline contrast between leasehold land (5b, left) and a paddock used for rotational grazing by dairy cattle on a game farm (5a, right). The photographs were taken in March 2005.

This contrast did not indicate significant (P>0.05) differences in soil cover and perennial grass density, nor in bush canopy cover, species composition and height class. However there were significant (P<0.05) differences in grass species composition (Figure 4.21), with a greater proportion of *Schmidtia pappophoroides* in the dairy paddock. The rangeland condition index was only slightly and not significantly (P>0.05) higher on the commercial farm (322 versus 309).



Bare = no perennial grass within 1 m; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 4.24 Perennial grass species composition at Contrast 5 in the Camelthorn Savanna.

The bush density was lower on the leasehold side of the fence, giving a density index of only 151 bushes ha^{-1}, compared to 512 bushes ha^{-1} on the dairy paddock.

A significantly (P<0.05) higher number of stems of *Elephantorrhiza elephantina* were recorded on the dairy paddock, giving a mean density estimate of 3 000 stems ha^{-1} compared to 1 470 plants ha^{-1} on the leasehold side.

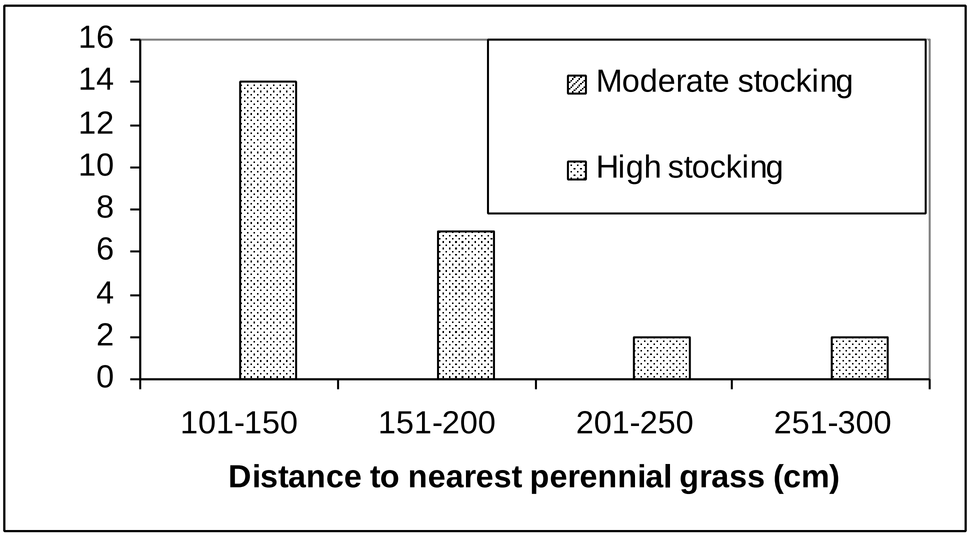
4.5.6 Contrast 6, between moderately and heavily stocked leasehold farms

Both 6a and 6b were on leasehold farms, with mixed livestock grazing continuously. The main difference was that 6a was stocked more lightly, at 26 kg liveweight ha^{-1} (17 ha AU^{-1}). Site 6b was one of the two paddocks on a farm that had an overall stocking rate identical to 6a, but it was the paddock containing the only water point on the farm and was stocked much more heavily. In fact the gate to the waterless paddock was closed during the time of the measurements and had not been used during the past two rainy seasons, because fires had swept through in both years and the farmer did not want his animals getting sick from feeding on the lush grass regrowth. Site 6a was approximately 1 500 m from the water point, compared to only 300 m for Site 6b.

The fenceline comprised an old game fence, since Site 6b had been a game paddock before conversion to leasehold in 1989, while Site 6a had been a commercial cattle farm. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.25.

Figure 4.25 Both sides of fenceline contrast between leasehold land under moderate stocking (6a, top) and high stocking (6b, bottom). The photographs were taken in March 2005.

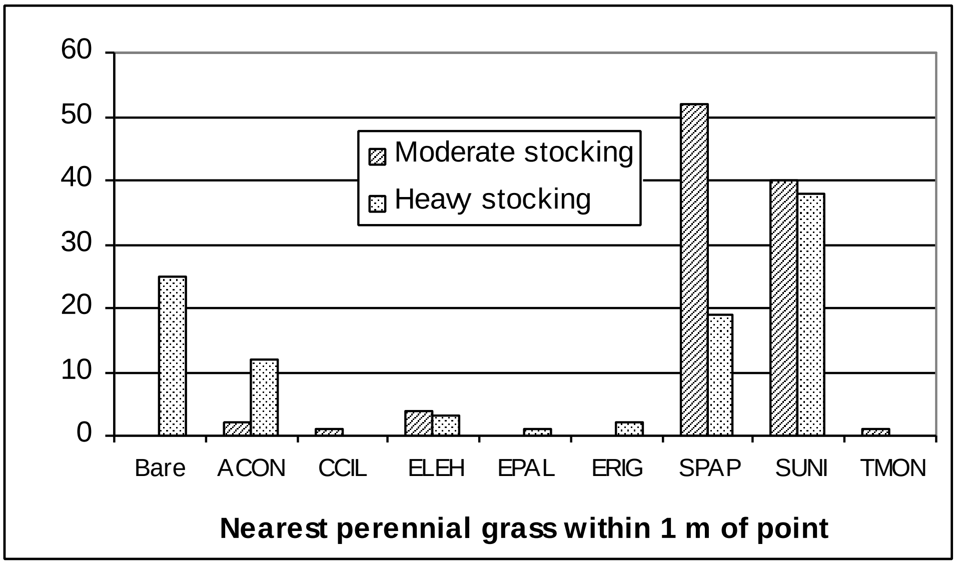
Both farmers believed their side of the fenceline was in worse condition. It was the absentee farmer of Site 6a who was wrong, at least for the measured contrast. The perennial grass density was more than double on the moderately stocked Site 6a, which is also borne out by the bare patch size frequencies presented in Figure 4.26. There were no points further than 1 m from a perennial grass on 6a, while 25% of the points on 6b were further than 1 m from the nearest perennial grass.



There were no bare patches found at Site 6a on the moderately stocked farm.

Figure 4.26 Bare patch size frequencies at Contrast 6 in the Camelthorn Savanna.

The proportion of mesophytes was also higher on 6a, with a higher abundance of *Schmidtia pappophoroides* and a smaller proportion of *Aristida congesta* (Figure 4.27). The rangeland condition index was significantly ($P<0.01$) higher at 6a (347 versus 156).



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; CCIL = *Cenchrus ciliaris*; ELEH = *Eragrostis lehmanniana*; EPAL = *E. pallens*; ERIG = *E. rigidior*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

Figure 4.27 Perennial grass species composition at Contrast 6 in the Camelthorn Savanna.

There were no significant (P>0.05) differences in the measurements of trees and bush of at least 0.5 m in height, and no encroacher bush species were recorded on either farm. However, a significantly (P<0.05) higher number of bush saplings shorter than 0.5 m were found on Site 6b, giving a mean density estimate of 1 810 saplings ha^{-1} compared to 400 saplings ha^{-1} on 6a.

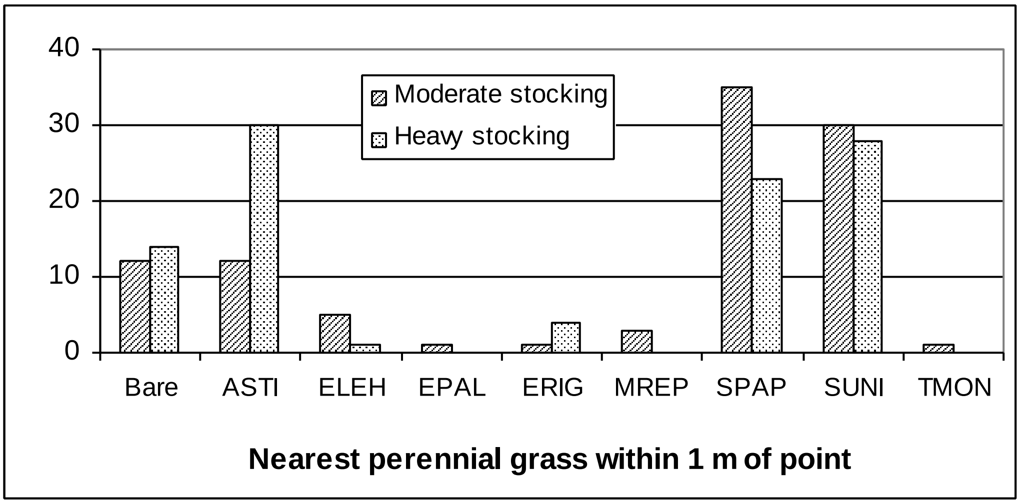
4.5.7 Contrast 7, between moderately and heavily stocked leasehold farms

Contrast 7 was similar to Contrast 6 in that both Sites 7a and 7b were on leasehold farms, with mixed livestock grazing continuously. The main difference was that 7a was stocked even more lightly, at 24 kg liveweight ha^{-1} (19 ha AU^{-1}), and 7b received more pressure from the livestock, being south of 6b, although in the same paddock. In addition, 7a had proportionately fewer cattle and small stock, and more horses and donkeys, than 7b.

Site 7a had been a commercial livestock farm before conversion to leasehold in 1989, while 7b had been a game paddock. Site 7a was a large paddock with the water point approximately 2 km away from the fenceline contrast. The farmer believed his farm was understocked, although he benefited from this during droughts. Photographs of the fenceline contrast are presented in Figure 4.28.

Figure 4.28 Fenceline contrast between leasehold land under moderate stocking (7a, left) and high stocking (7b, right). The photographs were taken in March 2005.

The perennial grass density did not differ significantly (P>0.05) between the two sides of the fence, but the proportion of mesophytes was higher on the moderately stocked 7a. There was a greater proportion of *Schmidtia pappophoroides* and a smaller proportion of *Aristida stipitata* on Site 7a (Figure 4.29). The rangeland condition index was slightly but not significantly (P>0.05) higher at 7a (214 versus 188).



Bare = no perennial grass within 1 m; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; EPAL = *E. pallens*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

Figure 4.29 Perennial grass species composition at Contrast 7 in the Camelthorn Savanna.

The bush canopy cover was almost twice as high at 29% on Site 7b, although the differences in bush density and height class were not significant (P>0.05). There was a greater proportion of *Acacia erioloba* amongst the bushes on 7a, with a correspondingly greater proportion of *Grewia flava* on 7b (Table 4.7).

A significantly (P<0.05) higher number of bush saplings shorter than 0.5 m were found on the moderately stocked Site 7a, giving a mean density estimate of 1 360 saplings ha^{-1} compared to 170 saplings ha^{-1} on the heavily stocked Site 7b. This is opposite to the findings at Site 6 where there were more saplings on the moderately stocked farm than on 6b, which is in the same paddock as 7b, although 7b experiences a heavier grazing pressure. On the other hand significantly (P<0.05) higher number of stems of *Elephantorrhiza elephantina* were found on Site 7b under heavy stocking, giving a mean density estimate of 1 640 stems ha^{-1} compared to 110 stems ha^{-1} on the moderately stocked side 7a.

4.5.8 Contrast 8, between moderately and heavily stocked paddocks on the same leasehold farm

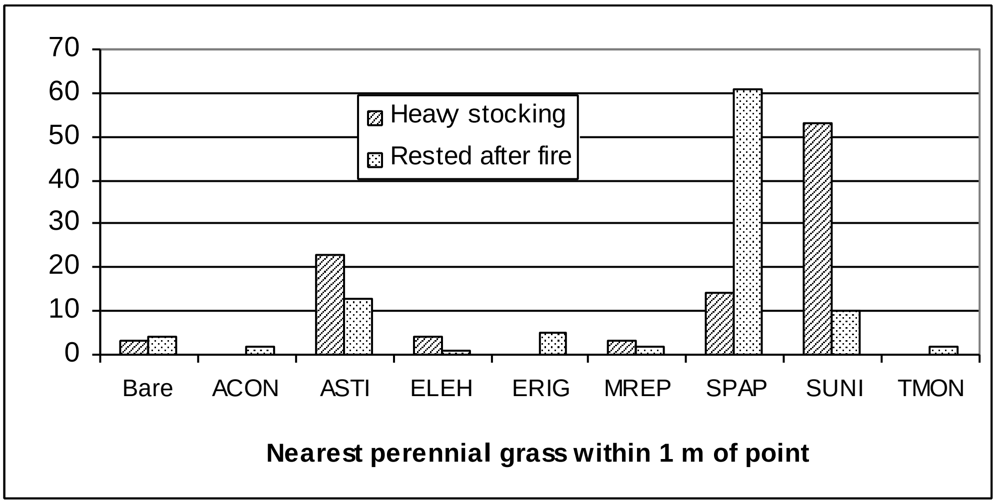
Contrast 8 was between the two paddocks that made up the same leasehold farm. Site 8a was in the southern portion of the paddock that also contained Sites 6b and 7b and received about the same grazing pressure as 7b. Site 6b was closer to the water point in the northern part of the paddock, but the tendency for animals to graze in a southerly direction was exacerbated by the funnelling effect as the paddock narrowed from 6b towards 7b and 8a. Site 8b was in the paddock that did not have a water point and had received rest from cattle and equines for the past two growing seasons, after fires had swept through.

The fenceline comprised the game fence that had separated the game paddock from the livestock portion of the commercial farm that had been converted to leasehold in 1989. Photographs of the fenceline contrast are presented in Figure 4.30.

Figure 4.30 Fenceline contrast between paddock with water point (8a, left) and paddock without water point and rested after fires (8b, right), on the same leasehold farm. The photographs were taken in March 2005.

Site 8b had a high organic cover of 38%, compared to 27% on 8a. This is surprising for only one growing season after the last fire, but the complete rest after the fire may have contributed towards it. The perennial grass density was only slightly but significantly ($P<0.05$) higher on 8b, at 1.8 grasses m^{-2}, compared to 1.4 on Site 8a. However the proportion of mesophytes differed tremendously, contributing to 72% of the perennial grasses on 8b, compared to 22% on 8a. It was mainly the difference in balance between *Schmidtia pappophoroides* and *Stipagrostis uniplumis* that contributed towards this (Figure 4.31). The rangeland condition index was lower at 8a (186 versus 274). This difference was not significant ($P>0.05$) by Mann-Whitney U test, but when tested by Chi-square, it was ($P<0.05$).

None of the differences in bushes and trees between the two sites were found to be significant ($P>0.05$), with canopy covers of 22 and 23%.



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; ELEH = *Eragrostis lehmanniana*; ERIG = *E. rigidior*; MREP = *Melinis repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

Figure 4.31 Perennial grass species composition at Contrast 8 in the Camelthorn Savanna.

4.5.9 Contrast 9, between commercial breeding farm and speculation paddock

Contrast 9 was between two commercial farms and both sides were used primarily for cattle, although some horses were also grazed occasionally at 9a. The main difference was that 9a was used together with five other paddocks through which a breeding herd of cattle was rotated to provide a rest of about six weeks during the growing season, whereas 9b was stocked opportunistically to raise oxen from weaners when the prices were right. The overall stocking rate is likely to have been somewhat higher for 9b than for 9a, but the figure of 60 kg liveweight ha^{-1} (8 ha AU^{-1}) in Table 4.1 is a rather rough estimate. The overall stocking rate for whole farm, mostly used for stud breeding, was only 31 kg liveweight ha^{-1} (15 ha AU^{-1}). Site 9b would have received the occasional rest after the oxen were sold.

The management of Site 9b was largely profit driven, while Site 9a was managed for sustainability. The farmer of 9a believed the fenceline contrast had developed in 1990, while the farmer of 9b believed it had developed in 1975. Both farms had been owned by one farmer with no fence between them until 1968. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.32. They were taken in March 2005.

Figure 4.32 Both sides of fenceline contrast between farm with beef breeding farm (9a, top) and paddock used for raising of oxen from speculation weaners (9b, bottom).

The perennial grass density of 3.4 grasses m^{-2} on Site 9a was much greater than the 1.0 grasses m^{-2} found on Site 9b. There were consequently many more bare patches on 9b (Figure 4.33).

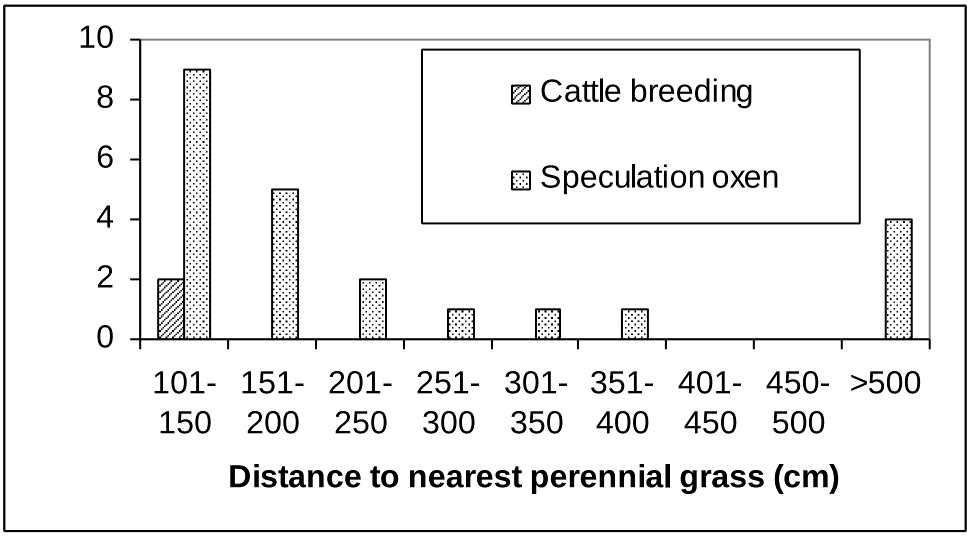
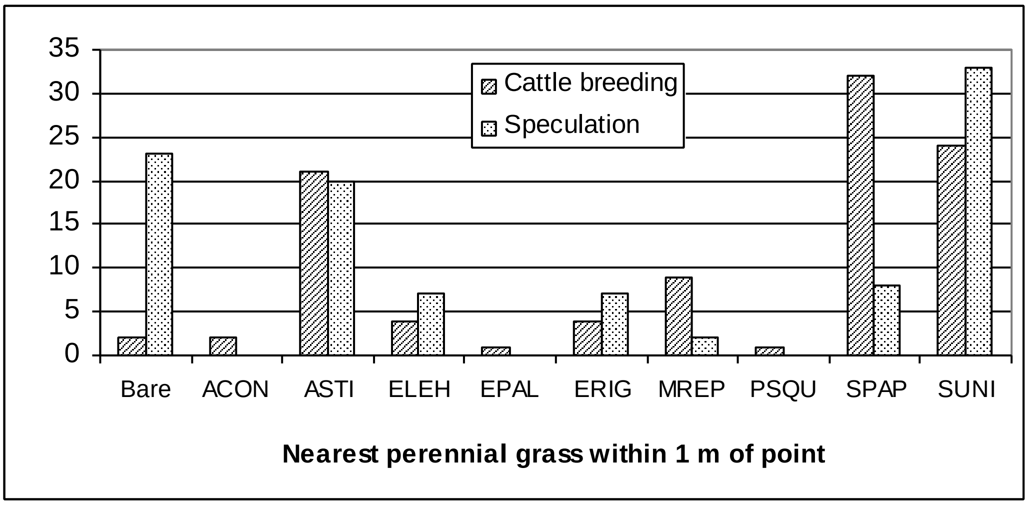


Figure 4.33 Bare patch size frequencies at Contrast 9 in the Camelthorn Savanna.

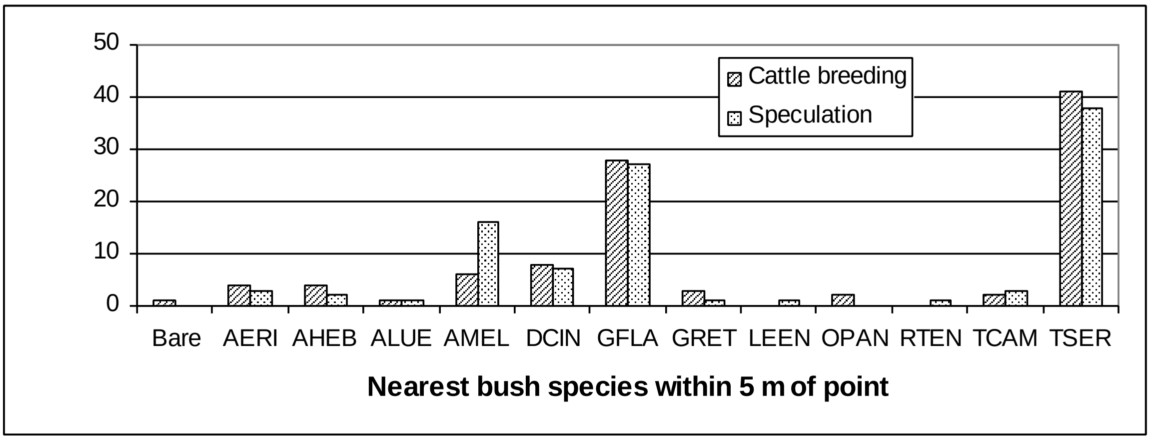
The perennial grass species composition also differed, with greater proportions of *Schmidtia pappophoroides* and *Melinis repens* on 9a (Figure 4.34). The rangeland condition index was significantly (P<0.0001) much higher at 9a (416 versus 111).



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; EPAL = *E. pallens*; ERIG = *E. rigidior*; MREP = *Melinis repens*; PSQU = *Pogonarthria squarrosum*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 4.34 Perennial grass species composition at Contrast 9 in the Camelthorn Savanna.

The bush density was higher on 9b, as was the canopy cover at 35%, which was the highest recorded among all sites measured in the Camelthorn Savanna. Although *Acacia mellifera* on 9b made up almost three times as many of the measured bushes as NB, there were greater proportions of both *Terminalia sericea* and *Grewia flava* bushes on both sides of the fence (Figure 4.35). The canopies of the encroacher species seemed to be greater, as they made up 41% of the canopy cover on 9b, compared to 25% on 9a.



Bare = no bush within 5 m; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; LEEN = *Lycium eenii*; OPAN = *Ozoroa paniculosa*; RTEN = *Rhus tenuinervis*; TCAM = *Tarchonanthus camphoratus*; TSER = *Terminalia sericea*.

Figure 4.35 Bush species composition at Contrast 9 in the Camelthorn Savanna.

4.5.10 Contrast 10, between hay field and paddock grazed by equines

Contrast 10 was between two paddocks that made up the same commercial farm that had Site 9b. Site 10a was a hay field from which bushes had been totally cleared approximately 25 years previously to convert to a maize field. The production of maize had not been successful so grasses were allowed to recolonise while newly recruited bushes were controlled and hay was harvested annually except for drought years. Some cattle were allowed to graze the paddock for a few weeks after the hay has been baled. Site 10b was in a paddock that had been allocated to the farm labourers to use for whatever they wished. They opted to graze 20 horses and 4 donkeys continuously in that paddock of roughly 180 ha. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.36.

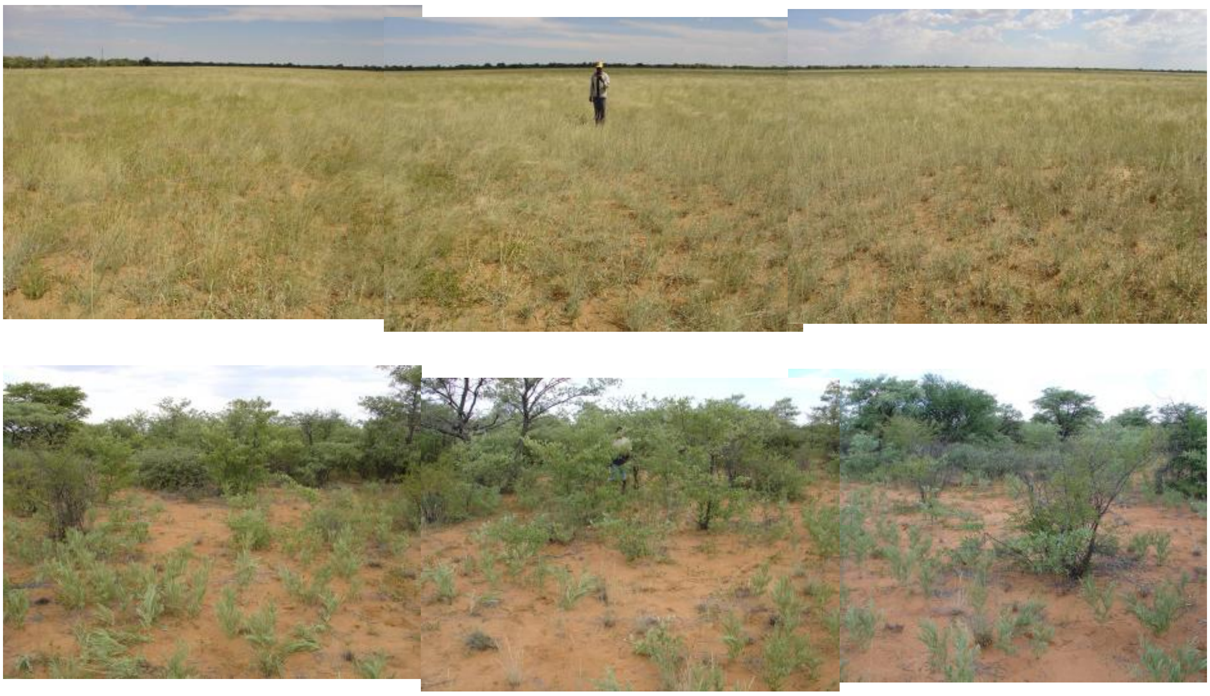
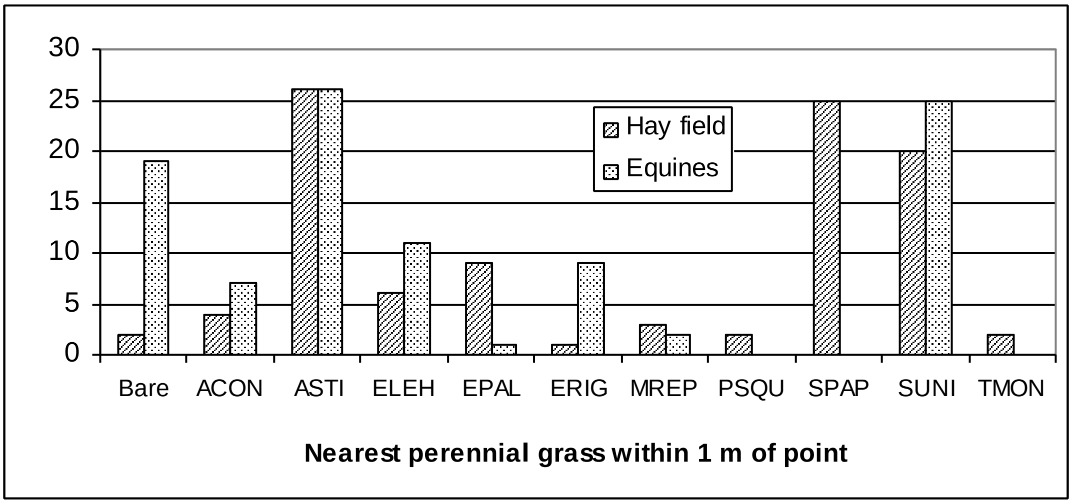


Figure 4.36 Both sides of fenceline contrast between hayfield (10a) on the top and paddock in which horses and donkeys graze continuously (10b) on the bottom. The photographs were taken in March 2005.

The density of perennial grasses was much higher on the hay field, estimated at 4.7 grasses m^{-2} compared to 0.9 grasses m^{-2} in the equine paddock. The species composition also differed, with *Schmidtia pappophoroides* found only in the hay field (Figure 4.37). The equine paddock had a greater proportion of *Eragrostis rigidior*, which is valued for hay making due to the high bulk it produces, while *Eragrostis pallens* contributed more to the perennial grasses found in the hay paddock. The rangeland condition index was significantly (P<0.0001) much higher on the hay field (371 versus 86).



Bare = no perennial grass within 1 m; ACON = *Aristida congesta*; ASTI = *Aristida stipitata*; ELEH = *Eragrostis lehmanniana*; EPAL = *E. pallens*; ERIG = *E. rigidior*; MREP = *Melinis repens*; PSQU = *Pogonarthria squarrosum*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*; TMON = *Tricholaena monachne*.

Figure 4.37 Perennial grass species composition at Contrast 10 in the Camelthorn Savanna.

Bushes over 0.5 m obviously differed tremendously, with none appearing in the hay field, compared to a canopy cover of 29% in the equine paddock. However there were some bush saplings shorter than 0.5 m in the hay field, giving a mean density estimate of 280 saplings ha^{-1}, although significantly ($P<0.05$) lower than the equine camp estimated at 1 190 saplings ha^{-1}. In addition there was a significantly ($P<0.05$) higher number of stems of *Elephantorrhiza elephantina* found in the equine paddock, giving a mean density estimate of 2 890 plants ha^{-1} compared to 1 020 plants ha^{-1} on the hay field.

4.5.11 Contrast 11, between paddocks of different sizes on the same farm

There were three sites that made up Contrast 11, all on the same farm which had been overstocked to repay a loan until five years previously. They were stocked at the same rate of about 67 kg liveweight ha^{-1} (7 ha AU^{-1}) by cattle, sheep and goats, but their paddocks differed in size and therefore experienced very different periods of grazing and slightly different periods of rest. Site 11a was in a paddock of 6 ha, Site 11b in a paddock of 120 ha and Site 11c in a paddock of 340 ha. The grazing periods during the growing season would have been about eight hours for 11a, about seven days for 11b and about 20 days for 11c, at stocking densities of approximately 8 100, 400 and 140 kg liveweight ha^{-1} (18, 0.9 and 0.3 AU ha^{-1}) respectively, while rest periods would have been about six, five and three weeks respectively. However the rates of rotation varied considerably according to circumstances and sometimes all herds on the farm were combined into one to provide 19 paddocks per herd. This farm was the most southerly of all those measured in the Camelthorn Savanna and therefore received the lowest mean annual rainfall of approximately 250 mm. Photographs of the measured sites on all three sides of the fenceline contrasts are presented in Figure 4.38

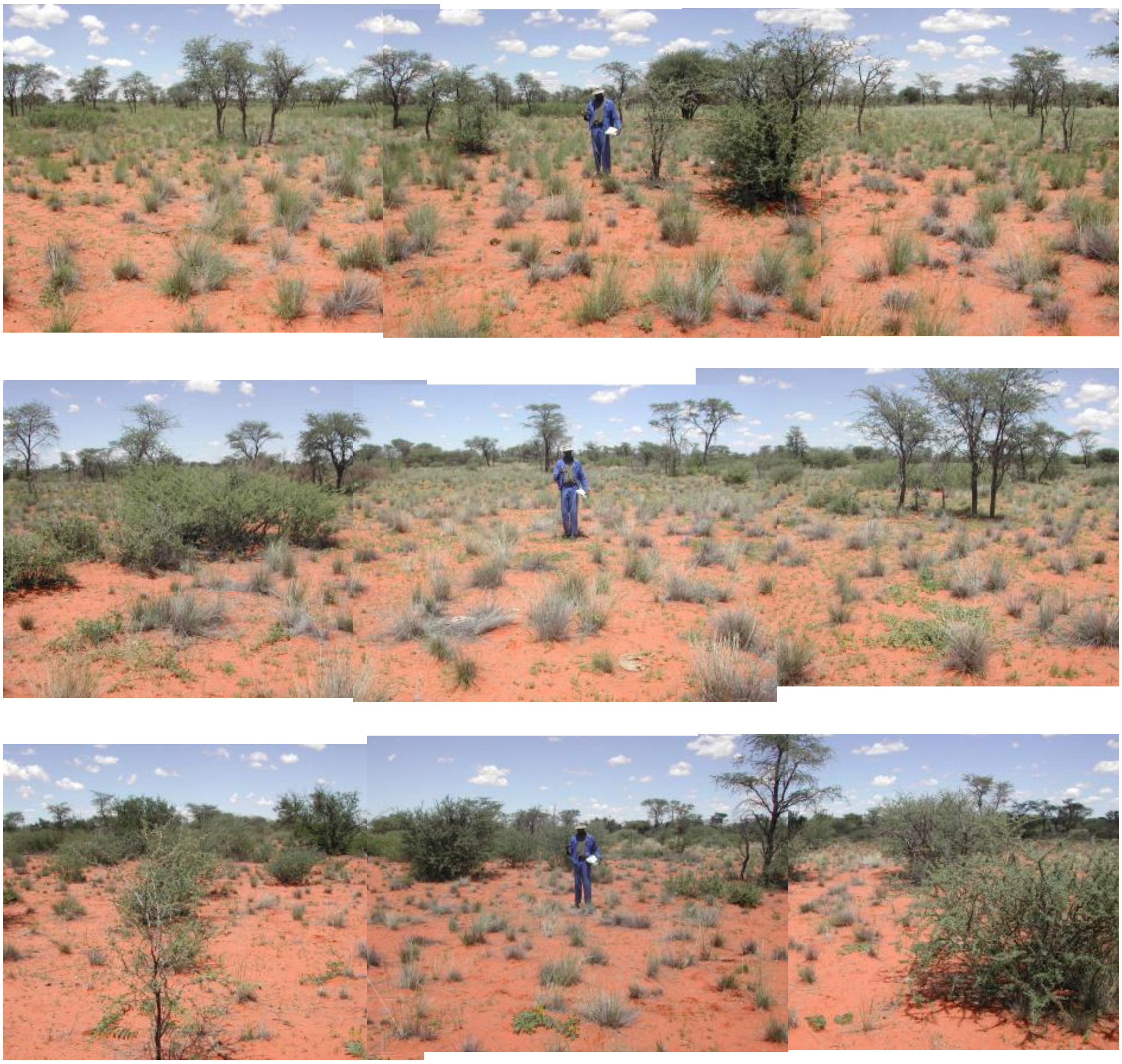
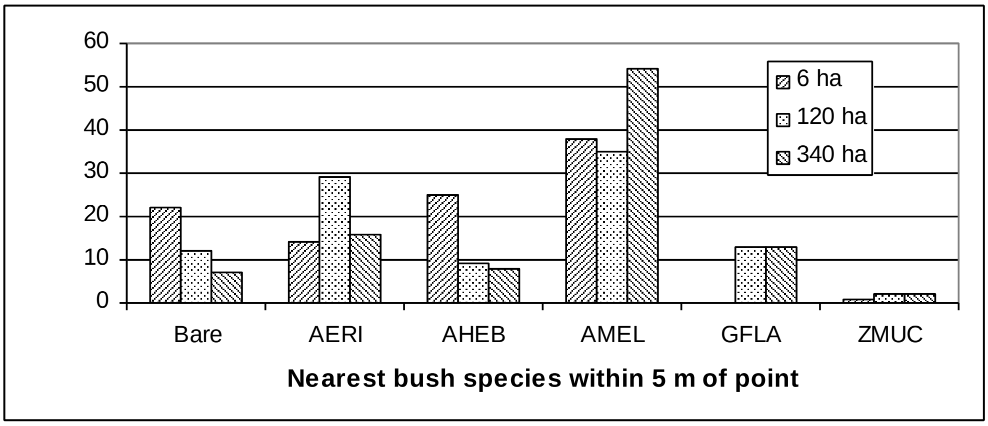


Figure 4.38 All three sides of fenceline contrast between paddocks of 6 ha (11a, top), 120 ha (11b, middle) and 340 ha (11c, bottom), all on the same farm. The photographs were taken in March 2004.

The perennial grass density was highest in the smaller paddock, at 2.3 grasses m^{-2}, but was the same for the two larger paddocks, at 1.3 grasses m^{-2}. The perennial grasses were largely dominated by *Stipagrostis uniplumis* (Table 4.5). Nevertheless the differences in composition of *Aristida stipitata* differed significantly ($P<0.05$) among all three paddocks, comprising 1%, 6% and 11% of the perennial grasses measured in the small, medium and large paddock respectively. The rangeland condition index was significantly ($P<0.05$) higher on the smaller paddock (225 versus 120 on the medium; and 123 on the largest paddock).

The bush density was highest in the biggest paddock, as was canopy cover at 22% compared to 17% and 15% for the intermediate and small paddock respectively. The species composition indicated a greater proportion of *Acacia hebeclada* in the smallest paddock, while the intermediate paddock had the greatest proportion of *Acacia erioloba* and the biggest paddock had the greatest proportion of *Acacia mellifera* (Figure 4.39).



Bare = no bush within 5 m; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; AMEL = *A. mellifera*; GFLA = *Grewia flava*; ZMUC = *Ziziphus mucronata*.

Figure 4.39 Bush species composition at Contrast 11 in the Camelthorn Savanna.

The height class differences between all three paddocks were significant (P<0.05), but it was the intermediate paddock that differed the most from the other two (Figure 4.36), with more bushes in the 0.5-1 m height class and fewer over 2 m than the other two paddocks.

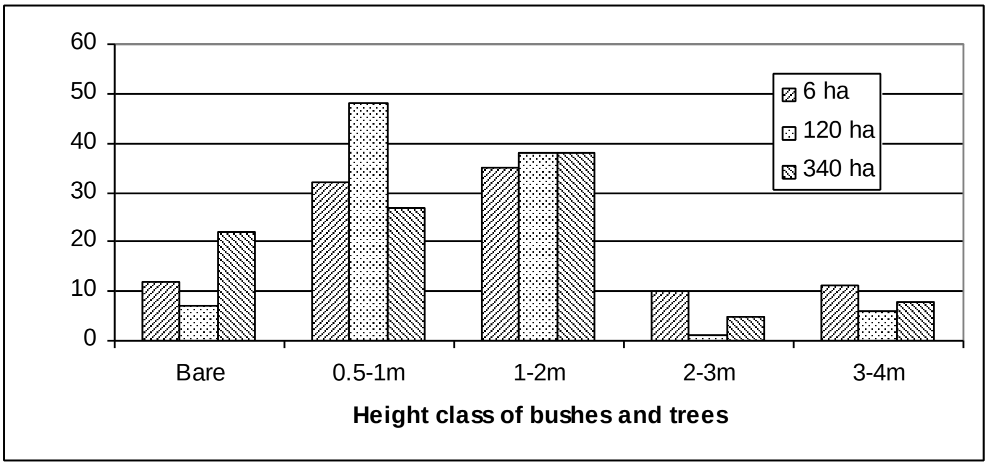


Figure 4.40 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 11 in the Camelthorn Savanna.

The number of bush saplings shorter than 0.5 m were found by Chi-Square test to differ significantly (P<0.05) between the three sites, although it was strictly not valid since the expected frequencies of points within 75 cm of a sapling fell just below five (Zar, 1999). The mean density estimates came to 60, 340 and 620 saplings ha^{-1} for the small, medium and large paddocks respectively.

4.5.12 Additional contrast on same farm as Contrast 11 of timing of trampling

The contrast was between a paddock that had received a short, heavy trampling at the start of that rainy season and a paddock that had not yet been trampled that rainy season. The stocking density to achieve that trampling was estimated at approximately 3 000 kg liveweight ha^{-1} (6.7 AU ha^{-1}), applied for one day. Only the count of perennial grasses (No P) and distance to nearest perennial grass (DistP) were measured at this contrast, for all perennial grasses including those with a basal diameter of less than 5 cm. The measurements were made in late January, approximately six weeks after the start of the rainy season. A close up photograph of perennial grass seedlings in the trampled paddock is presented in Figure 4.41.

Figure 4.41 A high density of seedlings of *Stipagrostis uniplumis* growing in the paddock that had received short, heavy trampling at the start of that rainy season. The photograph was taken in January 2007.

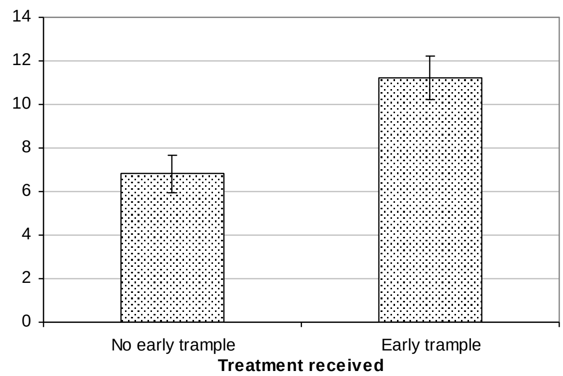


Figure 4.42 Densities of perennial grass ± 95 % confidence limits on each side of the fence, one side trampled at the start of that rainy season.

The mean perennial grass density was found to be 11.2 grasses m^{-2} on the site that had received the early season trampling, compared to 6.8 grasses m^{-2} on the site that had not yet been trampled since the start of that rainy season, as presented in Figure 4.38. Since these counts of perennial grasses (No P) had been normally distributed, the 95% confidence limits are presented in Figure 4.42. A t-test found a high level of significance (P<0.001) in the difference.

4.5.13 Contrast 12, between fixed grazing rotation and strategically applied trampling

Site 12a had apparently been in poor condition when the farm was bought four years earlier, but the new owner did not know about the previous management. At the time of the measurements he applied a slow fixed rotation through four paddocks per herd of cattle stocked at 33 kg liveweight ha^{-1} (14 ha AU^{-1}), providing six months of rest after two months of grazing at a stocking density of about 130 kg liveweight ha^{-1} (3 ha AU^{-1}). Site 12b was on the same farm as Contrast 11, with cattle, sheep and goats stocked at 67 kg liveweight ha^{-1} (7 ha AU^{-1}) rotated quickly in the growing season. The rate of rotation and paddocks per herd varied, with short trampling by all animals on the farm combined into one herd applied strategically, such as soon after good rain to conserve soil water by breaking the capillary connections to the soil surface. The more common stocking density would have been about 400 kg liveweight ha^{-1} (1 AU ha^{-1}) but may have increased more than tenfold to above 4 000 kg liveweight ha^{-1} (9 AU ha^{-1}). This adaptive management is described in more detail in the case study presented in Chapter 8. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.43.

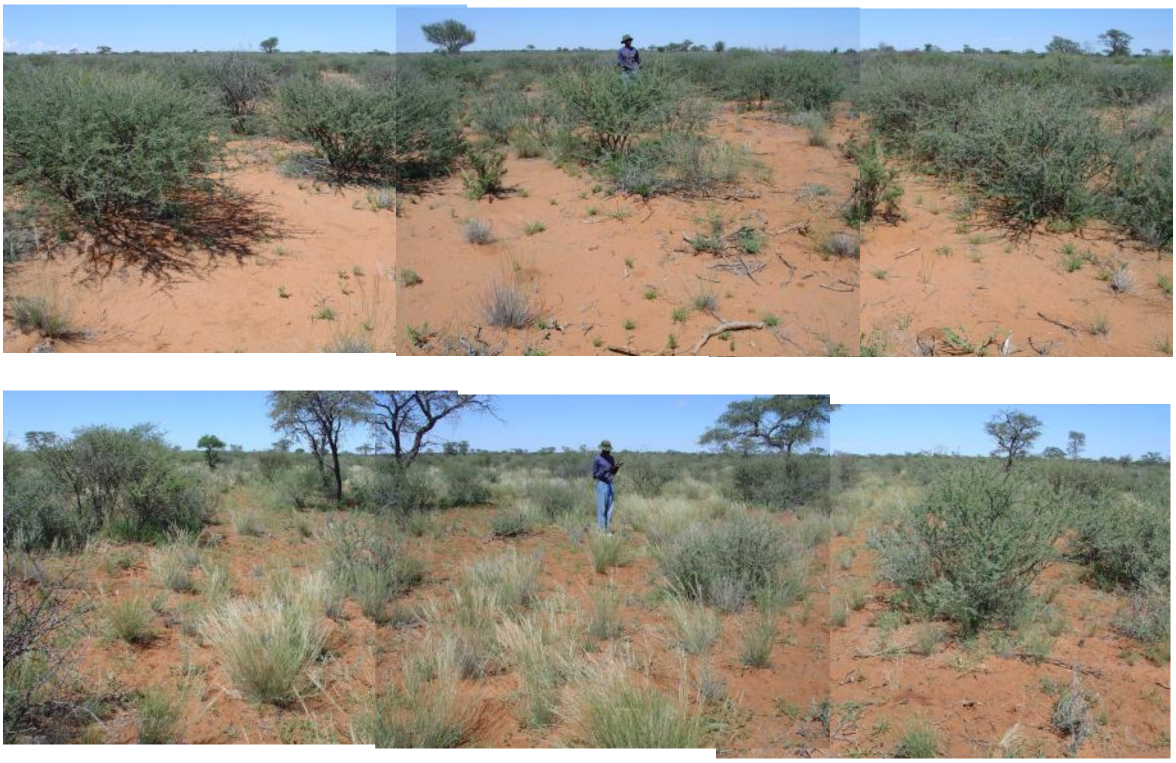


Figure 4.43 Both sides of fenceline contrast between land under slow fixed rotation (12a, top) and strategic trampling (12b, bottom). The photographs were taken in March 2005.

The perennial grass density was very low at Site 12 a, at only 0.4 grasses m^{-2}, compared to 1.8 grasses m^{-2} at 12b. The bare patch size frequencies in Figure 4.44 indicate this difference. The rangeland condition index was significantly ($P<0.0001$) much lower at Site 12a (40 versus 225).

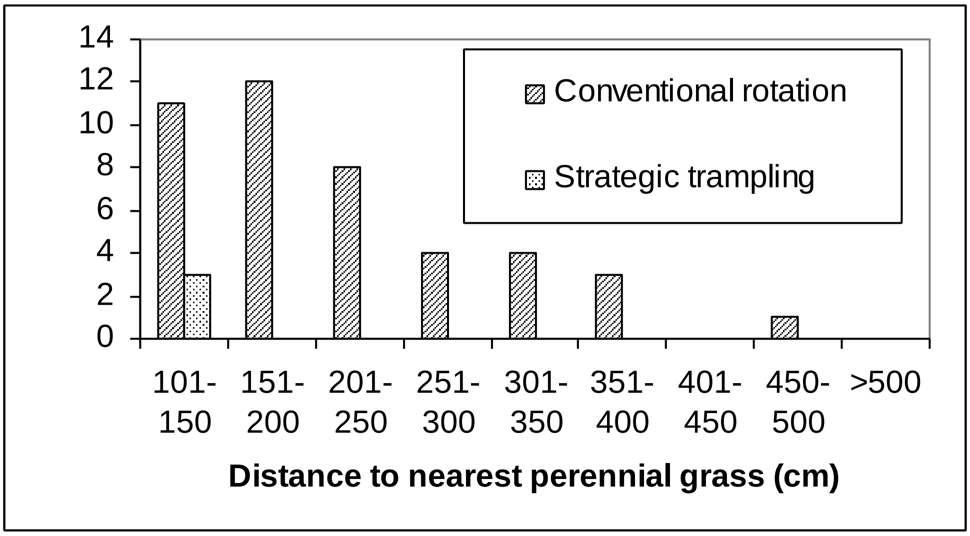


Figure 4.44 Bare patch size frequencies at Contrast 12 in the Camelthorn Savanna.

Site 12a had the highest bush density out of all sites recorded in the Camelthorn Savanna, with a median distance to nearest bush of only 92 cm and the second highest canopy cover of 33%. This compared to a median distance to nearest bush of 148 cm and a canopy cover of 20% on Site 12b. However the species composition and height classes of bushes did not differ significantly ($P>0.05$). There was a significant ($P<0.05$) difference in the case of the palatable leguminous perennial forb, *Otoptera burchellii*, of which the density was estimated at 450 plants ha^{-1} on Site 12a and 2 150 plants ha^{-1} on 12b.

The results of the soil water measurements are presented in Figure 4.45. They indicate slightly more soil water at the end of the dry season, in April, between 30 and 80 cm depth in the strategically trampled soil on 12b, suggesting that infiltration may have been improved. However, by mid dry season, in July, it appeared drier below 30 cm, possibly due to higher transpiration through the greater density of perennial grasses on that side of the contrast. Since the soil water profiles had only been replicated twice, no statistical analysis was performed.

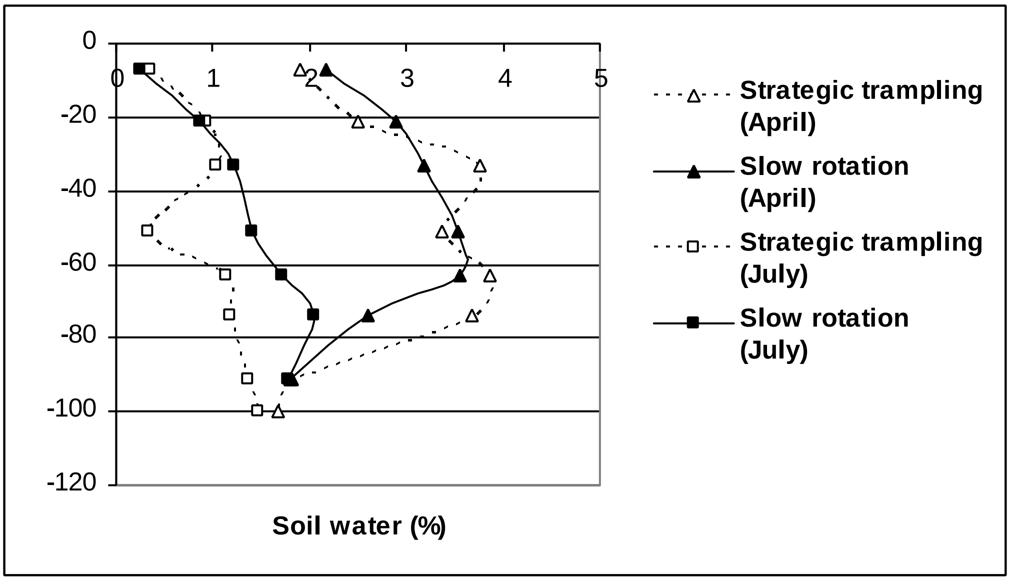


Figure 4.45 Successive soil water profiles at Contrast 12 in the Camelthorn Savanna.

4.5.14 Contrast 13, between selective bush control and no bush control

Both of the commercial farms at Contrast 13 were used for raising beef cattle. Site 13b had undergone selective bush control to thin bushes by hand application of arboricide about five years previously, while 13a had not experienced any control of bushes. The stocking rates were 34 kg liveweight ha^{-1} (13 ha AU^{-1}) at 13a and 47 kg liveweight ha^{-1} (10 ha AU^{-1}) at 13b. The paddocks provided per herd were eight for 13a and four for 13b, but the rotation was quicker on 13a so the rest in the growing season was only slightly higher at 9 weeks on 13a compared to 8 weeks on 13b.

The farmer of Site 13a applied a lower stocking rate to prevent his cattle from defoliating the grass too low, which would lower animal production. The farm had been overstocked in the 1960's when there were veterinary restrictions on animal movements. Historical development of all farms at Contrasts 13-16 was similar, with subdivision into paddocks started in the 1960's followed by further subdivisions in the 1980's.

Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.46.

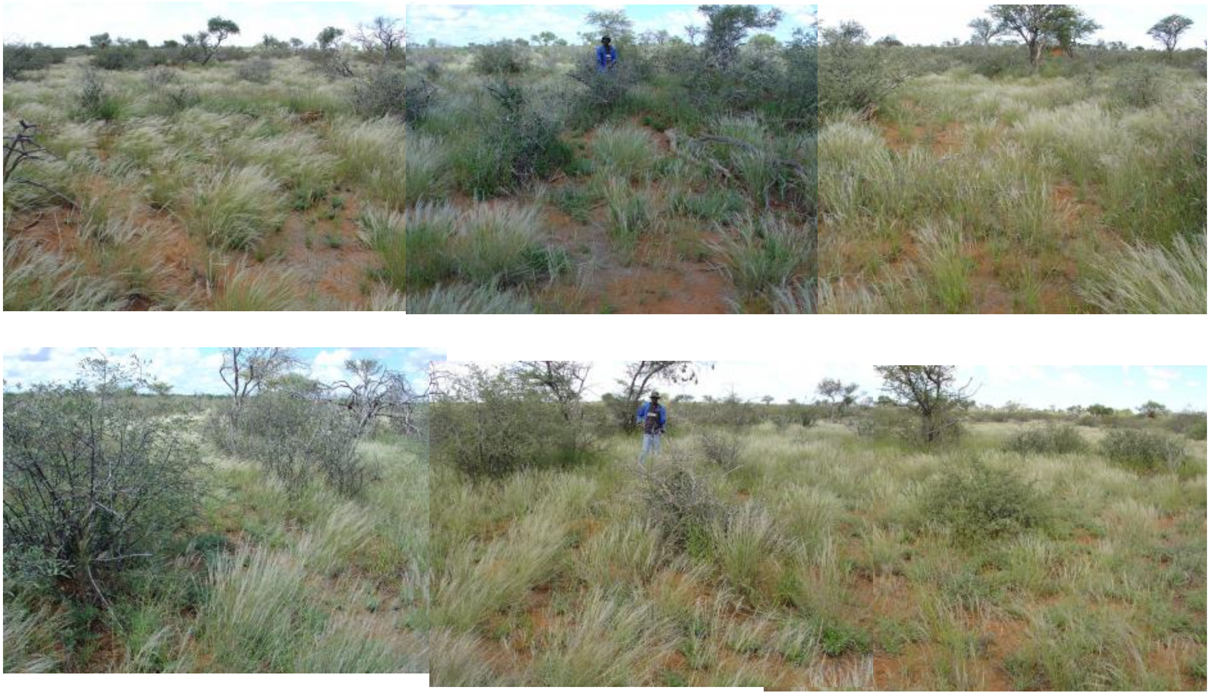


Figure 4.46 Both sides of fenceline contrast between untreated land (13a, top) and previously bush thinned land (13b, bottom). The photographs were taken in April 2005.

The perennial grass density was significantly ($P<0.05$) higher on the previously thinned land, with an estimate of 1.9 grasses m^{-2}, compared to 1.2 grasses m^{-2} on Site 13a. However the dominance by *Stipagrostis uniplumis* was greater there, at 96%, than at Site 13a where it was 86%. The rangeland condition index was lower at Site 13a (157 versus 225). This difference was not significant ($P>0.05$) by Mann-Whitney U test, but when tested by Chi-square, it was ($P<0.05$).

Despite the previous bush thinning on Site 13b, the differences in bushes were not significant ($P>0.05$) for any of the bush variables measured, except for a greater proportion of *Commiphora* spp. on 13a and a correspondingly greater proportion of *Catophractes alexandrii* on 13b, which may just reflect differences in distribution of calcrete layers between the sides of the fence. Dead bush canopies did not even appear in the Bitterlich measurements, so any bushes that had been killed by arboricide must have fallen and been largely consumed by termites and other decomposer organisms by the time of the measurements. The species of bush that had been targeted by the arboricide application were *Acacia mellifera, A. fleckii*, *A. luederitzii, and Dichrostachys cinerea*, but these totalled only 8% of the nearest bush species (NB) on the untreated side 13a, which did not differ significantly ($P>0.05$) from the 6% on 13b.

4.5.15 Contrast 14, between continuous and rotational grazing

Site 14a was on the same farm as Site 13b, but separated by a distance of approximately 5 km. It too had been selectively thinned by arboricide several years ago. Site 14b was on a farm used for speculation, either by renting out land to farmers with excessive cattle or raising oxen and heifers from weaners. No bush control had taken place at the site. For a few years before measurements were made, the site had been rented out to a farmer who had stocked it heavily and continuously. Although the farm is divided into different paddocks, the gates were left open for cattle to move as they wish, although some gates were closed when renting out portions of the farm. The overall stocking rate usually applied on the farm was 56 kg liveweight ha^{-1} (8 ha AU^{-1}), compared to 47 kg liveweight ha^{-1} (10 ha AU^{-1}) at Site 14a. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 4.47.

Figure 4.47 Both sides of fenceline contrast between previously thinned land (14a) under rotational grazing on the top and untreated land used almost continuously for speculation (14b) on the bottom. The photographs were taken in March 2006.

Bare patches predominated on both sides of the fence, although they were more at Site 14b on the continuously grazed farm (Figure 4.48) In fact Site 14b had, together with Site 16a, the lowest perennial grass density of all the sites measured in the Camelthorn Savanna, at 0.2 grasses m^{-2}. Although Site 14a had three times the density of 14b, it was still low, at 0.6 grasses m^{-2}.

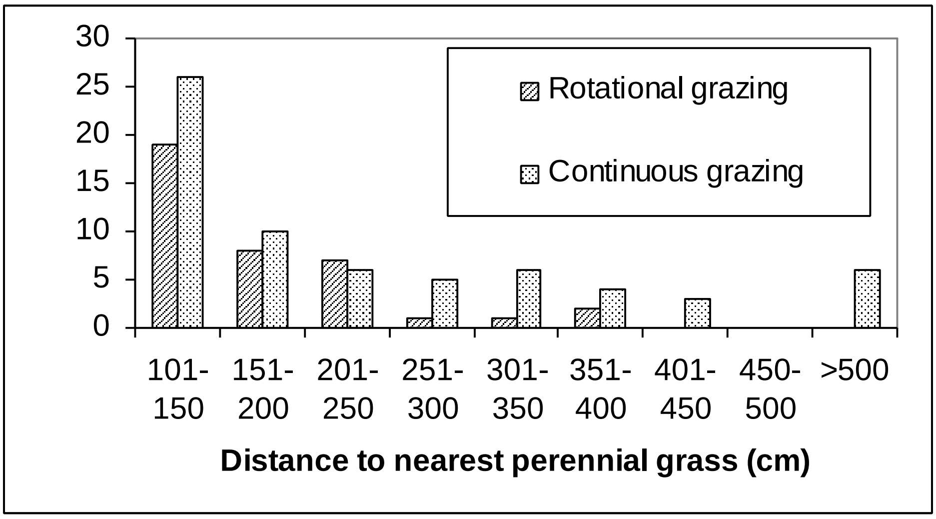
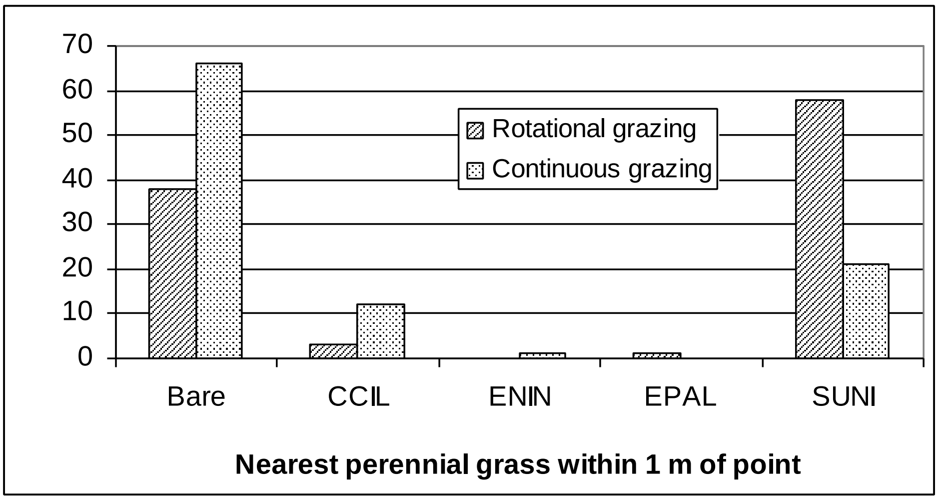


Figure 4.48 Bare patch size frequencies at Contrast 14 in the Camelthorn Savanna.

There was a greater proportion of *Cenchrus ciliaris* among the perennial grasses measured on the continuously grazed site 14b (Table 4.5 and Figure 4.49). The rangeland condition index was slightly but not significantly (P>0.05) higher at Site 14a (80 versus 65).



Bare = no perennial grass within 1 m; CCIL = *Cenchrus ciliaris*; ENIN = *Eragrostis nindensis*; EPAL = *E. pallens*; SUNI = *Stipagrostis uniplumis*.

Figure 4.49 Perennial grass species composition at Contrast 14 in the Camelthorn Savanna.

The bush density and canopy cover did not differ significantly (P>0.05), but the height class frequencies did (P<0.05), with a greater proportion of larger bushes on 14b (Figure 4.50).

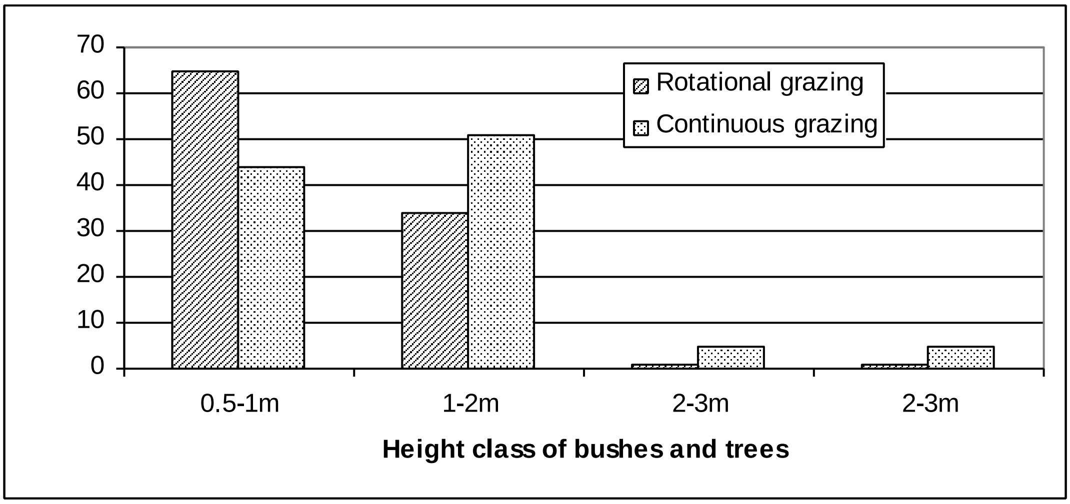
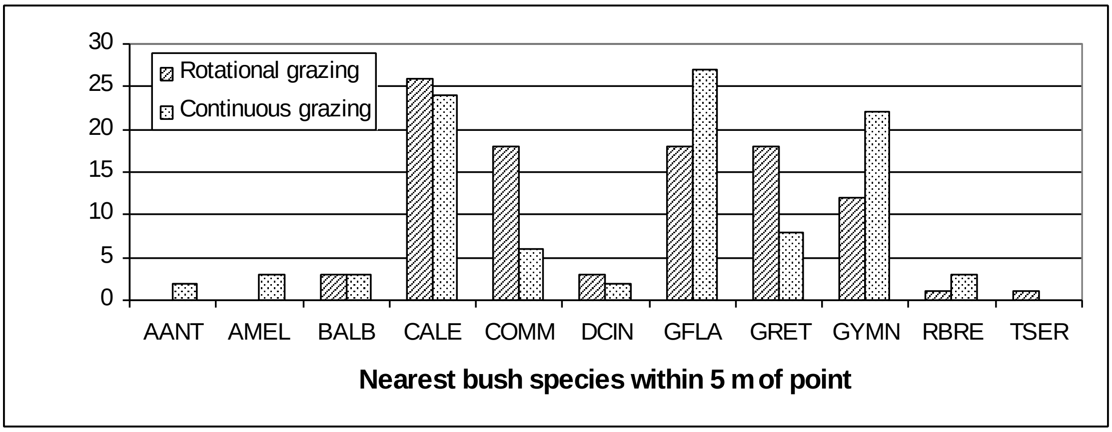


Figure 4.50 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 14 in the Camelthorn Savanna.

The significant (P<0.05) differences in bush species composition were a greater proportion of *Commiphora* spp. on Site 14a and a correspondingly greater proportion of *Grewia retinervis* on Site 14b (Figure 4.51).



AANT = *Albizia anthelmintica*; AMEL = *Acacia mellifera*; BALB = *Boscia albitrunca*; CALE = *Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; GYMN = *Gymnosporia* spp.; RBRE = *Rhigozum brevispinosum*; TSER = *Terminalia sericea*.

Figure 4.51 Bush species composition at Contrast 14 in the Camelthorn Savanna.

4.5.16 Contrast 15, between continuous and rotational grazing

Site 15a was also used for beef farming, with cattle stocked at 51 kg liveweight ha^{-1} (9 ha AU^{-1}) rotating slowly through six paddocks per herd to receive an average of 9 weeks rest in the growing season. Site 15b was in the same paddock as Site 14b, that had been stocked heavily and continuously by a tenant farmer for a few years before the measurements. The stocking rate normally applied by the farm owner was an average of 56 kg liveweight ha^{-1} (8 ha AU^{-1}). A photograph of the fenceline contrast is presented in Figure 4.52 below.

Figure 4.52 Fenceline contrast between periodically rested land (15a, right) and continuously grazed land (15b, left). The photograph was taken in March 2006.

Figure 4.53 Fenceline contrast between land rested for shorter (16a, right) and land rested for longer (16b, left). The photograph was taken in March 2006.

The perennial grass density was not significantly ($P>0.05$) different, estimated at 1.0 grasses m^{-2} on Site 15a and 0.8 grasses m^{-2} on Site 15b. The higher density of *Stipagrostis uniplumis* evident on 15a in Figure 4.48 was restricted to the road verges, presumably as a result of trampling by cattle that stimulated seedling production followed by rest when the grass seedlings could establish. The rangeland condition index was slightly but not significantly ($P>0.05$) higher at Site 15a (150 versus 115).

The only significant ($P<0.05$) differences found at Contrast 15 were in species compositions. In the case of perennial grasses there was a greater proportion of mesophytes on Site 15a, made up of *Cenchrus ciliaris* and *Eragrostis rigidior* (Table 4.5). In the case of bushes, there was a greater proportion of *Grewia flava* on 15a and a correspondingly greater proportion of *Catophractes alexandrii and Grewia retinervis* on 15b. The canopy cover was somewhat over 20% at both sites.

4.5.17 Contrast 16, between slower and faster rotation of cattle

Contrast 16 was between two cattle farms that each contained another site that had been measured and already described above. Site 16a was on the same farm as Site 13a, although separated by a distance of approximately 5 km. It was stocked at 34 kg liveweight ha^{-1} (13 ha AU^{-1}) and received an average of 9 weeks of rest in the growing season. However, this was extremely variable and, since this paddock had a problem with water supply, it tended to be used more in the growing season than in the dry season. Site 16b was in the same paddock as Site 15a. It was stocked at 51 kg liveweight ha^{-1} (9 ha AU^{-1}) and received an average growing season rest of about 13 weeks. A photograph of the fenceline contrast is presented in Figure 4.53 above.

Site 16a had, together with Site 14b, the lowest perennial grass density out of all sites recorded in the Camelthorn Savanna, with a mean of 0.2 grasses m^{-2}. It also had the greatest distance to nearest perennial grass (DistP), of 232 cm. The density was significantly (P<0.05) higher on 16b, although still fairly low at 0.9 grasses m^{-2}. Although the species composition indicated 18% of *Cenchrus ciliaris* there, compared to 1% on 16b, all of them had been recorded at more than 1 m from the point. The bare patch size frequencies in Figure 4.54 indicate that 25% of the points did not even have a perennial grass within 5 m. The rangeland condition index was significantly (P<0.05) lower on the faster rotated Site 16a (20 versus 120).

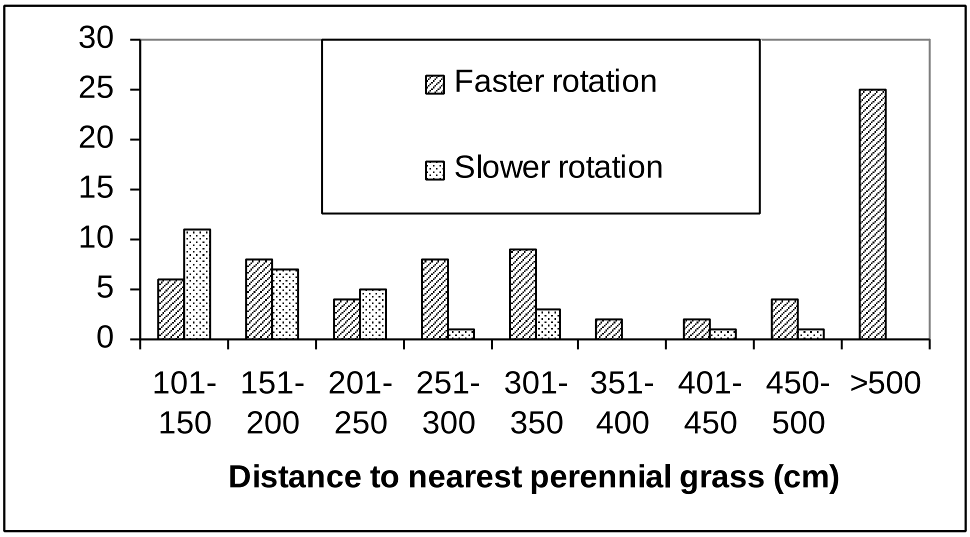


Figure 4.54 Bare patch size frequencies at Contrast 16 in the Camelthorn Savanna.

The bush canopy cover was not significantly (P>0.05) different when estimated by Bitterlich gauge (29% at Site 16a; 21% at Site 16b). However, when estimated by points the bush canopy cover did differ significantly (P<0.05) (37% at Site 16a; 23% at Site 16b). There was a greater proportion of shorter bushes, in the 0.5-1m height class, on 16a (Figure 4.55). The species composition indicated a greater proportion of *Catophractes alexandrii* on 16a, with a correspondingly greater proportion of *Gymnosporia senegalensis* on 16b (Table 4.7).

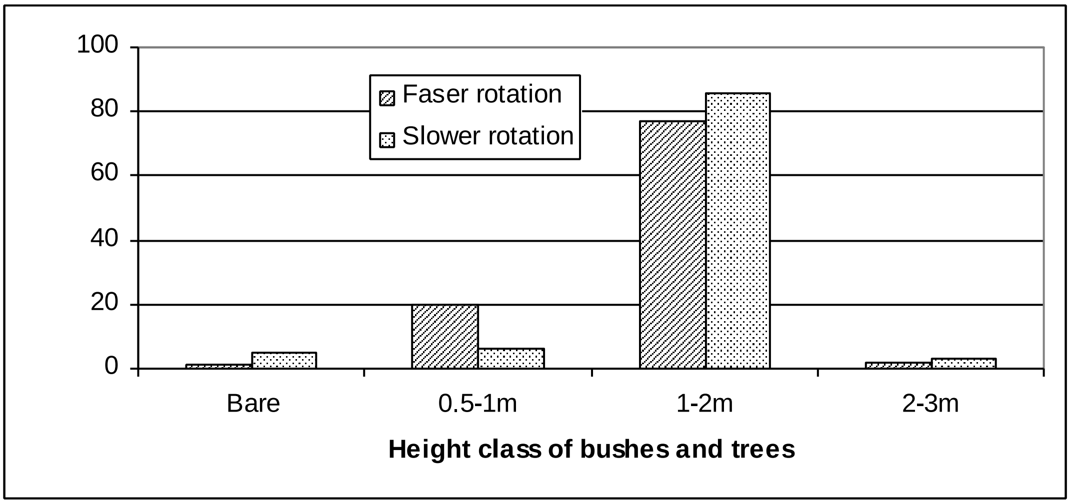


Figure 4.55 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 1 in the Camelthorn Savanna.

4.6 RELATIONSHIPS BETWEEN VARIABLES

Relationships were tested between variables measured at different contrasts, for which the comparability of the data needs to be borne in mind. Measurements had been taken by different groups of students at different contrasts, hence the results were less useful for comparison between contrasts than between sites at the same contrast, as pointed out in sections 3.5.6.1 and 4.2.1. In the case of the composite variable “Rangeland condition index”, it had not been related to benchmark sites and it too was therefore less suitable for comparison between contrasts than between sites at the same contrast (section 3.5.5)

4.6.1 Perennial grass and bush variables

The relationships between perennial grass and bush measurements across sites were tested between four bush variables and six perennial grass variables. The bush variables were median distance to nearest bush or tree (DistB); woody canopy cover by Bitterlich gauge (Bitterlich); % of encroacher species among the woody cover; and canopy cover of encroacher species. The perennial grass variables were median distance to nearest perennial grass (DistP); % of points with no perennial grass within 100 cm; mean density of perennial grasses from No P; % of mesophyte species among the perennial grasses; density of mesophytic grasses; and rangeland condition index. In the case of relationships with distance to nearest bush or tree (DistB), the two sites (5b and 10a) with median DistB of more than 500 cm were omitted, since their values were unknown. In the case of relationships with % encroacher species, Site 10a was omitted since it had no bushes.

Three of the perennial grass variables underwent log transformation to ensure normal distribution required for the Pearson product moment correlation (Dytham, 2003). Scatter plots suggested that the relationships were slightly more linear after the transformations, but in several cases the points were too scattered to be able to judge visually. Therefore, correlations were applied both before and after transformation, with a higher r-value after transformation confirming that transformed data gave a better linear fit. The results of the correlations are presented in Table 4.10. The correlations were not strong, although they indicate a slight tendency of less perennial grass with more encroacher bushes. The scatter plots did not indicate any non-linear relationship between grass and woody plant density as suggested by Friedel (1987).

Table 4.10 Results of product-moment correlations between bush and perennial grass variables from the sites measured at fenceline contrasts in the Camelthorn Savanna.

	Variables related to measurements of bushes			
Variables related to perennial grasses ↓	DistB [1]	Bitterlich [2]	% Encroachers [3]	Encroacher cover [4]
Log DistP [5]	r = −0.4400 P = 0.013 n = 31	r = 0.3548 P = 0.043 n = 33	r = 0.3618 P = 0.042 n = 32	r = 0.5275 P = 0.002 n = 33
Log % Bare [6]	r = −0.4932 P = 0.005 n = 31	r = 0.3409 P = 0.052 n = 33	r = 0.4204 P = 0.017 n = 32	r = 0.5340 P = 0.001 n = 33
Grass density [7]	r = 0.3119 P = 0.088 n = 31	r = −0.2295 P = 0.199 n = 33	r = −0.2892 P = 0.108 n = 32	r = −0.4459 P = 0.009 n = 33
% Mesophytes [8]	r = 0.1448 P = 0.437 n = 31	r = 0.0601 P = 0.74 n = 33	r = −0.4883 P = 0.005 n = 32	r = −0.4863 P = 0.004 n = 33
Log Mesophyte density [9]	r = 0.2004 P = 0.280 n = 31	r = 0.1408 P = 0.434 n = 33	r = −0.4468 P = 0.010 n = 32	r = −0.4866 P = 0.004 n = 33
Condition index [10]	r = −0.2760 P = 0.133 n = 31	r = −0.2264 P = 0.205 n = 33	r = −0.3837 P = 0.030 n = 32	r = −0.5133 P = 0.002 n = 33

Shaded P-values represent relationships that are significant (P<0.05).
[1] DistB = median distance from sample point to nearest tree or bush taller than 0.5 m.
[2] Bitterlich = Canopy cover as measured by Bitterlich angle gauge.
[3] % Encroachers = Percentage of encroacher species among the recorded bushes and trees.
[4] Encroacher cover = Canopy cover of encroacher species of bush.
[5] Log DistP = Logarithm to base ten of median distance from sample point to nearest perennial grass.
[6] Log % Bare = logarithm to base ten of percentage of points where there was no perennial grass within 1 m.
[7] Grass density = Density of perennial grasses.
[8] % Mesophytes = Percentage of mesophytic species among the recorded perennial grasses.
[9] Log Mesophyte density = logarithm to base ten of density of mesophytic perennial grass species.
[10] Condition index = Rangeland condition index

The poor relationships are not surprising, given the large difference in management received by the different sites. Interestingly, the bush variable which gave the strongest

relationship with perennial grass variables was the cover of encroacher species, while the total canopy cover had minimal relationship with any of the perennial grass variables.
The relatively low bush cover in the leasehold farms was probably the result of both increased chopping to make use of the wood and the browsing by goats and sheep kept there. The degree of bush control that the commercial sites had experienced varied from none on the majority of farms to total control on the hay field.

The influence between bushes and grasses can also be tested on a smaller scale by comparing median distance to nearest perennial grass (DistP) values obtained from points under bush or tree canopies with those obtained from points in the open, within sites. This was only worth doing for sites with at least 20 points having fallen under canopies to get a reasonably reliable median distance. This applied to 16 of the sites. The median distance was greater under canopies for 11 of these sites, but only significantly different ($P<0,05$) for six of them (Table 4.11). For all of the five sites where the medium distance was greater in the open the difference was not significant ($P>0.05$).

Table 4.11 Comparison between median distances to nearest perennial grass as measured from points under bush canopies and from points in the open, for the 16 sites where there were at least 20 points measured under canopies in the Camelthorn Savanna.

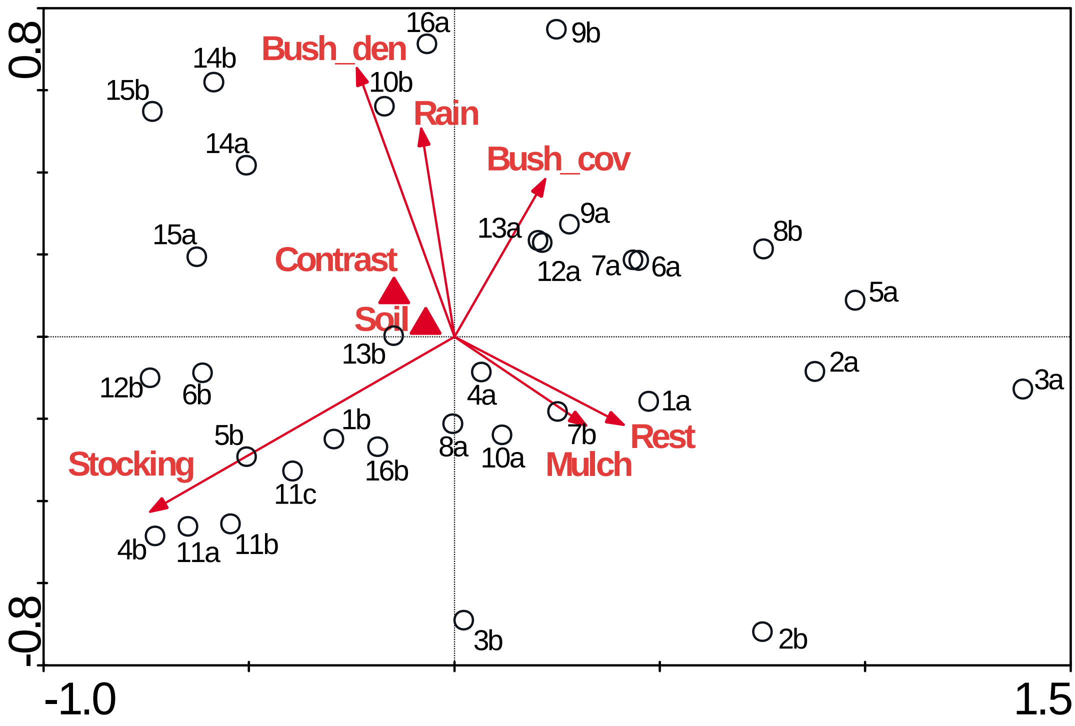
Site number	Position of point	Median distance to nearest perennial grass	Sample size (n)	P-value by Mann-Whitney U Test
2a	Under canopy	31.0	25	0.644299
2a	In the open	24.0	75	
6b	Under canopy	76.0	23	0.973864
6b	In the open	53.0	77	
7b	Under canopy	36.5	20	0.229322
7b	In the open	45.0	80	
9b	Under canopy	44.0	29	0.718231
9b	In the open	49.0	71	
10b	Under canopy	57.0	30	0.590711
10b	In the open	49.5	70	
11a	Under canopy	43.0	20	0.004966
11a	In the open	32.0	80	
11b	Under canopy	74.5	26	0.031306
11b	In the open	47.5	74	
11c	Under canopy	65.0	25	0.016573
11c	In the open	41.0	75	
12a	Under canopy	71.0	51	0.636698
12a	In the open	91.0	49	
12b	Under canopy	32.0	23	0.268838
12b	In the open	33.0	77	
12a	Under canopy	65.0	31	0.000011
13a	In the open	36.0	69	
13b	Under canopy	46.5	24	0.000032
13b	In the open	28.5	76	
14a	Under canopy	104.0	28	0.034432
14a	In the open	63.0	72	
14b	Under canopy	147.0	27	0.204293
14b	In the open	124.0	73	
16a	Under canopy	193.0	37	0.632411
16a	In the open	271.0	63	
16b	Under canopy	70.0	23	0.028749
16b	In the open	53.0	77	

Shaded cells show pairs of medians that were significantly (P<0.05) different.

4.6.2 Ordinations

The first axis gradient of the Detrended Correspondance Analysis (DCA) of perennial grass species densities had a length of 2.254, with an Eigen value of 0.423. Since the length was less than the four recommended by Ter Brak & Smilauer (2002) for DCA, a Principal Components Analysis (PCA) was then performed. This resulted in an Eigen value of 0.646 on the first axis and 0.260 on the second axis. Eight environmental variables were included in the Redundancy Analysis (RDA), as described in section 3.5.6.11. The resulting biplot is presented in Figure 4.56, while the results of the automated forward selection with permutations are presented in Table 4.12.

Site 3a, dominated by *Schmidtia pappophoroides*, was alone on the extreme right of the first axis, with 4b, 12b and 15b, dominated by *Stipagrostis uniplumis*, on the extreme left. The most significant (P<0.01) relationship was with the dummy variable of contrast, confirming that the contrasts were not in the same relatively homogenous area, as indicated in section 3.5.6.11. Other significant (P<0.05) relationships were with the stocking rate and bush canopy cover. The latter was aligned near the second axis, together with non-significant (P>0.05) variables of bush density and mean rainfall.



Eigen values: First axis = 0.303, Second axis = 0.144.

Arrows represent higher values of each of the following, except for the two nominal variables:

Bush_den = Density index of bushes; Rain = Mean annual rainfall for area of the contrast; Bush_cov = Canopy cover of woody plants taller than 0.5 m; Rest = Period of absence in or over the growing season; Mulch = Cover of mulch and bases of perennial grass over the soil; Stocking = current stocking rate for the farm; Soil = nominal variable for sand, loamy sand or calcrete; Contrast = nominal dummy variable for sites at the same contrast.

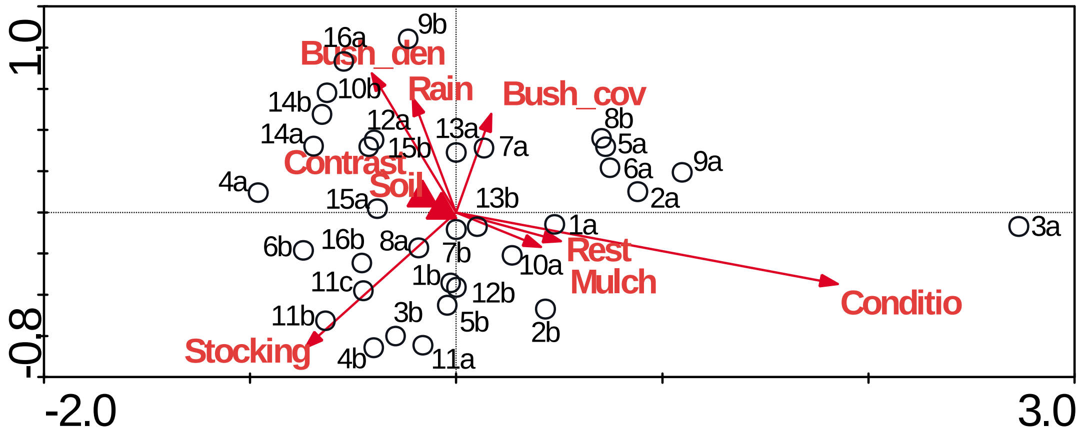
Figure 4.56 Biplot of Redundancy Analysis (RDA) ordination of densities of perennial grass species in the Camelthorn Savanna, with eight environmental variables.

Table 4.12 Results of forward selection of variables in the Redundancy Analysis (RDA) ordination of the density of perennial grass species in the Camelthorn Savanna.

Marginal Effects			
Variable	Lambda1		
ocking rate of farm	0.12		
ontrast number (Dummy variable)	0.11		
ush density	0.08		
oil type (Nominal variable)	0.08		
ean annual rainfall for the area	0.04		
Period of absence	0.04		
Canopy cover of bushes and trees	0.04		
Mulch cover on soil	0.02		
Conditional Effects			
Variable	LambdaA	P-value	F-value
Stocking rate of farm	0.12	0.020	4.12
Contrast number (Dummy variable)	0.15	0.002	6.41
Canopy cover of bushes and trees	0.09	0.020	3.73
Soil type (Nominal variable)	0.03	0.280	1.37
Period of absence	0.02	0.250	1.31
Bush density	0.06	0.058	2.68
Mean annual rainfall for the area	0.02	0.412	0.92
Mulch cover on soil	0.01	0.684	0.40

The rangeland condition index was then added as an environmental variable. The resulting biplot is presented in Figures 4.57, while the results of the automated forward selection with permutations are presented in Table 4.13.

Rangeland condition index had the greatest influence along the first axis. However, this may be largely a consequence of auto correlation, since perennial grass density was a major component of the rangeland condition index. However it indicates the direction of degradation along the fist axis, from better condition on the right to worse condition on the left.



Eigen values: First axis = 0.357, Second axis = 0.152.

Arrows represent higher values of each of the following, except for the two nominal variables:

Bush_den = Density index of bushes; Rain = Mean annual rainfall for area of the contrast; Bush_cov = Canopy cover of woody plants taller than 0.5 m; Conditio = Rangeland condition index; Rest = Period of absence in or over the growing season; Mulch = Cover of mulch and bases of perennial grass over the soil; Stocking = current stocking rate for the farm; Soil = nominal variable for sand, loamy sand or calcrete; Contrast = nominal dummy variable for sites at the same contrast.

Figure 4.57 Biplot of Redundancy Analysis (RDA) ordination of densities of perennial grass species in the Camelthorn Savanna, with rangeland condition index included among nine environmental variables.

Table 4.13 Results of forward selection of variables in the Redundancy Analysis (RDA) ordination of the density of perennial grass species in the Camelthorn Savanna, with rangeland condition index included as an environmental variable.

Marginal Effects	
Variable	Lambda1
Rangeland condition index	0.42
Stocking rate of farm	0.12
Contrast number (Dummy variable)	0.11
Bush density	0.08
Soil type (Nominal variable)	0.08
Mean annual rainfall for the area	0.04
Period of absence	0.04
Canopy cover of bushes and trees	0.04
Mulch cover on soil	0.02

Conditional Effects			
Variable	LambdaA	P-value	F-value
Rangeland condition index	0.42	0.002	22.7
Stocking rate of farm	0.09	0.014	5.51
Canopy cover of bushes and trees	0.08	0.004	5.69
Soil type (Nominal variable)	0.03	0.114	2.06
Mean annual rainfall for the area	0.03	0.128	2.15
Period of absence	0.02	0.202	1.57
Bush density	0.02	0.248	1.47
Contrast number (Dummy variable)	0.01	0.422	0.83
Mulch cover on soil	0	0.892	0.19

CHAPTER 5

RESULTS: THORNBUSH SAVANNA

5.1 INTRODUCTION

Results from alternative methods of measuring the same vegetation characteristic in the Thornbush Savanna are presented first. They will be used in Chapter 9 to evaluate measuring methods. Thereafter the plants species recorded at the contrasts are listed according to groups and some explanations on abbreviations are given. An overview of all contrasts in the Thornbush Savanna is then presented, before describing the results from the 15 individual fenceline contrasts. To ease identification of sites, the order of their presentation in charts and photographs is always Site a followed by Site b (and then Site c where three sites were measured at a contrast). Finally, results are presented of the relationships between some variables, including the ordination analyses.

5.2 COMPARISON BETWEEN METHODS OF MEASURING

5.2.1 Woody canopy cover by points and by Bitterlich gauge

When comparing the estimates of canopy cover obtained by Bitterlich gauge (Bitterlich) and by points (Canop), the relationship was better than for the Camelthorn Savanna, although still not good (Figure 5.1). Analysis by product moment correlation (Dytham, 2003) resulted in $r = 0.885$ and $P < 0.0001$ ($n = 30$). As in the Camelthorn Savanna, it appears that the Bitterlich count underestimated the canopy cover when the canopy cover was high, such as over 50%, probably due to overlapping bushes being counted as a single large canopy instead of many small canopies.

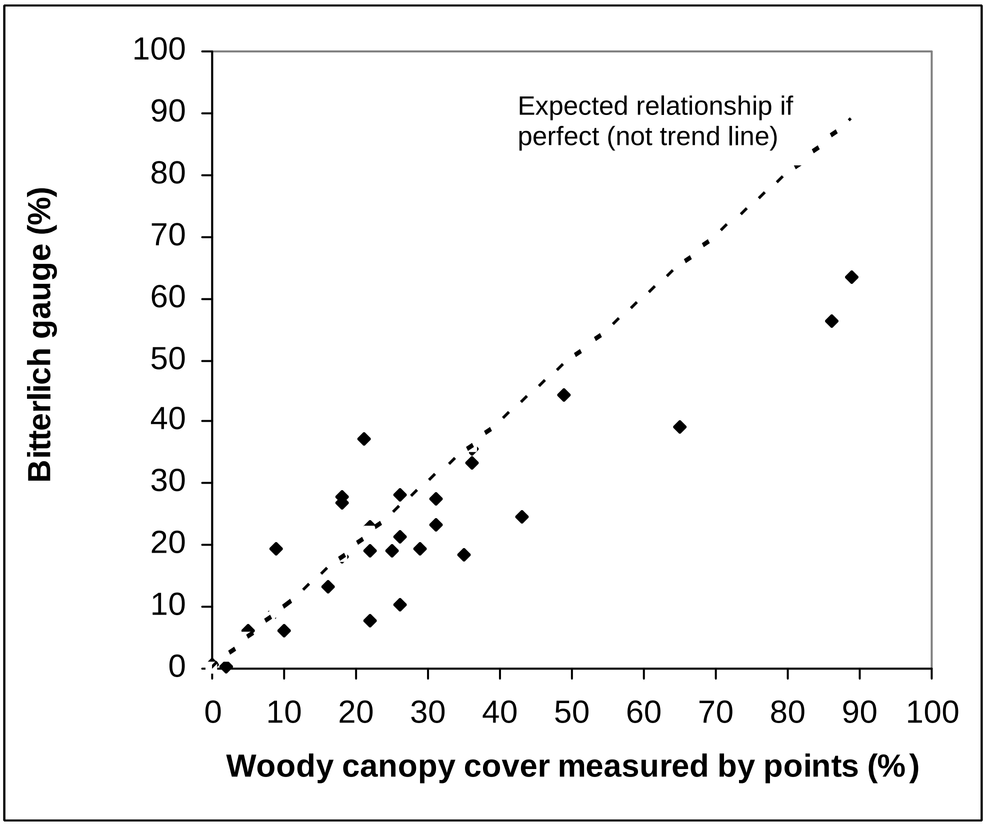


Figure 5.1 Relationship between the woody canopy cover measured by points and by Bitterlich gauge at 31 sites in the Thornbush Savanna.

5.2.2 Distance to nearest perennial grass and count of density

The relationship between distance to nearest perennial grass (DistP) and density of perennial grasses (No P) recorded in the Thornbush Savanna, was investigated in the same way as for the data from the Camelthorn Savanna (section 4.2.2). The direct plot of No P against DistP is presented in Figure 5.2 (Density index = $187.68 * DistP^{-1.3205}$, $r^2 = 0.9162$, $P<0.0001$, $n = 29$). As with data from the Camelthorn Savanna, this power relationship between Dist P and No P may provide a useful predictor of perennial grass density in the Thornbush Savanna.

The density index calculated from the median distance to nearest perennial grass (DistP) is compared with the mean counted perennial grass density in Figure 5.3. The other way of representing the relationship, in terms of the degree of clumping, is presented in Figure 5.4. The degree of clumping of grasses seems similar to that for the Camelthorn Savanna, apart from a few outliers.

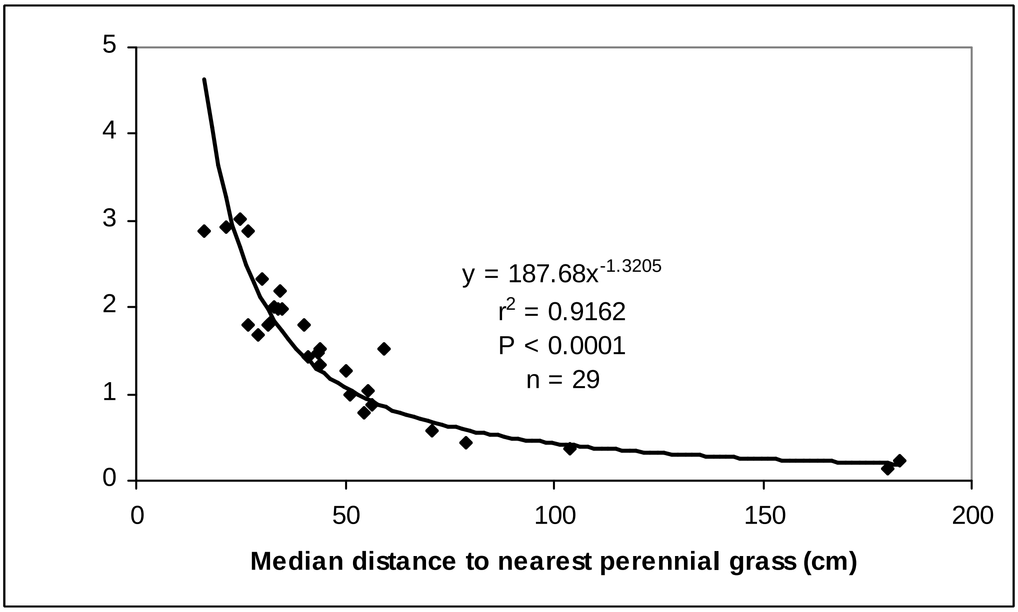


Figure 5.2 Relationship between the median distance to the nearest perennial grass and the mean grass density counted at 29 sites in the Thornbush Savanna, with the resulting power regression.

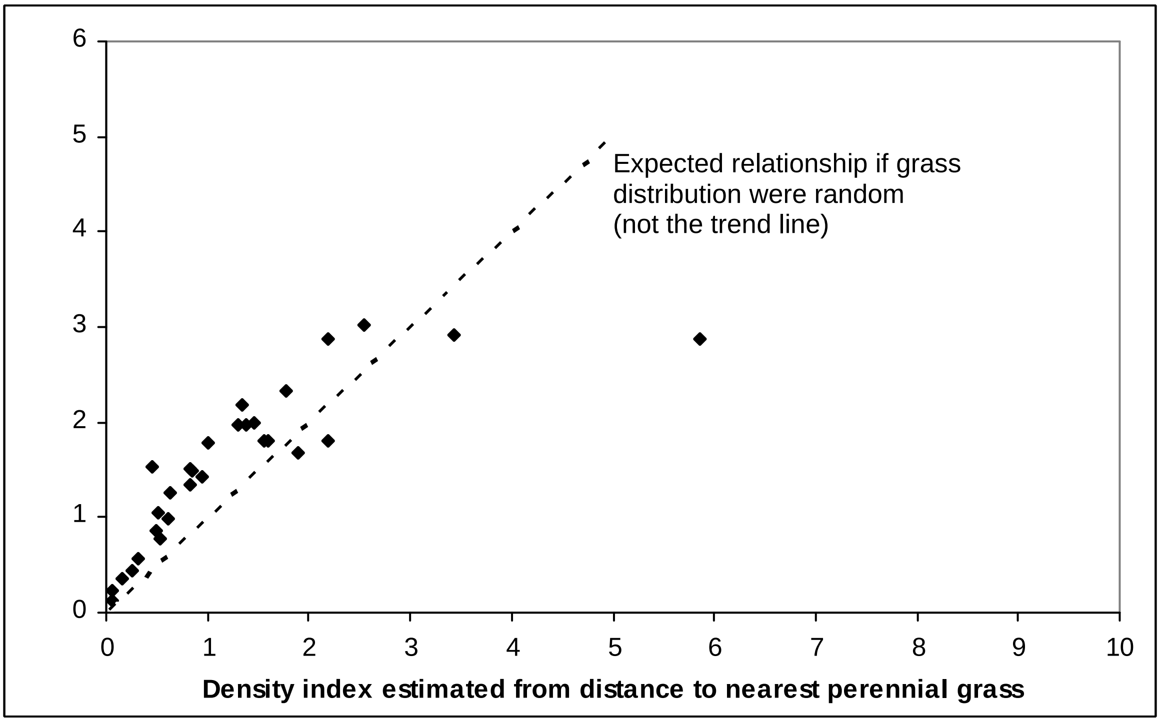
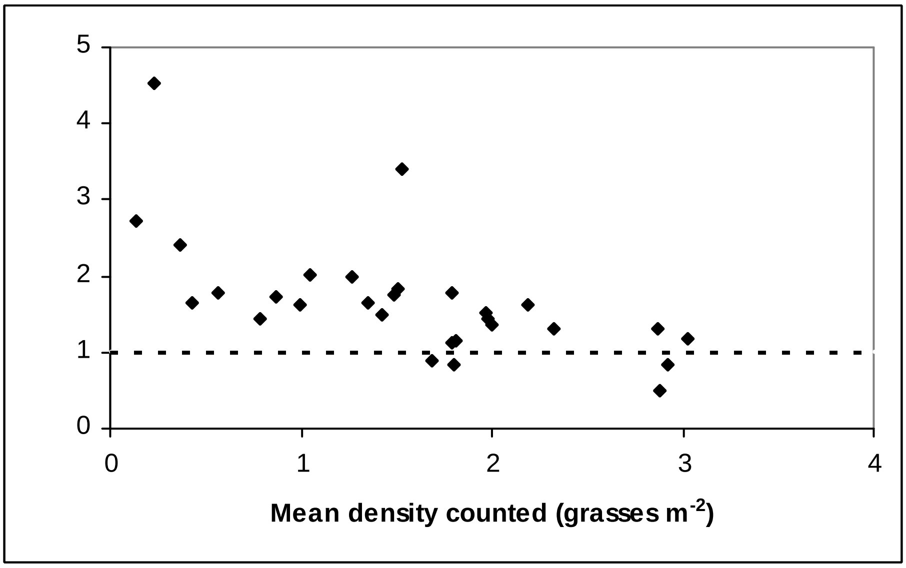


Figure 5.3 Relationship between the perennial grass density index - estimated from the median distance to nearest perennial grass - and the mean grass density counted at 29 sites in the Thornbush Savanna.



The stippled line represents the expected relationship if the distribution of grass plants were random, with no clumping.

Figure 5.4 Relationship between the mean perennial grass density and the degree grass clumping at 27 sites in the Thornbush Savanna.

5.3 PLANT SPECIES RECORDED

Since other plant species, apart from those mentioned for the Camelthorn Savanna, were recorded in the Thornbush Savanna, their abbreviations are presented in Table 5.1 for perennial grasses and in Table 5.2 for bush and tree species.

Table 5.1 Species of perennial grasses assigned subjectively to broad categories of xerophytic and mesophytic species in the case of the Thornbush Savanna.

Xerophytic species	Mespohytic species
Aristida congesta (ACON)	*Andropogon chinensis* (ACHI)
Stipagrostis uniplumis (SUNI)	*Anthephora pubescens* (APUB)
	Aristida meridionalis (AMER)
	Bothriochloa radicans (BRAD)
	Brachiaria nigropedata (BNIG)
	Cenchrus ciliaris (CCIL)
	Eragrostis echinochloidia (EECH)
	E. nindensis (ENIN)
	E. rigidior (ERIG)
	E. rotifer (EROT)
	E. tricophora (ETRI)
	Enneapogon scoparius (ESCO)
	Fingerhuthia africana (FAFR)
	Heteropogon contortus (HCON)
	Melinis repens var. repens (MREP)
	Panicum maximum (PMAX)
	Schmidtia pappophoroides (SPAP)
	Sporobolus ioclados (SIOC)
	Triraphis ramosissima (TRAM)
	Urochloa oligotricha (UOLI)

The abbreviated names used in other tables and charts for these species appear in brackets.

Table 5.2 Species of bushes assigned subjectively to broad categories of encroacher and non-encroacher species in the case of the Thornbush Savanna.

Encroacher species	Non-encroacher species
Acacia fleckii (AFLE)	*Albizia anthelmintica* (AANT)
A. hebeclada (AHEB)	*Acacia erioloba* (AERI)
A. luederitzii (ALUE)	*A. hereroensis* (AHER)
A. mellifera (AMEL)	*Boscia albitrunca* (BALB)
Catophractes alexandrii (CALE)	*Combretum apiculatum* (CAPI)
Dichrostachys cinerea (DCIN)	*C. hereroensis* (CHER)
Gymnosporia spp. (GYMN)	*Commiphora spp.* (COMM)
Rhigozum brevispinosum (RBRE)	*Croton gratissimus* (CGRA)
	Ehretia rigida (ERIG)
	Grewia bicolor (GBIC)
	G. flava (GFLA)
	G. retinervis (GRET)
	Lycium bosciifolium (LBOS)
	L. eenii (LEEN)
	Maerua schinzii (MSCH)
	Ozoroa paniculosa (OPAN)
	Phaeoptilum spinosum (PSPI)
	Phylenoptera nelsii (PNEL)
	Rhus pyroides (RPYR)
	Rhus tenuinervis (RTEN)
	Tarchonanthus camphoratus (TCAM)
	Terminalia prunioides (TPRU)
	Ziziphus mucronata (ZMUC)

The abbreviated names used in other tables and charts for these species appear in brackets.

5.4 OVERVIEW OF ALL CONTRASTS

The overview tables that follow use the same format as for the Camelthorn Savanna (section 4.4). The overview of management information is presented in Table 5.3. Details are presented in section 5.5.

Table 5.4 summarises the rangeland data. Significant ($P<0.05$) differences were found at all contrasts, although not in all variables. These are presented in section 5.5. Soil cover ranged from 2% to 37%. The median distance to nearest perennial grass (DistP) ranged from 22 cm to 183 cm. The median distance to nearest bush or tree (DistB), ranged from 57 cm to >500 cm. The density of perennial grasses ranged from 0.1 to 3.0 grasses m^{-2}, and canopy cover by Bitterlich angle gauge ranged from 0% to 63%. The mesophytic grass species ranged from 3% to 99%, while the encroacher bush cover ranged from 0% to 96%.

Table 5.5 indicates the percentage perennial grass species composition obtained from measurements of nearest perennial grass (NP). Since there was insufficient space for all the species in this and the next table, the four rarest species were combined with the species they were mostly associated with, namely *Brachiaria nigropedata* with *Anthephora pubescens*; *Andropogon chinensis* and *Triraphis ramosissima* with *Heteropogon contortus*; and *Aristida congesta* with *Stipagrostis uniplumis*. Each of these rare species made up less than 0.1% of the recorded grasses, and the combination was done only for presentation in the table, not for the analyses. Significant ($P<0.05$) differences were found at all but three of the 15 fenceline contrasts, with two of those exceptions being contrasts with hayfields. *Eragrostis rigidior* was the most common species at 19 of the 31 sites. *E. rigidior* was also the most common species for which the difference in species composition occurred, usually counterbalanced by differences in *Stipagrostis uniplumis*.

The densities of the different perennial grass species, calculated from nearest perennial grass (NP) and mean density of perennial grasses (No P), are presented in Table 5.6. Since it had not been possible to count the perennial grasses (No P) at Contrast 31, the values for distance to nearest perennial grass (DistP) were used to estimate the densities at those two sites, using the power regression obtained from the relationship between median DistP and mean density from No P for all other sites in the Thornbush Savanna (Figure 5.2).

The percentage species compositions for bushes and trees are presented in Table 5.7 as related to density (obtained from species of nearest bush (NB)), and in Table 5.8 as related to canopy cover (obtained by Bitterlich gauge). The density index for the bush and tree species, calculated from distance to nearest bush or tree (DistB), is presented in Table 5.9. It has to be borne in mind that this index is likely to be an underestimation of true density, due to the tendency for bushes and trees to clump.

There were four sites, all hayfields, where fewer than 10 points had bushes within 5 m of the sample point, hence proportional bush data were not determined for these sites. Since there was insufficient space for all the species in these three tables, the rarest species were combined subjectively with species of perceived palatability, as follows: *Albizia anthelmintica, Combretum apiculatum, Ehretia rigida, Phylenoptera nelsii* and *Maerua schinzii* with *Boscia albitrunca*; *Combretum hereroense, Commiphora* spp., *Gymnosporia* sp., *Ozoroa paniculosa* and *Terminalia prunioides* with *Croton gratissimus*; *Grewia bicolor* with *G. retinervis*; *Phaeoptilum spinosum* and *Lycium bosciifolium* with *L. eeni.* Neither of these rare species made up more than 1% of the total recorded bushes and trees.

Significant ($P<0.05$) differences in bush species across the fenceline were found at all contrasts (Table 5.7), except for the three contrasts with hay fields (Contrasts 20-22), where it could not be determined due to the lack of bushes. *Acacia mellifera* was the most common species for which the difference in species composition occurred. It was also the most common species at 13 of the sites, followed by *Grewia flava* as the most common at six of the sites.

Table 5.3 Overview of management data for sites at the fenceline contrasts in the Thornbush Savanna.

Contrast number	Main management or tenure difference between sides of fence	Paddocks per herd	Growing season rest (weeks)	Type of animals	Farm size (ha)	Stocking rate		Animal Production kg ha^{-1} a^{-1}
						ha AU^{-1}	kg ha^{-1} a^{-1}	
17a	Communal	1	0	Cattle, goats, sheep, equines	6 000	8	58	6
17b	Commercial strip	8	9	Cattle, few goats	5 770	20	23	8
17c	Commercial thinned (same farm as 17b)	8	9	Cattle, few goats	5 770	20	23	8
18a	No bush control	4	6	Cattle	5 900	13	36	7
18b	Bush thinned	4	8	Cattle	3 780	9	51	6
19a	No bush control	1	0	Game	8 000	15	30	0
19b	Bush thinned	9	8	Cattle	6 000	11	40	10
20a	No bush control	1.5	5	Cattle	3 000	17	27	7
20b	Hayfield (same farm as 19b)	NA	NA	NA	6 000		NA	NA
21a	Bush thinned (farm of 19b)	9	8	Cattle	6 000	11	40	10
21b	Hayfield (same field as 20b)	NA	NA	NA	6 000		NA	NA
22a	Bush thinned (farm of 19b)	9	8	Cattle	6 000	11	40	10
22b	Hayfield (same farm as 19b & 20b)	NA	NA	NA	6 000		NA	NA
23a	No bush control (same farm as 19b)	9	8	Cattle	6 000	11	40	10
23b	Selective stem burnt, continuous grazing	1	0	Game	3 900	10	45	11
24a	No bush control	4	6	Cattle	3 860	9	50	9
24b	Selective stem burnt (same farm as 23b)	1	0	Game	3 900	10	45	11
25a	Selective stem burnt (same farm as 23b)	1	0	Game	3 900	10	45	11
25b	No bush control	10	18	Cattle	8 800	11	40	10
26a	Selective stem burnt (same farm as 23b)	1	0	Game	3 900	10	45	11
26b	Aerial arboricide 16 years before	6	6	Cattle	21 000	12	38	10
27a	Slow rotation	3	26	Cattle	4 550	8	60	7
27b	Selective stem burnt, continuous grazing	1	0	Game	5 300	20	23	6
28a	Selective stem burnt (same farm as 27a)	1	0	Game	5 300	20	23	6
28b	Fast rotation	4.5	6	Cattle	7 000	9	52	6
29a	Fast rotation	4	5	Cattle	4 335	10	44	6
29b	Slow rotation	9	26	Cattle	2 500	15	30	6
30a	No bush control (same farm as 29b)	9	26	Cattle	2 500	15	30	6
30b	Bush thinned	9	26	Cattle	3 325	9	50	11
31a	Bush thinned (same farm as 30b)	9	26	Cattle	3 325	9	50	11
31b	Bush cleared and burnt (farm of 30b)	9	26	Cattle	3 325	9	50	11

NA = Not applicable, as these were hayfields that were only grazed after mowing.

Table 5.4 Overview of rangeland results for sites at the fenceline contrasts in the Thornbush Savanna.

Contrast number	% soil cover [1]	Perennial grasses over 5cm base				Bushes over 0.5 m in height			% Bush height class		
		DistP [2] (cm)	Grasses m^{-2}	Rangeland condition index	% Mesophytes [3]	DistB [4] (cm)	% Canopy [5]	% Encroacher [6]	0.5-1 m	1-2 m	>2 m
17a	7	180	0.1	30	92	126	44	89	32	42	26
17b	2	33	2.0	238	61	>500	0	NA	NA	NA	NA
17c	5	34	2.0	213	53	131	19	79	39	55	6
18a	7	57	0.9	85	25	119	36	53	34	58	8
18b	26	25	3.0	335	3	244	8	19	37	62	1
19a	3	44	1.5	190	70	142	23	55	30	58	12
19b	6	32	1.8	283	74	324	6	0	34	63	3
20a	9	51	1.0	120	89	112	33	47	42	40	18
20b	30	41	1.4	170	88	>500	0	NA	NA	NA	NA
21a	24	40	1.8	205	72	122	27	60	44	50	6
21b	17	30	2.3	275	82	>500	0	NA	NA	NA	NA
22a	17	60	1.5	177	90	120	10	86	86	12	2
22b	22	71	0.6	145	68	>500	1	NA	NA	NA	NA
23a	29	27	2.9	295	94	196	28	54	44	45	11
23b	12	32	1.8	271	88	144	18	62	70	30	0
24a	21	35	2.2	210	92	110	27	62	27	51	22
24b	27	50	1.3	125	61	161	19	48	48	38	13
25a	9	44	1.3	213	61	166	19	45	2	81	17
25b	8	44	1.5	160	67	125	19	71	12	73	15
26a	15	29	1.7	306	79	131	8	54	25	64	11
26b	22	17	2.9	434	99	140	23	31	18	71	11
27a	3	55	0.8	100	54	121	37	64	73	26	1
27b	27	22	2.9	627	97	147	28	25	52	48	0
28a	18	27	1.8	465	86	97	13	61	35	59	5
28b	11	35	2.0	284	86	93	25	76	4	44	52
29a	18	104	0.4	54	61	87	39	86	47	31	22
29b	21	183	0.2	60	65	68	56	91	44	39	17
30a	37	79	0.4	86	62	57	63	96	32	62	6
30b	18	56	1.0	201	47	132	19	90	49	45	6
31a	23	67	NA	225	83	140	21	51	54	33	13
31b	18	45	NA	275	75	237	6	3	52	48	0

Shaded pairs (or groups of three) numbers differ significantly ($P<0.05$);

NA = Not applicable, as these included hayfields that had insufficient bushes to provide any useful estimates of bushes, and Site 31 where perennial grasses had not been counted.

[1] % soil cover = % of soil covered by mulch plus grass base; [2] DistP=Median distance from point to nearest perennial grass; [3] % Mesophytes = % of mesophytic species among recorded grasses; [4] DistB = Median distance from point to nearest bush or tree; [5] % Canopy = % of mesophytic species among recorded grasses; [6] % Encroacher = % of encroacher species among recorded bushes.

Table 5.5 Perennial grass species composition found at the fenceline contrasts sites in the Thornbush Savanna.

Contrast	Number of points at which the species abbreviated in the row below appeared as nearest perennial grass of at least 5 cm basal diameter																	
number	AMER	APUB	BRAD	CCIL	ESCO	EECH	ENIN	ERIG	EROT	ETRI	FAFR	HCON	MREP	PMAX	SPAP	SIOC	SUNI	UOLI
17a								42		41				1	7		8	
17b								56		3			1		1		39	
17c								44		5			2		2		47	
18a				3				18		1				2	1		75	
18b				1											2		97	
19a								57							13		30	
19b				1				60				1			12		26	
20a								89									11	
20b				1				86					1				12	
21a				1				68					1		2		28	
21b	2							74							6		18	
22a						2		61				1			17	9	10	
22b				8				35	1				1		23		32	
23a						1		91				1	1				6	
23b	1							79				2			6		12	
24a								92									8	
24b								60				1					39	
25a				3				49		2		1			6		39	
25b				1				65				1					33	
26a				1		1		53		11		11			2		21	
26b				6				78		11		2			2		1	
27a				3				39				2			10		46	
27b				2				13				17			65		3	
28a				20				11		1		23			31		14	
28b								59	1	17		4			5		14	
29a		1		22	6	6		6		2	7	11					39	
29b		10	2	15	11	5	4			1	1	15					35	
30a		1		5	9	7	8			5	1	26					38	
30b	1	1		9	2	2		2		3		24	1		1		53	1
31a			3	9		1		6		56			1		1		17	6
31b				15	1			6		42		1	2				25	8

The names for species abbreviations are: AMER = *Aristida meridionalis*; APUB = *Anthephora pubescens*; BRAD = *Bothriochloa radicans*; CCIL=*Cenchrus ciliaris*; ESCO = *Enneapogon scoparius*; EECH = *Eragrostis echinochloidea*; ENIN = *E. nindensis*; ERIG = *E. rigidior*; EROT = *E. rotifer*; ETRI = *E. tricophora*; FAFR = *Fingerhuthia africana*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; PMAX = *Panicum maximum*; SPAP = *Schmidtia pappophoroides*; SIOC = *Sporobolus ioclados*; SUNI = *Stipagrostis uniplumis*; UOLI = *Urochloa oligotricha*.

Table 5.6 Perennial grass species densities calculated from findings at the fenceline contrasts sites in the Thornbush Savanna.

Contrast number	Densities in plants per 100 m^2 of the species of perennial grass of at least 5 cm basal diameter abbreviated in the row below																		
	AMER	APUB	BRAD	CCIL	ESCO	EECH	ENIN	ERIG	EROT	ETRI	FAFR	HCON	MREP	PMAX	SPAP	SIOC	SUNI	UOLI	Total
17a								6		6					1		1		13
17b								112		6			2		2		78		200
17c								87		10			4		4		93		198
18a				3				16		1				2	1		65		87
18b				3											6		294		303
19a								85							19		44		148
19b				2				109				2			22		47		181
20a								88									11		99
20b				1				122					1				17		142
21a				2				121					2		4		51		179
21b	5							172							14		42		232
22a						3		93				2			26	14	15		153
22b				5				20	1				1		13		18		57
23a						3		261				3	3				17		287
23b	2							142				4			11		22		179
24a								202									18		219
24b								76				1					49		127
25a				4				66		3		1			8		53		135
25b				2				98				2					50		151
26a				2		2		89		19		19			3		35		169
26b				17				224		32		6			6		3		288
27a				2				30				2			8		36		78
27b				6				38				50			190		9		292
28a				36				20		2		41			56		25		180
28b								116	2	33		8			10		28		197
29a		0		8	2	2		2		1	3	4					14		36
29b		2	0	3	3	1	1					3					8		22
30a		0		2	4	3	3			2	0	11					16		43
30b	1	1		9	2	2		2		3		25	1		1		56	1	105
31a			2	7		1		4		41			1		1		12	4	74
31b				19	1			7		52		1	2				31	10	125

The names for species abbreviations are: AMER = *Aristida meridionalis*; APUB = *Anthephora pubescens*; BRAD = *Bothriochloa radicans*; CCIL=*Cenchrus ciliaris*; ESCO = *Enneapogon scoparius*; EECH = *Eragrostis echinochloidea*; ENIN = *E. nindensis*; ERIG = *E. rigidior*; EROT = *E. rotifer*; ETRI = *E. tricophora*; FAFR = *Fingerhuthia africana*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; PMAX = *Panicum maximum*; SPAP = *Schmidtia pappophoroides*; SIOC = *Sporobolus ioclados*; SUNI = *Stipagrostis uniplumis*; UOLI = *Urochloa oligotricha*.

Table 5.7 Species composition of nearest bush found at the fenceline contrast sites in the Thornbush Savanna.

Contrast number	Percent contribution to bushes of at least 0.5 m in height made up by the species abbreviated in the row below																	
	AERI	AFLE	AHEB	AHER	ALUE	AMEL	BALB	CALE	CGRA	DCIN	GFLA	GRET	LEEN	RBRE	RPYR	RTEN	TCAM	ZMUC
17a			3	3		54	3			5	3		3	26				
17b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17c			1			20	7	2	1				10	59				
18a	1	3	1		1	14	9	5	1	13	49	3						
18b	4		1		14	2	12	2		6	55	1	2					
19a	3	5	10	3		33	2			3	26	1			1		12	1
19b	1	6	1	1		3	7			3	64	6					4	3
20a	2	8	5			33			3		37	2	7		1		1	1
20b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21a	1	6	17		1	29	3		1	11	21		1				7	2
21b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22a			15		5	42	1	2	1	5	15				12			1
22b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
23a	4	11	11			27	1		1	26	6	4			1		6	1
23b		7	31			11	1			12	8	2			1		26	1
24a		5	7			43				24	4						17	
24b	2	5	24			5			2	22	12						28	
25a	1	2	12	2	1	2	11			31	33	4					0	
25b	2	8	5	4	2	19	9			22	22	2					4	1
26a	2	9	14	2		35				12	16						9	
26b			1		3	51	1			3	13						27	
27a		11	1	2	6	19				17	21		2		1		20	
27b		5	9	1	12	5			1	13	15		1		10		27	
28a			3	3			2			10	37		3			5	35	1
28b	1	1	13	4	19	28	1			5	15		2				10	
29a		3			10	36	2	3	22	5	11	4			3			
29b					9	50	1	10	15	1	5	1			8			
30a						85		5	2	1					1		5	1
30b		1				36	1	23	9	3	6				1	6	12	2
31a					13	11	2				13	51	8					1
31b			1								9	77	3				9	1

The names for species abbreviations are: AERI = *Acacia erioloba*; AFLE = *Acacia fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE=*Catophractes alexandrii*; CGRA = *Croton gratissimus*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; LEEN= *Lycium eenii*; RBRE = *Rhigozum brevispinosum*; RPYR = *Rhus pyroides*; RTEN = *Rhus tenuinervis*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.
NA = Not applicable, as these were hayfields that had insufficient bushes to provide any useful estimate.

Table 5.8 Species composition of bush canopy cover found at the fenceline contrast sites in the Thornbush Savanna.

Contrast number	% of bush canopy cover contributed by each of the species abbreviated in the row below, based on measurements with the Bitterlich gauge																	
	AERI	AFLE	AHEB	AHER	ALUE	AMEL	BALB	CALE	CGRA	DCIN	GFLA	GRET	LEEN	RBRE	RPYR	RTEN	TCAM	ZMUC
17a				0	0	75	8			2	0	0	2	11				
17b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17c						62	19		1				1	18				
18a	7	3	4		6	35	7	1		3	31	2		2				
18b	7			2	10	2	14			7	57							
19a	3	6	13	2	2	34	3				33	2					3	0
19b											87						10	3
20a	19	2	3	3		38			4	1	29	2						
20b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21a	7	12	28			16				4	29		2				1	1
21b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22a	2		43		2	31				10					4			8
22b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
23a	31	17	12			16	1			9	9						4	1
23b	3	11	42			3				6	13	3					16	2
24a	5	4	8			42				7	3	1					28	
24b	6	4	42							2	20	1					23	2
25a	7		17		1	5	7			22	39	1						1
25b	11	8	13		3	35	5			12	13							
26a	5	23	10	5		21	3				31							3
26b	11					31					30	28						
27a	2	5	5		4	40	1			10	23		3		1		7	
27b	9	4	9	1	4	4	1			4	15		1		8		40	
28a			5		44	12					6	9					24	
28b			29		17	29					9	4					11	
29a		3			24	56	2	2	3	2	3	4		1	2			1
29b	0				22	65	0	4	5	0	1				2			
30a					1	94	1	1	1		0						3	0
30b	1	1			4	65		18	1	2	2						3	3
31a		1			25	24				1	7	35	5					3
31b					3							87					10	

The names for species abbreviations are: AERI = *Acacia erioloba*; AFLE = *Acacia fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE=*Catophractes alexandrii*; CGRA = *Croton gratissimus*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; LEEN= *Lycium eenii*; RBRE = *Rhigozum brevispinosum*; RPYR = *Rhus pyroides*; RTEN = *Rhus tenuinervis*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.
A zero indicates that the species was counted by Bitterlich gauge at that site, but its counts comprised less than 0.5% of all Bitterlich counts at the site.
A blank cell indicates that the species was not counted by Bitterlich gauge at that site.
NA = Not applicable, as these were hayfields that had insufficient bushes to provide any useful estimate.

Table 5.9 Density index (plants ha^{-1}) of bushes of at least 0.5 m in height at the fenceline contrast sites in the Thornbush Savanna.

Contrast number	Density index (plants ha^{-1}) for the species abbreviated in the row below as estimated from NB and DistB, excluding rare species																		Total
	AERI	AFLE	AHEB	AHER	ALUE	AMEL	BALB	CALE	CGRA	DCIN	GFLA	GRET	LEEN	RBRE	RPYR	RTEN	TCAM	ZMUC	
17a			61	61		1092	61			101	61		61	526					2022
17b							24							8					32
17c			19			371	130	37	19				186	1095					1856
18a	22	67	22		22	315	202	112	22	292	1102	67							2249
18b	23		6		74	11	63	11		34	297	6	11						537
19a	47	79	158	47		521	32			47	411	16			16		190	16	1579
19b	4	17	4	4		9	22			9	196	17					13	9	304
20a	52	207	130			829			78		933	52	181		26		26	26	2539
20b	17																		17
21a	21	128	364		21	621	64	0	21	235	449		21				150	43	2140
21b	22		22		0	0	22	0	0	44									109
22a			339		113	925	23	45	23	113	339				271			23	2212
22b															20				20
23a	37	94	94			225	9		9	215	47	37			9		47	9	833
23b		102	478			171	17			188	119	34			17		392	17	1536
24a		132	184			1132				632	105						447		2632
24b	25	64	293			64			25	268	153						344		1236
25a	12	23	141	23	12	23	129			364	388	47							1163
25b	41	164	103	82	41	390	185			452	452	41					82	21	2055
26a	41	164	267	41		658	0			226	308						164		1870
26b			18		53	836	18			53	213						445		1637
27a		239	22	44	131	413				370	457		44		22		435		2175
27b		75	135	15	180	75			15	195	225		15		150		405		1484
28a			109	109			73			328	1237		109			182	1201	36	3385
28b	38	38	488	150	714	1014	38			188	564		75				376		3682
29a		129			430	1548	86	129	946	215	473	172			129				4256
29b					629	3495	70	699	1048	70	349	70			559				6990
30a						8332		490	196	98					98		490	98	9802
30b		18				658	18	420	164	55	110				18	110	219	37	1828
31a					218	184	34				218	821	134					17	1625
31b			6								49	441	18				49	6	569

The names for species abbreviations are: AERI = *Acacia erioloba*; AFLE = *Acacia fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE=*Catophractes alexandrii*; CGRA = *Croton gratissimus*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; LEEN= *Lycium eenii*; RBRE = *Rhigozum brevispinosum*; RPYR = *Rhus pyroides*; RTEN = *Rhus tenuinervis*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Dispersion around the median values for numerical variables are presented for: (i) distance to nearest perennial grass (DistP) in Figure 5.5; (ii) count of perennial grasses (No P) in Figure 5.6; (iii) distance to nearest bush or tree (DistB) in Figure 5.7; and (iv) canopy cover by Bitterlich gauge (Bitterlich) in Figure 5.8. No chart was plotted for count of bushes shorter than 0.5 m (Woodies), since all medians were zero.

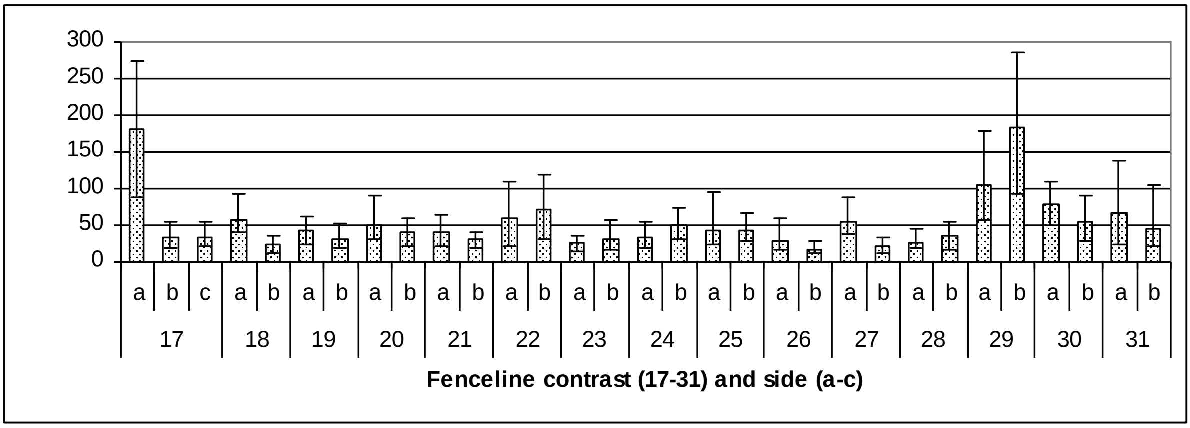
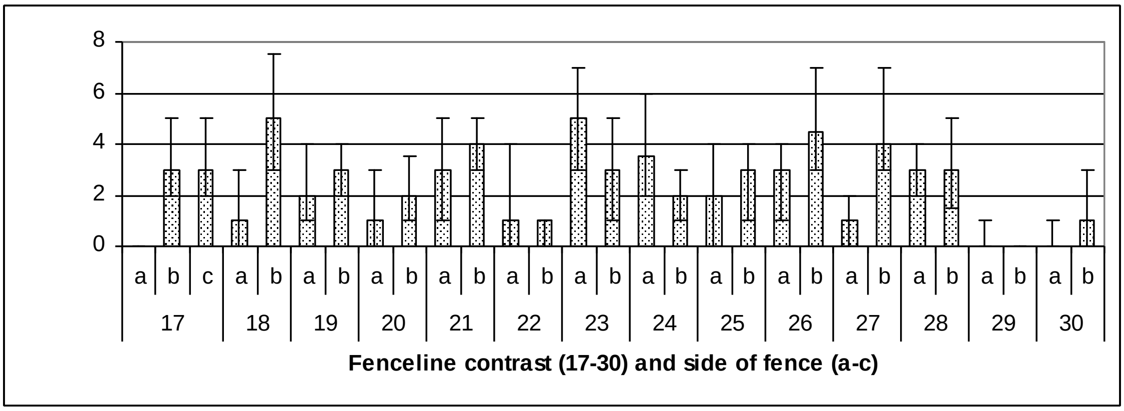
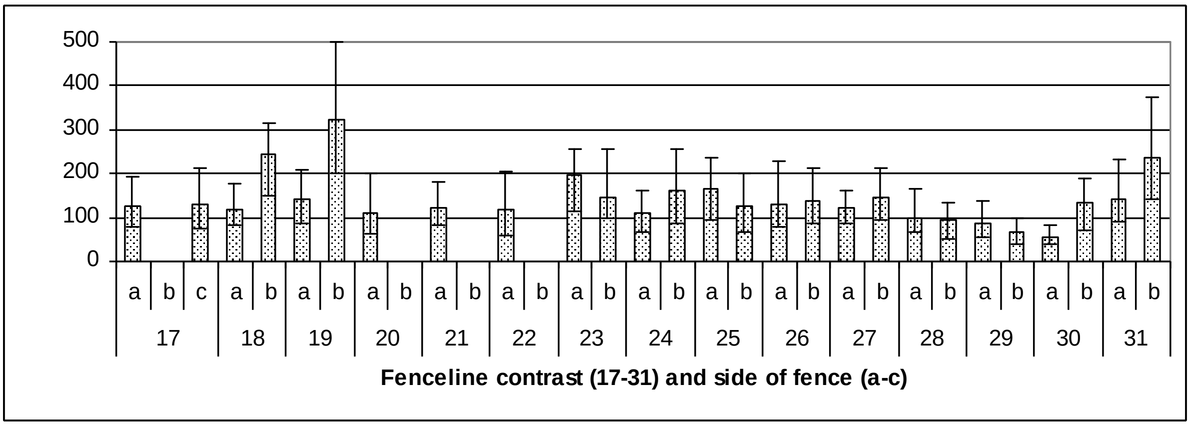


Figure 5.5 Median values and quartiles for the distance from sample point to nearest perennial grass of at least 5 cm basal diameter, for each of the sites measured at fenceline contrasts in the Thornbush Savanna.



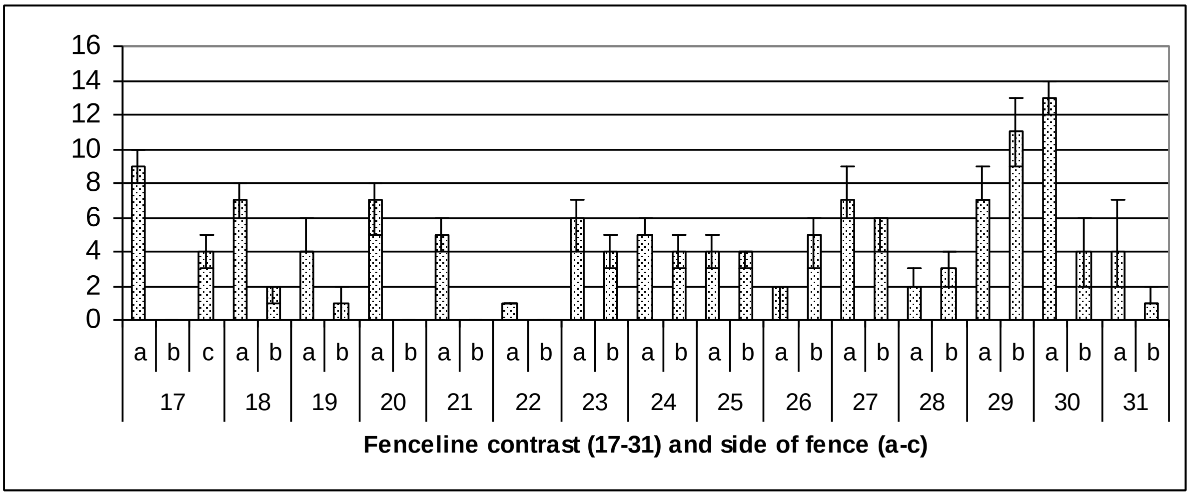
The perennial grass density was not measured at Contrast 31.

Figure 5.6 Median values and quartiles for the number of perennial grasses of at least 5 cm basal diameter counted in each of fenceline contrasts sites in the Thornbush Savanna.



The upper quartile for 19b, and the medians for 17b, 20b, 21b and 22b, were more than 500 cm and are therefore not presented.

Figure 5.7 Median values and quartiles for the distance from sample point to nearest bush or tree of at least 0.5 m in height, for each of the sites measured at fenceline contrasts in the Thornbush Savanna.



For some sites one of the quartiles was equal to the median and at Site 22a both quartiles were. Sites 17b, 20b, 21b and 22b were in hayfields where there were few or no canopies to count.

Figure 5.8 Median values and quartiles for the number of canopies of trees and bushes of at least 0.5 m in height counted by Bitterlich gauge in each of the fenceline contrast sites in the Thornbush Savanna.

Results from Soil cover (Hit) measurements are presented in Figure 5.9. Biological soil crust was generally more common than in the Camelthorn Savanna, but stones and rock were similarly scarce and only encountered at three of the sites.

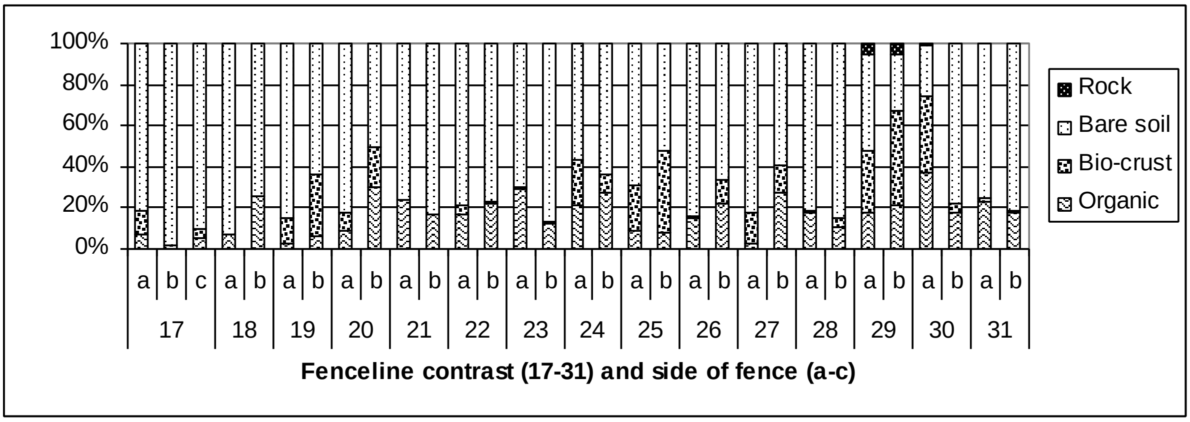


Figure 5.9 Proportions of organic cover over the soil (from mulch and bases of perennial grasses), biological soil crust, bare soil and rock found in each of fenceline contrast sites in the Thornbush Savanna.

5.5 INDIVIDUAL CONTRASTS

5.5.1 Contrast 17, between communal land and bush thinned commercial land

There were three sites that made up Contrast 17. Site 17a was the only site that was on true communal land, out of all the sites measured for this study. It was estimated to be stocked continuously at 58 kg liveweight ha^{-1} (8 ha AU^{-1}) by cattle, goats, sheep, horses and donkeys. Although boundaries with the neighbouring villages were not fenced, they were generally respected by the farmers, who would herd back their livestock that crossed the boundaries, in accordance with the findings of Homann & Rischkowsky (2001). There were 15 homesteads housing about 200 people, though the livestock ownership was skewed. The size of rangeland available for the village was not actually known, but was estimated to be 6 000 ha.

The contrasting sites were on a commercial farm where cattle were stocked at roughly 23 kg liveweight ha^{-1} (20 ha AU^{-1}), with provision of a growing season rest period of about nine weeks. The stocking rate had, however, been higher, at roughly 47 kg liveweight ha^{-1} (10 ha AU^{-1}) until the year before the measurements. Site 17b was a cleared strip of roughly two hundred metres width along the boundary fence from which most bush stumps had been dug out and hay harvested, to act as a firebreak and provide improved visibility to control stock theft. Site 17c was in the same paddock as 17b, but the bushes had only been thinned through chopping of major encroacher species, without de-stumping.

The village on the communal land had been established in 1923, when water was obtained from wells. The first borehole was drilled in the early 1950’s. The fence at the contrast was erected in 1954, when the rangeland was believed to have been in better condition and when the commercial farm was established, confining the livestock of the communal farmers to a smaller area. This is when the contrast is believed to have started its formation. The commercial farm started out with only one borehole and a few wells, while subdivision of paddocks progressed in stages. Arboricides were first applied in 1979, by air and later selectively by hand. Chopping subsequently became the preferred method of bush control. A higher stocking rate of 56 kg liveweight ha^{-1} (8 ha AU^{-1}) had been applied on the commercial farm, but the current farmer opted for a lower stocking rate of 23 kg liveweight ha^{-1} (20 ha AU^{-1}) to fetch higher prices per kg for cattle with good body condition.

Photographs of the measured sites are presented in Figure 5.10.

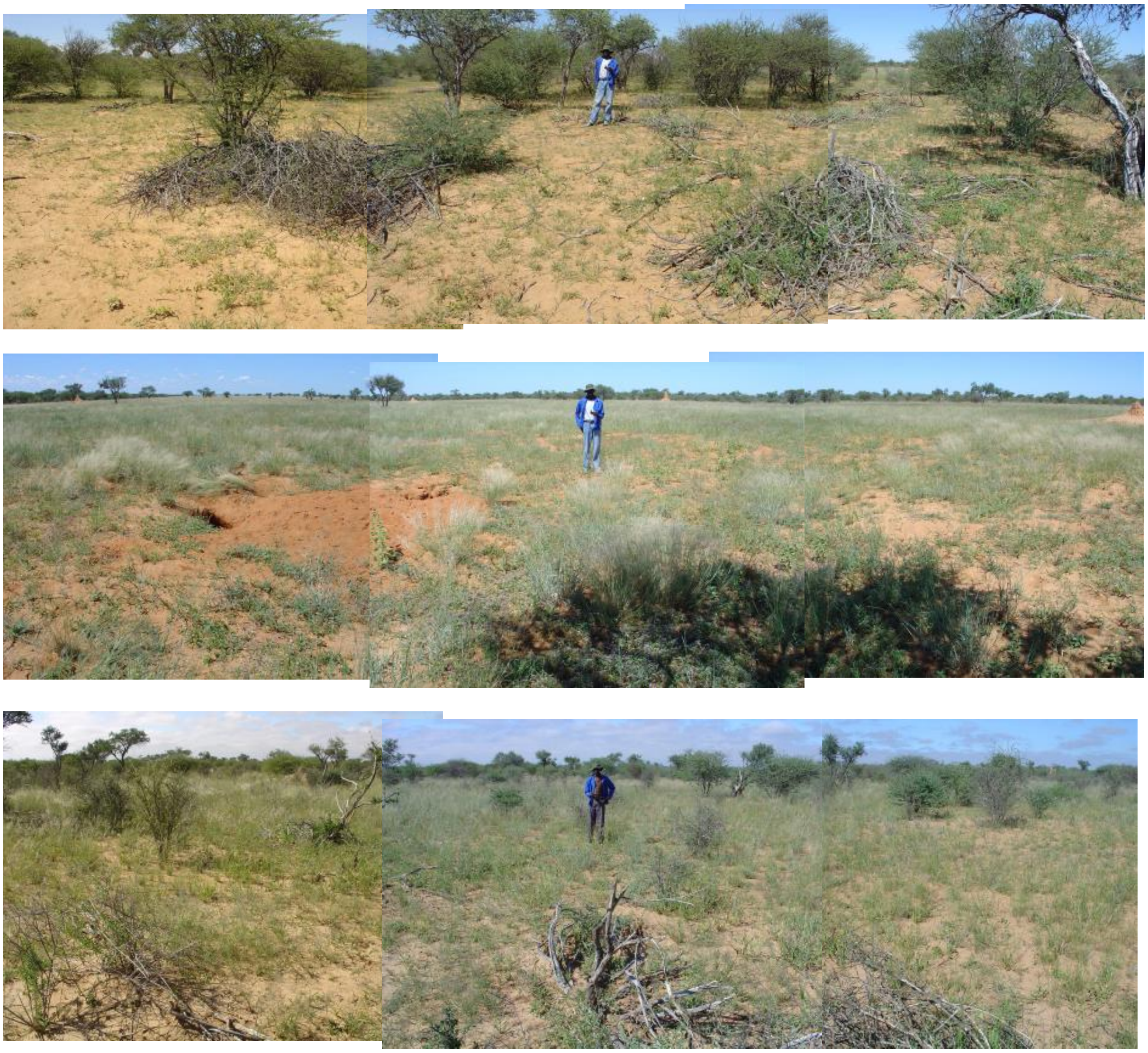


Figure 5.10 Contrasting sites between communal land (17a, top), a cleared strip on commercial land (17b, middle) and bush thinned commercial land (17c, bottom). The photographs were taken in April 2005.

For Sites 17a, 17b and 17c respectively the mulch covers of 7%, 2% and 5% were not significantly (P>0.05) different, but the biological soil crust covers of 12%, 0% and 5% were (P<0.05). All but one of the 17 points with these biological crusts were found under canopies of bushes, mostly of *Acacia mellifera*, which may explain the absence of biological crust cover in the cleared strip.

The perennial grass density was much lower on the communal land, estimated at only 0.1 grasses m^{-2}, compared to 2.0 grasses m^{-2} on the two commercial sites. The bare patch size frequencies in Figure 5.11 indicate the many large bare patches in the communal land.

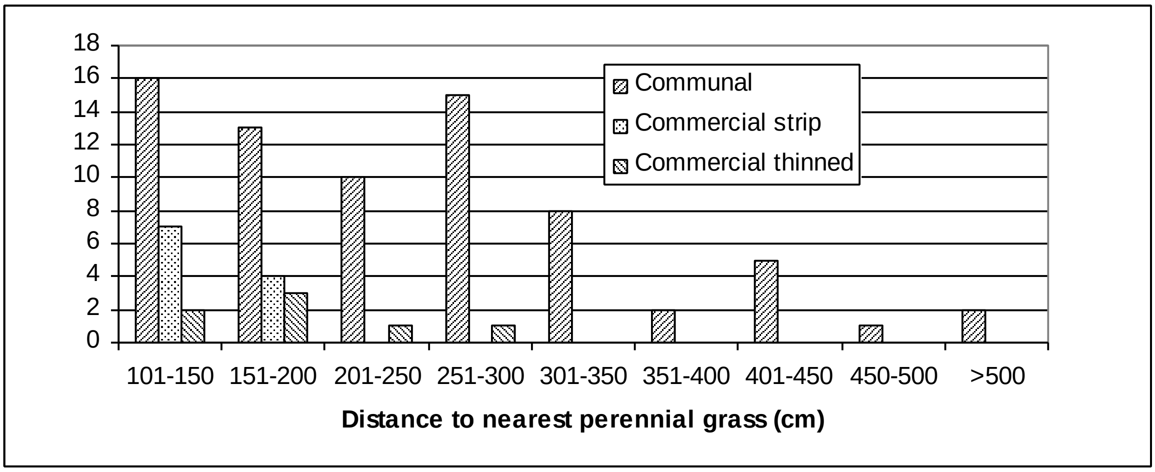
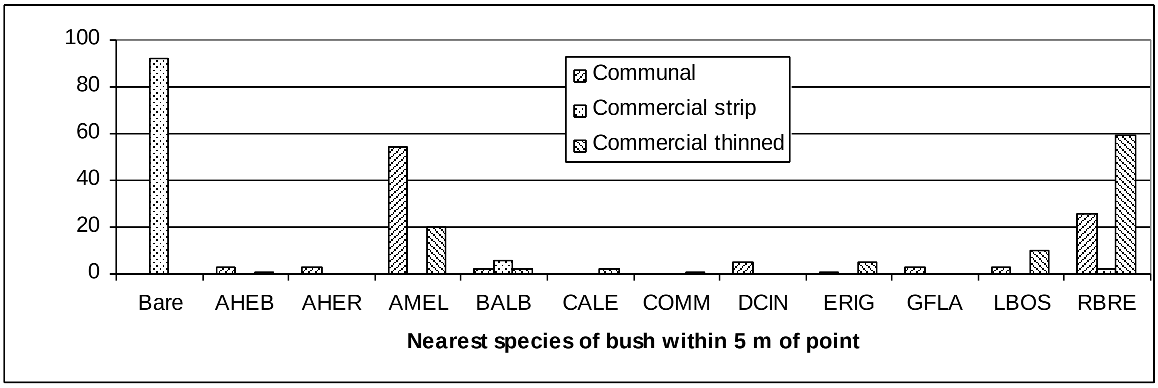


Figure 5.11 Bare patch size frequencies at Contrast 17 in the Thornbush Savanna.

The species composition of the perennial grasses also differed significantly (P<0.05), with more *Eragrostis tricophora* on the communal land and correspondingly more *Stipagrostis uniplumis* on the two commercial sites (Table 5.4). The rangeland condition index was significantly (P<0.0001) higher on the commercial farm (30 versus 238 on the cleared strip and 213 on the thinned area).

Not surprisingly, the communal land had a higher bush density and canopy cover than the cleared and thinned commercial sites. The species composition of bushes taller than 0.5 m also differed, with a greater proportion of *Acacia mellifera* on the communal land and a correspondingly greater proportion of *Rhigozum brevispinosum* on the thinned commercial land, as seen in Figure 5.12. The only species measured in the cleared strip was *Boscia albitrunca*, of which some trees had been left for browse and shade.



Bare = No bush or tree within 5 m of sample point; AHEB = *Acacia hebeclada*; AHER = *A. hereroensis*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE = *Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; LBOS = *Lycium bosciifolium*; RBRE = *Rhigozum brevispinosum*.

Figure 5.12 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 17 in the Thornbush Savanna.

The most common species of bush shorter than 0.5 m was *Rhigozum brevispinosum*, making up 60%, 79% and 33% of bushes shorter than 0.5 m measured at Sites 17a, 17b and 17c respectively. Its density differed significantly ($P<0.05$) across the sites, giving an estimate of 510 plants ha^{-1} on the communal land at Site 17a, 1 930 plants ha^{-1} on the commercial strip at Site 17b and 230 plants ha^{-1} on the bush thinned commercial site 17c.

The shortage of wood in the cleared strip seems to have forced termites to feed on the bark of *Acacia erioloba* saplings, which normally resist termite attack (Figure 5.13).

Figure 5.13 Termite attack on a sapling of *Acacia erioloba* in the cleared strip at Contrast 17 in the Thornbush Savanna. The photograph was taken in April 2005.

5.5.2 Contrast 18, between selective bush control and no bush control

Contrast 18 was between two commercial beef farms. Site 18a had not undergone any bush control while Site 18b had received arboricide application selectively by hand a few years previously. As a result it could be stocked more heavily, at about 51 kg liveweight ha^{-1} (9 ha AU^{-1}), compared to the 36 kg liveweight ha^{-1} (13 ha AU^{-1}) on the other side of the fence in 18a. Site 18a is also a guest farm where trophy hunting takes place. Both farms provided four paddocks per herd of cattle, although the growing season rest period was a little longer on 18b, at eight weeks compared to six weeks on 18a. In addition, Site 18b is provided with a complete growing season rest once every five years.

Site 18a had been heavily stocked by a dairy farmer who became bankrupt in 1954. The new owner stocked the farm very lightly, at approximately 9 kg liveweight ha^{-1} (50 ha AU^{-1}) until the 1970's when it was raised to the current average of 36 kg liveweight ha^{-1} (13 ha AU^{-1}), although total de-stocking had to take place in 1989 due to severe drought. The farmer believed that bushes encroached due to the lack of fires. However, he was reluctant to apply bush control as he believed his Brahman cattle benefited from the high phosphate content of *Acacia mellifera* leaves that they scoop up from the ground with their tongues. The farm at Site 18b had been established in 1947. The farmer reminisced of the area as wide open grassland with a few scattered trees and very few bushes. Even when he took over management of the farm in 1963, it had been dominated by palatable grass species such as *Anthephora pubescens*, *Brachiaria nigropedata* and *Schmidtia pappophoroides*. He believed that his efforts at bush thinning allowed him to maintain a steady stocking rate of approximately 51 kg liveweight ha^{-1} (9 ha AU^{-1}) over the decades, even during droughts. He furthermore believed that the fenceline contrast developed during the 1970's as a consequence of his bush thinning efforts. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.14.

Figure 5.14 Both sides of fenceline contrast between untreated land (18a, top) and bush thinned land (18b, bottom). The photographs were taken in April 2005.

The mulch cover was three times higher, at 24%, on the bush thinned site. The perennial grass density was also higher, estimated at 3.0 plants m^{-2}, compared to 0.9 plants m^{-2} on Site 18a, so there were also more bare patches on 18a (Figure 5.15).

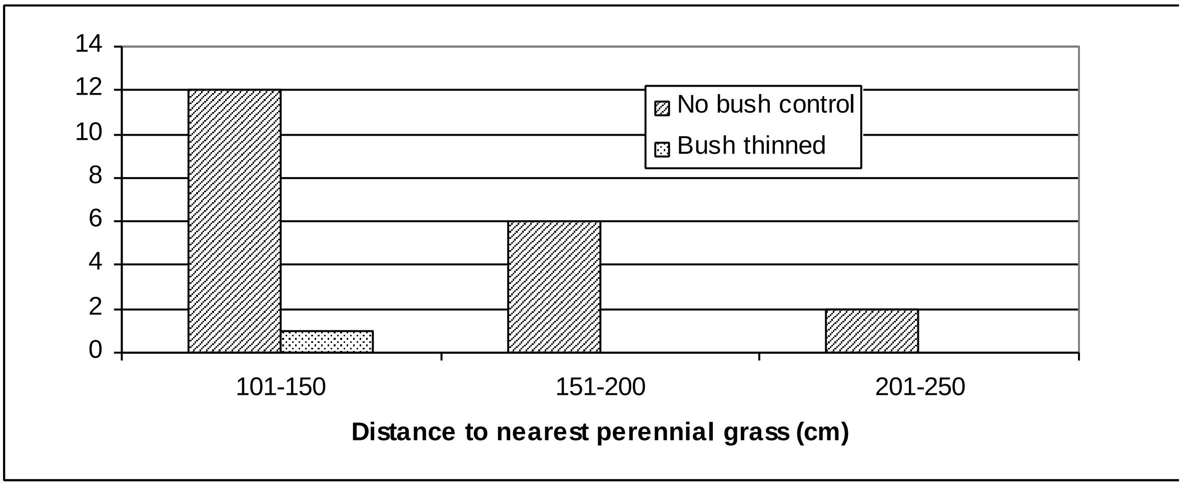
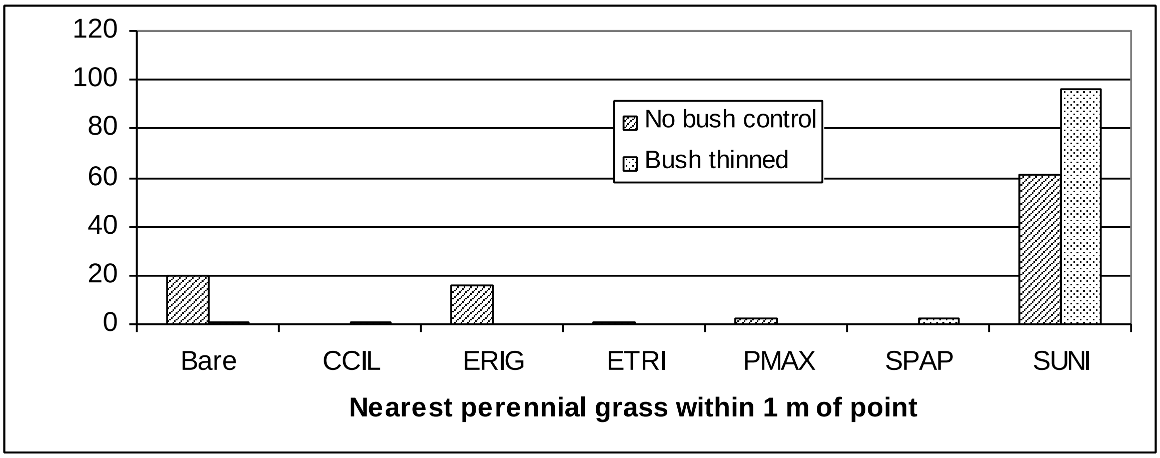


Figure 5.15 Bare patch size frequencies at Contrast 18 in the Thornbush Savanna.

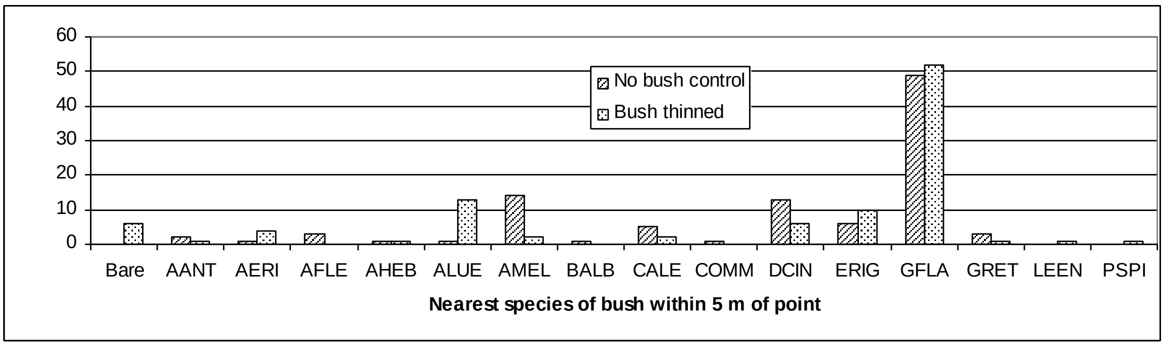
The proportion of mesophytes amongst the grasses was greater on Site 18a, comprised mainly of *Eragrostis rigidior* (Figure 5.16, although both sites were dominated by *Stipagrostis uniplumis*. The rangeland condition index was significantly (P<0.0001) lower on Site 18a (85 versus 335).



Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; ERIG = *E. rigidior*; ETRI = *E. tricophora*; PMAX = *Panicum maximum*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.16 Perennial grass species composition at Contrast 18 in the Thornbush Savanna.

As expected the bush density and canopy cover were higher on the untreated side of the fence, although the height class did not differ significantly (P>0.05). Despite domination by *Grewia flava* on both sides of the fence, the species composition differed, with a greater proportion of *Acacia mellifera* and *Dichrostachys cinerea* on the untreated side, and a correspondingly greater proportion of *Acacia luederitzii* on the bush thinned side (Figure 5.17), even though all these three species had been targeted for arboricide application on Site 18b. Only few woody plants shorter than 0.5 m were found within 75 cm of the point, and they did not differ significantly (P>0.05) across the fenceline.



Bare = No bush or tree within 5 m of sample point; AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AHEB = *A. hebeclada*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE = *Catophractes alexandrii*; COMM = *Commiphora* spp.; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; LEEN = *Lycium eenii*; PSPI = *Phaeoptilum spinosum*.

Figure 5.17 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 18 in the Thornbush Savanna.

5.5.3 Contrast 19, between game farm and bush thinned cattle farm

Site 19a had been converted to a game farm four years previously, by removal of most of the internal fencing that had been used for beef farming before. Some game animals such as giraffe, eland, wildebeest and zebra had recently been re-introduced, bringing the overall stocking rate to about 30 kg liveweight ha^{-1} (15 ha AU^{-1}). The re-introduced species were still being given the chance to increase in numbers, while oryx and kudu were about to be utilized, although none had been over the past four years. There had been no control of bushes on the farm. Site 19b was on a commercial beef farm where arboricide had been applied manually, but fairly intensively, five years previously and fires had swept through the previous year and four years previously. It was stocked with cattle at roughly 40 kg liveweight ha^{-1} (11 ha AU^{-1}) that were rotated through nine paddocks per herd, with weekly shifts in the growing season providing eight weeks of rest. The farm was also used for trophy hunting.

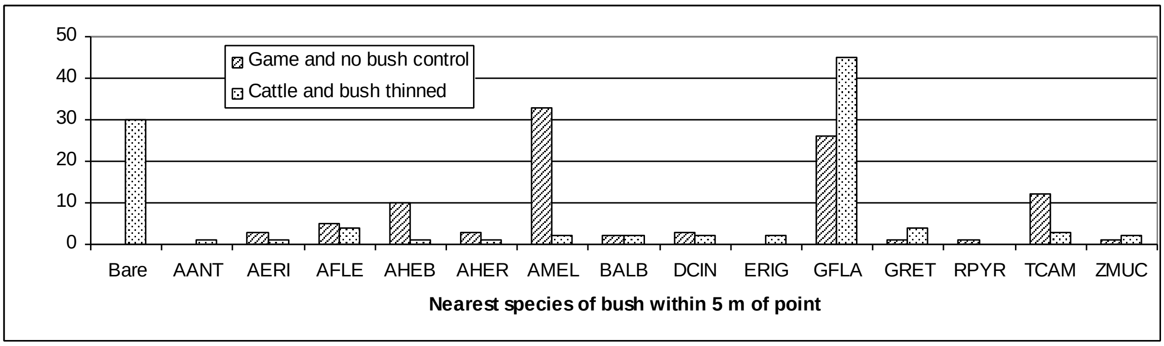
Details of the former management at Site 19a, when it was a cattle farm, are unknown. The farm of 19b had only three paddocks for cattle until the new owner started subdividing in 1956, with the most intensive developments taking place in the 1970's. Bush control had been started in 1984. There was a water point approximately 500 m from the fenceline contrast on the game side, and another approximately 1 000 m away of the cattle side. A photograph of the fenceline contrast appears in Figure 5.18.

Figure 5.18 Fenceline contrast between bush thinned farm (19b, left) and the game farm (19a) right. The photograph was taken in April 2004.

Figure 5.19 Fenceline contrast between farm with no bush control (20a, left) and the hayfield (20b, right). The photograph was taken in April 2004.

The mean of 1.5 perennial grasses m^{-2} on Site 19a did not differ significantly ($P>0.05$) from the mean of 1.8 perennial grasses m^{-2} on 19b. Nor was there a significant difference in grass species composition, with *Eragrostis rigidior* followed by *Stipagrostis uniplumis* dominating both sites. However the median distance to nearest perennial grass did differ significantly (P<0.05), with 44 cm on 19a and 32 cm on 19b. The rangeland condition index was lower at 19a (190 versus 283). This difference was not significant (P>0.05) by Mann-Whitney U test, but when tested by Chi-square, it was (P<0.05).

Not surprisingly, the bush density and canopy cover were higher on the side of the fence where bush thinning had taken place, although height class did not differ significantly (P>0.05). The proportions of *Acacia mellifera*, *A. hebeclada* and *Tarchonanthus camphoratus* were higher on Site 19a, with a correspondingly greater proportion of *Grewia flava* on the bush-thinned Site 19b (Figure 5.20).



Bare = No bush or tree within 5 m of sample point; AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; RPYR = *Rhus pyroides*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 5.20 Bush species composition at Contrast 19 in the Thornbush Savanna.

5.5.4 Contrast 20, between hayfield and farm with no bush control

Site 20a was on the game farm of 19a, but it was in a separate paddock used together with two other paddocks for two small herds of cattle, hence grazing periods of 10 weeks in the growing season were followed by rest of only 5 weeks. The overall stocking rate was estimated at 27 kg liveweight ha^{-1} (17 ha AU^{-1}). Site 20b was on the same farm as 19b, but it had been a hayfield for approximately eight years and mown every year, except in an extreme drought. A photograph of the fenceline contrast appears in Figure 5.15 above.

The hayfield had significantly (P<0.05) higher organic cover of 30% over the soil compared to 9% for the untreated Site 20a. The perennial grass density was also significantly (P<0.05) higher with a mean density of 1.4 grasses m^{-2} compared to 1.0 on the untreated site. There were more bare patches on the untreated side (Figure 5.21). However the perennial grass species composition did not differ significantly (P>0.05), with

Eragrostis rigidior strongly dominating both sides. The rangeland condition index was lower on Site 20a (120 versus 170) but the difference was not significant (P>0.05).

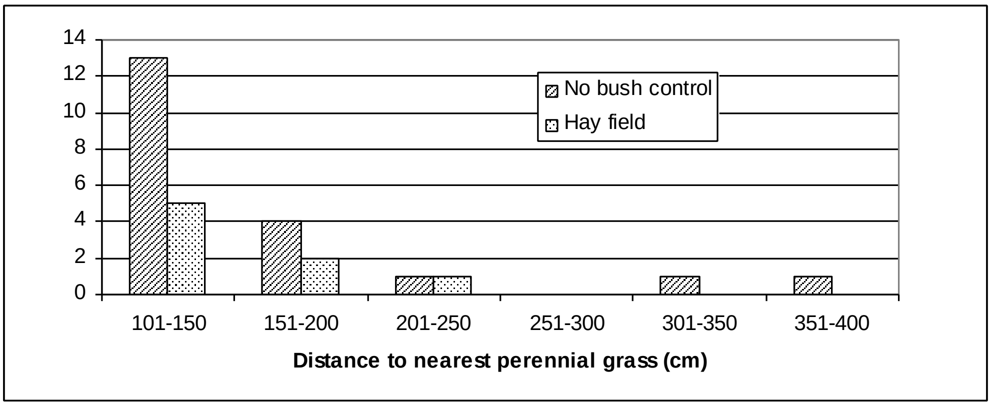


Figure 5.21 Bare patch size frequencies at Contrast 20 in the Thornbush Savanna.

The canopy cover of bushes and trees had been reduced to zero on the hayfield, compared to 33% on the untreated Site 20a, which was dominated by *Acacia mellifera*, followed by *Grewia flava* and *A. erioloba*. The bushes shorter than 0.5 m did not differ significantly (P>0.05) across the fenceline, estimated at 450 plants ha^{-1} on the hayfield and 740 plants ha^{-1} on the untreated site. However there were significantly (P<0.05) more plants of the weedy forb *Hirpicium gazanioides* found on the hayfield Site 20b, giving a mean density estimate of 5 780 plants ha^{-1} compared to 3 060 on the untreated Site 20a.

5.5.5 Contrast 21, between hayfield and previously bush thinned paddock

Contrast 21 was on the same farm as 19b, while Site 21b was in the same hayfield as 20b. Site 21a was an adjacent paddock where bushes had been thinned by selective hand application of arboricide more than ten years previously. As mentioned in section 5.5.3, the farm was stocked with cattle at roughly 40 kg liveweight ha^{-1} (11 ha AU^{-1}) that were rotated through nine paddocks per herd, with weekly shifts in the growing season providing eight weeks of rest. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.22.

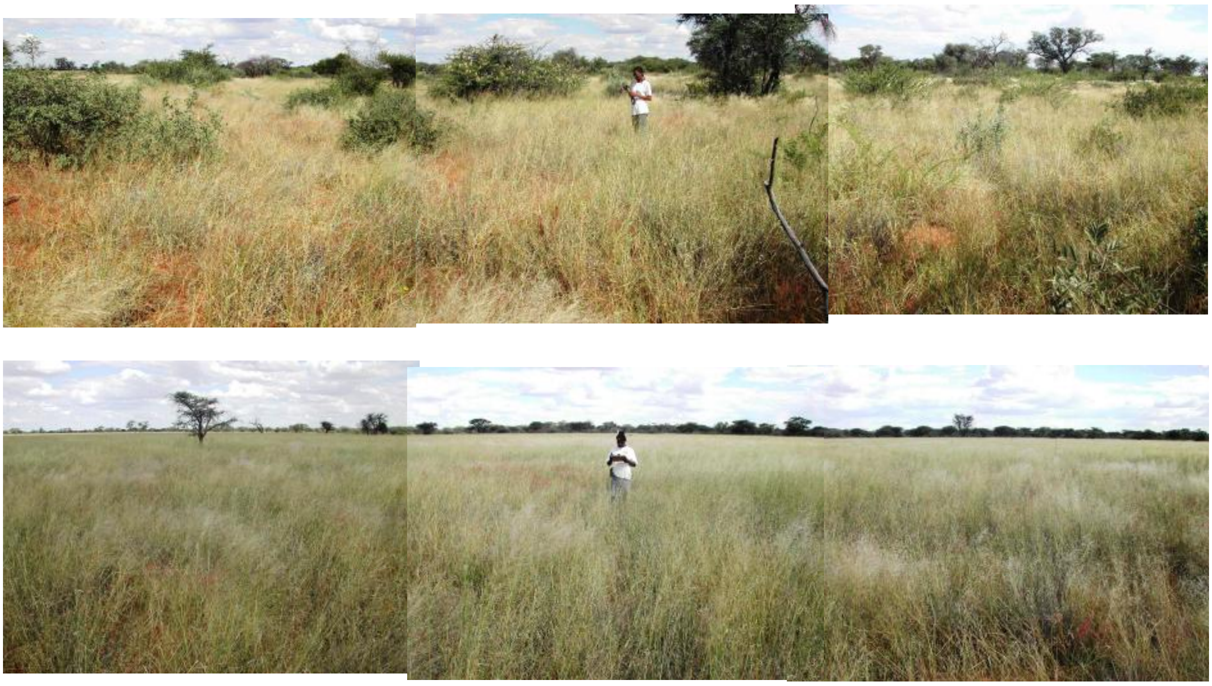


Figure 5.22 Both sides of fenceline contrast between previously bush thinned paddock (21a, top) and hayfield (21b, bottom). The photographs were taken in April 2004.

This contrast did not indicate significant (P>0.05) differences in soil cover and perennial grass species composition. However the perennial grass density was significantly (P<0.05) higher on the hayfield, where it was estimated at 2.3 grasses m^{-2}, compared to 1.8 grasses m^{-2} on the previously thinned site. The rangeland condition index was lower at 21a (205 versus 275). This difference was not significant (P>0.05) by Mann-Whitney U test, but when tested by Chi-square, it was (P<0.05).

The canopy cover of bushes and trees had been reduced to zero on the hayfield, but had increased to 27% on the previously thinned Site 21a, which was dominated by *Acacia mellifera*, the main target of the previous arboricide application, followed by *Grewia flava* and *A. hebeclada*.

5.5.6 Contrast 22, between hayfield and natural rangeland used for cattle

Contrast 22 was on the same farm as Contrast 21, and it was also between a hayfield and an adjacent paddock. However it was on a different part of the farm with heavier textured soil, which seemed to favour a lower cover of bushes, perhaps on a fossil river bed. The hayfield on Site 22b had been cleared of bushes 26 years previously and hay had been mown annually except for extreme drought years. Site 22a was an adjacent paddock where it had not been necessary to apply bush control.   It was stocked with cattle as described for 21a in section 5.4.5. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.23.

Figure 5.23 Both sides of fenceline contrast between paddock used for cattle (22a, top) and old hayfield (22b, bottom). The photographs were taken in April 2004.

On this hayfield the perennial grass density was lower than on the grazed paddock, with estimates of 0.8 and 1.5 grasses m^{-2} respectively. The median distance to nearest perennial grass was 60 cm on the hayfield and 71 cm on the natural rangeland. However this difference was not significantly (P>0.05) different, due to the strange distributions of distances as presented in Figure 5.24, with the hayfield having more distances in the 51-150 cm and 251-350 cm ranges.

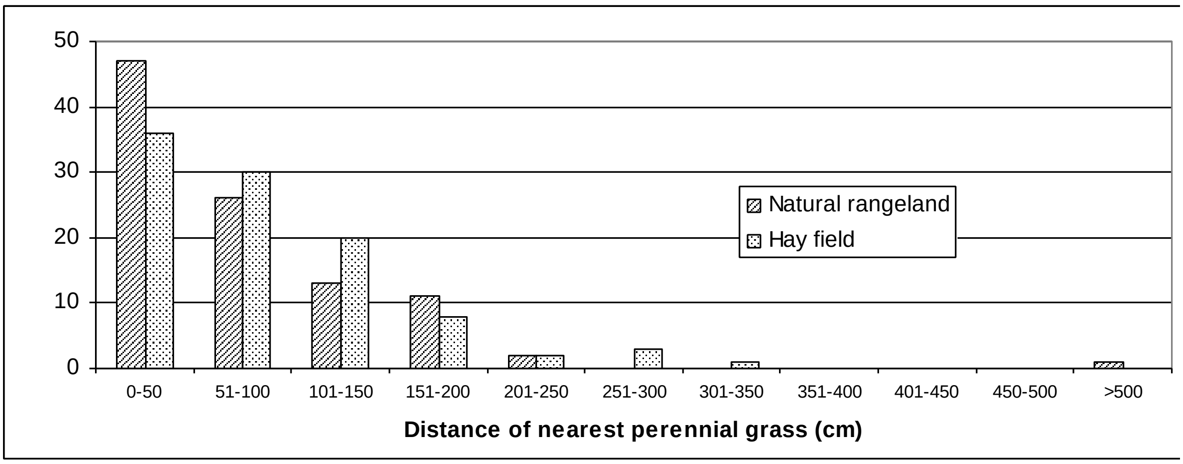
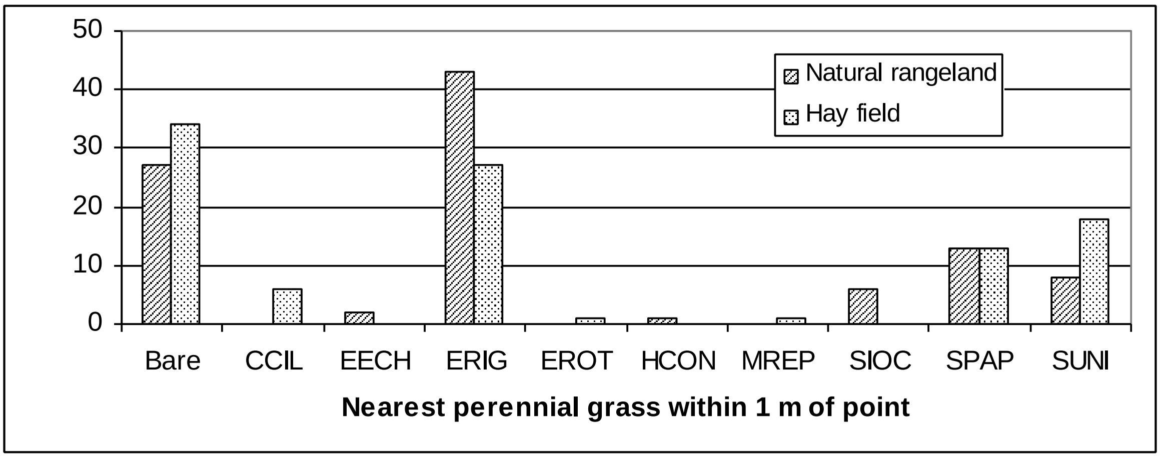


Figure 5.24 Frequencies of grouped distances to nearest perennial grass at Contrast 22 in the Thornbush Savanna.

The proportion of mesophytes was also higher on the natural rangeland, with a greater proportion of *Eragrostis rigidior* and a smaller proportion of *Stipagrostis uniplumis* (Figure 5.25). This is the only contrast where *Sporobolus ioclados* was encountered, a grass associated with poorly drained, often brackish, soil (Van Oudtshoorn, 1999). The rangeland condition index was higher on Site 22a (177 versus 145) but the difference was not significant (P>0.05).

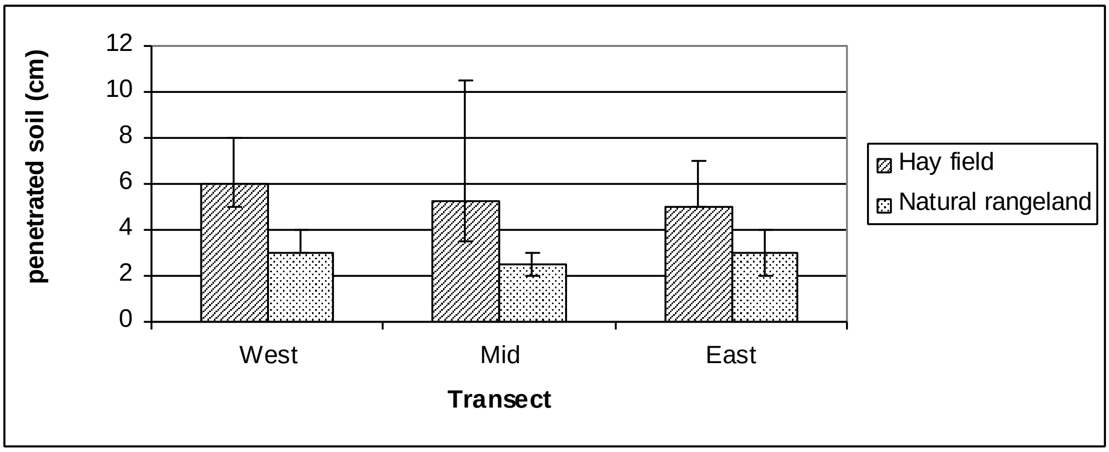


Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; EECH = *Eragrostis echinochloidea*; ERIG = *E. rigidior*; EROT = *E. rotifer*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; PMAX = *Panicum maximum*; SIOC = *Sporobolus ioclados*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.25 Perennial grass species composition at Contrast 22 in the Thornbush Savanna.

The canopy cover of trees and bushes of at least 0.5 m in height was 10% on the natural rangeland, dominated by *Acacia hebeclada*, and was estimated at 1% in the hayfield, thanks to some trees of *A. erioloba* and *Boscia albitrunca* with large canopies that had been left for shade. However those large trees were never found within 5 m of the sample point and the only bush encountered in the hayfield as the nearest bush within 5 m was *Rhus pyroides* found at just one point.

Surprisingly the soil was softer in the hayfield (Figure 5.26).



Error bars indicate upper and lower quartiles. The lower quartile was equal to the median on the western transect in the natural rangeland and on the eastern transect in the hayfield.

Figure 5.26 Compaction of the soil at Contrast 22 in the Thornbush Savanna, indicated as the median depth to which the soil probe penetrated along three pairs of transects.

5.5.7 Contrast 23, between cattle farm and bush thinned game farm

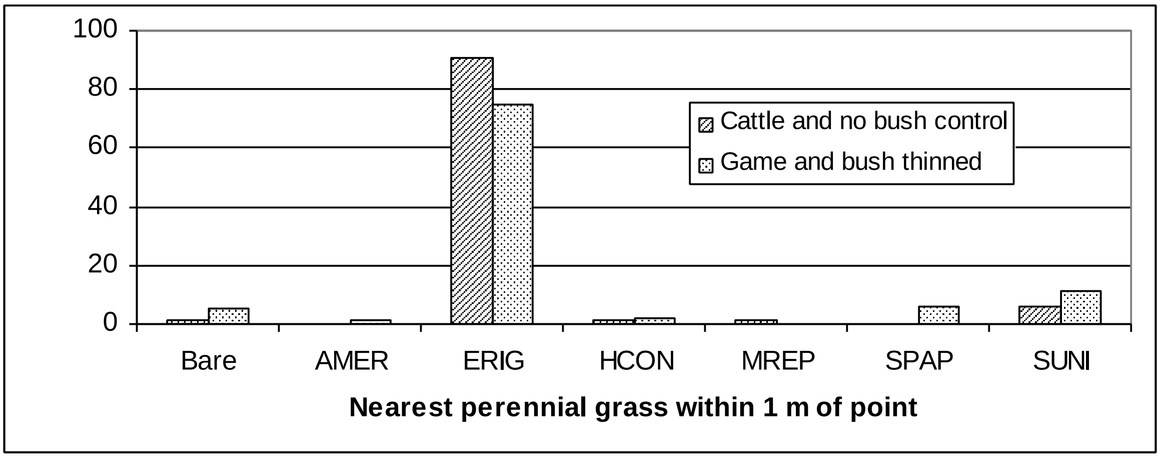
Although Site 23a was on the same farm as 19b, it had not yet undergone any bush control like most of the remainder of the farm. It was stocked with cattle as already described for 21a in section 5.4.5. The contrasting Site 23b was on a game farm where larger encroacher bushes had been selectively killed by stem burning and smaller bushes chopped below ground level about ten years previously. It was stocked continuously with a wide diversity of game species, dominated by blue and black wildebeest. The stocking rate was estimated at 45 kg liveweight ha^{-1}, (10 ha AU^{-1}) and the game animals were exposed to a high level of trophy hunting and live capture. The game farming had been started 20 years previously while it was still a cattle farm. Over the following eight years all the cattle were removed and the internal fencing dismantled. Intensive bush thinning over 5% of the farm every year had been completed by 2000, after which small scale follow-up was applied at scattered locations. It was believed that the contrasts at the boundary fences developed during the 1990’s as the bushes were being thinned at those sites.

A photograph of the fenceline contrast appears in Figure 5.27.

Figure 5.27 Fenceline contrast between cattle farm (23a,left) and the bush thinned game farm (23b, right). The photograph was taken in April 2004.

Figure 5.28 Fenceline contrast between cattle farm (24a,left) and the bush thinned game farm (24b, right). The photograph was taken in April 2004.

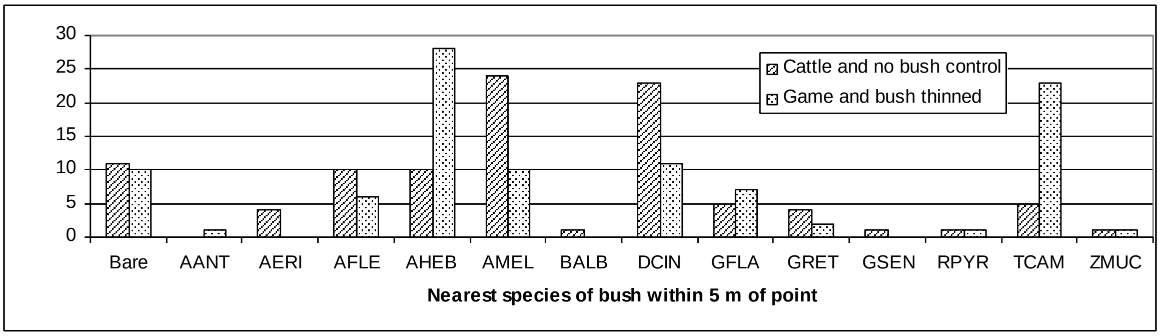
The organic cover over the soil was higher on the cattle side of the fence, at 29% compared to 12% on the game farm. The perennial grass density was also higher on the cattle side, estimated at 2.9 grasses m^{-2} compared to 1.8 on the game side. There was a greater proportion of *Eragrostis rigidior* on the cattle side (Figure 5.29), even though it dominated both sides of the fence. The correspondingly greater proportions of *Schmidtia pappophoroides* and *Stipagrostis uniplumis* on the game side were not significantly different (P>0.05) as individual species. The rangeland condition index was slightly higher on the cattle side (295 versus 271) but the difference was not significant (P>0.05).



Bare = no perennial grass within 1 m; AMER = *Aristida meridionalis*; ERIG = *Eragrostis rigidior*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.29 Perennial grass species composition at Contrast 23 in the Thornbush Savanna.

The bush canopy cover was significantly (P<0.05) higher on the cattle side, at 29% compared to 18% on the game side, although the difference in distance to nearest bush was not significant (P>0.05). There was a greater proportion of *Acacia mellifera and Dichrostachys cinerea* on the cattle side, with correspondingly greater proportions of *Acacia hebeclada* and *Tarchonanthus camphoratus* on the game side (Figure 5.30). The former two species had both been targets of bush control on the game farm while the latter two had not.



Bare = No bush or tree within 5 m of sample point; AANT = *Albizia anthelmintica*; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *Acacia hebeclada*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; GSEN = *Gymnosporia senegalensis*; RPYR = *Rhus pyroides*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 5.30 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 23 in the Thornbush Savanna.

The height classes of bushes also differed significantly (P<0.05), with a greater proportion of smaller bushes in the 0.5-1 m height class on the game side of the fence (Figure 5.31). The density of bush saplings shorter than 0.5 m was estimated at 1 530 plants ha^{-1} on the cattle side and 620 plants ha^{-1} on the game side, but this difference was not significant (P>0.05). However there were significantly (P<0.05) more saplings of Acacia *mellifera* on the cattle side, where it made up 44% of the saplings, compared to 18% on the game side.

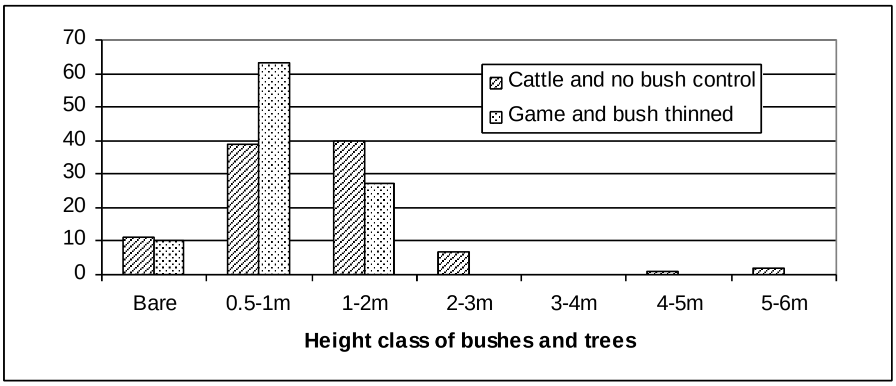
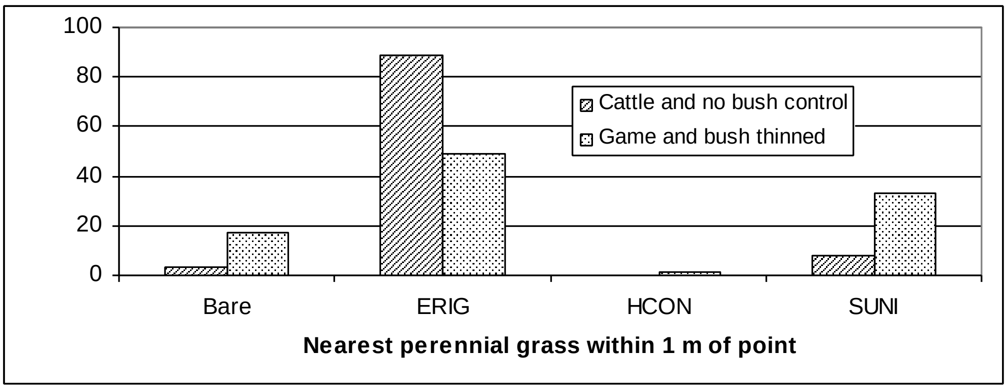


Figure 5.31 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 23 in the Thornbush Savanna.

5.5.8 Contrast 24, between cattle farm and bush thinned game farm

Site 24b was on the same game farm as 23b, but its contrasting site 24a was on a different cattle farm to 23a. The main difference between these sites on the cattle farms was that the cattle on 24a were rotated through only four paddocks per herd, providing a growing season rest of about 6 weeks, compared to 8 weeks rest and shorter grazing periods on 23a, and continuous grazing on the game farm. As on Site 23a, Site 24a had not undergone any bush control, even though most of the remainder of the farm had. Although Site 24a was on a farm that was stocked overall at 50 kg liveweight ha^{-1} (9 ha AU^{-1}), which was about 25% higher than 23a and also slightly higher than the game farm on 24b, the farm of 24a had some cultivated pastures of *Cenchrus ciliaris* where the breeding herd, that made up about 25% of the farm's liveweight, grazed for most of the growing season, so relieving pressure from the natural rangeland at 24a. The stocking rate had been kept steady over the previous three decades, while cultivated pastures had only been established a few years prior to the measurements. The farmer believed that rainfall had decreased, necessitating cultivated pastures to maintain the same stocking rate. A photograph of the fenceline contrast appears in Figure 5.28 above.

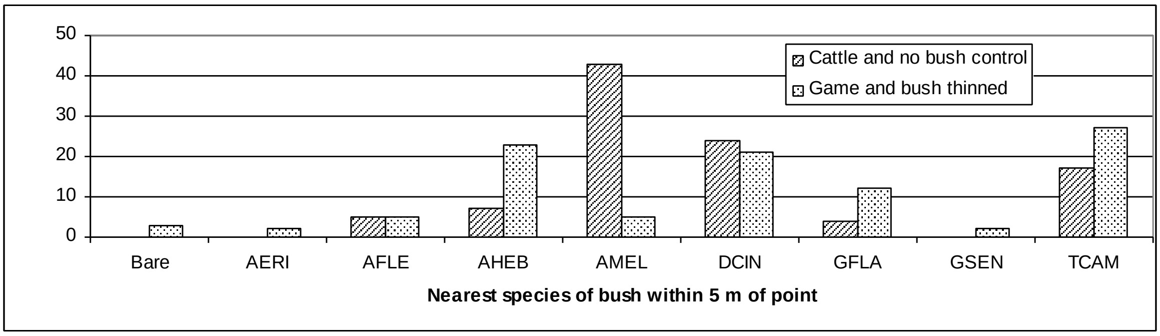
The organic cover over the soil did not differ significantly (P>0.05). The perennial grass density was higher on the cattle side, estimated at 2.2 grasses m^{-2} compared to 1.3 on the game side. As at Contrast 23, there was a greater proportion of *Eragrostis rigidior* on the cattle side (Figure 5.32), even though it dominated both sides of the fence. There was also a correspondingly greater proportion of *Stipagrostis uniplumis* on the game side. The rangeland condition index was significantly (P<0.05) higher on the cattle side (210 versus 125).



Bare = no perennial grass within 1 m; ERIG = *E. rigidior*; HCON = *Heteropogon contortus*; SUNI = *Stipagrostis uniplumis*.

Figure 5.32 Perennial grass species composition at Contrast 24 in the Thornbush Savanna.

The bush canopy cover was higher on the cattle side, at 27% compared to 19% on the game side and the median distances to nearest bush also differed significantly ($P<0.05$). There was a greater proportion of *Acacia mellifera* on the cattle side, with correspondingly greater proportions of *Acacia hebeclada*, *Tarchonanthus camphoratus* and *Grewia flava* on the game side (Figure 5.33).



Bare = No bush or tree within 5 m of sample point; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *A. hebeclada*; AMEL = *A. mellifera*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GSEN = *Gymnosporia senegalensis*; TCAM = *Tarchonanthus camphoratus*.

Figure 5.33 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 24 in the Thornbush Savanna.

The height classes of bushes also differed significantly ($P<0.05$), with a greater proportion of smaller bushes in the 0.5-1 m height class on the game side of the fence (Figure 5.34). The trend with bush saplings was opposite to the trend at Contrast 23, but at Contrast 24 the differences across the fenceline were not significant ($P>0.05$), with the density estimated at 910 plants ha^{-1} on the cattle side and 1 190 plants ha^{-1} on the game side. *Acacia mellifera* made up 66% of the saplings on the game side, compared to 19% on the cattle side, and this difference too was not significant ($P>0.05$).

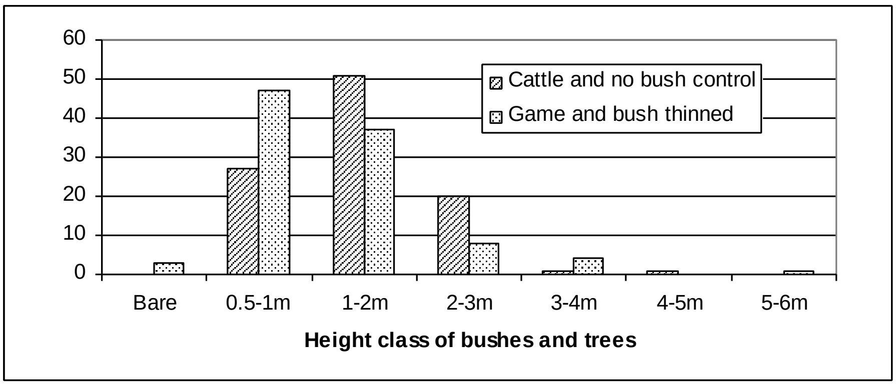


Figure 5.34 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 24 in the Thornbush Savanna.

5.5.9 Contrast 25, between cattle farm and bush thinned game farm

Site 25a was on the same game farm as 24b and 23b, although on the opposite side, while Site 25b was a cattle farm where the rate of rotation through the 10 paddocks per herd was slower than on the other two cattle farms at 23a and 24a, providing a rest period in the growing season of 18 weeks, although the stocking rate was similar, at about 40 kg liveweight ha^{-1} (11 ha AU^{-1}). Bush control had been applied on Site 25a by stem burning of larger encroacher bushes and chopping of smaller ones approximately seven years previously. The farmer at Site 25b had only taken over the management of the farm a few months earlier. He did not know the details of the previous grazing management. He believed that 25% of the farm had undergone bush thinning approximately 20 years previously, by the same method as at Site 25a, but was uncertain whether this had occurred at the measured site. Subdivision of the farm had mostly taken place in the 1980's. A photograph of the fenceline contrast is presented in Figure 5.35.

Figure 5.35 Fenceline contrast between the bush thinned game farm (25a, left) and cattle farm (25b, right). The photograph was taken in April 2004.

Figure 5.36 Fenceline contrast between the bush thinned game farm (26a, left) and cattle farm (26b, right). The photograph was taken in April 2004.

The differences across the fenceline at Contrast 25 were not great. There was no significant (P>0.05) difference in organic cover over the soil. Despite identical median distances to nearest perennial grass, there were more bare patches on the game side (Figure 5.37). The slight differences in density estimates of 1.3 grasses m^{-2} on the game side and 1.5 grasses m^{-2} found on the cattle side were significantly (P<0.05) different.

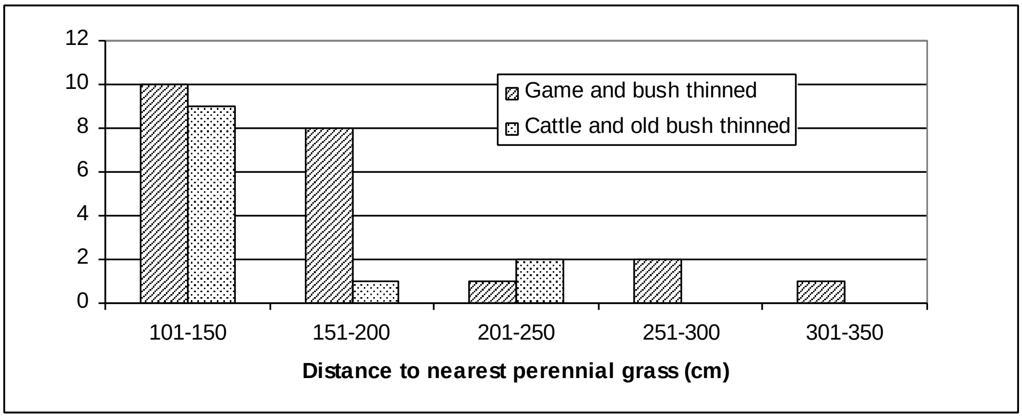
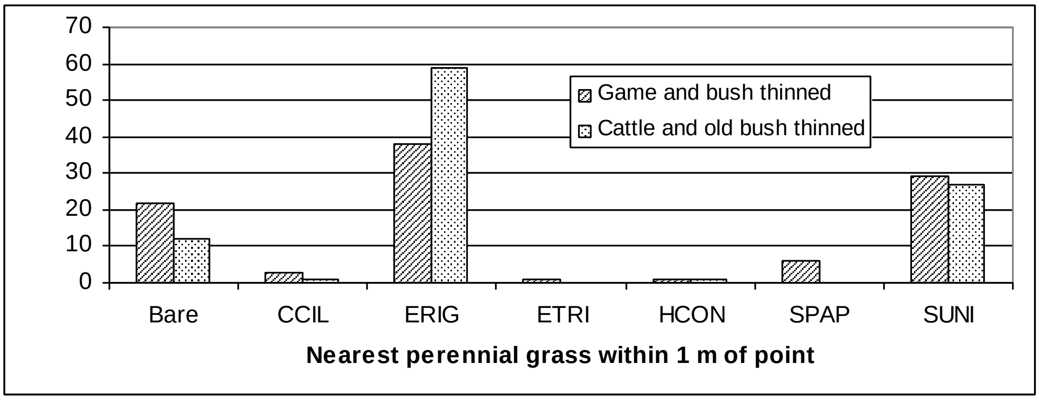


Figure 5.37 Bare patch size frequencies at Contrast 25 in the Thornbush Savanna.

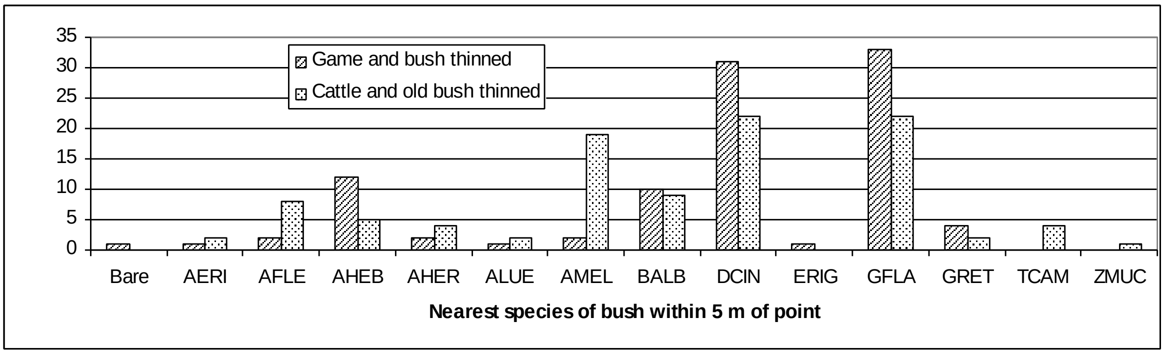
As on Contrasts 23 and 24, there was a greater proportion of *Eragrostis rigidior* on the cattle side of the fence (Figure 5.38). This was partly counterbalanced by *Schmidtia pappophoroides* that was found only on the game side, and a greater proportion of *Stipagrostis uniplumis* on the game side. The rangeland condition index was higher on the game side (213 versus 160) but the difference was not significant (P>0.05).



Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; ERIG = *Eragrostis rigidior*; ETRI = *E. tricophora*; HCON = *Heteropogon contortus*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.38 Perennial grass species composition at Contrast 25 in the Thornbush Savanna.

Unlike at Contrasts 23 and 24, there was no difference in bush canopy cover, estimated at 19% on both sides, while the density of bushes was actually higher on the game farm, where there were more of the bushes in the 0.5-1 m height class, although the overall difference in height class distributions did not differ significantly (P>0.05). As at Contrasts 23 and 24, there was more *Acacia mellifera* and less *A. hebeclada* on the cattle farm (Figure 5.39). However the trend of more *Tarchonanthus camphoratus* and less *Dichrostachys cinerea* on the cattle farm was opposite to that found at Contrasts 23 and 24.



Bare = No bush or tree within 5 m of sample point; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

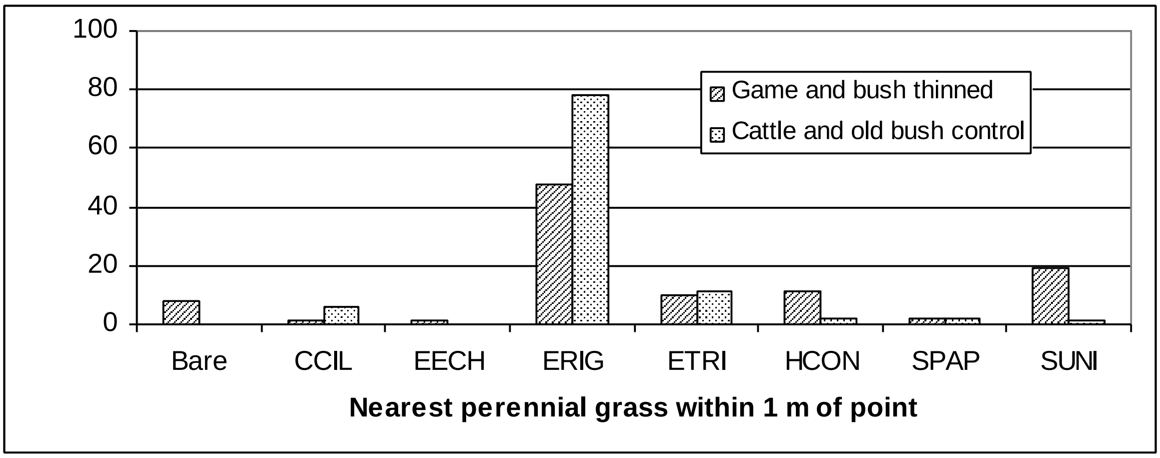
Figure 5.39 Bush species composition at Contrast 25 in the Thornbush Savanna.

In the case of bush saplings shorter than 0.5 m, there were significantly (P<0.05) more on the cattle farm, with an estimated density of 1 080 saplings ha^{-1}, compared to 280 saplings ha^{-1} on the game farm. *Acacia mellifera* made up 47% of the saplings on the cattle farm, which did not differ significantly (P>0.05) from the 40% on the game farm.

5.5.10 Contrast 26, between cattle farm and bush thinned game farm

Site 26a was still on the same game farm as 25a, already described in section 5.5.7, while the contrasting Site 26b was on a commercial beef farm. However it differed from the other three cattle farms that were measured in comparison with the same game farm in that arboricide had been applied by air 16 years earlier. The farm of Site 26b was stocked at about 38 kg liveweight ha^{-1} (12 ha AU^{-1}), compared to 45 kg liveweight ha^{-1} (10 ha AU^{-1}) on the game farm, and received rest in the growing season of about six weeks, compared to no rest on the game farm on 25a. According to the farmer, farming began in the area in 1907 when a single well served the livestock of several farmers who settled around there. Fencing started in the 1920's and the establishment of two additional wells in 1936 allowed herds to be separated. By 1946 the rangeland had become overgrazed and management was subsequently improved. Pipelines were established in 1957 to spread out water points and the rotational grazing was changed from a system of three paddocks per herd to a system of six paddocks per herd in 1970. A photograph of the fenceline contrast appears in Figure 5.36 above.

The perennial grass density was higher on the cattle side of this fence, estimated at 2.9 grasses m^{-2} compared to 1.7 grasses m^{-2} on the game farm. The species composition also differed, with a greater proportion of *Eragrostis rigidior* on the cattle side, as found at the other three contrasts of this game farm. There was a correspondingly greater proportion of *Stipagrostis uniplumis* and *Heteropogon contortus* on the game farm (Figure 5.40). The rangeland condition index was significantly (P<0.01) lower on the game side (306 versus 434).



Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; ERIG = *Eragrostis rigidior*; ETRI = *E. tricophora*; HCON = *Heteropogon contortus*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.40 Perennial grass species composition at Contrast 26 in the Thornbush Savanna.

The bush canopy cover was significantly (P<0.05) higher on the cattle side of the fence, estimated at 23%, compared to 8% on the game farm. However, the bush density did not differ significantly (P>0.05), suggesting a greater proportion of smaller bushes on the game farm, which is partly borne out by the height class frequencies in Figure 5.41.

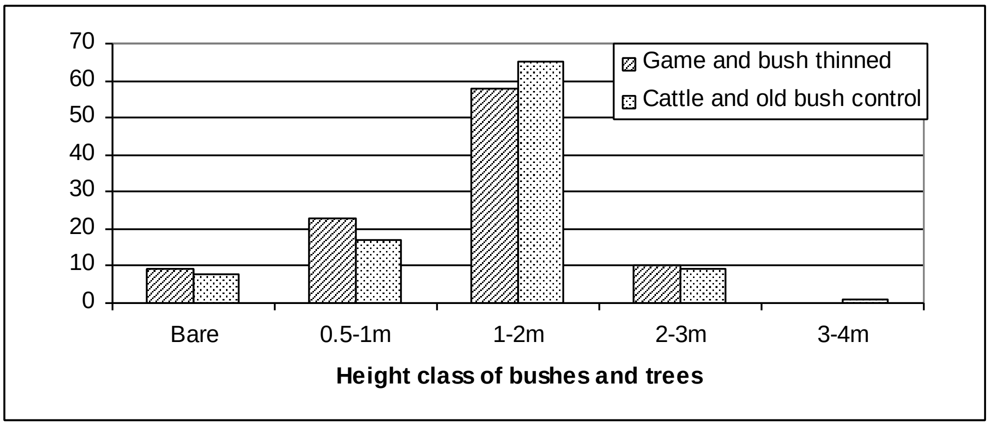
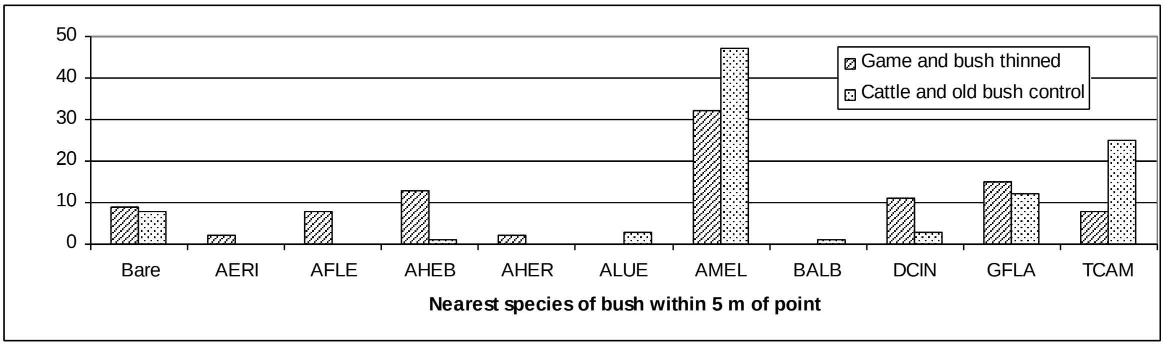


Figure 5.41 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 26 in the Thornbush Savanna.

The proportions of *Acacia mellifera* and *Tarchonanthus camphoratus* were greater on the cattle farm, which were partly counterbalanced by greater proportions of *A. hebeclada* and *A. fleckii* and *Dichrostachys cinerea* on the game farm (Figure 5.42).



Bare = No bush or tree within 5 m of sample point; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; TCAM = *Tarchonanthus camphoratus*.

Figure 5.42 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 26 in the Thornbush Savanna.

The density of bush saplings shorter than 0.5 m was estimated at 1 700 plants ha^{-1} on the cattle side and 340 plants ha^{-1} on the game side, but this difference was not significant (P>0.05). However there were significantly (P<0.05) more saplings of Acacia *mellifera* on the cattle side, where it made up 83% of the saplings, compared to 0% on the game side.

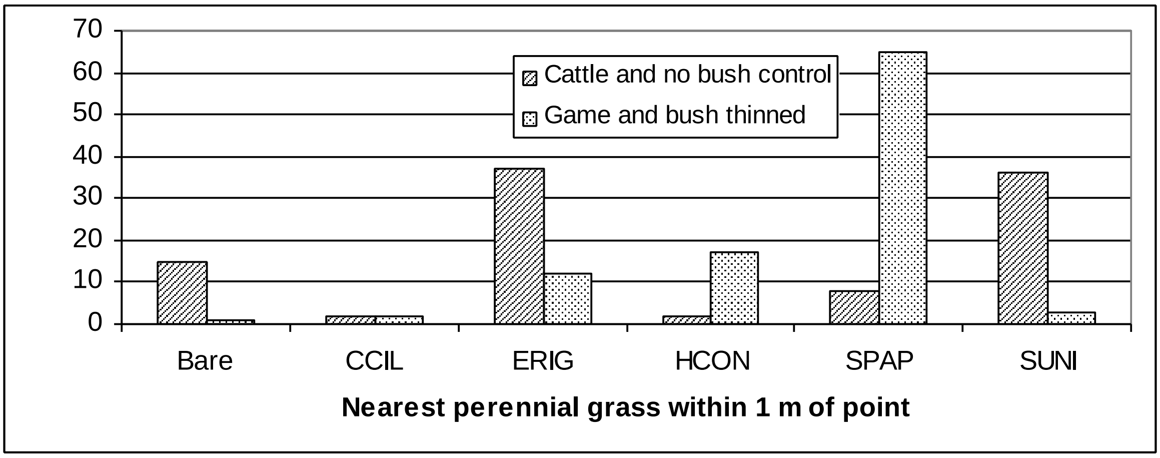
5.5.11 Contrast 27, between cattle farm and bush thinned game farm

Contrast 27 was also between a cattle farm and a bush thinned game farm, but on different farms to those of Contrasts 23-26. Site 27a was on a farm where cattle were rotated very slowly through three paddocks per herd, providing an average rest period of 26 weeks, although the availability of water often restricted the use of some paddocks. A high overall stocking rate, estimated at 60 kg liveweight ha^{-1} (8 ha AU^{-1}), was applied on this farm. The contrasting Site 27b was on a game farm where larger encroacher bushes had been selectively killed by stem burning and smaller bushes chopped below ground level, starting about twenty years previously, when it was still a cattle farm, and continued steadily for at least 15 years. The cattle had been lightly stocked, under the controlled selective grazing system (Tainton, 1985). It had been converted to a game farm only four years before the measurements and stocked with a wide diversity of game animals, including roan and sable antelopes and black rhinos. The stocking rate at the time of the measurements was estimated at 23 kg liveweight ha^{-1} (20 ha AU^{-1}). Some species were still being given the chance to increase, but the aim was to harvest about 25% annually by live capture and trophy hunting. Fires caused by lightning had swept through most of the farm two and five years previously. The contrast is believed to have developed in the 1980's as a result of the bush thinning on 27b.

According to the farmer of 27a, cattle were brought to the area in 1926, but the numbers that could be kept were limited by the availability of water and the vegetation was open grassland. Subdivision took place on the farm between 1967 and 1982. The previous owner applied a fast grazing rotation, which was changed to a slow rotation when the current owner bought the farm in 1981. Photographs of the fenceline contrast are presented in Figure 5.43.

Figure 5.43 Fenceline contrast between the bush thinned game farm (27b, left) and cattle farm (27a, right). The photographs were taken in April 2004.

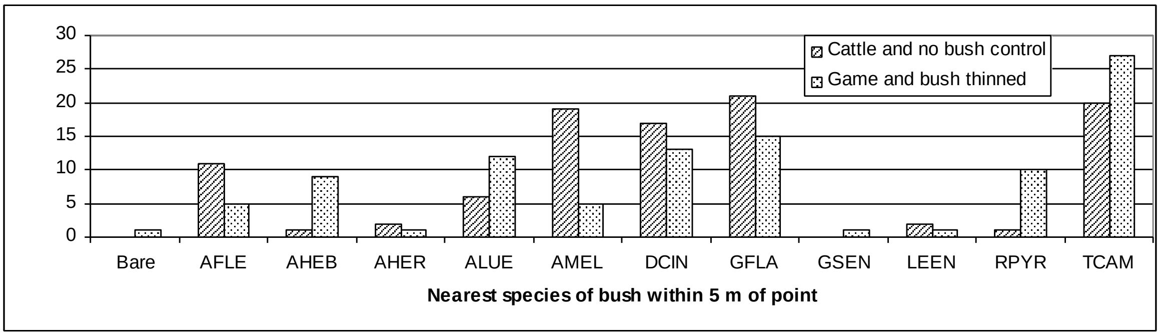
The organic cover of the soil was much higher on the game farm, estimated at 27% compared to only 3% on the cattle farm. The perennial grass density was also higher on the game farm, at 2.9 grasses m^{-2}, compared to 0.8 grasses m^{-2} on the cattle farm. The perennial grasses were largely dominated by *Schmidtia pappophoroides* on the game farm, with also a greater proportion of *Heteropogon contortus*, while *Eragrostis rigidior* and *Stipagrostis uniplumis* co-dominated on the cattle farm (Figure 5.44). The rangeland condition index was significantly (P<0.0001) much lower on the cattle side (100 versus 627).



Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; ERIG = *Eragrostis rigidior*; HCON = *Heteropogon contortus*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.44 Perennial grass species composition at Contrast 27 in the Thornbush Savanna.

The bush density was higher on the cattle farm, as was the bush canopy cover, estimated at 37%, compared to 28% on the game farm. The species composition indicated greater proportions of *Acacia mellifera*, *A. fleckii*, *Dichrostachys cinerea* and *Grewia flava* on the cattle farm, with correspondingly greater proportions of *Tarchonanthus camphoratus, A. luederitzii, A. hebeclada* and *Rhus pyroides* on the game farm (Figure 5.45).



Bare = No bush or tree within 5 m of sample point; AFLE = *Acacia fleckii*; AHEB = *A. hebeclada*; AHER = *A. hereroensis*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GSEN = *Gymnosporia senegalensis*; LEEN = *Lycium eenii*; RPYR = *Rhus pyroides*; TCAM = *Tarchonanthus camphoratus*.

Figure 5.45 Bush species composition at Contrast 27 in the Thornbush Savanna.

There was a greater proportion of shorter bushes in the 0.5-1 m height class on the cattle farm (Figure 5.46).

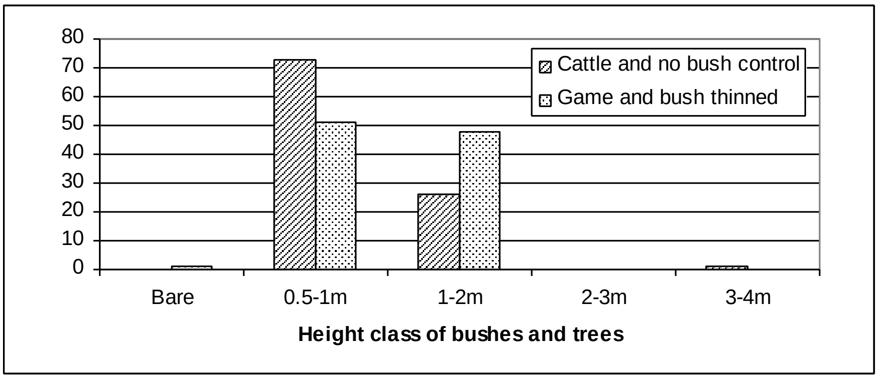


Figure 5.46 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 27 in the Thornbush Savanna.

The cattle farm also had more bush saplings shorter than 0.5 m, with the density estimated at 2 270 plants ha^{-1}, compared to 340 plants ha^{-1} on the game side. In addition the cattle farm had a greater proportion of *Acacia mellifera*, where it made up 93% of the saplings, compared to 33% on the game side.

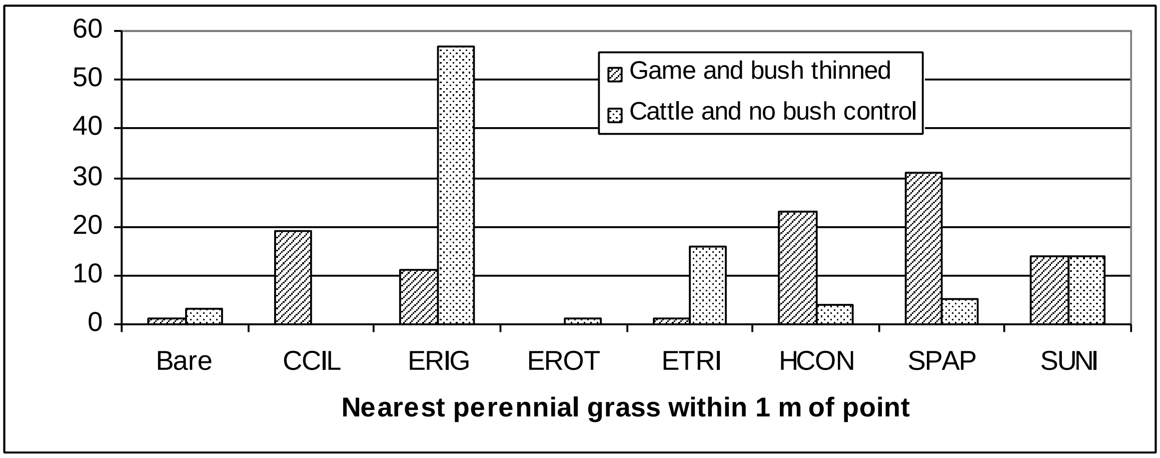
5.5.12 Contrast 28, between cattle farm and bush thinned game farm

Site 28a was on the same game farm as 27b, described in section 5.2.11, but on another side of the farm and in contrast with a different cattle farm at 28b. The cattle farm was stocked at about 52 kg liveweight ha^{-1} (9 ha AU^{-1}) and received about six weeks of rest in the growing season. Unlike on other cattle farms, the rate of rotation was increased in the dry season, simply because the rate at which borehole water could be extracted was very slow, so the reservoir in a paddock was filled and cattle moved in until they finished all the water. There had been no bush control on the part of the cattle farm containing Site 28b. The former owner had used Site 28b for speculation farming of non-breeding herds stocked at very high rates whenever good rains had produced abundant grass and drinking water.

Photographs of the fenceline contrast are presented in Figure 5.47.

Figure 5.47 Fenceline contrast between the bush thinned game farm (28a, right) and cattle farm (28b, left). The photographs were taken in April 2004.

At Contrast 28 there was no significant ($P>0.05$) difference in organic cover over the soil, nor in median distances to nearest perennial grass, but the slight difference in density estimates of 1.8 grasses m^{-2} on the game side and 2.0 grasses m^{-2} on the cattle side was significantly ($P<0.05$) different. The species composition of perennial grasses differed considerably, with greater proportions of *Eragrostis rigidior* and *E. tricophora* on the cattle farm, and correspondingly greater proportions of *Schmidtia pappophoroides, Heteropogon contortus* and *Cenchrus ciliaris* on the game farm (Figure 5.48). The rangeland condition index was significantly ($P<0.01$) higher on the game side (465 versus 284).



Bare = no perennial grass within 1 m; CCIL=*Cenchrus ciliaris*; ERIG = *Eragrostis rigidior*; EROT = *E. rotifer*; ETRI = *E. tricophora*; HCON = *Heteropogon contortus*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.48 Perennial grass species composition at Contrast 28 in the Thornbush Savanna.

The bush canopy cover was higher on the cattle side of the fence, estimated at 25%, compared to 13% on the game farm. However, the bush density did not differ significantly (P>0.05), suggesting a greater proportion of smaller bushes on the game farm, as borne out by the height class frequencies in Figure 5.49.

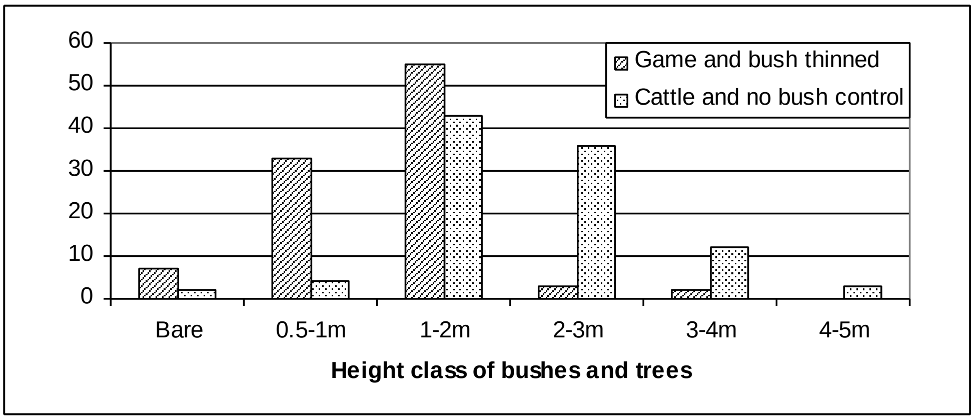
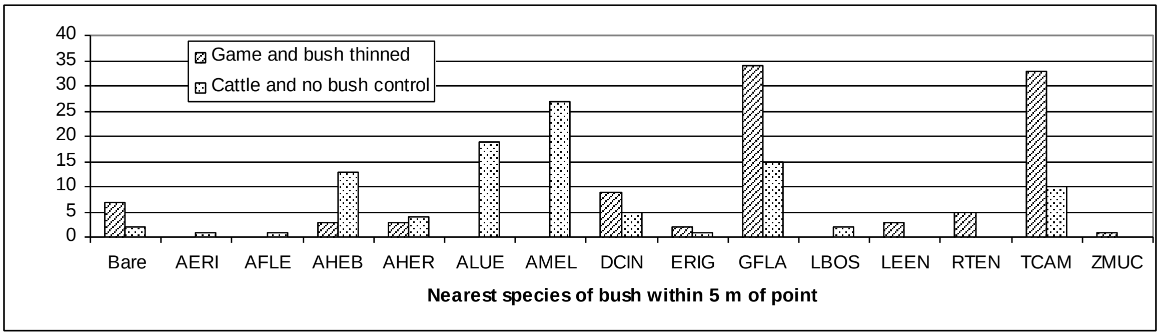


Figure 5.49 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 29 in the Thornbush Savanna.

The species composition of bushes also differed considerably, with greater proportions of *Acacia mellifera, A. luederitzii* and *A. hebeclada* on the cattle farm, and correspondingly greater proportions of *Tarchonanthus camphoratus* and *Grewia flava* on the game farm (Figure 5.50).



Bare = No bush or tree within 5 m of sample point; AERI = *Acacia erioloba*; AFLE = *A. fleckii*; AHEB = *Acacia hebeclada*; AHER = *A. hereroensis*; ALUE = *Acacia luederitzii*; AMEL = *A. mellifera*; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; LBOS = *Lycium bosciifolium*; LEEN = *Lycium eenii*; RTEN = *Rhus tenuinervis*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 5.50 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 28 in the Thornbush Savanna.

The density of bush saplings shorter than 0.5 m was identical on each side of the fence, estimated at 620 plants ha^{-1}, with *Dichrostachys cinerea* as the most common species.

5.5.13 Contrast 29, between cattle farms with slow and fast rotation

Contrast 29 was between two cattle farms, with a faster rotation applied on Site 29a that provided five weeks of rest in the growing season compared to a complete growing season rest provided every third year on Site 29b, where the fodder flow grazing system (Smit, 1998) had been applied for the previous five years. Before then each herd of cattle had been rotated through four paddocks, spending one week per paddock. No bush control had been applied at either of the sites. As a consequence of the lower bush cover on Site 29a, it was stocked more heavily at 44 kg liveweight ha^{-1} (10 ha AU^{-1}), compared to 30 kg liveweight ha^{-1} (15 ha AU^{-1}) on Site 29b.

The previous owner of Site 29a had applied a high stocking rate of dairy cattle to produce cream. The current owner had bought the farm in 1984 and believed that the previous overstocking had caused the bush encroachment. The farm of Site 29b had already been well developed when it was purchased in 1987. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.51.

Figure 5.51 Both sides of fenceline contrast between land under relatively fast rotation (29a, top) and very slow rotation (29b, bottom). The photographs were taken in April 2005.

The perennial grass density was low on both sides of Contrast 29, although Site 29a had twice as many, estimated at 0.4 grasses m^{-2}, compared to 0.2 on 29b where the slow rotation was applied. The bare patch size frequencies in Figure 5.52 indicate this difference.

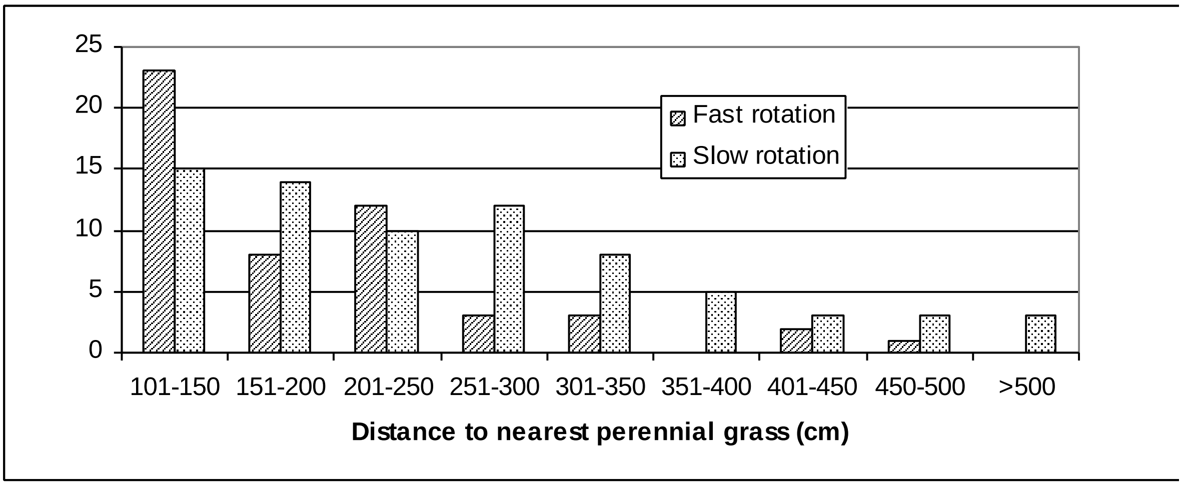
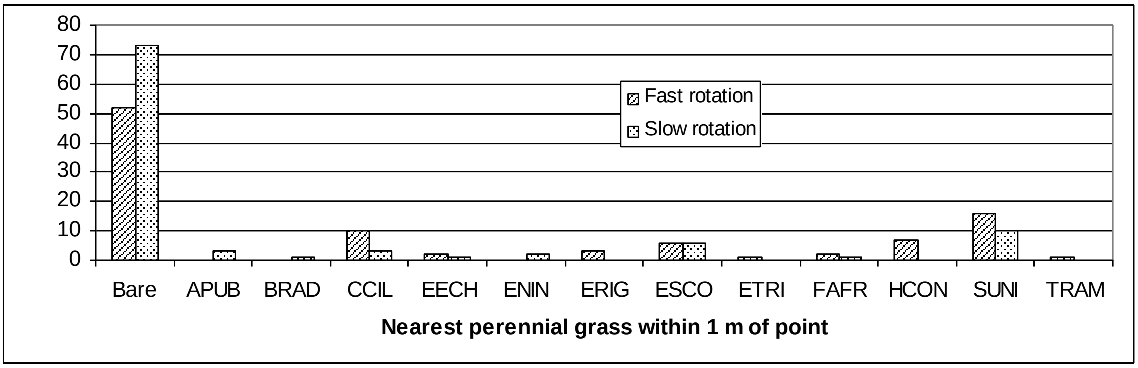


Figure 5.52 Bare patch size frequencies at Contrast 29 in the Thornbush Savanna.

The only significant (P<0.05) difference in perennial grass species composition was a greater proportion of *Anthephora pubescens* on Site 29b (Table 5.5). This difference is masked in Figure 5.53 due to the domination of points that had no perennial grass within

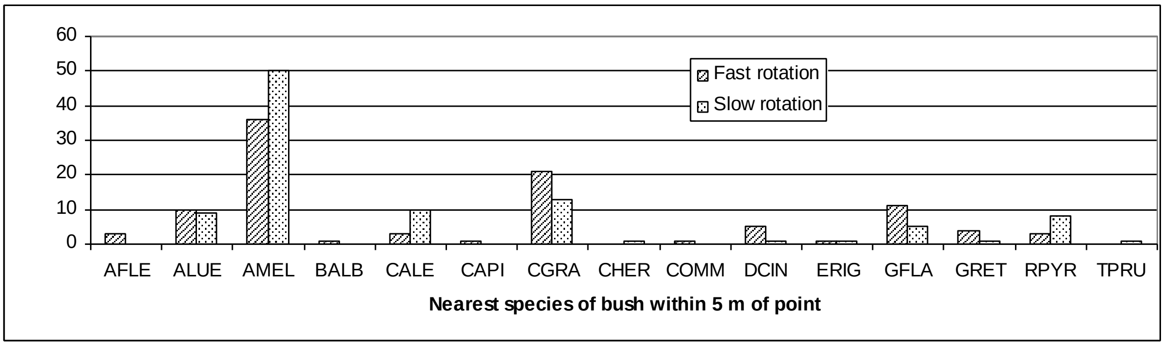
1 m of the point. The rangeland condition index was lower on Site 29a (54 versus 60) but the difference was not significant (P>0.05).



Bare = no perennial grass within 1 m; APUB = *Anthephora pubescens*; BRAD = *Bothriochloa radicans*; CCIL=*Cenchrus ciliaris*; EECH = *Eragrostis echinochloidea*; ENIN = *E. nindensis*; ERIG = *E. rigidior*; ESCO = *Enneapogon scoparius*; ETRI = *Eragrostis tricophora*; FAFR = *Fingerhuthia africana*; HCON = *Heteropogon contortus*; SUNI = *Stipagrostis uniplumis*; TRAM = *Triraphis ramosissima*.

Figure 5.53 Perennial grass species composition at Contrast 29 in the Thornbush Savanna.

The bush density was high on both sites, but higher on Site 29b, where the canopy cover was estimated at 56%, compared to 39% on Site 29a with the faster rotation. The proportion of encroacher species amongst the canopy cover only differs slightly, from 86% on Site 29a to 91% on 29b. This difference was however significant (P<0.05), thanks to the large sample size. The difference was mainly caused by the greater proportions of *Acacia mellifera* and *Catophractes alexandrii* on Site 29b (Figure 5.54) for the nearest bush data (NB).



AFLE = *Acacia fleckii*; ALUE = *A. luederitzii*; AMEL = *A. mellifera*; BALB = *Boscia albitrunca*; CALE = *Catophractes alexandrii*; CAPI = *Combretum apiculatum*; CGRA = *Croton gratissimus*; CHER = *Combretum hereroensis*; DCIN = *Dichrostachys cinerea*; ERIG = *Ehretia rigida*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; RPYR = *Rhus pyroides*; TPRU = *Terminalia prunioides*.

Figure 5.54 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 29 in the Thornbush Savanna.

The height classes of bushes did not differ significantly (P>0.05), while the density of bush saplings shorter than 0.5 m was similar, estimated at around 3 250 plants ha^{-1}, with *Acacia mellifera* making up almost 20% and *Croton gratissimus* roughly double that.

The biological soil crust cover was estimated at 30% on Site 29a, compared to 46% on Site 29b. Although significantly (P<0.05) higher on the site with the higher bush cover, the points with biological crust did not occur significantly (P>0.05) more under canopies as expected from the percent of points under canopies at those sites.

5.5.14 Contrast 30, between bush controlled and uncontrolled paddocks

Site 30a was on the same farm as Site 29b and experienced the same the same management, described in section 5.4.13. Site 30b was on a farm where bushes had been thinned and where the stocking rate was as a result higher, at 50 kg liveweight ha^{-1} (9 ha AU^{-1}) compared to 30 kg liveweight ha^{-1} (15 ha AU^{-1}) at the untreated Site 30b. However the rotation was similar on both sides of the fence, with the fodder flow grazing system, started five years previously, providing a complete growing season's rest for two consecutive years every third year. The bushes on 30b had first been subjected to selective arboricide application eleven years previously and more recently some bushes had been selectively chopped and the thicker branches converted to charcoal together with dead wood remaining from the arboricide treatment. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.55.

Figure 5.55 Both sides of fenceline contrast between untreated land (30a, top) and previously thinned land (30b, bottom). The photographs were taken in April 2005.

The perennial grass density was higher on the previously thinned land, with an estimate of 1.0 grasses m^{-2}, compared to 0.4 grasses m^{-2} on Site 30a. This difference can also be seen from the bare patch size frequencies in Figure 5.56.

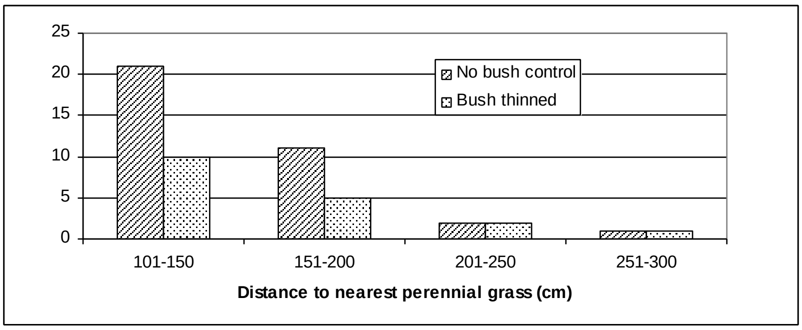
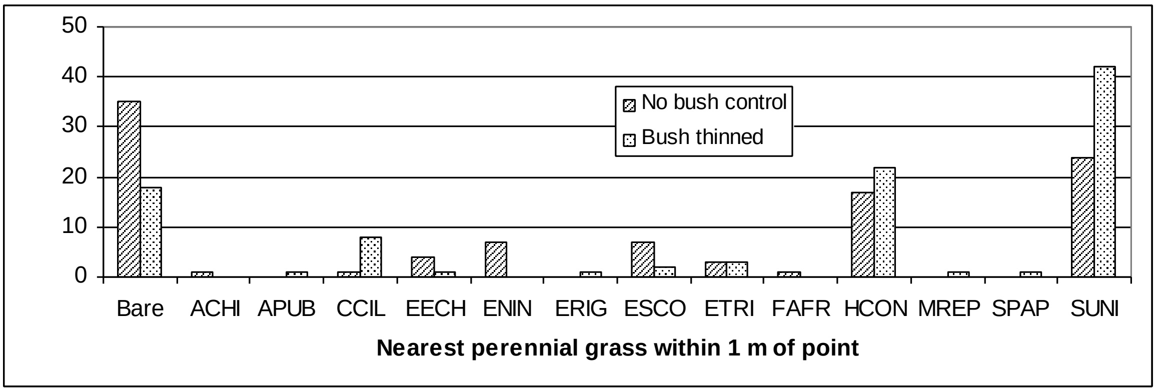


Figure 5.56 Bare patch size frequencies at Contrast 30 in the Thornbush Savanna.

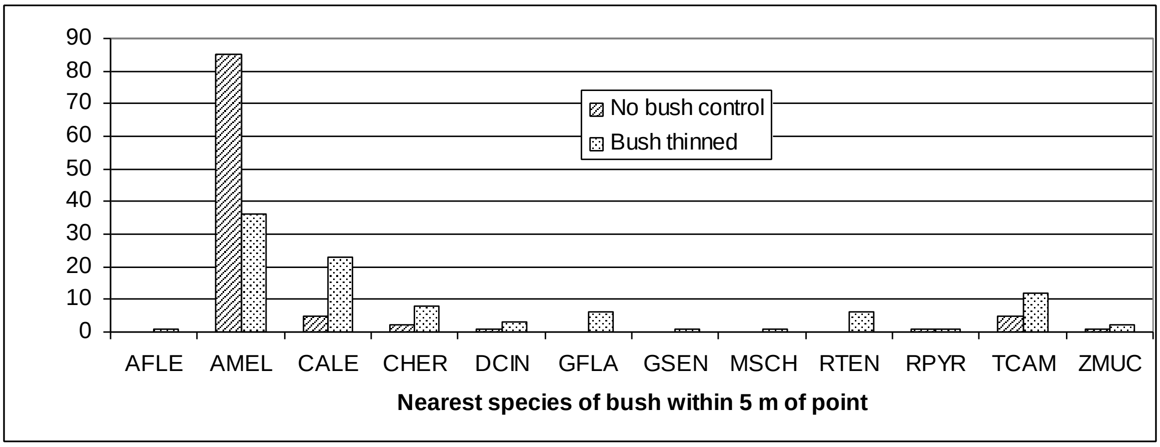
The perennial grass dominance by *Stipagrostis uniplumis* was greater on the bush controlled Site 30b, at 53%, than at Site 30a where it was 38% of the species measured as NP. Differences proportions of other species evident in Figure 5.57 and Table 5.5 were not significant ($P>0.05$). The rangeland condition index was significantly ($P<0.05$) lower on the untreated site (86 versus 201).



Bare = no perennial grass within 1 m; ACHI = *Andropogon chinensis*; *meridionalis*; APUB = *Anthephora pubescens*; CCIL=*Cenchrus ciliaris*; EECH = *Eragrostis echinochloidea*; ENIN = *E. nindensis*; ERIG = *E. rigidior*; ESCO = *Enneapogon scoparius*; ETRI = *E. tricophora*; FAFR = *Fingerhuthia africana*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; SPAP = *Schmidtia pappophoroides*; SUNI = *Stipagrostis uniplumis*.

Figure 5.57 Perennial grass species composition at Contrast 30 in the Thornbush Savanna.

Site 30a had the highest bush canopy cover of all the sites in this study, estimated at 63%, compared to 19% at the previously bush thinned Site 30b (Table 5.4). The diversity of bush species was higher on Site 30b (Figure 5.58), with greater dominance of *Acacia mellifera* on 30a and correspondingly greater proportions of *Catophractes alexandrii*, *Tarchonanthus camphoratus* and *Combretum hereroensis* on 30b, where several other species were encountered which had not been recorded on 30a.



AFLE = *Acacia fleckii*; AMEL = *A. mellifera*; CALE = *Catophractes alexandrii*; COMM = *Commiphora* spp.; CHER = *Combretum hereroensis*; DCIN = *Dichrostachys cinerea*; GFLA = *Grewia flava*; GSEN = *Gymnosporia senegalensis*; MSCH = *Maerua schinzii*; RTEN = *Rhus tenuinervis*; RPYR = *Rhus pyroides*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 5.58 Bush species composition of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 30 in the Thornbush Savanna.

The height class frequencies in Figure 5.59 indicate a higher proportion of shorter bushes in the 0.5-1m class on Site 30b, where bush control had taken place.

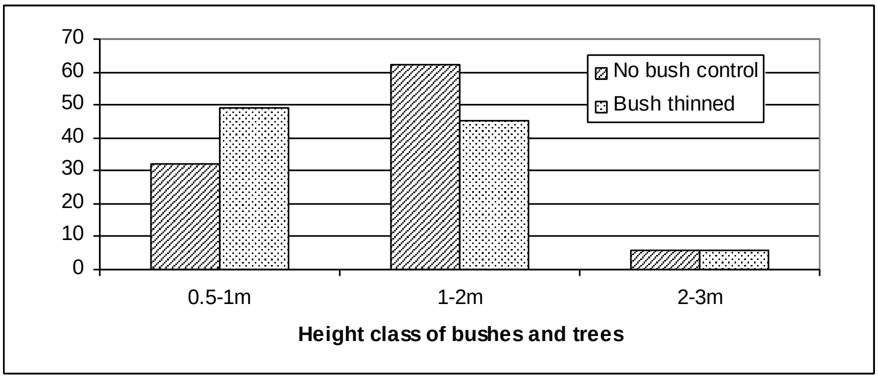


Figure 5.59 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 30 in the Thornbush Savanna.

The biological soil crust cover was estimated at 37% on Site 30a, compared to 4% on Site 30b. Although higher on the site with the higher bush cover, the points with biological crust did not occur significantly (P>0.05) more under canopies as expected from the percent of points under canopies at Site 30a. The Chi-Square test indicated significance for Site 30b, where all four points with biological soil crust fell under canopies that had been found at 22% of the points, but it was invalid due to expected values of less than five. The mulch cover of 37% was also significantly (P<0.05) higher on the site with the higher bush cover, compared to 18% on Site 30b, but on each side the Chi-Square test indicated that the greater number of mulch points found under canopies than expected was not significant (P>0.05).

5.5.15 Contrast 31, between burnt and unburnt paddocks

Both sides of Contrast 31 were on the same farm as Site 30b, and had both received similar bush control and grazing management. However Site 31b had been more recently and intensively thinned for charcoal and the resulting higher grass mass had been burnt at the end of the previous dry season. Photographs of the measured sites on both sides of the fenceline contrast are presented in Figure 5.60.

Figure 5.60 Both sides of fenceline contrast between unburnt land (31a, top) and recently burnt land (31b, bottom). The photographs were taken in April 2005.

The median distance to nearest perennial grass of 67 cm on the unburnt Site 31a, did not differ significantly (P>0.05) from the 45 cm for the burnt Site 31b, and perennial grasses had not been counted at this Contrast. However, on the unburnt Site 31a there were more large bare patches with no perennial grass within 250 cm of the point (Figure 5.61).

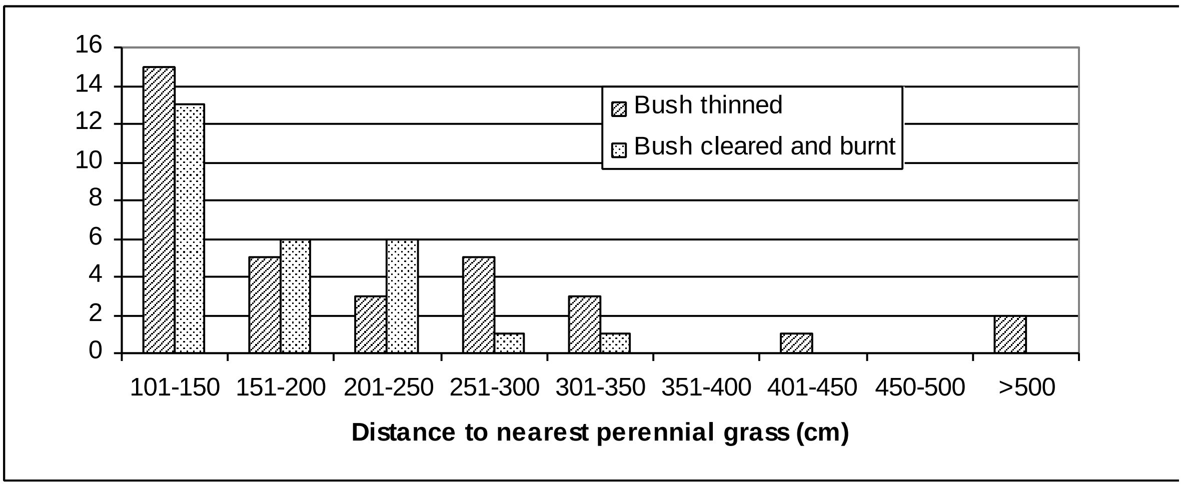
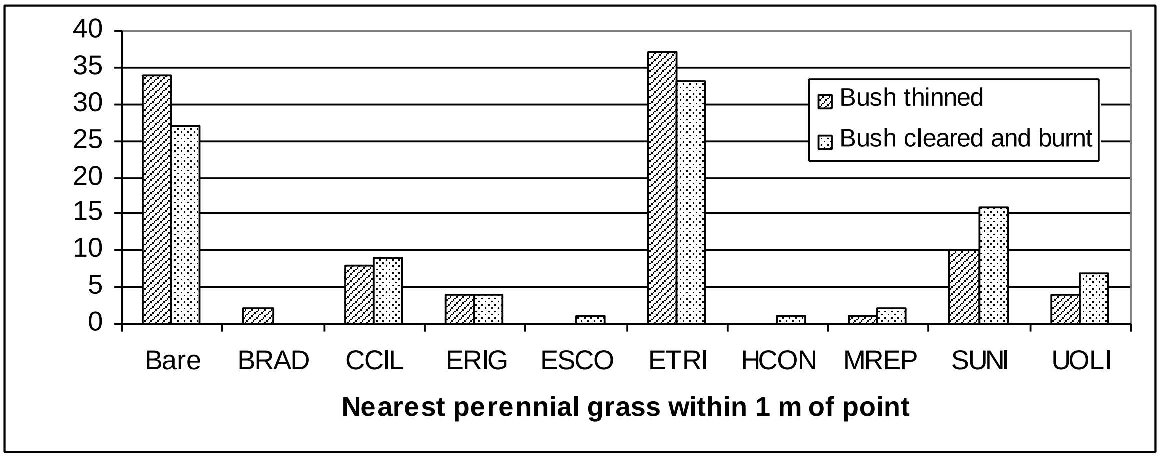


Figure 5.61 Bare patch size frequencies at Contrast 31 in the Thornbush Savanna.

The species composition of the perennial grasses did not differ greatly (Table 5.5 and Figure 5.62). The only species for which the difference was significant (P<0.05) is *Eragrostis tricophora*, which dominated at both sites but more so on the unburnt Site 31a.

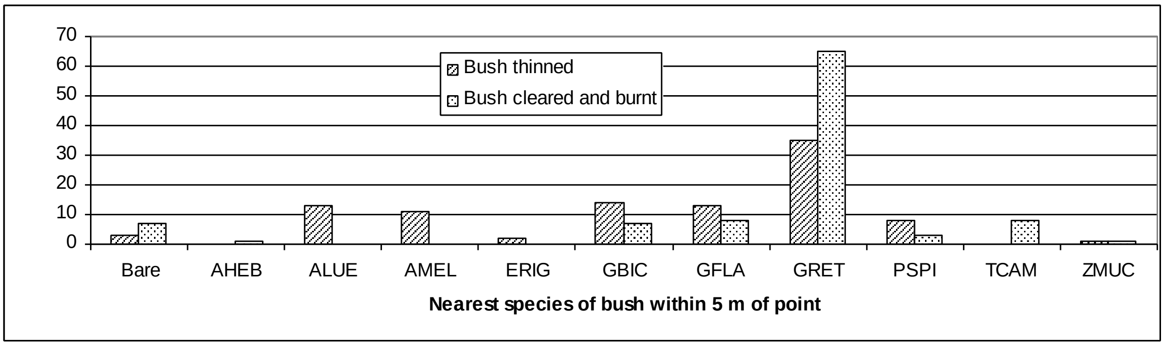
The rangeland condition index was lower on Site 31a (225 versus 275) but the difference was not significant (P>0.05).



Bare = no perennial grass within 1 m; BRAD = *Bothriochloa radicans*; CCIL=*Cenchrus ciliaris*; ERIG = *Eragrostis rigidior*; ESCO = *Enneapogon scoparius*; ETRI = *E. tricophora*; HCON = *Heteropogon contortus*; MREP = *Melinis repens* var. *repens*; SUNI = *Stipagrostis uniplumis*.

Figure 5.62 Perennial grass species composition at Contrast 31 in the Thornbush Savanna.

The bush density was higher on the unburnt Site 31a, where the canopy cover was estimated 21%, compared to 6% on 31b. Both sites were dominated by *Grewia retinervis* (Figure 5.63). This domination was greater on 31b, where encroacher species such as *Acacia luederitzii* and *A, mellifera* had been more recently targeted for charcoal and not encountered as NB on the 31b side of the fence.



Bare = No bush or tree within 5 m of sample point; AHEB = *Acacia hebeclada*; ALUE = *Acacia luederitzii*; AMEL = *A. mellifera*; ERIG = *Ehretia rigida*; GBIC = *Grewia bicolor*; GFLA = *Grewia flava*; GRET = *Grewia retinervis*; PSPI = *Phaeoptilum spinosum*; TCAM = *Tarchonanthus camphoratus*; ZMUC = *Ziziphus mucronata*.

Figure 5.63 Bush species composition at Contrast 31 in the Thornbush Savanna.

The burnt site 31b had no bushes taller than 2 m (Figure 5.64). This may be a result of the fire having knocked back the bushes and/or because taller bushes were targeted for charcoal.

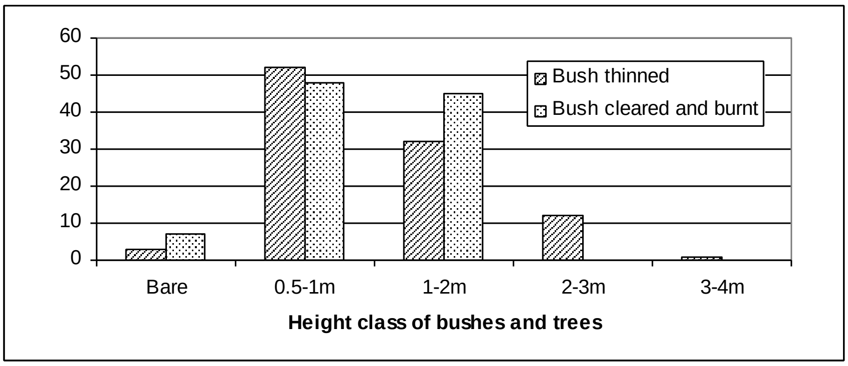


Figure 5.64 Height class frequencies of nearest woody plants taller than 0.5 m within 5 m of the point at Contrast 31 in the Thornbush Savanna.

5.6 RELATIONSHIPS BETWEEN VARIABLES

Relationships were tested between variables measured at different contrasts, for which the comparability of the data needs to be borne in mind. Measurements had been taken by different groups of students at different contrasts, hence the results were less useful for comparison between contrasts than between sites at the same contrast, as pointed out in sections 3.5.6.1 and 4.2.1. In the case of the composite variable “Rangeland condition index”, it had not been related to benchmark sites and it too was therefore less suitable for comparison between contrasts than between sites at the same contrast (section 3.5.5)

5.6.1 Perennial grass and bush variables

The relationships between perennial grass and bush measurements across sites were tested between the same four bush variables and six perennial grass variables used for data from the Camelthorn Savanna (section 4.5.2). The behaviour of the data was the same in terms of normality of distribution and response to log transformation. Therefore the data was handled in the same way (section 4.5.2). In the case of relationships with distance to nearest bush or tree (DistB), four sites (17b, 20b, 21b and 22b) with median DistB of more than 500 cm were omitted, since their values were unknown. In the case of relationships with % encroacher species, three sites (17b, 20b and 21b) were omitted since they had too few trees or bushes to provide reliable estimates.

The results of the correlations are presented in Table 5.10. The correlations were not strong, although they indicate a tendency of less perennial grass with more bush cover and a greater proportion of encroacher species.

Table 5.10 Results of product-moment correlations between bush and perennial grass variables from the sites measured at fenceline contrasts in the Thornbush Savanna.

Variables related to perennial grasses ↓	Variables related to measurements of bushes			
	DistB [1]	Bitterlich [2]	% Encroachers [3]	Encroacher cover [4]
Log DistP [5]	r = −0.3683 P = 0.064 n = 26	r = 0.5610 P = 0.001 n = 31	r = 0.5985 P = 0.001 n = 27	r = 0.6961 P = 0.000 n = 31
Log % Bare [6]	r = −0.2231 P = 0.273 n = 26	r = 0.3605 P = 0.046 n = 31	r = 0.4622 P = 0.015 n = 27	r = 0.4942 P = 0.005 n = 31
Grass density [7]	r = 0.3353 P = 0.094 n = 26	r = −0.4586 P = 0.009 n = 31	r = −0.5206 P = 0.005 n = 27	r = −0.5794 P = 0.001 n = 31
% Mesophytes [8]	r = 0.1016 P = 0.621 n = 26	r = −0.0363 P = 0.846 n = 31	r = 0.0158 P = 0.938 n = 27	r = −0.0757 P = 0.686 n = 31
Log Mesophyte density [9]	r = 0.3110 P = 0.122 n = 26	r = −0.3782 P = 0.036 n = 31	r = −0.3305 P = 0.092 n = 27	r = −0.4923 P = 0.005 n = 31
Condition index [10]	r = 0.2888 P = 0.152 n = 26	r = −0.4118 P = 0.021 n = 31	r = −0.5567 P = 0.003 n = 27	r = −0.5428 P = 0.002 n = 31

Shaded P-values represent significant (P<0.05) relationships.
[1] DistB = median distance from sample point to nearest tree or bush taller than 0.5 m.
[2] Bitterlich = Canopy cover as measured by Bitterlich angle gauge.
[3] % Encroachers = Percentage of encroacher species among the recorded bushes and trees.
[4] Encroacher cover = Canopy cover of encroacher species of bush.
[5] Log DistP = Logarithm to base ten of median distance from sample point to nearest perennial grass.
[6] Log % Bare = Logarithm to base ten of percentage of points where there was no perennial grass within 1 m.
[7] Grass density = Density of perennial grasses.
[8] % Mesophytes = Percentage of mesophytic species among the recorded perennial grasses.
[9] Log Mesophyte density = Logarithm to base ten of density of mesophytic perennial grass species.
[10] Condition index = Rangeland condition index

The poor relationships are not surprising, given the large difference in management received by the different sites. The degree of bush control that had been applied varied from none on many of farms to total control on the hayfields.

Interestingly, the bush variable which gave the strongest relationship with perennial grass variables was the cover of encroacher species, as had been the case with the data from the Camelthorn Savanna. However, in the case of data from the Thornbush Savanna, the total canopy cover related significantly (P<0.05) with five of the six perennial grass variables, while the distance to nearest bush indicated no significant (P>0.05) relationship.

The influence between bushes and grasses was also tested on a smaller scale by comparing median distance to nearest perennial grass (DistP) values obtained from points under bush or tree canopies with those obtained from points in the open, within sites. This was only done for sites with at least 20 points having fallen under canopies or in the open, to get a reasonably reliable median distance. This applied to 17 of the sites. The median distance was greater under canopies for 12 of these sites, but only significantly (P<0.05) different for four of them (Table 5.11). For all of the five sites where the medium distance was greater in the open the difference was not significant (P>0.05).

Table 5.11 Comparison between median distances to nearest perennial grass as measured from points under bush canopies and from points in the open, for the 16 sites where there were at least 20 points measured under canopies or in the open in the Thornbush Savanna.

Site number	Position of point	Median distance to nearest perennial grass	Sample size (n)	P value by Mann-Whitney U Test
17a	Under canopy	228.0	49	0.051429
17a	In the open	139.0	51	
17c	Under canopy	38.0	29	0.465853
17c	In the open	33.0	71	
18a	Under canopy	75.5	36	0.009632
18a	In the open	49.0	64	
19a	Under canopy	45.0	31	0.609686
19a	In the open	43.0	70	
20a	Under canopy	68.5	36	0.066011
20a	In the open	51.0	64	
22a	Under canopy	80.0	26	0.151535
22a	In the open	50.5	74	
23a	Under canopy	34.5	26	0.005087
23a	In the open	24.0	74	
24a	Under canopy	38.0	31	0.276542
24a	In the open	34.0	69	
25a	Under canopy	40.0	25	0.864109
25a	In the open	45.0	75	
25b	Under canopy	48.0	35	0.015949
25b	In the open	35.0	65	
26a	Under canopy	30.0	22	0.347083
26a	In the open	29.0	78	
26b	Under canopy	12.0	22	0.626419
26b	In the open	17.0	78	
27a	Under canopy	59.0	21	0.324183
27a	In the open	51.0	79	
28b	Under canopy	45.0	42	0.012660
28b	In the open	25.5	58	
29a	Under canopy	103.0	65	0.825549
29a	In the open	112.0	35	
30b	Under canopy	56.0	22	0.963498
30b	In the open	54.5	78	
31a	Under canopy	65.5	26	0.623326
31a	In the open	73.0	74	

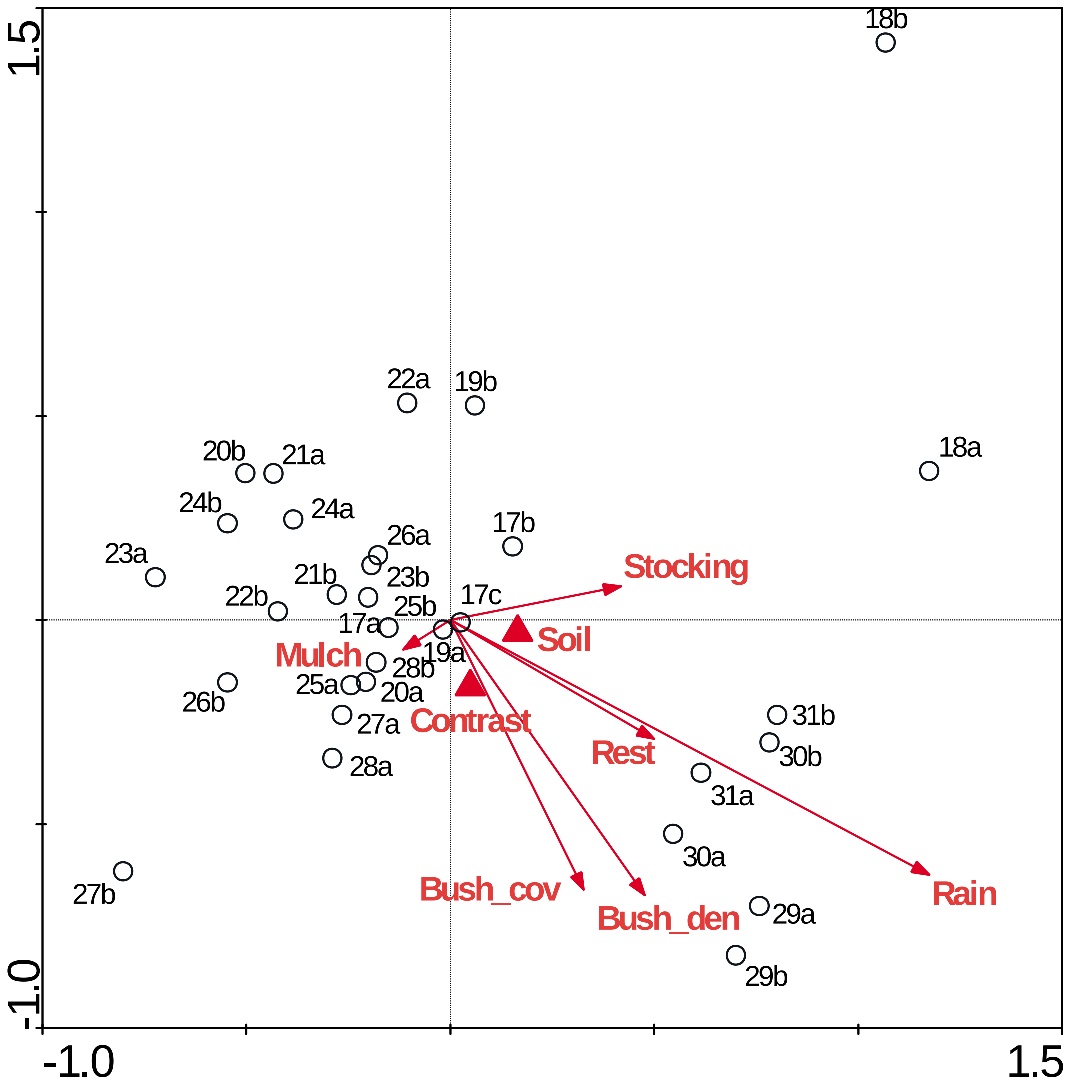
Shaded cells indicate pairs of medians that differ significantly (P<0.05).

5.6.2 Ordinations

The first axis gradient of the Detrended Correspondance Analysis (DCA) of perennial grass species densities had a length of 2.199, with an Eigen value of 0.439. Since the length was less than the four recommended by Ter Brak & Smilauer (2002) for DCA, a

Principal Components Analysis (PCA) was then performed. This resulted in an Eigen value of 0.560 on the first axis and 0.278 on the second axis. Eight environmental variables were included in the Redundancy Analysis (RDA), as described in section 3.5.6.11. The resulting biplot is presented in Figures 5.65, while the results of the automated forward selection with permutations are presented in Table 5.12.

Sites 18a and 18b, dominated by *Stipagrostis uniplumis*, occurred on the extreme right of the first axis, with 27b, dominated by *Schmidtia pappophoroides*, on the extreme left. These same two species also occurred at the two extremes of the first axis of the RDA ordination of data from the Camelthorn Savanna, but on opposite sides to those of the Thornbush Savanna (section 4.6.2). The most significant ($P<0.01$) relationship was with the dummy variable of contrast, confirming that the contrasts were not in the same relatively homogenous area, as indicated in section 3.5.6.11. Other significant ($P<0.05$) relationships were with the stocking rate and bush canopy cover. The latter was aligned near the second axis, together with non-significant ($P>0.05$) variables of bush density and mean rainfall.



Eigen values: First axis = 0.277, Second axis = 0.178.
Arrows represent higher values of each of the following, except for the two nominal variables: Bush_den = Density index of bushes; Rain = Mean annual rainfall for area of the contrast; Bush_cov = Canopy cover of woody plants taller than 0.5 m; Rest = Period of absence in or over the growing season; Mulch = Cover of mulch and bases of perennial grass over the soil; Stocking = current stocking rate for the farm; Soil = nominal variable for sand, loamy sand or calcrete; Contrast = nominal dummy variable for sites at the same contrast.

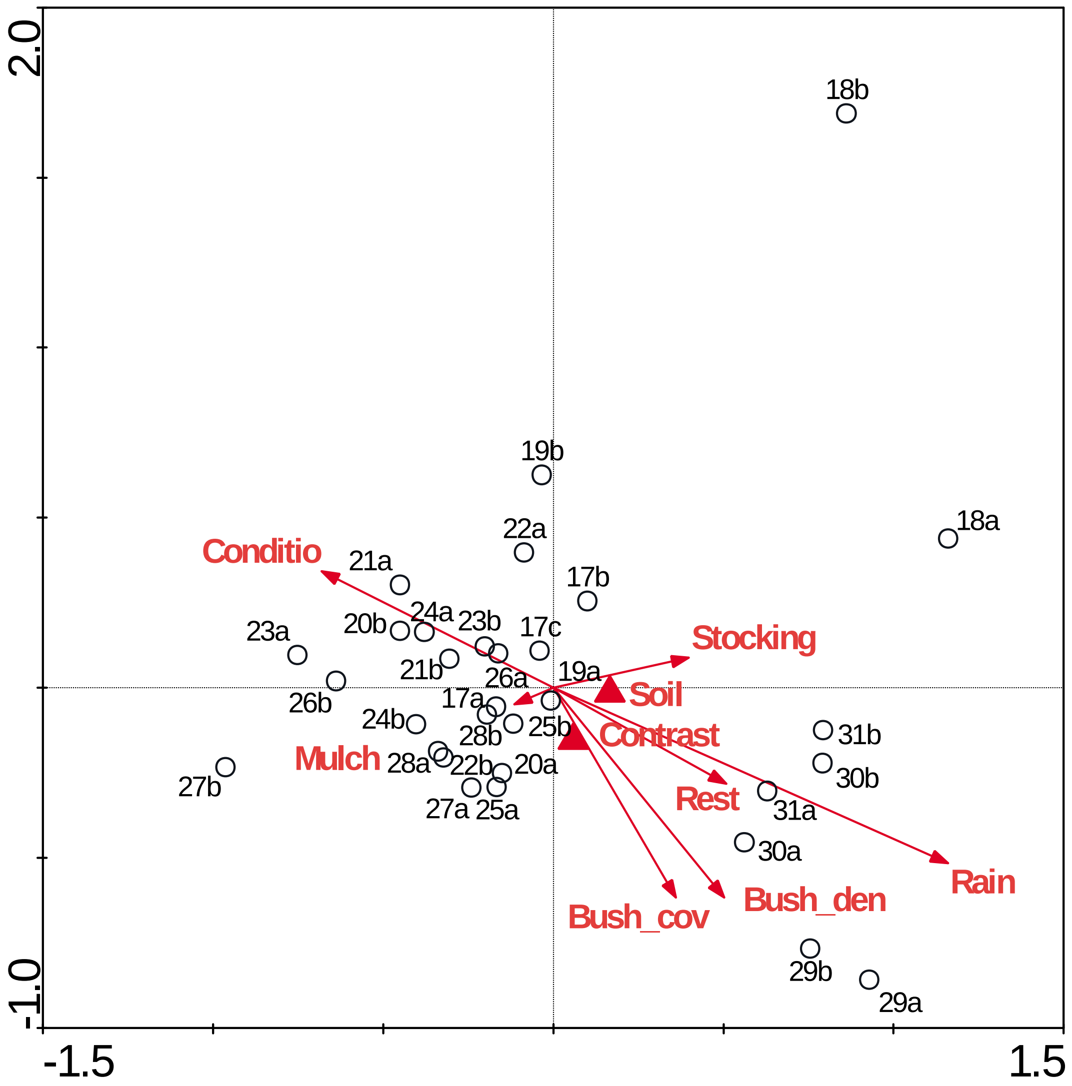
Figure 5.65 Biplot of RDA ordination of densities of perennial grass species in the Camelthorn Savanna, with eight environmental variables.

Table 5.12 Results of forward selection of variables in the Redundancy Analysis (RDA) ordination of the density of perennial grass species in the Camelthorn Savanna.

Marginal Effects			
Variable	Lambda1		
Soil type (Nominal variable)	0.23		
Mean annual rainfall for the area	0.19		
Contrast number (Dummy variable)	0.09		
Bush density	0.08		
Canopy cover of bushes and trees	0.06		
Period of absence	0.04		
Stocking rate of farm	0.02		
Mulch cover on soil	0		
Conditional Effects			
Variable	LambdaA	P-value	F-value
Soil type (Nominal variable)	0.23	0.002	8.83
Contrast number (Dummy variable)	0.10	0.006	4.07
Mean annual rainfall for the area	0.04	0.144	1.81
Mulch cover on soil	0.03	0.292	1.20
Canopy cover of bushes and trees	0.02	0.344	1.05
Stocking rate of farm	0.04	0.178	1.53
Period of absence	0.02	0.386	1.01
Bush density	0.02	0.396	0.93

The rangeland condition index was then added as an environmental variable. The resulting biplot is presented in Figures 5.66.

Rangeland condition index had the greatest influence along the first axis. However, this may be largely a consequence of auto correlation, since perennial grass density was a major component of the rangeland condition index. Nevertheless, it indicates the direction of degradation along the fist axis, from better condition on the left to worse condition on the right. This is opposite to the direction indicated by the RDA ordination of data from the Camelthorn Savanna (section 4.6.2).



Eigen values: First axis = 0.280, Second axis = 0.192.
Arrows represent higher values of each of the following, except for the two nominal variables: Bush_den = Density index of bushes; Rain = Mean annual rainfall for area of the contrast; Bush_cov = Canopy cover of woody plants taller than 0.5 m; Conditio = Rangeland condition index; Rest = Period of absence in or over the growing season; Mulch = Cover of mulch and bases of perennial grass over the soil; Stocking = current stocking rate for the farm; Soil = nominal variable for sand, loamy sand or calcrete; Contrast = nominal dummy variable for sites at the same contrast.

Figure 5.66 Biplot of RDA ordination of densities of perennial grass species in the Camelthorn Savanna, with rangeland condition index added to the eight environmental variables.

CHAPTER 6

RESULTS: DWARF SHRUB AND HIGHLAND SAVANNAS

6.1 INTRODUCTION

According to the NARIS map (MAWF, 2003) only two fenceline contrasts were measured in the true Dwarf shrub Savanna. A third contrast, as well as the plots that received experimental grazing treatments, occurred within the Highland Savanna. However, it was near the southern boundary between the Highland Savanna and Dwarf shrub Savanna, and its vegetation resembled more of the Dwarf shrub Savanna than the Highland Savanna. The experimental plots that were measured on three different occasions, in 2005, 2007 and 2008, were situated along one of the fenceline contrasts in the Highland Savanna.

Results from alternative methods of measuring the same vegetation characteristic in the Dwarf shrub and Highland Savannas are presented first. They will be used in Chapter 9 to evaluate measuring methods. Thereafter the plants species recorded at the contrasts are listed according to groups and some explanations on abbreviations are given. An overview of all contrasts in the Dwarf shrub and Highland Savannas is then presented, before describing the results from the three individual fenceline contrasts and the six experimental grazing plots. To ease identification of sites, the order of their presentation in charts and photographs is always Site a followed by Site b and lastly Site c.

6.2 COMPARISON BETWEEN METHODS OF MEASURING

The shortage of bushes at most of the sites in the Dwarf shrub and Highland Savannas resulted in too few measurements to compare the two methods of measuring canopy cover. The only meaningful comparison possible is between the distance to nearest perennial grass and density counts.

6.2.1 Distance to nearest perennial grass and count of density

The relationship between distance to nearest perennial grass (DistP) and density of perennial grasses (No P) recorded in the Dwarf shrub and Highland Savannas, was investigated in the same way as for the data from the Camelthorn Savanna (section 4.2.2). The direct plot of No P against DistP is presented in Figure 6.1 (Density index = $97.998 \times \mathrm{DistP}^{-0.9736}$, $r^2 = 0.7673$, $P<0.0001$, $n = 24$). As with data from the Camelthorn and

Thornbush Savannas, this power relationship between Dist P and No P may provide a useful predictor of perennial grass density in similar areas of the Dwarf shrub and Highland Savannas.

The density index calculated from the median distance to nearest perennial grass (DistP) is compared with the mean counted perennial grass density in Figure 5.2. The other way of representing the relationship, in terms of the degree of clumping, is presented in Figure 5.3. The grasses were more clumped than those in the Camelthorn and Thornbush Savannas (Figures 4.4 and 5.4).

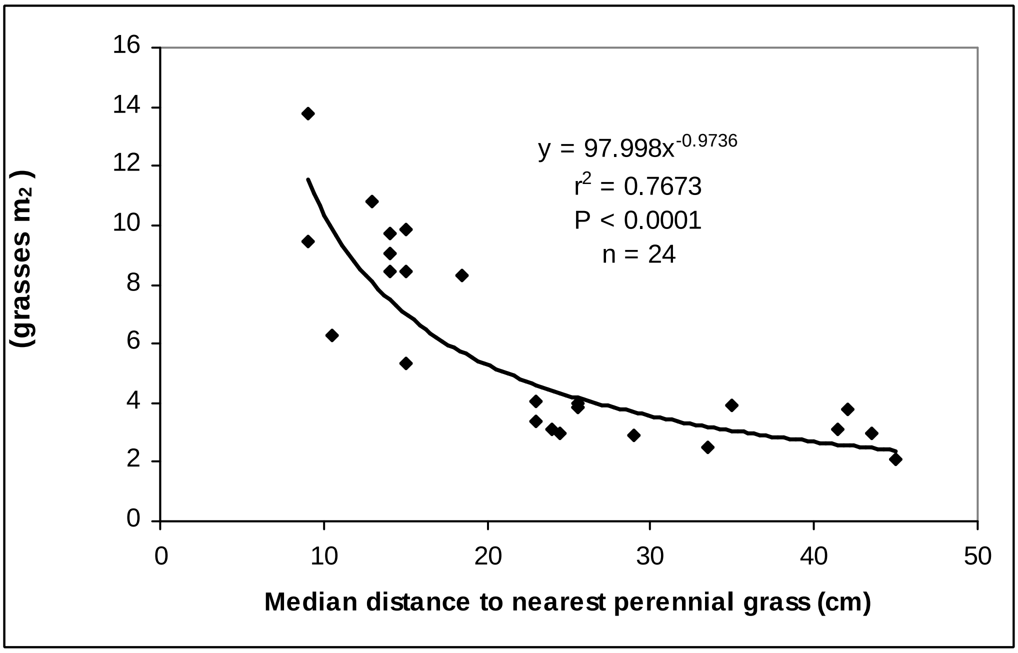


Figure 6.1 Relationship between the median distance to the nearest perennial grass and the mean grass density counted within 75 cm of points, at 24 sites in the Highland and Dwarf shrub Savannas, with the resulting power regression.

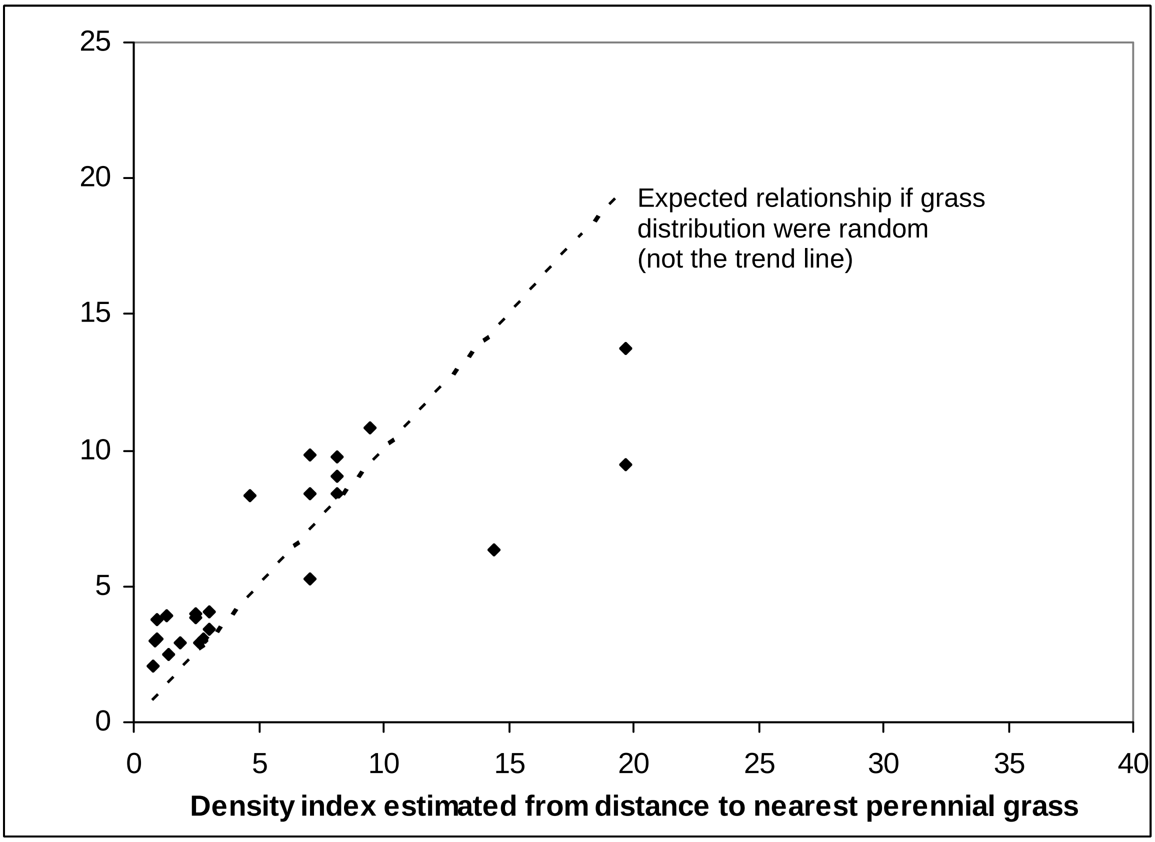


Figure 6.2 Relationship between the perennial grass density index - estimated from the median distance to nearest perennial grass - and the mean grass density counted at 24 sites in the Highland and Dwarf shrub Savannas.

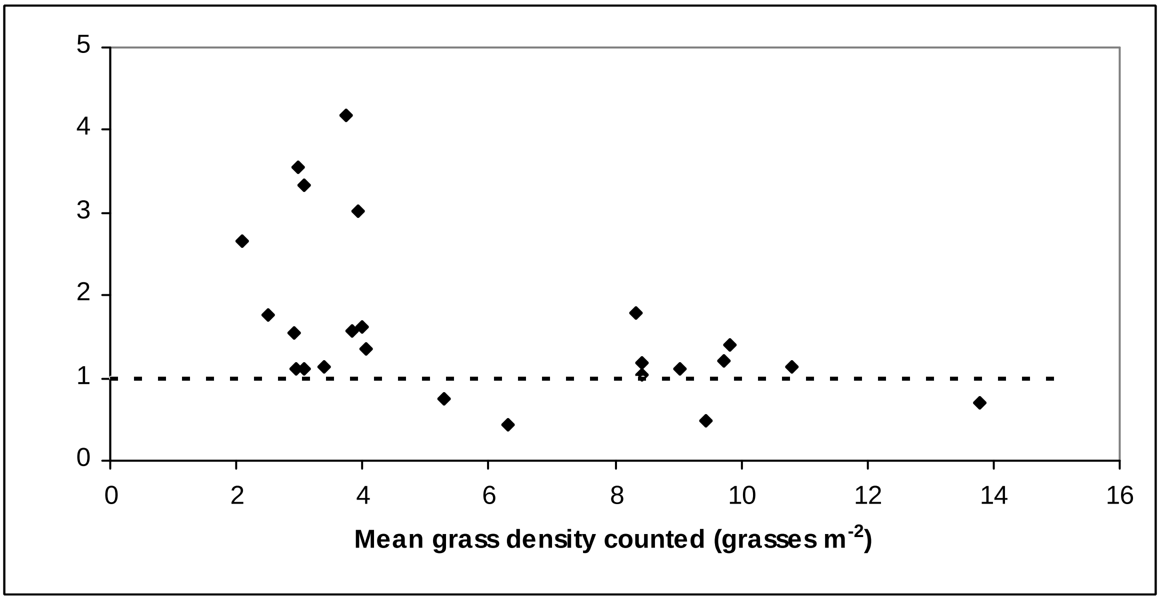


Figure 6.3 Relationship between the mean perennial grass density and the degree of grass clumping at 24 sites in the Highland and Dwarf shrub Savannas.

6.3 PLANT SPECIES RECORDED

The abbreviations of plant species recorded in the Highland and Dwarf shrub Savannas appear in Table 6.1 (perennial grasses); in Table 6.2 (bush and tree species); and in Table 6.3 (dwarf shrub species and bushes shorter than 0.5 m).

Table 6.1 Species of perennial grasses assigned subjectively to broad categories of xerophytic and mesophytic species of the Dwarf shrub and Highland Savannas.

Xerophytic species	Mespohytic species
Aristida congesta (ACON)	*Anthephora pubescens* (APUB)
Microchloa caffra (MCAF)	*Aristida meridionalis* (AMER)
Stipagrostis ciliata (SCIL)	*Cenchrus ciliaris* (CCIL)
S. hochstetteriana (SHOC)	*Eragrostis bicolor* (EBIC)
S. obtusa (SOBT)	*E. echinochloidia* (EECH)
S. uniplumis (SUNI)	*E. lehmanniana* (ELEH)
	E. nindensis (ENIN)
	E. rotifer (EROT)
	E. tricophora (ETRI)
	E. truncata (ETRU)
	Fingerhuthia africana (FAFR)
	Panicum coloratum (PCOL)

The abbreviated names used in other tables and charts for these species appear in brackets.

Table 6.2 Species of bushes assigned subjectively to broad categories of encroacher and non-encroacher species in the case of the Dwarf shrub and Highland Savannas.

Encroacher species	Non-encroacher species
Acacia hebeclada (AHEB)	*Acacia erioloba* (AERI)
A. mellifera (AMEL)	*Lycium bosciifolium* (LBOS)
Catophractes alexandrii (CALE)	*L. cinereum* (LCIN)
Laggera decurrens (LDEC)	*L. eenii* (LEEN)
Rhigozum trichotomum (RTRI)	*Phaeoptilum spinosum* (PSPI)

The abbreviated names used in other tables and charts for these species appear in brackets.

Table 6.3 Species of dwarf shrubs and bushes shorter than 0.5 m assigned subjectively to less palatable and more palatable species (for sheep) measured in the Dwarf shrub and Highland Savannas.

Less palatable species	More palatable species
Eriocephalus luederitzianus (ELUE)	*Acacia erioloba* (AERI)
Gnidia polycephala (GPOL)	*A. hebeclada* (AHEB)
Laggera decurrens (LDEC)	*A. mellifera* (AMEL)
Pentzia calva (PCAL)	*Aizoon schellenbergii* (ASCH)
Rhigozum brevispinosum (RBRE)	*Boscia foetida* (BFOE)
R. trichotomum (RTRI)	*Leucosphera bainsii* (LBAI)
Thesium lacinulatum (TLAC)	*Lycium bosciifolium* (LBOS)
	L. cinereum (LCIN)
	Monechma genistifolium (MGEN)
	Pteronia glauca (PGLA)
	P. mucronata (PMUC)

The abbreviated names used in other tables and charts for these species appear in brackets.

6.4 OVERVIEW OF ALL CONTRASTS

The overview tables that follow use the same format as in Chapters 4 and 5 for the fenceline contrasts, which are numbered 32 to 34 and are followed by a lower case letter to denote the side of the fence. The experimental grazing plots are labelled by two letters followed by two numbers. The first letter represents the main management difference between the two farms, with R for the rotationally grazed farm and C for the continuously grazed farm. The second letter represents the treatment, with N for the unfenced plot that receives the normal management applied by the farmers; G for the plot that is grazed to the same extent as the surrounding paddock but for a short time twice a year; and E for the exclosure that received no grazing by livestock since February 2005. The two letters represent the year of the measurement, with the baseline data indicated by 05, while 07 and 08 are used for data obtained in the growing seasons of 2007 and 2008 respectively. For example, RG 07 is the plot on the rotationally grazed farm that receives short grazing and long rest, as measured in 2007. There is no data for CN 05, because the part of the continuously grazed surrounding paddock that was measured in 2005 was found to have different soil conditions and the control plot was therefore shifted to another side of the fenced plots for the next measurements in 2007.

Summarised information on the management applied at the contrasts and plots is presented in Table 6.4. More details of individual farms are presented in section 6.5. The stocking rates of the plots during 2007 and 2008 were derived from figures kept by the farmers of their actual stocking, while the production rates were calculated as a proportion of the stocking rate, based on the stocking rate for the farm as a whole. It is apparent from these figures that the plots (RN and CN) in the paddocks surrounding the other plots, were stocked at a different rate to that for the whole farm. On the rotationally grazed farm the paddock was farthest from the homestead and was stocked more lightly than the rest of the farm. This was due to the fact that its water had to be pumped at great expense up a considerable height, resulting in the farmer making less use of that paddock compared to other paddocks on the farm. On the farm with the continuously grazed paddock, the stocking rate was higher than the rest of the farm, as it was nearest the homestead and was used continuously by high densities of sheep, goats, cattle, horses and donkeys.

Table 6.5 provides an overview of the rangeland data. Significant ($P<0.05$) differences were found at all contrasts, and over the years at all plots, although not for all variables. These are presented in section 6.5. Because there were too few bushes to get reliable data for these variables by the method used for measurements, results for bush and tree height classes and percentage of encroacher species are omitted from Table 6.5. Fewer perennial grasses and slightly more dwarf shrubs were recorded at the experimental plots on the lightly stocked farm, while on the same farms at a distance of less than 1 km the reverse occurred (between Sites 34a and 34c).

The percentage perennial grass species composition obtained from the nearest perennial grasses (NP) is presented in Table 6.6. Few significant ($P<0.05$) differences were found and only involving a few species. *Eragrostis nindensis* was the most abundant species at the two contrasts in the Dwarf shrub Savanna, while *Stipagrostis obtusa* was the most abundant species on the two farms in the Highland Savanna. This resulted in much higher rangeland condition scores at the latter, possibly as a result of the more fertile soil (Table 2.3).

The densities of the different perennial grass species, calculated from the nearest perennial grass species (NP) and mean count of perennial grasses (No P), are presented in Table 6.7. Since it had not been possible to count the number of perennial grasses (No P) at Contrast 31, the distance to nearest perennial grass (DistP) values were used to estimate the densities of perennial grasses at those three sites. The estimation was made by applying the power regression obtained from the relationship between median distance to nearest perennial grass (DistP) and mean density from the count of perennial grasses (No P) for all other sites in the Highland and Dwarf shrub Savannas (Figure 6.1).

The estimated densities for bushes and trees are presented in Table 6.8. In five of the sites there were sufficient bushes to calculate the density index from the distance to nearest bush (DistB), which is likely to be an underestimate of true densities, due to the tendency for bushes and trees to clump. At Site 33a and on all plots there were insufficient bushes to obtain a reliable median distance to nearest bush (DistB) from which to calculate the density index. Therefore, an attempt was made to count all bushes and trees within Site 33a and the plots. This too is likely to have been an underestimate of true densities, as some bushes of slightly over 0.5 m in height were obscured by tall grass. Table 6.8 only contains data of the 2008 count of bushes within plots, since there had been no significant change over the three years of measurements. The most common bush species on Contrasts 32 and 33 in the Dwarf shrub Savanna were *Lycium bosciifolium* and *L. eenii*; while *L. cinerium* was the most common in the Highland Savanna. There were few bushes of at least 0.5 m in height, especially in the Highland Savanna.

The estimated densities for dwarf shrubs and bushes shorter than 0.5 m are presented in Table 6.9. There were fewer dwarf shrubs in the Dwarf shrub Savanna, and no species of dwarf shrub had been recorded at all six sites. In the Highland Savanna, on the other hand, the most common dwarf shrub species of *Pteronia mucronata, Eriocephalus luederitzianum, Aizoon schellenbergii* and *Leucosphera bainsii*, were recorded on all sites and plots during each of the three years of measurements.

Table 6.4 Overview of management data for sites at the fenceline contrasts and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot number	Main management difference between sides of fence	Paddks per herd	Growing season rest (weeks)	Type of animals	Farm /plot size (ha)	Stocking rate ha AU^{-1}	Stocking rate kg ha^{-1}	Animal production kg ha^{-1} a^{-1}
32a	Short rest	2	6	Cattle, sheep, goats, horses	4 940	16	29	7
32b	Yearly continuous grazing and alternating rest	2	0 then 1 full	Cattle, sheep, goats, equines	3 000	18	25	9
32c	Long rest	6	13	Cattle, sheep, goats	4 000	15	30	7
33a	Yearly grazing and rest (same farm as 32b)	2	0 then 1 full	Cattle, sheep, goats, equines	3 000	18	25	9
33b	Continuous grazing	3	0	Cattle, sheep, goats, horses	2 480	18	25	4
33c	Long rest (same farm as 32c)	6	13	Cattle, sheep, goats	4 000	15	30	7
34a	Rotation of cattle at low stocking	7	3	Cattle, few goats	8 760	19	24	4
34b	Currently as for 34a, but previously as for 34b	7	3	Cattle, few goats	8 760	19	24	4
34c	Continuous high stocking by multiple species	2	0	Cattle, sheep, goats, equines	4 090	11	42	5
RN 05	Same paddock as 34a, in 2005	1	3	Cattle	1.4	19	24	4
RN 07	Same paddock as 34a, in 2007	1	12	Cattle	1.4	90	5	1
RN 08	Same paddock as 34a, in 2008	1	12	Cattle, but none since Feb 07	1.4	150	3	1
RG 05	Grazed and rested plot in paddock of 34a, in 2005	120[1]	3	Cattle	1.4	19	24	4
RG 07	Grazed and rested plot in paddock of 34a, in 2007	120[1]	12	Cattle	1.4	30	15	3
RG 08	Grazed and rested plot in paddock of 34a, in 2008	120[1]	12	Cattle, but none since Apr 07	1.4	10	44	7
RE 05	Exclosure since 2005 in paddock of 34a, in 2005	0	3	Cattle	1.4	19	24	4
RE 07	Exclosure since 2005 in paddock of 34a, in 2007	0	Full	None since February 2005	1.4	Infinite	0	0
RE 08	Exclosure since 2005 in paddock of 34a, in 2008	0	Full	None since February 2005	1.4	Infinite	0	0
CN 05	Same paddock as 34c, in 2005, but not measured	1	0	Cattle, sheep, goats, equines	1.4	11	42	9
CN 07	Same paddock as 34c, in 2007	1	0	Cattle, sheep, goats, equines	1.4	5	90	19
CN 08	Same paddock as 34c, in 2008	1	0	Cattle, sheep, goats, equines	1.4	6	71	15
CG 05	Grazed and rested plot in paddock of 34c, in 2005	120[1]	0	Cattle, sheep, goats, equines	1.4	11	42	9
CG 07	Grazed and rested plot in paddock of 34c, in 2007	120[1]	12	Sheep, horses	1.4	9	51	11
CG 08	Grazed and rested plot in paddock of 34c, in 2008	120[1]	12	Cattle, sheep, goats, equines	1.4	5	98	20
CE 05	Exclosure since 2005 in paddock of 34c, in 2005	0	0	Cattle, sheep, goats, equines	1.4	11	42	9
CE 07	Exclosure since 2005 in paddock of 34c, in 2007	0	Full	None since February 2005	1.4	Infinite	0	0
CE 08	Exclosure since 2005 in paddock of 34c, in 2008	0	Full	None since February 2005	1.4	Infinite	0	0

[1] The number of 120 paddocks per herd is not the actual number provided but under this treatment the livestock would effectively graze a different area every day of the growing season, which would be achieved more economically by herding or moveable fencing than by permanent fencing.

Table 6.5 Overview of rangeland results for sites at the fenceline contrasts and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot number	% soil cover [1]	% biological soil crust	Perennial grasses > 5cm base: DistP [2] (cm)	Perennial grasses > 5cm base: Density (plants m^{-2})	Perennial grasses > 5cm base: Rangeland condition index	Perennial grasses > 5cm base: % Mesophyte species	Bushes taller than 0.5 m: DistB [3] (cm)	Bushes taller than 0.5 m: % Canopy	Dwarf shrubs & bushes shorter than 0.5 m: Density (plants m^{-2})	Dwarf shrubs & bushes shorter than 0.5 m: % palatable
32a	11	67	26	3.8	242	91	321	1.2	0.0	N/A
32b	29	33	14	9.0	302	76	240	2.0	0.1	18
32c	21	38	14	8.4	342	76	266	1.6	0.1	56
33a	18	42	12		435	83	>500	0.2	0.2	4
33b	12	47	9		398	68	235	2.2	0.2	6
33c	22	46	10		379	89	236	4.0	0.1	16
34a	14	50	15	5.3	702	9	>500	0.0	0.9	96
34b	4	37	24	3.1	571	8	>500	0.0	2.0	91
34c	2	37	23	3.4	611	10	>500	0.2	1.4	95
RN 05	13	50	45	2.1	371	8	>500	0.0	2.0	91
RN 07	13	50	42	3.1	348	3	>500	0.2	2.7	95
RN 08	2	49	44	3.0	349	4	>500	0.0	1.8	94
RG 05	16	47	25	2.9	524	9	>500	0.0	2.3	69
RG 07	6	49	26	4.0	523	9	>500	0.0	3.9	51
RG 08	4	42	23	4.0	528	10	>500	0.2	1.7	71
RE 05	16	41	34	2.5	393	31	>500	0.2	2.0	64
RE 07	8	57	35	3.9	363	35	>500	0.2	3.2	53
RE 08	5	48	42	3.8	294	43	>500	0.0	2.0	67
CN 05										
CN 07	8	29	13	10.8	788	1	>500	0.0	2.3	66
CN 08	8	29	19	8.3	739	3	>500	0.0	1.8	78
CG 05	9	19	11	6.3	784	1	>500	0.2	1.1	92
CG 07	5	6	14	9.7	801	1	>500	0.4	1.8	89
CG 08	7	16	15	9.8	781	1	>500	0.6	2.4	89
CE 05	12	28	9	9.5	918	0	>500	0.0	0.8	92
CE 07	14	25	9	13.8	936	2	>500	0.0	1.4	81
CE 08	12	28	15	8.4	821	4	>500	0.0	1.2	91

Groups of three (or paired) shaded values indicate significant ($P<0.05$) differences.
[1] % soil cover = % of soil covered by mulch and bases of perennial grasses; [2] DistP = Median distance from point to nearest perennial grass; [3] DistB = Median distance from point to nearest bush or tree
There are no data for CN 05 and for perennial grass density at Contrast 33.

Table 6.6 Perennial grass species composition found at the fenceline contrasts and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot No.	Percentage of points at which the species abbreviated in the row below appeared as nearest perennial grass of at least 5 cm basal diameter																	
	ACON	AMER	APUB	CCIL	EBIC	EECH	ELEH	ENIN	EROT	ETRI	ETRU	FAFR	MCAF	PCOL	SCIL	SHOC	SOBT	SUNI
32a	2				26			56	4				5	5				2
32b	10				25	1		49					14	1				
32c	7	1	1		7	1		63		2			13	1				4
33a								78			5		1			5	10	1
33b					6			62					32					
33c	4				7			82					7					
34a								6				3			6		85	
34b				4				2			1	1			5		84	3
34c				4				1				5			13		73	4
RN 05				1			1	5				1			6		83	3
RN 07						2		0				1			7		76	14
RN 08				2				2							11		79	6
RG 05						2		5				2			33		57	1
RG 07						2		2				5			25		63	3
RG 08				1				8				1			36		48	6
RE 05		1		1				16				13			20		43	6
RE 07						1		13				21			12		42	11
RE 08								26				17			13		38	6
CN 05																		
CN 07								1							20		78	1
CN 08								3							20		76	1
CG 05								1							5		93	1
CG 07						1									10		89	
CG 08								1							15		84	
CE 05															1		99	
CE 07								2							3		93	2
CE 08				1				3							2		94	

Groups of three shaded values indicate significant ($P<0.05$) differences.
Names of species abbreviated as follows: ACON=*Aristida congesta*, ACON=*Aristida meridionalis*, APUB=*Anthephora pubescens*, CCIL= *Cenchrus ciliaris*, EBIC= *Eragrostis bicolor,* EECH= *Eragrostis echinochloidea,* ELEH= *Eragrostis lehmanniana,* ENIN= *Eragrostis nindensis,* EROT= *Eragrostis rotifer,* ETRI= *Eragrostis tricophora,* ETRU=*Eragrostis truncata,* FAFR=*Fingerhuthia africana,* MCAF=*Microchloa caffra,* PCOL=*Panicum coloratum,* SCIL= *Stipagrostis ciliata,* SHOC= *Stipagrostis hochstetteriana,* SOBT= *Stipagrostis obtusa,* SUNI=*Stipagrostis uniplumis*.
There are no data for CC05.

Table 6.7 Perennial grass species densities (plants 100 m^{-2}) calculated from findings at the fenceline contrasts and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot No.	Densities in plants per 100 m^2 of the species of perennial grass of at least 5 cm basal diameter abbreviated in the row below																	
	ACON	AMER	APUB	CCIL	EBIC	EECH	ELEH	ENIN	EROT	ETRI	ETRU	FAFR	MCAF	PCOL	SCIL	SHOC	SOBT	SUNI	Total
32a	8				100			214	15				19	19				8	383
32b	90				226	9		442					126	9					903
32c	59	8	8		59	8		531		17			110	8				34	842
33a								705			46		9			46	93	9	909
33b					69			715					369						1 154
33c	42				73			854					73						1 041
34a								32				16			32		451		530
34b				12				6			3	3			15		258	9	307
34c				14				3				17			44		247	14	339
RN 05				2			2	11				2			13		174	6	210
RN 07						6						3			22		234	43	307
RN 08				6				6							33		236	18	299
RG 05						6		15				6			97		167	3	294
RG 07						8		8				20			100		251	12	399
RG 08				4				32				4			146		194	24	405
RE 05		3		3				40				33			50		108	15	250
RE 07						4		51				83			47		165	43	394
RE 08								98				64			49		143	23	375
CN 05																			
CN 07								11							216		842	11	1 079
CN 08								25							167		633	8	833
CG 05								6							32		587	6	631
CG 07						10									97		867		974
CG 08								10							148		826		983
CE 05															9		936		945
CE 07								28							41		1 281	28	1 377
CE 08				8				25							17		791		841

Names of species abbreviated as follows: ACON = *Aristida congesta*; ACON = *Aristida meridionalis*; APUB = *Anthephora pubescens*; CCIL = *Cenchrus ciliaris*; EBIC = *Eragrostis bicolor*; EECH = *Eragrostis echinochloidia*; ELEH = *Eragrostis lehmanniana*; ENIN = *Eragrostis nindensis*; EROT = *Eragrostis rotifer,* ETRI = *Eragrostis tricophora*;, ETRU = *Eragrostis truncata*; FAFR = *Fingerhuthia africana*; MCAF=*Microchloa caffra*; PCOL=*Panicum coloratum*; SCIL = *Stipagrostis ciliata*; SHOC = *Stipagrostis hochstetteriana*; SOBT = *Stipagrostis obtusa*; SUNI = *Stipagrostis uniplumis*.

There are no data for CC05. The densities of 33a-c were estimated by the distance to nearest perennial grass (DistP).

Table 6.8 Densities of bushes and trees recorded at the fenceline contrast sites and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot No.	Density estimates (plants ha^{-1}) for the species of trees and bushes taller than 0.5 m, abbreviated in the row below											Total
	AERI <2m	AERI >2m	AHEB	AMEL	CALE	LDEC	LBOS	LCIN	LEEN	PSPI	RTRI	
32a			9			18	275		31			333
32b	7		45			15	453		52			572
32c		17	28				377		90			512
33a	8	1		0			18		1		2	30
33b							408		48		180	637
33c		7					348		125		139	619
34a	2	0	1	0	0							3
34b	1		1	1								2
34c	1	1	3	2	0			1				7
RN 08		1			2			7				10
RG 08		1		1	1			3	1	1		7
RE 08	1	1		3	1				1			6
CN 08	2	1	1	5	3			6				19
CG 08	8	3	1	2	1			6	1			23
CE 08	1	7	3	1	1			9				23

In the case of 32a-c and 33b-c the density was estimated by distance from sample point to nearest bush or tree. For all other sites the density was estimated from total counts within the site area of 3.75 ha for fenceline contrast sites and 1.44 ha for the experimental plots.

Names of species abbreviated as follows: AERI = *Acacia erioloba* (separated into shorter and taller than 2 m); AHEB = *Acacia hebeclada*; AMEL = *Acacia mellifera*, CALE=*Catophractes alexandrii*, LDEC = *Laggera decurrens*; LBOS = *Lycium bosciifolium*; LCIN = *Lycium cinereum*; LEEN = *Lycium eenii*; PSPI = *Phaeoptilum spinosum*; RTRI = *Rhigozum trichotomum*.

A zero indicates that the species was counted at that site, but its density estimate was less than 0.5 bushes ha^{-1} for that site. A blank cell indicates that the species was not encountered during the measurements.

Table 6.9 Density (plants 100 m^{-2}) of dwarf shrubs and bushes shorter than 0.5 m in height at the fenceline contrast sites and experimental plots in the Dwarf shrub and Highland Savannas.

Contrast /plot No.	Density (plants 100 m^{-2}) for the dwarf shrub species, and bushes shorter than 0.5 m, abbreviated in the row below																		Total
	AERI	AHEB	AMEL	ASCH	BFOE	ELUE	GPOL	LDEC	LBAI	LBOS	LCIN	MGEN	PCAL	PGLA	PMUC	RBRE	RTRI	TLAC	
32a										1									1
32b				1						1							8		10
32c	2			1		2													5
33a						1	11	1			1						2		16
33b					1	2					1		3			1	10		18
33c	1					4				1			3						8
34a				5		3			10		2	55			18			1	95
34b				18		3	1		12		3	138		1	10			15	200
34c				11		3	1		14			97		1	15			3	145
RN 05				48		18			40						94				200
RN 07				54		12	1		52		2	1	1	2	149				273
RN 08				35		8			41		2		3	1	95				185
RG 05				20		52			22				20		116				230
RG 07				28		186	1		28		3		6	1	139				391
RG 08	9		1	23		47			20		1		1		63				165
RE 05			1	33		52	3		36		2		18	1	58			1	204
RE 07				46		132	8		49		1		8	6	67				316
RE 08				40		52	1		52		6		14	1	38				203
CN 05																			
CN 07	1			39		42	7		15		1	5	31	1	91				231
CN 08				35		20	1		18			2	20	2	85				182
CG 05				15		5	4		17		4			3	61				109
CG 07		1		12		8	6		10		18		6	1	121				182
CG 08				14		14	6		16		2		6		181				238
CE 05				15		5	2		11			1			47				80
CE 07				15		23	2		14				3		86				143
CE 08				19		2	1		14		12		8		61				116

Names for species abbreviated as follows: AERI = *Acacia erioloba*; AHEB = *Acacia hebeclada*; AMEL = *Acacia mellifera*; ASCH = *Aizoon schellenbergii*; BFOE= *Boscia foetida*; ELUE = *Eriocephalus luederitzianus*; GPOL = *Gnidia polycephala*; LDEC = *Laggera decurrens*; LBAI= *Leucosphaera bainsii*; LBOS=*Lycium bosciifolium*, LCIN = *Lycium cinerium*, MGEN = *Monechma genistifolium*; PCAL= *Pentzia calva*; PGLA= *Pteronia glauca*; PMUC = *Pteronia mucronata*, RBRE= *Rhigozum brevispinosum;* RTRI = *Rhigozum trichotomum*; TLAC = Thesium lacinulatum.
There are no data for CC 05.

Dispersion around the median values for numerical variables is presented separately for the fenceline contrasts and the experimental plots. Figures 6.4 – 6.7 present the fenceline contrast dispersions for the distance to nearest perennial grass (DistP); count of perennial grasses (No P); distance to nearest bush (DistB); and combined count of all species of dwarf shrubs (Woodies), respectively. No chart was plotted for canopy cover by Bitterlich gauge, since all medians were zero.

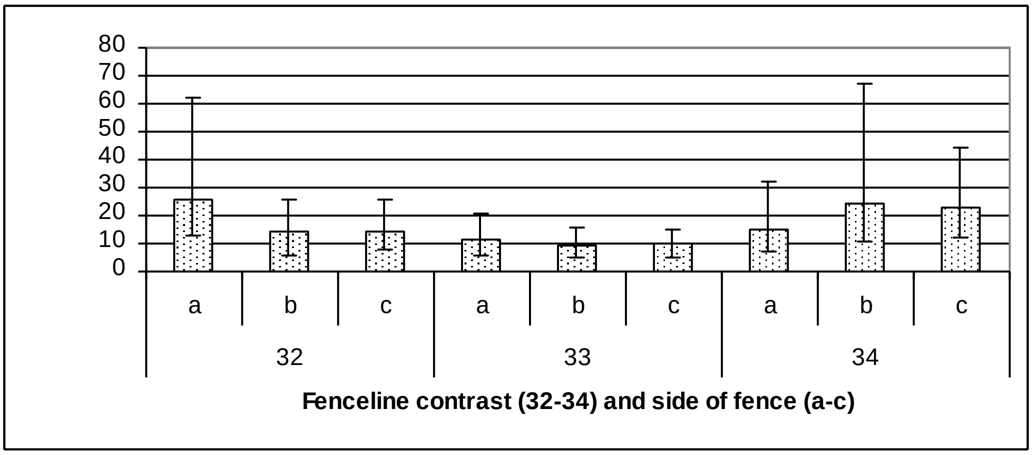
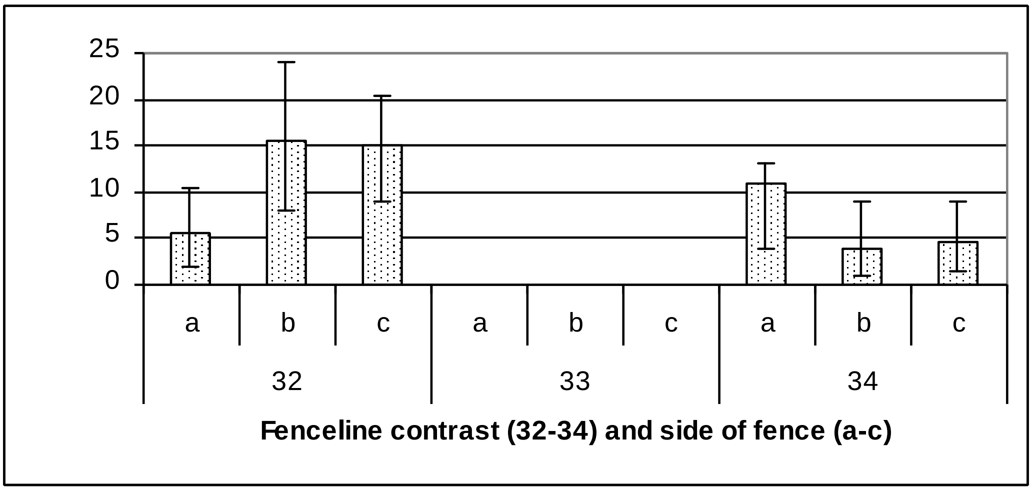
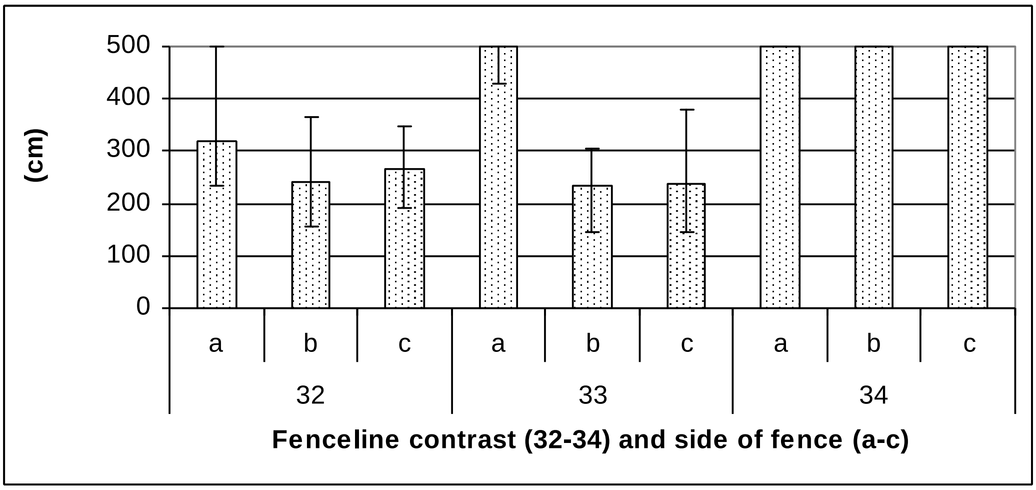


Figure 6.4 Median values and quartiles of the distance from sample point to nearest perennial grass of at least 5 cm basal diameter, for each of the sites measured at fenceline contrasts in the Dwarf shrub and Highland Savannas.



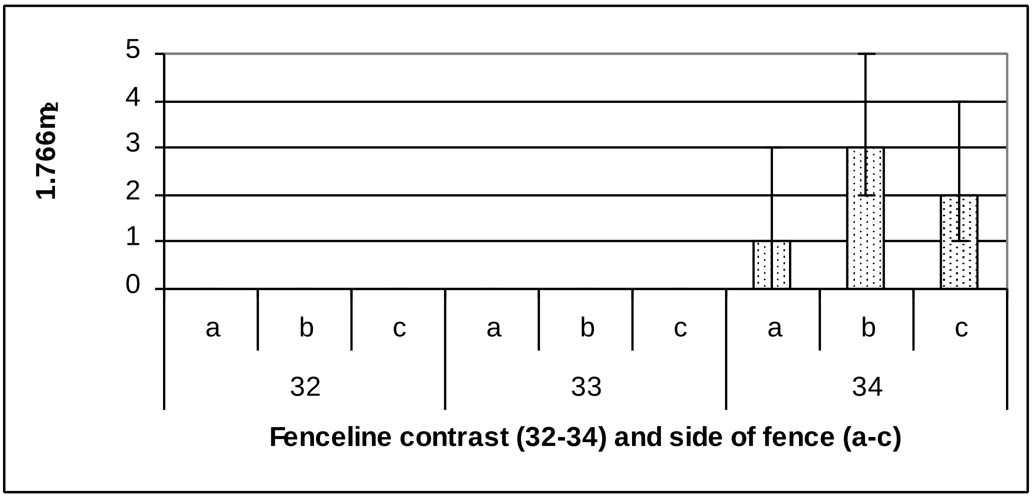
The perennial grasses were not counted at Contrast 33.

Figure 6.5 Median values and quartiles of the number of perennial grasses of at least 5 cm basal diameter, counted in each of two fenceline contrast sites in the Dwarf shrub and Highland Savannas.



The upper quartile for 32a, the median and upper quartile for 33a, and the median and both quartiles for 34a-c, were more than 500 cm and are not presented, because their actual values are unknown.

Figure 6.6 Median values and quartiles of the distance from sample point to nearest bush or tree of at least 0.5 m in height, for each of the sites measured at fenceline contrasts in the Dwarf shrub and Highland Savannas.



For 32 and 33a-c even the lower quartiles were all zero.

Figure 6.7 Median values and quartiles of the number of dwarf shrubs and bushes shorter than 0.5 cm counted in each fenceline contrast site in the Dwarf shrub and Highland Savannas.

Results of measurements of soil cover (Hit) for the fenceline contrasts are presented in Figure 6.5. Biological soil crusts were more common than in the Thornbush and Camelthorn Savannas. Stones and rock were particularly common in the Highland Savanna but absent from the sites measured in the Dwarf shrub Savanna.

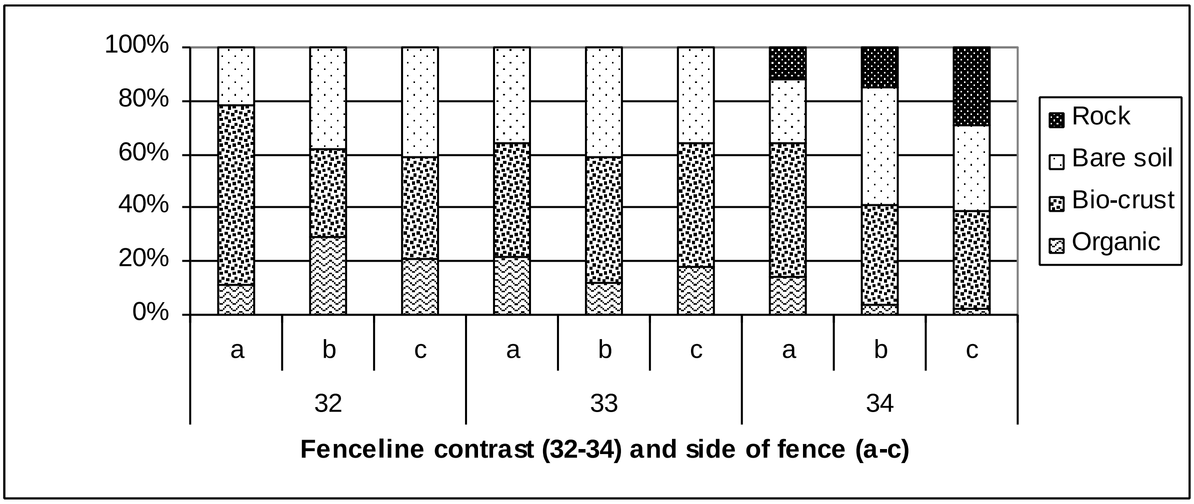
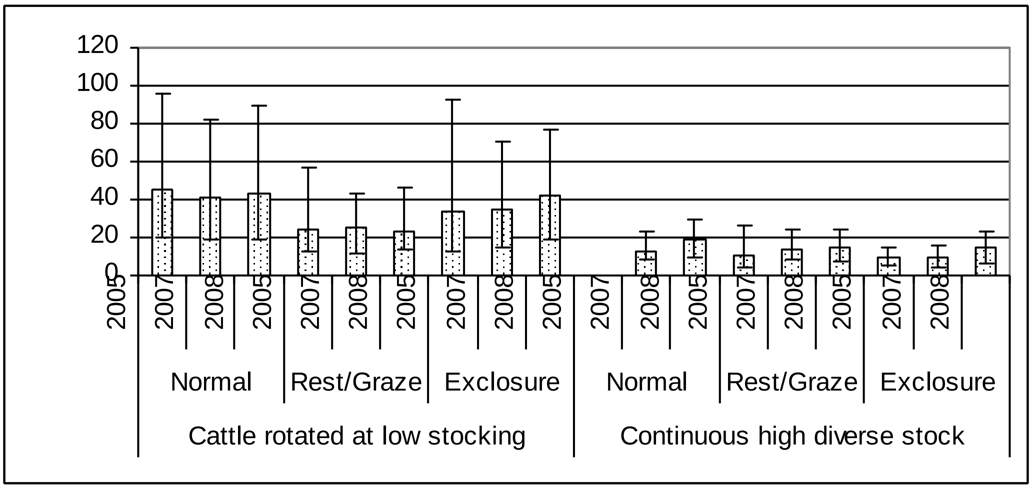


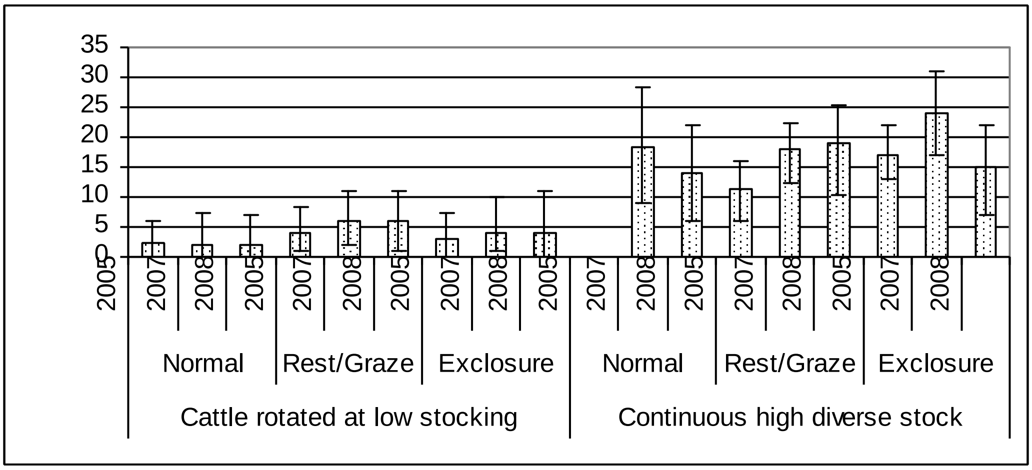
Figure 6.8 Proportions of organic cover over the soil (from mulch and bases of perennial grasses), biological soil crust, bare soil and rock found in each of fenceline contrast sites in the Dwarf shrub and Highland Savannas.

Experimental plot dispersions for distance to nearest perennial grass (DistP); count of perennial grasses (No P); and combined count of all dwarf shrub species (Woodies) are presented in Figures 6.9 – 6.11, respectively. No chart was plotted for canopy cover by Bitterlich gauge, since all medians were zero, and no chart was plotted for distance to nearest bush (DistB) as median values are unknown since they were all over 5 m (Table 6.5).



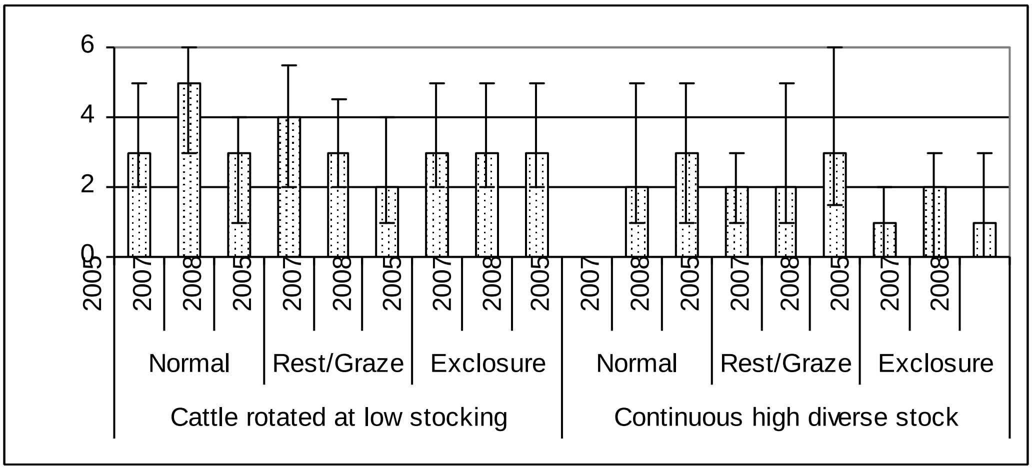
There were no data in 2005 for the normal plot on the continuously grazed farm.

Figure 6.9 Median values and quartiles of the distance from sample point to nearest perennial grass of at least 5 cm basal diameter, for each of the experimental plots in the Highland Savanna over three years.



There were no data in 2005 for the normal plot on the continuously grazed farm.

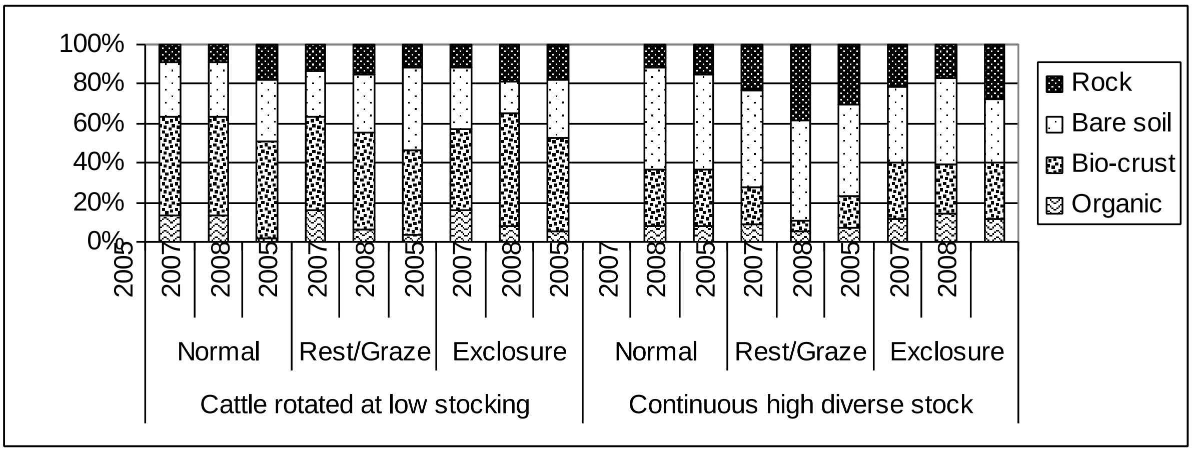
Figure 6.10 Median values and quartiles for the number of perennial grasses of at least 5 cm basal diameter counted in each of the experimental plots in the Highland Savanna over three years.



There were no data in 2005 for the normal plot on the continuously grazed farm.

Figure 6.11 Median values and quartiles for the number of dwarf shrubs and bushes shorter than 0.5 m counted in each of the experimental plots in the Highland Savanna over three years.

Results from soil cover (Hit) measurements are presented for the experimental plots in Figure 6.12. Biological soil crusts were particularly common on the lightly stocked farm, while bare soil and stones and rock predominated on the heavily stocked farm.



There were no data in 2005 for the normal plot on the continuously grazed farm.

Figure 6.12 Proportions of organic cover over the soil (from mulch and bases of perennial grasses), biological soil crust, bare soil and rock found in each of the experimental plots in the Highland Savanna over three years.

6.5 INDIVIDUAL CONTRASTS

6.5.1 Contrast 32, between three farms that differed in period of absence

The utilisation of the three farms that made up Contrast 32 differed mainly in the period of absence of grazing stock. Site 32a was allowed a six week period of absence in the growing season, compared to 13 weeks for Site 32c, while Site 32b alternated between continuous grazing in one year and a complete growing season's rest the following year. All three farms were stocked with cattle, sheep and goats, with the addition of equines on the farms of Site 32b and 32c. The stocking rates were estimated to be 29, 25 and 30 kg liveweight ha^{-1} (16, 18 and 15 ha AU^{-1}) for Sites 32a, 32b and 32c respectively, with animal production estimated at 7, 9 and 7 kg liveweight ha^{-1} respectively.

All three farms had been continuously grazed by karakul sheep until subdivision into paddocks started approximately 40 years previously. Stocking rates were said not to have changed much on Sites 32a and 32c, while on 32b they had peaked at 56 kg liveweight ha^{-1} (8 ha AU^{-1}) 26 years ago. The absentee farmer of 32a believed there was no difference in rangeland condition across fencelines, while the resident farmer at 32b believed his rangeland was in worse condition as he had raised the stocking rate five years previously. The absentee farmer of 32c believed that both his neighbours had stocked at a higher rate than he had over the previous 10 years.

Photographs of the measured sites on each side of the fenceline contrast are presented in Figure 6.13.

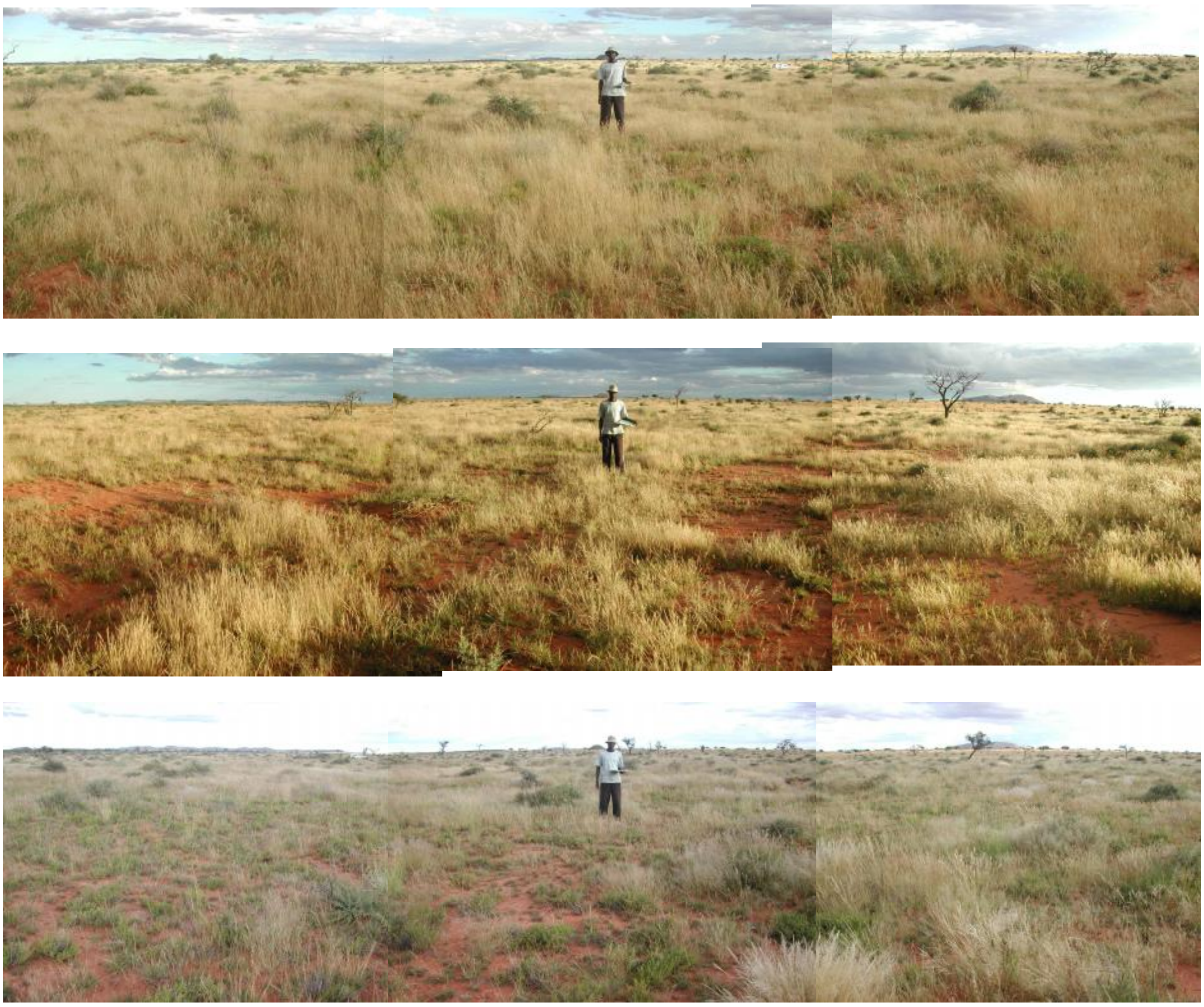


Figure 6.13 Three sides of fenceline contrast between farms providing an absence period in the growing season of 6 weeks (32a, top); alternating years of continuous grazing and complete growing season rest (32b, middle); and an absence period of 13 weeks in the growing season (32c, bottom). The photographs were taken in April 2004.

On Sites 32a, 32b and 32c the mulch covers of 11%, 29% and 21% respectively, differed significantly ($P<0.05$). The highest cover was recorded on Site 32b, which alternated yearly between complete growing season rest and continuous growing season grazing. On this part of the farm the long period of absence was coming to an end, which may have allowed for a greater build up of mulch there. The biological soil crusts were, however, significantly ($P<0.05$) higher on Site 32a, which was at 67%, the highest recorded at any of the sites in this study. The perennial grass density was significantly ($P<0.05$) lower at this site, estimated at 3.8 grasses m^{-2}, compared to 9.0 and 8.4 grasses m^{-2} on Sites 32b and 32c respectively. The proportion of mesohpytic grass species was also significantly ($P<0.05$) higher on this site. In addition, the density of both bushes and dwarf shrubs was significantly ($P<0.05$) lower on Site 32a, but the estimated canopy cover of 1.2% did not differ significantly ($P>0.05$) from the 2.0% at Site 32b and the 1.6% at Site 32c.

The perennial grass species composition is presented in Figure 6.14. *Eragrostis nindensis* was the most abundant species at all three sites. The only species that the differed significantly (P<0.05) among sites is *Eragrostis bicolor*, which had the lowest abundance at Site 32c.

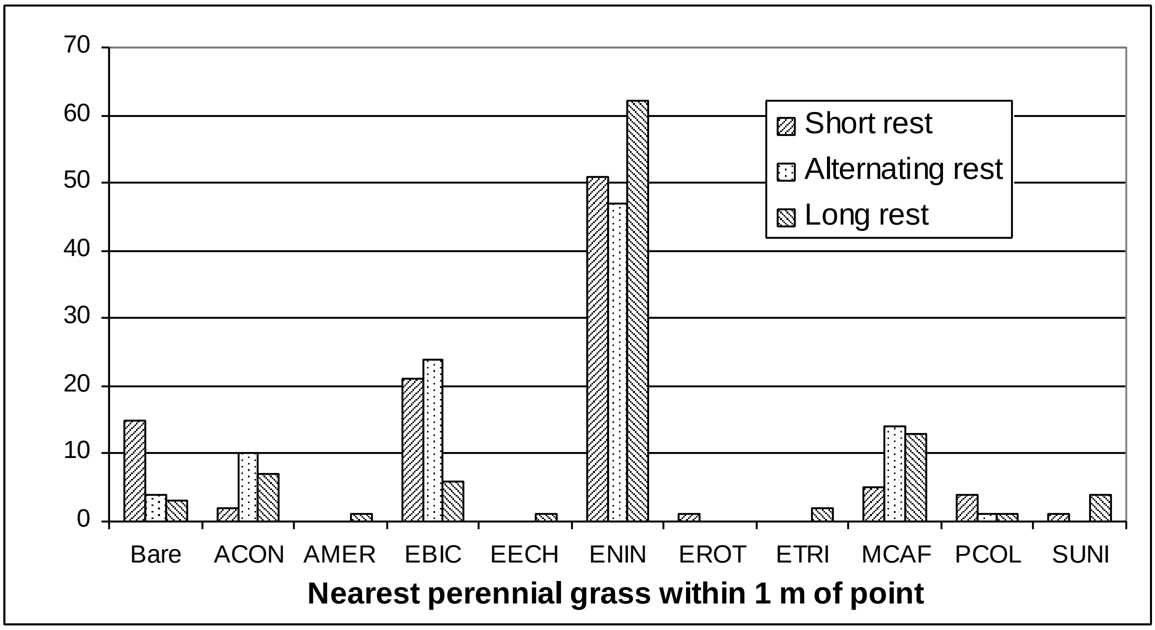


Figure 6.14 Perennial grass species composition at Contrast 32 in the Dwarf shrub Savanna.

The rangeland condition indices were calculated as 242, 302 and 342 for Sites 32a, 32b and 32c respectively, which differed significantly (P<0.001). However, when judged by different criteria there is no clear ranking of rangeland condition between these sites. Based on the higher proportion of mesophytes among the perennial grasses and the greater cover of biological soil crusts, Site 32a would be in the best condition. Based on perennial grass density and mulch cover, Site 32b would be in the best condition. Based upon rangeland condition index and upon proportion of palatable species among the dwarf shrubs, Site 32c would be in the best condition.

6.5.2 Contrast 33, between three farms that differed in period of absence

Similar to Contrast 32, the utilisation of the three farms that made up Contrast 33 differed mainly in the period of absence of grazing stock. In fact, two of the sites were on the same farms as at Contrast 32 (Site 33a was on the same farm as Site 32b, and Site 33c on the same farm as Site 32c). Site 33a alternated between continuous grazing in one year and a complete growing season's rest the following year; while Site 33b was grazed continuously and Site 33c was allowed a period of absence of about 13 weeks in the growing season. The farmer of Site 33b had recently retired to the farm, where his grandfather had previously kept many horses. All three farms were currently stocked with cattle, sheep and goats, with the addition of equines on the farms of Site 33a and 33b. The stocking rates were estimated to be 25, 25 and 30 kg liveweight ha^{-1} (18, 18 and 15 ha AU^{-1}) for Sites 33a, 33b and 33c respectively, with animal production estimated at 9, 4 and 7 kg liveweight ha^{-1} respectively.

Photographs of the measured sites on all three sides of the fenceline contrast are presented in Figure 6.15.

Figure 6.15 Three sides of fenceline contrast between farms that provide alternating years of continuous grazing and complete growing season rest (33a, top), continuous grazing (33b, middle), and an absence period of 13 weeks in the growing season (33c, bottom). The photographs were taken in April 2004.

On Sites 32a, 32b and 32c the median distance to nearest perennial grass (DistP) of 12, 9 and 10 cm respectively, differed significantly (P<0.05). The highest density index of perennial grasses was on Site 33b, which was grazed continuously. However, the proportion of mesohpytic species amongst those grasses was significantly (P<0.05) lower on this site. On Site 32a both the density and cover of bushes were significantly (P<0.05) lower, but the estimated canopy cover of 1.2% there did not differ significantly (P>0.05) from the 2.0% at Site 32b and the 1.6% at Site 32c.

The perennial grass species composition appears in Figure 6.16, with *Eragrostis nindensis* dominating at all three sites. The two species that differed significantly (P<0.05) among sites are *Eragrostis nindensis* and *Microchloa caffra*, of which the latter was most abundant at Site 33b.

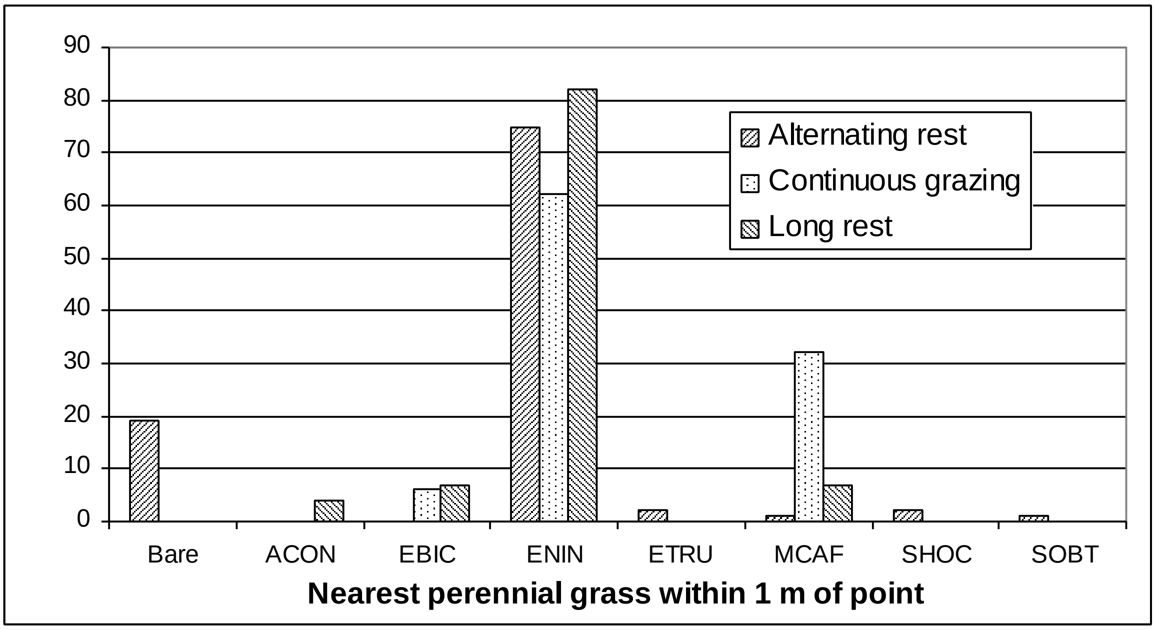


Figure 6.16 Perennial grass species composition at Contrast 33 in the Dwarf shrub Savanna.

The rangeland condition indices were calculated as 435, 398 and 379 for Sites 33a, 33b and 33c respectively, which differed significantly (P<0.001). However, site 33a was the worst of the three when judged by different criteria. It was on the same farm as Site 32b, alternating yearly between complete growing season rest and continuous growing season grazing. However, on this part of the farm the continuous grazing had taken place during the months preceding the measurements. In addition, it was closer to the homestead and therefore received heavier grazing from the small stock than Site 32b on the same farm. There is no clear ranking of rangeland condition between the other two sites, 33b and 33c. Based on the higher proportion of mesophytes among the perennial grasses, the higher proportion of palatable species among the dwarf shrubs and the greater organic cover over the soil, Site 33c would be the best. Based on perennial grass density and rangeland condition index from composition of perennial grasses within 30 cm of the point, Site 33a would be the best.

6.5.3 Contrast 34, between two paddocks in cattle farm and a mixed farm

Sites 34a and 34b were both on the same farm which was lightly grazed by cattle at approximately 24 kg liveweight ha^{-1}. (19 ha AU^{-1}) The cattle were rotated rapidly through seven paddocks per herd, providing a period of absence of only three weeks between grazing periods. However, Site 34b had been bought by the farmer 14 years previously, when it had been stocked heavily and continuously by cattle, sheep, goats, horses and donkeys. Site 34c was stocked heavily and continuously at about 44 kg liveweight ha^{-1} (10 ha AU^{-1}) by cattle, sheep, goats, horses and donkeys. Eleven years previously it had been stocked at approximately 16 kg liveweight ha^{-1} (28 ha AU^{-1}). The paddocks at the fenceline contrast did not receive the same stocking as the rest of the farms on which they were located. Sites 34a and 34b, being farthest from the homestead, received a much longer period of absence and lighter stocking, while Site 34c was nearest the homestead and received a higher stocking. Photographs (March 2005) are presented in Figure 6.17.

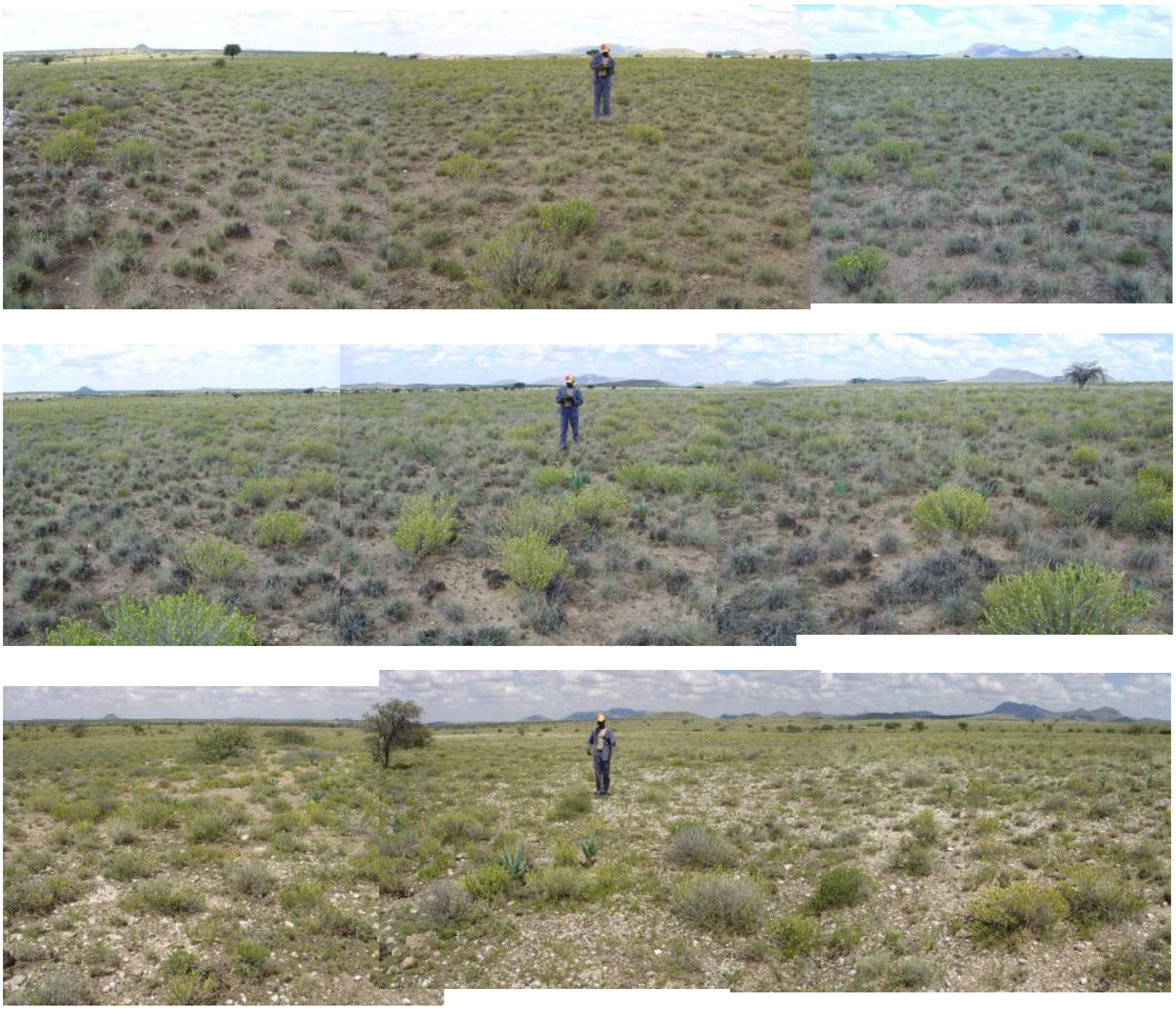


Figure 6.17 Three sides of fenceline contrast between a paddock stocked lightly with cattle for many years (34a, top); a paddock on the same farm that was previously heavily stocked before being lightly stocked with cattle for 14 years (34b, middle); and another farm that had been heavily stocked with cattle, sheep, goats and equines for many years (34c, bottom).

The paddock with the long history of light stocking at Site 34a had significantly (P<0.05) higher cover of organic matter and a higher density of perennial grasses, while the density of dwarf shrubs was significantly (P<0.05) lower than at Sites 34b and 34c. The rangeland condition score was also higher, at 890, compared to 806 and 839 for Sites 34b and 34c respectively, which differed significantly (P<0.05). The composition of perennial grasses did not differ significantly (P>0.05) for any of the species recorded, with *Stipagrostis obtusa* comprising 85%, 76% and 79% of the species composition at Sites 34a, 34b and 34c respectively. There were very few bushes of at least 0.5 m in height at any of the three sites.

Results of the count of dwarf shrubs (Woodies) are presented in Figure 6.15. *Monechma genistifolium* was the most abundant species, especially at Site 34b.

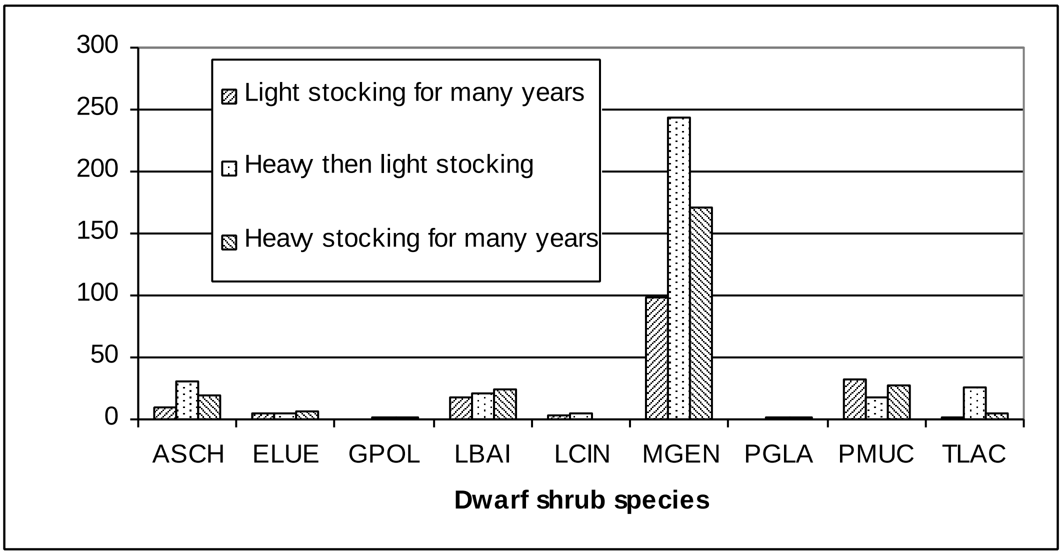


Figure 6.18 Density estimates of species of dwarf shrubs and bushes shorter than 0.5 m at Contrast 34 in the Highland Savanna.

6.6 EXPERIMENTAL GRAZING PLOTS, MEASURED OVER TIME

The annual rainfall recorded by a farmer within 2 km of the six plots is presented in Figure 6.19. Although each rainy season is indicated over parts of two successive years, on average only 22% of the rain fell before January. The initial measurements, taken shortly after establishment in 2005, served as the baseline data, although Site CN 05 was subsequently shifted after finding that it did not compare well with the other plots. Follow-up measurements were made in the same month of March, two and three years later, in 2007 and 2008. The exceptionally high rainfall of 2006 may have influenced the 2007 results, but most of the high rainfall of 2008 fell during and after the measurements in March 2008.

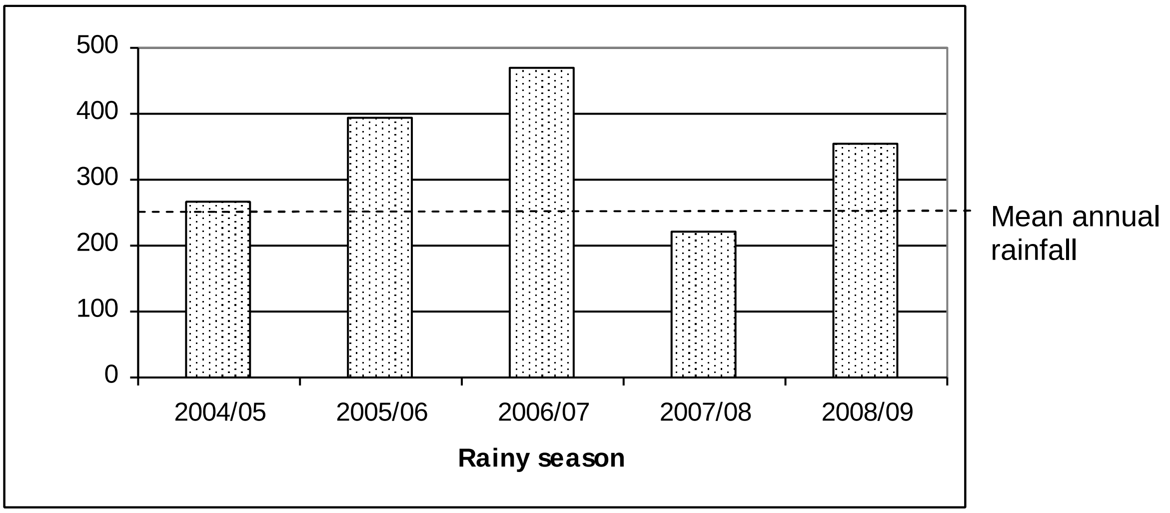


Figure 6.19 Annual rainfall recorded by farmer nearby experimental grazing plots in the Highland Savanna, in relation to the long-term mean annual rainfall of 250 mm.

Photographs of the measured sites taken in each of the three years of measurement are presented in Figures 6.20-6.25, for Sites RC, RG, RE, CC, CG and CN respectively.

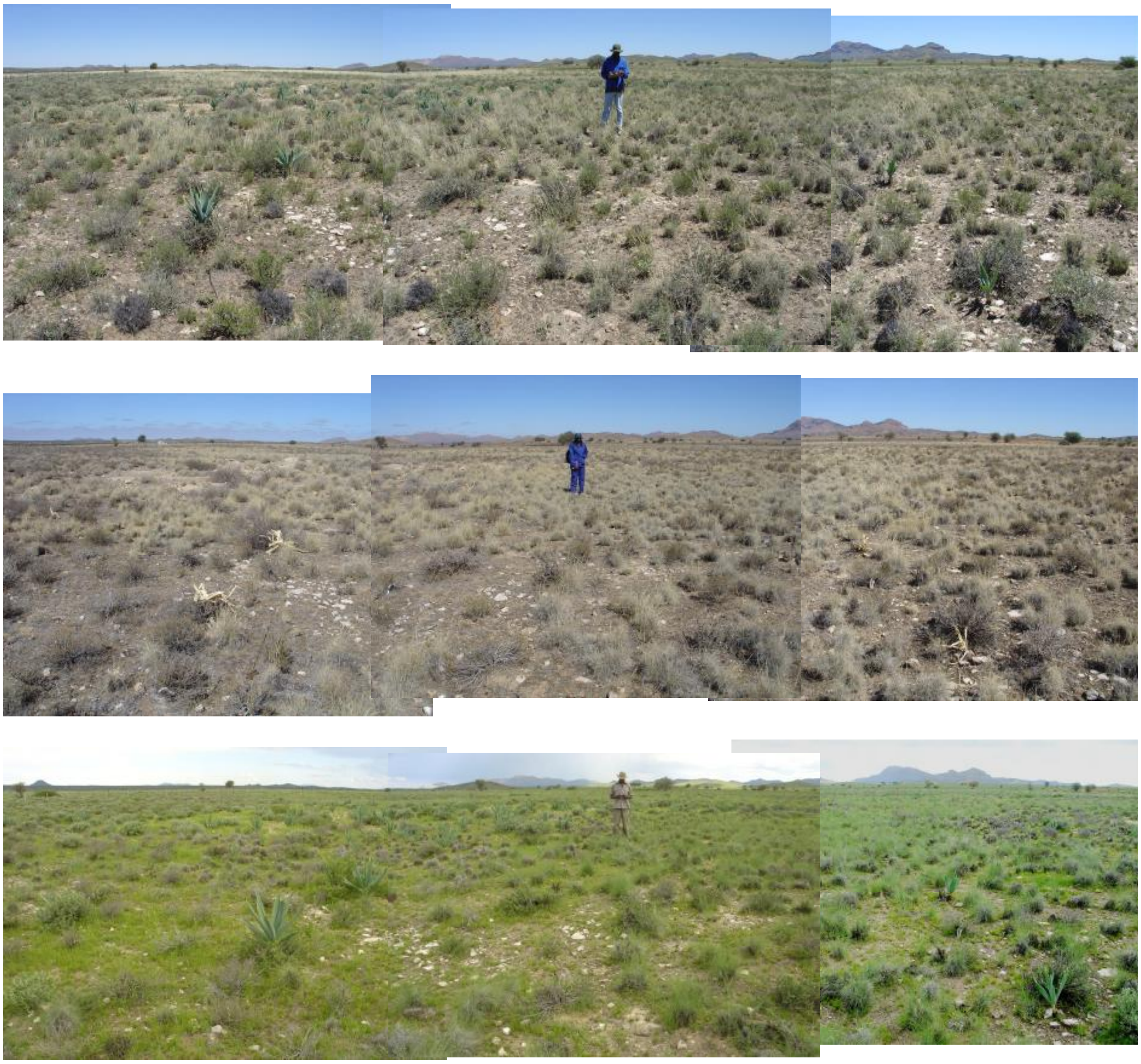


Figure 6.20 Successive views of the normally grazed experimental plot on the rotationally grazed and lightly stocked farm taken in 2005 (RN 05, top), 2007 (RN 07, middle), and 2008 (RN 08, bottom).

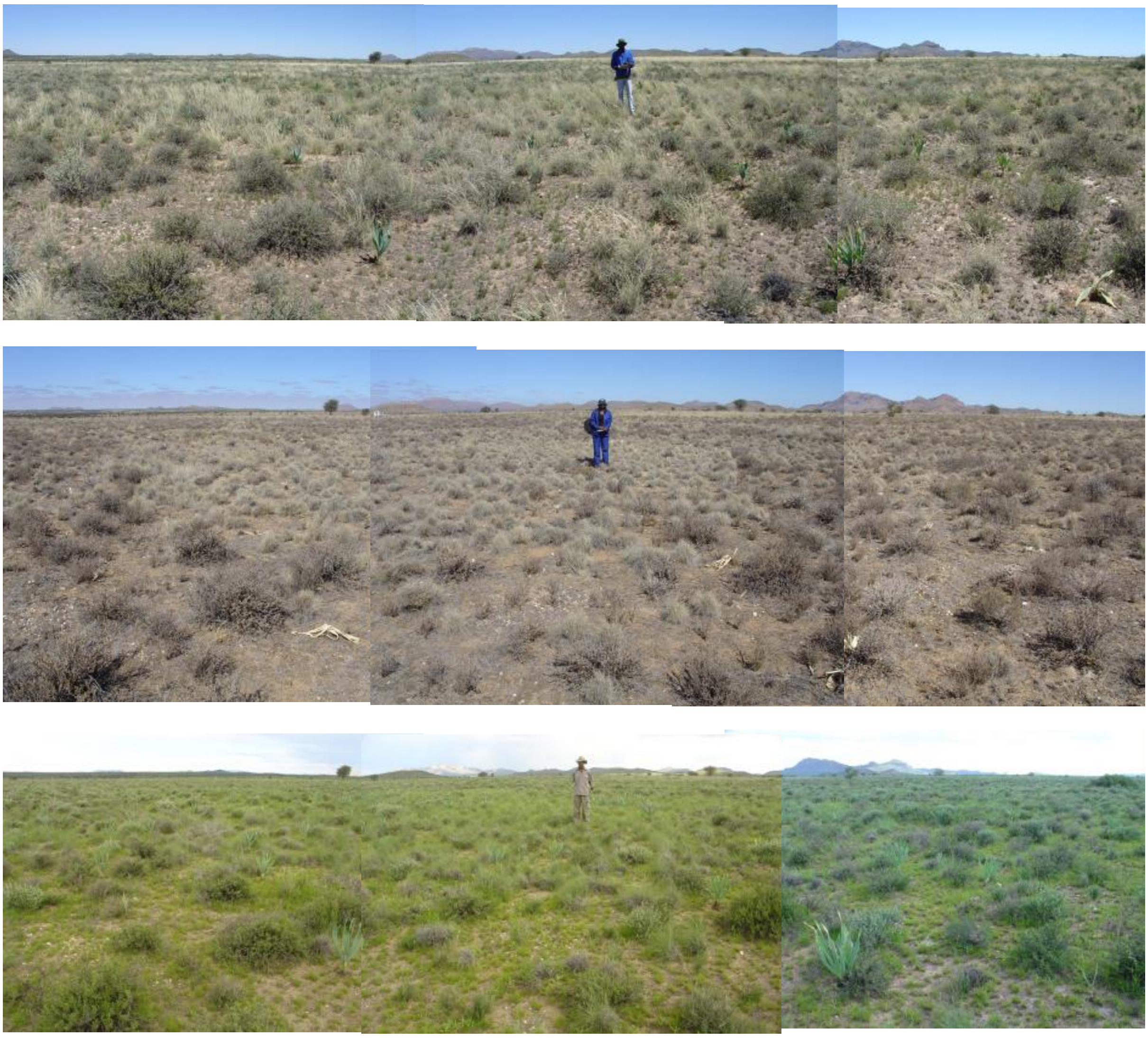


Figure 6.21 Successive views of the experimentally grazed and rested plot on the rotationally grazed and lightly stocked farm taken in 2005 (RG 05, top), 2007 (RG 07, middle), and 2008 (RG 08, bottom).

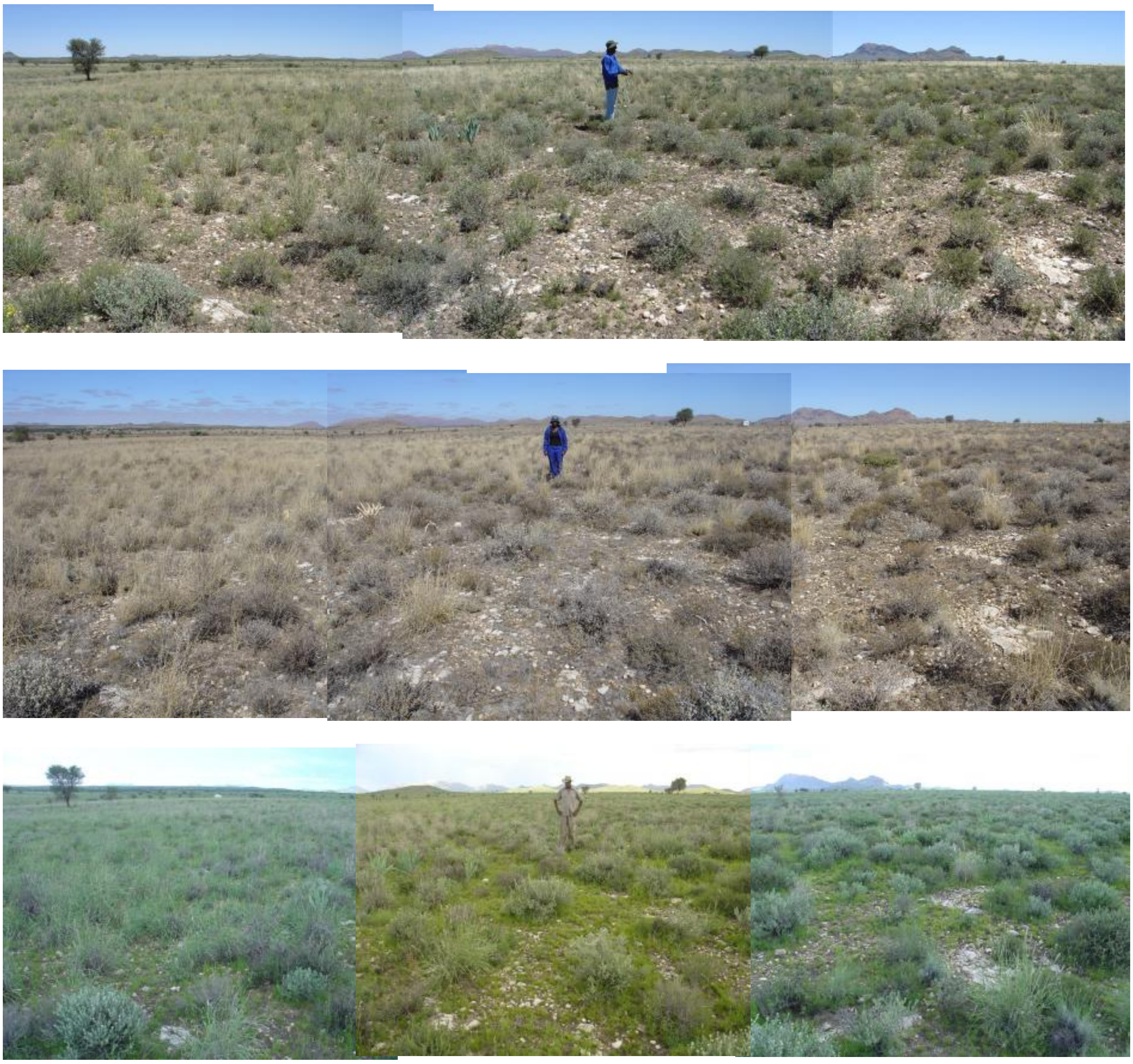


Figure 6.22 Successive views of the exclosure plot on the rotationally grazed and lightly stocked farm taken in 2005 (RE 05, top), 2007 (RE 07, middle), and 2008 (RE 08, bottom).

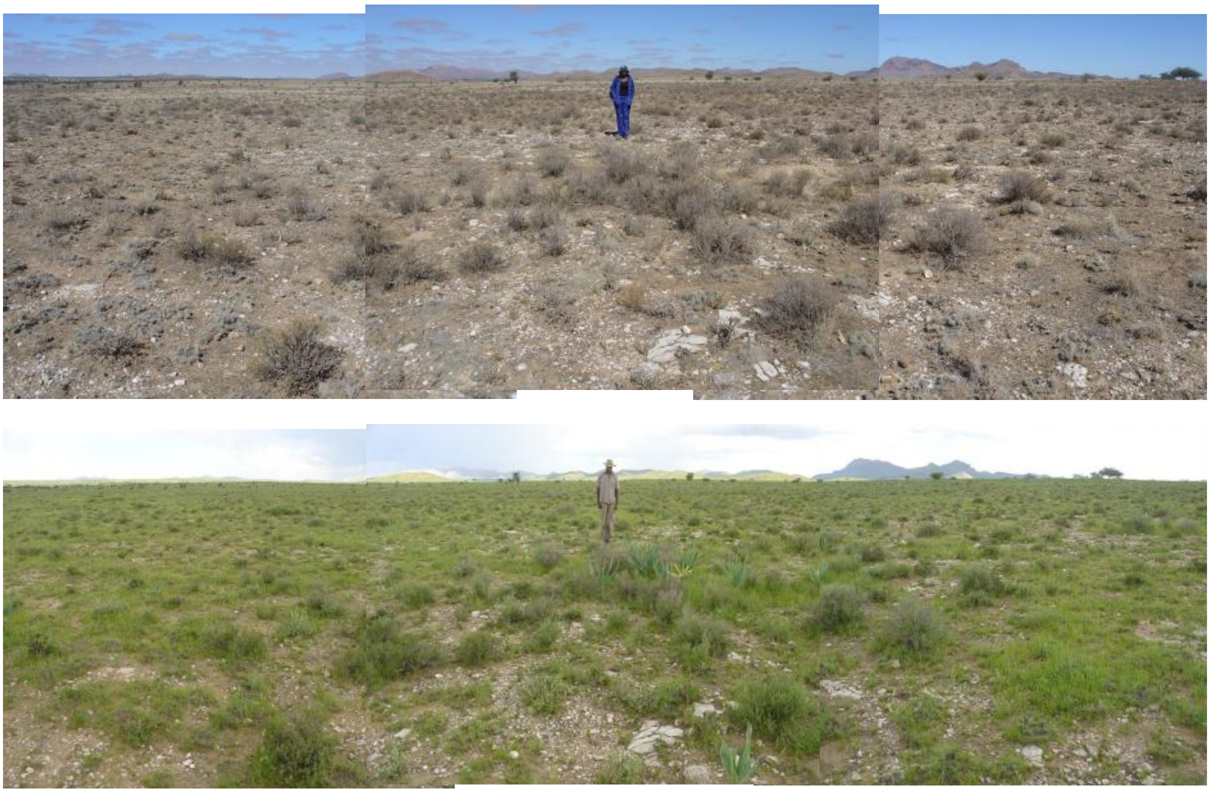


Figure 6.23 Successive views of the normally grazed experimental plot on the continuously grazed and heavily stocked farm taken in 2007 (CN 07, middle), and 2008 (CN 08, bottom).

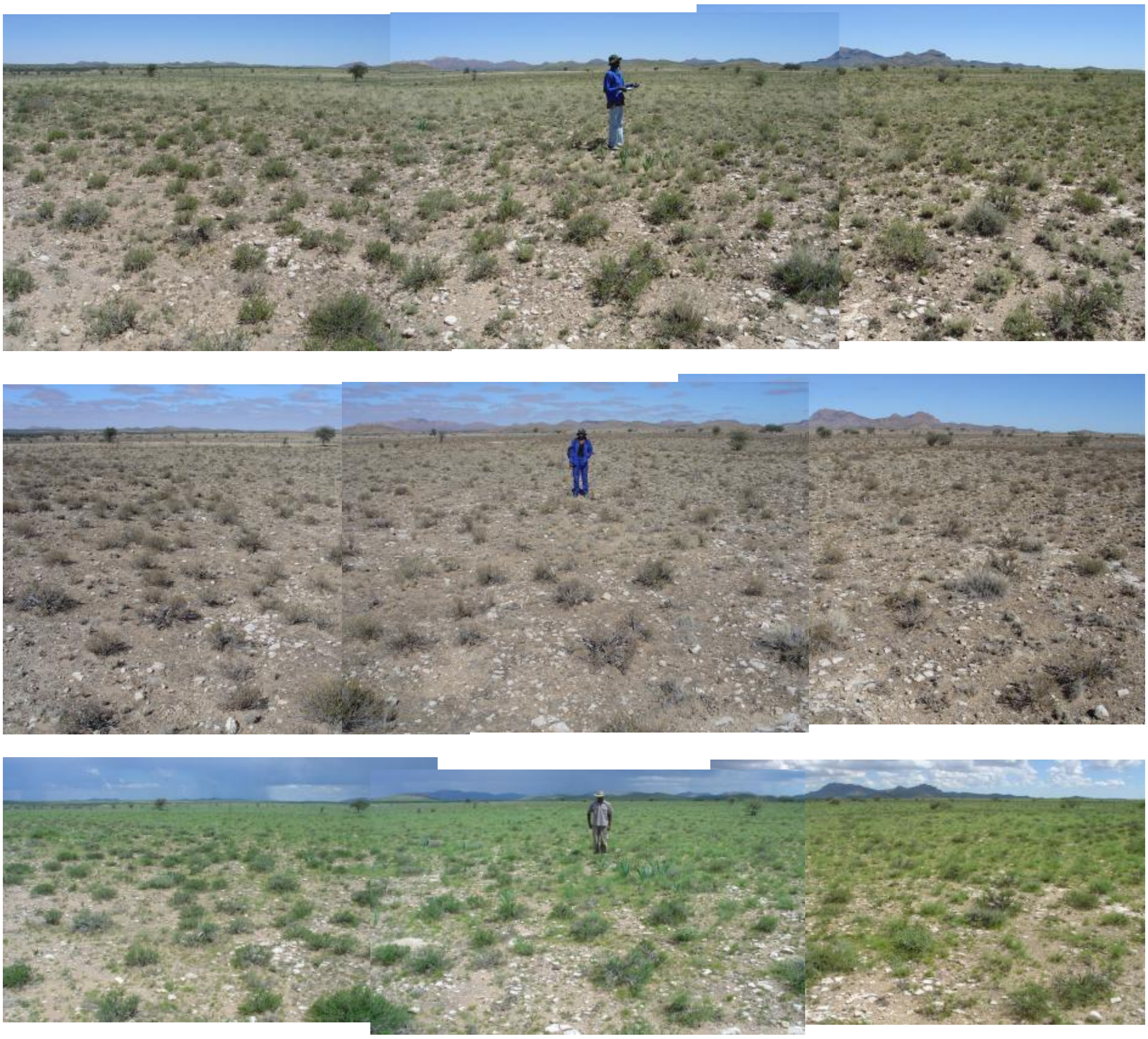


Figure 6.24 Successive views of the experimentally grazed and rested plot on the continuously grazed and heavily stocked farm taken in 2005 (CG 05, top), 2007 (CG 07, middle), and 2008 (CG 08, bottom).

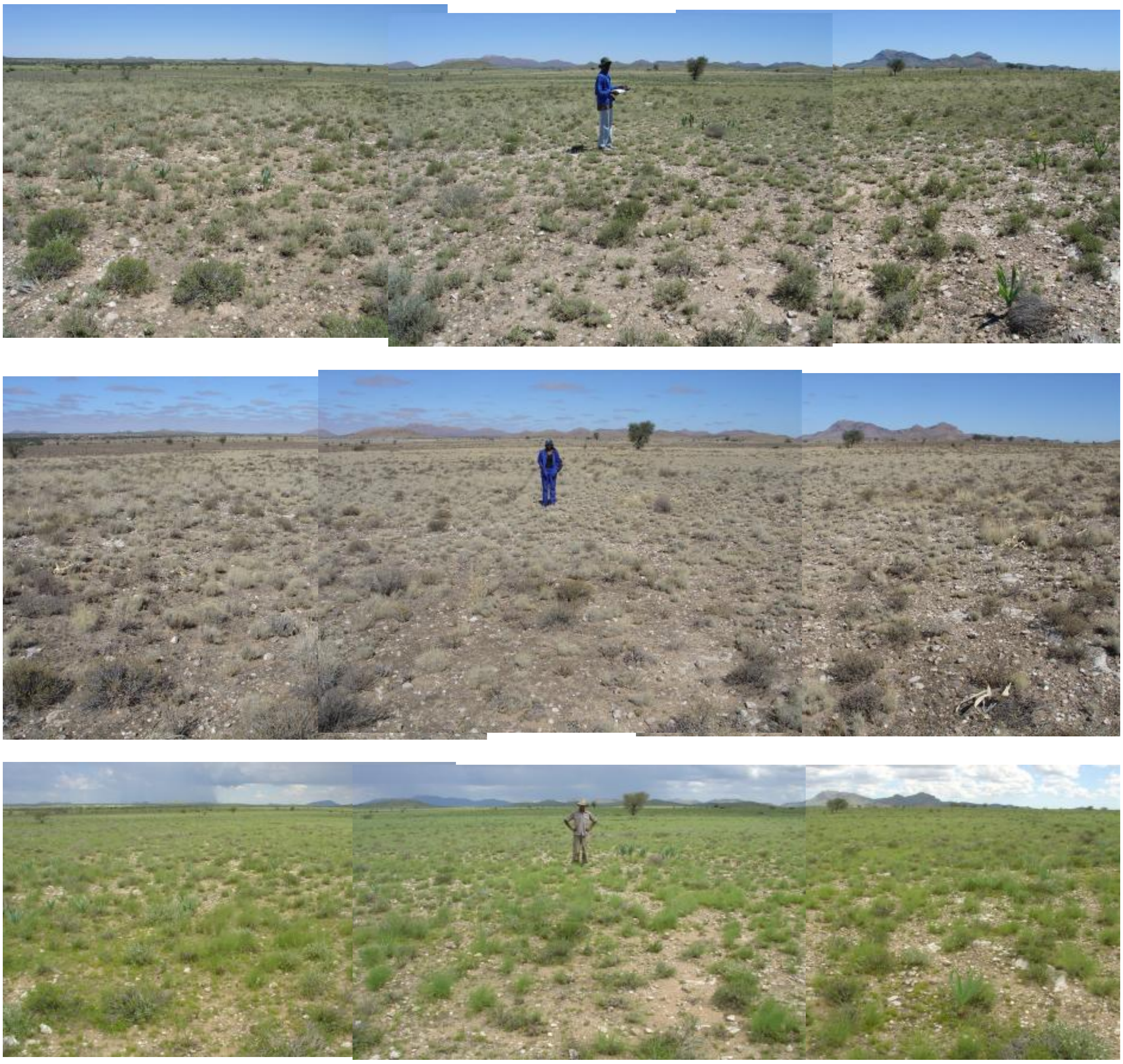
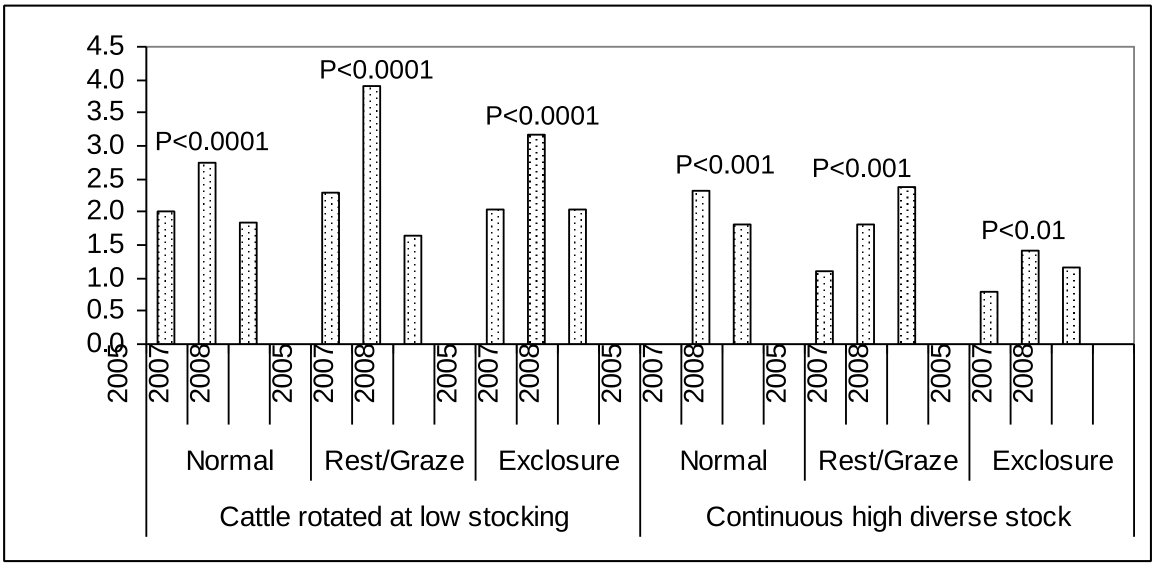


Figure 6.25 Successive views of the exclosure plot on the continuously grazed and heavily stocked farm taken in 2005 (CE 05, top), 2007 (CE 07, middle), and 2008 (CE 08, bottom).

The high degree of heterogeneity in the area resulted in differences between the three plots per farm at the time of the baseline measurements when they had received similar treatment (Table 6.5). Unfortunately, this heterogeneity could not be dampened by replicating the experimental plots, so a different focus of analysis was required. Due to the large variation in annual rainfall, the change over time within a plot is more likely to be the consequence of changing rainfall than of grazing treatment. Therefore, the effects of treatments are better analysed by assessing differences in the patterns of change each plot experienced over time.

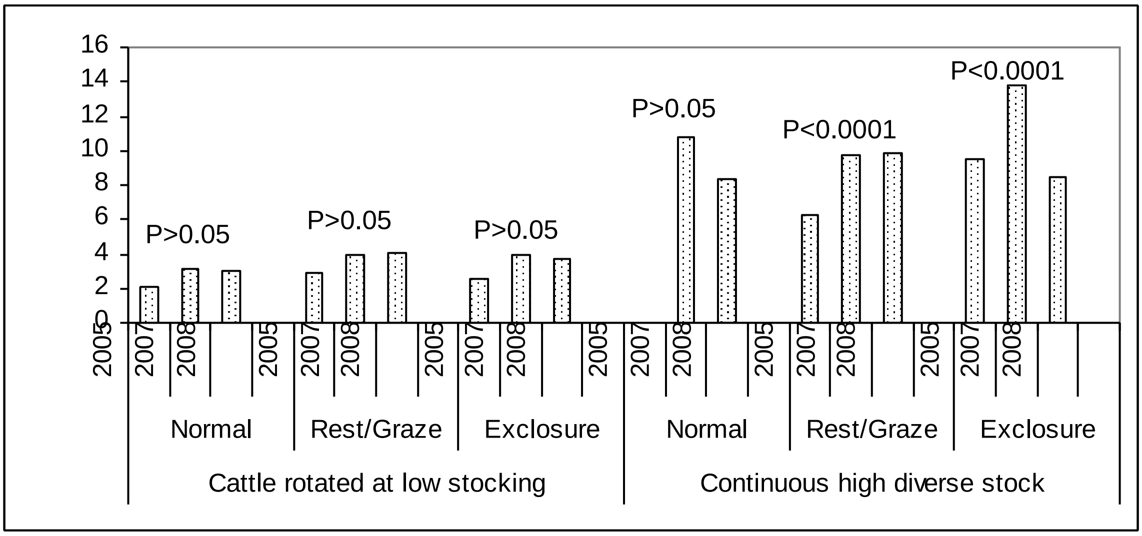
From Table 6.5 it is clear that on the rotationally grazed farm the only significant ($P<0.05$) changes over time were evident in the organic cover of the soil and density of dwarf shrubs. The pattern of change was similar for all three plots, therefore no difference could be attributed to treatment. This is not surprising given the very low stocking rates and long periods of absence applied. The organic cover of the soil decreased on all three plots between 2005 and 2008, possibly due to the reduction in stocking rate compared to the pre-2005 period. In the case of the dwarf shrubs, density increased between 2005 and 2007, but then decreased again by 2008 - probably a reflection of the previous season's rainfall. The perennial grass density (No P) followed a similar pattern, but on all three plots the differences were not significant (P>0.05).

On the continuously grazed farm significant (P<0.05) changes occurred over time in (i) the density of dwarf shrubs on all three plots; (ii) density of perennial grasses (No P) on the grazed and rested plot and the exclosure; (iii) cover of biological soil crust on the grazed and rested plot only; and (iv) distance to nearest perennial grass (DistP) on the exclosure only. The patterns of change could only be compared for the two variables that indicated significant (P<0.05) changes between two or more plots. In the exclosure the pattern of change in dwarf shrub density was similar to those in all three plots on the other farm, with a peak in the 2007 records. In the normally grazed plot the pattern of decline from 2007 to 2008 was similar, while the pattern before 2007 could not be discerned due to lack of 2005 data. However, for the grazed and rested plot the pattern differed (Figure 6.26), indicating a steady increase in dwarf shrub density between 2005 and 2008. A similar difference in pattern was evident for perennial grass density (Figure 6.27).



The level of significance in the differences over the years within each plot is indicated by the P-values.

Figure 6.26 Density of dwarf shrubs on each of the experimental plots in the Highland Savanna over three years. There were no data in 2005 for the normal plot on the continuously grazed farm.



The level of significance in the difference over the years within each plot is indicated by the P-value above each.

Figure 6.27 Density of perennial grasses on each of the experimental plots in the Highland Savanna over three years. There were no data in 2005 for the normal plot on the continuously grazed farm.

The difference in patterns suggests that both dwarf shrubs and perennial grasses were increasing in the rested and grazed plot on the continuously grazed farm. This can be attributed to the long rest periods, interspersed with stimulatory grazing, received since 2005. Visually the tussocks of *Stipagrostis obtusa* appeared to be more vigorous (Figure 6.24), although no formal measure of vigour was attempted. On the other hand the sharp decline in the perennial grasses on the CE exclosure from 2007 to 2008 suggests that they were starting to suffer from over resting. Visually the tussocks of *Stipagrostis obtusa* appeared to be more moribund in the southern half of the exclosure (Figure 6.24), while on the northern half the activity of harvester termites appeared to have removed many of the dead leaves from the grasses, possibly preventing them from becoming moribund.

Figure 6.28 Responses of the grass *Stipagrostis obtusa* to the treatments in the experimental plots on the continuously grazed farm, with weak regrowth in the normally grazed plot (CN 08, left); vigorous regrowth in the rested and grazed plot (CG 08, middle); and moribund in the exclosure (CE 08, right). The photographs were taken in March 2008, before the rested and gazed plot was to be stocked and when the exclosure had received rest for over three years.

The 2007 decrease in biological soil crusts on the plot that was rested and grazed, is likely to have been the result of stocking primarily with cattle one month before the measurements, whereas at other times the stocking was primarily with sheep. Observations suggested that the trampling by sheep did not damage these hard crusts as easily as cattle trampling.

6.7 RELATIONSHIPS BETWEEN VARIABLES

Relationships were tested between variables measured at different contrasts, for which the comparability of the data needs to be borne in mind. Measurements had been taken by different groups of students at different contrasts, hence the results were less useful for comparison between contrasts than between sites at the same contrast, as pointed out in sections 3.5.6.1 and 4.2.1. In the case of the composite variable “Rangeland condition index”, it had not been related to benchmark sites and it too was therefore less suitable for comparison between contrasts than between sites at the same contrast (section 3.5.5)

6.7.1 Perennial grass and dwarf shrub variables

The relationships tested between perennial grass and dwarf shrub measurements across sites were between two dwarf shrub variables and five perennial grass variables. The perennial grass variables were median distance to nearest perennial grass (DistP); the mean density of perennial grasses from No P; the rangeland condition score; the percentage of points with no perennial grass within 1 m; and the percentage of mesophyte species among the perennial grasses. The latter two underwent log transformation to improve normality of distribution and linearity of the relationship for testing by tested by product moment correlations (Dytham, 2003). The dwarf shrub variables were the density of dwarf shrubs; and the percentage of palatable species among the dwarf shrubs; both of which remained untransformed.

The relationships between the dwarf shrub and perennial grass variables were weak (Table 6.10). Although there was a slight tendency of less perennial grass with more dwarf shrubs, the rangeland condition seemed to improve with more dwarf shrubs, especially the palatable species. This may be due sites with more dwarf shrubs also being dominated by the grass *Stipagrostis obtusa.* Although xerophytic, it was allocated the highest relative index value of 10 in the rangeland condition scoring (section 3.5.5.)

Table 6.10 Results of product-moment correlations between dwarf shrub variables and perennial grass variables from the sites measured at fenceline contrasts and experimental plots in the Highland and Dwarf shrub Savannas.

	Variables related to dwarf shrubs	
Variables related to perennial grasses ↓	Density of dwarf shrubs	% palatable species among dwarf shrubs
Distance to nearest perennial grass (DistP)	r = 0.5602 P = 0.002 n = 27	r = 0.3400 P = 0.083 n = 27
Log % Bare (points with no perennial grass within 1 m)	r = 0.3180 P = 0.106 n = 27	r = 0.1718 P = 0.392 n = 27
Number of perennial grasses (No P)	r = −0.2754 P = 0.193 n = 24	r = −0.1140 P = 0.596 n = 24
Log % Mesophytes among perennial grass species	r = −0.4456 P = 0.020 n = 27	r = −0.6688 P = 0.000 n = 27
Rangeland condition score	r = 0.5708 P = 0.002 n = 27	r = 0.7026 P = 0.000 n = 27

The density of mesophytic grasses failed to follow a normal distribution even after transformation. It was therefore not valid for inclusion in the product-moment correlation analyses mentioned above (Dytham, 2003). However, its scatter plots had suggested stronger negative relationships with the dwarf shrub variables. Therefore it was tested by Spearman rank-order correlation (Dytham, 2003) and the best fit was with the percentage of palatable species among dwarf shrubs (r_s = -0.5885, $P<0.01$, n = 27).

CHAPTER 7

RESULTS: FARMERS' MANAGEMENT AND PERCEPTIONS

7.1 INTRODUCTION

This chapter presents results from the interviews with the 36 farmers, described in section 3.6. Information on responses to the questions on the type of farm and its history has already appeared in the descriptions of individual contrasts, in chapters 4-6. The results presented here are mainly those that quantify frequencies of response categories, although a few relationships between numerical data are also presented. Responses to the interviews did not indicate clear differences between the farmers according to savanna types and the results were therefore grouped for all savanna types.

7.2 TYPE OF FARMER

7.2.1 Categorisation

The separation of farmers into categories of commercial and subsistence farmers, or into categories of communal, emerging commercial (or affirmative action) and established commercial farmers, is not very helpful, because most farmers on communal land are commercial to some extent. The type of land tenure was applied to some of the descriptions of individual fenceline contrasts in chapters 4-6. Due to Namibia's recent colonial past, when access to land and education was limited according to race, the categorisation of type of farmer according to race still has validity in terms of understanding some of the differences. Therefore, the 36 farmers in this study were divided into 21 white farmers, 9 black farmers and 6 Baster farmers.

The use of Chi-square analysis (Zar, 1999) to test for differences in responses between categories of farmers would be invalid in most cases, due to the small sample size leading to expected frequencies of less than five. In only three cases were significant ($P<0.05$) differences found by Chi-square tests that were justified after grouping two categories of farmers and grouping some categories of responses.

7.2.2 Proportion of working time devoted to farming

By far the majority of the interviewed farmers claimed that they were full-time farmers, with 69% of them spending at least 80% of their working time on farming (Figure 7.1). Only 25% of them spent less than half of their working time farming, mostly by holding jobs during the week and farming on weekends.

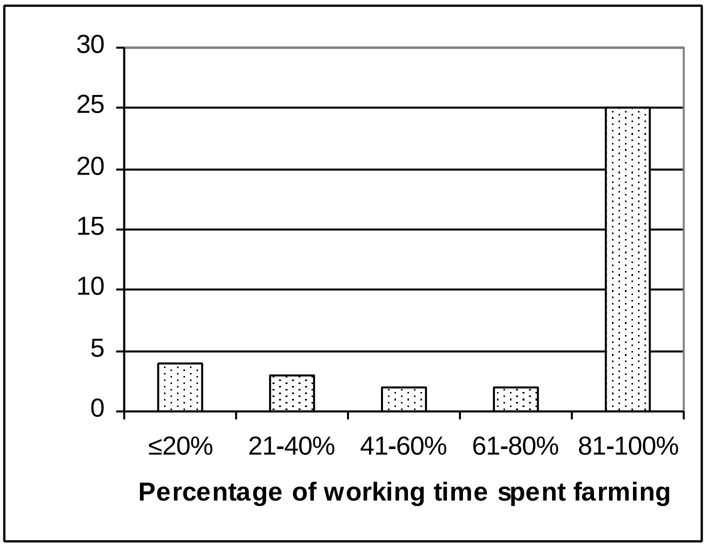


Figure 7.1 Frequency chart of the proportion of working time spent on farming by the 36 interviewed farmers.

7.2.3 Main objective of the farming enterprise

The diverse responses of the farmers to the question about their main management objective for their farming were divided into seven categories (Figure 7.2). They were fairly similar, with all seeking to benefit from the secondary productivity of the rangeland, and differed mainly in their main focus, whether on production, profit, development, sustainability or lifestyle.

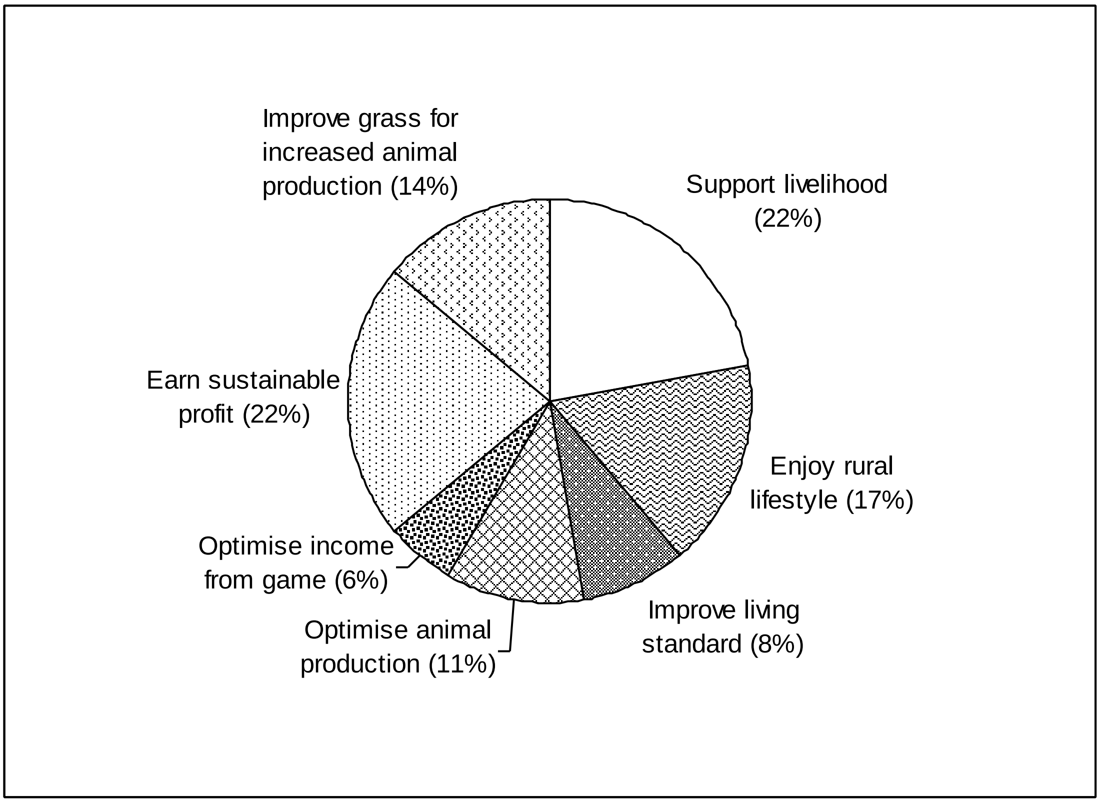


Figure 7.2 Pie chart of the main farming objectives of the 36 interviewed farmers.

7.3 TYPE OF FARM

7.3.1 Type of farming enterprises

The income of the interviewed farmers was derived from the sale of 15 categories of products and services (Table 7.1). There was also a category of "none" for the resettled farmer who had been crammed onto a former commercial farm together with many other resettled farmers who were struggling to survive and were unable to produce for the market. The most common enterprise by far was the sale of cattle, practiced by 92% of the interviewed farmers, followed by goats at 44%, sheep at 31% and trophy hunting at 19%.

Table 7.1 The products and services sold by the 36 interviewed farmers.

Items sold (products and services)	Number, of farmers, deriving income from this item	Highest percentage of any farmer's income derived from this item
Cattle	33	100
Goats	16	30
Sheep	11	40
Trophy hunts	7	70
Tourism services	4	36
Game animals	3	25
Hay	3	10
Horses	2	10
Devil's claw	2	4
Processed meat	2	3
Wood	2	1
Milk	1	2
Eggs	1	5
Charcoal	1	10
Lease of land	1	8
None	1	N/A

Cattle also contributed the highest proportion of income for the majority of the interviewed farmers (Figure 7.3). The three farmers who derived no income from cattle were two game farmers and the resettled farmer. Two of them kept cattle mainly for their own consumption of milk.

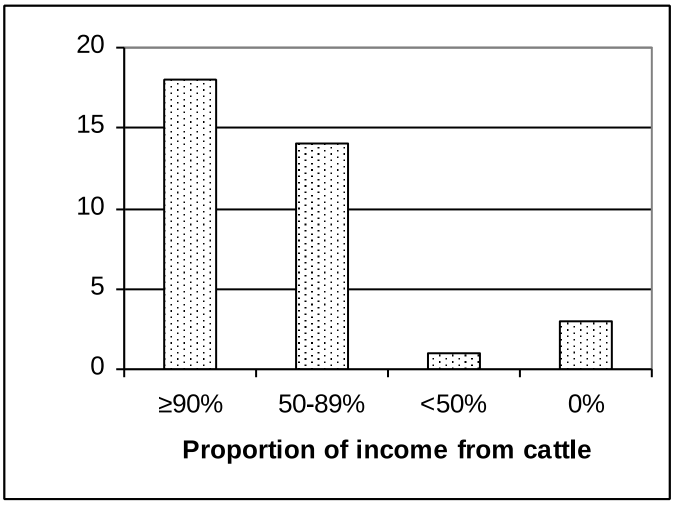


Figure 7.3 Frequency chart of the % of income derived from the sale of cattle, for the 36 interviewed farmers.

The number of different farming enterprises per farmer varied from 0 to 5 (Figure 7.4). The zero was attributed to the resettled farmer.

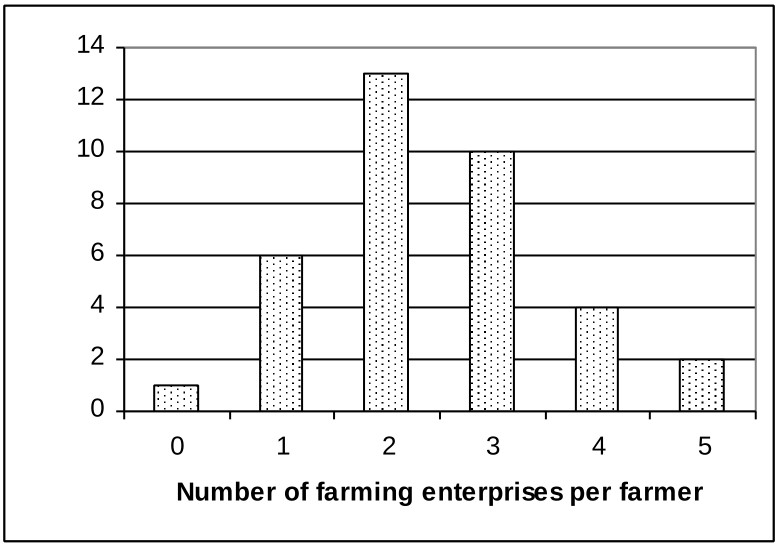


Figure 7.4 Frequency chart of the diversity of farming enterprises engaged in by the 36 interviewed farmers.

7.3.2 Infrastructure

The basic farm infrastructure at the disposal of each of the interviewed farmers is presented in Table 7.2 alongside the site numbers on which the farmers apply their management. The level of investment varied enormously. The mean paddock size per farm varied from 3 900 ha for one of the game farms to 68 ha for an intensively managed cattle farm. The mean size of area supplied per water point varied from 6 000 ha on the communal land to 2 000 ha on a poorly developed but fenced farm to 186 ha on a highly developed farm, with the median at 488 ha. The numbers of boreholes appearing as proportions in Table 7.2 are for leasehold farms sharing boreholes with neighbours, and the portion of the resettled farm. Several farmers also provided water for their animals through earthen dams, which held water for the first few weeks or months before drying up until the next rains.

All nine black farmers used only diesel to power the borehole pumps they had access to. This contrasts significantly ($P<0.0001$) with the Baster and white farmers, who used wind power, either alone or in combination with diesel, mains electricity or photovoltaic panels.

Table 7.2 Basic farm infrastructure of each of the 36 interviewed farmers.

Sites	Farm size (ha)	Number of paddocks	Number of borehole pumps powered by					Water points	Km of pipe
			Wind only	Diesel only	Wind + Diesel	Mains Electric	Solar		
1b	425	3		0.2				1	1
2a & 3a	6 184	53	3		1	2		15	19
2b	460	4		0.2				1	2
3b	400	3		0.25				1	0
4a & 5a	2 000	8	2					8	18
4b	425	4		0.2				1	7
5b	600	2		0.2				1	1
6a	375	1		0.2				1	0.1
6b, 7b, 8a&b	450	2		0.2				1	3
7a	800	3		0.5				2	3
9a	4 562	37	3			1		10	13
9b, 10a&b	4 500	25			4	2		9	10
11a,b,c & 12b	3 000	19	1			1		7	6
12a	3 144	17	3			1		17	8
13a,16a & 17b&c	5 769	50	2			4		11	18
14b & 15b	3 275	10	5			1		6	0
15a & 16b	12 441	41	15	2				21	11
17a	6 000	0		1				1	0
18a	5 900	35	17					10	12
13b,14a & 18b	3 780	17	2	3				8	4
19a & 20a	10 000	4	5	5			2	10	0
19b, 20b, 21a&b, 22a&b, 23a	6 000	88	14		1			30	18
23b, 24b, 25a, 26a	3 900	1	6					5	1.5
24a	3 860	28	5					9	8
25b	8 800	43	13			2		15	31
26b	21 000	140	18	3				23	32
27a	4 550	23	2	1			2	22	8
28b	6 997	28	4		3			30	16
29a	4 335	24	6			2		5	0
29b, 30a&b, 31a&b	3 325	26	5			2		7	5
32a	4 938	8	1	2				8	1
32b & 33a	3 000	8	1	1				2	1.8
32c & 33c	4 001	12	1	1				2	1
33b	2 476	3	1	3				2	0
34a&b	8 762	21			6			6	5
34c	4 093	7		7	1			3	0.5
Median	3 950	15	1.5	0.2	0	0	0	7	4.5

7.4 GRAZING MANAGEMENT

7.4.1 Management of stocking rate

7.4.1.1 When is carrying capacity determined?

Although farmers were asked about determination of carrying capacity for setting of stocking rates, most referred only to grazing capacity. Farmers were asked to name the most common month in which they ascertain their farm's carrying capacity. When they mentioned a range of months, the mid point between them was used to facilitate the analysis. The mid point was assumed to represent the mode, which would therefore be more comparable with farmers who named their most common month. The results are presented in Figure 7.5. The peak coincided with the end of the growing season, during April. One of the farmers who determined the carrying capacity during February did so then because it is the start of the breeding season and he adjusts his stocking rate by controlling the number of cows presented to bulls. The farmer who determined the carrying capacity in November did it because he signs contracts for the sale of animals in the following year at that time.

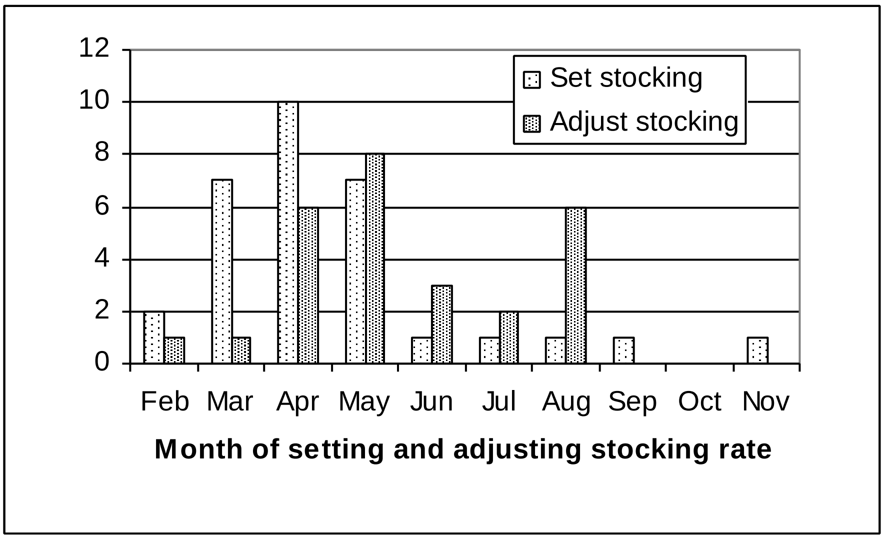


Figure 7.5 Frequency chart of the months when farmers determine the carrying capacity of their farms and subsequently adjusted their stocking rates.

7.4.1.2 When is stocking rate adjusted?

The months when farmers adjusted their stocking rates are also presented in Figure 7.5, peaking in May, followed by another peak in August. Some of the farmers who adjusted their stocking rates earlier in the year explained that they responded proactively before the effects of the change in availability of forage harmed their animals or degraded their rangeland. Some of the farmers who adjusted their stocking rates later in the year tended to apply crisis management.

The interval between the time a farmer determines the carrying capacity and the time he adjusts the stocking rate was calculated for each the 24 farmers who named both months (Figure 7.6). Seven farmers (29%) adjusted stocking rates within the same month as setting it, while five (21%) adjusted it the following month. The longer time intervals to a maximum of seven months were mainly due to the time needed to organise the marketing of the de-stocked animals.

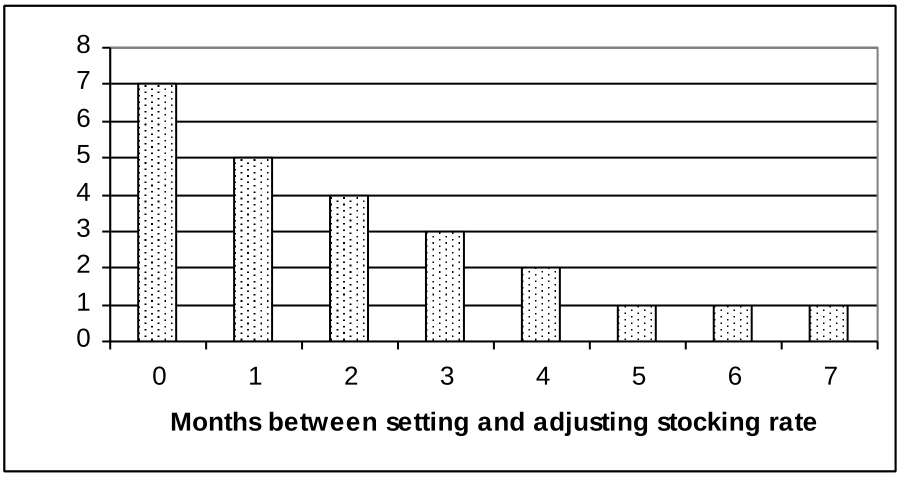


Figure 7.6 Frequency chart of the interval between setting and adjusting the stocking rate, for the 24 farmers who named the most common month for each of the two activities.

7.4.1.3 **How is carrying capacity determined?**

The main criteria that farmers used for determining the carrying capacity of their rangeland and the frequencies with which they are used, are presented in Figure 7.7.

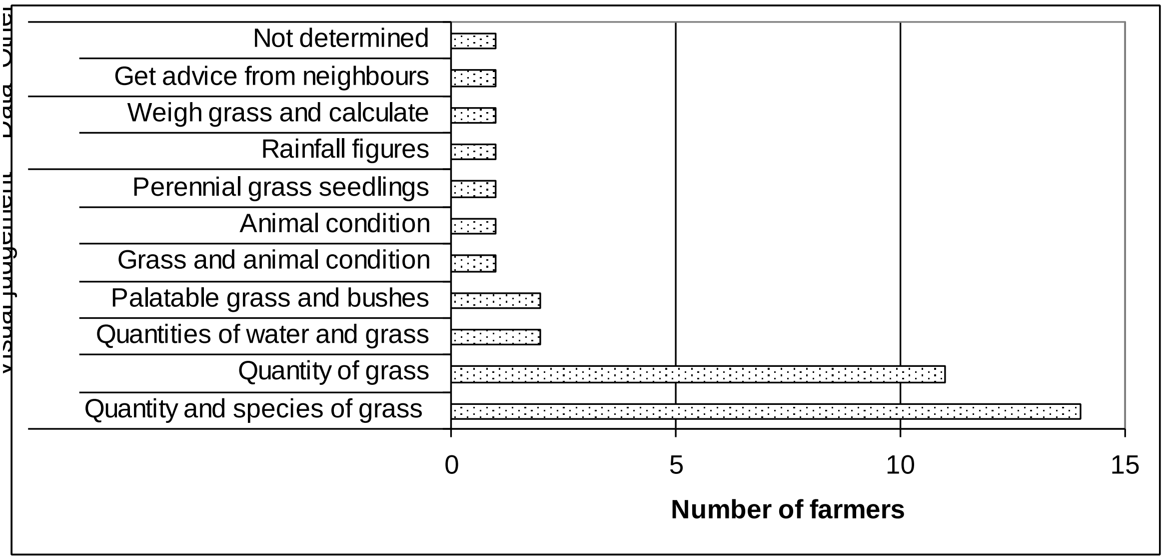


Figure 7.7 Frequency chart of the main criteria used by the 36 interviewed farmers to determine the carrying capacity of their farms.

Visual judgement, based upon experience gained, was by far the most popular approach, followed by 89% of the farmers. Of these farmers, 44% considered both the quantity and species of grass, taking account of the palatability of the species and whether they were annual or perennial, while 34% considered only the quantity of grass available on their farms. Only one farmer pointed out that poor quality grass would be grazed by his animals if sufficient lick was provided. Only two of the farmers (6%) specifically included palatable bushes in their observations, one to cater for browser game species and the other for goats. Another two farmers (6%) included the availability of water in their assessment of carrying capacity, as they had low yields from boreholes. Three farmers further added that it is important to walk through the paddocks, or go through on horseback, to get an overall impression of the rangeland, rather than viewing from the roadside.

The broad category that relied mainly on data to determine the carrying capacity was included only two of the farmers. One of them used rainfall figures of his farm, which he then related to carrying capacity through experience he had gained. The other clipped grass in 16 quadrats spread over the middle of four paddocks of his farm, for drying and weighing before calculating the grazing capacity. One of the farmers currently using visual judgement had previously clipped grass, but after a few years had gained sufficient experience to judge the grass yield fairly accurately by observation alone.

7.4.1.4 Extent to which stocking rate is adjusted

The question about the extent to which stocking rate gets adjusted was answered in many different ways by the 21 farmers who provided data. The answers only referred to downwards adjustments in stocking rates. The most consistent way the data could be analysed was to calculate the highest % reduction that farmers ever applied at any one time, usually in response to severe drought (Figure 7.8).

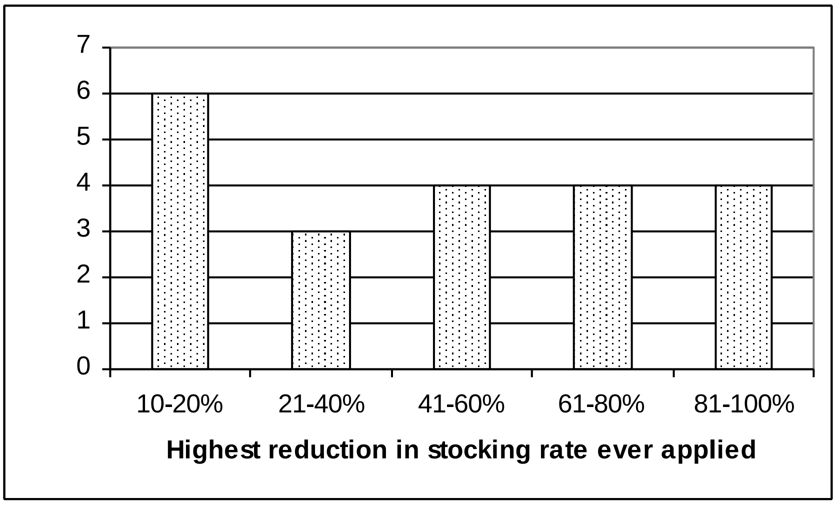


Figure 7.8 Frequency chart of the highest % reduction in stocking rate that had been applied by the 21 farmers who provided data that it could be calculated from.

Three (19%) of the farmers had removed all their cattle from the farm for a few months during a severe drought. The cattle were either taken to another of their farms or to land that had been leased. Only six (29%) of the farmers were able to limit reductions to 20% or less through conservative stocking, even during years with an abundance of grass.

7.4.2 Rangeland management strategies used by farmers

7.4.2.1 Strategies to maintain good rangeland condition

Most farmers provided a combination of strategies when asked about their main strategy to maintain good rangeland condition. In these cases the first strategy they mentioned was used for the analysis, with the results presented in Figure 7.9. The most common strategy, used by 47% of the farmers, was to limit the stocking rate, followed by 31% who provided rest in the growing season as their main strategy. The farmer who responded that he spread out his animals indicated that this strategy, applied in the dry season, prevented the concentrations of animals he considered to be the cause of erosion paths.

The farmer who responded that he tramples down uneaten grass, applied this strategy at the end of the dry season in October to *Aristida stipitata*, which in his view created a good mulch that encouraged germination of better grasses after rain had fallen. Interestingly, all responses provided long-term strategies rather than once-off measures in response to specific circumstances such as drought.

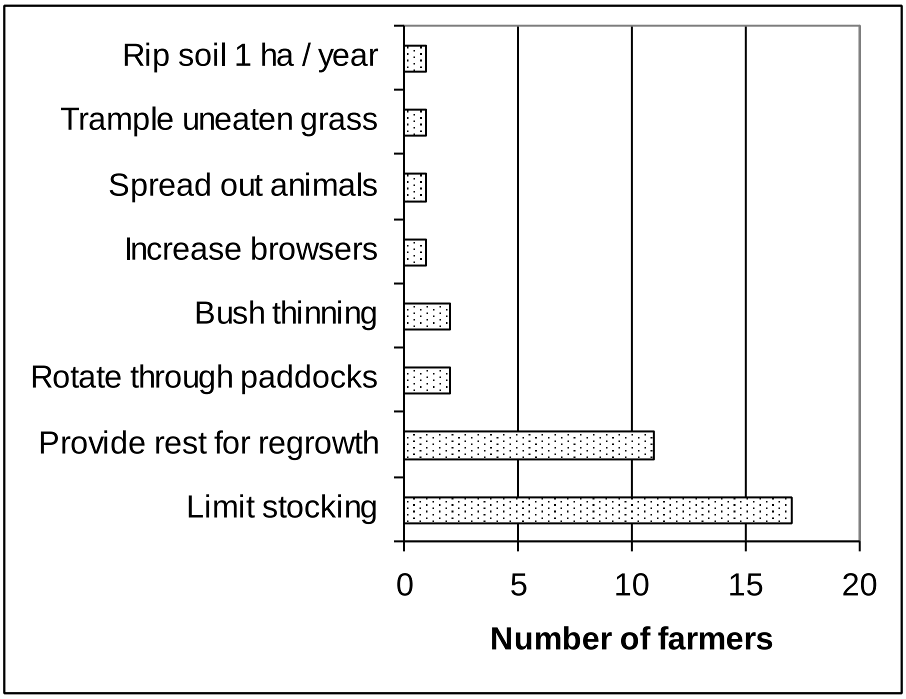


Figure 7.9 Frequency chart of the main strategies used by the 36 interviewed farmers to maintain good rangeland condition.

7.4.2.2 Proportion of rangeland rested for a growing season

The majority (64%) of interviewed farmers never set aside any portion of their farms to receive a full growing season's rest (Figure 7.10). Some added that they would have liked to, but felt they had insufficient land for their stock to do so, or that game animals would otherwise prevent those grasses from resting. Others mentioned that they considered it wasteful to leave grass ungrazed and to allow maturing into tall, less palatable material. One farmer rested 100% of his farm every second year, since his entire cattle operation was based on the speculation of weaners that took 18 months to reach the optimum size for marketing. He preferred to purchase stock after the start of the dry season and sell them before the growing season of the following year. Another farmer only applied a full growing season's rest to portions of his farm after severe droughts, to allow the worst affected paddocks to recover more rapidly.

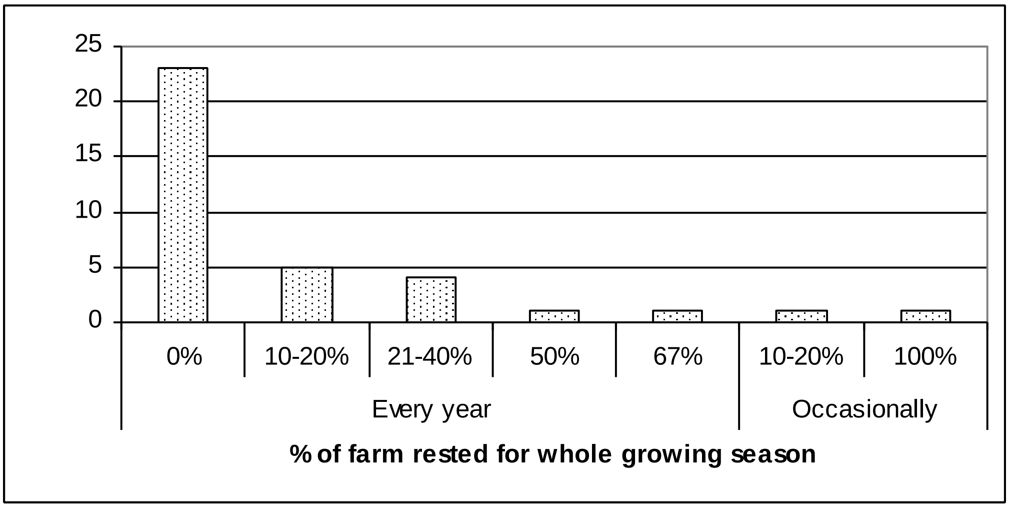
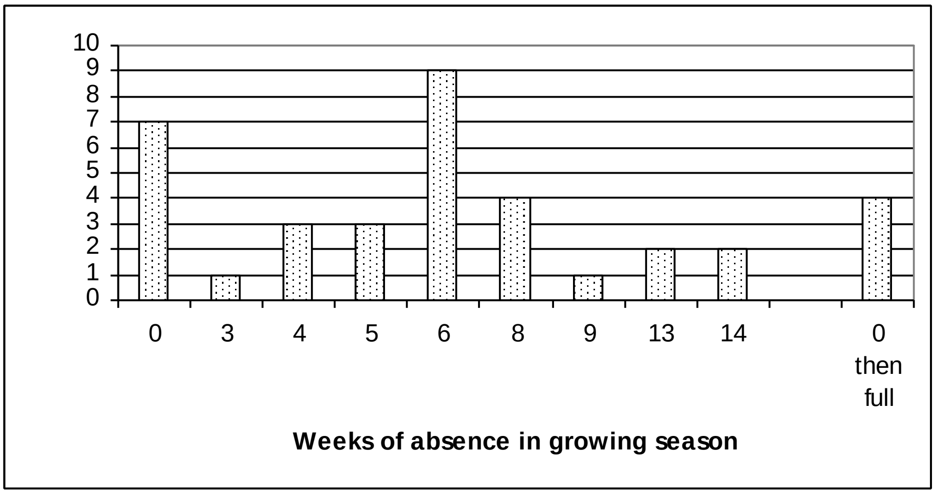


Figure 7.10 Frequency chart of the proportion of the farms rested for the full growing season every year by the 36 interviewed farmers.

The farmers who rested a portion of their farm for a full growing season used different strategies to do so. Some applied resting to the same portion every year, usually sweetveld areas that can still be utilised effectively during the dry season after maturation. Others alternated areas rested, so that all paddocks would receive a full growing season's rest every few years. The farmer who rested two-thirds of his farm for each growing season applied the fodder bank grazing system (Smit, 1998).

7.4.2.3 Average period of absence provided in growing and dry seasons

The most commonly applied period of absence by 25% of the interviewed farmers during the growing season was six weeks, while 19% applied continuous grazing (Figure 7.11).



"0 then full" = Provision of a complete growing season's rest in alternative years.

Figure 7.11 Frequency chart of the periods of absence provided in the growing season by the 36 interviewed farmers.

The seven farmers who applied continuous grazing and the four farmers who rested during alternative years were omitted from analyses of the periods of absence in the dry season. The proportions by which the period of absence changed from growing season to dry season are presented in Figure 7.12. One farmer increased the rate of rotation during the dry season, because the water supply was insufficient to allow the animals to remain in any paddock for the same period they remained during the growing season. Eight of the farmers (32%) applied the same rate of rotation during both growing and dry seasons. Nine of the farmers (36%) slowed down the rotation to provide double the periods of absence during the dry season, while seven farmers (28%) slowed down the rate of rotation even more, to provide up to five times longer periods of absence in the dry season.

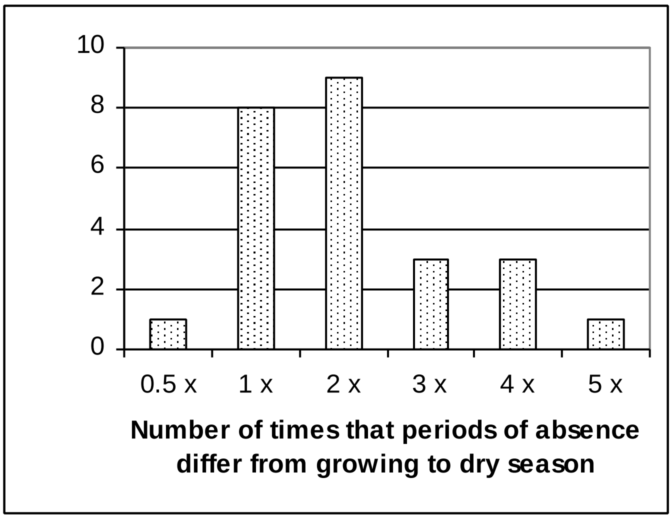


Figure 7.12 Frequency chart of the difference in periods of absence between the growing season and dry season applied by 25 interviewed farmers.

7.4.2.4 **Basis for deciding on rate of rotation through paddocks**

Amongst the 36 interviewed farmers, 29 rotated their livestock through paddocks. The criteria upon which these 29 farmers decided when to move their animals to another paddock in the growing season are presented in Figure 7.13. Nine farmers (31%) had prior experience with rates of rotation that worked well for them and they continued to apply these rates as fixed rotations. Ease to their workers in following a regular routine was mentioned as motivation for fixed rotation. Visual judgement was used by the other farmers, but focussed on different paddocks. Ten of the farmers used the extent to which grass was grazed in the current paddock to determine whether there was enough grazing or whether the grasses were grazed too short to ensure quick regrowth. Five of the farmers (17%), instead evaluated the paddock to where the animals were to be moved next, to determine whether the grasses had regrown sufficiently to replenish their growth reserves and were ready to be re-grazed. Hence they tended to increase the rate of rotation when the growth rate of grasses increased and slowed down the rotation when the growth rate decreased. Three of the farmers (10%) were limited more by the availability of water in the paddocks. They needed to move animals out of paddocks when the water supply ran out. They also had to ensure that reservoirs were filled from low yielding boreholes, or that earth dams held enough rainwater, for the animals to drink when moved to a destination paddock. Two of the farmers (7%) relied on animal condition to indicate the necessity of a shift to the next paddock, using indicators such as body conformation, bone protrusion, consistency of dung and the behaviour of the animals, such as whether they started to crowd around gates.

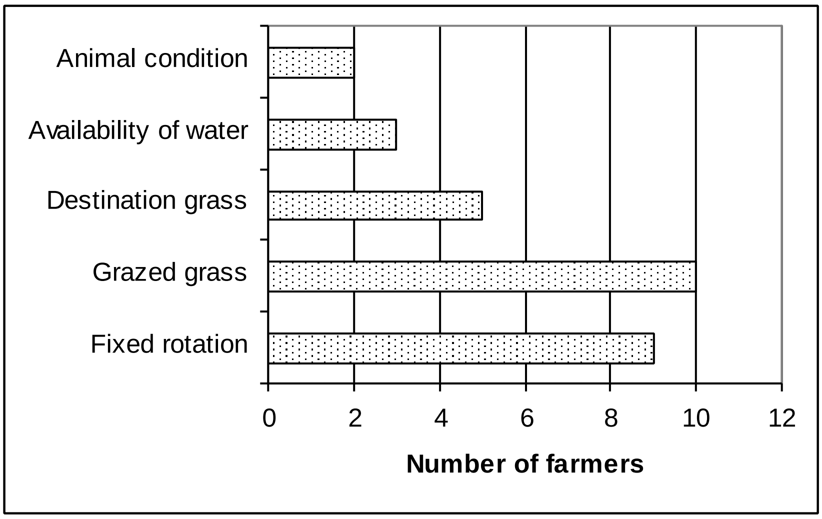


Figure 7.13 Frequency chart of the criteria used by 29 interviewed farmers to determine when to shift their livestock to another paddock in the growing season.

The criteria used for determining the dry season rotation were the same as for the growing season. The only differences occurred in some of the indicators used. One farmer moved his cattle in the dry season whenever lick consumption increased, indicating that the cattle had consumed the best quality grass and started to consume forage of poorer quality. Two farmers (7%) used browse and pod availability on bushes in the destination paddock rather than grass, which had been the main indicator in the growing season.

7.4.2.5 Strategies to minimise overgrazing when grasses are sensitive to grazing

Two questions asked farmers for their main strategy to minimise overgrazing at times when perennial grasses are more sensitive to being grazed; (i) in spring, when the growth reserves are being translocated upwards; and (ii) in autumn, when reserves are being translocated from the leaves downwards. The periods when these translocations predominate vary annually, depending on factors such as rainfall and temperature. Usually the spring translocation occurs in November or December and the autumn translocation in April. In response to the question on spring sensitivity, 14 of the farmers (39%) replied that they do not apply any particular strategy in spring, but just continue with their normal rangeland management strategies (Figure 7.14).

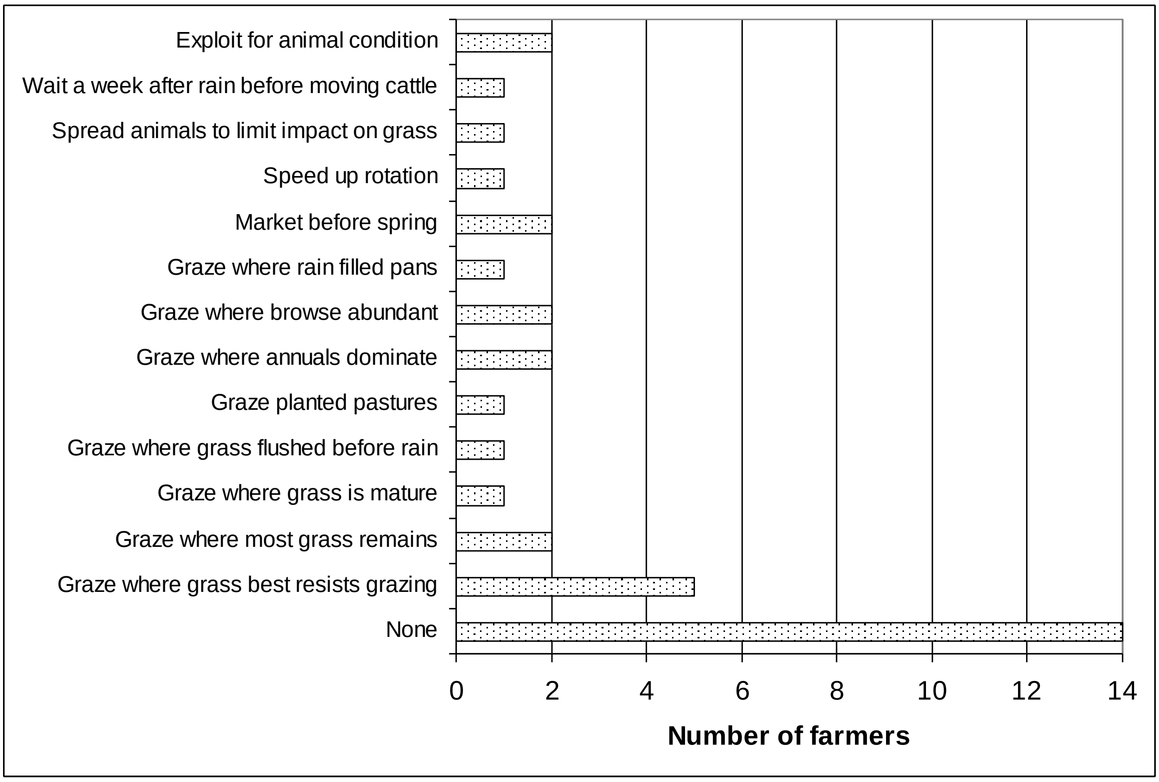


Figure 7.14 Frequency chart of the main strategy used by the 36 interviewed farmers to minimise overgrazing in spring, when the grass is sensitive to grazing.

Five (14%) of the farmers replied that they attempted to graze the paddocks in spring where the perennial grasses best resisted grazing, such as those that had rested for most or all of the previous growing season. The two farmers (7%) who preferred to graze their stock where most grass remained were more concerned about providing enough forage to their livestock than about resting sensitive grass. The farmer who preferred to graze where the grass was the oldest and most mature did so to get standing dead grass material trampled down. This occurred as the livestock walked long distances in search of green shoots providing small quantities of high quality forage. The farmer who preferred to graze his stock where grass had flushed before the rain gave the example of *Eragrostis rigidior*, which grew abundantly on the portions of his farm where soil water seemed to be well retained. This water can be used by the grass for regrowth before the rain. However, the farmer preferred to wait for rain to fall before moving his cattle to that area to ensure that they eat green forage while the grasses in the more sensitive parts of his farm were given the opportunity to re-gain vigour after flushing. Another farmer preferred to graze his cow herd with new calves on planted pastures of *Cenchrus ciliaris* in spring, in order to provide good nutrition to the calves and to reduce grazing pressure on the natural rangeland.

Two farmers (7%) preferred to graze their herds in paddocks where browse was abundant. Another two farmers preferred to graze where annual grasses and forbs were more abundant, with the objective of providing alternative forage while the perennial grasses gained vigour. One of those farmers who made use of browse pointed out that in spring the leaves were more palatable, having lower concentrations of chemicals that deter browsing. The farmer who moved his cattle to paddocks where rainwater has collected in pans was more concerned with conserving his ground water, but also pointed out that the grass growing in the vicinity of pans tended to resist grazing well. Two of the farmers timed the marketing of their saleable stock before spring, when prices tend to be good and when the rangeland benefited from the reduced grazing pressure. Two farmers tried to lessen the extent to which individual grass plants were grazed down, while increasing the number of grass plants that were grazed at the start of the rainy season. One tried to achieve this by speeding up the rotation through paddocks, while the other tried to achieve it by spreading out his cattle over the whole farm to graze where they wished.

One farmer waited a week after the first significant rain of the season before moving his livestock to the next paddock. He had only three paddocks available and wanted to ensure sufficient green growth for his stock, rather than inhibiting flushing which occurred in the currently grazed paddock. Two farmers were of the opinion that the opportunity provided by the nutritious regrowth of perennial grasses for their animals to regain condition was more important than the sensitivity of the grass, which they believed to be an exaggerated claim. Therefore, they moved their livestock to paddocks where grasses were flushing new growth.

The question to the farmers on how they limit pressure on perennial grasses at the other sensitive period, in autumn, received identical responses from 24 of the farmers (67%) to the same question about spring sensitivity. Five of the farmers (14%) who applied strategies in spring, mainly to benefit from newly flushed grass, applied no particular strategy in summer. Four farmers (11%) who preferred different strategies in spring, decided to speed up the rotation of their stock in autumn in an attempt to decrease grazing pressure. One of these farmers also pointed out that the faster rotation loosened more of the soil surface which reduced evaporation losses of soil water from the soil profile. The farmer who preferred to graze his stock in areas where grass was most abundant in spring, preferred to rest the paddocks with sweet grass in autumn, assuming that it would remain abundant during the dry season. The farmer who preferred to graze his stock in areas where *Eragrostis rigidior* dominated in spring, also preferred to alternate the paddock grazed in autumn from year to year. One of the farmers who marketed his animals before spring, added maize to the lick in autumn, mainly to maintain animal condition through the dry season. He also pointed out that starting maize additions in autumn helped to reduce pressure on the grasses during that period.

7.4.2.6 **Optimising the use of annual grasses and forbs during spring**

The strategies used by the interviewed farmers to optimise use of annual grasses and forbs are presented in Figure 7.15. Thirteen of the farmers (36%) applied no particular strategy. Eleven of the farmers (31%) increased the speed of rotation through paddocks, three farmers (8%) allowed their animals to choose where to graze and two farmers moved their livestock to paddocks where grasses predominate. This was done to allow their livestock to benefit from the annual grasses and forbs before they became dry and lost some of their nutritive value. One of these farmers would move his stock to paddocks where commando worms or ground crickets started to appear on annual plants in large numbers. His rationale was that the insects had selected the area with the most nutritious plants and he wished his livestock to benefit from those plants instead. Two farmers (6%) cut the annual grasses for hay and one kept goats near the waterpoint where annual plants predominate and benefit from the dung enriched soil. On the other hand there were four farmers (11%) who preferred to reserve annual grasses for provision of ecological services, such as nurse plants for perennial grass seedlings, mulch and fuel for fire. One of these farmers placed lick away from the water points, to reduce the grazing pressure near them.

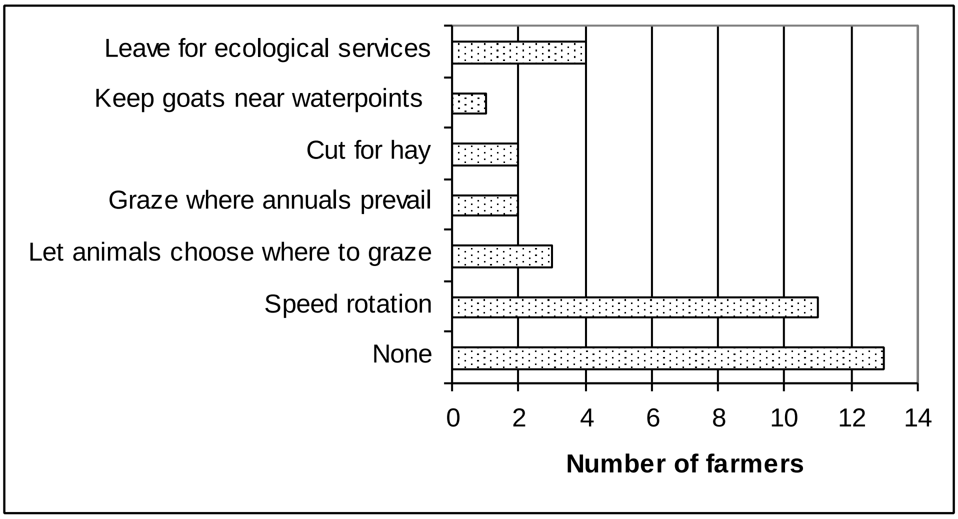


Figure 7.15 Frequency chart of the main strategy used by the 36 interviewed farmers to optimise use of annual grasses and forbs during spring.

7.4.2.7 Encouraging valuable browse species

The strategies used by the 36 interviewed farmers to encourage valuable browse species are presented in Figure 7.16. Strategies are applied by only a few farmers. Twenty five of them (69%) did not apply any strategy, either because they focus their management on grass or because they believe that they have sufficient browse species under their prevailing management.

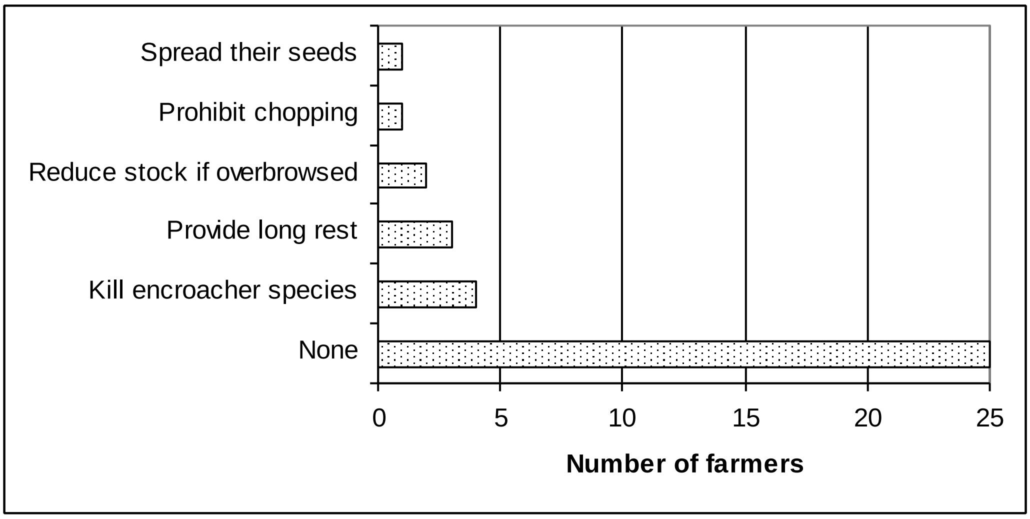


Figure 7.16 Frequency chart of the main strategy used by the 36 interviewed farmers to encourage valuable browse species.

Four of the farmers (11%) selectively killed encroacher species of bush, allowing browse species to increase. Three of the farmers (8%) provided a long period of absence to allow browsed bushes to regrow and two of the farmers (6%) used the extent of browsing on bushes as indicators of carrying capacity and reduced their stocking rates if bushes were becoming over browsed. One farmer did not allow palatable bushes to be chopped. Another farmer collected seeds of *Terminalia sericea* and *Tarchonanthus camphoratus* to spread over portions of the farm, while pods of *Acacia erioloba* were fed to cattle, which then spread the seeds in their dung.

7.4.2.8 Encouraging establishment of perennial grass seedlings

The main strategies used by the 36 interviewed farmers to encourage establishment of perennial grass seedlings are presented in Figure 7.17. Eleven of the farmers (31%) did not apply any strategy to encourage establishment of perennial grass seedlings. Seven of the farmers (19%) encouraged perennial grass seedlings by mainly applying a high stocking density of livestock for a short time followed by rest in the growing season. Five of the farmers (14%) provided a long period of absence in the growing season as their main strategy.

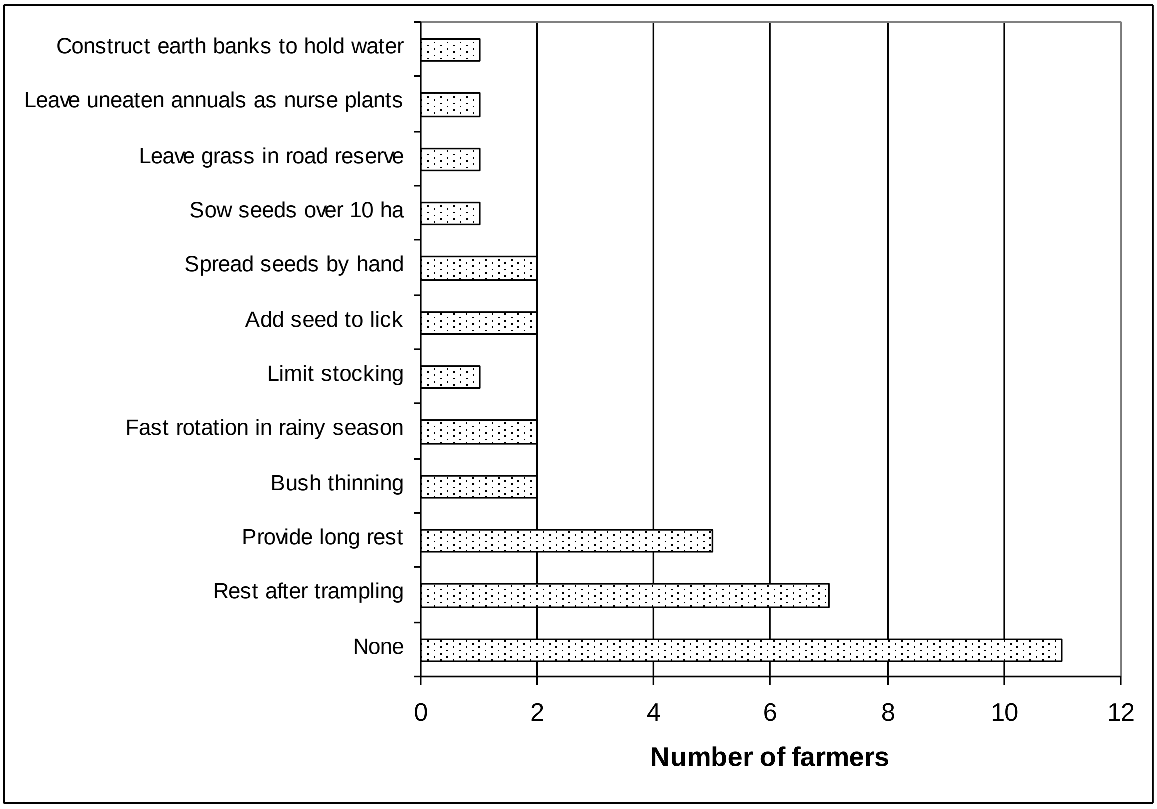


Figure 7.17 Frequency chart of the main strategy used by the 36 interviewed farmers to encourage establishment of perennial grass seedlings.

Two of the farmers (6%) considered their bush control measures to have resulted in better establishment of perennial grasses. Another two farmers applied fast rotation in the rainy season so that sufficient seeds would be produced by ungrazed or lightly grazed perennial grasses to improve their chances of establishment after the start of the following rainy season. Another farmer felt that his strategy of limiting the stocking rate achieved the same effect. Five farmers (14%) introduced additional grass seeds. Two of them scattered the seeds by hand over limited areas and two of them mixed the seeds into the lick so that cattle would spread them in their dung. The other farmer sowed seeds over 10 ha that had been lightly disked, after which he drove over the area to apply pressure to improve contact between seeds and soil. Although many farmers harvest grass in nearby road reserves for hay, one of the interviewed farmers indicated that he did not harvest the grass in the road reserve running through his farm but instead left it to produce seeds, from where some could be blown into his farm and establish seedlings. The strategy of one farmer was to avoid heavy grazing of annual grasses so that they could act as nurse plants for perennial grass seedlings to establish. Another farmer constructed earth banks where rainfall normally ran off, so that some of the water would be retained and have a chance to infiltrate the soil and improve chances for perennial grass seedlings to establish.

7.4.2.9 Control of bush encroachment

The strategies used by the 36 interviewed farmers to control bush encroachment are presented in Figure 7.18.

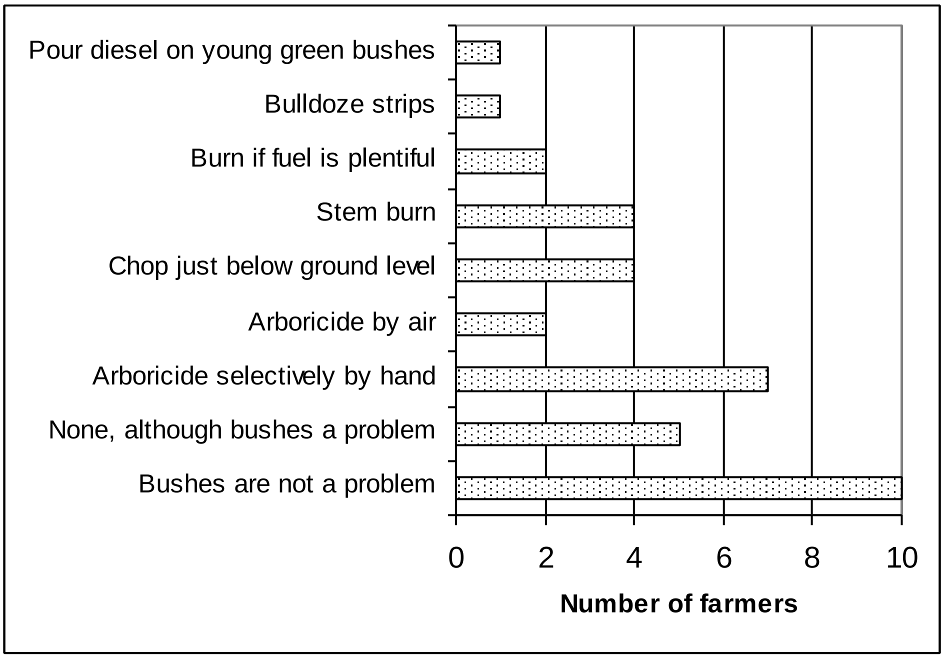


Figure 7.18 Frequency chart of the main strategy used by the 36 interviewed farmers to control bush encroachment.

Fifteen of the farmers (42%) did not apply any direct bush control, ten of them because they did not consider bushes to be a problem on their farms and five of them because they could not afford to treat the excessive bushes on their farms. Nine of the farmers (25%) applied arboricides on portions of their farms as their main strategy. Five of them did so selectively by hand, while two applied arboricide by air. Four of them chopped bushes just below ground level, and utilised the chopped bushes to produce droppers or charcoal while spreading the smaller twigs as a mulch cover over the soil. Four farmers (11%) applied stem burning around individual bushes, which was a slow process only covering a few hectares per year. Two of the farmers (6%) used fire as their main strategy to control bushes, but only after sufficient fuel had accumulated. To achieve this one of the farms required initial chopping. One farmer cleared strips of bush by bulldozer, which provided access to cattle, whereafter the bushes along the sides of the cleared strips apparently started to die. Another farmer applied diesel over the leaves of young bushes, at the rate of about 100 ml per bush, and claimed that 95% of them died.

Most of the farmers who applied direct control of bushes mentioned the importance of follow-up treatment some years later. Many of them used more than one method of control, such as using manual application of arboricide as a follow-up on bushes that regrew after chopping.

7.4.2.10 Fire as a management tool

The views held by the 36 interviewed farmers on the use of fire as a rangeland management tool are presented in Figure 7.19. Twelve of the farmers (33%) viewed fire as being harmful to the rangeland as well as wasteful of potential forage. Thirteen of the farmers (36%) considered fire to be helpful but would never use it. Seven of them held this view because it was too risky, both in terms of spreading to neighbouring rangeland and being uncertain whether the following rainy season would be good enough for the grass to recover. Four of those farmers considered conditions for a successful burn to be very rarely present, and two thought it destroyed grass that could otherwise support more animals. Two farmers considered the benefits from fire to be only temporary, causing top kill of bushes that quickly regrow from the base. Another two farmers tried burning but found that the fires were not successful in controlling bushes, probably due to insufficient fuel loads. Three of the farmers controlled bushes with fire and continued to view fire as a useful tool. Another farmer applied patch burning in order to improve the heterogeneity of the rangeland and subsequently biodiversity. Two farmers intended to apply burning when the conditions would be right, for which they were still trying to accumulate enough fuel. One farmer experienced wild fires on parts of his farm, which he was thankful for, as the bushes were reduced and perennial grasses flourished.

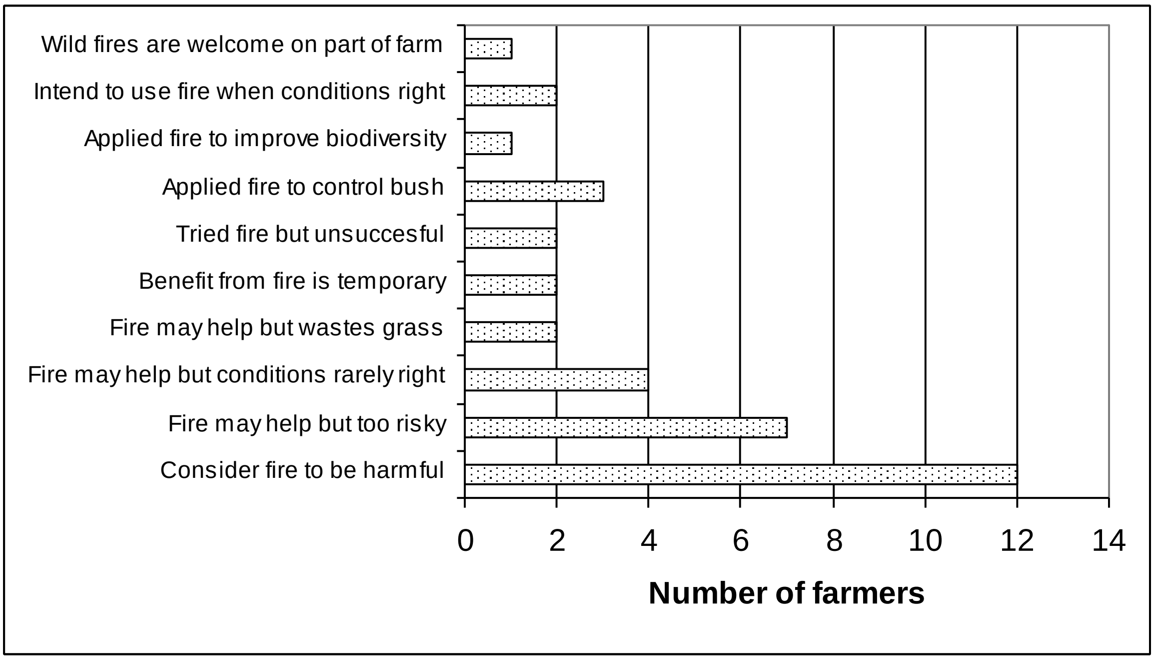


Figure 7.19 Frequency chart of the views held on fire as a management tool by the 36 interviewed farmers.

7.4.2.11 Landscape on the farm

The number of soil or landscape types recognised by the 36 interviewed farmers on their farms are presented in Figure 7.20, ranging from one to five. Most farmers (89%) recognised different soil or landscape types on their farms, with 53% of them differentiating their management accordingly, such as stocking at different rates or grazing some landscapes preferentially at different seasons.

When applying a Chi-square test (Zar, 1999) to determine significance of the increase in proportion of farmers who managed the soil or landscape types differently with increasing types from two upwards, the data for 3-5 types were lumped to ensure expected frequencies greater than five. This indicated that the difference was significant ($P<0.05$).

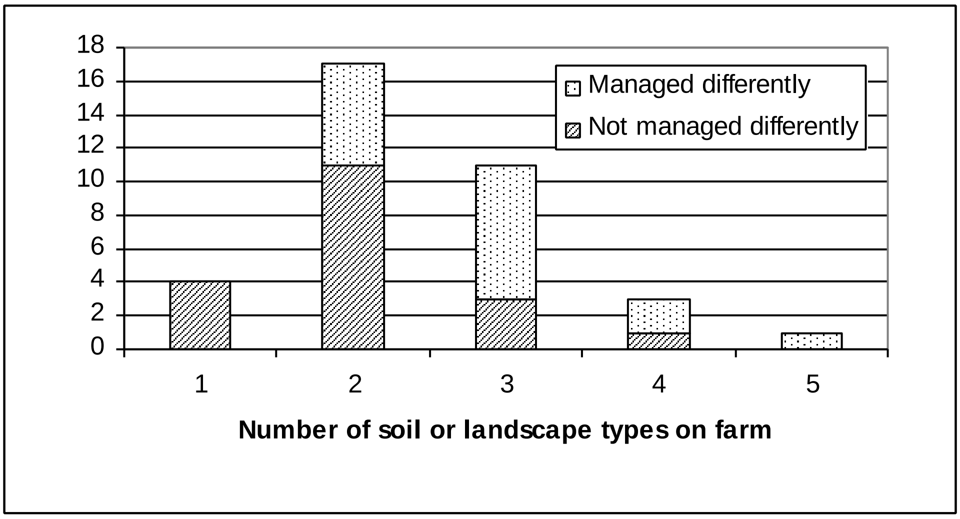


Figure 7.20 Frequency chart of the number of soil or landscape types recognised on the farms by the 36 interviewed farmers and whether they received different management.

7.5 PERCEPTIONS OF FARMERS ON BIODIVERSITY

7.5.1 Plant species

When farmers were asked to name the five species of plants they considered to be the most valuable in their rangeland, some farmers named more than five. Therefore, to avoid inclusion of species of lesser importance, only the first five mentioned were used in the analysis. A few farmers named fewer than five species, but these species were not given extra weight in the analysis. The results are presented in Figure 7.21. The species mentioned most by 61% of the farmers, was *Stipagrostis uniplumis*, followed by *Acacia erioloba*, mentioned by 44% of the farmers. In all cases the main reason given for the value of the plant species was its contribution to animal forage, with some farmers putting more emphasis on quantity and others emphasising quality more. The single farmer who mentioned *Aristida stipitata* explained that it formed the bulk of forage consumed by his livestock, even though he was aware of its poor quality. This farmer also mentioned *Acacia mellifera* as being very valuable to him, again because its leaves were consumed by his livestock. Another farmer who mentioned *Acacia mellifera* indicated that it allowed his livestock to survive during severe droughts, when they sought out the bushes to pick up fallen leaves from the ground. Other reasons mentioned by farmers why they value some tree species, secondary to the forage value, included the provision of fencing droppers and aesthetic value. No mention was made of ecological services provided by the plants.

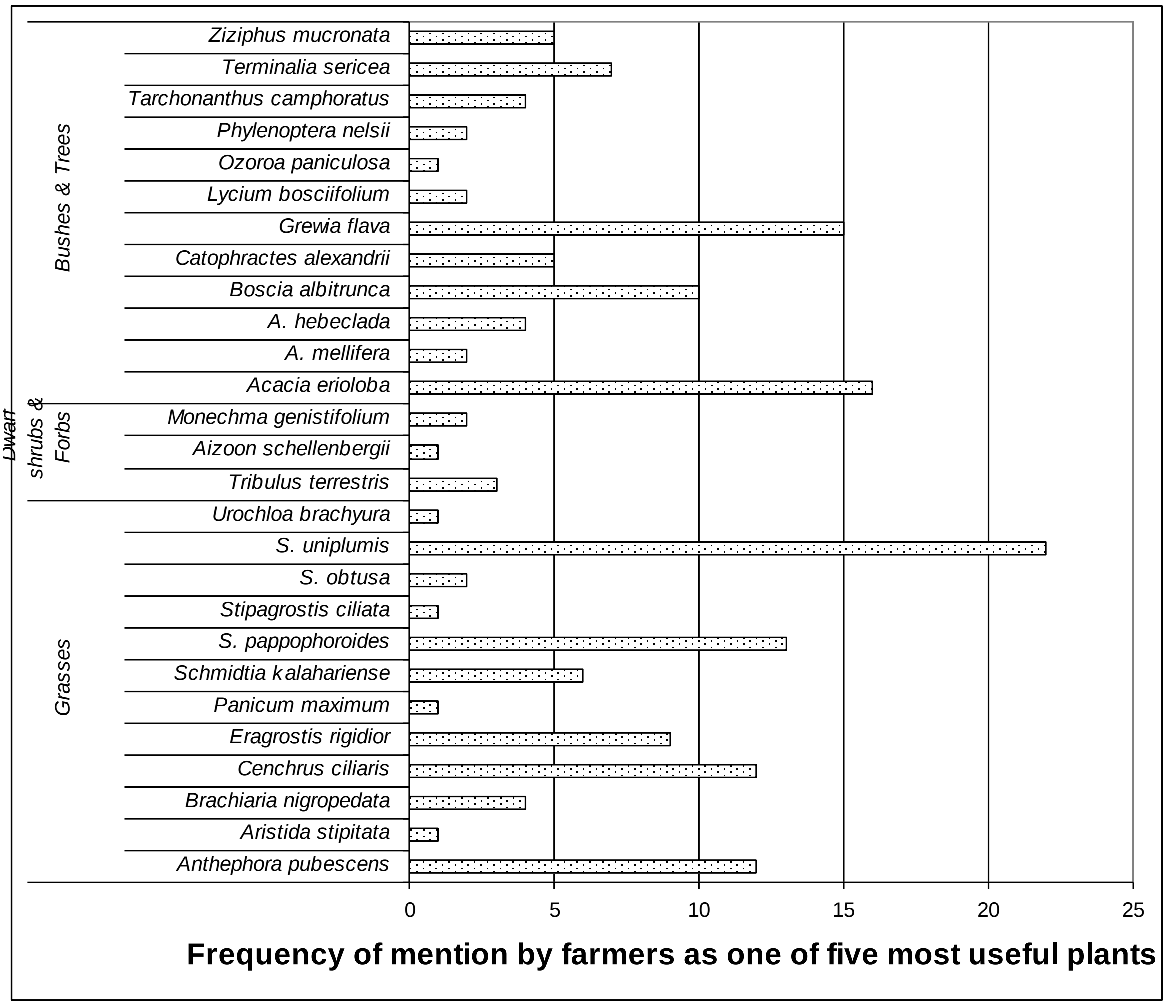


Figure 7.21 Frequency of the five most important plants mentioned by the 36 interviewed farmers.

The results of the response by farmers to the question of which five plant species are the most harmful to them are presented in Figure 7.22. Three farmers (8%) expressed the opinion that no plant species was harmful to them and pointed out that all species played a useful role in maintaining rangeland health. The species that received the most mention, by 61% of the farmers, was *Acacia mellifera*, followed by *Acacia hebeclada* (39%) and *Acacia luederitzii* (33%). In fact, 82% of the plant species mentioned were bush species and the reason given for all of them was that they encroached and outcompeted grasses. The non-bush species that received most mention was *Drimia sanguinea*, commonly known by its Afrikaans name of slangkop, mentioned by 31% of the farmers. The main reason given for this choice of non-bush species was that it was poisonous to livestock, followed by unpalatable plants that outcompeted valuable grasses. Most of the farmers who included slangkop in their list of harmful species mentioned that they had experienced livestock losses as a result of this plant. One of the farmers added that he tried to strengthen the immunity of his livestock against the plant by placing a bulb of it in their drinking water.

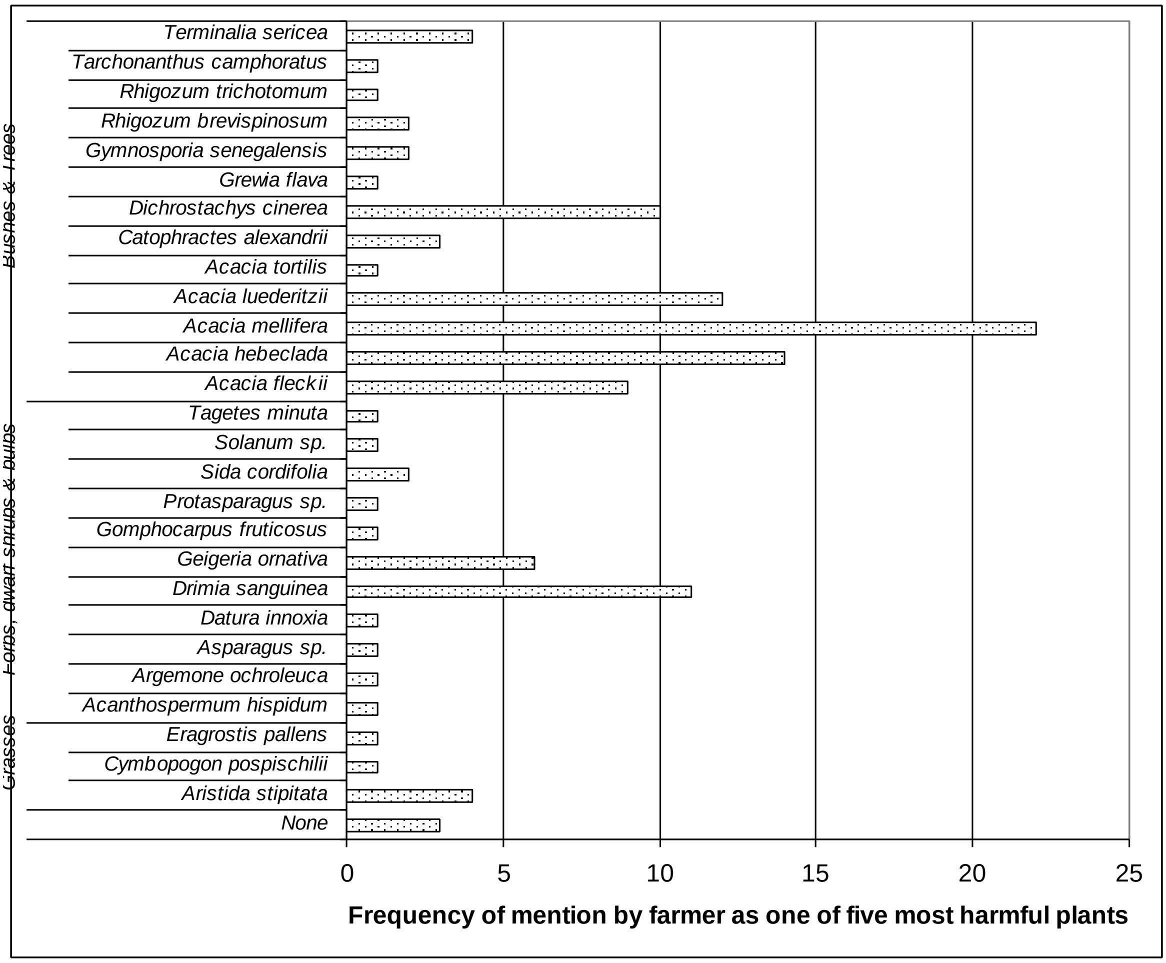


Figure 7.22 Frequency chart of the five most harmful plants mentioned by the 36 interviewed farmers.

Six species were mentioned as both one of the five most useful plants and one of the five most harmful plants, although not by the same farmer. This applied to *Acacia mellifera, A. hebeclada, Catophractes alexandrii, Grewia flava*, *Terminalia sericea* and *Aristida stipitata*. The view on specific bush species as useful or harmful was likely related to the abundance of the species on their specific farms, with farmers listing the species as harmful, having an overabundance of the plants and all but one of the farmers listing the species as of value to them having a better balance of these species in relation to other species. The exception was the farmer who mentioned both *Acacia mellifera* and *Aristida stipitata* as valuable plants, since he had an overabundance of them in relation to other species to the extent that his livestock had little choice but to consume large quantities of them.

7.5.2 Insect types

Two of the interviewed farmers did not respond to the questions on insects and birds. The results of which insect species were most beneficial applied to the 34 farmers who responded and are presented in Figure 7.23. Fourteen of the farmers (41%) expressed the opinion that no insect was useful to them. Eleven farmers (32%) considered the dung beetle as their most useful insect, for its role in fertilising the soil, followed by seven farmers who named the honey bee, for its role in pollinating plants and/or providing honey. One farmer named the harvester termite for its role in fertilising the soil and feeding other species such as guinea fowl that in turn provided services, such as scratching the soil and controlling the population levels of other insects. There was also a farmer who replied that all species of insects were valuable to the rangeland.

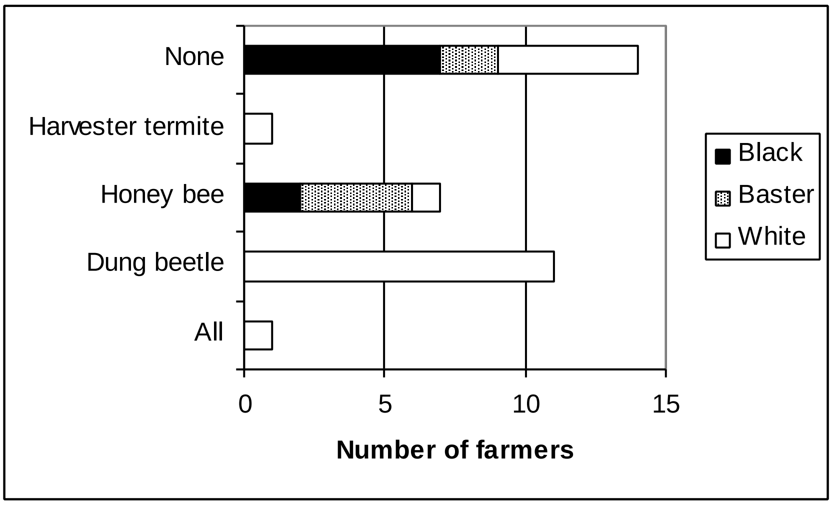


Figure 7.23 Frequency chart of the insect considered the most valuable to the 34 interviewed farmers that answered this question, divided according to race.

The responses to the question differed according to race, with all farmers who named the dung beetle being white. To determine the level of significance by Chi-square test (Zar, 1999) the responses from farmers who were Baster and black were grouped, as were the responses other than dung beetles. The difference in dung beetle response was significant ($P<0.001$).

The results from the response by farmers to the question on which insect is most harmful to them are presented in Figure 7.24. There were four farmers (12%) who expressed the opinion that no insect species was harmful to them. Nine of the farmers (26%) named the tick, although not strictly an insect, as being the most harmful to their livestock, with three farmers naming the horse fly as harming their livestock. Fifteen farmers (44%) mentioned insects that harm the rangeland, by consuming forage, namely harvester termites, commando worms, ground crickets and locusts. Three farmers chose insects that harm, or are a nuisance to humans, namely mosquitoes and wasps.

The harvester termite received mention as both the most useful insect and the most harmful insect, although not by the same farmer.

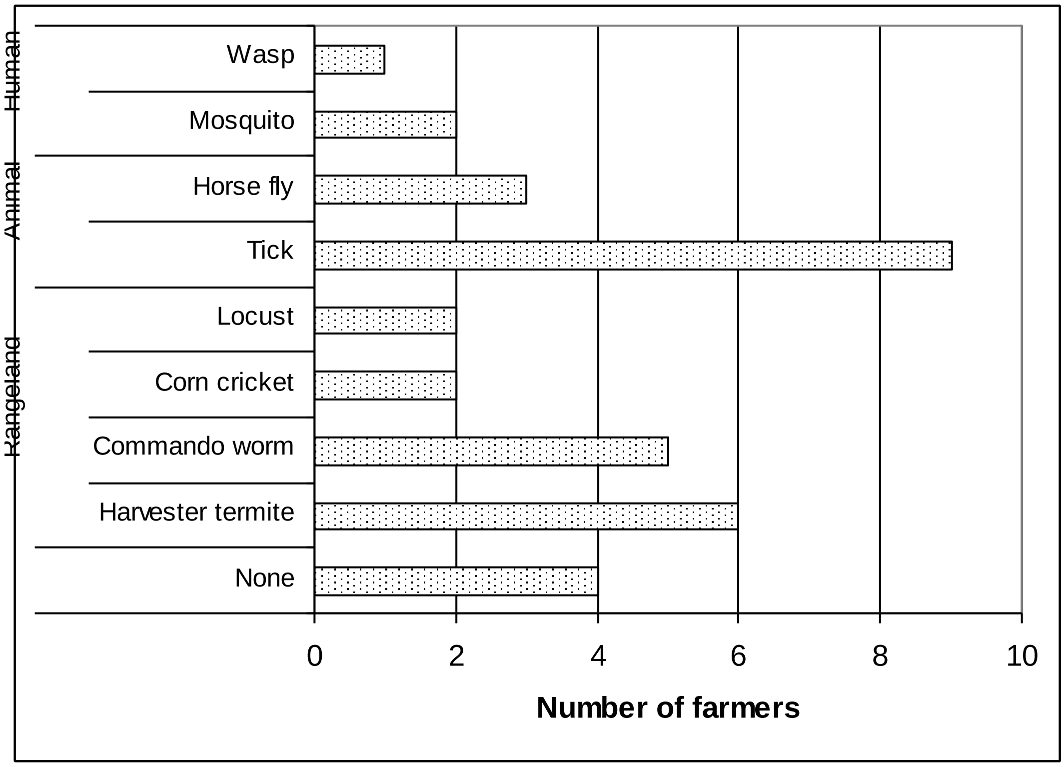


Figure 7.24 Frequency chart of the insect perceived to be the most harmful to the 34 interviewed farmers that answered this question, according to where the harm is considered to occur.

7.5.3 Bird species

The results from the response by farmers to the question on which bird species is of greatest benefit to them are presented in Figure 7.25. Four farmers (12%) expressed the opinion that no bird was beneficial to them, and another four claimed that all birds were useful. Eleven of the farmers (32%) chose the vulture as their most useful bird, mainly for cleaning up carcasses to reduce transmission of diseases such as botulism, and also to indicate where carcases lay in the veld, which assisted the farmers to retrieve the meat and/or trace predators that may have caused the deaths. The vulture was not named by species, although the most common vulture species in the study area is the white-backed vulture. Six of the farmers (18%) chose the guinea fowl as their most useful bird, not only for providing meat but also for controlling insects such as harvester termites and commando worms, and for scratching the soil surface. Other birds considered useful for controlling populations were the cattle egret and cape glossy starling, which control ticks and the secretary bird that controls snakes. Birds that were chosen for their aesthetic value were the saddlebill stork and bateleur eagle. Although no specific bird species was mentioned, one farmer expressed his belief that fruit eating birds play an important role in controlling bushes, by spreading seeds of mistletoe that weakens the bushes it grows on.

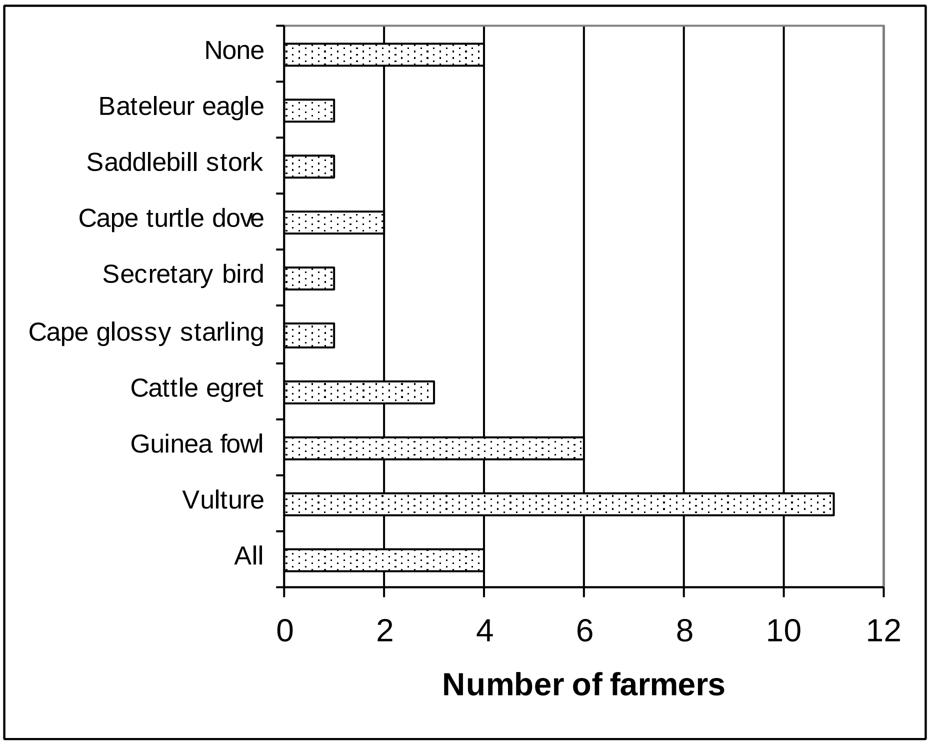


Figure 7.25 Frequency chart of the bird considered the most valuable by the 34 interviewed farmers that answered this question.

The results from the response by farmers to the question on which bird species is most harmful to them are presented in Figure 7.26. Half of farmers expressed the opinion that no bird species was harmful to them, some adding that all bird species have a role to play in maintaining a healthy rangeland. Nine of the farmers (26%) named bird species that they considered harmful in the rangeland, namely eagles that predate on lambs and kids, guinea fowl that feed from lick intended for livestock, buffalo weavers that build nests in windmills, cattle egrets that make a mess under the trees they roost in and vultures that steal meat from carcasses that could otherwise be used by humans or dogs. Eight of the farmers (24%) named birds that are harmful around the homestead, namely yellow-billed kites that predate on chicks, and cape glossy starlings, red-eyed bulbul, grey louries and red-faced moosebirds that damage fruits growing in orchards or alone.

Four bird species received mention as both the most useful bird and the most harmful bird, although not by the same farmer. They were the guinea fowl, cape glossy starling, cattle egret and vulture.

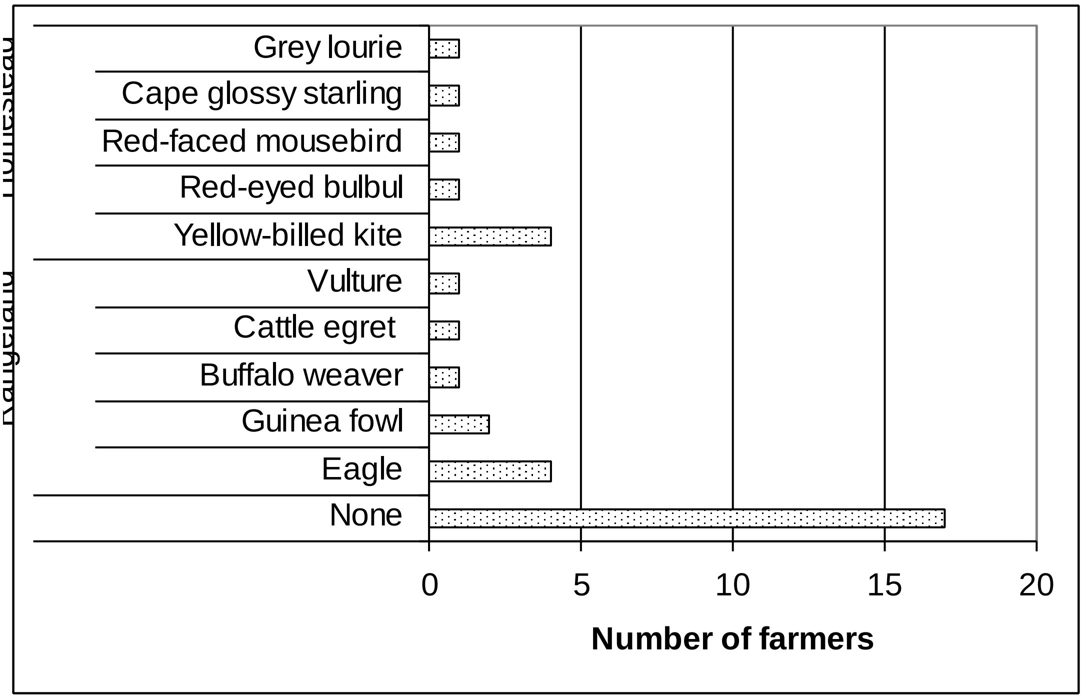


Figure 7.26 Frequency chart of the bird perceived to be the most harmful by the 34 interviewed farmers that answered this question, according to where the harm is considered to occur.

7.6 ANIMAL MANAGEMENT

7.6.1 Strategies to attain good animal condition

Most farmers provided a combination of strategies when asked about their main strategy to attain good animal condition. In these cases the first strategy they mentioned was used as their main strategy for the analysis, with the results presented in Figure 7.27. The most important main strategy given by 44% of the farmers, was to provide the animals with sufficient lick. The main strategy of four farmers (11%) was to supplement their animals with fodder, such as crushed pods of *Acacia erioloba* or hay. Eleven of the farmers (31%) considered their light stocking rate as their main strategy, ensuring sufficient natural grazing for their animals. Four farmers (11%) considered their main strategy to be the frequent moves of their animals to new paddocks to optimise use of seasonally available forage, such as leaves dropping from palatable bushes and trees. One farmer considered his frequent use of veterinary inputs as his main strategy to attain good animal condition. Some farmers also mentioned their strict removal from the herd of any animal in poor condition as a supplementary strategy of attaining good animal condition. This ensured that offspring would be bred from superior animals and that forage and lick would not be wasted on poor quality animals that could not efficiently convert them to animal growth.

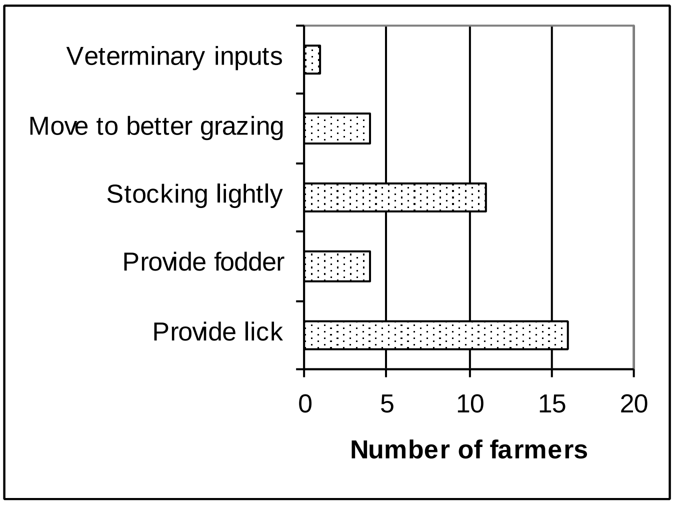


Figure 7.27 Frequency chart of the main strategy used by the 36 interviewed farmers to encourage establishment of perennial grass seedlings.

7.6.2 Kraaling of animals

The rationale of asking about kraaling of animals was to get an idea of likely consequences on re-distribution of mineral nutrients and build up of diseases. Twelve of the farmers (33%) did not kraal any of their animals, and only one kept small stock, which remained out on the rangeland to fend for themselves. The other 23 farmers (64%) that kept small stock used to kraal them every night, to protect against predators and in some cases from stock theft. One of these farmers had temporary kraals out on the rangeland, which were moved around every few days or weeks, to create nutrient hotspots scattered over the rangeland. Other farmers had their kraals near the homestead and most of them occasionally used some of the manure on their small vegetable gardens, or crop fields, while thick layers of old manure kept on accumulating in the kraals of most farmers. Another use of manure was for spreading out on bare areas of the rangeland, in the hope of improving grass growth there. This was done by two of the farmers. The sale of manure in Windhoek was done by a weekend farmer. Two of the farmers occasionally kept some cattle in kraals. One farmer did this to round off stud bulls for four weeks before selling. Another farmer, who also kraaled small stock every night, used to kraal his cows for about two weeks when calving, to protect them from predators and avoid loss of calves, such as down antbear holes.

7.6.3 Provision of licks

The farmers all mixed various ingredients to make their own licks, with different ratios for summer and winter. The ratios and ingredients differed considerably among farmers, and no attempt was made to categorise them. A form of phosphate lick, mixed with salt, was usually given during both winter and summer. Winter lick usually included a source of concentrated energy, such as molasses or maize, and a source of nitrogen, such as urea or crushed pods of *Acacia erioloba*. Other types of ingredients added by some farmers included fish oil, vitamins and sulphur.

The amounts of lick provided and consumed also differed tremendously among farmers. For farmers who provided lick *ad lib* and kept records, the lick consumption varied from 10 g AU^{-1} day^{-1} of phosphate lick alone during summer to 750 g AU^{-1} day^{-1} of mixed lick during winter.

7.6.4 Veterinary inputs

The majority of farmers provided some veterinary care in addition to compulsory vaccinations. Of the 33 farmers who responded to the question, six farmers (18%) never applied chemicals to control parasites, while another two farmers (6%) only applied chemicals to dose newly bought stock. Another farmer stopped dosing animals after the dung beetles had been killed by dosing on his brother’s farm, although he still applied chemical tick control. Two other farmers noticed that dung beetles died after they had dosed their livestock. One of these stopped dosing because of it. The other restricted his dosing to the dry season to minimise the harm to dung beetles. Fifteen farmers (45%) dosed small stock regularly, between one and four times per year, compared to five farmers (15%) who also dosed their cattle. Tick control was not applied regularly, but only when tick loads were found to be high. The most common treatment against ticks was by pour-on, applied by 17 of the farmers (52%), while six farmers (18%) sprayed water soluble carbaryl or rubbed on tick oil. At least one farmer applied a pour-on to his cattle to control both internal and external parasites. Other veterinary inputs included injections of vitamins, with two of the farmers injecting vitamin A alone and another injecting a combination of vitamins A, D and E, and pregnancy testing that was done by two of the farmers, so that cows that had not conceived would be removed from the herd.

7.6.5 Breeding seasons

The majority of farmers (61%) did not apply breeding seasons for their animals. The other 14 farmers (39%) applied breeding seasons to their cattle, while only two of them applied breeding seasons to their small stock. Nine farmers applied one breeding season to their cattle, with the most common period being around February to April, while five farmers applied two breeding seasons, with the most common being February to March and August to September. One of the farmers who left their bulls with cows throughout the year noted that there was a natural calving period that coincided with the onset of the growing season, while another observed two natural calving periods, with one from September to December and another from April to July. Only one farmer applied artificial insemination on his cattle.

7.7 ANIMAL PERFORMANCE

Before presenting results on animal performance, a reminder is given that the greatest source of error in the production figures obtained from the farmers is likely to have been the memories of the majority of interviewed farmers who did not base their answers on accurate records. Even for farmers who kept records of overall figures it was difficult to keep track of all the different movements of herds of their stock to and from rented land, to be able to give an overall figure of the average size of land used for their production each year. Hence the results need to be treated with some caution.

7.7.1 Variation in animal production

When the 36 farmers were asked about the highest animal production achieved in any year and lowest they experienced in any year, 15 of them were unable to answer and the answers from the 21 other farmers were provided in different units, so the results are presented as proportional differences between highest and lowest years (Figure 7.28).

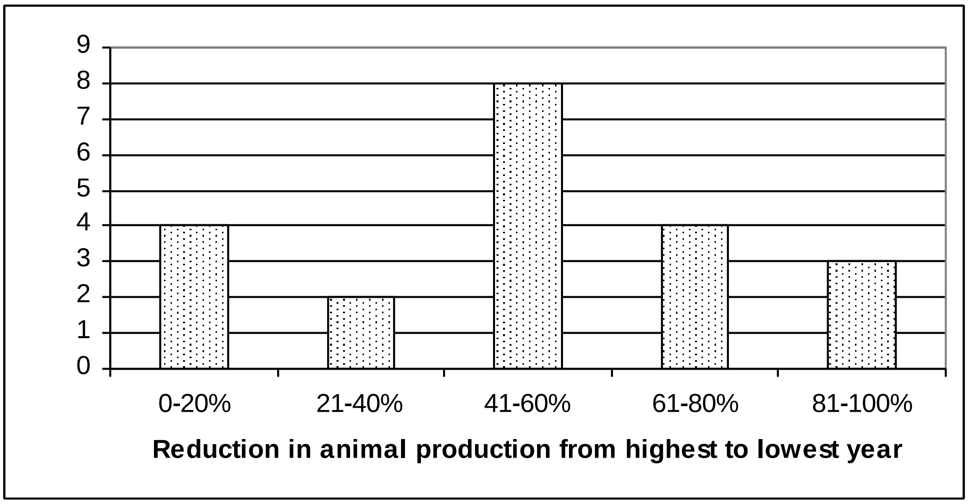


Figure 7.28 Frequency chart of the percent reduction from the highest animal production achieved in any year to that achieved in the lowest year, for the 21 farmers who provided information from which it could be determined.

Eight farmers (38%) experienced a reduction in animal production of between 41 and 60% from the highest to lowest year. There were also three farmers who experienced a drop between 81 and 100%, when they had to trek their cattle to rented land or had to provide fodder just for survival. A further four farmers managed to keep the reduction in animal production to under 20%, mainly through conservative stocking in years of abundant rain.

7.7.2 Relationship between animal production and stocking rate

The data from a new game farmer who did not know his animal production and had not yet harvested any game, was omitted when analysing the relationship between the estimated stocking rate and production of each of the remaining 35 farmers (Figure 7.29). Increasing stocking rate accounted for only 22% of the increase in production.

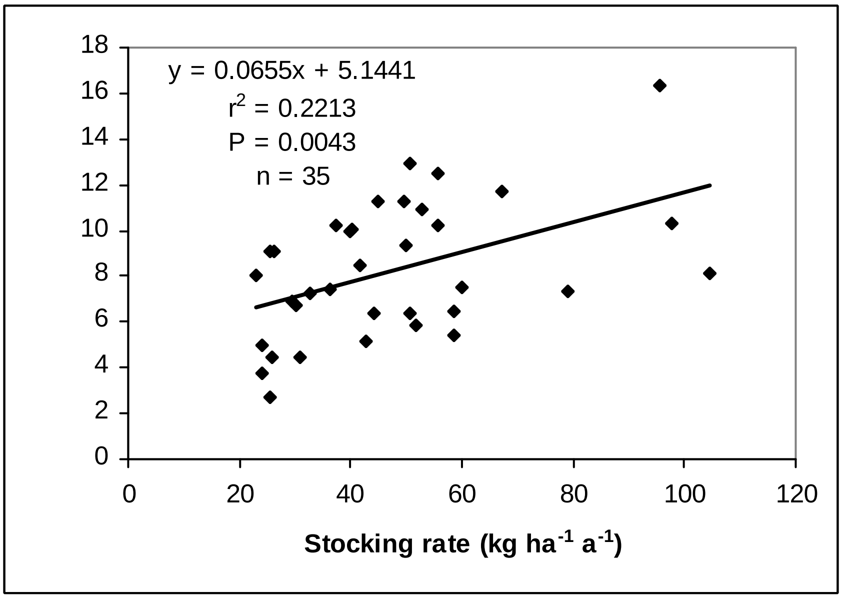


Figure 7.29 Relationship between stocking rate and annual production.

The accuracy of the data is questionable, as was explained in section 3.6, but the large variation in points along similar stocking rates suggests that there was a major difference among farmers in their efficiency in managing their animal production. This was further examined by calculating animal production as a percentage of the stocking rate (Figure 7.30).

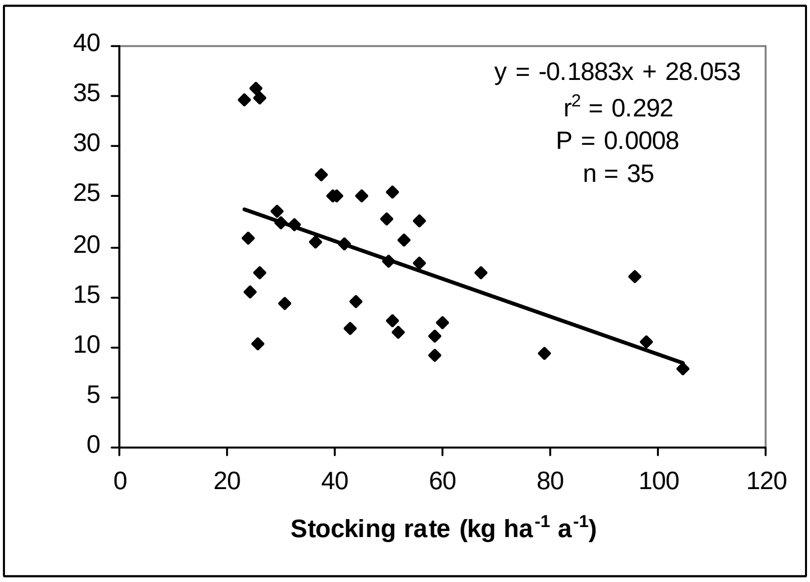


Figure 7.30 Relationship between stocking rate and annual production as a percentage of the stocking rate.

The trend of the relationship is as expected, with declining production per animal as stocking rate increases, but the relationship is not strong ($r^2 = 0.292$, P=0.0008, n = 35).

7.8 FINANCE

Results from analysing the answers by farmers to questions on farm income and expenditure are summarised in Table 7.3, alongside some other relevant data. There are several gaps in the data due to some farmers not knowing the answers and the reluctance of other farmers to answer these type of questions. When estimating the number of workers employed by each farmer, three seasonal workers were subjectively equated to one full time worker, since they are often employed for three or four months per year. The financial data were converted to units that could be compared among farmers with different sized farms, on a per hectare basis.

Their input costs varied from between N$ 5 ha^{-1} for two of the leasehold farmers, to N$ 42 ha^{-1} for a cattle farmer and up to N$ 211 ha^{-1} for a game farmer, with the median at N$ 24 ha^{-1}. Their gross income varied from between zero for the resettled farmer to N$ 125 ha^{-1} for a cattle farmer and up to N$ 231 ha^{-1} for the game farmer who spent heavily, with the median at N$ 48 ha^{-1}. Their profit varied from negative for the resettled farmer, a weekend farmer and a farmer who recently retired to the farm, to N$ 102 ha^{-1} for the cattle farmer with the highest income. The game farmer who invested heavily in his business achieved a profit of N$ 20 ha^{-1}, which was also the median among all 26 farmers who provided data from which profit could be estimated. The efficiency of animal production per year varied from 8% of the stocking rate for one of the leasehold farmers to 36% of the stocking rate for a Baster farmer, with the median among the 35 farmers who provided the information at 19% of the stocking rate.

The proportion of expenditure spent on lick varied from 3% for a Baster farmer and one of the game farmers to 82% for one of the leasehold farmers, with the median among the 21 farmers who provided the information at 20% of income costs. The number of workers employed for every 1 000 ha of farmland exhibited extremes among the leasehold farmers, four of whom hired no workers while one hired three on his small farm, resulting in a figure of 7.1 workers per 1 000 ha. The other three leasehold farmers each hired one worker, resulting in figures between 2.2 and 2.7 workers per 1 000 ha. The highest among the other farmers was 3.8 for a game farmer, with 1.9 the highest among freehold cattle farmers and the median among all 36 farmers coming to 1.0 worker per 1 000 ha.

The median number of farming enterprises per farmer was two. Employment and/or enterprises other than farming were undertaken by 14 of the farmers (39%), although a portion of the income derived thereof was not necessarily invested into the farm. The main other form of non-farming income was pensions, either paid to the farmer or to relatives living on the farm.

Table 7.3 Summary of financial data obtained from interviewed farmers who were willing to provide such information, in relation to some other data.

	N$ ha^{-1} a^{-1}			Prod a^{-1} as % stocking[1]	% lick in costs[2]	Number of enterprises	Workers 1 000 ha^{-1}	Range cond. index[3]
Site	Costs	Sales	Profit					
1b	39	0	-39	11	6	0	0.0	303
2a & 3a	N/A	N/A	N/A	20	12	2	1.7	530
2b	5	26	21	18	N/A	3	2.2	391
3b	5	20	15	8	N/A	4	0.0	210
4a & 5a	N/A	N/A	N/A	9	N/A	2	2.5	216
4b	51	94	43	17	82	3	7.1	266
5b	18	22	4	9	17	2	0.0	345
6a	12	5	-7	10	19	1	2.7	347
6b, 7b, 8a&b	24	107	83	35	14	2	2.2	275
7a	6	57	51	21	20	2	0.0	230
9a	N/A	N/A	N/A	21	N/A	2	1.3	460
9b, 10a&b	25	33	8	14	10	2	0.6	245
11a,b,c & 12b	40	94	54	17	30	4	1.3	176
12a	17	51	34	22	26	1	0.5	40
13a,16a & 17b&c	N/A	61	N/A	35	N/A	4	0.5	157
14b & 15b	22	64	42	23	35	2	1.8	90
15a & 16b	31	80	50	25	26	6	1.1	135
17a	N/A	41	N/A	11	N/A	5	0.0	30
18a	N/A	68	N/A	21	50	4	1.0	85
13b,14a & 18b	25	48	23	13	N/A	1	1.6	213
19a & 20a	24	N/A	N/A	N/A	N/A	3	0.5	155
19b, 20b, 21a&b, 22a&b, 23a	23	125	102	25	N/A	3	1.9	221
23b, 24b, 25a, 26a	211	231	20	25	3	4	3.8	229
24a	29	79	50	19	22	1	0.8	210
25b	42	52	10	27	N/A	1	0.7	160
26b	36	48	11	25	20	2	0.8	434
27a	N/A	N/A	N/A	12	N/A	1	0.4	100
28b	19	38	18	11	22	1	0.3	284
29a	N/A	N/A	N/A	15	N/A	3	1.6	54
29b, 30a&b, 31a&b	N/A	52	N/A	23	N/A	2	0.7	169
32a	25	33	7	36	N/A	3	1.0	242
32b & 33a	18	29	11	23	N/A	3	1.0	369
32c & 33c	7	41	34	22	4	3	0.7	361
33b	19	8	-10	17	3	3	1.2	398
34a&b	13	29	16	16	7	2	0.6	637
34c	21	21	0	12	13	2	1.5	611
Median	24	48	20	19	20	2	1.0	230

[1] Prod a^{-1} as % stocking = Annual animal production as a percentage of the stocking rate.
[2] % lick in costs = Percentage of overall expenditure spent on lick.
[3] Range cond. index = Rangeland condition index.

The socio-economic data were not well suited for relating with rangeland condition for all farmers together, largely because: (i) the rangeland condition index had not been related to benchmarks for the different areas, therefore it would not be strictly valid to compare them across areas; (ii) the socio-economic data applied to the whole farm(s), while rangeland condition had only been measured at the fenceline contrast(s) and (iii) rangeland condition may have been more a reflection of historical management, with different socio-economic consequences, than of current circumstances.

Bearing these limitations in mind, the results of product moment correlations (Dytham, 2003) on the data from Table 7.3 are presented in Table 7.4. The exceptionally high costs and income of the game farm at Site 23b were omitted from the analysis, as they had strongly influenced initial results as an outlier and had prevented the income data from being normally distributed. Although auto-correlation exists between expenditure, income and profit, it is of interest that the strongest relationship occurs between income and profit ($r = 0.9288$, $P < 0.001$, $n = 25$), while there is almost no correlation between expenditure and profit ($r = 0.0267$, $P = 0.899$, $n = 25$), and a weak correlation between expenditure and income ($r = 0.3952$, $P = 0.051$, $n = 25$). A greater efficiency of animal production is weakly related to sales ($r = 0.5124$, $P = 0.009$, $n = 25$), and profit ($r = 0.4825$, $P = 0.015$, $n = 25$).

Table 7.4 Cross tabulation indicating r-values of product-moment correlations between socio-economic variables of Table 7.3.

	N\$ ha^{-1} a^{-1}			Prod a^{-1} as % stocking[1]	% lick in costs[2]	Number of enterprises	Workers 1 000 ha^{-1}
	Costs	Sales	Profit				
Sales	r=0.3952						
	P=0.051						
	n = 25						
Profit	r=0.0267	r=0.9288					
	P=0.899	P=0.000					
	n = 25	n = 25					
Production a^{-1} as % of stocking[1]	r=0.1860	r=0.5124	r=0.4825				
	P=0.373	P=0.009	P=0.015				
	n = 25	n = 25	n = 25				
% lick in costs[2]	r=0.6001	r=0.5722	r=0.3885	r=0.0769			
	P=0.008	P=0.012	P=0.111	P=0.762			
	n = 18	n = 18	n = 18	n = 18			
No. of enterprises	r=−0.060	r=0.2970	r=0.3474	r=0.2807	r=0.2215		
	P=0.776	P=0.149	P=0.089	P=0.102	P=0.377		
	n = 25	n = 25	n = 25	n = 35	n = 18		
Workers 1 000 ha^{-1}	r=0.4039	r=0.3974	r=0.2696	r=0.0775	r=0.8137	r=0.1672	
	P=0.045	P=0.049	P=0.192	P=0.658	P=0.000	P=0.330	
	n = 25	n = 25	n = 25	n = 35	n = 18	n = 36	
Rangeland condition index	r=−0.200	r=−0.480	r=−0.442	r=−0.127	r=−0.361	r=0.1747	r=0.0775
	P=0.338	P=0.015	P=0.027	P=0.467	P=0.141	P=0.308	P=0.653
	n = 25	n = 25	n = 25	n = 35	n = 18	n = 36	n = 36

Shaded cells indicate relationships that are significant ($P<0.05$).
[1] Prod a^{-1} as % stocking = Annual animal production as a percentage of the stocking rate.
[2] % lick in costs = The percentage of overall expenditure spent on lick.
The results were the same regardless of which of the two variables was set as the dependent variable, so the "mirror image" figures are omitted from the matrix.

The only significant correlations of rangeland condition index with financial variables were both negative, with income ($r = -0.4801$, $P = 0.015$, $n = 25$) and profit ($r = -0.4418$, $P = 0.027$, $n = 25$). The only significant ($P<0.05$) correlation between current stocking rate and any of the other variables in Table 7.4, was with the production efficiency ($r = -0.5404$, $P = 0.001$, $n = 35$) in accordance with Figure 7.30. Even the negative correlation between current stocking rate and rangeland condition index and was not significant ($r = -0.1006$, $P = 0.559$, $n = 36$) using data in Table 7.3. However, when the correlation was performed on data from individual sites it was significant ($r = -0.2575$, $P = 0.04$, $n = 64$) although very weak. This difference is due not only to the larger sample size, but also the grouping of sites belonging to the same farmer in Table 7.3, and the omission of hay fields and sites with localized over or under stocking from the correlation using data from individual sites.

CHAPTER 8

CASE STUDY OF ADAPTIVE MANAGEMENT BY AN INNOVATIVE FARMER

8.1 INTRODUCTION

Rangeland experimentation is costly, laborious and occupies large tracts of land (Edwards, 1969). Experimental research alone cannot produce a rigid rangeland management formula due to the infinite combinations of variables that would need to be tested and the complexity of rangeland dynamics that interplay with those variables (Stuart-Hill, 1989). However, there are many experienced farmers who are continuously experimenting and monitoring on their farms, albeit in a subjective manner, and then adjusting their management accordingly. This adaptive management is considered by Stuart-Hill (1989) to be the solution to rangeland management, together with some input from formal research, preferably on-farm. Norton (2003) is of the opinion that scientists cannot duplicate the success of commercial producers who are proving that rotational grazing ‘works’ both biologically and financially.

An adaptive farmer, Jan Labuschagne, has achieved remarkable results with his rangeland. He was willing to share what he has learnt and how he has adapted his management. Clear fenceline contrasts are visible between his farm, Weiveld (23.06^{0}S, 18.88^{0}E), in the Omaheke Region of Namibia, and his neighbours. The farm covers approximately 3 000 ha in the Camelthorn savanna (Giess, 1971), dominated in the herbaceous layer by *Stipagrostis uniplumis*, in the bush layer by *Acacia mellifera* and *Grewia flava*, and in the tree layer by *Acacia erioloba*. The farm falls within the agro-ecological zone known as Kalahari Sands Plateau AE2 (De Pauw *et al.*, 1999) dominated by Ferralic Arenosol with low stabilised dunes and some Petric Calcisol with pans. The clay content over most of the farm varies between 3 and 8 %. Rainfall is highly erratic with a long-term annual mean of approximately 250 mm, falling only in summer. Annual evaporation is about 2 m, with an average maximum temperature of approximately 33^{0}C in the hottest month and an average minimum of approximately 2^{0}C in the coldest month (Mendelsohn *et al.*, 2002). Stocking rates vary with rainfall and market prices. At the start of the study in 2004, there were about 230 cattle and 1 300 sheep, representing an overall stocking rate of 67 kg liveweight ha^{-1} or 7 ha AU^{-1} (assuming 6 sheep AU^{-1}). On the neighbouring farm the overall stocking rate was approximately 33 kg liveweight ha^{-1} (14 ha AU^{-1}) and a slow rotation was applied through four paddocks per herd. The contrast between these two farms was described in section 4.4.18, since Site 12b was on Weiveld and Site 12a was across the fence on the neighbouring farm.

The farmer describes the objective of his management on Weiveld as being to improve both grass and animal production in a balanced way. He implies that the improved production should be sustainable and that the end point would be the maximum production level that could be supported by the landscape and its climate. The fluctuating nature of the latter implies that the maximum potential of production would also fluctuate annually.

The farmer inherited from his father not only the farm, but also a large debt, since the farm was still on mortgage. In order to be able to repay the inherited debt, the farmer was forced to stock the farm excessively over the first few years. The farmer observed the degradation that took place, but could only afford the luxury of adaptive management after the loan had been paid off. Thereafter the farmer was able to convert his observations to management and apply some degree of experimentation through trial and error. Since soil water is such a limiting factor in this environment, a significant number of the farmer's observations were based upon the depth to which soil remained moist at different times after rain on different types of soil under different influences of management. The farmer carried a spade whenever he travelled around the farm, in order to dig the soil to investigate its water profile.

8.2 PROCEDURE

The procedure used in this case study has already been described in Chapter 3. Descriptions of the rangeland measurements were presented in section 3.4, data processing in section 3.5 and obtaining information from the farmers in section 3.6.

8.3 RESULTS

8.3.1 Observations by farmer

Tables 8.1 to 8.4 list observations made by the farmer, possible reasons given by the farmer for those observations and the management actions that the farmer applied as a result of having made the observations. The 31 observations have been broken down into four groupings, each presented in a separate table.

Table 8.1 Observations related to animal behaviour and performance, and their conversion to management applications by the case study farmer.

Observation of farmer	Possible explanation given by farmer	Management application
1.1 When few cattle are sent ahead of the main herd rotation, they grow fast and consume less phosphate lick per animal.	The greater availability of forage per animal allows them to select higher quality food.	Lower the stocking rate to improve animal performance and reduce lick costs, while leaving more grass to feed soil micro-organisms.
1.2 When urea lick is withdrawn, cattle stop feeding on moribund grass material and old mulch.	Urea provides nitrogen needed by rumen microflora to digest the high carbon / low nitrogen moribund material.	Stop using urea lick, to leave moribund grass to be trampled onto the soil for supplying important humus (and save costs).
1.3 When less phosphate lick is provided to cattle, they browse more.	Browse leaves have higher phosphate content than grasses.	Provide less phosphate lick, to help control bush encroachment and save costs.
1.4 Animals prefer feeding on grasses growing under bushes to feeding on those growing in the open.	Bushes improve mineral status of soil under them and their shade reduces evaporation from the soil.	Maintain a good balance between bushes and grasses. Do not try to eradicate any bush species. All species are useful if in balance.
1.5 When artificial breeding seasons are discontinued, cattle do not just breed all year round.	Cattle naturally apply two breeding seasons, one in winter and one in summer.	Keep bulls with the herd throughout the year. Not only is this simpler to manage, but it allows rangeland to rest for longer and be grazed for shorter, due to a higher number of paddocks per herd.
1.6 Dung beetles die after livestock are dosed against intestinal worms.	The dosing chemical passes out in the dung and is still toxic when dung beetles feed on the dung.	Stop dosing livestock against internal parasites. Rather disrupt parasite life cycle by rotating livestock through paddocks, and build up natural livestock resistance through sufficient good quality forage.
1.7 Livestock stop feeding for a few days at the start of the rainy season, after which they only feed on green flush and no longer on dry material.	The livestock knows there will soon be green flush to feed on, so it gives its rumen microflora a chance to switch adaptation from dry to green feed.	Lower the stocking rate and allow livestock to feed on newly established annual grasses and forbs. The animals then move further and uneaten dry grass gets trampled into mulch and raises soil organic matter.
1.8 Smaller breeds of cattle perform better in this environment than larger breeds.	Smaller cattle breeds and small stock are better adapted to this environment than larger breeds of cattle. Larger animals need to spend more time feeding.	Change breed of cattle from Brahman to Nguni or Beefmaster, and also farm with sheep and goats. However, actual breed is less important than fertility within the herd.
1.9 Sheep prefer to follow cattle in the grazing rotation, but goats prefer to go ahead.	Sheep prefer to feed on shorter grass where cattle have grazed and shortened the grass. Goats face increased tannin content in browse leaves, in response to previous browsing by cattle.	No solution applied yet, because it is logistically difficult to separate goats and send them up ahead.

Table 8.2 Observations related to animal trampling, and their conversion to management applications by the case study farmer.

Observation of farmer	Possible explanation given by farmer	Management application
2.1 A large amount of the annual grass, *Schmidtia kalahariensis*, grows at the start of the rainy season on the side of a fence recently trampled by sheep and not on the other side where it was not recently trampled.	Grasses such as *S. kalahariensis* germinate better when their seeds are covered by soil blown into hoof marks.	Make use of sheep trampling as a rangeland management tool.
2.2 In the occasional year when cattle are disturbed by small biting flies (possibly stable flies), the cattle push themselves into bushes of *Grewia flava* and grass subsequently grows more abundantly under those bushes.	The trampling by cattle creates hoof marks that trap grass seed, where they are then covered with some soil and mulch. The hoof marks also encourage water infiltration during the next rain.	Make use of cattle trampling as a rangeland management tool.
2.3 Trampling on soil low in organic matter results in abundance of the weed *Tribulus terrestris* and encourages establishment of bush seedlings, while trampling on soil with sufficient organic matter results in abundance of grass after rain.	Soil low in organic matter gets hotter than soil with sufficient organic matter. Grass seed cannot survive or germinate successfully in hot soil, while *Tribulus terrestris* and bush species can.	Only apply intensive trampling where the soil organic matter content is high or where there is abundant standing dry grass to trample down into the mulch layer.
2.4 Trampling on sandy soil in the dry season does not increase subsequent perennial grass density, while trampling it in the growing season does, if followed by rest.	Trampling in the dry season loosens the soil around grass roots, so that they become desiccated or uprooted. When soil is moist, it is not loosened so easily and hoof marks remain fairly firm.	Only apply trampling to sandy soil in the growing season (if soil organic content is sufficient).
2.5 Trampling on loamy soil with low organic matter when it is moist, causes hardening of the soil.	Moist loamy soil cannot resist trampling pressure and becomes compacted. When hard and dry, it resists compaction.	Reduce the stocking rate on loamy soil in the growing season.
2.6 Trampling before rain on loamy soil improves water infiltration and establishment of grass seedlings.	Trampling causes hoof marks that encourage seeds and mulch to settle into them before rain and hold water during rain.	Apply brief trampling before rain to capture more rain water, seeds and mulch.
2.7 Trampling after rain on soil with sufficient organic matter conserves the water already in the soil. If low in organic matter, the loosened soil dries out fast.	Trampling breaks the capillary connections in the soil surface, thus reducing capillary rise of water after evaporation of soil water from near the surface.	To reduce evaporation loss from the soil, apply brief trampling after good rain, provided there is sufficient organic matter in the soil.
2.8 Trampling after good rain on soil where there are few perennial grasses, tends to favour bush growth.	The soil water conserved by the trampling is used by bushes, since there are insufficient grasses to use it.	Rather trample such poor paddocks after first rain of season to encourage perennial grass emergence.
2.9 Damara and Van Rooi sheep provide a better trampling service on hard ground than Dorper sheep.	Damara and Van Rooi sheep have sharper hooves than Dorper sheep and have retained their herding and mothering instincts better.	Farm mainly with Damara and Van Rooi sheep, mixed with limited Dorper genes to provide a larger animal demanded by the market.
2.10 The presence of a few jackals causes sheep to remain bunched together and provide a better trampling service.	Sheep feel more secure when bunched together, in the presence of jackals. Therefore they create a higher density of hoof marks.	Control jackals to a limited extent and sacrifice the loss of a few sheep, so that the herd bunches well and mothering instincts continue to be selected.

Table 8.3 Observations that convert to applications of grazing, wood harvest and farm design by the case study farmer.

Observation of farmer	Possible explanation given by farmer	Management application
3.1 When stocking rate is increased a bit, young plants are the first to suffer while middle-aged plants still recover.	Plants are more sensitive or resistant to being eaten or trampled as they go through different stages of their life cycles.	Adjust the rate of rotation through a paddock depending on the life cycle stage of its dominant plants.
3.2 When senescing perennial grasses are grazed or trampled, they tend to rejuvenate and therefore compete with new grass seedlings while not producing sufficient mulch or forage of good quality.	Removal of old grass parts allows buds to obtain sufficient sunlight and air for continued growth.	Rest a paddock dominated by senescing grasses for longer (effectively lowering the stocking rate) to allow the grasses to subsequently be converted into mulch and encourage the establishment of new grass seedlings.
3.3 Mole mounds often appear where bulls have fought previously in the rainy season. Moles do not appear where rangeland was rested for the full growing season.	Moles prefer to burrow where the soil is moister. Fighting bulls conserve soil water by loosening topsoil that breaks capillary connections with the moist subsoil. Rangeland rested in the growing season loses more water.	Mole mounds can be used as an indicator of where soil water is higher. If grasses dominate, then conserve the water by trampling. If bushes dominate, then it is not a priority to conserve the water.
3.4 The condition of perennial grass is much better in a small paddock than in the neighbouring large paddock, despite being grazed at the same stocking rate.	The much shorter grazing period and slightly longer rest received by the small paddock, protect the perennial grass better from overgrazing. However, if a paddock is too small, the crowding of animals restricts them from selecting better grass.	Subdivide large paddocks to improve perennial grass cover (down to the most economically efficient size of about 100 ha for that agro-ecological zone, or down to the most functionally efficient size of 50 ha if moveable electric fencing is available).
3.5 After a drought, animals like to graze in areas dominated by annual grasses.	When drought breaks, annual grasses grow fast, while perennial grass takes a long time to provide forage.	Keep a good balance between paddocks dominated by perennial grasses and annual grasses to benefit from both.
3.6 When mature bushes of *Acacia mellifera* are harvested for droppers, they are only replaced by seedlings if chopped during a year of good rain and not if chopped during drought.	Mature bushes of *A. mellifera* suppress seedlings unless weakened - such as by chopping. Seeds of *A. mellifera* do not remain viable for long and their seedlings die easily unless sufficient follow-up rain falls.	If it is necessary to treat the symptom of excess mature *A. mellifera*, do so in drought years. Although prevention - by treating the cause - is better than cure, if applied early enough.
3.7 Runoff rainwater tends to soak into the ground on a certain part of the farm.	There might be deeper soil or cracks in the layer of calcrete.	Align roads to bring their runoff rain water to this area, to recharge the aquifer.

Table 8.4 Observations that convert to applications of fire by the case study farmer.

Observation of farmer	Possible explanation given by farmer	Management application
4.1 After years of exceptionally high rainfall, perennial grass starts to regrow in spring, before new rain has fallen.	There is still sufficient soil water remaining from the previous rainy season to allow grass to regrow in response to rising temperatures.	Only apply the tool of fire after exceptionally high rainfall, so that the risk of damaging perennial grass is lowered. Even if there is little or no rainfall after the fire, the grass will still be able to rely on stored soil water.
4.2 During years of exceptionally high rainfall, much more grass grows than can be consumed by the livestock, and the cost of renting land drops.	The higher soil water allows grass to grow throughout the growing season and livestock does not reproduce as fast. As the supply of forage increases the demand decreases and hence its price drops.	After a year of exceptionally high rainfall, restrict livestock to only part of the farm, or rent land during the whole dry season, so that sufficient fuel remains to apply burning in some of the rested paddocks.
4.3 If rest is provided after many animals have grazed a paddock with high cover of *Acacia mellifera* bushes, then many annual grasses establish under the bushes after the next rain.	Animals are attracted to feed on fallen leaves under the bushes, where they provide a trampling service that favours subsequent grass establishment.	Apply trampling especially the season before wanting to apply burning, so as to increase the fuel load underneath excessive bushes.
4.4 In the dry season annual grass burns better than perennial grass,.	Annual grasses have more leafy material and less water in the dry season.	Apply trampling to encourage annual grass germination at the start of the growing season before fire.
4.5 Many bushes of *Acacia mellifera* produce seeds after years of exceptionally high rainfall.	*Acacia mellifera* does not get enough water to produce pods under conditions of moderate or low rainfall.	Apply burning to kill the seeds when they are abundant (where sufficient fuel and soil water has accumulated).
4.6 Animals prefer feeding on grasses growing under taller bushes with wide canopies rather than feeding on grasses growing in the open.	Bushes improve the mineral status of soil under them and their shade reduces evaporation from the soil.	Before applying fire to a paddock, send in a few cattle to reduce and trample fuel under large bushes, to minimise fire damage to those valuable bushes.

8.3.2 Conceptual model of rangeland dynamics

The farmer has developed a conceptual model that he visualises to explain the basics of rangeland dynamics and help his decision-making on rangeland management, illustrated in Figure 8.1. The situation of the rangeland in any paddock is indicated in the model by two variables. Distance from the centre of the circles represents the state or succesional stage of the rangeland in the paddock, illustrated in Figure 8.1, as three concentric circles. The innermost, middle and outer circles represent rangeland dominated by annual plants, perennial grasses and woody plants, respectively. Regarding the rate of rotation, Figure 8.1 should not be viewed as a clock, with the arm performing equal revolutions regardless of distance from the centre, but rather as the closer to the centre, the faster the rotation.

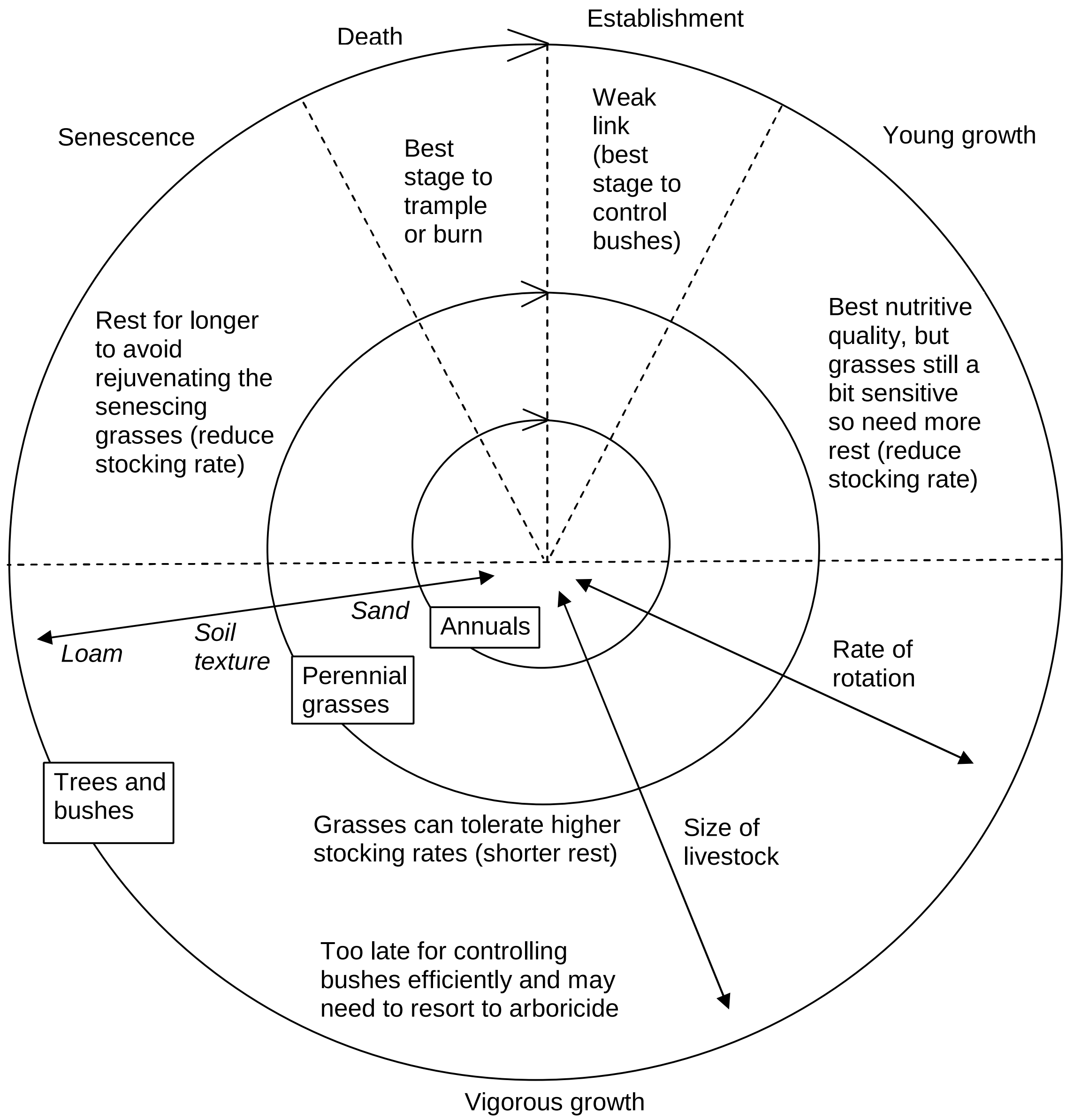


Figure 8.1 Conceptual model developed by case study farmer to explain rangeland dynamics on his farm.

Position of rotation represents the life cycle stage of the dominant vegetation in the paddock starting at the 12 o'clock position in Figure 8.1. Annual plants have the shortest life cycle of only one growing season, perennial grasses have a life cycle of several years or decades, while woody plants have a life cycle of several decades or centuries. Therefore, in the conceptual model the rate of one revolution is fast for the inner circle and slows down as the circles progress outwards. The five stages of the life cycle are labelled on the outside of the outer circle, although they apply to both perennial grasses and woody plants.

Some management implications in different stages of the life cycle are written between the outer and middle circles in Figure 8.1. The two double-ended arrows on the right indicate management implications that change with type of plant dominating the forage intake, although they apply to all life cycle stages and not only to the vigorous growth stage where they were drawn. The double-ended arrow on the left indicates the influence of soil texture on the type of plants generally favoured on different soil.

When the forage intake is dominated by annual plants that do not need long rest, the rate of rotation through paddocks can be fast, to optimise use of the "fast food" while it is available. Sandier soils favour such conditions and small stock thrives under them. When animals graze more on perennial grasses, requiring moderate rest, the rate of rotation should be slowed down. Such conditions, usually on the intermediate textured soils, favour moderate sized stock. Browsed trees and bushes need longer rest, so rotation should be slowed down even further if the browse is more important to the manager. Larger animals tend to perform well under such conditions, which are favoured on the more loamy soils.

8.3.3 Current management

At the time of the study the farmer applied many of the principles that he learnt through his adaptive management. He farms with sheep, goats and cattle of fairly small frame. In those paddocks that have jackal-proof fencing, the cattle and small stock are combined. The overall stocking rate is adjusted so that sufficient grass material remains to be later trampled onto the soil. The rate of rotation through paddocks depends on the season.

In the growing season all the livestock are combined into one large herd that is rotated quickly, spending between 1 and 14 days per paddock. This allows stocking to be applied strategically to provide a trampling service at critical times, such as after significant rainfall to conserve soil water. By the end of the growing season, each paddock has usually been grazed twice. The time that the animals spend in any paddock depends largely on the condition of its rangeland, such as shorter if the dominant perennial grasses are senescing or just establishing and longer if middle-aged. The more common stocking density would have been about 400 kg liveweight ha^{-1} (1 AU ha^{-1}) but may have increased more than tenfold to above 4 000 kg liveweight ha^{-1} (9 AU ha^{-1}) for just one day. After heavy rain, the rate of rotation is increased to ensure that the capillaries at the soil surface get broken and thereby reduce evaporation loss of water from the soil. The sequence of rotation from paddock to paddock is not fixed, but is flexible to make use of opportunities that present themselves. Some paddocks dominated by annual grasses get trampled after the first rain of the season, to encourage perennial grass seedlings to establish. The rate of rotation might be increased again at the end of the growing season to ensure that there are hoof marks over most of the farm, to trap grass seeds and a mulch of leaves.

In the dry season the animals are split into seven herds, and the rate of rotation is slowed down considerably. Each herd then rotates slowly through the three or four paddocks surrounding a single water point, grazing each paddock either once or twice during the long dry season of about eight months. No supplementary feed is provided, except for the rare occasions when livestock condition suffers from exceptionally late rains, when twigs of the evergreen tree, *Boscia albitrunca,* get milled and mixed with the phosphate lick.

The farmer no longer imposes breeding seasons on the livestock, but lets them settle into their own breeding seasons and give birth out on the rangeland. None of the livestock is kraaled at night, so the animals learn to care for themselves and their dung and urine re-distribute mineral nutrients over the rangeland rather than concentrating them at the kraals. The farmer even tolerates low predator densities, to retain mothering instincts of his livestock and benefit from trampling services provided by the tighter bunching of his herd. He stopped supplementing his livestock with urea, so that moribund grass and mulch would not be eaten by the livestock but would instead feed the soil micro-organisms. He also stopped use of most chemicals for pest control, and only doses newly acquired sheep before release onto his farm. Apart from encouraging well fed animals that are more resistant to parasites, and avoiding parasite concentration in kraals, control is largely achieved by adjusting the rate of livestock rotation. By grazing a paddock in the growing season for no more than 14 days, and resting it for up to three months, the life cycle of the parasites is broken. Useful organisms, such as dung beetles, started to increase noticeably about three years after the broad scale use of chemicals was stopped.

8.3.4 Results of surveys at fenceline contrasts

8.3.4.1 Contrast with neighbouring farm

The results of the surveys at the contrast between Weiveld (Site 12b) and the neighbouring farm (Site 12a) have already been presented in detail in section 4.5.13, with photographs presented in Figure 4.43, so only a summary is presented here.

The mean perennial grass density of 1.8 grasses m^{-2} was significantly higher ($P<0.0001$) on the strategically trampled farm Weiveld (as explained in section 8.2.3) than the 0.4 grasses m^{-2} estimated on the neighbouring farm where conventional rotation is applied through four paddocks per herd. The palatable leguminous perennial forb, *Otoptera burchellii*, was also significantly ($P<0.05$) more abundant on Weiveld, where the density was estimated at 2 150 plants ha^{-1}, compared to 450 plants ha^{-1} on the neighbouring farm. In contrast the bush canopy cover was less on Weiveld, especially of *Acacia mellifera* (Figure 8.2). All this evidence attests to the better rangeland condition of farm Weiveld, presumably due to the good management taking place there, although historical mismanagement may also have contributed to the poorer condition on the neighbouring farm.

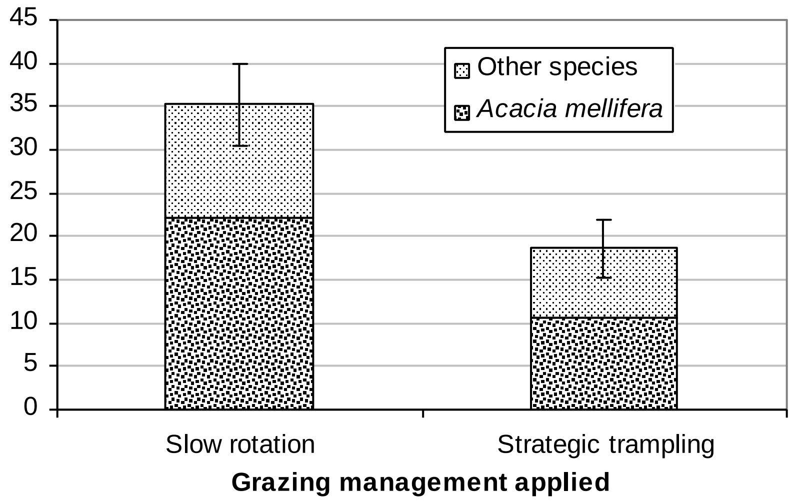


Figure 8.2 Canopy cover of bushes taller than 0.5 m, divided into *Acacia mellifera* and other species, ± 95 % confidence limits on each side of the boundary fence between farm Weiveld, managed by strategic trampling, and the neighbouring farm, managed by slow rotation of paddocks through four paddocks per herd.

8.3.4.2 Contrast resulting from short term management

The grass densities at this contrast have been described in section 4.4.12. All perennial grasses, including those with a basal diameter of less than 5 cm, had been counted at this contrast in late January 2007, approximately six weeks after the start of the rainy season. There was a higher (P<0.001) density of perennial grasses on the side of the internal fence that had received short trampling early in the growing season (Figure 4.38), presumably due to the hoof action having buried seeds at that critical time of the year and supporting observation 2.2. Whether or not such young grasses survive, depends on the follow-up rains and the rest they receive.

8.3.4.3 Contrast between paddocks of different sizes

The rangeland characteristics at this contrast between three paddocks on Weiveld were described in section 4.4.11. They had been grazed at the same stocking rate, but the smaller the paddock, the higher stocking density and the shorter the period of occupation, with a marginal increase in period of absence. The perennial grass density was highest in the smaller paddock, at 2.3 grasses m^{-2}, but was the same for the two larger paddocks, at 1.3 grasses m^{-2}. The small paddock (Site 11a) of only 6 ha had a higher density of perennial grasses, estimated at 2.3 grasses m^{-2}, than the two larger neighbouring paddocks of 120 ha (11b) and 340 ha (11c), both of which were estimated to have 1.3 grasses m^{-2}. The difference was significant (P<0.0001) by Chi-Square test and supports observation 3.4. The density of small bushes lower than 0.5 m increased significantly (P<0,05) with increasing size of paddock, from an estimate of 113 plants ha^{-1} in the 6 ha paddock, to 340 plants ha^{-1} in the 120 ha paddock, to 1 175 plants ha^{-1} in the 340 ha^{-1} paddock, suggesting that the weakened perennial grasses in the larger paddocks allowed bushes to establish more easily.

8.4 DISCUSSION

Decision-making on farm management is extremely complex and needs to take many factors into account. Different options, such as those emanating from the observations in Tables 1 to 4, need to be weighed against each other, with priority given to the weak link in the production system. Management decisions for one part of the farm must take into account the situation in the other parts of the farm and must plan for the changes expected over the seasons. A farm manager can usefully exploit the diversity of soils and vegetation on a farm (Scoones, 1995), such as by making more use of areas with sandy soil in the growing season and more use of heavier textured soils in the dry season at Farm Weiveld. Management interventions may also need more precise timing, such as in relation to rainfall events. The optimum time to trample a paddock would depend not only on its predominant soil texture and organic matter content, but also on the balance between bushes and grasses growing there and their stages of maturity. For example, paddocks with few perennial grasses and many young bushes should rather be trampled after the first good rain of the season, to encourage the establishment of more grasses, while trampling after rain later in the growing season should be avoided, otherwise the conserved soil water would likely become more available for the young bushes to grow rapidly.

Stocking rate is generally recognised as being the major management variable that influences the condition of rangeland and animal production (Tainton, 1985; O'Reagain & Turner, 1992). Observation 1.1 accounts for both the improved animal performance and increased soil organic matter from lower stocking rates. Du Preez & Snyman (2003) confirm that soil organic matter declines with degradation of the rangeland, while Observation 1.2 suggests that withdrawal of urea lick may contribute to higher soil organic matter. However, the raising of soil organic matter is a very slow process in this type of environment (Birru, 2002). Urea withdrawal might also help animal performance by avoiding high levels of blood urea nitrogen that put stress on the animals' livers (Brunetti, 2004) that could be indicated by high urine pH. Some farmers measure the pH of cattle urine as an indicator of when to move cattle to the next paddock or when to start or stop nitrogen supplementation (Schultheiss, 2005), although this is not done at Farm Weiveld.

Observation 1.3 is supported by data tabulated by Moleele (1998) that demonstrated higher phosphate content in browse than in grasses of south-east Botswana. Although cattle generally prefer to grazing to browsing at Sandveld Research Station (Rothauge *et al.*, 2007), the extent to which they browse may sometimes be considerable. This observation is supported by Katjiua & Ward (2006) who found that cattle spent 71% of feeding time browsing on bushes in a communal grazing area near Otjinene, where grass is less abundant. Observation 1.4 is supported by the findings of Rothauge *et al*. (2007) that grasses occurring in canopied habitats had a significantly higher nutritive value than those occurring in the open at Sandveld Research Station, even if they were of the same species. It is also supported by the findings of Hagos & Smit (2005) of a gradient in soil nutrient status, from higher near the stem of free standing *Acacia mellifera* trees, to lower further away from the canopy in open ground. Observation 1.5, that cattle naturally synchronize into two breeding seasons, might result from the carried over momentum of the two artificial breeding seasons applied until four years previously, made possible by the low predator pressure on the calves. It is possible that over a long time period (possibly decades) the calving seasons would continue to slowly migrate through the calendar year until they reunited at a single most ideal natural time of year if the management practices allowed it (Ruechel, *pers. comm.*[1]). There is also a small possibility that photoperiod had an influence, since sexual activity and breeding tend to peak during the equinoxes (Ruechel, 2006) and current groups of calves appear to have been conceived near the time of the two equinoxes. However, the effect of photoperiod is less pronounced in tropical latitudes, resulting in longer calving seasons that revolve around the cycles of the rainy/dry seasons rather than the photoperiod (Ruechel, 2006).

Observation 1.6 is of concern because dung beetles perform essential services, not only by bringing nutrients, organic matter and beneficial micro-organisms into the soil, but also by reducing the breeding opportunities for parasites and flies in dung that otherwise remains on the soil surface (Losey & Vaughan, 2006). Therefore the danger posed to dung beetles by toxic treatments used for control of both internal parasites (Krüger & Scholtz, 1998) and external parasites (Chihiya *et al.*, 2006) may have severe consequences for the health of both rangeland soils and animals. Fortunately, parasites can be controlled without the use of toxic chemicals, as is now done on Farm Weiveld by rotational grazing to disrupt the parasite life cycle; selective breeding for greater resistance; and ensuring a good level of nutrition from a high diversity of forage species that enhances resistance against parasites and diseases. Literature could not be found supporting Observation 1.7, that animals stop feeding for a few days of transition from dry season to growing season. However, the combination of less dry grass and more green material would allow the rumen microflora to adapt more slowly. Cattle need to adapt to lush spring growth after a season on dry feed, otherwise they may suffer from severe rumen upsets, laminitis, bloat, nitrate poisoning or even death (Conroy, 2007). If cattle do indeed stop feeding, it might be a result of their physiological response to an upset rumen resulting from a sudden intake of lush green material (Conroy, *pers. comm.*[2]). Alternatively, it might be a result of cattle preferring to wait for the fresh growth that they know will soon be available rather than continuing to feed on poor quality dry material, which may have lost further quality if it can be assumed that some of the remaining nutrients will be leached from the plants after the first rain (Ruechel, *pers. comm.*[1]). Observation 1.8 is supported by the findings of Els (2007) that small frame cattle delivered a higher production per hectare than large frame cattle at comparable stocking rates at Sandveld Research Station. The explanations given for observation 1.9 fit with findings of Bell (1971) that grazing by larger species breaks down stemmy grass swards, thereby

[1] Ruechel, J. Personal communication. Rancher and author, 4004 Coachwood Close, Coldstream, BC, V1B 3Y4, Canada.

[2] Conroy, A.B. Personal communication. Animal Science Lecturer, Polytechnic of Namibia, P/Bag 13388, Windhoek.

exposing leafy material for smaller grazers, and with findings of van Hoven (1991) that tannin content of leaves increases rapidly in response to browsing.

The observations in Figure 4.38 are supported by the findings of Rotundo & Aguiar (2004) that sheep trampling doubled the emerged seedlings of *Bromus pictus* in Patagonia. They suggested trampling as a low-input technique for increasing grass recruitment. According to Adams (1996), the increased emergence of seedlings after the application of high stocking density is a consequence of the removal of existing vegetation rather than the burial of seeds. The use of trampling as a management tool is a contentious issue that has received a lot of criticism. A review by Thurow (1991) indicated that trampling tends to result in lower infiltration rates where it destroys stable soil aggregates and leads to a deterioration of soil structure. A review by Holechek *et al.* (2000) reports that various studies on short-duration grazing consistently found increased erosion compared to continuous or full season grazing. However, the observations at Farm Weiveld suggest that trampling can bring benefits if applied at the right time under the right conditions, and when followed by sufficient rest in the growing season for the rangeland plants to recover.

Dean (1992) found reduced water infiltration rates in sheep paths of Karoo soils, but that infiltration rates were higher where there was more organic matter and insect activity in the soil. Chaichiu *et al.* (2003) found that sheep trampling reduced the water infiltration rate into soil. Such observations may be due to lack of sufficient rest after the trampling, if not due to the soil conditions at the time of trampling, or to the duration and intensity of the trampling applied. An account of trampling applied by three South African farmers by Howell (1976) emphasised that timing is an important factor in trampling. While Savory (1999) seems to treat animal impact as a fairly simple tool, with variables of type of animal, stocking density and timing, observations at Farm Weiveld suggest that trampling is more complex and should furthermore be differentiated between its variables of season, soil texture, soil water profile and organic matter content of the soil. Ssemakula (1983) reported on the results of hoof pressure measurements of different species of ungulate, which demonstrate that cattle apply significantly more hoof pressure than either sheep or goat, among other differences between game species. The observations on Farm Weiveld suggest that results for a species should furthermore be divided into breeds. An additional explanation for Observation 2.9, that Damara sheep provide a better trampling service, could be that they walk longer distances than other sheep (Conroy, *pers. comm.*[3]).

[3] Conroy, A.B. Personal communication. Animal Science Lecturer, Polytechnic of Namibia, P/Bag 13388, Windhoek.

Observations 3.1 and 3.2 contributed to the conceptual model in Figure 8.1 and are taken into account when decisions are made on grazing management. Observation 3.4 and Figure 5 demonstrates the advantage of smaller paddocks, but at higher financial outlay for fencing. The upper limit of paddocks per herd beyond which an increase in resting benefit is only slight, was considered by Booysen (1969) to be about six. At Farm Weiveld the paddocks per herd varies between 19 when the tool of trampling is applied in the growing season, to 3 in the dry season. Observation 3.6 is supported by the contention by Smit (1998) that competition from well established bushes prevents new bushes from establishing within their root zones, which are extensive for species such as *Acacia mellifera*.

Burning, like trampling, is a contentious issue with a variety of pros and cons (Scott, 1970). Stehn (2008a) doubts whether the use of fire as a management tool can be viably applied within a farming operation that has to care for itself financially, because of the removal of potential forage and the long rest needed both before and after the fire. However, if fire is only applied rarely, at opportune times, then the benefits might outweigh the costs. The wise advice of Mr. Labuschagne is that burning needs to be prepared for years in advance, to build up the soil organic matter and the widespread cover of annual grass, while waiting until there is enough residual water in the soil from the previous rainy season to ensure that perennial grass will be able to regrow even in the event of no rain falling soon after the fire. There will only be sufficient water in the soil after exceptional rainfall, coinciding with times when grass is also likely to be abundant and when there is risk of encroacher bushes establishing *en masse* from seed (Joubert *et al*., 2008a).

Observations related to the control of bush encroachment are scattered throughout Tables 1 to 4, at 1.3, 1.4, 2.8, 3.3, 3.6, 4.3 and 4.5, while Figure 8.1 illustrates some of their applications in the conceptual model. A healthy diversity of bushes and grasses is encouraged by good grazing management. However, when bushes of *Acacia mellifera*, the main encroacher species on Farm Weiveld, show signs of threatening to dominate, they should be controlled at their weakest link that is at the start of their life cycle (Joubert *et al.,* 2008a). This could start with the application of hot fire if masses of pods appear on the parent bushes and if there is sufficient fuel and soil water (Observation 4.5). However, there is still the possibility that if not burnt, the seedlings that emerge from the masses of seeds will die instead from lack of follow-up rain, so it might be more economical to wait and see the circumstances in the following season. Nevertheless, since only a portion of the farm should be burnt in any year, one or a few paddocks could be burnt after masses of pods are observed on *A. mellifera*. If follow-up rain is good and many bush seedlings establish in other paddocks, then the next opportunity to burn some of them might occur at the end of the following dry season. Alternative burning of individual paddocks spaced apart on a farm can achieve the type of patch burning as advocated by Fuhlendorf & Engle (2001).

8.5 CONCLUSIONS

Although no hard scientific conclusions can be drawn from rangeland experimentation unless all variables have been controlled or are capable of assessment (Edwards 1969), there are valuable lessons that can be learned from the adaptive management practiced by this farmer. Other farm managers can usefully experiment in a similar way on their own farms and the lessons could, if felt necessary, be put to the test by scientific experimentation.

CHAPTER 9

DISCUSSION: ECOLOGICAL ISSUES

9.1 INTRODUCTION

Before discussing the findings on differences in rangeland condition at fenceline contrasts at the end of this chapter, an attempt is made to analyse some of the complexities of ecological dynamics that influence rangeland condition. In order to differentiate between symptoms and causes of rangeland problems it is useful to identify causal linkages that lead to different symptoms of rangeland degradation. This can be done by the construction of problem trees, of which four examples follow, to explain the symptoms of bush encroachment, water and wind erosion, and high loads of intestinal parasites. Background information on problem trees and their method of construction were provided in section 3.7.2.

9.2 BUSH ENCROACHMENT

It is estimated that approximately 260 000 km^2 (30%) of Namibia (Bester, 1999) is affected by bush encroachment. Species of indigenous bush that contribute to bush encroachment through excessive increase in their density include *Acacia mellifera, A. reficiens, A. luederitzii, A. erubescens, A. fleckii, A. nilotica, Colophospermum mopane, Dichrostachys cinerea, Terminalia prunioides*, *T. sericea* (De Klerk, 2004), *Grewia flava* and *A. tortilis* (Moleele *et al.*, 2002). Bush encroachment had occurred at many of the fenceline contrasts in this study, and was the worst at Site 30a, where the canopy cover was estimated at 63%, of which 96% were encroacher species (Table 5.4).

Widespread bush encroachment seems to be a problem resulting largely from mismanagement of the rangeland (De Klerk, 2004). However, bush encroachment can also be viewed as a natural patch dynamic process (Britz & Ward, 2007; Meyer *et al.*, 2007), with the landscape consisting of many patches in different states of transition between grassy and woody dominance.

The problem tree for bush encroachment is presented in Figure 9.1.

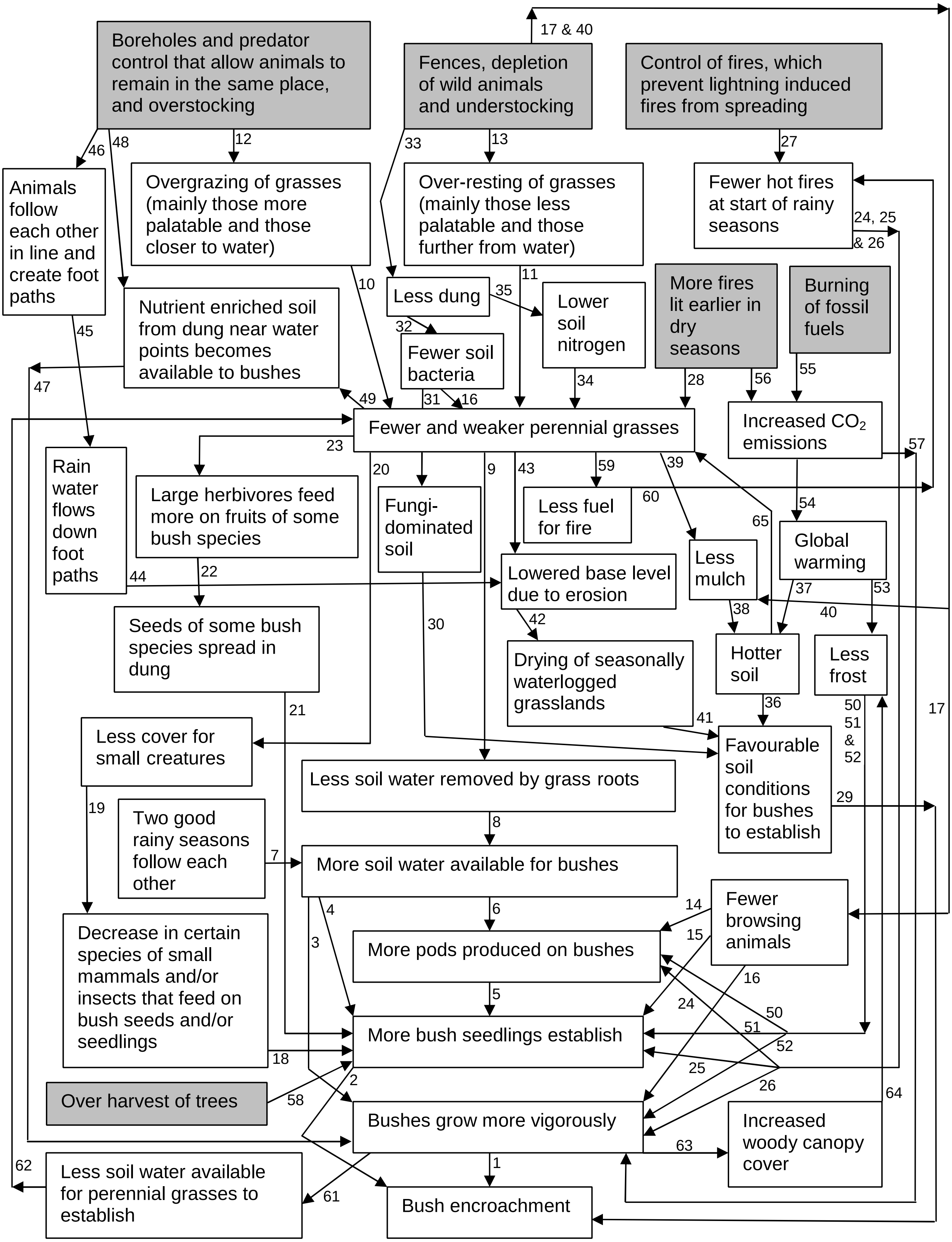


Figure 9.1 A diagnostic problem tree for bush encroachment, with root causes shaded and numbers providing reference for text, where they appear in brackets.

9.2.1 Discussion on construction of problem tree for bush encroachment

When analysing the causal linkages below, the numbers in brackets refer to the number alongside arrows in Figure 9.1.

9.2.1.1 Availability of soil water

Bushes increase, and hence encroach, by established bushes growing bigger (1), and by the recruitment of new bushes (2). Previously established bushes grow every year, if not already overcrowded, and more so in years of good rain. An increased availability of soil water to bush roots, without prolonged waterlogging, allows bushes to grow more vigorously (3). More soil water also allows more bush seedlings to establish (4), provided there are sufficient viable seeds. More bush seedlings establish when there are more viable seed available (5), provided the soil water is sufficient. An increased availability of soil water to *Acacia mellifera* roots leads to a higher production of pods with viable seeds on those bushes (6) (Joubert*, et al.*, 2008a). In fact, there is generally no production of viable seed in below average rainfall years, and seeds are produced *en masse* in exceptionally high rainfall years.

When discussing the establishment of new bush seedlings a distinction needs to be made between species such as *A. mellifera*, with seeds that cannot survive in the soil from one season to the next and those species such as *A. tortilis* with small seeds and hard testa that can survive for many years in the soil seed bank. The establishment of new bush seedlings tend to be extremely episodic events, perhaps occurring on average once every few decades, at least for *A. mellifera* (Joubert *et al*., 2008a). First a good rainy season is needed to produce sufficient flowers during the following dry season. The viable seed subsequently produced during the next rainy season also needs good rain to ensure survival after germination. A third good rainy season may be needed to ensure successful establishment of the small seedlings from the previous season. Hence recruitment of *A. mellifera* may require two or three good successive rainy seasons (7), so that all of linkages 4, 5 and 6 take place.

Although there is no arrow in the problem tree towards the box with the successive good rainy seasons, it is not actually a root cause, but rather a rare environmental prerequisite for establishment of bush seedlings of certain species, if at least one of the root causes has taken effect. Ludwig & Tongway (1997) would term it the ”trigger” in their framework. Other species such as *Dichrostachys cinerea* might be able to establish with one season of exceptional rain, since they produce viable seed banks due to their hard seed coat (Bell

& Van Staden, 1993). They are therefore independent of an initial wet season required for seed production.

For a given amount of rain that has infiltrated the soil, more water becomes available to bushes if less gets removed by grass roots (8), which happens when grass cover decreases (9) (Mworia *et al.,* 1997). This competition occurs between bushes and grasses, regardless of whether their roots occupy two different layers in the soil as postulated by Walter (1971). It is also influenced by differences in osmotic potential and wilting points between woody plants (that use the C3 photosynthetic pathway) and grasses (using the C4 photosynthetic pathway). Generally grasses utilize soil water faster than woody plants, but reach wilting point sooner at a higher soil water matrix potential than woody plants (Smit & Rethman, 2000). On the other hand, a lack of grass cover may increase the run-off from heavier textured soils, resulting in less soil water available for bushes (Smit & Rethman, 2000).

***9.2.1.2* Grazing herbivores**

Most African perennial grasses are believed to have evolved under conditions of occasional severe grazing followed by long rest periods (Savory, 1999). They can become weakened by opposite extremes, either by overgrazing or by over-resting. Both can occur on the same rangeland, if animals are stocked lightly and continuously or under fast rotation with short periods of absence, as occur on many commercial farms. The most palatable grasses, especially those closest to the water point, are then overgrazed (10), while the less palatable species, especially those further from the water point, are over-rested (11), both resulting in decreased grass vigour (McNaughton, 1979). Under natural conditions, the predominant species of wild herbivores remained tightly bunched in large herds that were controlled by predators. Sources of permanent water were unsafe due to predator ambush and the herds of herbivores were unlikely to have remained in their vicinity for long. Wherever the herds grazed they were likely to have fouled the rangeland with dung, making that rangeland unsuitable until cleaned by dung beetles and rain, by which time the severely grazed and trampled grasses would have replenished root reserves and were ready to be re-grazed (Savory, 1999). The natural movements of animals were disrupted by pioneer farmers who replaced the wild herbivores with domestic livestock; controlled the predators; changed the natural range by sinking boreholes and putting up fences; and thereby allowed overgrazing and undergrazing to become widespread (12 & 13) thus contributing to the root causes of bush encroachment.

9.2.1.3 Browsing herbivores

Another reason why bushes flourish is because of fewer browsing animals that allow more pods to be produced on bushes (14), more seedlings to establish (15) and established bushes to grow more vigorously (16). Browsing by mainly kudu, goats and impala, was found by Roques *et al.* (2001) to impact on encroachment, mainly on *Dichrostachys cinerea*, in the early stages of encroachment only. Although browsing by ruminants may actually stimulate bush growth (Scogings, 2003; Stuart-Hill, 1988), megaherbivores such as elephant and black rhino were especially important in keeping bushes under control in the past (Grossman & Gandar, 1989). Many large herbivores were depleted by the construction of fences and hunting (17). Small browsing herbivores such as hares, squirrels, gerbils and bruchid beetles feed on bush seeds and/or seedlings. In fact, small browsers may be more important regulators of bush densities (Belsky, 1984; Ostfeld *et al.*, 1997; Weltzin *et al.*, 1997). A decline in these small browsers allows more seedlings to establish (18). Declining grass cover may be responsible for the decline in some of them (19), which itself results from fewer and weaker perennial grasses, thereby rejoining the main trunk of the problem tree (20). Bush seedlings of some species also increase as a result of their seeds being spread by large herbivores that browsed on the bush pods (21) (Coe & Coe, 1987). In the dry season this applies particularly to bush species with palatable pods and seeds with a hard testa that can survive the digestive systems of the animal, such as *D. cinerea* (but not *A. mellifera*), especially if there is insufficient palatable grass available (22). The lack of palatable grasses again leads back to the main trunk of the problem tree through fewer and weaker perennial grasses (23).

9.2.1.4 Fire

Bushes also flourish because of fewer hot, high intensity fires at the start of the rainy season, when bush stems and shoots are more sensitive to fire after having broken dormancy when their phloem is active and growth buds exposed. Hot fires tended to burn in years following high rainfall when a high fuel load was produced and there were insufficient large herbivores to graze the fuel down. The high rainfall would also have resulted in high production of pods on the bushes, which are destroyed by the fire (24) and with plants failing to produce viable seed. Small bush seedlings and saplings are sensitive to fire and are probably also killed, even in cool fires (25). Well-established bushes usually only suffer top kill from a hot, high intensity fire, although their loss of food reserves may weaken them (26), especially when their regrown shoots get browsed (Trollope, 1980). Lightning usually ignites natural fires at the start of rainy seasons, during the short window when the period of dry fuel availability overlaps the occurrence of thunderstorms. However, effective fire-fighting by commercial farmers over the past decades has resulted in such fires being quickly extinguished or contained within firebreaks (27), further contributing to bush encroachment.

Despite fewer fires at the start of the rainy season, there has been an increase in fires burning earlier in the dry season, usually as a result of negligence or vandalism. Perennial grasses evolved together with fire at the start of the rainy season and are not well equipped to deal with earlier fires that tend to weaken the grasses (28). Perennial grasses respond to fire by breaking dormancy and exposing their new shoots to hardships of aridity, frost and continuous grazing. All these hardships are ameliorated at the start of the rainy season but impose their toll if the rainy season is still a long way off. Bushes on the other hand, are far less affected by fires early in the dry season, since they are dormant with inactive phloem and buds well protected by bark. Therefore the balance between bushes and grasses tends to favour bushes when a fire burns early in the dry season, and such fire contributes to the root causes of bush encroachment.

9.2.1.5 **Soil conditions**

Some soil conditions, other than those related to competition for soil water mentioned above, may also favour bush encroachment (29). Soil dominated by fungi favours bushes (30) while soil dominated by bacteria favours grasses (31) (Kingdon, 2005). Dung is dominated by bacteria, so less dung results in fewer bacteria in the soil (32). Less dung is a result of fewer large herbivores (33), which is shaded in Figure 9.1 as one of the root causes of bush encroachment. Lack of dung beetles to process dung, resulting from the use of chemicals for parasite control that contaminates dung, might also reduce bacteria in the soil.

Soil nitrogen is needed more by C4 grasses than by leguminous C3 bushes that have symbiotic nitrogen fixing bacteria on their roots (Smit & Swart, 1994). Lowered soil nitrogen may therefore weaken grasses (34) more than bushes (Kraaij & Ward, 2006). Soil nitrogen will be lower when less dung is present (35).

Higher soil temperatures seem to favour the establishment of bushes (36) (Labuschagne, *pers. comm*.[4]). Soil temperatures increase as a result of global warming (37) (New *et al.*, 2006) and less mulch cover to shade the soil (38). Less mulch results from fewer and

[4] Labuschagne, J. Personal communication. Observant farmer. P.O. Box 53, Gobabis, Namibia.

weaker grasses (39), as well as from lack of animals to trample down standing dry grass (40).

Soil conditions in specific locations can influence the growth of bushes. For example, seasonally waterlogged soils tend to be dominated by a good grass cover because bushes suffer when waterlogged (Tinley, 1982). Although covering only a small proportion of Namibian rangeland, these hydromorphic grasslands are key habitats that provide important resources for livestock and game. Bushes are likely to flourish when water is drained from waterlogged soil (41) as a result of erosion that lowers the base level (42), which used to retain the water (Pringle *et al.*, 2006). According to Pringle (2008) base level incision is clearly etching away some of Namibia's most productive, drought buffering landscapes at local to total catchment levels of ecological organisation. The erosion of the base level is usually a result of fewer and weaker perennial grasses (43) and often by water flowing down foot paths (44). These resulted from cattle following each other (45) to permanent water points supplied by boreholes (46). Another local effect is of established bushes that grow vigorously in the vicinity of water points, often developed into valuable shade trees under which animals rest and devour the masses of pods normally produced. The bushes benefit from nutrient enrichment of the soil from dung (47) of animals attracted to the water point (48) (Moleele & Perkins, 1998), yet do not face competition from grasses (49), which are unable to survive due to continuous trampling by animals. The dung from animals supplemented with phosphate lick is likely to improve soil fertility more, considering the low availability of phosphorous in Namibian soils, but a large quantity is wasted when accumulating in the heavily impacted zone around water points, benefiting only a few desirable large shade trees.

9.2.1.6 **Climate change**

Less frost results in fewer bush pods being killed by freezing (50), fewer seedlings killed (51) and fewer established bushes experiencing top kill (52), especially of the more frost sensitive species such as *Dichrostachys cinerea*. In encroached stands the bushes are less susceptible to damage by cold (frost), compared to more open stands, since the bushes protect each other under these circumstances (Smit, 1990). Global warming may result in less frost (53) (New *et al*., 2006), which results from increased emissions of carbon dioxide and other greenhouse gasses (54), caused by the burning of fossil fuels (55) and bush fires (56). The increased emission of carbon dioxide also favours the growth of C3 plants, including bushes (57), over C4 plants, including grasses of semi-arid rangelands (Midgley *et al*., 2000), especially under xeric, rather than mesic, conditions (Palmer & Eamus, 2008).

9.2.1.7 Loss of large trees

The loss of large trees due to harvesting for fence posts or charcoal/firewood production, while leaving smaller trees and bushes, or through indiscriminate/non-selective application of arboricides, is another root cause of bush encroachment (58). The roots of large trees suppress smaller bushes through competition (Smit, 2004), so when chopped and killed the smaller bushes are able to grow bigger and new seedlings establish in the vicinity of where the big trees were killed.

9.2.1.8 Positive feedback

The problem tree has four positive feedback loops that reinforce some of the causal linkages to further favour bush encroachment. Fewer and weaker perennial grasses result in less fuel for fire (59), reinforcing the fewer hot fires at the start of rainy seasons (60). Increasingly vigorous bushes remove water from the soil (61), leaving less available for perennial grasses, thereby supporting fewer and weaker perennial grasses (62). The increasingly vigorous bushes also provide greater canopy cover (63), which causes a microclimate that in turn results in less frost (64). Hotter soil causes fewer and weaker perennial grasses (65) due to poor germination of perennial grass seed in soil exposed a lot to the sun while favouring germination of weeds such as *Tribulus terrestris* and bush seedlings (Labuschagne, *pers. comm*.[5]).

The increase of biological soil crusts under impenetrable *Acacia mellifera* bushes (Thomas *et al.*, 2002) might also provide positive feedback by restricting water infiltration (Eldridge *et al.*, 2000). However, there might also be negative feedback since a higher density and increased vigour of annual grasses under bushes than between bushes are often observed, so the benefits of shade and leaf mulch provided by bushes might outweigh the disadvantages of some biological soil crusts. In addition, the soil crusts that tend to develop on soil under bushes might consist more of the beneficial types of organisms that fix nitrogen, protect soil from wind erosion and possibly enhance water infiltration, since biological soil crusts can be extremely diverse in both species composition and properties (Eldridge & Greene, 1994). Therefore the possible role of biological soil crusts in bush encroachment is not yet presented in the problem tree of Figure 9.1, but could be added when there is more clarity on their overriding influence.

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[5] Labuschagne, J. Personal communication. Observant farmer. P.O. Box 53, Gobabis, Namibia.

9.2.2 Discussion on management applications of bush encroachment

For the problem tree to assist decision-making, it is necessary to determine which of the multiple pathways are of greater significance to any particular situation. Pathways will differ, depending on factors such as the land-use and rainfall history, the agro-ecological zone, the soil conditions and the species of bush that is considered to be the problem. For example, Midgley & Bond (2001) suggest that fires contribute more significantly to bush dynamics in higher rainfall areas, while rainfall contributes more significantly to bush dynamics in lower rainfall areas. In addition, herbivores exert their influence on bush dynamics in the higher rainfall areas largely through consuming the fuel load that determines the occurrence and effect of those fires while exerting their influence on bush dynamics in lower rainfall areas largely through feeding on bush seedlings and saplings (Midgley & Bond, 2001).

The problem tree has five shaded boxes containing root causes. It is unlikely that more than three of them would apply to a particular situation, and most likely that one will be of overriding importance. When management is applied to a particular level within the problem tree, the arrows pointing down to it will indicate which factors are likely to counter the management efforts. Even if specific trees appear complicated at a glance, they become clearer when interpreted one step at a time. A PowerPoint presentation is ideally suited to this purpose, as small amounts of information are released at intervals, making the construction of the complete tree easier to follow. By involving farmers in the construction of a problem tree, discussion is stimulated and a more holistic understanding of the problem is developed.

9.2.2.1 **Treating the symptom**

Farmers commonly react to bush encroachment by wanting to treat the symptom, usually by what is perceived to be a quick fix such as the application of arboricides. Observations in the field suggest that widespread aerial application of arboricide appears to result in other “problem” species dominating after “problem” bushes have died. For example, *Laggera decurrens* has been observed to replace dead *A. mellifera* and *D. cinerea* bushes in the Thornbush Savanna. Apart from the high cost of this “solution”, it may simply bring temporary relief until the root causes (still in place) result in further bush encroachment. However, if the root causes have indeed been addressed, the simultaneous treatment of the symptoms may be justified to ensure a quicker recovery of the rangeland.

If arboricides are opted for, application costs could be minimised by applying it selectively and at critical times, such as when bushes of *A. mellifera* failed to produce viable seed, so that the killed bushes will not be replaced by masses of seedlings. It may be more economical to use arboricide as follow-up treatment some years after another method has been applied. The arboricide then only needs to be applied to those target bushes that were not sufficiently weakened by the previous treatment. Arboricide may also be applied to cut stumps in conjunction with selective chopping, to prevent regrowth. Selective thinning can structure the surviving bushes in a way that their roots will suppress re-establishment of excessive replacement bushes while encouraging grasses (Smit, 2004).

With increasing worldwide demand for energy it is likely that manual chopping will become a viable option for many farmers. There is the risk that chopping will be insufficiently selective, or favour the chopping of bigger bushes over smaller bushes to maximise wood yield per unit of effort. This may lead to rangeland degradation due to exposed soil, as does the unselective application of arboricide.

9.2.2.2 **Treating root causes**

Since the root causes of widespread bush encroachment are related to human interference in nature, treating the root causes implies reverting back to nature. This may be partly possible in only a few situations where neighbouring farmers can join forces to form a large conservancy, temporarily close down water points, remove fencing and re-introduce megaherbivores and other wild animals that were exterminated in recent centuries on their farms. In most cases this is impractical, and the next best alternative is to treat intermediate causes as close as possible to the root causes. The root cause that is probably the easiest to treat is the disruption in natural fire regimes, through the combination of regular fire control and the infrequent application of strategically timed burning. This is only possible when and where sufficient fuel has accumulated, which is unlikely where a high density of mature bushes already exists. The root cause of over-harvesting would require lengthy treatment where few or no trees remain, requiring protection for tree seedlings over the decades as they are sensitive to browsing.

9.2.2.3 **Focussing on perennial grass**

Since the box with fewer and weaker perennial grasses features so prominently in the problem tree, it has a key influence on the development or prevention of bush encroachment by a multitude of pathways. Management of the perennial grass is therefore key to managing bush encroachment. Perennial grass can be kept healthy by alternating short grazing periods with long rest periods in the growing season for replenishment of the grass' growth reserves. A vigorous perennial grass cover might weaken bush seedlings and saplings through competition for water. Whether this prevents establishment of the young bushes or not is still debatable (Kraaij & Ward, 2006; Joubert *et al.,* 2008a*).* A soil rich in manure, well worked in by dung beetles, seems to favour grasses, while causing premature weakening of mature bushes by fungal disease, as indicated by the sound of a hollow thud when striking the main stem with a heavy stick and abundant lichens growing on the bark (Richardson, *pers. comm*.[6]).

9.2.2.4 **Reversing rangeland desiccation**

Where there is massive loss of water from the rangeland as a result of soil erosion, instead of infiltration, the root causes need to be addressed and it may be necessary to treat the symptom simultaneously. If a gully is expanding towards a seasonally waterlogged grassland, then repair of the gully will save the grassland from bush encroachment (Pringle, *et al*., 2006). A gully system can be healed by the strategic placement of filters to slow down flowing water and trap sediment, provided that the root causes of the gullies have also been addressed. In cases where there are encroached bushes nearby, this problem can be converted into a solution, by providing filter material for the gully system (Shamathe *et al.*, 2008).

9.2.2.5 **Occasional use of fire**

There are many risks associated with the use of fire, including the accidental spread of fire to other areas and the possibility that there will be insufficient rain after the fire to allow proper recovery of the burnt grass. One way to minimise the latter risk is to never use fire unless there is still sufficient residual soil water remaining from the previous rainy season to allow the grass to recover, even with no follow-up rain (Labuschagne, *pers. comm*.[7]). Fire also consumes organic matter that would otherwise be added to the soil, so it may be wise to never use fire unless there has been a build up of sufficient soil organic matter over previous years. According to Bond (1997) the natural frequencies of fire in arid savanna vary from five to 30 or more years.

[6] Richardson, D. Personal communication. Observant farmer and consultant. P.O. Box 1853, Vryburg, South Africa.

[7] Labuschagne, J. Personal communication. Observant farmer. P.O. Box 53, Gobabis, Namibia.

Situations where a burn may be warranted are after exceptionally heavy rains that produce high yields of grass that cannot be consumed by the available animals, and where it may be beneficial to open up some bushy areas or lower the threat of mass seed production on bushes. Perhaps the most important role of fire is to prevent a mass emergence of bush seedlings and thus prevent a new wave of encroachment during the limited window of opportunity when bush seedlings and saplings are still sensitive to burning (Joubert *et. al*., 2008a).

9.2.3 Conclusion on management of bush encroachment

The problem tree is one of several tools that can assist decision-making on appropriate rangeland management. The constructed tree is by no means inflexible, and can be revised as new information becomes available. It can be more effective when used in combination with other tools, such as a state and transition model (Joubert *et al*., 2008a), a decision support system for rangeland management (Joubert, *et al.*, 2008b) accessible at http://chameleon.polytechnic.edu.na/wiki/, and the conceptual model of rangeland dynamics designed by the case study farmer described in chapter 8.

The problem tree is based on a wide range of information sources including informal observations. Some aspects thus need further research to verify assertions. For this reason, there should be a greater emphasis on research into the dynamics of the processes implicated in the overall process of bush encroachment in Namibia, such as the demographic studies proposed by Midgley & Bond (2001).

Since problem trees are aimed at controlling problems, there is a risk that all bushes will be perceived as undesirable, rather than only excessive bush being considered the problem. In their natural environment all species of bush, whether encroacher or not, perform useful ecological functions (Belsky *et al*., 1989; Durr & Rangel, 2000; Smit & Swart, 1994; Stuart-Hill *et al*., 1987). Most rangeland management aims at achieving a reasonable balance between bushes and grasses, so that each may contribute to a healthy and productive rangeland.

9.3 WATER EROSION

Although accelerated water erosion is a more serious problem on heavier textured soils and steep slopes, it also occurs on gentle slopes where the soil is predominantly sandy but with sufficient clay to seal the surface pores - all situations which are fairly common in Namibia. The problem tree for the symptom of a gully is presented in Figure 9.2.

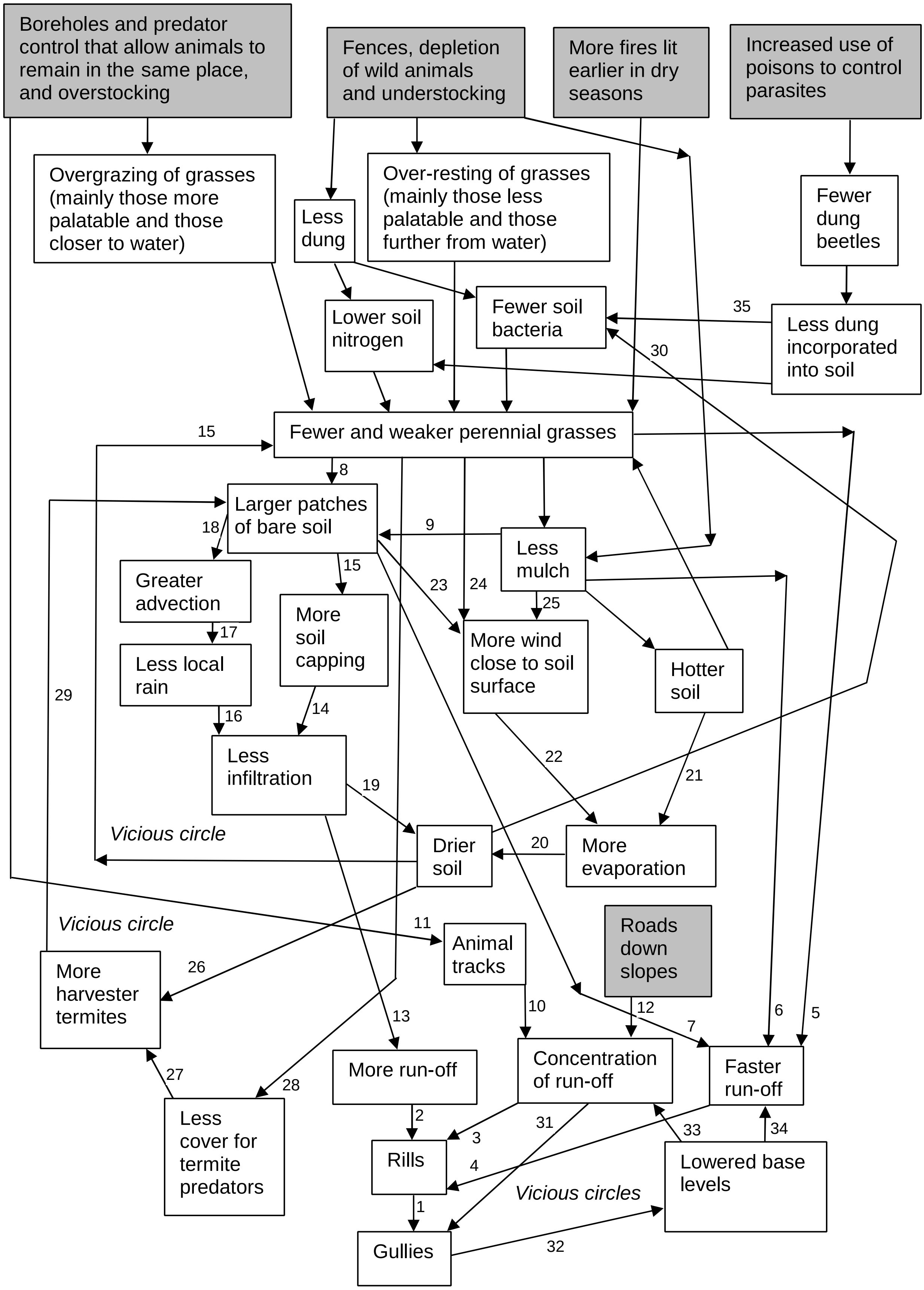

Figure 9.2 A diagnostic problem tree for gully erosion, with root causes shaded and numbers providing reference for text. Arrows already explained in a previous section, or still to be explained in a further section, are not numbered.

The only fenceline contrast where gullies occurred in this study, was at Contrast 34.

9.3.1 Discussion on construction of problem tree for water erosion

Gullies are formed from rills that become deeper (1), resulting from a greater quantity of rain water run-off (2), which concentrates in rills (3), where the slope of the land exceeds about 0.5% (Ludwig & Tongway, 1997), and travels at a faster speed (4). The rain water runs off faster because of fewer perennial grasses (5) and mulch (6) to slow it down, which are consequences of intermediate and root causes already explained for the problem tree of bush encroachment in section 9.2.1. Another reason for faster run-off of rain water is larger patches of bare soil over which water picks up momentum (7) (Tongway & Ludwig, 1997), which are also a consequence of fewer and weaker perennial grasses (8) and less mulch (9). Run-off tends to concentrate in animal tracks (10) that result from the root causes of overstocking, boreholes and predator control (11) already explained in section 9.2.1, and in roads that are aligned down slopes (12) (Pringle & Tinley, 2003) and which are also a root cause.

The higher run-off results from less infiltration of rainwater into the soil (13), due to increased soil capping (14) of surface pores by clay particles (Mills & Fey, 2004b), which is favoured by larger patches of bare soil (Mills & Fey, 2004c) (15) resulting from reasons already explained above. Another reason for less infiltration of water, but on a much larger scale, is less localised rainfall (16) due to greater advection of dry air (17) from the hot soil of larger bare patches (18). The lower infiltration also leads to drier soil (19), worsened by higher evaporation (20) from soil that is hotter (21) and that experiences a faster wind speed close to the surface (22) due to larger bare patches of soil allowing wind to pick up momentum (23), and less perennial grass (24) and mulch (25) to slow the wind down.

There are several positive feedback loops that reinforce the formation of gullies with subsequent triggers of rain. The drier soil favours harvester termites (Milton *et al*., 1994) (26) that are also favoured by less cover for their predators (27) resulting from the reduction in perennial grass (28), which is further reduced through the increase in harvester termites (29). The drier soil also harms the activity of beneficial soil bacteria (30). A mass of water flowing down a gully (31) can wash away barriers that provided base levels (Pringle & Tinley, 2003) (32), such as rock bars, which effectively steepens the slope and causes a higher concentration of water (33) travelling at faster speed (34). The harm caused to beneficial soil bacteria by less dung being incorporated into the soil (35) will be explained in section 9.5.1.

The root causes of gullies are similar to most of those for bush encroachment, due to the central role that a healthy cover of perennial grass plays in both maintaining grass vigour over bushes and protecting soil from erosion.

9.3.2 Discussion on management applications for water erosion

Farmers commonly react to gullies by wanting to treat the symptom, often by placing solid objects, such as rocks, tyres and logs, into the gullies to act as barriers. This usually results in the next heavy rain widening the gully alongside the barrier, since the fast flowing water diverts to the weakest side of the barrier. However, even when the root causes are treated, such as by the provision of rest, the natural healing process may be too slow to satisfy farmers. The positive feedback loops sometimes continue to worsen the situation and prevent perennial grasses from re-establishing where run-off continues to flow rapidly. In such situations it may be necessary to treat the symptom, after the root cause has been treated, so as to speed up the recovery. This is unlikely to be financially viable as a restoration exercise for all but the most valuable portions of rangeland, or where a gully can be prevented from expanding into a key area that would otherwise get drained by the gully and become desiccated.

Where a gully is to be treated, after removing the root cause, the use of filters may be more appropriate than solid barriers, unless a concrete weir or gabion is firmly anchored into the bedrock and a large spillway provided. Strategically placed filters, such as branches chopped from encroached bushes, will slow down the water and trap some of its sediment, while allowing most of the water to pass through and continue its downward journey. It may be necessary to tie the branches together and to nearby bushes that are well rooted (Shamathe *et al.*, 2008). The branches will rot and decay after a few years, but they encourage the growth of perennial grasses that should then take over the filtering function from the branches.

As with the problem tree for bush encroachment, the role of a good perennial grass cover is essential to the control of water erosion, thus necessitating sufficient rest in the growing season after being grazed. Herbivores are often attracted to gully sites and therefore temporary exclusion may be necessary. Where the gully started from an animal track, the soil may be more fertile there if the track was caused by animals attracted to graze on the better quality grass. Since water gets redirected from other areas to be concentrated in a gully, the relatively more moist conditions along the gully favour plant growth that attracts herbivores. Farmers often drill boreholes alongside gully systems, especially at the keyline where the flow changes from concentrated to dispersed. Where tracks of animals moving to and from the borehole exacerbate the situation, it may be necessary to pipe the water some distance from the borehole (Pringle & Tinley, 2003).

9.4 WIND EROSION

Wind erosion is widespread in Namibian rangelands, although more apparent in sandier areas where sand may accumulate under low-spreading bushes to create coppice dunes (also known as Nebkha dunes) (Dougill & Thomas, 2002). Coppice dunes occurred at some of the fenceline contrasts in this study, especially in the Camelthorn Savanna, such as at Site 3b (Figure 9.3).

Figure 9.3 A coppice dune forming around a bush of *Grewia flava* at Site 3b in the Camelthorn Savanna. The photograph was taken in August 2005.

The problem tree for the symptom of coppice dunes is presented in Figure 9.4.

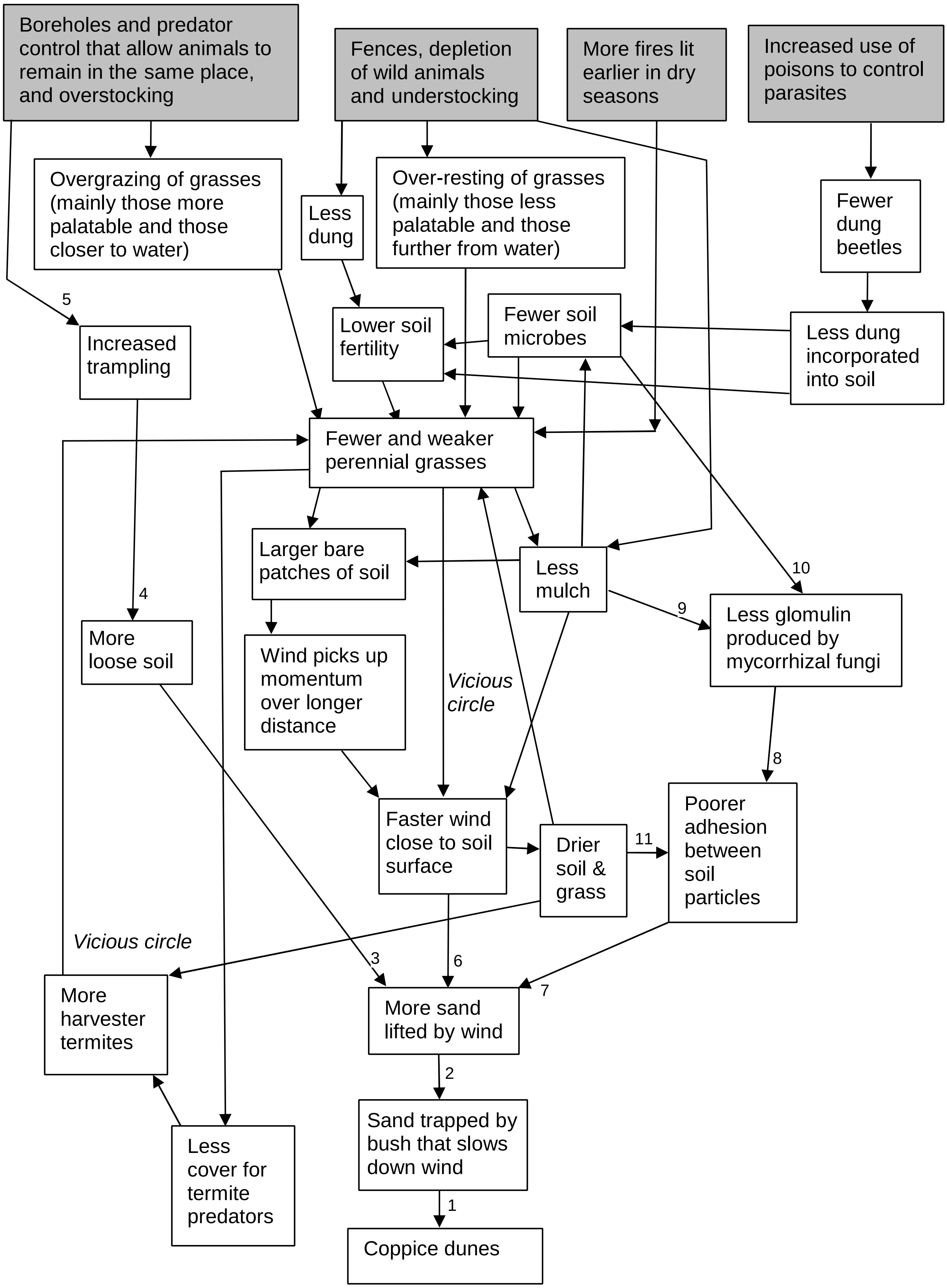

Figure 9.4 A diagnostic problem tree for wind erosion, with root causes shaded and numbers providing reference for text. Arrows already explained in a previous section, or still to be explained in a further section, are not numbered.

9.4.1 Discussion on construction of problem tree for wind erosion

Coppice dunes form around low-spreading bushes that trap sand (1), which had been saltating along the ground after being lifted by the wind (Tongway & Ludwig, 1997) (2). More sand is lifted when the sand has been loosened (3) by increased trampling (4) resulting from the root causes of boreholes, predator control and overstocking (5). More sand is also lifted by wind that blows faster close to the soil surface (6), which is an intermediate cause already explained in section 9.3.1. More sand is lifted when there is poor adhesion between the particles (7), resulting from less glomulin produced by mycorrhizal fungi (8) due to less mulch (9) and fewer soil microbes (10) as explained in section 9.3.1. Some adhesion between soil particles occurs when soil is moist, but it dries prematurely and remains loose for longer and sand is more easily lifted (11). The positive feedback loops have also been explained in section 9.3.1.

9.4.2 Discussion on management applications for wind erosion

Provided the size of bare patches is not too large, the sand, seeds and organic matter trapped under bushes create fertile patches that favour the growth of at least annual grasses. However, once the bare patches exceed a threshold size, which differs for different environments, there is a net loss of fertility from the rangeland and a degradation cycle follows. Therefore, management needs to ensure sufficient cover of the soil, preferably of perennial grass, but also sufficient bush density. Adjusting the stocking rate of both grazers and browsers is key to the control of wind erosion, especially in the dry season when more damage is caused by trampling. Where large bare patches occur in critical areas, restoration measures may be applied to speed up their recovery, such as the use of brush mulch (Van Rooyen, 2000), pegged into place if likely to be blown away. Game animals often concentrate on particular bare areas where perennial grasses will be prevented from establishing unless protected temporarily by brush mulch. It is thus wasteful to try rehabilitating these patches when game animals have access to them.

9.5 PARASITE INFESTATIONS

Regular dosing of livestock with chemical anthelmintics was carried out by 45% of the farmers in this study (section 7.6.4). The problem tree for the symptom of an infestation of intestinal worms in livestock such as sheep, is presented in Figure 9.5.

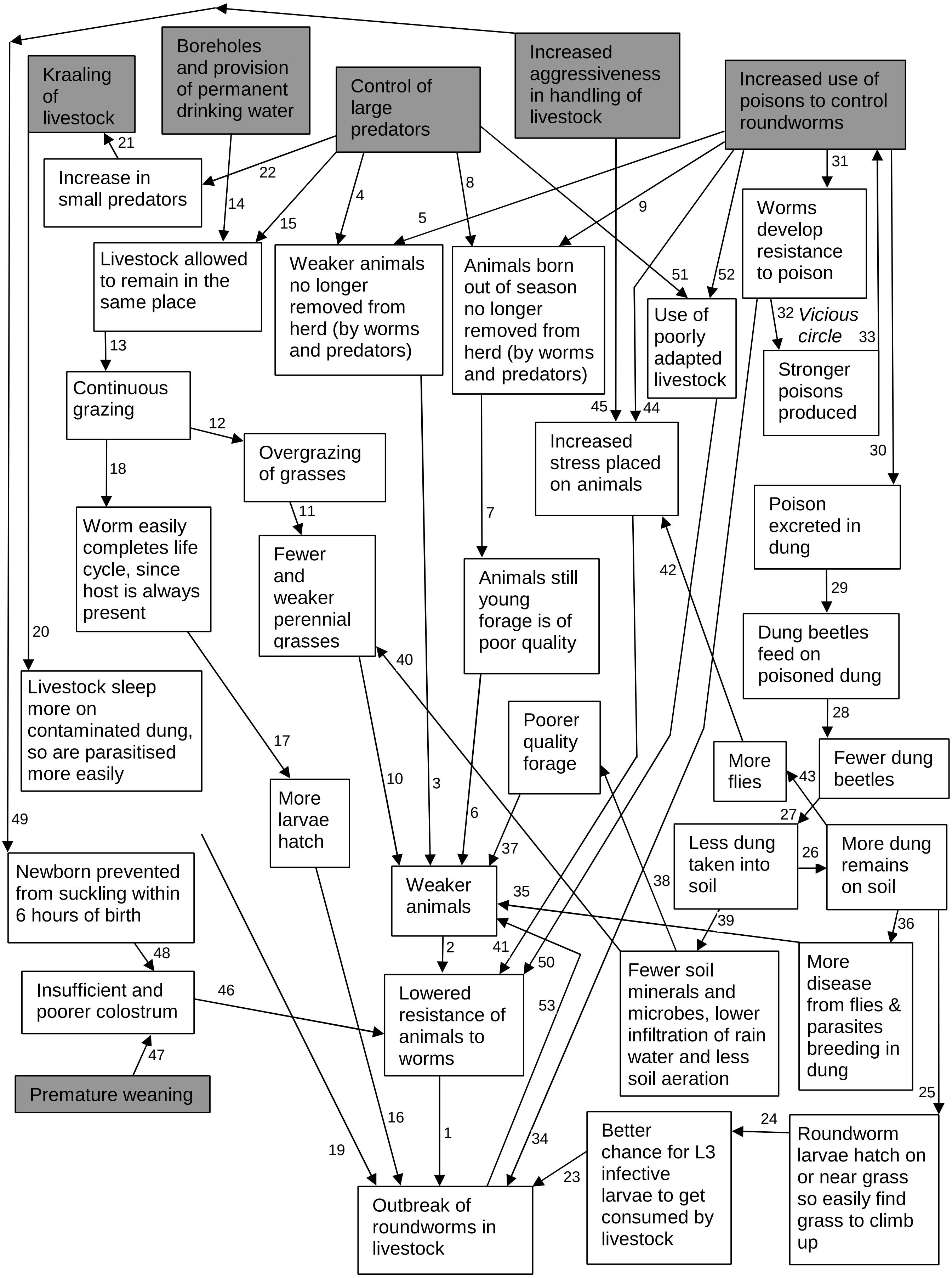

Figure 9.5 A diagnostic problem tree for the infestation of roundworms in livestock, with root causes shaded and numbers providing reference for text.

Roundworms are used as the example in this problem tree. They occur throughout the farming areas of Namibia (Schneider, 1994). Small stock (sheep and goats) are particularly susceptible, as they take longer than cattle to develop immunity to roundworms (Oberem *et al*., 2006). Many farmers respond to roundworms by wanting to treat their small stock with nematicides. Routine use of nematicides is now discouraged by enlightened veterinarians (Bath, 2006; Bath & Van Wyk, 2005; Miller, 2008a). On the other hand, Namibian farmers still receive advice from some quarters to treat their small stock regularly with anthelmintics (e.g. De Lange, 2008).

9.5.1 Discussion on construction of problem tree for roundworm infestations

An infestation of roundworms occurs when sheep are not able to resist the parasites (1) because they are weaker (2). Strong and healthy sheep can resist roundworms by immunological defence and by self-curing of any ill effects from the parasites. In the distant past, under natural conditions, the weakest animals were removed from the herd by predators and diseases, favouring the survival of only the strongest animals through natural selection. However, under human management, the sheep flock becomes weaker because more weaker animals are allowed to breed, since they are no longer removed from the flock (3) by large predators that were eliminated by extreme predator control (4) and by parasites that were killed by toxic treatments (5), both of which are root causes of parasite infestations today. Under natural conditions many animal species synchronise births to the optimum season (Ruechel, 2006) to satiate predators and optimise nutrition for the new born. However, under human management, sheep become weaker if born when grass is of poor quality (6) because they are born out of season (7) as a result of the extreme control of large predators (8) and treatments to kill roundworms (9). Another intermediate cause of weak sheep is the reduction in perennial grass (10), resulting from overgrazing (11), caused by continuous grazing (12), when animals have been allowed to remain in the same place (13), by provision of water from boreholes (14) and by the control of large predators that would otherwise have kept the animals on the move (15). These causes provide a link to the problem tree for the symptom of bush encroachment (Figure 9.1), which could join the two problem trees together.

The continuous grazing also makes it easier for roundworms to complete their life cycle, with their hosts always present, so that more infective L3 larvae moult and contribute to the infestation of worms in the sheep (16-18). When sheep are bunched overnight in kraals the parasites spread even more easily due to closer and constant contact of sheep with dung contaminated with parasitic L3 larvae (19 & 20). This particularly favours roundworms of the *Strongyloides* genus (Pienaar *et al*., 1980), which happily survive in old kraals, are resistant to severe environmental conditions and also directly penetrate the skin of the pregnant ewe. They differ from most of the other roundworms, which penetrate orally and through the intestinal tract. The kraaling of sheep is a root cause of worm infestations, but it has been necessitated in many areas by the increase in small predators (21), such as jackal, due to lack of competition from large predators that have been exterminated (22).

Parasitic worms in sheep increase when their infective L3 larvae are abundant on grass (23), which is likely if the L1 larvae hatch on or near the grass (24). This occurs when more dung remains on the soil surface during the rainy season (25), as less dung was buried in the soil (26), because of fewer dung beetles (27). This results from poisoned dung (29) (Krüger & Scholtz, 1997; Spratt, 1997), excreted by sheep that were recently treated with toxic chemicals (30), another root cause of worm infestations in sheep. This root cause creates a vicious circle as the parasitic worms develop resistance to the treatments (31), resulting in new treatments needing to be developed (32) and higher dosages applied (33). The development of resistance in the worms also contributes to increased infestations of worms in sheep (34). According to Van Wyk *et al*. (1998), sheep and goat production in South Africa is threatened by the development of resistance among nematode parasites to nematicides.

Sheep are also weakened by diseases and their vectors (35) (Oberem *et al*., 2006), which proliferate in beetle-unprocessed dung remaining on the soil surface (36), because it was not buried in the soil by dung beetles. Sheep are furthermore weakened by poor quality forage (37), resulting from poorer soil conditions (38), due to less dung being buried in the soil (39) (Fincher, 1981; Walters, 2004) (Figures 9.6 & 9.7).

Figure 9.6 Fertile patches where cow dung was buried by dung beetles on a farm where neither small nor large stock are treated with nematicides.

Figure 9.7 Unprocessed cow dung remaining on the soil surface on a farm where small stock is regularly treated with nematicides.

These poorer soil conditions also contribute to fewer and weaker perennial grasses (40).

Another reason for the lowered resistance of sheep to parasitic worms is the increased stress placed on the animals (41). One source of stress comes from more flies (42) that breed prolifically in the dung remaining on the soil surface (43), due to the increased use of nematicides that kill beetles, while the toxicity of the nematicides places further stress on the sheep (44). Another source of stress comes from incorrect handling of sheep (45), involving lots of shouting or dog barking and throwing of sticks or stones when herding and capturing animals, which may be another of the root causes of parasite infestations. Yet another reason for lowered resistance in some sheep is insufficient or poorer quality colostrum (46), when lambs are weaned prematurely (47), or when lambs are prevented from suckling within six hours of birth (48) due to rough handling (49). A further reason for lowered resistance occurs when farmers use poorly adapted livestock (50), especially exotic breeds of sheep that was facilitated by the control of large predators (51) and the use of nematicides to control parasites (52). Exotic breeds tend to be less adapted to cope with predators and parasites than indigenous breeds, but even within breeds there is enormous variability in resistance to parasites. A positive feedback loop occurs from the infestation of worms further weakening the animals (52).

9.5.2 Discussion of management applications for parasite infestations

There are farmers who manage to produce healthy livestock without the use of any toxic treatments. They tend to farm holistically with nature and thereby treat the root causes, or intermediate causes close to the root causes, thus preventing the conditions that favour the parasites. By leaving their animals out in the rangeland they avoid the close contact between dung and animals that would otherwise occur during kraaling, thus addressing arrow 20 in Figure 9.5. This requires holistically balanced control over jackal and other predators, especially for their small stock. The ways they achieve this include conservation of wild animals to provide natural and favoured prey for the predators; hunting down of only individual problem animals; regular maintenance of jackal-proof fencing; raising puppies with lambs to imprint them to become guard dogs; narrow breeding seasons to avoid providing predators with year-round lambs; and the use of indigenous sheep breeds with strong mothering and herding instincts. A few farmers even welcome lower, but still balanced, densities of jackals for the selective pressure they apply by removing the sick and weak animals from the herd and maintaining mothering and herding instincts, such as the case study of Chapter 8. However, more farmers apply their own selection by selling or slaughtering individual animals with high parasite loads. These management actions address arrows 4 and 8 in Figure 9.5.

Farmers who practice correct rotational grazing are able to interrupt the life cycle of parasites so that the infective L3 larvae which moulted after sheep were removed from a paddock find no host and may, when weather conditions are also considered, die before the sheep return to the paddock. This management action address arrow 18 in Figure 9.5. A possible disadvantage of rotational grazing is the disruption of the life cycle of those species of dung beetle that do not fly far. There are also a few farmers who treat the root cause of aggressive handling by applying methods of stress-free herding, based on animal behaviour, as described by Ruechel (2006). Gentler handling of livestock has long been recommended by Miller (2008b). Such management actions address arrow 45 in Figure 9.5.

When farmers are still forced to overnight their livestock in kraals, there are ways to administer toxic treatments that minimise their negative effects, and there are non-toxic treatments that will at least avoid the interactions on the right hand side of the problem tree (Figure 9.5), starting with arrow 30. To minimise the impact of toxic treatments on dung beetles, they could be applied only to individual sheep with high worm loads – if the farmer cannot afford to cull them – and/or only during the dry season when dung beetles are inactive. The identification of individuals with high loads of wireworm, *Haemonchus contortus*, could be facilitated by use of the FAMACHA© card (Van Wyk & Bath, 2002; Molento *et al*., 2009), which relies on the whitening of mucous membrane of the eyes for screening the level of anaemia as it applies to these blood sucking worms. However, *H. contortus* is common mainly in northern Namibia, but less common in central and southern Namibia (Bishi, *pers. comm*.[8]), where genera of *Strongylus* and *Strongyloides* are more prevalent and do not suck blood that leads to visible anaemia. Commercial nematicides differ in their level of toxicity to dung beetles, with labelling of "dung beetle friendliness" applied voluntarily to various nematicides in South Africa (Dung beetles for Africa, 2007). Therefore, if farmers must occasionally resort to nematicides, they should rather select those less toxic to dung beetles. The South African labelling is somewhat misleading for those who are unfamiliar with it. The picture of a smiling, thumbs-up beetle appears on even the most toxic product. It is the number of accompanying stars that indicate the toxicity level, with three stars appearing on the least toxic and one star on the most toxic product (Figure 9.8). There is a need for stricter registration of products (Oberem, 2007), requiring the effects on non-target organisms to be more explicit in the labelling.

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[8] Bishi, A.S. Personal communication. Veterinary Epidemiologist, Directorate of Veterinary Services, P/Bag 12022, Windhoek, Namibia

Absent			
Absence of the trademark means that the product has not been tested for non-target toxicity	Product's use should be limited, e.g. to stock feedlots, and should not be used in pastures as the effects on dung beetles would be severe	Product is suitable for occasional use in the pasture	Product has a minimal impact on dung beetles and is considered suitable for regular use in the pasture

Figure 9.8 Labelling for dung beetle friendliness of nematicide products applied voluntarily in South Africa. Source: Dung beetles for Africa (2007).

A high incidence of intestinal worms often coincides with the rainy season (Biggs & Anthonissen, 1982), thereby making it difficult for farmers to apply the option of using nematicides only when dung beetles are inactive. Namibian farmers are being advised to alternate their use of the type of toxic treatment they apply (Kruger & Lammerts-Imbuwa, 2008), presumably under the belief that it would slow the rate at which the parasites develop resistance to the treatments. However, the usefulness of this practice is doubtful and may even result in the parasites developing multiple resistance to all the toxic treatments that are alternated between.

A low incidence of worms is useful to stimulate immunity of the host and possibly for other functions, such as helping the host "get through periods of adaptation and change" and "aerating the digestive system when it is overloaded" (Duval, 1994). If the latter are true, the disruption of these functions by nematicides would contribute to arrow 44 in Figure 9.5.

There are various non-toxic treatments that have been used to control roundworms, including diatomaceous earth and various herbs (Duval, 1994; Ruechel 2006). Local knowledge of indigenous plants having anthelminthic properties could be exploited (Kunene *et al*., 2003), such as Devil's claw (Kumba *et al*., 2001). Two doses of anthelmintic herbs should be applied, three weeks apart (Dettloff, 2004). Another non-toxic treatment involves the use of Effective Microorganisms (EM) comprising different types of naturally-occurring micro-organisms, principally a consortium of lactic acid bacteria, yeasts and phototrophic bacteria. These create the right conditions to support each other and outcompete harmful pathogens, while producing useful substances such as vitamins, enzymes, hormones, amino acids and anti-oxidants that create a reducing environment (Higa, 1996). Chamberlain *et al*., (1999) found that EM in drinking water and sprayed onto pasture resulted in lower numbers of faecal eggs of internal parasites in lambs. Derivatives of EM are being tried on sheep in Rehoboth District (Muheua & Zimmermann, 2009).

The constructed problem tree (Figure 9.5) should be considered a conceptual model. It is by no means inflexible, and should be revised as new information becomes available. It can be referred to when making decisions on parasite control, complementary to an integrated and holistic approach (Bath, 2006). Farmers who still treat livestock with unsafe nematicides could learn useful lessons from enlightened veterinarians and those farmers who successfully raise livestock without the need of toxic treatments, because they farm with nature. Roundworm infestation should be viewed as a symptom caused by imbalances in regulatory processes. Treating the imbalances will be far more effective for long-term sustainability than will treating the symptoms with quick fix, but short-term, toxic chemicals. Treating the symptoms with environmentally friendly remedies should be viewed as a temporary measure until the wider imbalances have been corrected.

9.6 FENCELINE CONTRASTS

9.6.1 Factors influencing identification of the causes of fenceline contrasts

The condition of the rangeland at the time of the measurements is unlikely to have been a reflection of only the management that was currently applied. This is particularly evidenced at Contrast 34, where Sites 34a and 34b had received similar management for the previous 14 years when the farmer of Site 34a bought the land of Site 34b to incorporate into his farm, yet Site 34b was still more similar to the heavily grazed Site 34c than to Site 34a. Clearly the rate of recovery after destocking is a very slow process in this environment and may take many decades. This makes it difficult to identify the causes of the observed differences across fencelines, since the main data gathered in this study were the current condition of rangeland at the measured site and the current management being applied on the whole farm. Data on historic management was far less detailed and in many cases unknown. Furthermore, the data on current management for the whole farm may have differed from the management received at the measured site, due to factors such as distance from homestead as at Site 34. In addition the rangeland condition at the site may not have been a reflection of the rangeland condition in the whole paddock, let alone of the whole farm or group of farms owned or being rented by the farmer.

Small scale differences in soil conditions over short distances are likely to have influenced the results when comparing contrasts. For example, although sites 6b, 7b and 8a were all in the same paddock, *Aristida congesta* was only found at Contrast 6, where there was a slightly higher clay content and *Aristida stipitata* was only found at Contrasts 7 and 8 on soil that was more sandy. The same difference occurred between Contrasts 4 and 5. However, the reliance on contrasts of nearby sites is likely to have minimised the effect of differences in soil type when comparing sites at the same contrast.

In chapter 3 two causes of fenceline contrasts that are not a consequence of difference in management were mentioned. These are distance from water point and time of last stocking, the latter of which results in temporary contrasts. This study observed a third cause, resulting from the tendency of livestock to graze in a particular direction. The tendency for the livestock to graze in a southerly direction in the growing season was observed at Sites 4-8. The reason is unclear, but may possibly be the result of an attraction to the Aminuis pans further south, which are a westward continuation of the "Schwelle" band of mineral rich pans in Botswana where wild ruminants used to concentrate in the growing season for calving (Bergström & Skarpe, 1999). On the other hand Begall *et al.* (2008) found a tendency for cattle to align their bodies along a north-south axis, which they attribute to the magnetic field. Berry *et al.* (1984) found that wildebeest aligned their bodies in relation to both sun angle and wind direction, mainly for thermoregulation. According to Genis (*pers. comm.*[9]) goats tend to forage into the wind and move far when the wind is strong and steady, while cattle are less affected by wind direction.

The opportunistic nature of this study resulted in various types of management data from which the likely causes of differences in rangeland condition across contrasts could only be derived by speculation, based upon opinions of farmers and personal experience. There was no systematic way of distinguishing which of the numerous management aspects had been more responsible than the other for bringing about the observed differences in rangeland condition, nor which different type of historic management may have brought about greater differences than current management. Opinions sometimes differed, as in the example of Contrast 3 where the interesting observation had been made of a higher density of young plants of *Dichrostachys cinerea* on the commercial farm side, despite better grass conditions there. One farmer was of the opinion that the high density of small stock and equines may have been responsible for preventing the establishment of the young *D. cinerea* on the leasehold side of the contrast, while another

[9] Genis, A.E. Personal communication. Observant farmer. P.O. Box 420, Gobabis, Namibia.

farmer believed that two large fires which swept through the leasehold side more than a decade earlier had been responsible for the difference.

Some of the management data that was provided through the responses of farmers also had to be supplemented with personal observations. For example, although the overall stocking rate in the paddock of Site 4a, on the northern side of the fence, was lower than that in the paddock of Site 4b, the grazing pressure was clearly seen to be greater on Site 4a, presumably due to the tendency of animals to move southwards. This supplementation of data could not be quantified and had therefore to remain qualitative, such as describing the stocking rate at Site 4a as "locally very high".

9.6.2 Likely main causes of the fenceline contrasts

Out of the 34 fenceline contrasts that were measured, there were only 20 sites that met the two conditions of (i): indicating rangeland condition indices that differed significantly ($P<0.05$); and (ii) having a management difference that stood out as being the likely main cause of the difference in rangeland condition. As summarised in Table 9.1, the most likely main causes of difference in rangeland condition are: (i) bush thinning (6 contrasts); (ii) bush clearing (3 contrasts); (iii) stocking rate (5 contrasts); (iv) period of rest (4 contrasts); and (v) stocking density during occupation of a paddock (2 contrasts).

Table 9.1 Likely main causes of differences in rangeland condition at 20 of the fenceline contrasts.

Site	Rangeland condition index[1]	Likely main cause of difference in rangeland condition	Current difference in the main cause on each side of fenceline	Type of farm or paddock
3a 3b	650 210	Stocking rate of farm	42 kg $ha^{-1} a^{-1}$ 105 kg $ha^{-1} a^{-1}$	Large cattle farm Small leasehold farm
4a 4b	82 266	Stocking rate of farm	Locally very high 96 kg $ha^{-1} a^{-1}$	Large game paddock Small leasehold farm
6a 6b	347 156	Stocking rate of farm	26 kg $ha^{-1} a^{-1}$ Locally high	Small leasehold farm Small leasehold farm
8a 8b	210 302	Stocking rate of farm	High Low	Paddock with water Paddock without water
9a 9b	460 155	Rest	6 weeks Sporadic	Cattle & horse breeding Speculation weaners
10a 10b	455 126	Bush clearing	Cleared of all bush No bush control	Hay field Mixed livestock
11a 11b	225 120	Stocking density of paddock	8 100 kg ha^{-1} 400 kg ha^{-1}	Small paddock of 6 ha Paddock of 120 ha
12a 12b	40 225	Stocking density of paddock	130 kg ha^{-1} 400 - 4 000 kg ha^{-1}	Slow cattle rotation Strategic trampling
13a 13b	157 225	Bush thinning	No bush control Thinned <10 years ago	Commercial cattle farm Commercial cattle farm
16a 16b	20 120	Rest	9 weeks but varies 13 weeks	Commercial cattle farm Commercial cattle farm
17a 17b	30 238	Bush clearing	No bush control Cleared of all bush	Communal farm land Hay field
18a 18b	85 335	Bush thinning	No bush control Thinned <10 years ago	Commercial cattle farm Commercial cattle farm
19a 19b	190 283	Bush thinning	No bush control Thinned <10 years ago	Game farm Commercial cattle farm
21a 21b	205 275	Bush clearing	Thinned >10 years ago Cleared of all bush	Cattle paddock Hay field
24a 24b	210 125	Rest	6 weeks None	Commercial cattle farm Game farm
26a 26b	306 434	Rest	None 6 weeks	Game farm Commercial cattle farm
27a 27b	100 627	Bush thinning	No bush control Thinned <10 years ago	Commercial cattle farm Game farm
28a 28b	465 284	Bush thinning	Thinned <10 years ago No bush control	Game farm Commercial cattle farm
30a 30b	86 201	Bush thinning	No bush control Thinned <10 years ago	Commercial cattle farm Commercial cattle farm
34a 34b	702 571	Stocking rate >14 years ago	24 kg $ha^{-1} a^{-1}$ 24 kg $ha^{-1} a^{-1}$	Commercial cattle farm Commercial cattle farm

[1] Rangeland condition is comparable between sites at the same contrast but less comparable between contrasts, because it was not related to the condition of benchmark sites for the different areas.

9.6.2.1 Bush thinning

At all six of the contrasts where bush thinning had been identified as the main cause, and had taken place on only one side of the fence (Sites 13b, 18b, 19b, 27b, 28a & 30b), the rangeland condition was better on the side where the bush thinning had taken place (Table 9.1).

Bush thinning treats the symptom of bush encroachment. Unless sufficient attention is paid to treating the root causes of bush encroachment, it is likely that more bushes will reappear. The high proportion of bushes in the 0.5-1 m height class at all seven of these thinned sites, ranging from 37% to 86%, suggests that this is already underway. Preventative management that treats the root causes, or the intermediate causes near the top of the problem tree, may be more effective in the long term. However, on many of Namibia's rangelands the symptom of bush encroachment is so well entrenched that it would likely take decades before treating the root causes brings about substantial mortalities of established bushes. In such situations, treating the symptom of bush encroachment may be warranted, but only after the root causes have been treated too. The management of bush encroachment was discussed in section 9.2.2, where emphasis was placed on preventative management and the limited windows of opportunity presented by episodic events for preventing establishment of bush seedlings and saplings.

The interesting comment by one of the interviewed farmers that fruit-eating birds are valuable in spreading mistletoe seeds to help control bush encroachment, may warrant further investigation. Mistletoe is also valued as dry season fodder for small stock (Madibela *et al*., 2002). When applying selective thinning, the bushes with mistletoe and fungal infection should not be targeted.

One of the interviewed farmers did not view the bush encroachment on his farm, mainly by *Acacia mellifera*, as a problem. He believed that on parts of the farm where the bushes grew very dense, they would eventually get thinned out by fungus, such as *Phoma glomerata*. The farmer valued the forage produced by the bushes, especially the leaves that fell to the ground during the dry season. He even took measurements by placing a tarpaulin under an *A. mellifera* bush 2 m in height until after leaf fall, then gathered together the dry leaves to weigh them, finding 4 kg DM. When presented with this figure other farmers expressed the opinion that this was a poor use of the large quantity of water transpired by *A. mellifera* bushes.

The transpiration rate of 65 l day^{-1} by an *A. mellifera* bush (Donaldson, 1969) is well known amongst commercial farmers. Less well known is that it was measured from a bush with a canopy area of 6 m^2 and probably represents close to the maximum transpiration rate. Members of a farmers' association, including three of the interviewed farmers, applied Donaldson's figure on the area of bushes they cleared to estimate the amount of water saved, thereby justifying their abstraction of ground water for irrigation of olive groves or crop fields. This farmers' association also monitored the ground water levels in its members' boreholes to back up their calculations. Undoubtedly an enormous amount of water gets transpired through encroached bushes and runs off more due to poorer grass cover (Smit & Rethman, 2000). Bockmühl (2008) reported a significant rise in the water table from a 60 mm rainfall event where bushes were cleared, compared to no noticeable rise in water table under areas of thick bush that received the same rainfall.

9.6.2.2 Bush clearing

Three of the sites (10a, 17b & 21b) had undergone complete removal of bushes and been converted into hay fields, one of them (10a) after serving as a maize field in the interim. The rangeland condition index was higher on the side where the bush clearing had taken place (Table 9.1). They were still in fairly good condition despite annual mowing, which was usually done in autumn to optimise both quantity and quality of harvested hay, before grasses translocated their food reserves to storage organs. Some hay from three of the sites was sold, thus exporting nutrients from those farms, while the only import of nutrients was through lick, with no artificial fertilizer applied to the hay fields. The only manure applied was from the cattle that were allowed to forage on the hay fields after harvest. The lesser degree of soil compaction at the hay field of Contrast 22, described in section 5.4.6, was also surprising. It seems the hay fields retain their resilience for at least several decades after establishment. It is becoming more common for farmers to leave large trees standing in hay fields, usually those of *Acacia erioloba* and *Boscia albitrunca*, when converting natural rangeland to new hay fields. This practice not only provides shade for animals and enriches the soil, but may also reduce the rate of re-establishment of bush seedlings through their competitive advantage (Teague & Smit, 1992).

9.6.2.3 Stocking rate

Figures provided by farmers to determine current stocking rate differences between both sides of the fence were only available for one of the five contrasts where stocking rate was identified as the main cause. At three of the sites (4a, 6b and 8a) the evidence for heavier stocking came from personal observation of more severely grazed grass and greater abundance of dung and hoof marks. At the other site (34a), which was at the time stocked the same as one of the opposite sides (34b), the farmer gave a historic account of a much higher stocking on Site 34a, without being able to provide figures. Assuming these inferences to be correct, the rangeland condition was better on the more lightly stocked side at all five contrasts (Table 9.1), even where the overstocking had taken place more than 14 years earlier. The lowest stocking rate at any of these sites was 24 kg liveweight ha^{-1} (19 ha AU^{-1}), which is presumably higher than the stocking rate at which rangeland condition starts to deteriorate due to understocking, although such degradation is a slower process than degradation caused by overstocking.

The stocking rate of 105 kg liveweight ha^{-1} (4 ha AU^{-1}) on one of the leasehold farms (3b) was clearly excessive and unsustainable, while the rate of 42 kg liveweight ha^{-1} (11 ha AU^{-1}) on the commercial farm on the contrasting side (3a) maintained a better rangeland condition index (650 versus 210). There is no fixed grazing capacity that can be recommended, as it changes with factors such as the condition of the rangeland (Barnes, 1990), the amount and distribution of rainfall in any season (Tainton, 1999), the grazing system applied (Norton, 2003) and the objective of the farmer (Trollope, 1990). The accuracy of the visual judgement used by most farmers to estimate grazing capacity could be improved by occasional calibration with clipping and weighing of palatable grass (Friedel & Shaw, 1987) converted to grazing capacity by the method of Bester (2003). Nevertheless, it may also be useful to refer to general guidelines such as those based on a long-term stocking rate trial at Sandveld Research Station in the Camelthorn Savanna. The trial was evaluated by Rothauge (2006) who recommended a maximum of 45 kg liveweight ha^{-1} (10 ha AU^{-1}) for farmers who try to optimise production per hectare, and 25 kg liveweight ha^{-1} (18 ha AU^{-1}) for stud farmers who try to optimise production per animal. A map of grazing capacities in Namibia (Mendelsohn *et al*., 2002) indicates 10-20 kg liveweight ha^{-1} for the contrasts in the Dwarf shrub Savanna, 20-30 kg liveweight ha^{-1} for the contrasts in the Highland and Camelthorn Savannas and 30-40 kg liveweight ha^{-1} for the contrasts in the Thornbush Savanna (23-45; 15-23; and 11-15 ha AU^{-1}, respectively). The effect of a given stocking rate on the rangeland also depends on the type of animals stocked, not only according to species of animal but also breed of livestock. When compared at similar stocking rates in long-term grazing trials, Kirkman (2002) found that sheep grazing led to worse rangeland condition than cattle grazing, while Rothauge (2006) found that grazing by large-frame cattle led to worse rangeland condition than grazing by small frame cattle.

9.6.2.4 **Rest**

There were four contrasts where the rest provided to grazed grasses in the growing season was considered the main cause of the difference in rangeland condition. At Site 9b the farmer bought weaners at times when prices were low and grazed continuously until the prices rose sufficiently to earn substantial profit. This was done without regard for season and sensitivity of the rangeland. The contrasting farm (9a) that provided an average rest period of six weeks, had a higher rangeland condition index than the farm that provided sporadic periods of absence between selling and subsequent re-stocking (460 versus 155). Another contrast was between farms (16a & 16b) that provided average rest periods of 9 and 13 weeks, with the latter being in better rangeland condition (120 versus 20). However, the actual rest periods varied considerably, especially on Site 16a where the water supply was extremely limited and likely to have resulted in this paddock being used predominantly after substantial rain, when water was available in pans, and when perennial grasses were more sensitive to being grazed. It is likely that the very poor condition of rangeland at Site 16a was more a consequence of the timing of grazing within the growing season. At two other contrasts the continuous selective grazing by gregarious game species on the same farm at Sites 24b and 26a is likely to have been mainly responsible for the poorer rangeland condition index in comparison to the contrasting cattle farms (24a & 26b) that each received average rest periods of 6 weeks in the growing season.

The period of rest is closely tied to the period of occupation, depending on the number of paddocks per herd. Rest for grazed grasses to regain vigour is required during periods of active growth (Smit & Rethman, 1992). Severely grazed grasses are likely to require longer rest than lightly defoliated grasses. Although the severity of defoliation increases with longer period of occupation and higher stocking density, the most preferred grasses may experience severe defoliation even under lighter stocking for a shorter period. Grazing animals preferentially revisit previously grazed grasses (O'Connor, 1992). Overgrazing of the most preferred grasses can occur in relation to periods of occupation and rest when: (i) the period of occupation is too long, allowing animals to repeatedly eat regrowth from the same plant, and (ii) the rest period is too short, allowing animals to eat regrown leaves that have not yet had time to replenish the growth reserves that were used to regrow new leaves. Avoiding both types of overgrazing may require too many paddocks per herd to be viable, necessitating a compromise to be reached. It is likely to be more harmful when the rest period is too short than when the period of occupation is too long. When animals remain too long in a paddock they would only be able to take small bites from the regrowth and would therefore still be forced to feed on other, previously ungrazed, grasses. Whereas, when animals return too soon to a previously grazed paddock, they would find plenty of regrowth available and would be unlikely to feed on the previously uneaten grasses. Hence, they would remove a large quantity of organic matter that had been borrowed from the food reserves of the best grasses and not yet been replaced, thereby weakening those grasses. Therefore, if faced with too few paddocks per herd, it may be preferable to exceed the maximum grazing period rather than return to a paddock before the minimum rest period has been achieved.

This is one of the bases upon which the fodder bank grazing system (Smit, 1998) was developed, so that the damage done by a complete growing season's continuous grazing every third year may be repaired during the followed two full growing seasons of rest. This principle was promoted in Namibia in the late 1950's (Rowland, 1974), but the many farmers who overstocked during the severe drought of the early 1960's, either over utilised the paddocks being grazed or increased the speed of rotation. The veterinary restrictions imposed at that time as a result of the foot-and-mouth outbreak made it difficult for farmers to de-stock economically (Rowland, 1974). Setting the stocking rate at carrying capacity is a prerequisite for successful grazing rotations, to ensure sufficient forage until the end of a safety period that provides a drought reserve after the next rainy season is expected. Excessive rest not only leads to moribund forage that is less palatable, but may also lower the invigorating effect of grazing on soil microbes through root exudates (Hamilton & Frank, 2001).

Another grazing system that has been promoted in Namibia is that of controlled selective grazing (Tainton, 1985). This had previously been practiced at Sites 27b and 28a, where bush thinning had been identified as the major cause of the better rangeland condition of this site compared to two neighbouring farms. When the farm had been visited a decade earlier, the palatable perennial grasses were seen to be thriving and the less palatable grasses were seen to be accumulating masses of ungrazed material. This observation confirmed the objectives of this grazing system that relies on a low stocking rate. However, the moribund grass tussocks appeared to be ideal nursing sites for the establishment of bush seedlings. Numerous bush seedlings and saplings were seen growing vigorously from within the bases of moribund grass tussocks. The labour-intensive chopping programme was keeping the bush saplings under control, but at high cost.

As an alternative to costly permanent fencing for providing sufficient paddocks per herd, a few farmers use moveable electric fencing. They enclose the herd within a relatively small area surrounded by the electric fencing that is frequently moved. Herding is also an option to keep animals off rested portions of rangeland and is being applied by a community in north western Namibia as part of a pilot project (Kangombe & Kapi, 2008).

The provision of rest may be facilitated by cultivated pastures. Although it is a common perception that cultivated pastures should be used during the dry season when quantity and quality of natural rangeland forage is at its lowest, Kirkman and De Faccio Carvalho (2003) considered it wiser to use cultivated pasture in the growing season "when productivity and quality are optimum and livestock demand for quality feed is at its highest, so that rested rangeland be used during the dry season when quality demand is relatively low". Two of the interviewed farmers who has cleared natural rangeland and replaced some with cultivated pastures of *Cenchrus ciliaris*, used them in the rainy season as part of their strategy to rest the perennial grasses in their rangeland at this sensitive stage.

Where high densities of game animals have access to paddocks that are being rested, the grasses are likely to be weakened. There are several farmers who observed that game animals tend to follow the rotation of their livestock by a few days or weeks in the growing season, to nibble on the regrowth. This could be avoided by reducing game numbers and/or providing disturbance to chase game animals off resting paddocks, such as by applying bush chopping measures in paddocks at their most sensitive stage of recovery.

A synthesis by Briske *et al.*, (2008) concluded that evidence from numerous grazing experiments throughout the world failed to support the common perception that rotational grazing wais superior to continuous grazing, both in terms of animal production and rangeland condition. Norton (2003) pointed out some flaws in grazing experiments and the way they were interpreted, choosing instead to support anecdotal evidence of farmers who applied rotational grazing to raise the carrying capacity of their rangeland with minor loss in individual animal productivity. The reluctance of interviewed farmers to provide figures of average rest periods, attests to the need for flexibility in the application of rotational grazing. Rest is only effective for parts of the growing season, after substantial rainfall events. Hence the period of absence required to provide grasses with sufficient rest, varies tremendously and requires an adaptive management approach.

One of the interviewed farmers who opened all the internal gates of his farm noticed that each new herd of speculation weaners followed the same three-day rotation passing through each of the farm's water points, and in the same direction. This occurred despite the fact that the entire previous herd had been removed approximately six months earlier and no animal remained on the farm to teach the new herd this movement. Grazed grasses would not receive sufficient rest under this self induced rotation of the cattle, although it presumably optimised their performance.

Two of the interviewed farmers expressed the opinion that palatable perennial grasses were very resilient and able to withstand frequent defoliation, as described in section 7.4.2.7. One of these farmers based his opinion on observations that the cattle in the communal area were in excellent condition and repeatedly took small nibbles from severely grazed grasses that continued to survive, albeit at low density, a short distance from the water point. The free movement of cattle under communal management may allow them to select the most nutritious forage available, as suggested by Mbatha & Ward (2006) after finding higher concentrations of crude protein in the dung of cattle in a communal ranch. However, a higher crude protein content in dung may reflect a greater proportion of browse that cattle were forced to feed on due to a lack of grass. Furthermore, the grasses growing a short distance from the water point may benefit from the dung and urine of animals concentrating there. However, recruitment of perennial grasses can only occur within the safety of low bushes, and the long-term survival of the established grasses under that heavy grazing pressure does not conform to the predominant paradigm among rangeland scientists. Ward *et al.*, (2004) hypothesised that the relatively small differences in rangeland condition between commercial and communal farming areas, despite much higher stocking on the latter, were a consequence of farmers' response after drought, when grasses need time to recover before being grazed. Whereas this rest is provided in communal areas because farmers cannot afford to restock quickly after a drought, the commercial farmers restock immediately after the drought and prevent the grasses receiving the rest they so urgently need. This may have occurred in the past, but is unlikely to take place now that communal farmers who work in towns invest in livestock to be cared for by relatives in communal areas.

The use of dung consistency by one of the interviewed farmers as an indicator of animal diet concurs with the findings by Zimmermann (1980) that the moisture content of fresh dung correlated well with the digestibility of forage intake.

9.6.2.5 **Stocking density and trampling**

The two contrasts where stocking density was considered to be the main cause of differences in rangeland condition have been described in the case study presented in Chapter 8. One contrast was between a small paddock of 6 ha (11a) that was stocked at the same rate as the contrasting paddock of 120 ha (11b), at a higher stocking density (8 100 versus 400 kg liveweight ha^{-1}; or 18 versus 1 AU ha^{-1}) and shorter period of occupation (0.3 versus 7 days). The rangeland condition index was higher in the smaller paddock (225 versus 120).

The other contrast was between the farm where strategic trampling was applied by the case study farmer (12b) and the neighbouring farm where a slow fixed rotation was applied (12a). The stocking density was normally 400 kg liveweight ha^{-1} (0.9 AU ha^{-1}), but increased to 4 100 kg liveweight ha^{-1} (9,1 AU ha^{-1}) when strategic trampling was applied, while on the conventionally managed farm the stocking density was only 130 kg liveweight ha^{-1} (0.3 AU ha^{-1}). The rangeland condition was better where the strategic trampling had been applied (225 versus 40), although the poorer condition on the neighbouring farm is also likely to be the result of unknown historical management by the previous owner.

The use of trampling as a management tool has already been discussed in section 8.3. If applied strategically in relation to rainfall events and soil conditions, and if followed by sufficient rest in the growing season, trampling could be used over localised areas for achieving different objectives. One of those is increasing the establishment of grass seedlings, as was evidenced after trampling at the start of the rainy season at the additional fenceline contrast described in section 4.4.12. The need to occasionally re-establish perennial grasses from seedlings is particularly strong for species with fast turnover rates. Zimmermann *et al.* (2008c) found annual mortality rates of *Stipagrostis uniplumis* to exceed 20% in Etosha National Park.

No evidence of other claimed benefits of trampling, such as knocking down standing grass material and increasing the mulch cover (Savory, 1999), could be found in this study. There was no significant (P>0.05) difference in mulch cover between both sides of Contrast 12. The type of mulch cover may have differed, but was not measured. Fallen leaves from *Acacia mellifera*, which was abundant on Site 12a, may have constituted a greater proportion of the mulch cover of that site. Whether or not trampling can improve water cycling by increasing infiltration and/or reducing soil evaporation (Labuschagne, *pers. comm*.[10]) is being investigated in a follow-up study (Zimmermann *et al*., 2008a). The higher soil water found under strategic trampling shortly after rain (Figure 4.41) was only based on two replicates and is therefore inconclusive.

Disadvantages of trampling include the loss in animal condition and the risk of damaging the rangeland if growing season rest cannot be provided for recovery after the trampling.

9.6.2.6 **Game farming**

Four game farms contributed to eight of the contrasts, seven of which were in the Thornbush Savanna and one in the Camelthorn Savanna. At four of these contrasts the game farms had a lower rangeland condition index than the contrasting cattle farms, at three of the contrasts the rangeland condition was better on the game farms, while at one

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[10] Labuschagne, J. Personal communication. Observant farmer. P.O. Box 53, Gobabis, Namibia.

contrast the difference was only slight. Factors other than the type of animal stocked, are likely to have contributed more to these differences.

At Contrast 4 the lower rangeland condition index on the game farm (82 versus 266) is likely to have been caused mainly by the high concentration of game animals near the fence at 4a, as described in section 9.6.2.2. The most numerous game species on the paddock containing Site 4a were wildebeest (both blue and black) and blesbok, all gregarious short-grass grazers (Smit, 2002). At Contrast 19 the relatively worse rangeland condition on the game farm (19a) is likely to have resulted mainly from bush thinning that kept the rangeland in better condition on the cattle farm (19b), as described in section 9.6.2.1.

Contrasts 23-26 were between a single game farm and four of its neighbouring cattle farms. This game farm was stocked primarily with gregarious short-grass grazers (Smit, 2002), including species exotic to the area such as black wildebeest, blesbok and impala. The rangeland condition index was higher at two of those cattle farms (24a & 26b), similar at one (23a) and lower at one (25b). The stocking rates did not differ much across contrasts, with 45 kg liveweight ha^{-1} (10 ha AU^{-1}) on the game farm and ranging between 38 kg liveweight ha^{-1} and 50 kg liveweight ha^{-1} (9-12 ha AU^{-1}) on the cattle farms. Therefore, it is likely that the continuous grazing by the more selective and gregarious game species was mainly responsible for the lower rangeland condition index compared to two of the cattle farms (24a & 26b), as described in section 9.6.2.3, despite the intensive bush thinning that had taken place on the game farm. The bush thinning may have compensated for the continuous grazing at Site 23b, resulting in similar rangeland condition index to the cattle farm (23a). It is unclear why the other cattle farm (25b) had a lower rangeland condition index (160) than the game farm (213) and all three cattle farms (295, 210 & 434). It may have been the result of unknown historical management by the previous owner of the cattle farm.

Another, more recent, game farm had a better rangeland condition index than both of the contrasting cattle farms (27a and 28b). This game farm had the same owner as the game farm at Contrasts 23-26 mentioned above. The difference was that it was stocked with a greater proportion of tall grass grazers, such as roan and sable antelope, and bulk grazing zebra, and it had only been converted to a game farm four years previously. The game farm at Contrasts 23-26 had been a game farm for 20 years already and was stocked primarily with concentrate grazers, such as wildebeest. Before conversion to the game farm at Contrasts 27 & 28, it had been a cattle farm under controlled selective grazing (Tainton, 1985), and undergone intensive but selective bush thinning, which is likely to have been the main cause of the better rangeland condition there, as discussed in section 9.6.2.1. The rangeland may deteriorate on this game farm, due to continuous grazing, as seems to have occurred on the other game farm that had been converted from a cattle farm 20 years previously. On the other hand, if the game animals remain dominated by bulk and tall grass grazers and browsers, the deterioration may not be as rapid.

The difficulty of controlling the movements of game animals on farms surrounded by game fencing poses a threat to rangeland condition. However, on a small scale limited rest was provided to some grasses on the second and third game farms mentioned above, by the use of brush mulch. The branches of stem burnt bushes collapsed a few months later to provide brush mulch that protected grasses growing underneath for a few years before they rotted, while smaller bushes that had been chopped were also left lying on the ground as brush mulch.

9.6.2.7 **Fire**

The effects of fire are extremely variable, depending not only on the intensity and direction of the fire in relation to wind, but also on the physiological stage of the plants and the concentration of animals attracted to feed on regrowth (Trollope, 1999). The fire regime of the fires that had been experienced within the previous two years, at four of the sites in this study, is unknown. However, they all had a better rangeland condition index than the contrasting unburnt sites, (302 versus 210 at Contrast 8; 627 versus 100 at Contrast 27; 465 versus 284 at Contrast 28; and 275 versus 225 at Contrast 31), although at the latter contrast the difference was only slight and not significant ($P>0.05$). Three of the fires were started by lightning at the start of the growing season, while the fourth at Site 31b was deliberately applied at the end of the dry season to control bush seedlings and saplings. However, it is likely that factors other than fire contributed more to their better condition. At the three sites burnt by unplanned fires (8b, 27b & 28a), it was largely the lack of fuel on the contrasting sides that prevented the fires from crossing the fencelines. Therefore the better condition of rangeland is likely to have preceded the fires, although the fires may have subsequently helped to invigorate the grass growth, because they were natural fires that were started by lightning at the beginning of the growing season, and the burnt paddocks were then rested or grazed only lightly. The light grazing was by game animals at Sites 27b and 28a that did not concentrate on a small area since more than half of the game farm had burnt. The rest was provided at Site 8b by the farmer who feared his cattle would get sick if allowed to feed on the lush regrowth from burnt grasses. Site 31b received rest for the whole growing season after the fire, since the farmer applied the fodder bank grazing system (Smit, 1998). The farmer also intended to burn each paddock on his farm at six-yearly intervals, at the start of the rainy season to simulate lightning induced fires.

According to Stander *et al*. (1993) the minimum mean return period of lightning induced fires in Etosha National Park is 9.3 years. Controlled burning was applied there with the objective of maintaining biodiversity, using a decision support system to guide the burning programme (Du Plessis, 1997). Variables used to determine which of the park's 25 blocks would be burnt at the end of the dry season included the maximum normalised difference vegetation index (NDVI) of the preceding rainy season, the period since the last burn in that and neighbouring blocks, their game densities, the extent to which the season's rainfall exceeded the 20-year mean for the block, the degree of moribundness of perennial grasses and the fuel load.

Fire has shaped rangelands for at least six million years (Bond *et al.*, 2003) and numerous plants, especially C4 grasses, evolved strategies and mechanisms that depend on burning or herbivory. The benefits of fire include control of bush encroachment, as discussed in section 9.2.2, and invigoration of moribund grass (Trollope, 1993). Grossman, *et al*. (1981) found that a slow back-fire actually weakened unpalatable moribund grasses, while stimulating the palatable grasses. According to Zimmermann *et al.* (2008c), the recruitment of perennial grasses is triggered by periodic fires in Etosha National Park. However, over the past four decades fires have been well controlled in Namibia's commercial farming areas (De Klerk, 2004). A few farmers in Namibia now apply fire to control bush, sometimes followed up with browsing pressure by goats (Zimmermann & Mwazi, 2002).

The opportunities for controlled burning are limited by the availability of fuel, which may only be sufficient after seasons of above average rainfall, especially for the drier rangeland. According to Du Plessis (1997) the fuel load should be at least 2 t ha^{-1}. To ensure sufficient fuel, paddocks may need to remain free of livestock, or be only lightly grazed, from before the end of the previous growing season. To favour perennial grasses, the fires should be as close to the start of the rainy season as possible. However, some farmers in the northern part of the Thornbush Savanna wait until annual grasses have grown to a height of approximately 20 cm before burning, to favour perennial grasses by removing the competitive effect of the annual grasses, while reducing ground temperature during the fire to minimise harm to soil biota (Bagot-Smith, *pers. comm*.[11]). The timing of

[11] Bagot-Smith, A. personal communication. Innovative farmer. P.O. Box 165, Otjiwarongo, Namibia.

burning is critical, not only in terms of plant and fuel conditions, but also in terms of weather conditions at the time of the fire, especially wind speed and direction, temperature, and humidity of air and fuel (Trollope, 1999).

Farmers who apply fire usually burn a fairly large portion of their farm at a time, to spread out pressure from game animals that inevitably get attracted when the burnt grasses flush. However, one of the interviewed farmers applied burning to patches of approximately 10 ha for the purpose of improving biodiversity. A higher fertility was found in soil from burnt patches than on nearby unburnt rangeland on that farm (Zimmermann *et al*., 2008b). The dung and urine of the animals attracted to the burnt patches seem to have created nutrient hotspots, which are significant to savanna dynamics (Scholes & Walker, 1993).

9.6.2.8 **Heterogeneity of rangeland**

Rangeland heterogeneity occurs at different scales and provides different benefits. On a smaller scale, soil under trees tends to be more fertile and support preferred grass (Rothauge *et al*., 2003; Smit & Swart, 1994), while bare patches may serve as sites to harvest rain water that runs off to irrigate surrounding grass (MacDonald, 1978). On a larger scale, a farm with a single water point achieves some degree of heterogeneity in the form of piospheres at different distances from the water, providing “grazing reserves” at the farthest distance (Dougill, *et al*., 1999). The recollection by animals of where they had grazed more and better forage, improves the likelihood of return visits that result in uneven grazing distribution (Bailey, *et al*., 1996) usually leading to further heterogeneity (Adler *et al*., 2001). The complex interactions and processes brought about by heterogeneity are threatened by intensification of land use (Ash *et al*., 2004). Fuhlendorf & Engle (2001) proposed rotated patch burning as a means of restoring rangeland heterogeneity.

Only one of the interviewed farmers undertook management aimed at increasing the heterogeneity of his rangeland, by patch burning and chopping bushes to construct temporary kraals. The condition index of his rangeland was higher than that of both his neighbours, but still rather low (150 versus 115 and 120 versus 20). The usual approach to grazing is to intensify rangeland use by spreading water points and subdividing paddocks, which tends to homogenise the rangeland. However, the usual approach to bush control, such as converting paddocks with the best soil to hay fields, or rotating areas for thinning, unintentionally increases heterogeneity, probably to the benefit of animals that thereby gain access to a greater diversity of plants and habitats. The balance between different types of animals stocked, such as short grass versus tall grass grazers (Smit, 2002), may also influence heterogeneity.

Termite mounds may contribute to heterogeneity at a smaller scale. An interesting observation by one of the interviewed farmers was that the density of termites was far lower on one side of the boundary fence until seal oil was omitted from the lick, whereupon the termites became equally abundant on both sides of the fence. The farmer attributed this to the effect of seal oil deterring termites (*Macrotermes* spp.) from feeding on the dung, but no literature could be found to substantiate this. Termites play an important role in a healthy rangeland, such as taking over the dung processing service from dung beetles for the dry season. It is only after ecological processes have been interfered with when termites may become excessive (2008).

9.7 MEASUREMENT OF RANGELAND CHARACTERISTICS

9.7.1 Dimensionless point measurements

The use of a dart was a convenient way to generate sample points, compared to the cumbersome wheel point apparatus (Tidmarsh & Havenga, 1955) and the step point (Mentis, 1981), which cannot easily be placed in bushes that form an integral part of most rangelands.

The variables measured without dimension at the dart point had been soil cover (Hit) and woody canopy (Canop) over the point as well as by Bitterlich gauge, as described in sections 3.4.6.1 and 3.4.6.2. According to Friedel (1990), cover should be at least 20% for point sampling to be worth the effort needed to obtain a reliable estimate. The soil cover points were useful as a quick estimate of the organic cover (mulch plus basal cover of perennial grasses). Significant ($P<0.05$) differences in organic cover were found at eleven of the 34 contrasts, and in three of the successive measurements at six of the experimental plots.

The point measurements of canopy cover were useful when the canopy cover was too high to measure accurately by Bitterlich gauge, such as at Contrast 29 and Site 30a. They also served a purpose when comparing grass densities under woody canopies and in the open. The only other purpose they served was to control the reliability of students, by comparing with the Bitterlich estimate of canopy cover. Bitterlich gauge readings provided a more precise estimate of canopy cover due to the greater sample size, with a median of 3.5 more canopies counted by Bitterlich gauge than by point at the 59 sites where canopy cover exceeded 5%. The Bitterlich gauge estimates led to significant ($P<0.05$) differences in canopy cover detected at 20 contrasts, in comparison to 12 contrasts where significant ($P<0.05$) differences were detected by points.

Although the time taken for the different measurements was not recorded, the Bitterlich gauge readings were subjectively estimated to take twice as long to perform in the field, and five times as long for students to master. A disadvantage of the point method is that it records canopy only at the point and some students tend to avoid bushes, whereas the Bitterlich gauge measures canopies around the point, which would still be detected by students who avoid bushes. Due to this and to its greater precision, the Bitterlich gauge would seem to be a more appropriate method for determining canopy cover up to 50%, beyond which it tends to underestimate canopy cover as evidenced in Figures 4.52 and 5.61. In the event that canopy cover needs to be related to variables under the canopies, the point method would be more appropriate.

Variables measured as occurrence near the dart point were the species of nearest perennial grass at least 5 cm wide at the base (NP) and species and height class of nearest bush at least 0.5 m high (NB & Height). Significant ($P<0.05$) differences across fencelines were found at 29 of the 34 contrasts for grass species and at 25 contrasts for bush species, where it could not be determined for the five contrasts with hay fields. On its own, species composition is not very useful, as it is a proportional measure rather than an absolute measure (Kirkman, 2002). This was partly overcome by including a pseudo-species “Bare” for points that had no plants of the type being recorded within a given distance from the point, making use of the distance measurements described in the following section.

The inclusion of height class of bush or tree was only useful for lower height classes, due to the small sample size ($n \leq 100$), which necessitated lumping of taller height classes when performing a Chi-square test (Zar, 1999). The abundance of understory bushes discriminated against species of taller trees, since under canopies of trees there was often an understory bush closer to the dart point than the stem of the tree. When information is required on density of tree species in the rangeland, other methods should be used, such as counting in belt transects (Smit, 1989). In this study some information on tree species was included in the Bitterlich gauge readings, but height class was not differentiated due to the difficulty of estimating it from a distance.

The time taken to search for the nearest plant increased with increasing distance from the point. The use of the point centred quarter method (Mueller-Dombois & Ellenberg, 1974) would cut the search time down by up to a quarter in rangeland where the plants to be measured are sparse.

9.7.2 Plotless distance measurements

Distances were measured from dart point to nearest perennial grass (DistP) and nearest bush or tree (NB). Due to the clumped nature of plants, the distance measurements cannot be used to estimate density (Bonham, 1989). However, the density index obtained by assuming a random distribution can be compared across fencelines. In addition, the bare patch size frequencies can be determined (Friedel *et al*., 2000) and a relative index of cover can be obtained (Peel *et al*., 1991). Distance measurements allow the inclusion of pseudo-species "Bare" for difference cut-off distances. Different distances can be determined from the same data set and used for different purposes. For perennial grass the cut-off distance was 100 cm for displaying frequency charts, to provide a visual impression of abundance when presenting species composition. When determining the rangeland condition index, the cut-off distance of 30 cm was used for perennial grasses, which had been found by Zimmermann *et al*., 2001a to relate to rangeland condition in the Camelthorn Savanna, and had been used a cut-off distance by Smit & Rethman (1999). For bushes the cut-off distance was 5 m, which had been the maximum search distance and appeared adequate to achieve the visual impression of abundance in frequency charts.

Significant differences across fencelines were found at 21 of the contrasts for distance to nearest perennial grass, and at 20 of the contrasts for distance to nearest bush.

9.7.3 Plot measurements

Circular plots of 0.75 m radius were used for counting perennial grasses and dwarf shrubs as described in section 3.4.6.8. When densities were high, this was by far the most time consuming of the measurements taken at points.

The relationships between distance to nearest grass and counted grass density, appearing separately for the different savanna types in Figures 4.53, 5.62 and 6.24, suggest that the quicker distance measurements could be used as a rough predictor of grass density. However, the precision of the counted density was better than that of the distance measurements, since significant ($P<0.05$) differences across fencelines in counted density of perennial grasses were found at 27 of the 32 contrasts where grasses had been counted, compared to 22 of all 34 contrasts for the distances to nearest perennial grass. The higher degree of grass clumping in the Dwarf shrub and Highland Savannas (Figure 9.9) would mean that the regression for the specific savanna type should be used to estimate perennial grass density from distance measurements. The higher degree of clumping is probably due to the tendency of the larger tussocks of the dominant *Stipagrostis obtusa* species in the Highland Savanna to fragment into smaller plants.

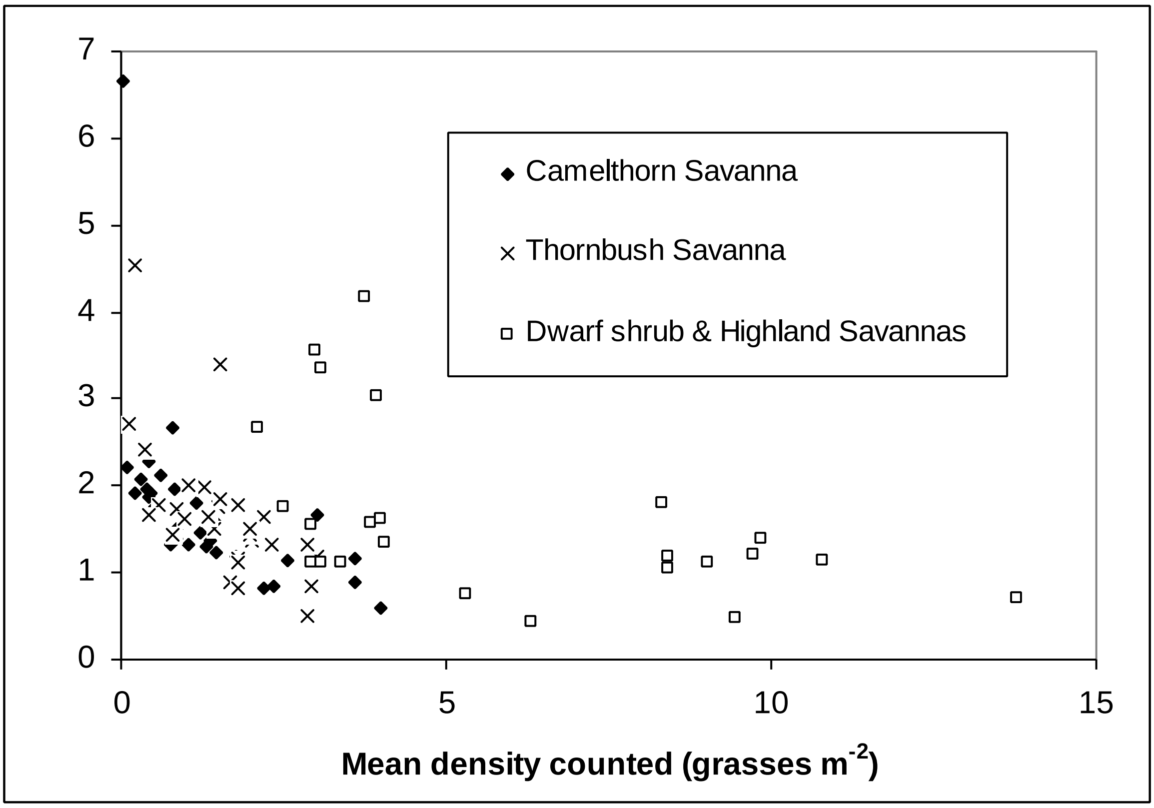

Figure 9.9 Relative degrees of clumping among perennial grasses in relation to grass density in each of the three savanna types.

The use of 100 plots of 0.75 cm radius per site was insufficient to reliably estimate densities of dwarf shrubs, bush seedlings and saplings in the Camelthorn and Thornbush Savannas. Increasing the number of plots would be preferable to increasing the plot size, due to the difficulty of finding small plants amongst taller grasses. In the Highland and Dwarf shrub Savannas densities were high enough for 100 plots of 0.75 cm radius to be adequate. Significant ($P<0.05$) differences across the fenceline were found at two of the three contrasts, and significant ($P<0.05$) differences were found over the years within each of the six experimental plots.

9.7.4 Monitoring

Monitoring took place at the experimental plots, starting with baseline data gathered at the time of establishment, followed by repeat measurements two and three years later. Data were also collected in the fourth year, but not yet analysed. Although greater differences could be expected across fenceline contrasts than changes over time at a single site, the significant changes ($P<0.05$) detected over time at each of the experimental plots, in at least one of the measured variables, suggests that the 100 points were sufficient to indicate changes over time. Farmers should ideally be performing their own monitoring, and the fewer measurements they could get away with the more likely they would take those measurements.

Most farmers monitor rainfall, usually at several locations around the farm, but very few monitor the rangeland. At the very least, it would be useful if farmers were to take fixed point photographs at various sites in each landscape around their farms, to provide a visual record of changes. For farmers willing to invest a little more time in monitoring, it would be useful if they were to estimate abundances of grass and bush. Measurements would be ideal, but unlikely to be carried out by farmers who have many other activities they give priority to (Friedel *et al*., 2004). Therefore subjective judgement based on visual observation would be the next best alternative, preferably guided by a photo scale and preferably with photos taken on those farms (Klintenberg *et al*., 2007). The accuracy of subjective judgement could be greatly improved by occasional calibration with measurements (Stuart-Hill, 1991).

The experimental plots on the heavily stocked farm have provided useful information as described in section 6.4, despite lack of replication in a heterogeneous landscape. However, on the lightly stocked farm the lack of stocking over the past two years has meant that the plots will not serve much purpose until re-stocking takes place. The plot that was grazed twice a year at the same overall stocking rate as the surrounding paddock is more useful to show farmers the potential of their land under production, rather than the exclosure that grows no animals. The rest/graze plot serves as a benchmark that provides farmers with a vision of what they could achieve under the prevailing climatic conditions. Friedel (1990) presented the view that variable events over space and time, such as rainfall and fire, render benchmark sites ineffectual. This would apply more to a single benchmark site expected to serve an enormous area. However, a single benchmark site would be suitable for comparison to the rangeland immediately surrounding it, which could be visited by other farmers to learn from. Better still would be if all farmers had their own benchmarks. Any fenceline contrast between the benchmark and surrounding rangeland would show that there is still potential for the farmer to improve the surrounding rangeland. Similarity between benchmark and surroundings would show that either the potential of the rangeland under that climate has been reached, or that the benchmark has not yet had time to recover from its former mismanagement, which may take some years depending on the extent of degradation.

CHAPTER 10

DISCUSSION: SOCIO-ECONOMIC ISSUES

10.1 INTRODUCTION

The success of attempts at sustainable farming depends not only on maintaining good rangeland condition but also on earning profit and supporting livelihoods from the rangeland. Therefore, socio-economic issues were included in this study - although to a limited extent - in the hope of determining the socio-economic consequences of differences in rangeland condition as found at fenceline contrasts.

The socio-economic data were obtained during interviews with 36 farmers, as described in section 3.6. However, farmers did not provide answers to all questions, especially those pertaining to finances, as explained in section 7.7.

10.2 SOCIO-ECONOMIC RELATIONSHIP WITH RANGELAND CONDITION

The analyses relating socio-economic variables to rangeland condition, were presented in section 7.7, where limitations were also pointed out. The only significant ($P<0.05$) correlations of rangeland condition index to socio-economic variables had been negative, with income ($r = -0.4801$, $P = 0.015$, $n = 25$) and profit ($r = -0.4418$, $P = 0.027$, $n = 25$). This provides a slight hint that, on the whole, greater income and profit may have occurred at the expense of rangeland condition. However, given the unreliability of the data, this is not conclusive. The negative correlation between stocking rate and rangeland condition index was weak ($r = -0.2575$, $P = 0.04$, $n = 64$). Sometimes a higher stocking rate is the cause of poorer rangeland condition (such as at Contrast 3) and sometimes it is the consequence of a better rangeland condition that raised the carrying capacity (such as at Contrast 12 due to stocking density and at contrast 18 due to bush thinning).

10.3 LIVELIHOODS SUPPORTED

10.3.1 Workers employed

The median of 1.0 workers employed per 1 000 ha of farmland found in this study, is identical to that calculated from figures of the Namibia Agricultural Union quoted by Buss (2006). Intensification of management should be able to support more workers if labour intensive methods are used, such as bush control through chopping. The farm where this study found the highest intensity of bush control, employed 1.9 workers 1 000 ha^{-1}. Trophy hunting also provided more jobs, with 3.8 workers 1 000 ha^{-1} employed at one of the game farms.

10.3.2 Diversity of farm enterprises

Although there was no significant (P>0.05) relationship in this study between diversity of farm enterprises and workers employed, diversification could create more jobs. Von Alten (2008) advises emerging farmers to focus on the most profitable enterprise, based upon his experiences that many farmers spend a disproportionately large amount of time pursuing enterprises that provide little profit, at the expense of the most profitable enterprise. However, by allocating responsibilities for enterprises to different people, be it family members or workers, each can focus on their specialisation while the farmer coordinates to ensure complementarity rather than competition between enterprises.

Value addition provides opportunities to diversify and support more livelihoods. It took place on three of the farms in this study. Two had butcheries to convert meat into a variety of processed products. Another cleaned, milled and encapsulated Devil's Claw (*Harpagophytum procumbens*). Although the main motivation for converting harvested wood into charcoal rather than selling the wood is to reduce transport costs, the mobile kilns used by one of the farmers release valuable products into the air rather than add value to the wood. The value of harvested wood could be greatly enhanced by pyrolysis techniques that capture gases and oils that can be used or sold as well as the charcoal (Honsbein, 2007). Some of these products may require the establishment of new markets.

10.4 PROFITABILITY

10.4.1 Expenditure

The median expenditure in this study was 48% of income. This is somewhat higher than the 40% assumed by Horshthempke (2000) to apply to commercial farms. Perhaps this difference is partly due to the increasing cost of inputs in relation to prices obtained for products since Horshtempke's study, and partly due to the inclusion of some less efficient farms in this study. Nevertheless, the stronger relationship reported in section 7.7 between profit and income ($r = 0.9288$, $P < 0.001$, $n = 25$) than between profit and expenditure ($r = 0.0267$, $P = 0.899$, $n = 25$), is greater than would be expected from either of these ratios between expenditure and income. This suggests that some of the extra expenditure is not being returned through proportionately increased production.

According to Von Alten (2008), the key to profitability lies in reducing costs for non-essentials. He believes that many commercial farms in Namibia have been overcapitalized. For example, he suggested 1 600 ha per water point as being adequate, compared to a median of 488 ha in this study. Regular maintenance can increase the functional lifespan of basic infrastructure, thereby reducing the need for costly new purchases. Reliance on local resources and renewable energy can result in great savings in expenditure. Although bushes can provide droppers for fencing, the need for permanent fencing can be reduced by the use of moveable fencing, such as electrical, which can save overall fencing costs by confining the herd(s) to small grazing areas at a time.

Increasing numbers of commercial farmers are facing indebtedness (Buss, 2006), which leads to overstocking if they opt for higher production per hectare to repay loans. The positive relationship between stocking rate and animal production per hectare was apparent over the range of farms in this study (Figure 7.28). This higher production per hectare occurs at the expense of production per animal (Figure 7.29) and condition of the rangeland. This is in accordance with the model of Jones & Sandland (1974), as cited by Rothauge (2006). Von Alten (2008) advises emerging farmers to avoid the debt trap associated with taking out loans and focus instead on making best use of the resources available on the farm.

Since prices fluctuate dramatically it is impossible to provide rigid guidelines on what is and is not worthy of buying or doing. By maintaining good records and keeping abreast of price fluctuations, farmers can determine the viability of any purchase or activity under consideration, to determine its expected returns in comparison to alternatives.

10.4.2 Animal production

By far the greatest revenue earner amongst the farmers in this study was cattle (Figure 7.3). The median annual production of 19% of stocking found in this study is close to the 20% estimated for Namibia's commercial farming area (Kruger & Lammerts-Imbuwa, 2008). Lange *et al*. (1998) reported that the annual production rose steadily from around 15% in the 1960's to around 30% in the 1990's as a result of improved management. Stehn (2008b) provides benchmark production figures for three different cattle production systems: (i) 32% for breeding weaners for sale; (ii) 35% for breeding slaughter cattle, and

(iii) 42-45% for growing slaughter cattle from bought weaners. The latter production system makes it easier to apply good rangeland management, since there is less need to separate herds; and rangeland can be rested between sale and purchase. However, according the bio-economic model of Buss (2006), the optimal management strategy comes from a flexible combination of cattle breeding and opportunistic speculation farming.

A high calving percentage is key to achieving high animal production (Von Alten, 2008). This can be achieved by good rangeland management to ensure a high plane of nutrition for pregnant and lactating cows, and strict culling of under-performing cows. Different factors determine whether or not the restriction of breeding to particular season(s) is viable. It could help to synchronise calving with expected times of optimum forage quality, and reduce loss to predators, but it limits opportunities for good rangeland management and requires additional expenditure.

The prices that farmers are able to fetch for their animals depend on various factors. Better prices may be fetched by those who speculate by waiting for prices to rise before selling, whereas those who sell in response to demands for cash are at the mercy of prevailing prices. The natural conditions under which most cattle are raised on Namibia's rangelands, provide the opportunity to negotiate premium prices with markets where consumers demand naturally raised beef (Pringle & Tinley, 2001). One of the farmers in this study had achieved organic certification for his farm. In order to comply with the certification requirements, he stopped providing urea lick to his animals.

10.4.3 Bush control

The financial viability of bush control depends on many factors. The interest rate on loans has an enormous bearing on the financial viability of farmers who rely on loans to control bushes (Horsthempke, 2000). Van Eck & Van der Merwe (2004) found that manual arboricide treatment in the Thornbush savanna doubled the grazing capacity in years of normal rain, while attaining a five-fold increase in dry years, recovering the arboricide cost within three years. On the other hand, Horsthempke (2000) concluded that arboricide application would not be financially viable, whether by air or by hand, unless accompanied by charcoal production. His conclusions were reached by cost-benefit analyses over 20 years on the Thornbush Savanna, including follow-up treatment after eight years and the repayment of loans. Favourable loans have recently been made available by the agricultural bank to encourage bush control, with the terms being more favourable when labour intensive methods are applied. A bio-economic model shows little incentive for farmers in the Thornbush Savanna to apply bush control without subsidies (Buss, 2006).

The cost-benefit analysis of Horsthempke (2000) predicted the use of fire to be financially viable, although there is often insufficient fuel to apply this method of bush control successfully. The main cost associated with burning is the loss of forage to provide fuel for the fire, and the rest needed for grasses to regrow after the fire.

10.4.4 Hay production

Only three of the interviewed farmers sold hay, while another four produced hay for own use, obtaining an average yield of approximately 2 400 kg ha^{-1} from the uncultivated fields. It is apparent from the limited data provided by the farmers, that the income they could earn from hay fields would be 45 times higher than the mean income per hectare obtained from their whole farm. The capital outlay for mowing equipment is high, but can be put to additional use by contract mowing for other farmers and harvesting in road reserves. One farmer pointed out that when the yield drops below 700 kg ha^{-1} it becomes uneconomical to harvest the hay.

The 20-year cost-benefit analysis of Horsthempke (2002) predicted that the cost of planting and maintaining cultivated pastures of *Cenchrus ciliaris* would not be financially viable. However, there are farmers who have converted some of their rangeland to cultivated pastures and not regretted doing so.

It seems to be viable to use only the better soils on the farm for conversion to hay fields or cultivated pastures - usually those with the highest clay content. This contributes to heterogeneity of the rangeland. Farmers who produce hay have the added advantage of flexibility in deciding how much to sell and how much to use for own livestock.

10.4.5 Farm size

The division of larger farms into smaller farms increases relative input costs and diminishes the wealth generated (Lang, 2005). Farmers who are no longer able to meet their needs from small farms, may overstock (Düvel & Lategan, 1997), as discussed in section 10.4.1, or seek off-farm employment. In the latter case they tend to resort to routine management that is easier for workers to follow, in favour of adaptive management that takes advantage of changing conditions.

Farm fragmentation has resulted from traditions of inheritance (Lang, 2005) and from Namibia's resettlement programme, such as at Site 1b. The problem of farms that are too small to be viable has been recognized by the Ministry of Lands and Resettlement. Recommendations have been made for a minimum of 1 000 ha for north and north east Namibia, and a minimum of 3 000 ha for the drier land in the south (Imbuwa, 2008).

10.4.6 Renting land

The renting of land is a common practice, also amongst the interviewed farmers. It adds flexibility to management, providing the opportunity to relieve grazing pressure on own land or to earn extra income when own land is understocked, depending on changing circumstances such as prices, cash flow and spatial variability in rainfall. However, a farmer's own land is usually treated better and rented land may be abused, as had occurred on Sites 14&15b. If farmers wish to rent out land they should set clear conditions and ensure that those conditions are adhered to by the tenant.

10.5 CO-OPERATION AMONGST NEIGHBOURS

Neighbours help each other in different ways and the need to co-operate increases with decreasing farm size. Though farmers with large farms have enough resources to manage their livestock, they still need to co-operate with neighbours to manage factors that cross farm boundaries, such as fires, game animals, predators, water flow and wind-blown sand.

Commercial farmers in Namibia tend to co-ordinate their fire-fighting activities very effectively. This strong reliance on neighbours brings many benefits, but it also prevents some farmers from applying controlled burning, because their neighbours disapprove. On the other hand, this provides an opportunity for the farmer to offer the portion of his farm intended for burning as a demonstration trial for the neighbours to lean from, while gaining physical support from neighbours to prevent the fire from spreading to their farms.

The formation of conservancies to jointly manage game animals and tourism activities across neighbouring farms has facilitated co-operation. The farmers meet regularly to discuss their management plans and they undertake game counts on each farm simultaneously. Some farmers have formed study groups to share data and conduct trials with various management interventions.

There is also some joint management of river basins, with committee members including representatives of farmers in the catchment, downstream users of water and relevant local government agencies. The committee decides on integrated water resource management aimed at their shared vision.

Co-operation is also called for where farmers have been resettled onto portions of former commercial farms and each farmer has insufficient land on which to apply rotational resting (Kruger, 2001). The combination of herds belonging to different resettled families for rotation through their portions of land is being jointly planned with them (Kruger, 2008).

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

11.1 EXTENT OF ACHIEVING STUDY OBJECTIVES

The objectives of this study were revisited to evaluate the extent to which each objective was achieved, and to draw conclusions from the findings relevant to each.

11.1.1 Assessing various methods of measuring rangeland characteristics

The ten variables used in this study to characterise rangeland had been selected for their contribution to rangeland condition. However, only two of these were used in combination to determine the rangeland condition index, namely the distance to nearest perennial grass (DistP) and species of nearest perennial grass (NP). Six of the variables provided supplementary information related to rangeland condition, namely cover over the soil (Hit), woody canopy over the point (Canop), species of nearest bush (NB), distance to nearest bush (DistB), height class of nearest bush (Height) and density of woody plants shorter than 0.5 m (Woodies). Two of the variables provided alternative measures of characteristics represented by other variables. These were density of perennial grasses (No P), as an alternative to DistP, and woody canopy cover by Bitterlich gauge (Bitterlich), as an alternative to Canop.

The density of perennial grasses (No P) provided an absolute density, unlike distance to nearest perennial grass (DistP), which provides only an index of density, related to the degree of clumping among the perennial grasses. However, the counting of No P took longer, especially where the density was high. Another advantage of DistP is that it can be combined with the species of nearest perennial grass (NP) to determine the proportion of the pseudo-species “Bare” for use in the rangeland condition index. It can also be used to characterise bare patch size frequencies. When examining differences in perennial grass abundance, DistP can be used as a direct distance measurement, without conversion. However, when density values are required, DistP can be converted to a density index or an estimate of density through the power regressions obtained in Figures 4.53, 5.62 or 6.24.

The Bitterlich gauge provided a more precise measure of canopy cover than points (Canop) and require only slightly greater effort. It probably also provided a more accurate measure for canopy cover up to 50%. Beyond this the cover is too dense for most farming practices and the effort required to accurately measure its cover is hardly worth the effort required to reach all the sample points in thick bush.

The 100 sample points per site appeared adequate to characterise the rangeland by providing a quantitative description for most of the variables, and to identify significant ($P<0.05$) differences across fencelines. Although some significant ($P<0.05$) differences were found in the density of dwarf shrubs (Woodies), this variable would require a greater intensity of sampling to provide a precise measure where densities are as low as those encountered at most of the sites in this study. The height class data for bushes (Height) was useful to differentiate between lower height classes, but 100 points were insufficient to adequately represent the greater significance of trees at the relatively low densities encountered.

The resulting characterisation of rangeland at any site was mainly useful to compare with the other side of the fence at the same contrast. It was less useful to compare with other sites within the same cluster due to differences in soil, and even less useful to compare with sites at other clusters, due to differences in rainfall.

11.1.2 Comparing rangeland condition on both sides of fenceline contrasts

At most of the fenceline contrasts it had been obvious from visual inspection that the rangeland was in better condition on one side compared to the other side. The measurements were performed to quantify the differences and identify the variables for which the differences were significant. Significant ($P<0.05$) differences occurred in at least one of the measured characteristics at each of the 34 contrasts. The rangeland condition index was significantly ($P<0.05$) higher on one side than on the other at 22 of the contrasts. Since the coordinates were recorded of points from where the dart was thrown, the sites can easily be re-surveyed at a later date to determine the change over time.

11.1.3 Determining the management inputs that caused the contrasts

It was more difficult to determine which of the many management inputs, applied over variable time periods, had been responsible for causing the differences in rangeland condition at the contrasts. Information on historical management was difficult to obtain and incomplete and recollections from memories of farmers may have been unreliable. In some cases the farmers had recently acquired the farm and historical management information was unknown to them. Information provided by farmers on current management was often applicable to the whole farm, and may have differed at the contrast. Sometimes visual judgement had to be relied on instead to determine which side of the fence had been subjected to heavier stocking. Subjective judgement was also used to identify the single most likely factor responsible for the differences at 22 of the sites (Table 9.1), namely bush control, stocking rate, stocking density and period of rest.

Responses from farmers on their management strategies (Chapter 7) provided valuable insight that should be useful to other farmers, extension officers and scientists. The case study of an innovative and observant farmer (Chapter 8) highlighted the importance of strategically timing certain management interventions in relation to rainfall events. The lessons learnt should be of interest, not only in Namibia, but also in other countries facing increased desertification. Namibia experiences fluctuating climate, and some farmers have learnt how to adapt.

11.1.4 Determining ecological and socio-economic consequences of the contrasts

The characterisation of rangeland, from measurement of the variables mentioned in section 11.1.1, provided descriptions of the ecological consequences of the differences at the contrasts. Since there are no state-and-transition models for these areas, it is not possible to determine whether thresholds have been crossed to irreversible states.

The reliability of the socio-economic data was discussed in section 7.7. These data serve as socio-economic descriptions of the consequences of the differences at the contrasts, but only to the extent that they indicate what is achievable from the current condition of the rangeland. They do not indicate whether it is sustainable, nor do they allow differentiation between causes and consequences of the contrasts. The correlation between stocking rate and rangeland condition index was very weak and only just significant ($r = -0.2579$, $P = 0.04$, $n = 64$), with the negative sign only hinting that there may have been more farms where a higher stocking rate was the cause of poorer rangeland than farms where the higher stocking rate was the consequence of a higher carrying capacity, resulting from better rangeland.

The stronger correlation between profit and income ($r = 0.9288$, $P < 0.001$, $n = 25$) than between profit and expenditure ($r = 0.0267$, $P = 0.899$, $n = 25$), suggests that some of the extra expenditure is not being returned through proportionately increased production. The highest income earned per hectare was from a game farm, but the continuous selective grazing by gregarious game animals led to poorer rangeland condition there, despite intensive bush thinning.

11.1.5 Encouraging improved rangeland management

The workshops facilitated in each savanna type provided an opportunity for the farmers to discuss management implications with each other. The extent to which established commercial farmers were willing to advise emerging farmers was very encouraging. Some farmers expressed appreciation at having learnt about the ecological services provided by species they had not valued before. However, the workshops only reached a small audience of 28 farmers in the Camelthorn Savanna, 47 in the Thornbush Savanna and 32 in the Dwarf shrub Savanna. A greater audience will be reached by publications.

Follow-up studies have been initiated on various aspects, including the influence of patch burning on plant mortality and soil fertility, the influence of strategic trampling on plant density and soil water, the use of non-toxic treatments to control internal nematodes and ticks, and the restoration of a gully system in a key valley.

11.2 RECOMMENDATIONS ON METHODS FOR MEASURING RANGELAND

Based upon the experience gained from using the ten variables to characterise the rangeland, the rank order from most to least cost-effective variable is considered to be: distance to nearest perennial grass (DistP); species of nearest perennial grass (NP); woody canopy cover by species, using a Bitterlich gauge (Bitterlich); cover over the soil (Hit); density of woody plants shorter than 0.5 m (Woodies); height class of nearest bush (Height); distance to nearest bush (DistB); and species of nearest bush (NB). The other two variables could be omitted, woody canopy over the point (Canop), because it is less precise than Bitterlich, and density of perennial grasses (No P), because it is too time consuming.

In order to save on the time that is required to find the nearest perennial grass at low perennial grass density, it may be more appropriate to use the point centred quarter method (Mueller-Dombois & Ellenberg, 1974) from 25 points, which would correspond with the required number of Bitterlich gauge readings. However, more than 100 points would be required to obtain a precise density estimate of woody plants shorter than 0.5 m on most rangeland. A more effective way may be to count short woody plants occurring 75 cm either side of the path followed between points from where the dart is thrown, which would increase the area sampled by approximately 8.5 times. Bush seedlings and saplings were often encountered while walking between points, while rarely occurring within 75 cm of the points.

11.3 RECOMMENDATIONS FOR FARMERS

11.3.1 Grazing management

11.3.1.1 Vision of achievable rangeland condition

Due to the fluctuating nature of Namibia's climate, the condition of even the best rangeland changes annually. It is useful for farmers to know what condition of rangeland is achievable under the prevailing climatic conditions. Such a vision could be provided by a benchmark site, where the same overall stocking rate as the surrounding area is applied twice a year, followed by long periods of absence. It is therefore recommended that farmers establish small benchmarks for their rangeland so that they may differentiate between the effects of climate and management, as discussed in section 9.7.4. Apart from providing the farmer with information upon which to base management decisions, the benchmark may serve as a source of seed of good grass species, for spreading out into the surrounding rangeland.

11.3.1.2 Stocking rate

Again due to the fluctuating nature of Namibia's climate, it is essential to include provision of a drought reserve when estimating the carrying capacity of the rangeland. If the stocking rate needs to be reduced, the best time to do so for the benefit of rangeland condition and animal performance is at the start of the dry season, although seasonal changes in price may sometimes warrant holding on to animals for longer. If the stocking rate can be raised after a drought, it may be helpful to wait until perennial grasses had an opportunity to regain vigour before increasing the stocking rate. It is recommended that farmers who have not yet gained experience in estimating the grazing capacity by visual judgement should initially apply a quantitative method such as that of Van Wyk (1988).

11.3.1.3 Provision of rest

Periods of absence should ideally be flexible so that they may be adjusted by adaptive management. The condition of grass in the destination paddock provides a more valuable indicator of when to move, for the health of the grass, than the condition of grass where livestock are currently grazing, which may be more important for animal performance. If periods of absence during the growing season need to be fixed in advance, then longer periods are better than shorter periods during which there might not be enough rain for grazed grasses to regain vigour.

11.3.1.4 Application of trampling

It is recommended that farmers note the observations on trampling as applied by the case study farmer (Chapter 8) and pay close attention to the effects of trampling on their farms to determine whether it could be applied to help their rangeland. They need to bear in mind that long rest should be provided after trampling and that animal performance will be sacrificed to some extent.

11.3.2 Fire management

The greatest concern in fire management is to control accidental fires. This is something that many commercial farmers in Namibia have been very good at, through investment in fire fighting equipment and regular maintenance of firebreaks, together with co-operation amongst neighbours, usually achieved by good radio communication. This level of preparedness has been more difficult for resource poor farmers such as at Contrast 8.

Fire can be used to achieve different objectives, but opportunities for using fire as a management tool in Namibia are extremely limited and need to be timed fairly precisely. This limitation increases from the moister to the drier parts of the country. Controlled burning is also a trade-off between the expected benefit of the fire and the temporary loss of forage and mulch.

It is recommended that farmers note the points raised on the use of fire in sections 9.2.1.4, 9.2.2.5 and 9.6.2.6 to determine whether the occasional use of controlled burning could help a portion of their rangeland, whether for the control of bushes, the rejuvenation of perennial grass or the creation of nutrient hotspots. If fire is considered helpful, then the conditions required for successful burning will either need to be in place, waited for or encouraged to develop, such as sufficient fuel and sufficient residual water and organic matter in the soil.

11.3.3 Bush control

It is recommended that farmers note the problem tree for bush encroachment presented in section 9.2 and consult the decision support system (Joubert *et al.*, 2008b) accessible at: http://chameleon.polytechnic.edu.na/wiki/

Farmers should preferably attempt to prevent bush encroachment from taking place, by applying management closer to the root causes in the problem tree. However, in cases where the symptom of bush encroachment needs to be treated, the decision support system mentioned above provides linkage to a data base of experiences by Namibian farmers (Barac *et al*., 2004). If arboricides are to be used, the risk of killing non-target bushes and trees should be minimised.

11.3.4 Soil and water management

It is recommended that farmers note the problem trees for water and wind erosion presented in sections 9.3 and 9.4. Although soil fertility and soil water should normally be maintained by a vigorous plant cover that encourages infiltration and feeds soil microbes, in many circumstances the harm caused to the rangeland has been too great for the restorative processes of nature to function without assistance. Therefore symptoms of rangeland degradation may also need to be treated, although this is usually not financially viable in the short term. To improve the rate of return on investment, the most critical locations in the landscape should be targeted, and the treatment applied strategically to maximise efficiency.

Management of ground water, from where most farmers obtain drinking water for their animals, is crucial for the sustainability of farming. It is recommended that farmers monitor their ground water levels and, where found to be lowering, to consider action to recharge the aquifer such as bush control (Bockmühl, 2008) or aligning roads towards recharge sites (Table 8.3).

11.3.5 Parasite management

It is recommended that farmers control parasites without, or with minimal use of, poisons, as discussed in section 9.5. Those who are unable to apply rotational grazing to disrupt parasite life cycles, and those who are still forced to kraal their animals at night, could at least try non-toxic treatments, while making an effort to eliminate animals with high parasite loads from the herd.

11.3.6 Financial management

Farmers could benefit by examining their financial records, to determine whether their expenses are justified, if they are not already doing so. If farmers focus on reducing non-essential expenditure they are likely to increase profitability, as discussed in section

10.4.1. Before making any new investment it is recommended that farmers perform cost-benefit analyses on the intended investment and on alternatives, to determine which brings the best returns per dollar spent, especially when those dollars need to be repaid at interest. Reliance on overstocking to increase profitability provides only short-term relief, as the resulting reduction in carrying capacity limits this option for the future. Farmers who obtain poor prices for their products should seek alternative markets, including those that pay premium prices for “green” products raised on natural rangeland.

11.3.7 Monitoring and record keeping

The majority of farmers keep financial records, as required by the receiver of revenue. A fair number of farmers keep records of their animals, to improve herd performance, while only few farmers keep records of the rangeland that provides the resource base to support their animals and ensure their financial viability. When farmers observe their rangeland they keep mental records, but without formal records it is only unreliable memory that can be relied upon. It is therefore recommended that farmers undertake more formalised monitoring together with record keeping of their rangeland. This could be as simple as taking regular fixed point photographs at labelled sites and perhaps estimating abundances of bushes and grasses as discussed in section 9.7.4. Those that are more adventurous could back up the visual impressions with measurements such as those as suggested in section 11.2. Farmers who co-operate with neighbours to form study groups can benefit by the sharing of information and joint monitoring of their test sites (section 10.5).

SUMMARY

This study formed part of the Biodiversity Monitoring Transect Analysis in Africa (BIOTA) programme. It made use of the opportunity provided by fenceline contrasts in Namibia to measure differences in rangeland and learn from farmers about the inputs and outputs of management on both sides of the fence.

Chapter 1 provides background information and objectives of the study. Numerous fenceline contrasts are clearly evident when flying over Namibian rangeland. Different management practices that have brought about the contrasting and persistent rangeland conditions are a potentially valuable source of information. However, the knowledge on what brought about those contrasts, and their consequences, are rapidly being lost as resettlement brings about changing ownership of the land. An important objective of this study was to capture some of the existing knowledge, process it and make it available to land users to help them make wiser decisions on how to manage the land. This may also be invaluable to the scientific community in order to better understand similar contrasts in other geographical regions.

The study area is described in Chapter 2. The 34 measured fenceline contrasts were mostly clustered within the Camelthorn and Thornbush Savannas, with only one in the Highland Savanna and two in the Dwarf shrub Savanna of Namibia. The contrasts occurred in areas receiving long-term mean annual rainfall ranging from 235 mm at the most southerly contrasts, to 475 mm at the most northerly contrasts.

The procedure is described in Chapter 3. Rangeland measurements, on each side of the fenceline contrasts, focussed on well established perennial vegetation to avoid the fluctuating effect of ephemerals. Perennial grasses were only measured if they had a basal diameter of at least 5 cm, except at one contrast where the effect of a recent management action was being investigated. The ten measured variables, representing eight characteristics, were (i) density of perennial grasses; (ii) distance from sample point to nearest perennial grass; (iii) species of nearest perennial grass; (iv) woody canopy cover by species, using a Bitterlich gauge; (v) woody canopy cover over the sample point; (vi) ground level cover over the soil; (vii) density of woody plants shorter than 0.5 m; (viii) height class of nearest bush; (ix) distance to nearest bush; and (x) species of nearest bush. A rangeland condition index was calculated based on the data from the distance to nearest perennial grass and the species.

Unreplicated experimental plots of 1.4 ha were established on two neighbouring farms to demonstrate and compare the effect of (i) zero stocking; (ii) long rest interrupted twice a year by brief grazing at the same overall stocking rate (in terms of AU-grazing days ha^{-1}) as the surrounding paddock; and (iii) the normal grazing applied by the farmer in the surrounding paddock. Baseline measurements were taken when the plots were established. Follow-up measurements were taken two and three years later.

The farmers responsible for management on each side of fenceline contrasts were interviewed with the help of a formal questionnaire. Some questions were those aimed at understanding the previous and current management applied to the farms while others aimed at quantifying the production levels achieved. Certain answers were followed up as necessary during and after the interviews.

Results from the research were summarised and presented to farmers at workshops for discussion between commercial farmers, affirmative action farmers, communal farmers, resettled farmers and extension workers.

The results of rangeland measurements in each of the savanna types are presented Chapters 4-6. An overview of the fenceline contrasts and their results is tabulated for each savanna type. Significant ($P<0.05$) differences occurred in at least one variable measured at each of the 34 contrasts. At 22 of the contrasts the rangeland condition index was significantly ($P<0.05$) higher on one side of the fence compared to the other side. Each fenceline contrast is briefly described and illustrated by photographs and charts.

The benefit of long rest after short grazing was evident from the experimental plots on the highly stocked farm. The neighbouring farm had been too lightly stocked to show any significant difference from the treatment.

The results of the interviews with the 36 farmers are presented in Chapter 7. The most common farming enterprise was the sale of cattle, practiced by 92% of the interviewed farmers, followed by goats at 44%, sheep at 31% and trophy hunting at 19%. Median figures were a stocking rate of 44 kg liveweight $ha^{-1}a^{-1}$ (10 ha AU^{-1} a^{-1}), animal production of 8 kg liveweight $ha^{-1}a^{-1}$, paddock size of 214 ha, 488 ha per water point and 1.0 workers employed per 1 000 ha. Most of the farmers (89%) relied on visual judgement to determine the carrying capacity of their rangeland. A minority (28%) applied continuous grazing and 31% set aside a portion of their farm to receive a full growing season's rest. Of the 29 farmers who undertook rotational grazing, 31% applied fixed rotations because it was easy for their workers to follow a regular routine. No bush control had been undertaken by 42% of the farmers, while the main bush control strategy applied was arboricides by 25% of the farmers, chopping bushes by 11%, stem burning by 11%, and controlled veld fires by 6%. *Stipagrostis uniplumis* was mentioned by most farmers as a useful plant while *Acacia mellifera* was reported by most farmers to be harmful, although some considered it to be useful. Vultures were considered by most farmers as useful birds and the dung beetle as a useful insect. Most farmers (89%) recognised different soil or landscape types on their farms, and out of those, 53% applied different management to them, such as stocking them at different rates or preferentially grazing them at different seasons.

A case study of an innovative farmer who applied adaptive management based on his observations and experiences gained over the decades, is presented in Chapter 8. The study records 31 of the observations made by the farmer, relating to aspects such as animal behaviour and performance, animal trampling, applications of grazing and fire. They are tabulated together with possible reasons for these observations and how they are converted into management actions. The conceptual model that the farmer has built to aid his understanding and decision-making, is also illustrated by a diagram and explained. Of critical importance is the strategic timing of management interventions on different parts of the farm in relation to rainfall events, texture and organic content of the soil and maturity of the vegetation. Data are presented to support some of the observations.

The ecological issues raised by this study are discussed in Chapter 9. The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse the sequence of events that eventually lead to a problem. Diagnosis through drawing a problem tree is useful in allowing the consequences of different interventions to be better visualised and understood, thereby guiding decisions on management of the problem. Four problem trees were constructed to show multiple causes of the general problems of bush encroachment, gully erosion, wind erosion and parasite infestations. The problem trees were generalised by considering many possible causes, and not only those applying to a particular areas. To help decision-making by means of a problem tree, it is necessary to determine which of the multiple pathways are of greater significance to any particular situation. Management that addresses causes higher up a problem tree, closer to the root causes, is likely to be more effective in the long run than management that addresses the proximate causes or symptoms at the bottom of the tree.

There was no clear way to distinguish between the influence of different types and timings of management inputs that may have caused the fenceline contrasts. Therefore, subjective judgment was relied upon to identify bush thinning as the most likely single causative factor at six contrasts, bush clearing at four contrasts, stocking rate and period of rest at five contrasts respectively, and stocking density at two contrasts. At the remaining ten contrasts either the rangeland condition index did not differ significantly ($P>0.05$) or there was no single factor that stood out as the most likely cause of the contrast. At some of the contrasts, past management may have had a greater influence on rangeland condition than current management. At one site there was still a strong fenceline contrast, despite both sides have been subjected to the same management for the past 14 years since the farmer acquired the neighbouring degraded land.

The socio-economic issues raised by this study are discussed in Chapter 10. Management contributed to both causes and consequences of fenceline contrasts. The negative correlation between stocking rate and rangeland condition index was weak ($r = -0.2575$, $P = 0.04$, $n = 64$), suggesting that there may have been more farms where a higher stocking rate was the cause of poorer rangeland than farms where the higher stocking rate was the consequence of better rangeland raising the carrying capacity. Although auto-correlation would be expected in both, the stronger correlation between profit and income ($r = 0.9288$, $P < 0.001$, $n = 25$) than between profit and expenditure ($r = 0.0267$, $P = 0.899$, $n = 25$), suggests that farmers should focus on reducing non-essential expenditure to increase profitability. Game farming can earn high income, but continuous selective grazing by gregarious game animals may lead to poorer rangeland condition.

The extent to which the objectives of the study were met, is assessed in Chapter 11. Conclusions were drawn and recommendations made. From this study it is clear that much can be learnt by both scientists and other farmers from the management strategies applied by successful farmers who earn a reasonable profit while sustaining the rangeland.

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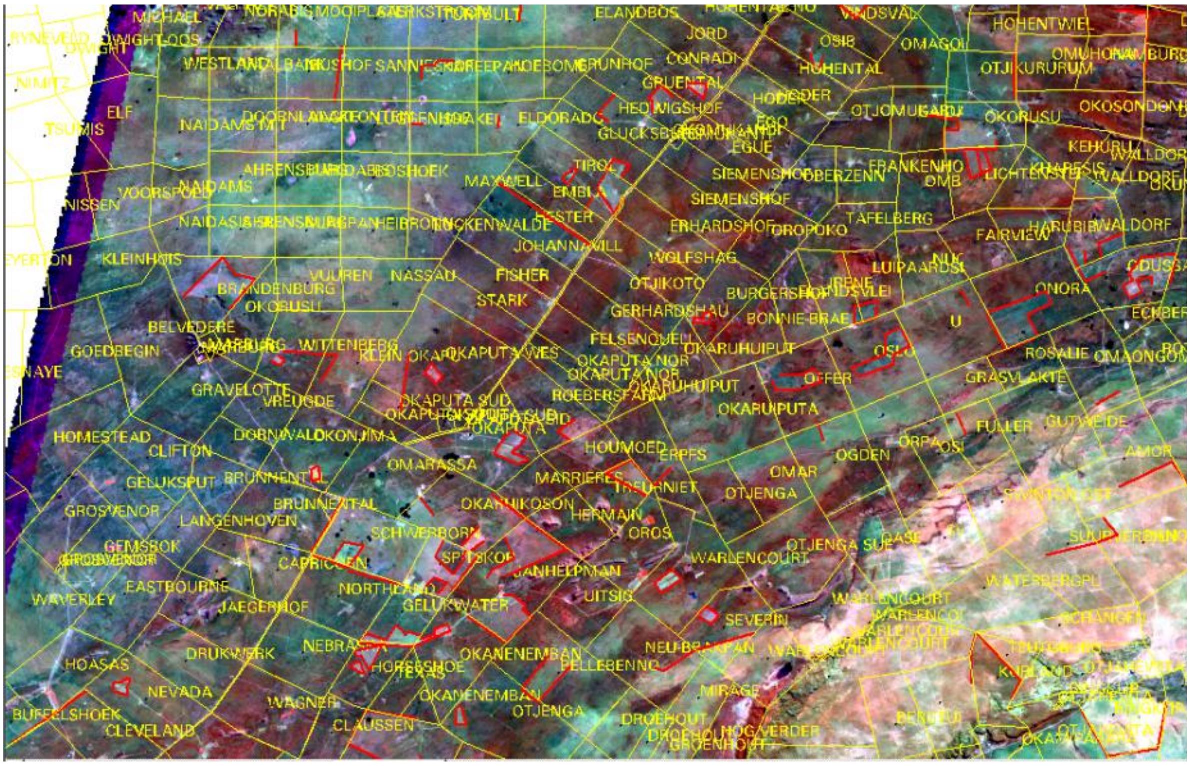
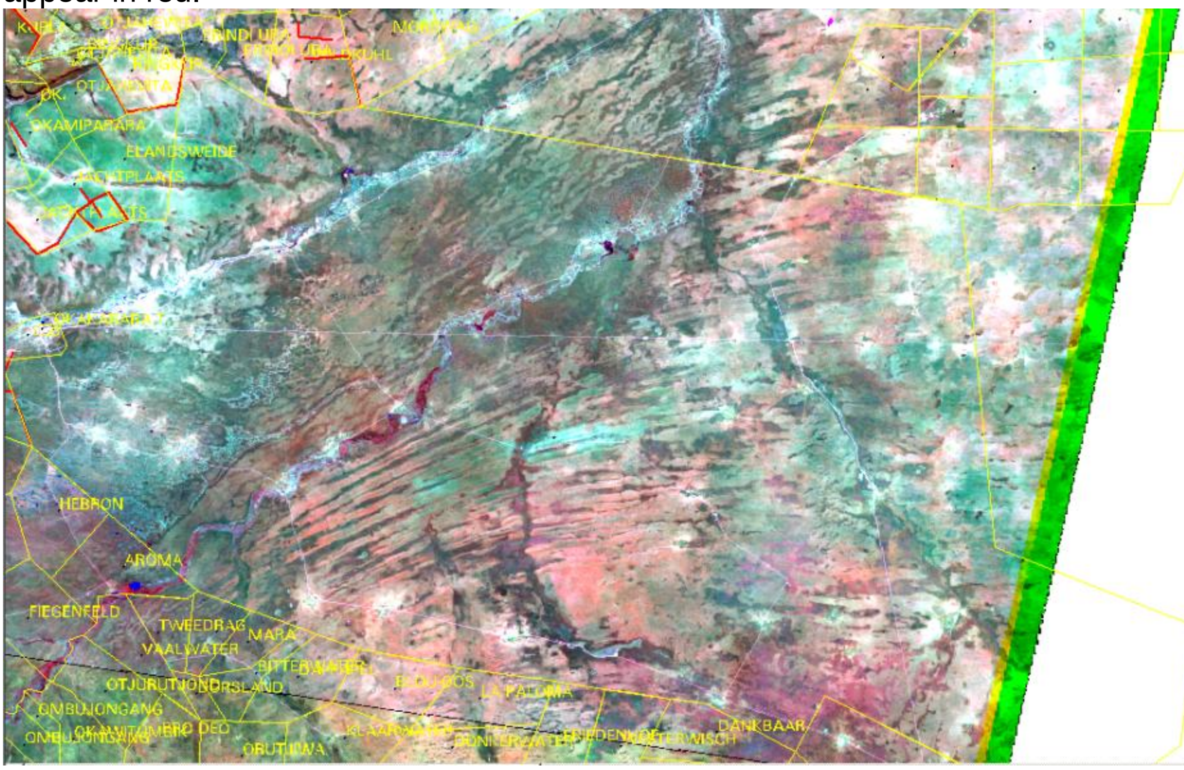
APPENDIX 1

Landsat images from 2000, covering study areas in the Thornbush Savanna (study sites have not been marked, to respect anonymity)

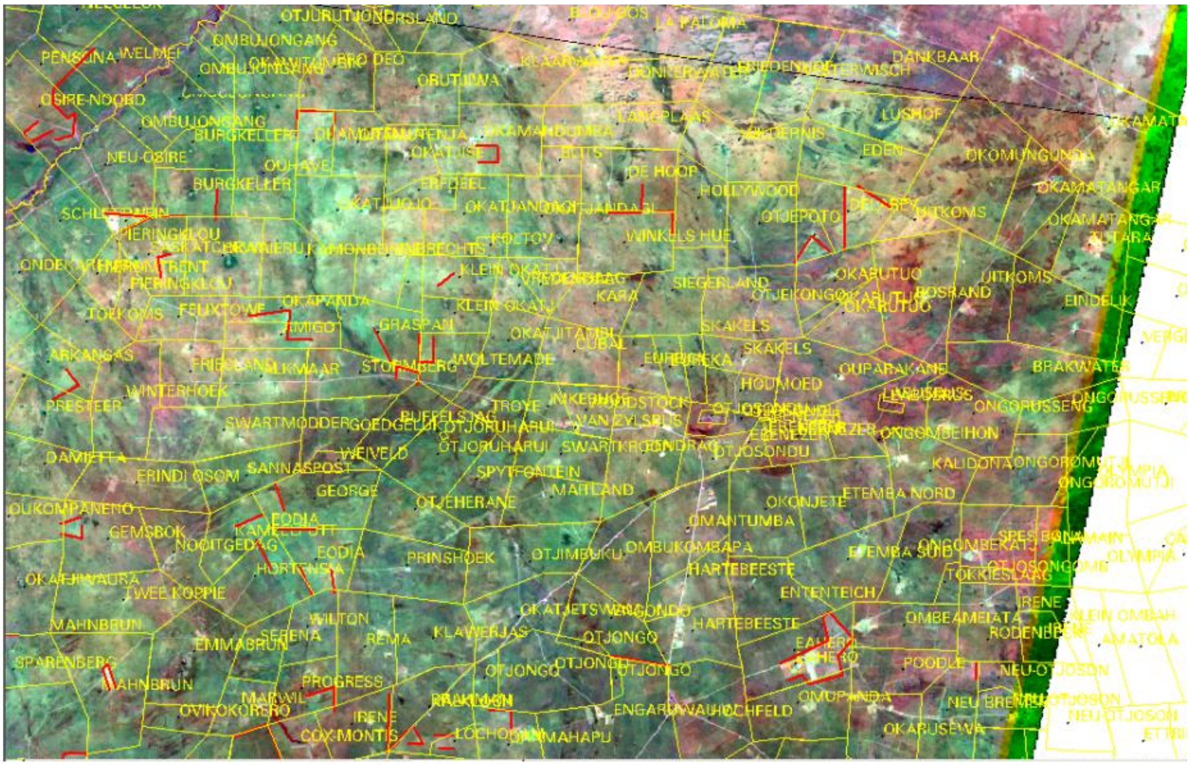


Fenceline contrasts, identified by an automated function in the GIS software, appear in red.

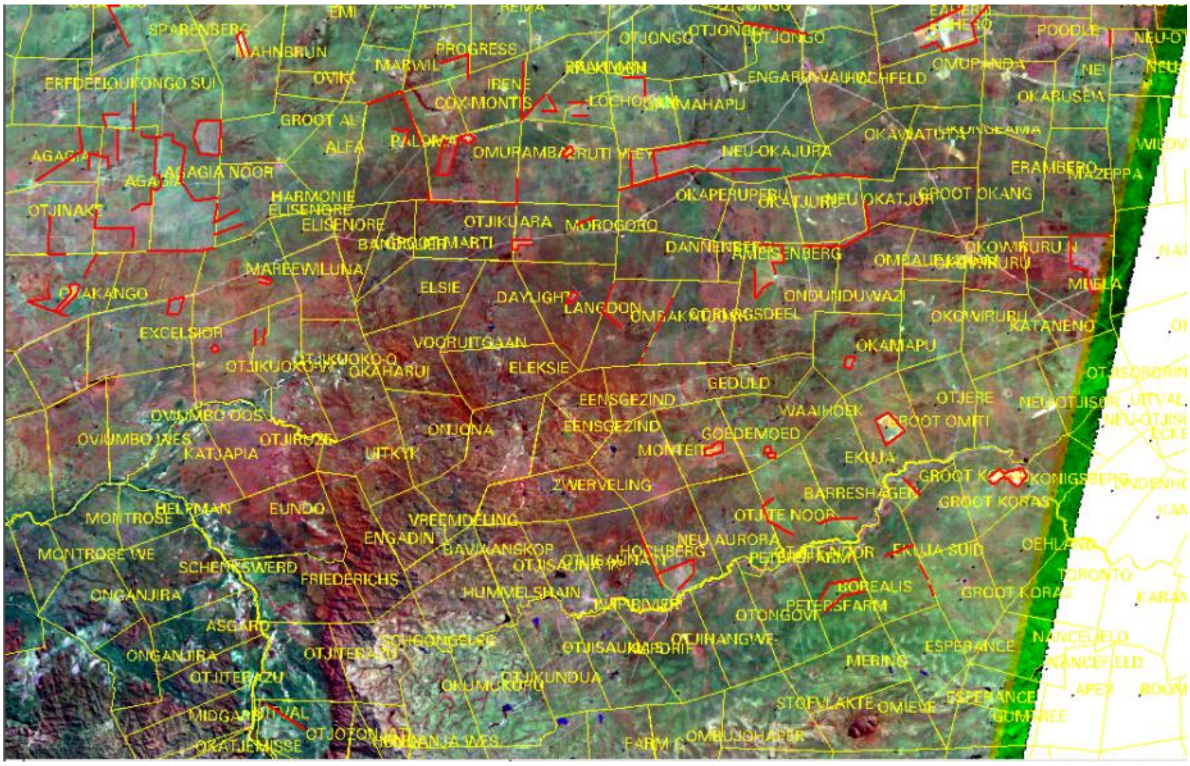


Fenceline contrasts, identified by an automated function in the GIS software, appear in red.

Appendix 1 continued



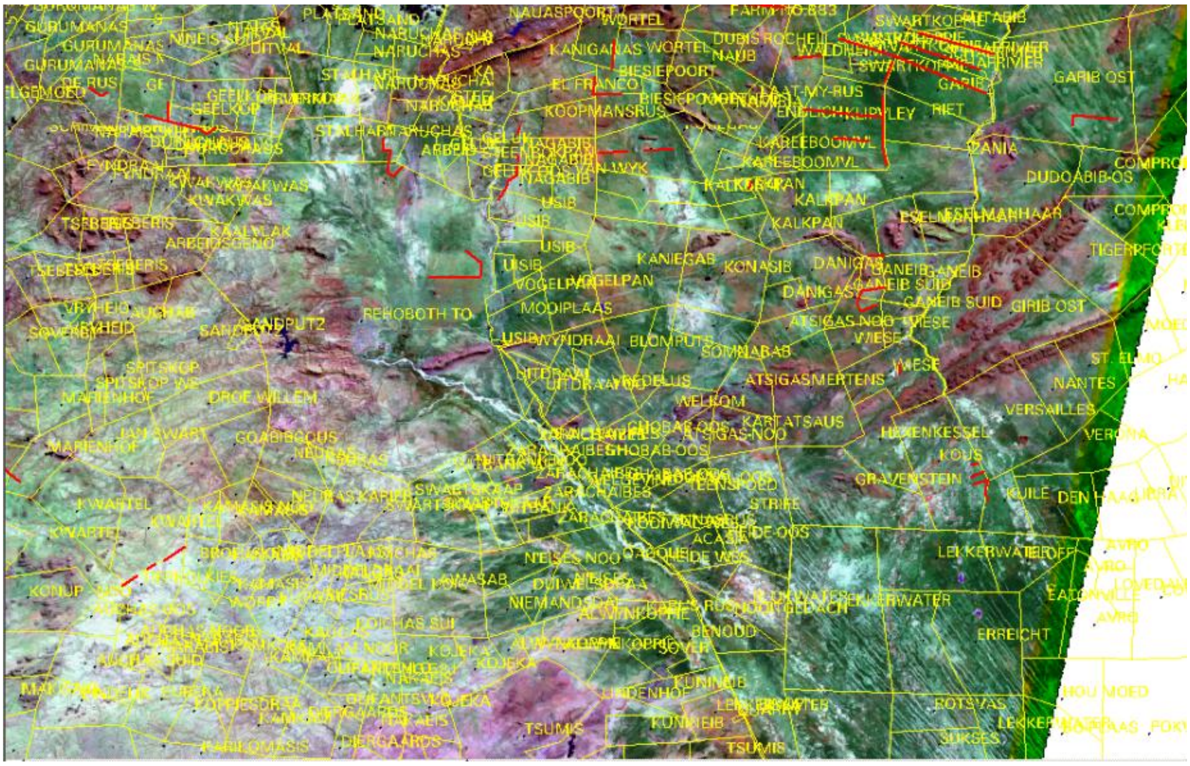
Fenceline contrasts, identified by an automated function in the GIS software, appear in red.



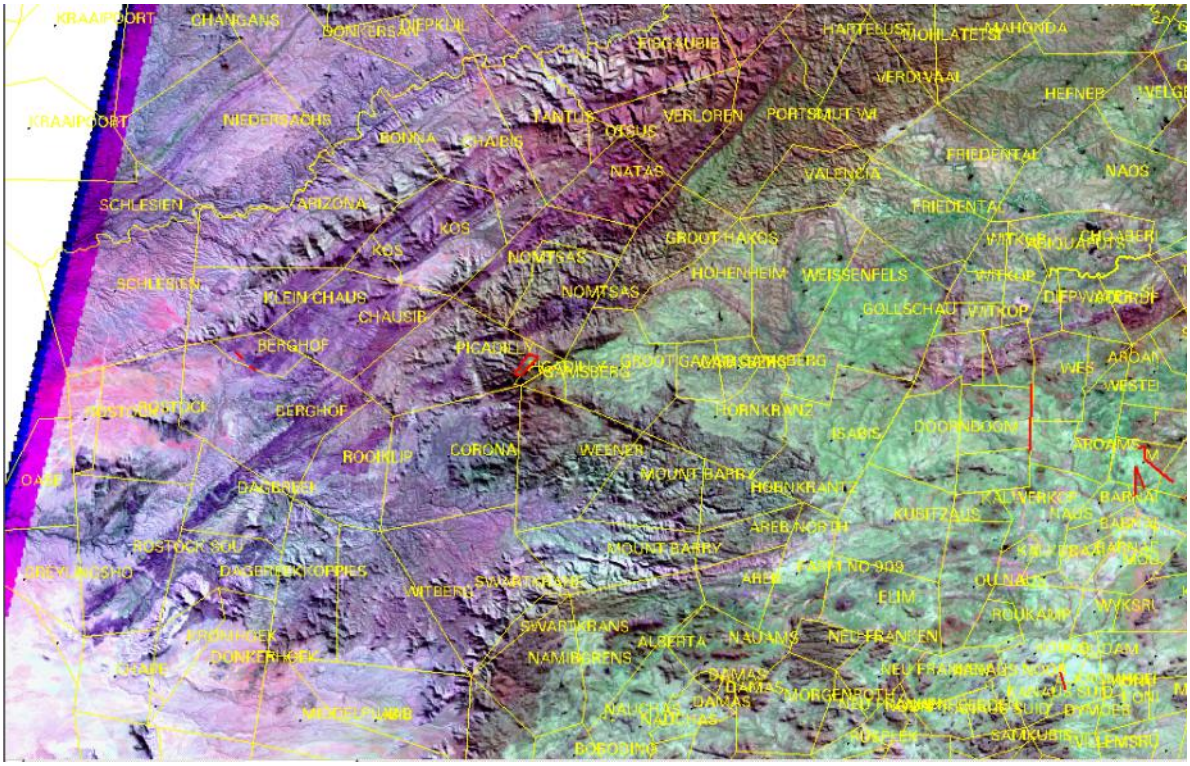
Fenceline contrasts, identified by an automated function in the GIS software, appear in red.

APPENDIX 2

Landsat images from 2000, covering study areas in the Mountain and Dwarf Shrub Savannas (study sites have not been marked, to respect anonymity)



The Highland Savanna is in the north western portion of this image. Fenceline contrasts, identified by an automated function in the GIS software, appear in red.



The Dwarf Shrub Savanna is covered by this image. Fenceline contrasts, identified by an automated function in the GIS software, appear in red.

APPENDIX 3

Data sheet for measurements at points along vegetation transects (1st page out of 4)

RANGELAND CONDITION MEASUREMENTS FROM POINT SURVEY Location:______________________

Management:____ Distance to water:______________

Date:__________ Site No.:_______ Names of surveyors____

Dominant forbs:__________________________ Annual grasses:________________________ (and % cover)

No	Hit	Canop	NP/A	DistP	NB	Height Class (m) <1	1-2	2-3	3-4	4-5	5-6	6-8	>8	DistB	No.P	CoorS	CoorE
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2																	
3																	
4																	
5																	
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► For Hit, record where the point of the dart lands. S = Soil (bare), M = Mulch (loose organic matter or dead grass base), C=Crust (biological soil crust), B = Base of live perennial grass, R = Rock (exposed rock or stone)

► For Canop, write the species of the tallest woody plant, taller than 0.5m, covering the point (write X if there is no woody canopy over the point, and write DEAD, if there is only a canopy of a dead woody plant over the point).

► For NP/A, write the species of nearest live perennial grass of at least 5cm diameter at its base, unless it is more than 5m away, in which case write the species of nearest grass, whether perennial of <5cm diameter or annual, but if that too is >5m away write X

► For DistP, write the distance, in cm, to the nearest live perennial grass of at least 5cm basal diameter. If it is further than 5m away, write >5m, even if NP/A is a perennial of <5cm diameter or an annual.

► For NB, write the species of live tree or bush more than 0.5m in height whose stem is nearest to the point, unless it is more than 5m away, in which case write X.

► For Height Class, tick the appropriate square, applicable to the bush recorded as NB. Leave blank if NB = X.

► For DistB, write the distance, in cm, to the stem of the bush that was recorded as NB. If > 5m away, write > 5m.

► For No.P, write the number of live perennial grasses, of at least 5cm basal diameter, within 75cm.

► For CoorS&E, write the last three digits of the GPS coordinates (WGS84, decimal degrees) from where the dart was thrown. The first four digits should appear in the two right hand cells in the title row of the table.

APPENDIX 4

Data sheet for count of woody plants shorter than 0.5 m within 0.75 cm of points

Survey No. ___ Date:__________ Place:______________ Surveyors:____________

Spcs	Type	Point Numbers																													
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If a woody plant shorter than 0.5m appears within 75cm of the point, write the point number (corresponding with that in the points data sheet) at the top of the blank column to the right of "Type". Write the name of its species in the uppermost blank cell of the species column, under "Spcs". Write the number of woody plants of that species and type counted within 75cm in the corresponding cell of the column with the point number. The abbreviations for type are S = Seedlings of the current season O = older plants. If more than 90 points have short woody plants, then please turn overleaf to record the 91^{st} and more.

APPENDIX 5

Data sheet for canopy cover by Bitterlich gauge of woody plants taller than 0.5 m

Survey No. ______Date:___________ Place:________________________Surveyors:_______________

Species		2	6	10	14	18	22	26	30	34	38	42	46
Species	50	54	58	62	66	70	74	78	82	86	90	94	98

If 50 or more out of the 100 sample points have no woody plant of >0.5 m in height within 5 m, then please use the reverse side of this paper to record a total count of these woody plants within 250 m x 150 m of the site area, by species and record the height and GPS coordinates of each.

APPENDIX 6

Questions asked of farmers during interviews

1	What % of your working time do you devote to farming and when e.g. Fulltime / Weekends?
2	What is the main objective of your management?
3	What is your perception of the main objective of your neighbours?
4	What are your different farming enterprises and what % of farming income do you derive from each of them?
5	What are your different non-farming enterprises?
6	When did rangeland change to its current condition?
7	Please describe the change, from what to what, and the sizes of the contrasting paddocks?
8	What caused the change?
9	How many paddocks is your farm divided into?
10	How many animals of the different species and breeds do you currently stock on the farm, including game, and what are their average weights?
11	What is the current overall stocking rate?
12	How many paddocks per herd do you allocate?
13	Please describe the management history as far back as you know about.
14	Please name the current management, on your side of the fenceline contrast.
15	Please name the current management, on the other side of the fenceline contrast
16	What was your previous average stocking rate?
17	When was stocking rate changed?
18	In which month do you determine carrying capacity?
19	How do you determine carrying capacity?
20	In which month do you adjust stocking rate?
21	To what level do you adjust stocking rate?
22	Please describe your main strategy to maintain good rangeland condition.
23	Please describe your main strategy to maintain animal condition.
24	What % of your rangeland do you rest for the full growing season every year?
25	What is average rest period in the growing season?
26	What is your average rest period in the dry season?
27	On which basis do you decide on rate of rotation in the growing season?
28	On which basis do you decide on rate of rotation in the dry season?
29	What is your main strategy to minimize overgrazing in spring, when perennial grasses are sensitive?
30	What is your main strategy to minimize overgrazing in autumn, when grasses are again sensitive?
31	What is your main strategy to optimize use of annual grasses?
32	What is your main strategy to encourage valuable browse species?
33	What is your main strategy to encourage germination of new grass seedlings?
34	Main strategy to control bush encroachment? (Dates when symptoms treated at fenceline)
35	Application of fire management, and views on it?
36	Which animals are kraaled, when and why?
37	Provision of lick: type, amount and season?
38	What are your veterinary inputs apart from compulsory vaccination and treating injuries?
39	When are your breeding seasons for your main livestock types?
40	What is the highest annual animal growth you had?
41	What is the lowest annual animal growth you had?
42	What is your average annual animal growth?
43	What are your different input costs, including fence maintenance and replacement per km?
44	What is your mean annual income (farm or /ha)?
45	How many labourers are employed on the farm?
46	How many boreholes on farm (diesel, wind, solar)?
47	How many water points and km of pipe
48	Which five plant species are most valuable to you and why?
49	Which five plant species are most damaging to you and why?
50	Which insect is most valuable to you and why?
51	Which insect is most damaging to you and why?
52	Which bird is most valuable to you and why?
53	Which bird is most damaging to you and why?
54	What are the main landscape types on your farm and how do you differentially manage them?
55	Any other important aspect of management or consequences not asked about?