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MODELLING THE HABITAT REQUIREMENTS AND

DEMOGRAPHY OF A POPULATION OF ROAN ANTELOPE

HIPPOTRAGUS EQUINUS

DPhil (Wildlife Management)   UP   1998

MODELLING THE HABITAT REQUIREMENTS AND DEMOGRAPHY OF A POPULATION OF ROAN ANTELOPE *HIPPOTRAGUS EQUINUS*.

by

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF DOCTOR OF PHILOSOPHY (WILDLIFE MANAGEMENT)

Centre for Wildlife Management

in the

FACULTY OF BIOLOGICAL AND AGRICULTURAL SCIENCES
UNIVERSITY OF PRETORIA
PRETORIA

July 1998

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ABSTRACT

The aim of this study was to model the roan-habitat relationships and the demography of the roan population in the Nylsvlei Nature Reserve. Habitat variables were measured at three sites in each of eight plant communities over 24 months. These were species composition, dry weight contribution per species, grass density, above-ground standing crop, total grass height, grass tuft height, grass canopy cover, woody plant density, woody plant canopy cover, % moisture, % N, % NDF, % ADF, % IVOMD, % OM, % Ca, % P, % K and % Na. Species density, species diversity, veld condition and biomass concentration were calculated from the above variables. Differences in habitat variables between seasons and between plant communities were tested with general linear modelling. They were further analyzed with correspondence analysis and logistic regression analysis to identify those variables that are most important in a plant community.

Seventeen habitat parameters were isolated with logistic regression analysis of which only 11 were used for constructing seasonal Habitat Suitability Index models. These models predict the suitability of habitats and the roan densities in each plant community. Regression analysis between HSI output and breeding herd densities indicated high correlations, suggesting some validity of these models. These models need further testing with independent field data.

The roan population and its distribution was monitored monthly for 24 months. A spatial segregation was found between the roan breeding herd and batchelor males. The floodplain with its high forage quality (mainly Na) and availability (high biomass concentration) is an important summer feeding area utilized by both social groups. The drying of the floodplain in autumn with a corresponding decrease in forage quality and availability forces roan out of this plant community and into more suitable areas. During winter the breeding herd selected the *Aristida bipartita - Setaria sphacelata* Grassland Variation probably because of the high Ca content and the large amounts of forage. The adjacent *Tristachya rehmannii - Digitaria monodactyla* and the *Rhus leptodictya - Combretum apiculatum* Variation were selected to a lesser extent. The *Eragrostis pallens - Burkea africana* Savanna was also utilized to a large extent and may serve as a calving area in winter because of the cover provided.

The high density and negative rate of increase of this population indicates that they have reached carrying capacity. The demography of the roan population was analyzed with a Population Viability Analysis (PVA) to predict its persistence and to identify those population parameters that negatively influence population growth. The PVA revealed that female calf mortality is an important parameter influencing population viability. This aspect needs to be monitored and controlled to ensure population persistence. Other important parameters identified were sub-adult female mortality and calf sex ratio. The harvesting and supplementation of animals will increase the genetic variation through the exchange of genetic stock.

A management plan was compiled with recommendations for improving the habitat for roan and to apply population management to ensure maximum population persistence.

KEYWORDS

Nylsvlei Nature Reserve, species diversity, veld condition, grass structure, above-ground standing crop, woody vegetation, forage quality, multivariate modelling, faecal analysis, population dynamics, Population Viability Analysis, Habitat Suitablity Index model

Dedicated to my family

Karin, Saskia and Kyra

When the game manager asks himself

whether a given piece of land is

suitable for a given species of game,

he must realize that he is asking no

simple question.

Aldo Leopold

Because man has difficulty in understanding the complex ecological processes at work, those who attempt to answer these questions, realize that ...

...all our science, measured against reality, is primitive and childlike - and yet it is the most precious thing we have.

Albert Einstein

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CHAPTER 1

Introduction

History

Roan antelope [*Hippotragus equinus equinus* (Desmarest, 1804)] (hereafter referred to as roan) are widely distributed over the central and western parts of Africa (Skinner & Smithers, 1990). Roan used to be common in parts of West Africa (Poché, 1974). South Africa was the most southern limit of its distribution (Wilson, Bartsch, Bigalke & Thomas, 1974) where they probably never occurred in large numbers. Roan densities varied considerably over their distribution range but were low over all habitats combined (Wilson & Hirst, 1977). Roan has been hunted to a large extent in hunting reserves in Upper Volta and Dahomey (Poché, 1974) and in the Sudan (Cloudsley-Thompson, 1992). The present status of roan is that they are diminishing, rare and endangered, practically exterminated or virtually extinct outside conservation areas over much of their historical distribution range (Von Richter, 1974; Wilson, *et al.*, 1974; Joubert, 1976; Wilson & Hirst, 1977; Allsopp, 1979; Smithers, 1986; Skinner & Smithers, 1990; Cloudsley-Thompson, 1992). In South Africa this rare species is classified as endangered (Smithers, 1986; Skinner & Smithers, 1990). Roan populations and their distribution ranges have also declined drastically throughout southern Africa over the past decades (Wilson & Hirst, 1977). This was mainly due to shooting and habitat destruction, such as bush encroachment and overutilization of the grasslands (Von Richter, 1974; Wilson & Hirst, 1977; Smithers, 1986; Cloudsley-Thompson, 1992). Habitat change has been the most important cause of population decline and species extinction at a global level (Stewart & Hutchings, 1996).

Roan have been reintroduced into areas within their former distribution where they showed to be good breeders (Smithers, 1986). However, while some populations increased (e.g. in Percy Fyfe Nature Reserve), other populations such as those in the Kruger National Park have declined from 250 to 300 in 1970 (Von Richter, 1974) to less than 50 in 1994 ([*]Viljoen, P. 1994. pers. comm.).

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[*] Viljoen, P. 1994. Kruger National Park, Private bag X402, Skukuza, 1350

Conservation biology

Remaining individuals of endangered species are often concentrated in a few populations or small areas. Fragmented habitats and isolated populations are common problems for endangered species (Doak, 1989; Lande, 1995) which not only reduce the distribution of animals, but also densities to levels where demographic and genetic constraints threaten the existence of populations (Murphy, Freas & Weiss, 1990). Once a population is small the influence of stochastic processes such as demographic stochasticity, environmental variation, catastrophic variation and genetic drift become more significant and they are more vulnerable to extinction than large populations (Berger, 1990; Lacy, 1995). Variations of these stochastic events place such populations at high risk of extinction (Lacy & Clark, 1990).

Evolutionary strategy

Many species are naturally rare because of their ecology which is commonly anthropomorphic in origin (Stewart & Hutchings, 1996). A challenge for conservationists is to identify a species' traits that make it sensitive to habitat changes such as fragmentation. The ecological patterns of rare species may ultimately lead to extinction. For example roan have biological characteristics that may be a cause of their rarity. These are:

a) Roan are found in dystrophic (nutrient poor) savannas such as miombo woodlands (Heitkönig, 1993). It is an ecotonal species which is particularly selective of open "dambo-like" grasslands (Pienaar, 1974; Joubert, 1976).

b) Roan are highly selective of food plants (in their diet) even under stress situations (Wilson & Hirst, 1977).

c) In the presence of more dominant species roan are always at an disadvantage in a competitive situation (Wilson & Hirst, 1977). Of major importance is their habit of avoiding large concentrations of other species and withdrawing to the more remote areas of their habitats (Joubert, 1976).

d) Newly born calves are hidden away from the herd for an extended period of up to 6 weeks (Wilson *et al.*, 1974) which results in high calf mortalities.

e) A high proportion of calves are weaned during a period when food availability is declining (Beudels, Durant & Harwood, 1992). At the end of the dry season forage protein and phosphorus levels are also too low to provide adequate nutrition (Wilson & Hirst, 1977).

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f)   Intraspecific aggression by the herd bull towards subadult males is a major limiting factor for that sex and age group in small areas (Wilson & Hirst, 1977).

In addition, artificially high densities caused by restricted movements or lack of dispersal possibilities increase the rates of transmission of direct life-cycle pathogens (Dobson & May, 1986 in Gottelli & Sillero-Zubiri, 1992). Roan are highly susceptible to ticks and anthrax (Wilson & Hirst, 1977). A parasite, *Cytauxzoon* also causes high mortalities in young roan calves (Wilson & Hirst, 1977) and could be an important limiting factor in the performance and conservation of roan populations.

Although the winter calving season or the time when calves are weaned cannot be changed, proper habitat management or the provision of supplementary feeding to improve quality food intake can play a vital role in roan management.

Previous research

Many aspects of the biology and ecology of roan have been studied (Skinner & Smithers, 1990). Wilson & Hirst (1977) studied biological characteristics, habitat utilization, feeding and nutrition, and diseases in four nature reserves in the Transvaal. The life history, food preferences, habitat preferences and management of roan in the Kruger National Park were studied by Joubert (1976). Ben-Shahar (1986) studied the habitat preferences and feeding habits of roan, sable antelope and tsessebe in the Lapalala Nature Reserve (Waterberg mountains). This environment differs markedly with regard to the topography, landscape and vegetation to that in Nylsvlei Nature Reserve (NNR) and other lowland areas. Only one study of roan was done in the NNR. Heitkönig (1993) studied the feeding strategy and area selection of roan. Some aspects of the sward structure and the chemical quality of the principal grasses were investigated in the *Eragrostis pallens - Burkea africana* Savanna.

Research needs

Problems regarding the management of roan are still being experienced in many areas in its natural distribution. Since ecosystems become increasingly fragmented, assessments of habitat and spatial requirements are important to assure the persistence of species (Berger, 1990). Most wildlife management objectives, for example maintaining species diversity, increasing population growth and harvest rate, can largely be met by maintaining suitable habitat conditions (Shaw, 1985).

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Animals select habitats based on a number of criteria which are difficult if not impossible to measure. For example Joubert (1976) described preferred roan habitats in the Kruger National Park as those with a well developed grass stratum and a low tree density. Instead, roan in the Lapalala Wilderness (Waterberg mountains) selected sandy acidic soils on flat areas (Ben-Shahar, 1986). He stated that open habitats may be favoured but they are not a prerequisite. Roan are sensitive to habitat change and further knowledge of their requirements would therefore be important (Smithers, 1986).

Aspects which have not been investigated in detail by other authors to date are habitat requirements such as habitat quality, forage availability and forage quality. Especially the importance of newly burnt areas and floodplain areas has been neglected. Artificial feeding and chemical treatment against ectoparasites as a management tool and its effect on the production of roan has also not been investigated. Causes of calf mortality should be identified and controlled to improve population growth. Habitat management and calf mortality should, therefore, be priorities in designing a management plan for roan.

Nylsvlei Nature Reserve was selected as the study area since it falls within the historical natural range of roan. A considerable part of the reserve is also covered by a seasonal grassland marsh. These marshy areas are selected by roan throughout Africa wherever they occur (Joubert, 1976). Consideration of the typical habitat of a species is necessary when determining basic ecological aspects such as habitat requirements (Stewart & Hutchings, 1996).

To manage a species effectively the relations between cause and effect as relating to the habitat and the animals must be investigated. To meet this requirement, evidence from both the environment and the animals at different levels of functioning has to be obtained. With regard to the environment, these are 1) occurrence (plant communities, species composition, standing biomass, forage quality), 2) utilization (utilization by animals) and 3) response (production in different plant communities and in post-burn areas). The functioning levels with regard to animals are 1) occurrence (total numbers), 2) utilization (habitat selection) and 3) response (physical condition, sex and age structure, calf/cow ratio).

Objectives

Specific objectives of this study were to:

a)   identify the most important habitat parameters that influence habitat selection of roan as an indication of their habitat requirements,

b)   construct a deterministic model based on these habitat parameters to predict habitat suitability,

c)   do a population viability analysis of the population to identify important demographic parameters for monitoring,

d)   assess the effects of different management strategies on roan population performance.

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CHAPTER 2

Study areas

2.1 Nylsvlei Nature Reserve

The section of the Nylsvlei Nature Reserve (henceforth NNR) where the roan population can range freely used to encompass 2 779 ha. Towards the end of 1995 this area was enlarged by a further 500 ha and is now 3 279 ha in size. All areas related calculations made during this study are based on the original size of 2 779 ha (Fig. 2.1).

This small reserve falls into the Savanna biome (Bosch & Tainton, 1988) and is situated in the Mixed Bushveld (Frost, 1987; Acocks, 1988) of the Northern Province (24°39'S, 28°42'E). The NNR falls on the border between a moist and dry savanna (Scholes & Walker, 1993). The reserve lies at an altitude between 1 080 m to 1 155 m above sea level (a.s.l.).

The longterm (56 years) mean annual rainfall is 623 mm with a standard deviation of 134 mm (Scholes & Walker, 1993). Monthly climatic data (rainfall, temperature and wind) for the study period were obtained from the Institute for Soil, Climate and Water for Roedtan, the closest weather station to the NNR (39.8 km) (Table 1.1, Appendix 1). These data showed that 1994 was drier (59.59 % of the 1995 rainfall) and slightly colder than usual with more wind (Table 1.1, Appendix 1). The total rainfall in the rainy season (September to April) was 480.5 mm for 1993/1994, 512.4 mm for 1994/1995, and 711.5 mm for 1995/1996.

The complex geology of the region consists of a variety of igneous, sedimentary rock (Waterberg sandstone), metamorphic rock (Rooiberg lavas - felsite) and recent sediments. The main soil types are well drained residual soils (sandstone), vertisols (turf), illuvial soils, alluvial soils (*Sporobolus ioclados - Acacia tortilis* Savanna areas), and lithosols (felsite) (Table 2.1; Table 1.2, Appendix 1, Land Type Survey Staff, 1988).

The many soil types, drainage lines and two small hills (Maroelakop and Stemmerskop) contribute to the habitat diversity. The vegetation composition is complex and consists of seven primary communities with 12 community variations and four subvariations, and three secondary

communities (Coetzee, Van der Meulen, Zwanziger, Gonsalves & Weisser, 1976). A more detailed description of the reserve is given by Coetzee *et al.*, (1976), Grossman (1981), Frost (1987), Heitkönig (1993) and Scholes & Walker (1993).

2.1.1 Plant communities

The identification and classification of plant communities into "manageable" units, often ignores functional interactions between sympatric species over time and environmental factors (West, 1988). The environmental factors which influence the natural development and stability of plant communities are climate (temperature, light, water), soil, topography, altitude, latitude, herbivores and fire (Tainton, 1981).

This study was conducted at the plant community level for ease of identifying different vegetation units and to assist in the interpretation of animal habitat selection. Because the identification of plant communities was not part of this study, existing vegetation maps were used.

An existing vegetation map of the Nylsvlei Nature Reserve (NNR) (Coetzee *et al.*, 1976; Frost, 1987; Scholes & Walker, 1993) was used to identify the plant communities. The selection of plant communities was based on broad geological and soil criteria, the physiognomy of the vegetation, the percentage cover of each plant community and the known distribution patterns of roan (Heitkönig, 1993). The area of each plant community was determined from the vegetation map with a digital planimeter (Placom KP-80). Eight plant communities were selected (Figs. 2.1 and 2.2; Table 2.1).

Table 2.1: The larger plant communities in terms of size and the associated soils (Coetzee *et al.*, 1976; Huntley & Morris, 1982; Frost, 1987) in the Nylsvlei Nature Reserve.

PLANT COMMUNITY	AREA (ha)	% OF TOTAL RESERVE AREA	SOILS	GEOLOGICAL ORIGIN	FORM	CLAY CONTENT	NUTRIENT LEVELS	WATER INFILTRATION
Lithosols (felsite areas)								
Rhus leptodictya - Combretum apiculatum Variation	340.8	12.26 %	Lithosols underlain by rock	Felsitic lavas of the Rooiberg Group	Hutton	low	low	high
Cymbopogon plurinodis - Combretum apiculatum Variation	210.9	7.59 %	Lithosols underlain by rock	"	"	"	"	"
Eragrostis nindensis - Digitaria monodactyla Variation	152.9	5.50 %	Lithosols underlain by rock	"	"	"	"	"
Alluvial soil areas (brack areas)								
Sporobolus ioclados - Acacia tortilis Savanna	349.9	12.59 %	Illuvial with high clay content	Water-borne sediments		high	high	low
Vlei areas								
Nyl River and floodplain	322.7	11.61 %	Alluvial	Water-borne sediments		high	high	
Vertisols (turf areas)								
Aristida bipartita - Setaria sphacelata Savanna Variation	178.9	6.44 %	Vertisols	Weathered basalt of the Karoo Group rocks			high	
Aristida bipartita - Setaria sphacelata Grassland Variation	150.5	5.42 %	Vertisols	"			high	
Sandveld								
Eragrostis pallens -Burkea africana Savanna (excluding *Acacia* areas and Maroelakop)	480.4	17.29 %	Well drained residual soils (sand)	Weathered Karoo sandstones and other sedimentary rocks of the Waterberg Group	Clovelly Hutton Mispah	low	low	high
TOTAL AREA OF PLANT COMMUNITIES	2 187	78.70 %						
TOTAL AREA FOR NNR	2 779							

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2.1.2 Burnt areas

Fire affects forage quality and quantity, patterns of succession, ectoparasites and disease levels (Homewood & Rodgers, 1991). Burnt areas are selected by many ungulate species (Novellie, 1987; Moe, Wegge & Kapela, 1990; Everett, Perrin & Rowe-Rowe, 1991; Homewood & Rodgers, 1991) mainly due to the increased quality of forage. Shackleton (1992) found that the grazing intensity in recently burnt areas can be up to 300 % greater than in recently unburnt swards. Fire can be used to provide the habitat and ecological diversity required by some animal species (Bailey, 1988) and as such is an important tool in wildlife management.

Burnt areas are not separate plant communities but are the same plant communities which have undergone a change in structure, biomass and forage quality. In habitat selection studies, burnt areas should, therefore, be treated as separate units. The aim of this section was to identify the size of burnt areas and the frequency of burning.

The plant community and area burnt, and the frequency and seasonality of the fire regime were recorded. Parameters measured monthly over a period of six months (November to April) in each burnt plant community, were:

Grass structure	(Chapter 5)
Above-ground standing crop	(Chapter 7)
Forage quality	(Chapter 10)
Habitat selection	(Chapter 16)

In October 1994, three plant communities, *Eragrostis nindensis - Digitaria monodactyla* Variation, *Aristida bipartita - Setaria sphacelata* Savanna Variation and *Aristida bipartita - Setaria sphacelata* Grassland Variation were burnt. The *Tristachya rehmannii - Digitaria monodactyla* Variation was also burnt. Although the latter plant community was not selected for this study, post burn vegetation data were collected. The total area burnt in the early summer of 1994 comprised approximately 672 ha or 24.18 % of the total reserve.

In October 1995 the *Rhus leptodictya - Combretum apiculatum* Variation and *Cymbopogon plurinodis - Combretum apiculatum* Variation plant communities were burnt. This was an area of approximately 551.7 ha or 19.85 % of the total area.

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2.1.3 Seasons and sample sites

Habitat data should be collected at various sites within a plant community to cover as much as possible of the environmental variation. The aim was to select a number of sites according to certain criteria. Due to logistic limitations only three sites were selected per plant community.

A stratified, non-random sampling approach was followed to collect vegetation data. Three sample sites were selected in each of the eight plant communities. In total 24 sample sites were distributed over the Nylsvlei Nature Reserve (Table 1.3, Appendix 1). The selection of sample sites was based on the representativeness of the plant community, homogeneity of the area to minimize within-location variability, and accessibility.

Data were collected over a period of two years since this provides a minimum statistical measure of how repeatable means are over time (Mitchell, Elderkin & Lewis, 1993). Collection of vegetation data (grass structure, above-ground standing crop and forage quality) was done on a seasonal basis, except for the recently burnt areas which were sampled on a monthly basis for a period of six months. The definition of seasons was based on the biomass accumulation rates and variation in chemical composition of the herbaceous layer, as described by Grossman (1981):

Winter is the dormant season (May-September)
Early summer is the early growing season (October-December)
Late summer is the late growing season (January-April)

Other data, such as grass species composition and woody plant structure, were collected once only (for further detail see Chapters 3 and 6 respectively). Grass cover was measured at 10 different sites in each plant community (random selection) during February 1995 (for further detail see Chapter 9).

Surveys of animal distribution were conducted at monthly intervals for a 24 month period (for further detail see Chapter 16).
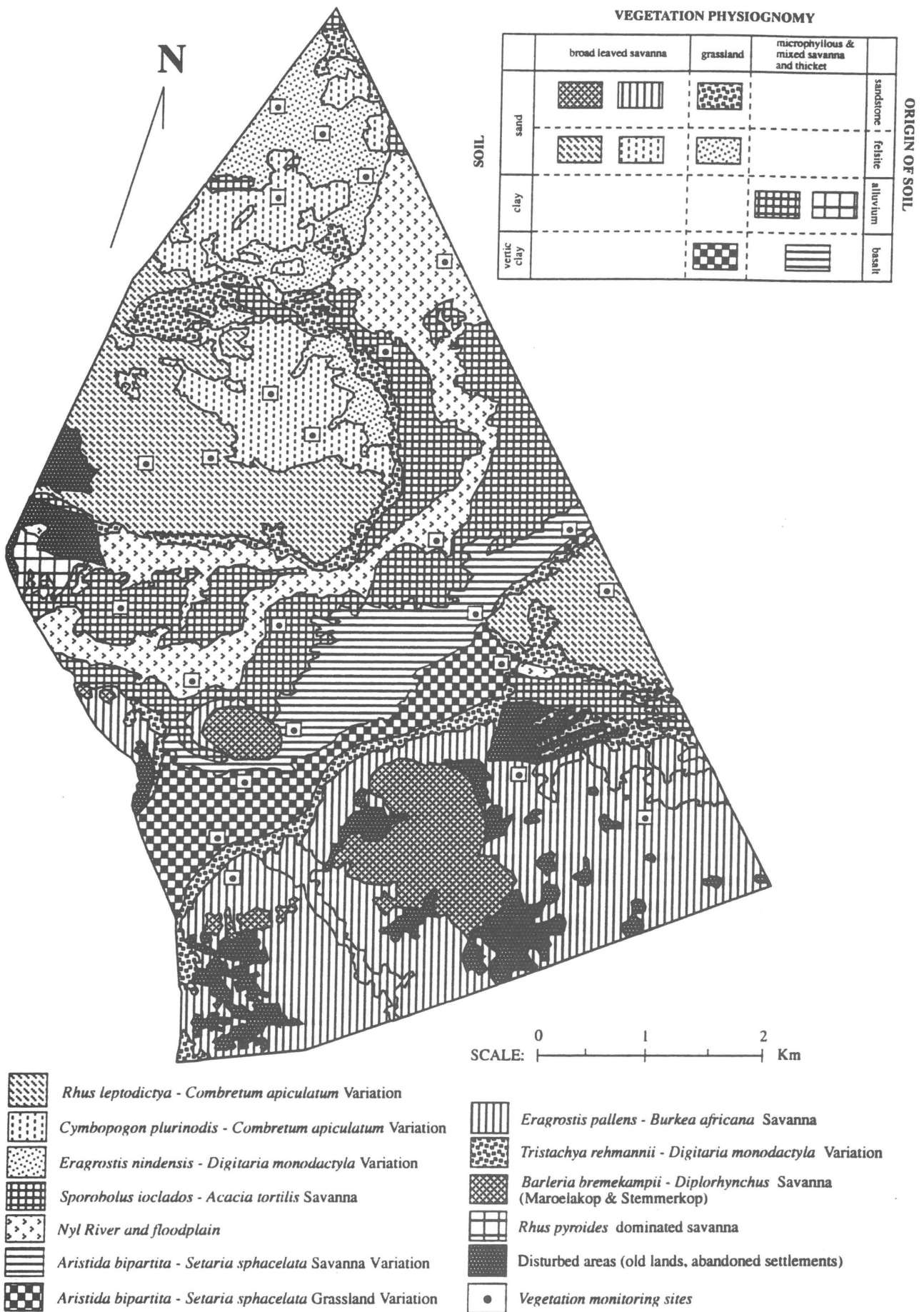
VEGETATION PHYSIOGNOMY

		broad leaved savanna		grassland	microphyllous & mixed savanna and thicket		
SOIL	sand	▨	▥	▦		sandstone / felsite	ORIGIN OF SOIL
		▧	▥	▦			
	clay				▦ ▦	alluvium	
	vertic clay			▨	▤	basalt	

SCALE: 0 —— 1 —— 2 Km

Legend (left column):
- ▨ *Rhus leptodictya - Combretum apiculatum* Variation
- ▦ *Cymbopogon plurinodis - Combretum apiculatum* Variation
- ░ *Eragrostis nindensis - Digitaria monodactyla* Variation
- ▦ *Sporobolus ioclados - Acacia tortilis* Savanna
- ▷ Nyl River and floodplain
- ▤ *Aristida bipartita - Setaria sphacelata* Savanna Variation
- ▨ *Aristida bipartita - Setaria sphacelata* Grassland Variation

Legend (right column):
- ▥ *Eragrostis pallens - Burkea africana* Savanna
- ▦ *Tristachya rehmannii - Digitaria monodactyla* Variation
- ▨ *Barleria bremekampii - Diplorhynchus* Savanna (Maroelakop & Stemmerkop)
- ▦ *Rhus pyroides* dominated savanna
- ■ Disturbed areas (old lands, abandoned settlements)
- • *Vegetation monitoring sites*

Fig. 2.1: Vegetation map based on Coetzee *et al.* (1976) of the main section of the Nylsvlei Nature Reserve as it was before 1996.

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Fig. 2.2: The *Rhus leptodictya - Combretum apiculatum* Variation (top) and the *Cymbopogon plurinodis - Combretum apiculatum* Variation (bottom).

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Fig. 2.2 (cont.): The *Eragrostis nindensis - Digitaria monodactyla* Variation (top) and the *Sporobolus ioclados - Acacia tortilis* Savanna (bottom).

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Fig. 2.2 (cont.): The Nyl River and floodplain (top) and the *Aristida bipartita - Setaria sphacelata* Savanna Variation (bottom).

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Fig. 2.2 (cont.): The *Aristida bipartita - Setaria sphacelata* Grassland Variation (top) and the *Eragrostis pallens - Burkea africana* Savanna (bottom).

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2.2 Other areas

In these areas limited data was collected for comparitive purposes only. Demographic data of each roan population and faecal samples were collected.

Percy Fyfe Nature Reserve

The Percy Fyfe Nature Reserve (24°02'S, 29°09'E) covers a total area of 3 462 ha (Wilson & Hirst, 1977). The roan in Percy Fyfe N.R. have access to only 1 649 ha which they shared with approximately 50 Cape buffalo and less than 30 kudu, waterbuck and impala combined ([*]Officer in Charge,1995. pers. comm.). At an altitude of 1 295 to 1 550 m a.s.l., the climate is temperate with mean monthly temperatures ranging from 12.0 °C in July to 22.8 °C in January. The wet season ranges from October to March with a long-term avarage rainfall of 421 mm (Wilson & Hirst, 1977) (Table 1.4, Appendix 1, Land Type Survey Staff, 1988).

The undulating topography, interspersed with granite hills and outcrops is underlain by granite geological formations with some chlorite intrusions from the Swaziland system (Wilson & Hirst, 1977). Soils are sandy, dystrophic and deep. The homogeneous vegetation consists of two veld types (Acocks, 1988) i.e.:

North-eastern mountain sourveld

Mountain sourveld mixed with Pietersburg plateau false grassveld.

Wilson & Hirst (1977) provided a more detailed description of the study area.

Rooipoort Farm

This farm with a size of 370 ha is situated in the Turf Thornveld (Acocks, 1988) in the Northern Province, approximately 10 km south of Potgietersrus (Northern Province) (Table 1.4, Appendix 1, Land Type Survey Staff, 1988). The mean annual rainfall is 596.3 mm. Intensive bush control is conducted and the largest part of the farm has been converted to planted pastures, mainly *Cenchrus ciliaris. Digitaria eriantha* and *Panicum maximum* were also planted on a small scale.

[*] Officer in Charge,1995. Percy Fyfe Nature Reserve, P.O. Box 824, Potgietersrus, 0600.

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Sable Ranch

Sable Ranch lies approximately 40 km north of the town of Brits (North West Province). The study area was an enclosure of 400 ha within a larger ranch of approximately 3 000 ha. The general vegetation is Sourish Mixed Bushveld (Acocks, 1988) and a mean annual rainfall of 619.0 mm. The grass layer was heavily overgrazed indicated by the predominance of pioneer species such as *Aristida* spp. (casual observation). The geology was predominantly red granite of the Bushveld Complex (Table 1.5, Appendix 1, Land Type Survey Staff, 1987) with an undulating topography.

Le Grange Farm

Le Grange Farm is situated 30 km north-west of Barkley-West in the Kalahari Thornveld (Acocks, 1988) and has a size of 1 600 ha. The mean annual rainfall is 383.1 mm. The general topography is flat interspersed with one small hill. The underlying lime stone is covered with Kalahari sands. In some areas the lime stone is found at the surface. Geological formations are andrasitic to basaltic lavas of the Ventersdorp Supergroup (Table 1.5, Appendix 1, Land Type Survey Staff, in press).

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CHAPTER 3

Relative grass species composition, diversity and density

Introduction

The composition of the herbaceous layer is continuosly changing in space and time due to a combination of factors such as grazing, fire and rainfall which differ in intensity, duration and timing. O'Connor (1991) found that rainfall variability could induce substantial changes in composition over a relatively short period of time. This composition is further mediated by the grazing regime.

The relative grass species composition has long been used as an index for range condition (Hurt & Bosch, 1991). For this purpose, species recorded are usually classified as decreasers or increasers based on their response to different grazing intensities (Hurt, Hardy & Tainton, 1993). However, some concern on the use of these ecological groups has been expressed (Martens, Danckwerts, Stuart-Hill & Aucamp, 1990; Snyman, Grossman & Rethman, 1990; O'Connor, 1991). To compare the herbaceous layer in different plant communities, grass species have been arranged into the ecological groups of Decreasers, Increasers I, II and III according to Van Oudtshoorn (1992). The biomass contribution of each species can also be estimated and serves as a measure of forage availability. Although this parameter has obvious advantages it is not commonly used in veld management.

When only a sample of species in the community is obtained, it is necessary to distinguish between numerical species richness, which is the number of species per specified number of individuals or biomass, and species density, which is the number of species per specified collection area (Magurran, 1991). Species evenness, or equitability, refers to how equally the abundances (number of individuals, biomass, cover etc.) are distributed among species (Goldsmith, Harrison & Morton, 1986; Ludwig & Reynolds, 1988; Morrison, Marcot & Mannan, 1992). Diversity indices combine both species richness and evenness into a single value (Ludwig & Reynolds, 1988; Magurran, 1991) and are, therefore, more suitable for the analysis of community structure. These are also called heterogeneity indices (Ludwig & Reynolds, 1988). The advantage of these

indices is that no assumptions about the distribution of individuals among species have to be made (Morrison *et al.*, 1992) and they are, therefore, referred to as non-parametric indices (Magurran, 1991). Although the biggest problem with diversity indices is the interpretation of their values, they are widely applied in community analyses (Ludwig & Reynolds, 1988; Magurran, 1991; Morrison *et al.*, 1992). These indices merely reflect community structure which changes with species richness, equitability and sometimes density (Morrison *et al.*, 1992).

Two diversity indices are commonly used, the Simpson's index and the Shannon index of diversity, sometimes incorrectly referred to as the Shannon-Weaver index (Magurran, 1991). While the Simpson's index is based on probability theory (Goldsmith *et al.*, 1986) the Shannon index is based on information theory (Ludwig & Reynolds, 1988; Magurran, 1991; Morrison *et al.*, 1992). The latter index measures the degree of uncertainty of predicting the species of an individual selected at random from the community. This uncertainty increases as the number of species and equitability increases.

Abundance or density of grasses is defined as the number of individuals of a particular species per unit area (Goldsmith *et al.*, 1986; Causton, 1988; Goldsmith, 1991) which is related to biomass. For the same height, grass quantity varies according to the density (Voisin, 1988).

The objectives of this study were to estimate and compare percentage composition and percentage dry weight per ecological group, species diversity, and grass density between plant communities. The hypotheses tested were that there are no differences between plant communities in terms of:

1) percentage composition and percentage dry-weight (% DW) per ecological group
2) species diversity
3) grass density

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Methods

Sample size

The recommended sample size for assessing relative species composition in grasslands is 200 points per site on a line transect (Hardy & Walker, 1991). However, point surveys can greatly underestimate actual species richness and species surveys using quadrats are therefore recommended (Novellie & Strydom, 1987). Causton (1988) recommended the use of a small quadrat size in non-random surveys. A small quadrat method can be used to estimate species richness, species density, species composition, species abundance and grass density. Estimating density with randomly distributed quadrats is an accurate method, allows direct comparison of different areas and species, and is an absolute measure of abundance (Kershaw, 1980). Snyman *et al.* (1990) suggested small quadrats methods, the dry-weight-rank method and the comparative yield method (Kelly & McNeill, 1980) to estimate herbaceous composition and phytomass respectively for the semi-arid savanna of the Northern Province The relative biomass contribution of grass species was estimated with the dry-weight-rank method, as developed by 't Mannetje & Haydock (1963) and described by Kelly & McNeill (1980), Barnes, Odendaal & Beukes (1982), Ben-Shahar (1991), and Shackleton (1992). Concurrently the herbaceous species composition, species density and grass density were also estimated with this small quadrat method.

 't Mannetje & Haydock (1963) recommended a quadrat size which includes at least three or more species in most quadrats. A general measure of selecting quadrat size is that most recorded species should have a frequency of 20 to 70 %. If one or more species have a frequency of 100 % the quadrat size is probably too big (Goldsmith, 1991). The inverse relationship between quadrat size and variance together with time and cost efficiency must be taken into account when evaluating size and number of quadrats (Brummer, Nichols, Engel & Eskridge, 1994).

 Surveys in the *Eragrostis pallens - Burkea africana* Savanna plant community were done with a 0.5 m² quadrat which followed the general recommendation of 't Mannetje & Haydock (1963). However, this quadrat size was impractical in the *Aristida bipartita - Setaria sphacelata* Grassland Variation due to the high density of plants (up to 350 per 0.25 m²). A 0.25 m² square (50 x 50 cm) was used instead and proved to be a more suitable size for all plant communities which was considerably larger than that recommended by Barnes *et al.* (1982) of 20 x 20 cm. The latter was used in dense sour grassveld in the Mpumalanga Province.

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To determine sample size a pilot study of the species density was done with 30 x 0.5 m² squares placed five metres apart on a single line transect in the *Eragrostis pallens - Burkea africana* Savanna. This plant community had a relatively high species density compared to the other plant communities. Species data was used to calculate sample size from the sample mean. A predeterminant is that the difference between $\bar{x}$ (sample mean) and μ (population mean) is not larger than *e* at a 95 % confidence level (Steyn, Smit, du Toit & Strasheim, 1995). The formula used to calculate sample size (*n*) with *e* taken as 0.5 was:

$$n = (\frac{1.96\sigma}{e})^2$$

where σ = sample standard deviation

   e = stipulated variation of the sample mean at a 95 % confidence level (taken as 0.5)

Another method applied to estimate sample size was done visually from data matrices. This is similar to the graphical method described by Wratten & Fry (1980), Kershaw & Looney (1985), Goldsmith *et al.* (1986) and Kent & Coker (1992). The basic principle is that a sample size is selected which gives a reasonably accurate measure of, for example, the number of species. A larger sample size shows little variation in the data. For most plant communities in the Nylsvlei Nature Reserve (NNR) the sample size varied between 10 to 15 quadrats (Table 2.1, Appendix 2). However, to achieve a better accuracy and to reduce standard error a sample size of 20 quadrats per site was decided on. Estimated sample sizes for *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation (lithosols) varied between 24 and 31 (Table 2.1, Appendix 2). These plant communities should have rather been sampled with 30 quadrats but 20 quadrats were used instead due to logistic and time constraints.

Sampling

Three sites in each plant community were surveyed once during February 1995. A stratified, non-random sampling approach was followed where at each site 20 quadrats (0.25 m²) were placed five metres apart on a single line transect, assuming independence between sampling points.

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Species composition and grass density

Each rooted grass species within a 0.25 m² square was identified (Gibbs Russell, Watson, Koekemoer, Smook, Barker, Anderson, & Dallwitz, 1991; Van Oudtshoorn, 1992) and counted. Forbs as a group (all species) were treated as a single species. Species composition and their abundances were used to calculate species diversity.

Density estimates were based on a convenient morphological unit; in this case each rooted aerial shoot was treated as a unit. It is almost impossible to determine the density of grass species which spread vegetatively (Goldsmith *et al.*, 1986). Rooted nodes of stolons of rhizomatic grasses and parts of tufts that had split and was at least two centimetres from the nearest other plant of the same species were counted as individuals. This was applied to all monocarpic (annuals and biennials) and polycarpic (perennials) species which usually have extensive below-ground vegetative growth systems (Causton, 1988).

Percentage dry-weight per species

The relative biomass contribution of the three most dominant grass species or forb was ranked. Herbage mass of each ranked species was calculated using the multipliers proposed by 't Mannetje & Haydock (1963). Barnes, *et al.* (1982) derived their own multipliers but these did not increase the precision of estimates significantly and they, therefore, recommended the use of multipliers of 't Mannetje & Haydock (1963).

Statistical analysis

Grass species were grouped into four ecological groups based on their response to grazing as described by Tainton (1981), Holechek, Pieper & Herbel (1989), Snyman *et al.* (1990) and Van Oudtshoorn (1992). These were Decreasers, those species which decrease under over or under-utilization, Increaser I, species increasing in under-utilized areas, and Increaser II and Increaser III species becoming dominant in moderately and heavily over-grazed areas respectively. Species were grouped according to Van Oudtshoorn (1992) except for the indicator species which were identified with ordination modelling (Chapter 4).

Species diversity

Results of the sample quadrats were pooled as suggested by Wratten & Fry (1980). The Simpson's index (*D*) was calculated from absolute species abundances. Species density is the most commonly used measure of species richness (number of species) (Magurran, 1991) and was calculated from the number of species per 15 m² for each plant community.

The Simpson's index was used because it is most sensitive to changes in common species, while the Shannon index is most sensitive to changes in rare species (Magurran, 1991; Morrison *et al.*, 1992). The Simpson's index measures the probability that two individuals selected at random from a sample belong to the same species and was calculated from absolute species abundances. Therefore, if the probability is high that both individuals belong to the same species, the diversity of the community is low. Because diversity decreases as *D* increases, the Simpson's index is usually expressed as 1-*D* (Magurran, 1991).

The equation of the Simpson's index is (Wratten & Fry, 1980; Goldsmith *et al.*, 1986; Ludwig & Reynolds, 1988; Magurran, 1991; Morrison *et al.*, 1992; Shukla & Srivastava, 1992):

$$D = 1 - \Sigma\{[n_i(n_i - 1)]/[N(N - 1)]\}$$

where D = diversity index

$\quad$ n_i = number of individuals of species *i*

$\quad$ N = total number of individuals of all species in the sample

The Simpson's index value varies from 0 to 1, for communites in which all individuals belong to the same species to a community in which each individual belongs to a different species. If the probability is high that most individuals belong to the same species, then the diversity of the community is low (Ludwig & Reynolds, 1988).

Since this index gives only one value per area, it is not possible to test for statistical differences in species diversity between plant communities. To overcome this problem bootstrapping or jacknifing techniques can be applied (Krebs, 1989). These techniques are also used to estimate the accuracy of ecological indices (Dixon, 1993). Each data set per plant community was "bootstrapped" where 10 000 iterations of the number and distribution of species in each plant community were randomly selected. A Simpson's index value was calculated for

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each one of these iterations, i.e. 10 000 Simpson's index values. Paired tests of these data sets were conducted between different combinations of plant communities.

Differences between plant communities in terms of percentage composition and % DW per ecological group were tested with the Mann-Whitney U test (Steyn *et al.*, 1995). Differences in species diversity and grass density between plant communities were tested with general linear modelling (PROC GLM) (SAS Institute, 1990) at a 95 % confidence level.

Results and discussion

Sample size

The quadrat size used (0.25 m²) with the dry-weight rank method complied with the recommendations of t' Mannetje & Haydock (1963) that it should be large enough to include at least three species in most quadrats. The lowest percentage of quadrats containing at least three species was 75 % with the average number of species per quadrat (0.25 m²) ranging from 3.40 to 5.42 for the entire (NNR) (Table 2.7, Appendix 2). A quadrat size of 0.25 m² is, therefore, recommended for similar vegetation analyses in Mixed Bushveld areas. However this quadrat size may not be suitable in over-utilized areas with a low species richness.

Calculating sample size showed an average sample size of 17.6 (range 9.27-26.85) quadrats (0.5 m²). Another survey with 20 quadrats (0.25 m²) gave a similar result (Table 2.1, Appendix 2). A sample size of 20 quadrats (0.25 m²) was regarded sufficient to sample the species composition in most plant communities at a 95 % confidence level and that no more than 0.5 new species would be encountered in more than 20 quadrats.

Percentage composition and % DW per ecological group

During the surveys a total of 79 grass species, including forbs as a group were recorded (Table 2.2, Appendix 2). Percentage composition, frequency and DW of the herbaceous layer per species and site for each plant community is given in Table 2.3, Appendix 2. A summary of the percentage composition and dry weight per ecological group is presented in Table 2.4, Appendix 2.

There were significant differences in percentage composition (U > 2; p < 0.05) and % DW contribution (U > 2; p < 0.05).of ecological groups between plant communities. In general Decreasers and Increasers I as a group, indicative of well managed (Decreaser dominated) and under-utilized veld (Increaser I dominated) (Booysen, Gouws, Nel, Stols & Van Zyl, 1996) respectively, had a higher percentage composition and % DW than the ecological groups indicative of over-utilized veld (Figs. 3.1 and 3.2, Table 2.3 and 2.4, Appendix 2). This indicates a low grazing pressure in the NNR which is reflected by the generally high veld condition values (Chapter 4).

Setaria sphacelata was generally the dominant species in terms of percentage composition and % DW in the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation. The over-grazed *Sporobolus ioclados - Acacia tortilis* Savanna had no recorded Increaser I species and was dominant by *Sporobolus ioclados* (Increaser III). *Leersia hexandra* (percentage composition) and *Panicum schinzii* (% DW) were dominant in the floodplain. *Ischaemum afrum* was the most common species in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (vertisols). In the latter plant community *Themeda triandra* was dominant in terms of % DW. In the *Eragrostis pallens - Burkea africana* Savanna *Digitaria eriantha* (percentage composition) and *Eragrostis pallens* (% DW) were dominant (Table 2.3, Appendix 2).

Forbs were more prominent in the *Sporobolus ioclados - Acacia tortilis* Savanna. In other plant communities its percentage composition was higher than the % DW (Figs. 3.1 and 3.2).

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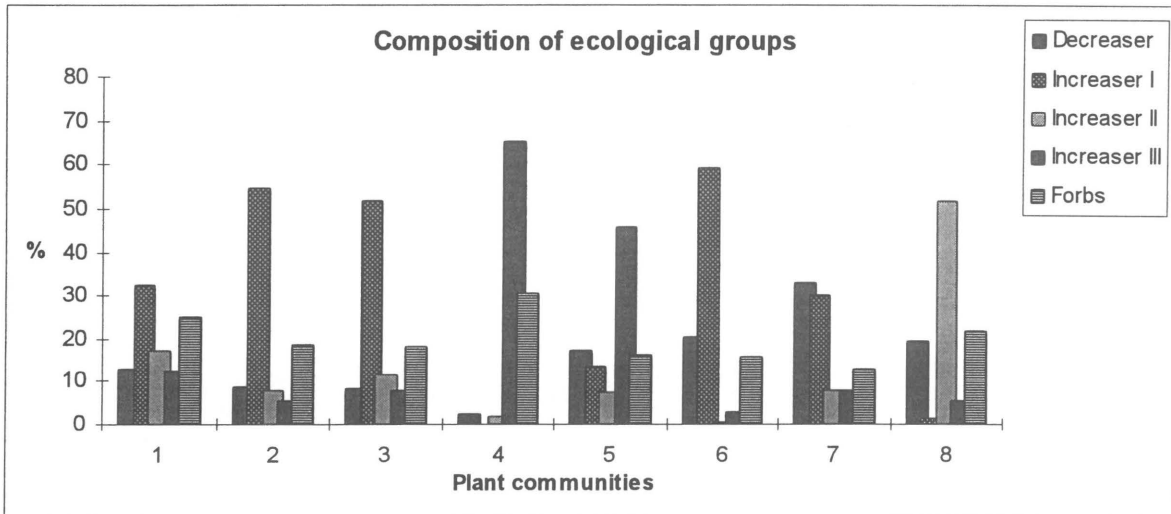
Fig. 3.1: Percentage composition of ecological groups per plant community. The plant communities are 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl River and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, and 8) *Eragrostis pallens - Burkea africana* Savanna.
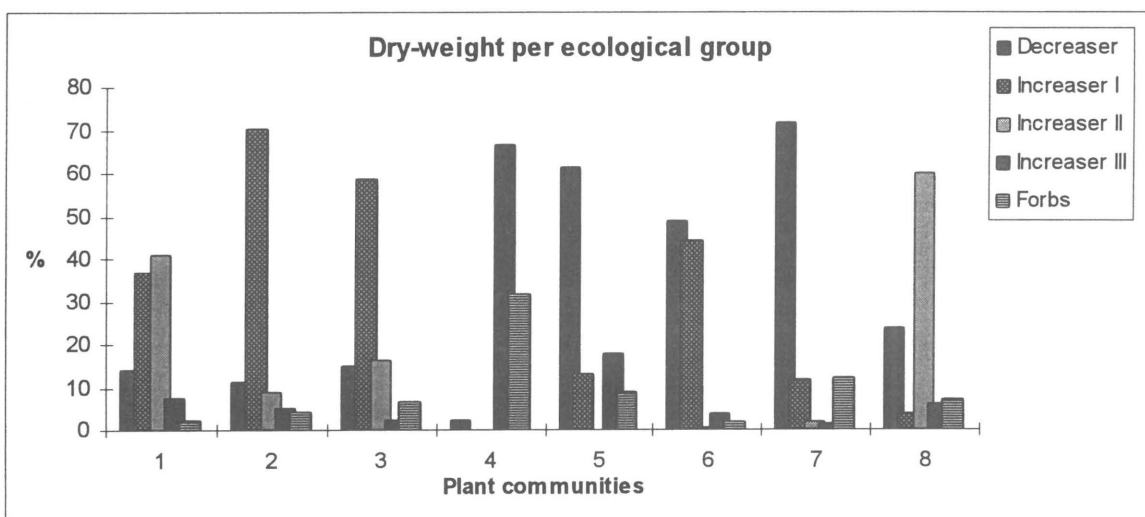
Fig. 3.2: Percentage dry-weight of ecological groups per plant community. See Fig. 3.1 for plant communities.

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Species diversity

The Simpson's index showed that the species diversity of all plant communities was relatively high (D > 0.72) (Table 2.5, Appendix 2). The high index values of the three plant communities on the lithosols (1, 2, and 3) indicate an even distribution of individuals among a large number of species. Fewer species and a less even distribution of abundances among species was found in the *Sporobolus ioclados - Acacia tortilis* Savanna and the *Aristida bipartita - Setaria sphacelata* Savanna Variation (Fig. 3.3, Table 2.5, Appendix 2).

Statistical tests of "bootstrapped" data based on species occurrence and eveness indicated that there were no significant differences (t < 1.96) in species diversity between all plant communities (Table 2.6, Appendix 2). Although there was a relatively large species density found in the NNR many species were found only in specific plant communities. The even distribution of species within each plant community resulted in similar species diversities between plant communities.
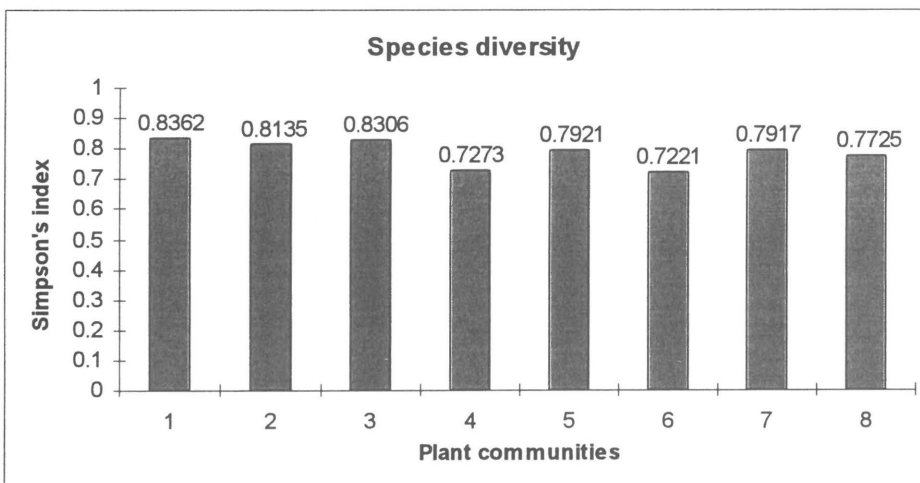
Fig. 3.3: The Simpson's index of species diversity per plant community. See Fig. 3.1 for names of plant communities.

Grass density

There were significant differences (p = 0.0001) in grass density between plant communities (Table 2.7, Appendix 2). The very high grass densities in the *Sporobolus ioclados - Acacia tortilis* Savanna differed significantly (p < 0.005) from all other plant communities. The floodplain, and the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (Fig. 3.4, Table 2.8,

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Appendix 2) differed significantly (p < 0.05) from the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis pallens - Burkea africana* Savanna (Table 2.7, Appendix 2). This could be ascribed mainly to *Eragrostis lehmanniana, Oryza longistaminata,* and *Cynodon dactylon* and *Ischaemum afrum* respectively. The subjective measure of these stoloniferous grasses could have resulted in the very high density of these species in some areas.

The densities of herbaceous plants varied from 53.07 plants/m² in the *Eragrostis pallens - Burkea africana* Savanna to 219.13 plants/m² in *the Sporobolus ioclados - Acacia tortilis* Savanna (Fig. 3.4, Table 2.8, Appendix 2). A negative correlation coefficient of r = -0.6654 was found between plant density and species density. This supports the general statement that as areas are being over-utilized, such as the *Sporobolus ioclados - Acacia tortilis* Savanna, species richness decreases with an accompanying increase in dominance of a few species (Morrison *et al.,* 1992). Therefore the system becomes more simple in terms of biodiversity.
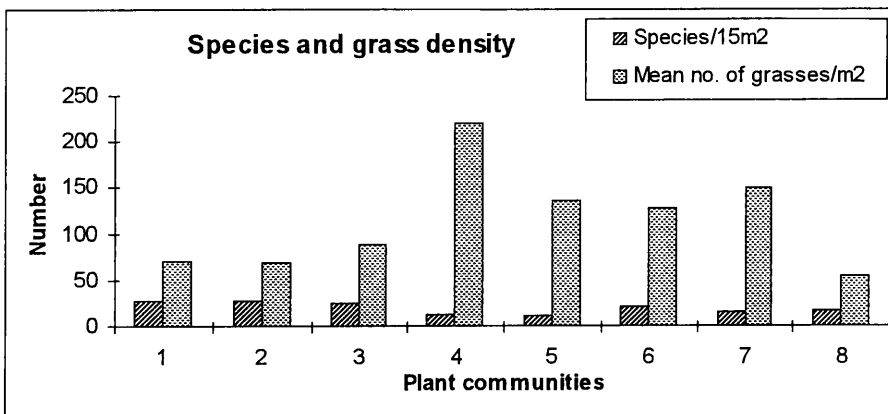
Fig. 3.4: Species density and grass density recorded during surveys in each plant community. See Fig. 3.1 for names of plant communities.

Conclusion

To measure grass species composition with a small quadrat method, a sample size of 20 quadrats per site with a size of 0.25 m² was suitable for all plant communities. These guidelines probably also apply to other Mixed Bushveld areas and support the recommendations of Snyman *et al.*, (1990).

The low grazing pressure in the NNR probably resulted in the predominance of Increaser I and Decreaser species which also produced the highest biomass. This is indicative of well managed to under-utilized veld and is reflected by the generally high veld condition. The high percentage of Increaser II species in the *Eragrostis pallens - Burkea africana* Savanna can mainly be ascribed to one species only, that is *Digitaria eriantha*. Although this species became more abundant in over-grazed areas on sandy soils, it is not known at what successional stage the vegetation was. The *Sporobolus ioclados - Acacia tortilis* Savanna was dominated by Increaser III species indicating patchy over-utilization and the present degraded state of the area.

The relatively high species diversity confirms the findings of the species composition. A low stocking density maintained for more than 20 years and the rotational burning regime may have resulted in the evenness of species and, therefore, similarities in species diversity between plant communities.

The species diversity was lower in the *Sporobolus ioclados - Acacia tortilis* Savanna and in the the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (on vertisols). These plant communities were historically subjected to long-term heavy grazing by cattle and game animals. The historic grazing regime (Scholes & Walker, 1993) may have changed the vegetation which often cause a reduction in species richness with the resulting uneven distribution in the abundance of grass species (Morrison *et al.*, 1992).

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CHAPTER 4

Veld condition

Introduction

Estimating veld condition is generally based on species composition as determined by their response to previous grazing pressures (Tainton, 1981; Hurt & Bosch, 1991; Hurt, Hardy & Tainton, 1993; Du Toit, 1995). Several methods for assessing the condition of vegetation have been proposed and used in southern Africa. These are described by Tainton, Foran & Booysen (1978); Vorster (1982); Heard, Tainton, Clayton & Hardy (1986); Willis & Trollope (1987); Friedel (1988); Tainton (1988); Trollope (1990); Bosch & Gauch (1991); Hurt & Bosch (1991); Stuart-Hill & Hobson (1991); Eckhardt, Van Rooyen & Bredenkamp (1993) and Du Toit, (1995). The most commonly used method is the Ecological Index Method (EIM). A superior methods is the Key Species Method (KSM) basing veld condition estimates on only a limited number of key species identified by multivariate analysis (Heard *et al.*, 1986). Trollope (1990) developed a technique for assessing veld condition based on key grass species for the Kruger National Park. One of the methods to estimate veld condition is the Grazing Index Method (GIM) which is based on agronomic attributes of plant species such as productivity, forage value and perenniality. This method should be used in the Karroo since it is more closely related to grazing capacities (Du Toit, 1995).

Hurt & Bosch (1991) suggested that the Weighted Key Species Method (WKSM) and the Degradation Gradient Method (DGM) have the greatest potential in assessing veld condition. Both methods apply multivariate procedures. Martens, Danckwerts, Stuart-Hill & Aucamp (1990) used multivariate techniques to identify homogeneous vegetation units and to detect trends in the vegegation. Multivariate analysis similar to that described by Bosch & Kellner (1991) was applied in this study.

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Objectives of this study were to:

a)   identify homogeneous vegetation units,

b)   identify indicator species which react to differences in grazing pressures,

c)   determine a veld condition value for each homogeneous vegetation unit

Methods

The estimation of veld condition was based on the relative percentage species composition of the herbaceous layer. Grass species composition was determined with the dry-weight rank method of 't Mannetje & Haydock (1963) and recommended by Snyman, Grossman & Rethman (1990) to determine species composition in arid areas. For a complete description of the survey refer to Chapter 3. In addition over-grazed and under-utilized areas were sampled outside the NNR and incorporated into the data analysis. Exclusion blocks in the *Sporobolus ioclados - Acacia tortilis* Savanna were also surveyed.

While two-way indicator species analysis (TWINSPAN program) is the most popular method for community classification, detrended correspondence analysis (DECORANA program) and canonical correspondence analysis (CANOCO program) are the most widely applied methods in ordination (Kent & Coker, 1992). Ordination modelling was applied to the data with DECORANA and degradation model construction (DMOC) which form part of the Integrated System for Plant Dynamics (ISPD) programme (Booysen, Gouws, Nel, Stols & Van Zyl, 1996). Clusters of sample points with their respective grass species were identified with detrended correspondence analysis and separated subjectively into relative homogenous grazing areas (RHGA). The *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation were combined into one RHGA. Also the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations were combined. The remaining three plant communities were separate RHGAs. A degradation model construction analysis was conducted on each of the five RHGAs (Table 4.1) to establish a grazing gradient. As a default the grazing gradient is divided into three domains indicating the position whereafter no natural recovery of vegetation is possible (Booysen *et al.*, 1996).

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From these ordination models, the trend in the abundance of each species was regressed along a gradient of grazing intensity. Species with a high coefficient of determination ($r^2 > 0.75$) were identified as indicator species (that is their ecological reaction to a grazing gradient) and were grouped into ecological classes as described by Bosch & Gauch (1991). Gradient analysis based on multivariate analysis is an objective identification procedure of species which respond to grazing (Hurt *et al.*, 1993) and this method provides the most precise index of veld condition (Heard *et al.*, 1986). A combined herbaceous species composition was calculated for each RHGA. The veld condition of each RHGA was determined with the ISPD programme (Booysen *et al.*, 1996), based on these combined species compositions (Table 4.1).

Results and discussion

The low stocking rate on Nylsvlei Nature Reserve (NNR) which has been maintained for approximately two decades, has resulted in veld in a generally good condition (Fig. 4.1, Table 4.1). The over-grazed areas monitored outside the NNR had a different species composition to those inside the reserve with *Cynodon dactylon* being the dominant species. This species occurs on disturbed areas and can withstand intensive grazing (Van Oudtshoorn, 1992). Trampling damages individual grass plants leading to a change in species compositon and/or ground cover. It may also cause soil compaction with adverse effects on soil structure, raindrop impact, infiltration and soil moisture (Homewood & Rodgers, 1991).

Grass species which were found in approximately 10 or more quadrats and showed a high correlation coefficient along a gradient of grazing intensity were selected as indicator or key species (Fig. 4.2, Table 4.2). These species should be used for monitoring range condition in each homogenous vegetation unit respectively (Hurt *et al.*, 1993). A high degree of precision can be achieved by using a limited number of key species to estimate veld condition (Heard *et al.*, 1986). However key species provide an indication of past grazing pressure (Hardy & Hurt, 1989) but not necessarily the grazing potential of an area (Eckhardt *et al.*, 1993).

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Table 4.1: Veld condition values (VCV) of relative homogenous grazing areas (RHGA). VCV are given as a percentage of veld in a good condition.

RHGA	VCV	Residual value	No. of records used for ordination
Plant communities on lithosols (felsite soils) *Rhus leptodictya - Combretum apiculatum* Variation *Cymbopogon plurinodis - Combretum apiculatum* Variation *Eragrostis nindensis - Digitaria monodactyla* Variation	83.12 %	5.37	51
Sporobolus ioclados - Acacia tortilis Savanna	58.26 %	5.63	20
Floodplain along Nyl River	38.23 %	9.55	22
Plant communities on vertisols (turf soils) *Aristida bipartita - Setaria sphacelata* Savanna Variation *Aristida bipartita - Setaria sphacelata* Grassland Variation	64.25 %	9.80	35
Eragrostis pallens - Burkea africana Savanna	69.45 %	13.16	32

Grazing gradients have been found for most areas except for the *Sporobolus ioclados - Acacia tortilis* Savanna and the floodplain which had not well defined gradients. Gradients for these two plant communities should be treated with caution. The *Sporobolus ioclados - Acacia tortilis* Savanna has been heavily over-grazed in the past. The species composition, grass density and above-ground standing crop in the exclusion blocks did not differ much from the grazed areas after more than 10 years of under-utilization. This plant community may be in an irreversibly degraded state.

Determining indicator species for the floodplain posed another problem. During summer large areas are flooded thereby effectively excluding any significant grazing pressure. In winter when the floodplain is dry some of the species are heavily grazed upon, for example *Oryza longistaminata* and *Paspalum scrobiculatum*. With the coming floods, species in the floodplain are revitalized, which may override the effect of grazing. Therefore the gradient found for the floodplain may not be determined by grazing but by some other factor such as frequency and duration of flooding (*Bredenkamp, G. 1996. pers. comm). The distribution of the common *Panicum schinzii* along a degradation gradient indicated it as a Decreaser species (Table 2.2, Appendix 2). However the low coefficient of determination ($r^2 = 0.474$) did not warrant its classification as an indicator species.

In the *Eragrostis pallens - Burkea africana* Savanna only *Digitaria eriantha* showed a change in abundance over the grazing gradient. This species increased in abundance in relation to grazing intensity and was classified as an Increaser II species. However it is not known at what stage of succession the vegetation was as this may influence the abundance of a species. O'Connor (1991) found a similar reaction of *D. eriantha* to grazing in sandy soils and ascribed it to the extensive vegetative recruitment from stoloniferous growth and the improved light conditions in the altered sward structure.

Conclusion

The veld in NNR was generally in a good condition due to the low stocking densities of game which have been maintained for many years. Nine key species were identified which can be used for monitoring veld condition in different RHGAs. For most areas or plant communities only two indicator species, one in each ecological group of Increaser I and Increaser III were found to be suitable for monitoring veld condition. In the *Eragrostis pallens - Burkea africana* Savanna only *D. eriantha* (Increaser II species) can be used as an indicator species. These indicator species should be monitored over time as their ecological position may change due to different successional stages of the vegetation.

*Bredenkamp, G. 1996. Directorate: Resource Conservation, Private Bag X120, Pretoria, 0001.
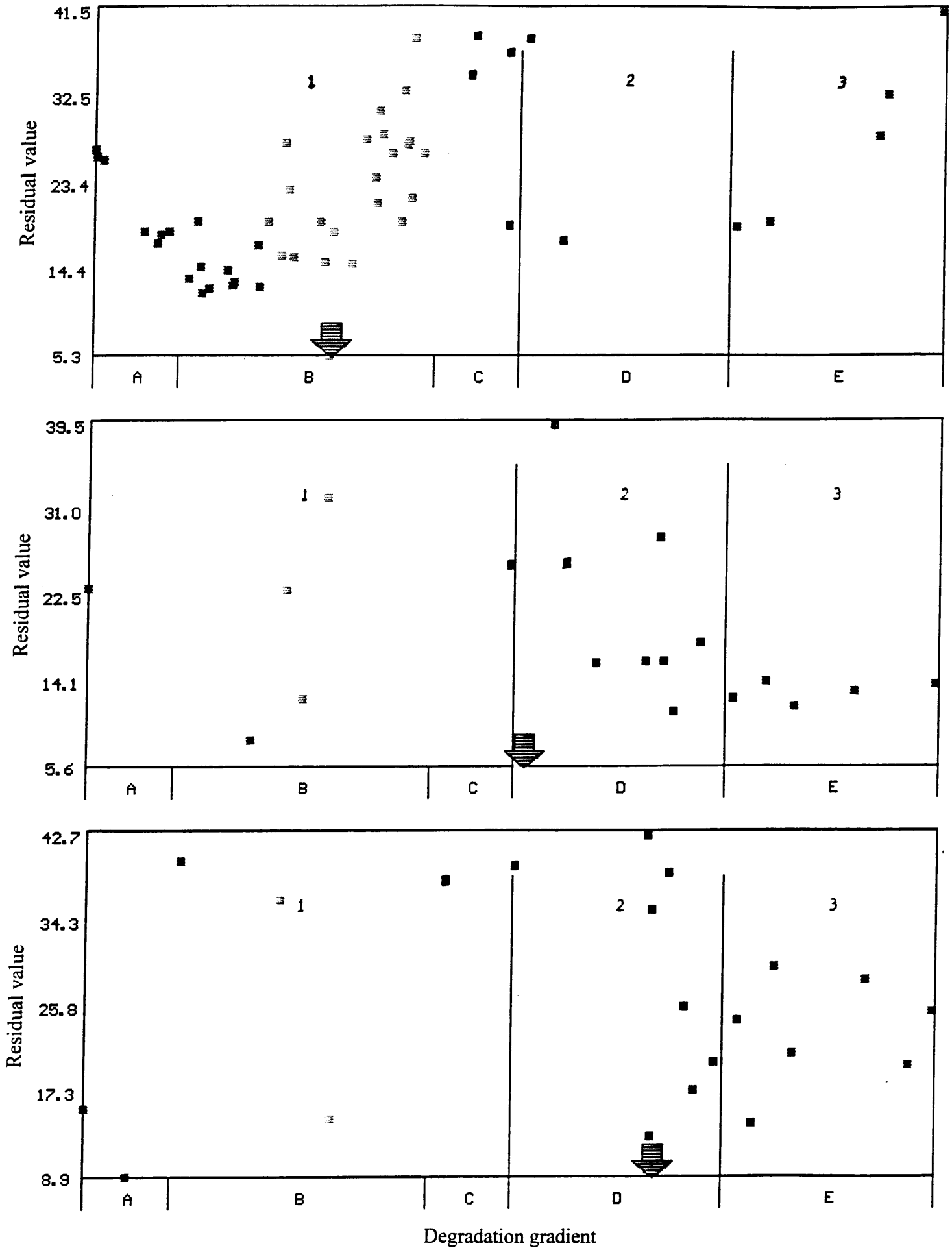
Fig. 4.1 (for title see next page).

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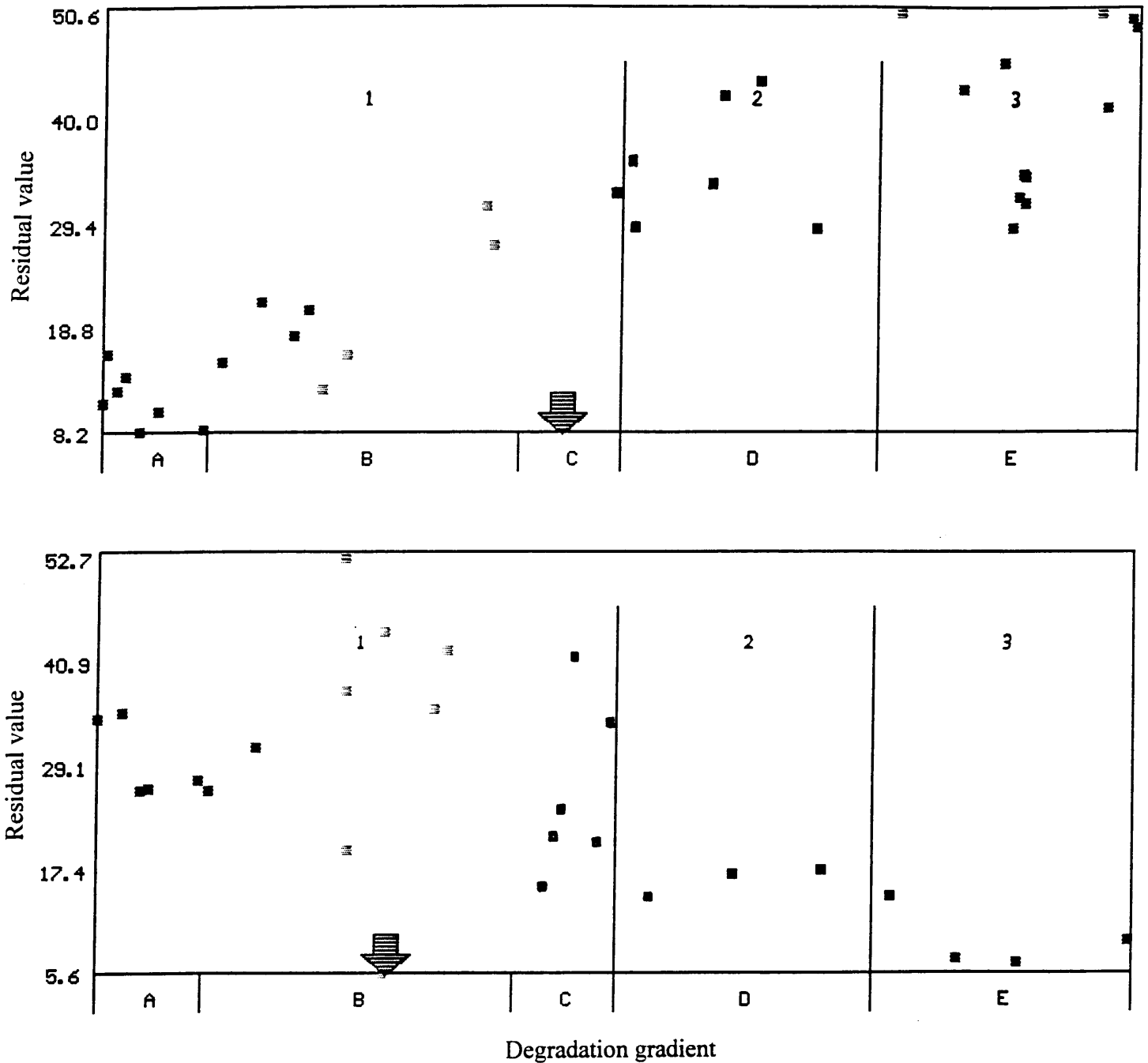
Fig. 4.1: Species distribution along a grazing gradient (utilization levels) from under-utilized (A) to over-grazed (E). Domain (1 - 3) boundaries indicate the position whereafter no natural recovery of vegetation is possible. The arrow indicates the current mean veld condition of that specific relative homogenous grazing area (RHGA) on the grazing gradient. The length of the degradation gradient is twice the size of the residual value. RHGAs are from top to bottom (previous page): plant communities on the lithosols, *Sporobolus ioclados - Acacia tortilis* Savanna and the floodplain, and on this page the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (top) and the *Eragrostis pallens - Burkea africana* Savanna (bottom).
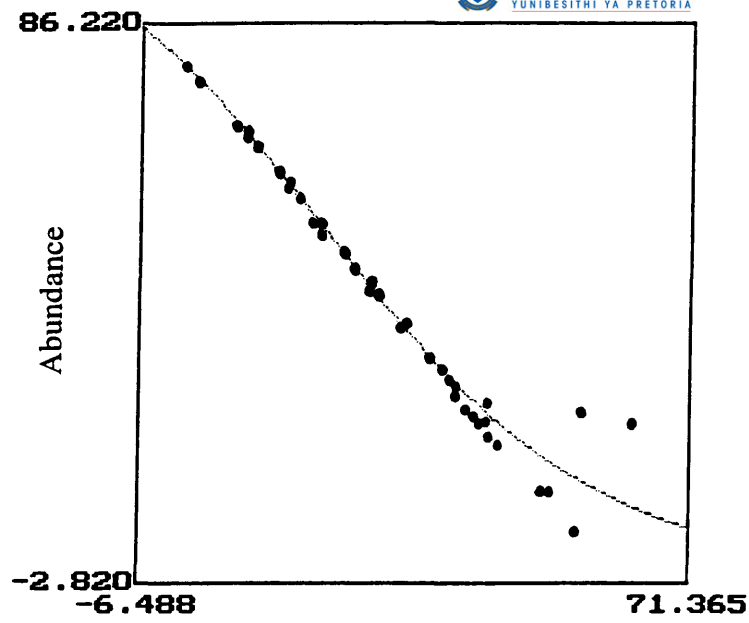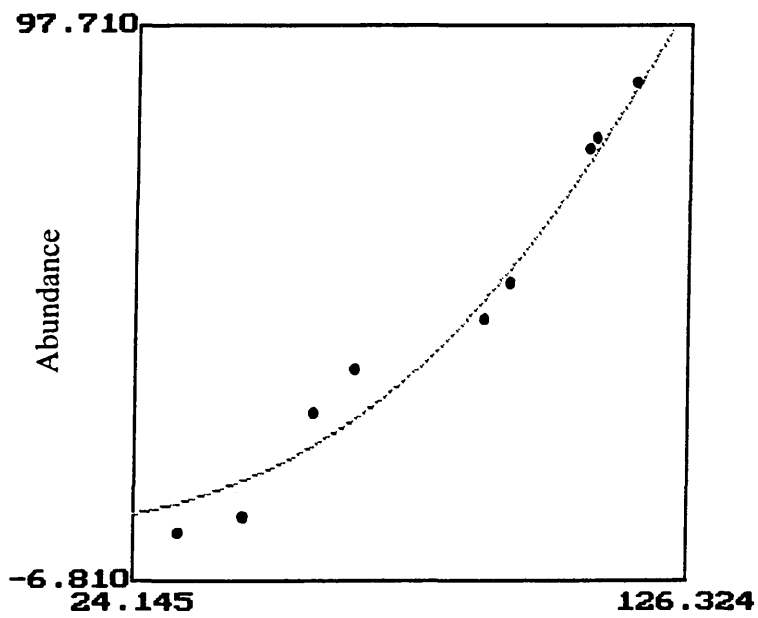
42

Fig. 4.2: Gaussian regressions of species abundance.

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Forbs

Oryza longistaminata

Leersia hexandra

Degradation gradient

Fig. 4.2 (cont.): Gaussian regressions of species abundance.

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Ischaemum afrum

Sporobolus pyramidalis

Digitaria eriantha
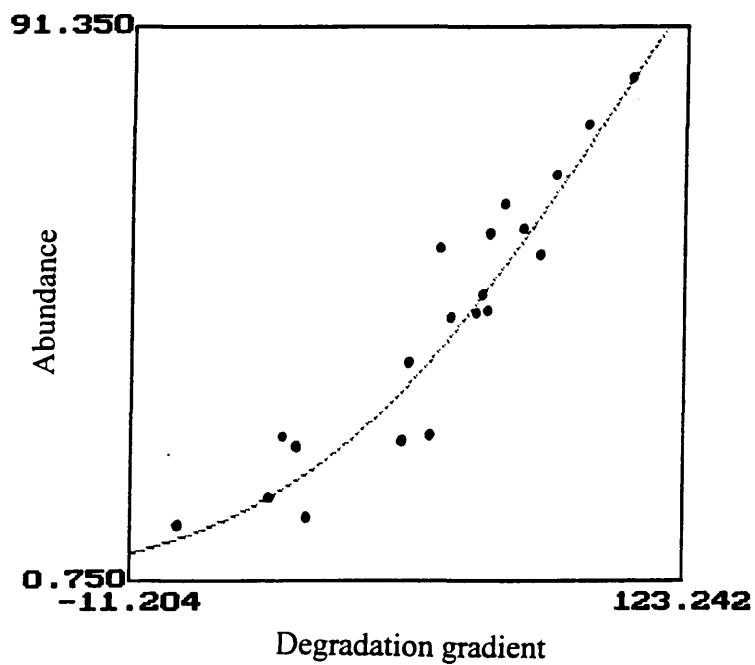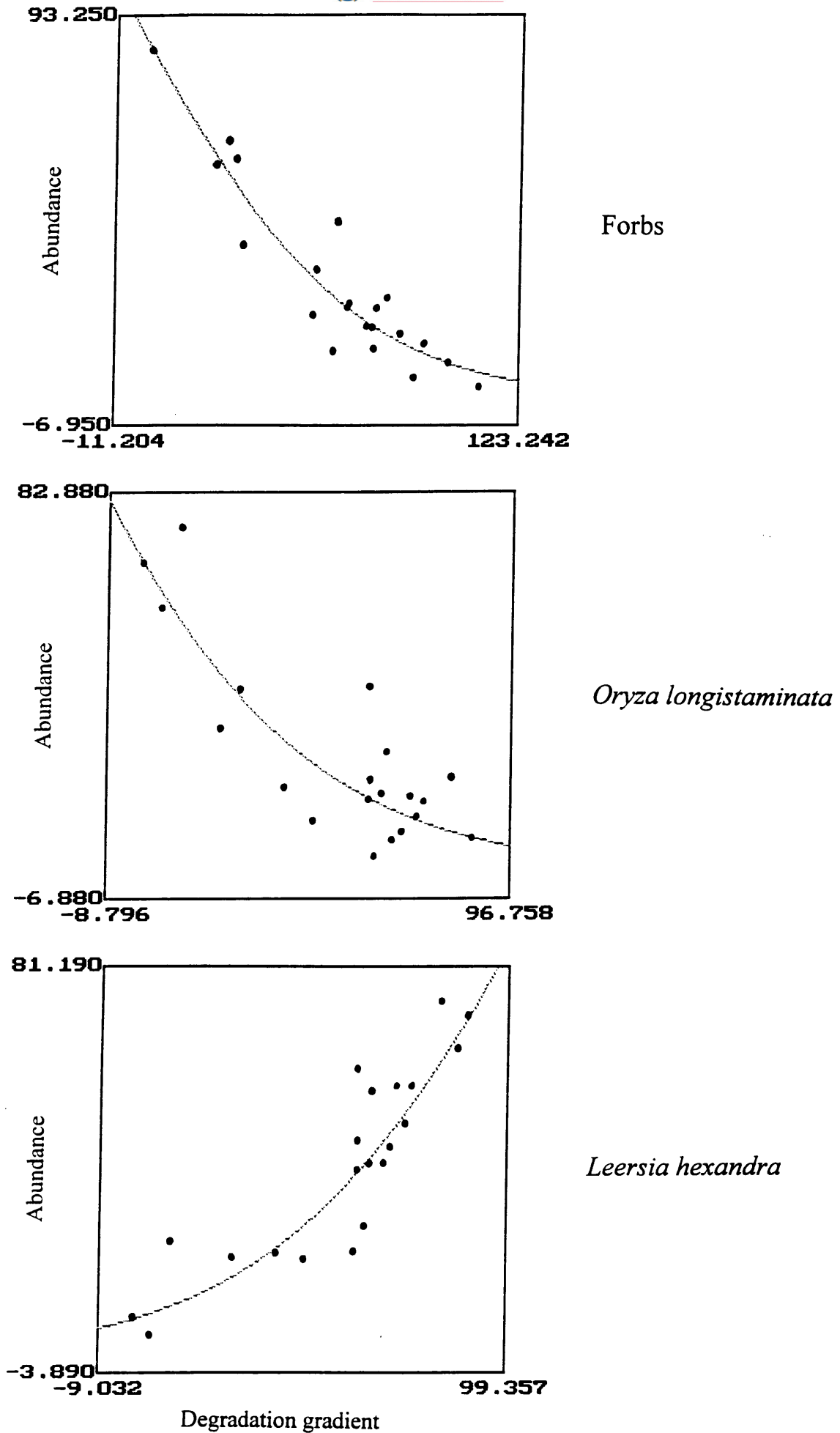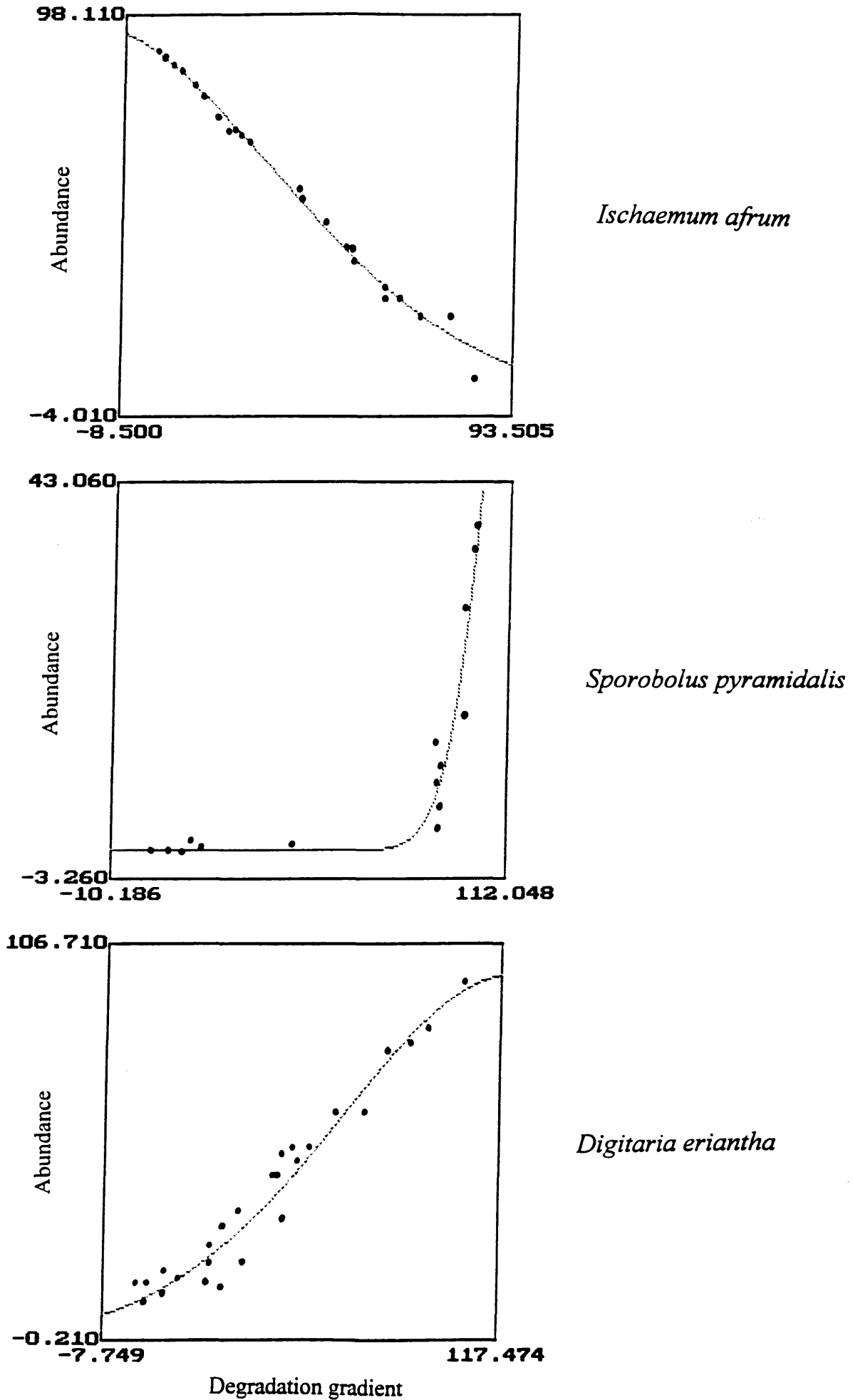
Fig. 4.2 (cont.): Gaussian regressions of species abundance.

Table 4.2: Indicator species which should be used for monitoring veld condition.

RHGAs and indicator species	Ecological group	r²	d value
Plant communities on lithosols (felsite soils) *Rhus leptodictya - Combretum apiculatum* Variation *Cymbopogon plurinodis - Combretum apiculatum* Variation *Eragrostis nindensis - Digitaria monodactyla* Variation			
Setaria sphacelata	Increaser I	0.97	0.992
Cynodon dactylon	Increaser III	0.968	0.992
***Sporobolus ioclados - Acacia tortilis* Savanna**			
Forbs as a group	Increaser I	0.882	0.968
Sporobolus ioclados	Increaser III	0.901	0.974
Nyl River and floodplain			
Oryza longistaminata	Increaser I	0.756	0.928
Leersia hexandra	Increaser III	0.804	0.943
Plant communities on vertisols (turf soils) *Aristida bipartita - Setaria sphacelata* Savanna Variation *Aristida bipartita - Setaria sphacelata* Grassland Variation			
Ischaemum afrum	Increaser I	0.993	0.998
Sporobolus pyramidalis	Increaser III	0.921	0.979
***Eragrostis pallens - Burkea africana* Savanna**			
Digitaria eriantha	Increaser II	0.953	0.988

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CHAPTER 5

Grass structure

Introduction

The structure of vegetation plays an important role in determining the selection of a habitat by wildlife (Van Rooyen, Bredenkamp & Theron, 1995) and the suitability of a habitat for wildlife (Joubert, 1996). Height distribution of the sward is an important factor determining niche separation among African herbivores (Novellie & Strydom, 1987). Sward structure such as the amount of leaf, leaf table height (tuft height) and the amount a tuft has been grazed previously may also influence food selection (O'Reagain, 1990; O'Connor, 1992) and strongly determines animal performance (Chacon, Stobbs & Dale, 1978 quoted by O'Reagain, 1990). The fundamental factor determining the quantity of grass harvested depends on the height (Thomas & Chamberlain, 1990) and density of the grass (Voisin, 1988). The optimum height of grass for grazing is where maximum grass yield and the greatest quantities with optimum nutritive value is found. If the grass is longer or shorter than this optimum, the harvestable quantity is reduced (Voisin, 1988).

Vegetation structure fluctuates due to climatic variation (Smith, 1988). Grasslands of the semi-arid regions (400 to 500 mm per annum) are typically tall, 0.75 m to two metres and grass height declines as rainfall increases. In high rainfall areas (800 to 1000 mm per annum) grasses are normally less than 0.5 m tall (Bosch & Tainton, 1988). Height differences are also found within the same species. For example *Themeda triandra* varies between 0.3 m at high altitudes to approximately two metres at low altitudes (Bosch & Tainton, 1988).

Usually the main requirement of field data is the comparison of parameter estimates between different areas (Causton, 1988). The objectives of this study were to test seasonal variation in total grass height and grass tuft height in non-burnt and burnt plant communities.

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Methods

In non-burnt plant communities grass height was measured seasonally (winter, early summer, late summer) and in newly burnt areas monthly for a period of six months (November to April). Grass height was measured at each site every two metres on a demarcated line transect (100 points per site) with the point-step method (Holechek, Pieper & Herbel, 1989). Grass height was measured from ground level as recommended by Voisin (1988). Grass height was subjectively judged as total height (including the infloresence) and tuft height, where most leaves of the tuft are bending over without extending the leaves. Tuft height is the height below which 80 % of the leaves occur (O'Reagain, 1990; Shackleton, 1990). In burnt areas tuft height could be measured only two to three months after the burn since grasses only developed culms later.

Grass height was ranked according to the following scale:

0) 0 cm; **1)** >0-5 cm; **2)** >5-10 cm; **3)** >10-15 cm; **4)** >15-20 cm; **5)** >20-40 cm; **6)** >40-60 cm; **7)** >60-80 cm; **8)** >80-100 cm and **9)** >100 cm. Height classes below 20 cm (1-5) are more applicable to short grass areas or recently burnt areas, and were adopted from Moe, Wegge & Kapela (1990).

Data analysis

In analysing the data the mean rank was calculated from the height classes for each site. A simple spread sheet model was developed to calculate grass height in cm from these rankings. The model was written with the EXCELL programme:

=IF(INT (A2)<5,5*(INT(A2)-1)+(A2-INT(A2))*5,20*(INT(A2)-4)+(A2-INT(A2))*20)

Differences in total grass height and grass tuft height were tested between years for each season with the Mann-Whitney U test (Steyn, Smit, Du Toit & Strasheim, 1995). Significant differences in terms of total grass height were found between the two winters ($U > 13$, $p < 0.05$) and early summers ($U > 5$, $p < 0.05$). Total grass height did not differ between late summer 1995 and late summer 1996 ($U < 5$, $p > 0.05$). Grass tuft height differed between years for winter ($U > 13$, $p < 0.05$), early summer ($U > 5$, $p < 0.05$) and late summer ($U > 5$, $p < 0.05$). Nevertheless as roan

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showed similar seasonal distribution patterns over time the data of two seasons (for example winter 1994 and winter 1995) was analysed as one data set. Spatial and temporal differences in grass height were tested with general linear modelling (PROC GLM) (SAS Institute, 1990) at a 95 % confidence level.

Results and discussion

Plant community differences by season (non-burnt)

The lowest and highest total grass height were found respectively in the *Sporobolus ioclados - Acacia tortilis* Savanna and in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (Fig. 5.1, Table 3.1, Appendix 3). The common and main contributing species to the high total grass height in the latter two plant communities was the leafy *Ischaemum afrum*. The *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations occur on fertile, periodic water-logged soils resulting in high grass growth. In dry savannas productivity is strongly correlated with plant water availability (Scholes & Walker, 1993) where a shortage of soil water content is one of the most important factors limiting yields (Jones, 1988; Barnes, Swart, Smith & Wiltshire, 1991). An interaction between water deficits and nutrient deficiencies influence plant growth (Jones, 1988).

The general linear modelling indicated that there are significant differences in total grass height (p = 0.0001) between plant communities during winter, early summer and late summer. Specific differences showed that the *Sporobolus ioclados - Acacia tortilis* Savanna and *Aristida bipartita - Setaria sphacelata* Savanna Variation differed significantly (p < 0.05) from all other plant communities throughout the year. However the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations did not differ significantly (p = 0.8417) from each other during late summer.

The analysis (PROC GLM) showed that there are significant differences in grass tuft height (p = 0.0001) between plant communities throughout the year. However an analysis of the combinations of plant communities indicated that in terms of grass tuft height, the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation did not

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differ (p > 0.05) from each other during all seasons. These plant communities also did not differ significantly (p > 0.05) from the *Eragrostis pallens - Burkea africana* Savanna.

Seasonal differences by plant community (non-burnt)

Seasonal differences in total grass height (p < 0.0005) and grass tuft height (p < 0.05) were found in the following plant communities: *Eragrostis nindensis - Digitaria monodactyla* Variation, *Sporobolus ioclados - Acacia tortilis* Savanna, Nyl River and floodplain, *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (Fig. 5.1, Table 3.1, Appendix 3).

Seasonal differences in total grass height and grass tuft height were not significant (p > 0.05) in the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and *Eragrostis pallens - Burkea africana* Savanna. The low grazing pressure (casual observations) in these plant communities may be the reason for these non significant differences in total grass height. For some plant communities (n = 6) there was no significant difference (p > 0.05) in total grass height between winter and early summer (Fig. 5.1, Table 3.1, Appendix 3). These seasons could therefore be redefined as the dry season (May to December) when grasses are dormant for most of the time.

Plant community differences in newly burnt areas

In general total grass height (p = 0.1997) and grass tuft height (p = 0.1259) reached after a six month growing period (November to April) did not differ significantly between newly burnt plant communities. However, the high total grass height (p = 0.0355) and grass tuft height (p = 0.0077) reached in the *Aristida bipartita - Setaria sphacelata* Savanna Variation (burnt October 1994) differed significantly from the *Rhus leptodictya - Combretum apiculatum* Variation (burnt October 1995) (Fig. 5.1, Table 3.2, Appendix 3). The rainfall over this period was 511.3 mm from October 1994 to April 1995 and 711.5 mm from October 1995 to April 1996. These differences in grass height can be ascribed to the high soil nutrients of the vertisols in the *Aristida bipartita - Setaria sphacelata* Savanna Variation (Chapter 2).

Plant community differences between burnt and non-burnt areas

Significant differences (p < 0.05) in total grass height and grass tuft height reached between burnt and non-burnt (summer) areas were found in the *Cymbopogon plurinodis - Combretum apiculatum* Variation, *Aristida bipartita - Setaria sphacelata* Savanna Variation, *Aristida*

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bipartita - Setaria sphacelata Grassland Variation. The *Rhus leptodictya - Combretum apiculatum* Variation showed no significant differences in total grass height (p = 0.2639) and the *Eragrostis nindensis - Digitaria monodactyla* Variation in grass tuft height (p = 0.1172) during summer when burnt and non-burnt (Fig. 5.1, Table 3.1 and 3.2, Appendix 3).

Conclusion

Aristida bipartita - Setaria sphacelata Savanna and Grassland Variations (on vertisol) maintained the highest total grass height and grass tuft height throughout the year. These grass heights differed significantly from the other plant communities. The *Sporobolus ioclados - Acacia tortilis* Savanna on illuvial soils had the lowest total grass height and grass tuft height throughout the year. These differed significantly from other plant communities.

Two plant communities that played an important role in roan distribution (Chapter 17) were the floodplain and the *Eragrostis pallens - Burkea africana* Savanna. The higher grass tuft height in the floodplain differed significantly (p = 0.0001) during late summer from the *Eragrostis pallens - Burkea africana* Savanna. Soil type and moisture retention of the soils may play an important role in grass growth (Scholes & Walker, 1993). This may suggest that roan seek the floodplain during late summer and the *Eragrostis pallens - Burkea africana* Savanna during winter to optimize forage intake. In winter and early summer these differences were not, however, significant, although grass height in the latter plant community was higher.

For most plant communities there was no difference in total grass height and grass tuft height, between winter and early summer. For practical purposes these two seasons could be treated as one, that is the dry season.

For most plant communities differences in grass height were significant between newly burnt swards and non-burnt. In general newly burnt plant communities did not differ from each other in terms of total grass height and grass tuft height.
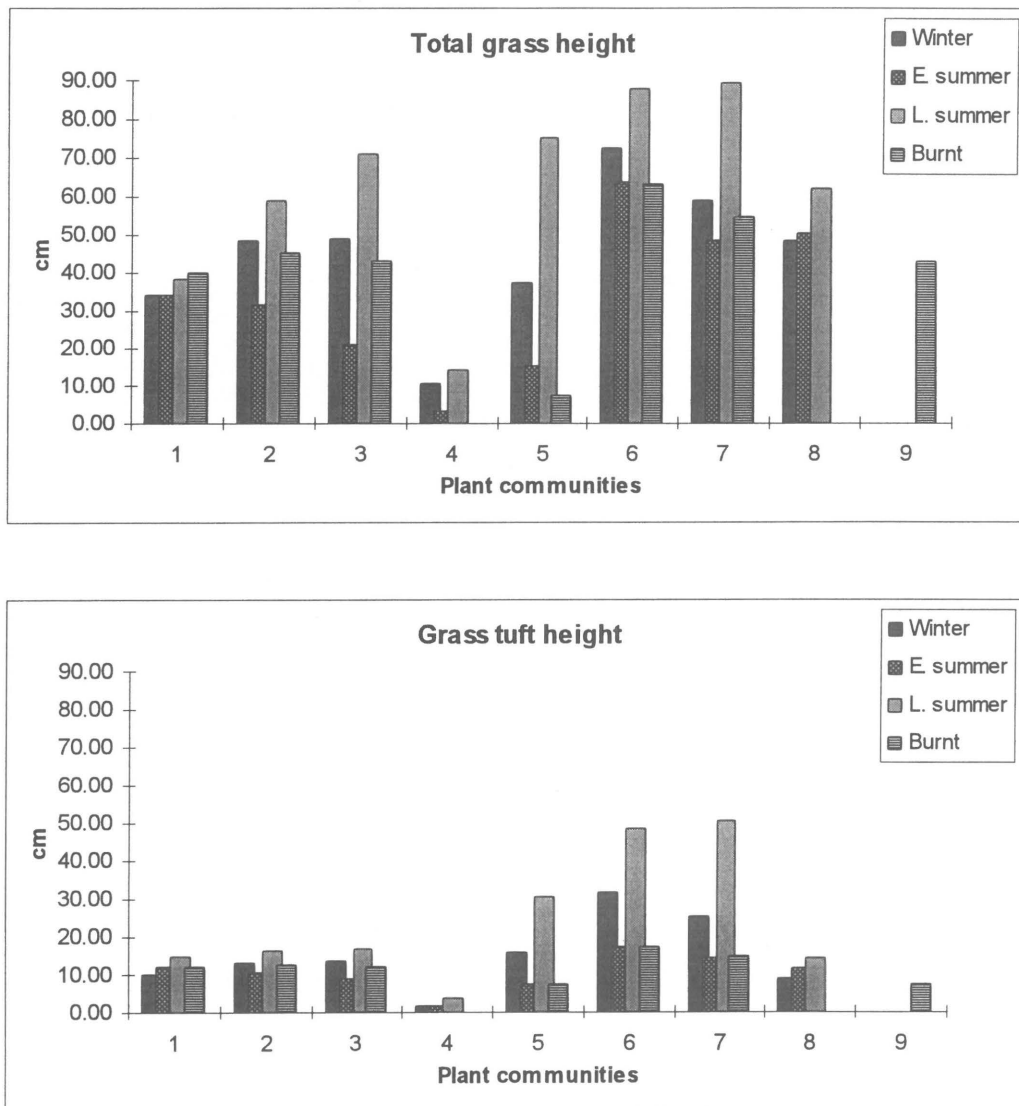
Fig. 5.1: Seasonal (winter, early summer and late summer) grass height of various non-burnt plant communities. Burnt plant communities indicate the grass height reached after six months growth (up to April). Plant communities are 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl river and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, 8) *Eragrostis pallens - Burkea africana* Savanna and 9) *Tristachya rehmannii - Digitaria monodactyla* Variation.

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CHAPTER 6

Woody vegetation

Introduction

Plant species composition, including the woody component, and the spatial distribution (structure and productivity) is influenced by soil properties such as type, texture, nutrients, pH, salinity and most importantly soil moisture (Tinley, 1982; O'Connor, 1985). Structure of the woody vegetation includes density, height and canopy cover. There is an inverse relationship between tree density and grass production (Trollope, 1981), and, especially at high tree densities, the yield of grass between tree canopies is negatively influenced (Smit & Swart, 1994). Trollope (1981) mentioned that grass yield is affected by tree density only beyond a certain limit. For example in the False Thornveld of the Eastern Cape Province this limit was at approximately 1 000 *Acacia karroo* trees/ha. Woody plant cover is often expressed in terms of canopy cover since their relatively small basal areas play a lesser role in the overall plant community (Holechek, Pieper & Herbel, 1989). The effect tree density and canopy cover has on grass production and visibility will influence the habitat selection of roan, as was shown by Joubert (1976).

The aim of this survey was to estimate density and canopy cover of the woody vegetation which formed part of a larger vegetation survey. The hypotheses that there were no differences in tree density and tree canopy cover between plant communities was tested.

Methods

Density and canopy cover of woody plants was measured in the larger plant communities except in the Nyl River and floodplain, and the *Aristida bipartita - Setaria sphacelata* Grassland Variation, which had very few trees (less than 1 tree/ha). Density was measured once (December 1994 to January 1995) with the quantitative method described by Smit (1989). At each site, two

belt transects, each 100 m by two metres and 20 m apart, were used. All woody plants higher than 0.5 m, including trees and shrubs were counted. Forbs were not counted.

Canopy cover was measured with the line intercept method as described by Shukla & Srivastava (1992). Two lines of 100 m each and 20 m apart were used at each site. The distance of canopy intercept was measured on the line for each woody plant.

The mean density and canopy cover were calculated for each plant community. Differences between plant communities in terms of woody plant density and percentage canopy cover were tested with the Kruskal-Wallis test at a 5 % significance level. The Q statistic was applied to test for differences between paired plant communities (Heath, 1995).

Results and discussion

A total of 59 woody species were recorded during the surveys in the Nylsvlei Nature Reserve (NNR) (Table 4.1, Appendix 4). The average density of woody plants in the NNR (all plant communities combined) was 1 508±601 woody plants/ha. The Kruskal-Wallis test showed that there are differences in woody plant density ($K > 11.07$, $p < 0.05$) and percentage canopy cover ($K > 11.07$, $p < 0.05$) between plant communities. A high variation in woody plant density and canopy cover can be expected from an area with a diverse vegetation as found in the NNR. This density was similar to that reported for the Mixed Bushveld in the Ellisras area found by Schmidt, Theron & Van Hoven (1995) (1 119 woody plants/ha).

The highest density of 3 816±1 173 woody plants/ha was found in the *Rhus leptodictya - Combretum apiculatum* Variation (Fig. 6.1, Table 4.2, Appendix 4) which differed significantly ($Q > 2.936$, $p < 0.05$) from all other plant communities. Friedel (1988) reported a tree density of 4 513 trees/ha for *Combretum apiculatum* veld in Mixed Bushveld in an area which had not been previously debushed, which was far from waterpoints and where there was little grazing pressure. Canopy cover of the *Rhus leptodictya - Combretum apiculatum* Variation (31.62 %; CI 11.35) also differed significantly ($Q > 2.936$, $p < 0.05$) from all other plant communities.

In plant communities on the lithosols, densities and canopy cover declined progressively from the *Rhus leptodictya - Combretum apiculatum* Variation to the *Eragrostis nindensis - Digitaria monodactyla* Variation (242±49 woody plants/ha) (Fig. 6.1, Table 4.2, Appendix 4). The lowest canopy cover of 5.43 % was found in the *Eragrostis nindensis - Digitaria monodactyla* Variation plant community (Fig. 6.1, Tables 4.2, Appendix 4). Woody plant density (2 183±703 woody plants/ha) of the *Cymbopogon plurinodis - Combretum apiculatum* Variation differed significantly (Q > 2.936, p < 0.05) from all but the *Eragrostis pallens - Burkea africana* Savanna. The woody plant canopy cover of the *Eragrostis nindensis - Digitaria monodactyla* Variation differed (Q > 2.936, p < 0.05) from most (n = 4) other plant communities.

Woody plant density of the *Sporobolus ioclados - Acacia tortilis* Savanna did not differ (Q > 2.936, p < 0.05) from the *Eragrostis nindensis - Digitaria monodactyla* Variation. Density in the *Sporobolus ioclados - Acacia tortilis* Savanna of 517±381 woody plants/ha was similar to that found by Friedel (1988) who reported an average tree density of 987 trees/ha for *Acacia tortilis* veld in the Northern Province Mixed Bushveld which had not been previously cleared, and was far from waterpoints. The canopy cover was 22.60 % (CI 17.55).

Woody plant density in the *Aristida bipartita - Setaria sphacelata* Savanna Variation differed significantly (Q > 2.936, p < 0.05) from other plant communities, but not from the *Eragrostis nindensis - Digitaria monodactyla* Variation. The woody plant density of 192±97 woody plant/ha in the *Aristida bipartita - Setaria sphacelata* Savanna Variation was considerably lower than that found by Friedel & Blackmore (1988) in Red Turfveld protected from fire and grazing for 50 years (9 440 trees/ha) and areas that have been subjected to various degrees of grazing (average 2 775 trees/ha). An increase in tree density can be expected in areas protected from fire since fires control woody plants especially at the seedling stage (Scholes & Walker, 1993). These authors found a tree basal area in broad-leafed savanna (protected from fire for 30 years) which was twice that of areas which were burnt regularly. The canopy cover of the *Aristida bipartita - Setaria sphacelata* Savanna Variation (18.03 %) did not differ (Q < 2.936, p < 0.05) from that of the *Sporobolus ioclados - Acacia tortilis* Savanna.

Woody plant density (2 100±796 woody plants/ha) in the *Eragrostis pallens - Burkea africana* Savanna differed signicantly (Q > 2.936, p < 0.05) from most (n = 4) other plant communities. The canopy cover (44.20 %) differed from all other plant communities. The *Eragrostis pallens - Burkea africana* Savanna had less woody plants than *the Rhus leptodictya - Combretum apiculatum* Variation (Fig. 6.1, Table 4.2, Appendix 4).

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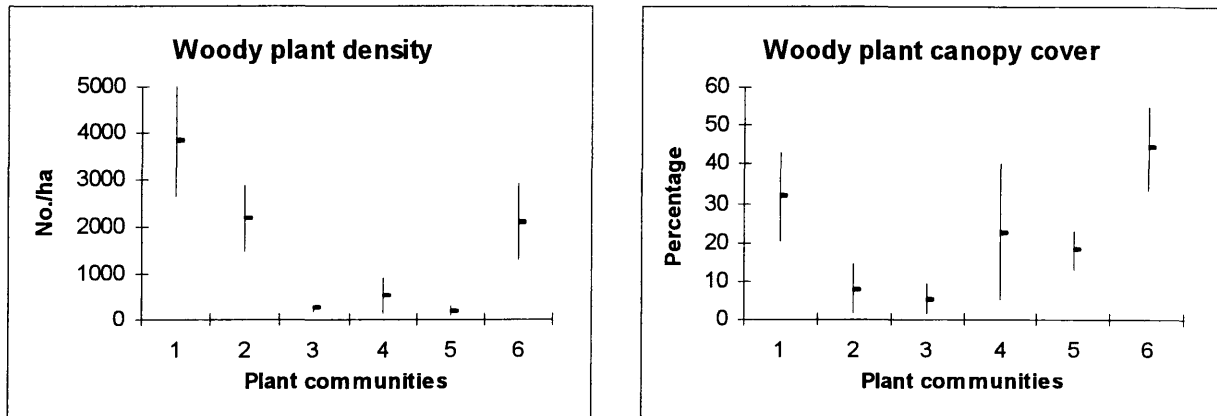
Fig. 6.1: Woody plant density (no./ha) and canopy cover (%) with confidence intervals of the plant communities 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon lurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria onodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) *Aristida bipartita - Setaria sphacelata* Savanna Variation, and 6) *Eragrostis pallens - Burkea africana* Savanna.

Conclusion

A large variation in woody plant density and canopy cover was found in the NNR. However the average density in the NNR was typical or rather lower than the Mixed Bushveld areas of the Northern Province. Scholes & Walker (1993) mentioned a thickening of the woody vegetation in the NNR. These data did not show high densities or canopy cover. Frequent burning, on average every two to three years, has probably regulated the woody plant density.

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CHAPTER 7

Above-ground standing crop

Introduction

A knowledge of the amount of herbage mass on offer to herbivores is important for formulating a management plan for grazing and fire regimes. Phytomass available for grazing changes seasonally (Willms, Adams & Dormaar, 1996) and is important in determining feeding habits and habitat utilization of large herbivores (Kinyamario & Macharia, 1992). Phytomass is the amount of plant material present in a unit area at a given time. An increase in phytomass over a unit of time is known as the yield or productivity (Goldsmith, Harrison & Morton, 1986; Holechek, Pieper & Herbel, 1989; Kent & Coker, 1992). Productivity is related to veld condition, rainfall, evapotranspiration, grazing regime, edaphic environment, slope, and temperature (Snyman & Fouché, 1993).

Direct harvesting is the most accurate method of determining above-ground phytomass (Causton, 1988; Holechek *et al.*, 1989) but it is not practical for monitoring extensive rangelands. Several techniques have been developed for the rapid, and fairly reliable, estimation of herbaceous phytomass. The method used to estimate above-ground standing crop depends on the desired precision, the objective of the data collection and available resources (Hardy & Mentis, 1985). An efficient and quick method is the use of the disc pasture meter (Hardy & Mentis, 1985). Trollope & Potgieter (1986) calibrated and used this apparatus for phytomass estimates in the Kruger National Park. They suggested that the disc pasture meter could be used for most veld conditions in the bushveld areas of the former Transvaal.

The objectives of this study were to calibrate the disc pasture meter for Nylsvlei Nature Reserve (NNR) for determining the seasonal above-ground standing crop (ASC) in each plant community; further, to determine the ASC changes in post-burn areas. The null hypotheses that there are no differences in phytomass between plant communities, seasons, and burnt and non-burnt areas were also tested.

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Methods

Disc meter calibration

Based on species composition five relative homogenous grazing units (RHGA) were defined with ordination modelling using the ISPD programme (Chapter 4). Because the species composition was similar (Chapters 3 and 4) in the plant communities on the lithosols (*Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and *Eragrostis nindensis - Digitaria monodactyla* Variation), and in plant communities on the vertisols (*Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations), these were treated as two RHGAs respectively. The disc pasture meter was calibrated for each of the five RHGAs. These RHGAs consisted of the plant communities 1) *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and *Eragrostis nindensis - Digitaria monodactyla* Variation occuring on the lithosols, 2) the *Sporobolus ioclados - Acacia tortilis* Savanna, 3) the floodplain along the Nyl River, 4) the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations on the vertisols and 5) the *Eragrostis pallens - Burkea africana* Savanna on sandy soils. Only one site in the floodplain along the Nyl River could be surveyed due to flooding of the other sites.

Calculating model coefficients for a particular area using site-specific data will slightly improve estimates (Mitchell, Elderkin & Lewis, 1993). Calibrations were done for each RHGA as suggested by Hardy & Mentis (1985) and Trollope & Potgieter (1986). Four squares (4 m² each) were used at each site (minimum of three sites per RHGA). The settling height of nine disc readings (nearest mm) per square was recorded. The grass layer within each square was cut to ground level and weighed. Nine subsamples of the four squares from each site were collected, weighed and dried at 100 °C for 48 hours. Sub-sample dry mass was measured to the nearest gram.

Above-ground standing crop

Seasonal variations of the above-ground standing crop were measured with the disc pasture meter. At each site one hundred readings of the settling height (nearest mm) of the disc were taken along two demarcated transects (100 m long and 20 m apart) at every 2 m. Above-ground standing crop was the sum of phytomass (standing live, green material) and necromass (dead standing material) as defined by Grossman (1982), Dunham (1990) and Shackleton (1991).

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Although the method used is a relatively crude measure of standing crop, the disc pasture meter is quick and easy to apply.

Data analysis

Disc readings were transformed to cm. The dry above-ground standing phytomass (kg/ha) was estimated and its precision expressed as maximum error (E) at a 95 % degree of confidence. Maximum error can be used to express confidence interval limits. The relationship between disc height readings and the dry above-ground standing phytomass was further investigated. The mean disc readings were square root, natural log, power and reciprocal transformed. Regression analyses were conducted with the different transformed disc readings as the independent variable and estimated dry above-ground standing phytomass (kg/ha) to find the best fit. Data transformations which gave the best fit in the regression analyses were selected (Table 7.1) and used for developing linear regression models (Table 7.2). Linear regression models were developed for each RHGA and for the entire NNR with the combined data (Table 7.1 and 7.2).

Differences in ASC between years were found for each season at 95 % confidence levels using the Mann-Whitney U test (Steyn, Smit, Du Toit & Strasheim, 1995). The significance of the differences were reflected by the values for the two winters (U > 13, p < 0.05), early summers (U > 5, p < 0.05) and late summers (U > 5, p < 0.05). Nevertheless as roan showed similar seasonal distribution patterns over time, the data of two seasons (for example winter 1994 and winter 1995) was analysed as one data set. Spatial and temporal differences in ASC were tested with general linear modelling (PROC GLM) (SAS Institute, 1990) at 95 % confidence levels.

Results and discussion

Calibrations and regression equations

The maximum errors of the estimated above-ground standing phytomass were very wide for the *Sporobolus ioclados - Acacia tortilis* Savanna (56.13 %), Nyl River and floodplain (44.46 %) and the *Aristida bipartita - Setaria sphacelata* plant communities (34.26 %) indicating that large

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variations were found in the above-ground standing phytomass data. A larger sampling size would have improved the data.

From the regression analyses with transformed disc height data (Table 7.1), the highest coefficients of determination (r^2) were selected. Regression equations for each RHGA are given in Table 7.2. While in some RHGAs the disc readings could be used unchanged in the regression models, others first had to be transformed (Table 7.1).

The linear regression models developed for each RHGA and the NNR (Table 7.2) were all significant ($p < 0.05$). The regression model for the entire NNR had an r^2 value of 0.7054 ($p = 2 \times 10^{-19}$). For practical purposes the model for the NNR could be used for all RHGAs to predict dry above-ground standing phytomass. The data also does not have to be transformed, making it easy to use. This regression model is similar to that calculated by Theron (1991) for the Sour-mixed Bushveld of the Northern Province, where $y = 567.2 + 279.9\ x$.

Table 7.1: Coefficients of determination (r^2) of linear regressions with different data transformations for each RHGA and the entire Nylsvlei Nature Reserve. Data transformations with the best fit and which were used in the ASC calculations are indicated in bold.

RHGA	Plant community	No trans-formation	Square root ($\sqrt{}$)	Natural log (ln)	Power^2 (x^2)	Reciprocal 1/x
1	*Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation, *Eragrostis nindensis - Digitaria monodactyla* Variation	**0.5428**	0.4934	0.4051	0.5452	0.1998
2	*Sporobolus ioclados - Acacia tortilis* Savanna	**0.7614**	0.7496	0.7168	0.7336	0.6068
3	Nyl River and floodplain	0.5929	0.6476	**0.6837**	0.4805	0.6511
4	*Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations	0.7928	**0.8280**	0.8218	0.6815	0.7047
5	*Eragrostis pallens - Burkea africana* Savanna	0.8295	0.8685	**0.8849**	0.7102	0.8521
	Nylsvlei Nature Reserve	**0.7054**	0.68	0.539	0.581	0.22

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Table 7.2: Linear regression models for transformed disc pasture meter readings to calculate above-ground standing crop (kg/ha dry-weight).

RHGA	Plant community	Data trans-formation	Coefficient of determination r^2	Intercept a	Slope b
1	*Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation, *Eragrostis nindensis - Digitaria monodactyla* Variation	no	0.5428	377.463	223.788
2	*Sporobolus ioclados - Acacia tortilis* Savanna	no	0.7614	-195.4	600.428
3	Nyl River and floodplain	ln	0.6837	173.502	2889.16
4	*Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations	square root	0.8280	-1633	1987.16
5	*Eragrostis pallens -Burkea africana* Savanna	ln	0.8849	-830.82	1402.4
	Nylsvlei Nature Reserve	no	0.7054	502.5	276.2

Above-ground standing crop (ASC)

Plant community differences by season (non-burnt)

In general a significant difference (p = 0.0001) in ASC was found between plant communities during winter, early summer and late summer (Fig. 7.1). However, some plant communities did not differ from each other. The *Cymbopogon plurinodis - Combretum apiculatum* Variation (2) and the *Eragrostis nindensis - Digitaria monodactyla* Variation (3) did not differ significantly (p > 0.05) from each other and from the *Rhus leptodictya - Combretum apiculatum* Variation (1) during winter and early summer. The ASC in the *Eragrostis pallens - Burkea africana* Savanna (8) also did not differ (p > 0.05) from the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation during early summer. In general the ASC reached its highest level only in April (Table 5.1, Appendix 5) after which it declined during winter to reach a low in September (Fig. 7.1). This seasonal change in ASC is linked to the summer rainfall pattern. Dunham (1990) found the standing crop in the Zambezi Valley to peak in February or March

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when grasses flowered. Shackleton (1991) found the ASC to reach a high from February to April in a sour grassland.

The highest ASC (mean = 8 272.59 kg/ha) was found in the Nyl River and surrounding floodplain (5) during late summer (Fig. 7.1) (Table 5.1, Appendix 5). The frequently flooded conditions during summer and the accumulated nutrients in the alluvial soils resulted in the high ASC. The growth of grasses can be affected by an excess of water (Jones, 1988) especially in dry savannas where productivity is strongly correlated with plant water availability (Scholes & Walker, 1993). Both the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variation (6 and 7) had an average ASC of more than 5 000 kg/ha (Table 5.1, Appendix 5). The main contributors to this high ASC were the *Ischaemum afrum*, *Themeda triandra* and *Setaria incrassata* (Table 2.3, Appendix 2) which are the most dominant grass species in these plant communities (Chapter 3). The fertile soils (Frost, 1987) and the frequently waterlogged conditions during summer enhanced its growth and thus resulting in the high ASC.

The lowest ASC (mean = 578.55 kg/ha) occurred in the *Sporobolus ioclados - Acacia tortilis* Savanna (4) in winter (Fig. 7.1) (Table 5.1, Appendix 5) and is a reflection of the unsuitable soils for grass growth as a result of a low infiltration rate (Frost, 1987; Scholes & Walker, 1993). Grass production may be impaired by unsuitable soil conditions such as a moisture deficiency, soil acidity, mineral deficiencies and by the presence of unproductive species (Holmes, 1989). A shortage of soil water is one of the most important factors limiting yields (Jones, 1988; Barnes, Swart, Smith & Wiltshire, 1991). Moisture deficiency is the main limitation of grassland production in semi-arid grasslands, whereas soil nutrient deficiency imposes the greatest limitation to production in the humid regions (Bosch & Tainton, 1988). However an interaction between water deficits and nutrient deficiencies will influence plant growth (Jones, 1988). Soil is the primary factor determining the potential forage production in an area within a particular climate (Holechek *et al.*, 1989).

Scholes & Walker (1993) estimated an annual consumption of plant material by large herbivores in this reserve as 18.2 g DM/m²/year. In the NNR the lowest ASC of 540.92 kg/ha (54.092 g/m²) was found in the *Sporobolus ioclados - Acacia tortilis* Savanna (4) during winter to early summer. The lowest total grass height during this time is approximately three cm (Table 3.1, Appendix 3), the minimum grazing height for most ungulates. In summer the ASC was nearly twice as high for this plant community (Table 5.1, Appendix 5). Comparing the ASC from other

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plant communities with that of the *Sporobolus ioclados - Acacia tortilis* Savanna suggests that forage availability in the NNR did not appear to be a limiting factor for the resident grazers.

Seasonal differences by plant community (non-burnt)

Seasonal differences ($p < 0.05$) in ASC were found for all plant communities except for the *Rhus leptodictya - Combretum apiculatum* Variation (1) ($p = 0.4038$) (Fig. 7.1). The non-significant seasonal difference in ASC in the *Rhus leptodictya - Combretum apiculatum* Variation (1) supports the finding of no seasonal difference in total grass height (Chapter 5). This suggests that this plant community is poorly utilized by herbivores. All plant communities showed no difference ($p > 0.06$) in ASC between winter and early summer. These seasons were collectively the driest time of the year and could probably be treated as one season. This similarity between winter and early summer was also found in terms of grass height (Chapter 5).

Differences between burnt plant communities

Significant differences ($p = 0.0001$) in ASC were found between most burnt plant communities. The *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and *Eragrostis nindensis - Digitaria monodactyla* Variation did not differ ($p > 0.05$) from each other when burnt (Fig. 7.1). The same soil type (lithosols) with similar water holding capacities probably resulted in this similar growth pattern of grasses. The grass layer in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variation (6 and 7) had the highest ASC, six months after being burnt (Table 5.2, Appendix 5) (Fig. 7.1). These latter two plant communities are found on fertile vertisols (Chapter 2). The lowest ASC was found in the *Tristachya rehmannii - Digitaria monodactyla* Variation (9) which has sandy soils.

Differences between burnt and non-burnt plant communities

The expected differences in ASC between a burnt and a non-burnt state were significant ($p = 0.0001$) for all plant communities tested. These were the *Rhus leptodictya - Combretum apiculatum* Variation (1), *Cymbopogon plurinodis - Combretum apiculatum* Variation (2), *Eragrostis nindensis - Digitaria monodactyla* Variation (3), Nyl River and floodplain (5), *Aristida bipartita - Setaria sphacelata* Savanna Variation (6) and the *Aristida bipartita - Setaria sphacelata* Grassland Variation (7). Not only were there differences in ASC between a burnt and a non-burnt state within the same plant community, differences were also found in the chemical

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quality (Chapter 10). Similar differences were found by Shackleton (1991) in Sourveld grassland communities in the Transkei.
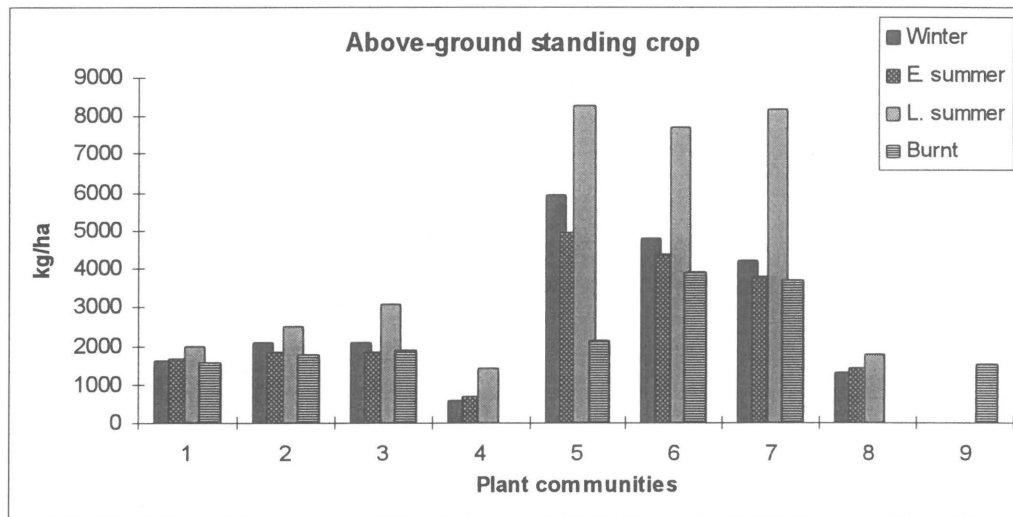
Fig. 7.1: Seasonal (winter, early summer and late summer) above-ground standing crop (ASC) of non-burnt plant communities. Burnt plant communities indicate the ASC reached after six months growth (November to April). Plant communities are: 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl river and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, 8) *Eragrostis pallens - Burkea africana* Savanna and 9) *Tristachya rehmannii - Digitaria monodactyla* Variation.

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Conclusion

The disc pasture meter was calibrated for different RHGAs and plant communities over a wide range of veld conditions. The significant correlation coefficients supported the suggestions by Trollope & Potgieter (1986) that the disc pasture meter could be used in the bushveld areas of the former Transvaal to estimate above-ground standing crop. A combination of the calibration data for the NNR showed a coefficient of determination of 0.7054. This regression equation could probably be used to estimate above-ground standing phytomass in the Mixed Bushveld veld type in general. It would, however, be more accurate to apply the specific regression model to each plant community or RHGA.

The high ASC in the Nyl River and floodplain, and the low phytomass in the adjacent *Sporobolus ioclados - Acacia tortilis* Savanna could be related to differences in water availability in the form of flooding, water infiltration and soil moisture, as well as soil type and structure. The *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variation also had an ASC of >5 000 kg/ha. The available herbaceous forage in the NNR did not appear to be a limiting factor for herbivores.

In recently burnt areas the highest ASC after six months might be expected in the floodplain. This plant community was monitored for three months only but a difference in phytomass was already noticed during this time. Other high ASC values were found in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variation.

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CHAPTER 8

Biomass/height relationships of the herbaceous layer

Introduction

Above-ground standing crop (ASC) and grass height are strongly correlated (Mitchell, Elderkin & Lewis, 1993) and can be expressed as biomass concentration (BC) or density of material. The fundamental factor determining the quantity of grass harvested depends on the height and density of the grass. If the grass is longer or shorter than this optimum, the harvestable quantity is reduced (Voisin, 1988). The height-weight method based on phenological data can be used to estimate utilization (Mitchell *et al.*, 1993).

The structure of vegetation plays an important role in determining the selection of a habitat by wildlife (Van Rooyen, Bredenkamp & Theron, 1995). Sward structure such as the amount of leaf and grass tuft height may also influence food selection (O'Reagain, 1990; O'Connor, 1992). Food selection is influenced to a larger extent by grass tuft size and the amount a tuft has been previously grazed rather than species identity, location or moribund material. Species selection is possibly a consequence of selection for plant structure to optimize forage intake (O'Connor, 1992). Biomass concentration is not commonly measured in natural systems and the extent to which herbivores are influenced by the physiognomy of the herbaceous layer such as BC has not been previously determined (Shackleton, 1990).

The objectives of this study were to determine the correlation between above-ground standing crop and tuft height as an index to measure above-ground standing crop. It was also determined whether there are seasonal differences in BC between plant communities, and between unburnt and newly burnt areas.

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Methods

Above-ground standing crop (kg/ha) was measured on a seasonal basis in each plant community and every month in newly burnt areas with the disc pasture meter (Trollope & Potgieter, 1986) (Chapter 7). Measurements of tuft height were taken for the same time period as for ASC. Tuft height was ranked into height classes. The mean rank was converted to cm (Chapter 5). Grass tuft height (cm) as the independent variable was regressed against above-ground standing crop (ASC in kg/ha), the dependent variable.

To calculate BC (kg/m³), grass tuft height was used in the equation as it is an indication of the amount of leaf material. The equation used was:

(ASC in kg/ha ÷ 10 000) x (100 ÷ grass tuft height in cm) = kg/m³

Spatial and temporal differences in biomass concentration were tested with general linear modelling (PROC GLM) (SAS Institute, 1990) at 95 % confidence levels.

Results and discussion

<u>Regression between ASC and grass tuft height</u>

The regressions to predict above-ground standing crop (kg/ha) from average grass tuft height were significant for some plant communities (Table 6.1, Appendix 6). There was no significant relationship between average grass tuft height and above-ground standing crop in the *Rhus leptodictya - Combretum apiculatum* Variation (Table 6.1, Appendix 6). The linear regression equation for the entire Nylsvlei Nature Reserve (NNR) with a coefficient of determination of $r^2 = 0.6089$ is:

$y = 853.4407 + 145.2934x$

where y = above-ground standing crop (kg/ha DM)

$\qquad x$ = grass tuft height (cm)

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These results indicate that grass tuft height is responsible for 24 % of the variation of the ASC. Mitchell *et al.*, (1993) found a correlation coefficient of more than 0.98 between grass height and above-ground standing crop but their data was based on the phenological development of grasses and not tuft height as in this study. Their study was also conducted in homogenous vegetation of western wheatgrass.

<u>Biomass concentration</u>

Differences between plant communities by season (non-burnt)

Significant differences (p ≤ 0.0003) were found between plant communities throughout the year. The *Sporobolus ioclados - Acacia tortilis* Savanna, and the floodplain (early and late summer) differed from all other plant communities (p < 0.02), but not from each other (p > 0.30) (Fig. 8.1). Both these had considerably higher BCs than those from other plant communities (Fig. 8.1, Table 6.2, Appendix 6).

The highest annual average BC (6.443 kg/m³) was found in the floodplain along the Nyl River. However the BC during early summer 1995 may be abnormally high due to the flooding of the floodplain. Also values from the late growing season in 1996 were based on only one site due to the flooding of the other sites. These values should therefore be treated with caution. During winter the grass decay caused a much lower BC in the floodplain (Fig. 8.1, Table 6.2, Appendix 6).

The second highest mean BC in the *Sporobolus ioclados - Acacia tortilis* Savanna (4.585 kg/m³) (Fig. 8.1, Table 6.2, Appendix 6) is probably a result of heavy grazing. A similar trend was also found by McNaughton, 1984 in Shackleton (1990) in the Serengeti where BCs in grazed plots were approximately twice as high as in ungrazed plots. Shackleton (1990) also indicated that the shortest sward had the highest BC.

The *Eragrostis pallens - Burkea africana* Savanna had the lowest mean BC of 1.358 kg/m³. Shackleton (1990) showed a BC for a sour grassland ranging from approximately 0.2 to 3.1 kg/m³ which is similar to those in the NNR (Fig. 8.1, Table 6.2, Appendix 6).
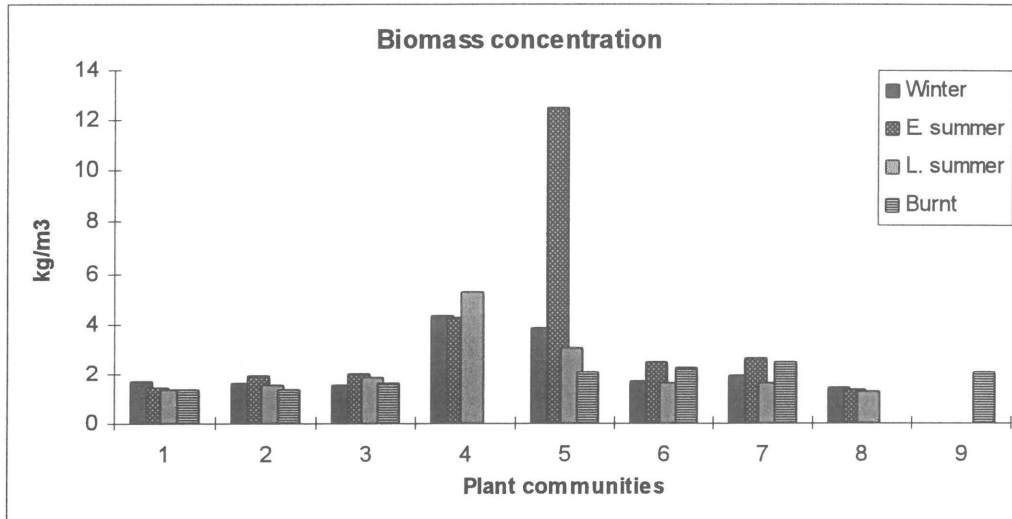
Fig. 8.1: Seasonal (winter, early summer and late summer) biomass concentration (BC) (kg/m³) per non-burnt plant community. Burnt plant communities indicate BC reached after six month growth (November to April). Plant communities are 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl river and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, 8) *Eragrostis pallens - Burkea africana* Savanna and 9) *Tristachya rehmannii - Digitaria monodactyla* Variation.

Seasonal differences by non-burnt plant community

No seasonal differences (p > 0.05) were found in the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation, *Sporobolus ioclados - Acacia tortilis* Savanna and the *Eragrostis pallens - Burkea africana* Savanna. BCs in the other plant communities generally did not differ (p > 0.05) between winter and early summer.

Differences between burnt plant communities

Significant differences (p = 0.0013) in BC existed between burnt plant communities. The *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation, and the *Eragrostis nindensis - Digitaria monodactyla* Variation did not differ (p > 0.06) from each other when burnt. The *Aristida bipartita - Setaria sphacelata* Savanna

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Variation differed from the *Rhus leptodictya - Combretum apiculatum* Variation (p = 0.4929) and the *Cymbopogon plurinodis - Combretum apiculatum* Variation (p = 0.0518) (Fig. 8.1, Table 6.3, Appendix 6). There was also no significant difference (p = 0.3058) between the *Aristida bipartita - Setaria sphacelata* Savanna and the Grassland Variations (vertisols).

The newly burnt plant communities had generally a lower BC compared to their non-burnt state. Only plant communities on the vertisols (turf soils) had a higher BC when burnt. The short grass sward and still actively growing grasses in burnt areas may lead to a lower BC compared to unburnt areas.

Differences between burnt and non-burnt plant communities

In most plant communities (4 out of 5) there was no difference (p > 0.29) in BC during summer whether in a burnt or non-burnt state. Only in the *Eragrostis nindensis - Digitaria mondactyla* Variation did the BC differ significantly (p = 0.0091) between a burnt and non-burnt state (Fig. 8.1).

None of the average BC values in burnt and non-burnt plant communities in the NNR were less than the 0.8 kg/m³ threshold (Table 6.2 and 6.3, Appendix 6), below which cattle-sized herbivores feeding in the area would allegedly lose body weight (Ludlow *et al.* in Shackleton (1990).

Conclusion

A regression analysis between tuft height and ASC for the entire NNR showed a significant coefficient of determination of $r^2 = 0.6089$. This relationship was improved by regressing the data for each plant community separately. Grass tuft height could therefore be used to estimate ASC in kg/ha. Height-weight models would give managers the ability to quickly and efficiently estimate ASC especially where the accuracy of results is not critical, for example in fire management decision making.

The relationship between tuft height and ASC as it was measured in this study may also be used to estimate utilization.. However it has to be assumed that this relationship does not vary with growth form, location or plant height. Findings have shown a variation in height-weight

ratios among growth forms (Mitchell *et al.*, 1993). Further investigation is needed to test its use for estimating utilization.

No differences (p > 0.05) in BC were found between the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation. In non-burnt plant communities there were no differences in BC between winter and late summer. Biomass concentrations were highest in the floodplain along the Nyl River and to a smaller extent in the *Sporobolus ioclados - Acacia tortilis* Savanna. There were differences in BC between burnt and non-burnt areas. Values were, however, never below the 0.8 kg/m³ threshold allegedly needed by cattle-sized herbivores to maintain their body mass, even during winter or in recently burnt areas. This indicates a food abundance in the NNR.

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CHAPTER 9

Grass cover

Introduction

Percentage cover is widely used in grassland surveys and is a good measure of plant abundance (Kershaw, 1980). For vegetation surveys canopy spread cover provides a rough indication of the quantity of forage available (Novellie & Strydom, 1987). Excessively lenient defoliation often leads to an increase in canopy spread cover, which detrimentally affects seedling establishment (Tainton, 1981).

Grass cover is an estimation of the area covered by given species and is expressed as a percentage of the total area. It is estimated from a number of sample points (Kershaw, 1980; Causton, 1988). Grass cover can be either estimated visually, calculated from the percentage cover by one or more species of the total area of a quadrat, or measured by taking a number of points from the sample area and determining the cover at each point (Kershaw, 1980).

The objective was to estimate the relative canopy cover and to determine the repeatability of the point-step method. The null hypotheses that there is no difference in canopy cover between plant communities was tested.

Methods

The point-step method is a rapid, objective method to determine cover and species composition in rangelands for inventory and monitoring procedures (Holechek, Pieper & Herbel, 1989). The point-step method (Kershaw 1980; Causton 1988; Holechek *et al.*, 1989; Goldsmith, 1991; Glatzle, Mechel & Vaz Lourenco, 1993) was used to measure the relative canopy cover. The survey was conducted by three observers which were trained before to minimize between observer variances. Each plant community was surveyed with 10 transect lines of 200 points each. Each transect line consisted of two parallel lines of 200 m long and 20 m apart. Canopy cover was

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recorded every two meters without applying the nearest plant method. When the wire rod dropped within the circumference of the canopy spread it was recorded. This included basal cover. A miss was recorded as bare ground.

Statistical analysis

Canopy cover was calculated from the number of strikes recorded as a percentage of the total number of point observations per site and per plant community. Precision was measured with the coefficient of variation (CV). General linear modelling (PROC GLM) (SAS Institute 1990) was applied to test for differences in grass canopy cover between plant communities at a 95 % confidence level.

Results and discussion

All plant communities had a canopy cover of more than 66 % (Table 9.1). Canopy cover differed significantly (p = 0.0001) between plant communities (Table 9.2). For example the canopy cover in the *Sporobolus ioclados - Acacia tortilis* Savanna and the floodplain differed significantly (p < 0.05) from most other plant communities (Table 9.2).

Brady, Mitchell, Bonham, & Cook (1995) stated that as the number of transects grouped into a sample increases, the variation in mean cover decreases and more estimated means fall closer to the true mean. The combined data of 2 000 points from 10 transects recorded in each plant community reduced the precision (coefficient of variation) to acceptable levels (< 20 %). The precision (% CV) found for canopy cover was generally < 11 % for the Nylsvlei Nature Reserve (NNR) except for the *Sporobolus ioclados - Acacia tortilis* Savanna (32.66 %) (Table 9.1). This indicates that the point-step method is a repeatable technique for measuring relative grass canopy cover (Table 9.1).

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Table 9.1: Mean grass canopy cover and coefficient of variation of eight plant communities in Mixed Bushveld.

Plant community	Mean canopy cover	CV
Rhus leptodictya -Combretum apiculatum Variation	81.25	8.86 %
Cymbopogon plurinodis -Combretum apiculatum Variation	90.45	3.59 %
Eragrostis nindensis -Digitaria monodactyla Variation	94.25	3.04 %
Sporobolus ioclados - Acacia tortilis Savanna	66.95	32.66 %
Nyl River and floodplain	95.00	4.11 %
Aristida bipartita - Setaria sphacelata Savanna Variation	84.20	5.89 %
Aristida bipartita - Setaria sphacelata Grassland Variation	83.65	6.27 %
Eragrostis pallens - Burkea africana Savanna	80.20	10.72 %
Mean for Nylsvlei Nature Reserve	84.49	14.58 %

Table 9.2: Asterics indicate significant differences ($p < 0.05$) in canopy cover between plant communities. An x shows no difference. Plant community names are described in Table 9.1 in chronological order.

Plant communities	1	2	3	4	5	6	7	8
1	x	*	*	*	*	x	x	x
2			x	*	x	x	x	*
3				*	x	*	*	*
4					*	*	*	*
5						*	*	*
6							x	x
7								x
8								

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Conclusion

The canopy cover of the herbaceous layer in the NNR was high. This was probably due to the low stocking density on the reserve and the low frequency burning (average every two to four years, Environmental Affairs Northern Province). The point-step method may be suitable to measure canopy cover.

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CHAPTER 10

Forage quality

Introduction

In sourveld areas forage quality is probably more important to grazing herbivores than aspects of forage availability such as biomass concentration (Shackleton, 1990). Forage quality in terms of chemical composition varies to a greater extent among species than between sites (Bailey, 1984; Minson, 1990). Variation in the organic composition (protein and fibres) is a function of the physiological state of the grasses (previous utilization and growth stage) and the seasons. The stage of growth is the most important factor influencing the composition and nutritive value of forage (Thomas & Chamberlain, 1990; McDonald, Edwards, Greenhalgh & Morgan, 1995). Other factors such as the stem/leaf ratio, season and climate may also influence the nutritive value (McDonald *et al.*, 1995).

The nutritional value of vegetation is generally measured by digestibility, crude protein and, to a lesser extent, minerals (Hanley, Robbins, Hagerman & McArthur, 1992; Shackleton & Mentis, 1992; Woodall, 1992). Crude protein provides a rough indication of the concentration of available nutrients in plant material (Novellie, Fourie, Kok & Van der Westhuizen, 1988) and is positively related to digestibility (Van Soest, 1982 in Soper, Lochmiller, Leslie & Engle, 1993) and negatively to acid detergent fibre (ADF) (Pehrson & Faber, 1994). Food quality with respect to available nitrogen is important for wildlife management (Crawley, 1983) as it is essential in the diet to allow normal growth, to maintain body tissues and other productive functions (Pond, Church & Pond, 1995). It also affects most aspects of the population dynamics of herbivores such as growth rate, dispersal, calf survival, productivity of young and age at sexual maturity (Crawley, 1983). Young growing animals and pregnant, or lactating, females require the highest percentage dietary protein (Pond *et al.*, 1995). Forage of a low nutritional quality also adversely affects the physical condition of animals, reproduction (Robinson & Bolen, 1989) and herbivore fecundity (Crawley, 1983).

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Digestibility is an important measure of the nutritional value of forages for ruminants (Pehrson & Faber, 1994) with organic matter digestibility as one of the main factors (McDonald *et al.*, 1995). Conversely Gill, Beever & Osbourn (1989) stated that organic matter digestibility is a better estimate of the nutritive value than dry matter digestibility because it excludes any possible effects of soil contamination of the forage. It is also more closely correlated with energy availability. Dry-matter digestibility is an important factor in the energy economics of animals (Hanley *et al.*, 1992) and forages with high *in vitro* dry-matter digestibilities (IVDMD) increase the intake rate, require less digestion time and increases nutrient availability (Westenskow-Wall, Krueger, Bryant & Thomas, 1994; Gray & Servello, 1995). There is little data on the seasonal changes in *in vitro* dry-matter digestibility (IVDMD) of natural vegetation in southern Africa (Shackleton & Mentis, 1992).

Habitat differences in the chemical composition among species will be found in the mineral contents, which are related to soil type. In this study macrominerals were used to compare the forage quality between various plant communities and to indicate habitat quality. Macrominerals such as calcium (Ca), sodium (Na), chloride (Cl) and phosphorus (P) are important in ruminant nutrition (Minson, 1990) generally functioning as components of tissue structure (Cheeke, 1991). Calcium is often the major cation in the diet (Soares, 1995a). Calcium and phosphorus are required structural components of the skeleton with approximately 99 % of the Ca and 80 % of the P being found there (Robbins, 1993; McDonald *et al.*, 1995; Pond *et al*, 1995; Soares 1995a & b). Potassium is essential for all animals and is the third most abundant mineral element in the body (Miller, 1995). Potassium and sodium play a vital role in osmotic pressure regulation and the maintanance of water and acid-base balance (Henry, 1995; McDonald *et al.*, 1995; Miller, 1995; Pond *et al.*, 1995). However, many minerals have more than one function (Pond *et al.*, 1995).

The aim of this study was firstly to estimate forage quality and secondly to compare the forage quality between various plant communities. Four null hypotheses were tested:

1)   there is no difference in forage quality between non-burnt plant communities by season
2)   there is no seasonal difference in forage quality within non-burnt plant communities
3)   there is no difference in forage quality between burnt and non-burnt plant communities
4)   there is no difference in quality of principal grass species for roan between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna.

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Methods

Analysis of collected forage samples underestimate nitrogen concentrations compared to that in ingested forage (Irwin, Cook, McWhirter, Smith & Arnett, 1993) because ruminants are able to select food that is of different composition to the average of the forage mass (Thomas & Chamberlain, 1990). Due to various limitations grass samples were collected and assumed to be representative of the herbaceous layer.

A)   Plant communities

To compare the seasonal forage quality between all plant communities, a mixture of grasses was used. Heitkönig (1993) found that roan feed on grass leaves at a height between five and 30 cm. This is common for ruminants having higher voluntary intakes of leaves than of stems (Holechek, Pieper & Herbel, 1989). Furthermore leaves of most forage plants have higher crude protein, P and cell soluble levels, and lower fibre and lignin levels than those of stems (Holechek *et al.*, 1989).

In each plant community, 10 quadrats (1 m²) were placed along a transect, five metres apart. A few leaves of each grass plant present in each quadrat were sampled at a height between five and 30 cm to simulate the feeding height of roan. Samples were collected each season (winter, early summer and late summer) in non-burnt plant communities and each month (November to April) in burnt areas (Chapter 2). Samples were collected in paper bags and kept in a cool, dry place before being frozen within five hours after collection for storage. Grass samples were also collected for chemical analyses from the burnt *Tristachya rehmannii - Digitaria monodactyla* Variation.

B)   Lower floodplain and Eragrostis pallens - Burkea africana Savanna

Weekly observations by staff from the Nylsvlei Nature Reserve (NNR) showed that roan generally concentrate in the lower floodplain in summer and in the *Eragrostis pallens - Burkea africana* Savanna during winter. In addition to the above analyses the forage quality of the principal grass species selected by roan (Heitkönig, 1993) was compared between the lower floodplain and the *Eragrostis pallens - Burkea africana* Savanna. A minimum of 50 g of leaves (between 5 and 30 cm) of each principal grass species was sampled at random once during winter, early summer and late summer. Samples were stored as described above.

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Grass species in the lower floodplain were selected on the basis of abundance, palatibility and degree of utilization. These were:

Oryza longistaminata
Panicum schinzii
Paspalum scrobiculatum
Leersia hexandra

Oryza longistaminata is utilized to a large extent by warthogs during winter (casual observation) and probably also by roan, the latter suggestion being confirmed by Hashim (1987) from the meadows in the Dinder National Park (Sudan) where *Oryza longistaminata* is common. In the Zambezi Valley, Dunham (1990) found that *Paspalum scrobiculatum* is highly utilized reflecting its high quality. *Leersia hexandra* was very common in the floodplain in the NNR. *Leersia, Themeda* and *Escothea* species were the most important grasses along the slopes in the Nyika National Park (Malawi) which were frequented by roan (Gewalt, 1987). *Panicum schinzii* is a palatable grass (Van Oudtshoorn, 1992).

The principal grass species selected by roan (Heitkönig, 1993) in the *Eragrostis pallens - Burkea africana* Savanna were:

Cenchrus ciliaris
Digitaria eriantha
Eragrostis lehmanniana
Eragrostis pallens
Heteropogon contortus
Hyperthelia dissoluta
Panicum maximum
Schmidtia pappophoroides

C) Chemical analysis

Each grass sample was weighed on a Mettler scale (PM11) to the nearest 0.1 g. Samples were dried at 80 °C for 48 hours and weighed again. The percentage moisture was calculated from the water or moisture content as a percentage of the total wet weight (water weight/wet weight x 100). Dried grass samples were ground with a Knifetech Mill to a grain size of 1 mm as suggested by Minson (1990).

Forage quality is usually expressed as increased crude protein, *in vitro* organic matter digestibility, and decreased acid detergent lignin (Kloppenburg, Kiesling, Kirksey & Donart, 1995). A sample of grasses (130) was analysed with wet chemical analysis for percentage nitrogen (N) (A.O.A.C., 1980), the fibre components, percentage neutral detergent fibre (NDF) and percentage acid detergent fibre (ADF) (Goering & Van Soest, 1970), % *in vitro* organic matter digestibility (IVOMD) (Tilley & Terry, 1963) and percentage organic matter (OM). These results were then used to derive regression equations for calibrating the near-infrared reflectance spectroscopy (NIRS). The highly significant coefficients of determination (Table 7.1, Appendix 7) enabled the direct prediction of the nutritive value from wavelengths with near-infrared spectrometry. The nutritional quality (above mentioned variables) of all grass samples, including the above 130 samples was analysed with the NIRS procedure developed by Norris, Barnes, Moore & Shenk (1976) and used extensively thereafter. This method has been used successfully to analyse forage and faecal samples for crude protein and digestible OM (Baker & Barnes, 1990; Pearce, Lyons & Stuth, 1993; Leite & Stuth, 1994; Lyons, Stuth & Angerer, 1995), IVDMD (Pehrson & Faber, 1994), and ADF, NDF, and the macrominerals Ca, K, P and magnesium (Mg) (Stoltz, 1990). All values are expressed on a % OM basis. Proteins contain about 16 % N. The protein content of forages can be calculated by multiplying the N content by a factor of 6.25 (Cheeke, 1991; Gauthier, Huot & Picard, 1991; McDonald *et al.*, 1995).

The macrominerals Ca, P, K and Na were analysed with the methods described by Steckel & Flannery (1971), Hambledon (1976), Zasoski & Burau (1977) and Bessinger (1988). Macrominerals were determined for each plant community during winter, early and late growing season.

All statistical analyses were done with general linear modelling (PROC GLM) (SAS Institute, 1990) at a 95 % confidence level.

Results

Differences in forage quality between non-burnt plant communities by season

Because there were no significant differences ($p > 0.05$) found in grass height and above-ground standing crop between winter and early summer, the seasons were divided into winter (winter and early summer or dry season) and late summer (wet season). A similarity in some chemical components between winter and early summer can also be seen in Fig. 10.1. Significant differences ($p < 0.05$) in most chemical components were found between plant communities in winter and in late summer. However inter-plant community differences were not significant during winter (winter and early summer) in terms of percentage moisture ($p = 0.3185$), % IVOMD ($p = 0.5690$), % P ($p = 0.5329$), % K ($p = 0.7911$), and in terms of % Ca ($p = 0.1236$) during late summer (Fig.10.1).

A comparison in forage quality between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna showed that most chemical components did not differ significantly ($p > 0.05$). Only the lower % NDF ($p = 0.0412$) and % OM ($p = 0.0001$) in the floodplain differed significantly from the *Eragrostis pallens - Burkea africana* Savanna during winter (Fig. 10.1, Table 7.2, Appendix 7). In late summer % OM ($p = 0.0057$) and % K ($p = 0.0107$) differed significantly between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna.

In general the forage quality did not differ ($p > 0.05$) between the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation during winter and late summer (Fig. 10.1, Table 7.2, Appendix 7). There were no significant differences ($p > 0.08$) in forage quality (most chemical components) between the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations in winter and late summer. Only % Ca in the *Aristida bipartita - Setaria sphacelata* Grassland Variation differed ($p < 0.02$) from all other plant communities during winter except from the *Aristida bipartita - Setaria sphacelata* Savanna Variation (Fig. 10.1, Table 7.2, Appendix 7).

Seasonal differences in forage quality within non-burnt plant communities

Forage quality in terms of % N, % IVOMD and the macrominerals was generally higher during the early summer than during winter and late summer (Fig. 10.1, Table 7.2, Appendix 7). The limited amount of data ($n = 9$) did not allow any statistical analysis with general linear modelling.

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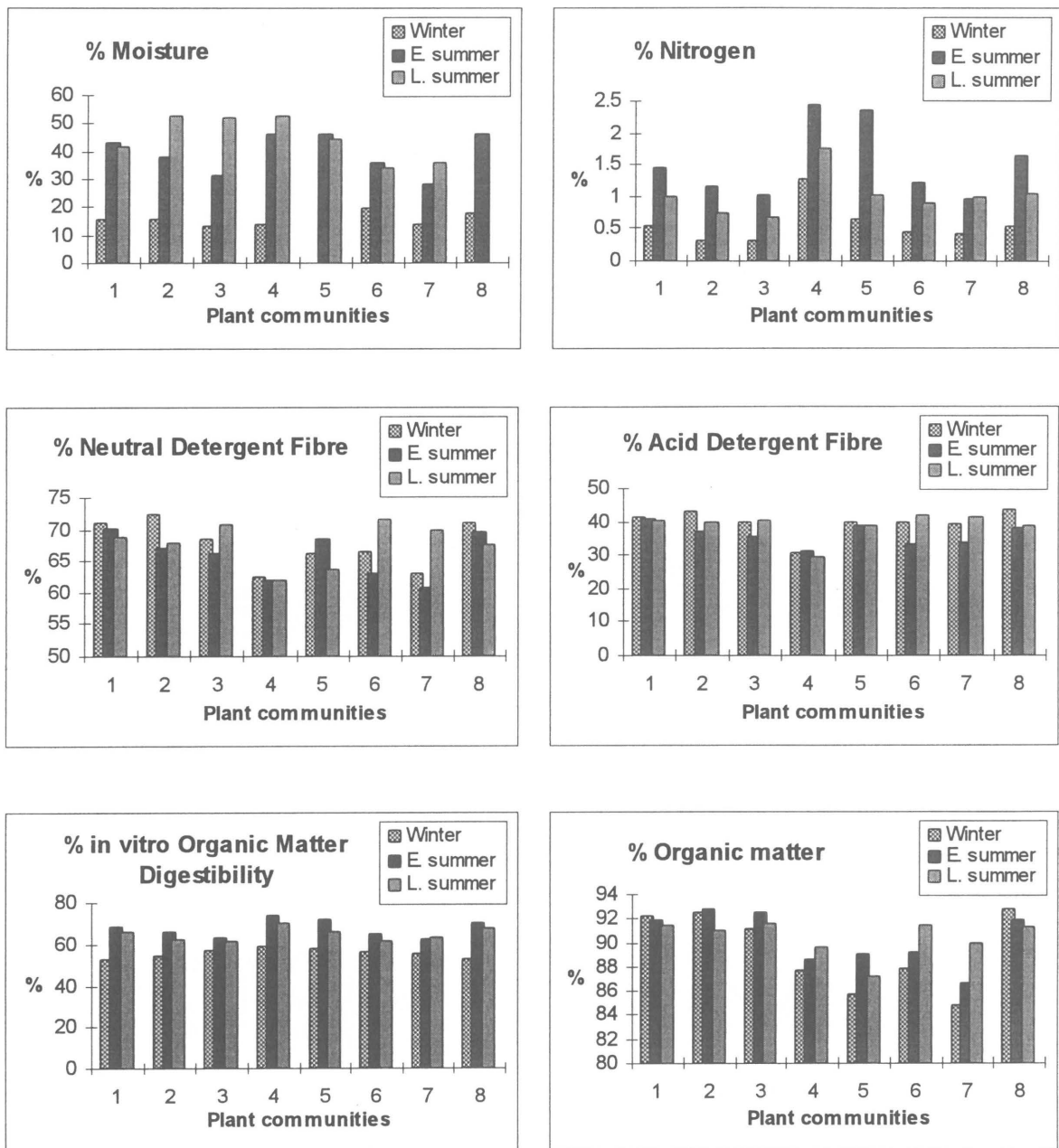
Fig. 10.1 (for title see next page)
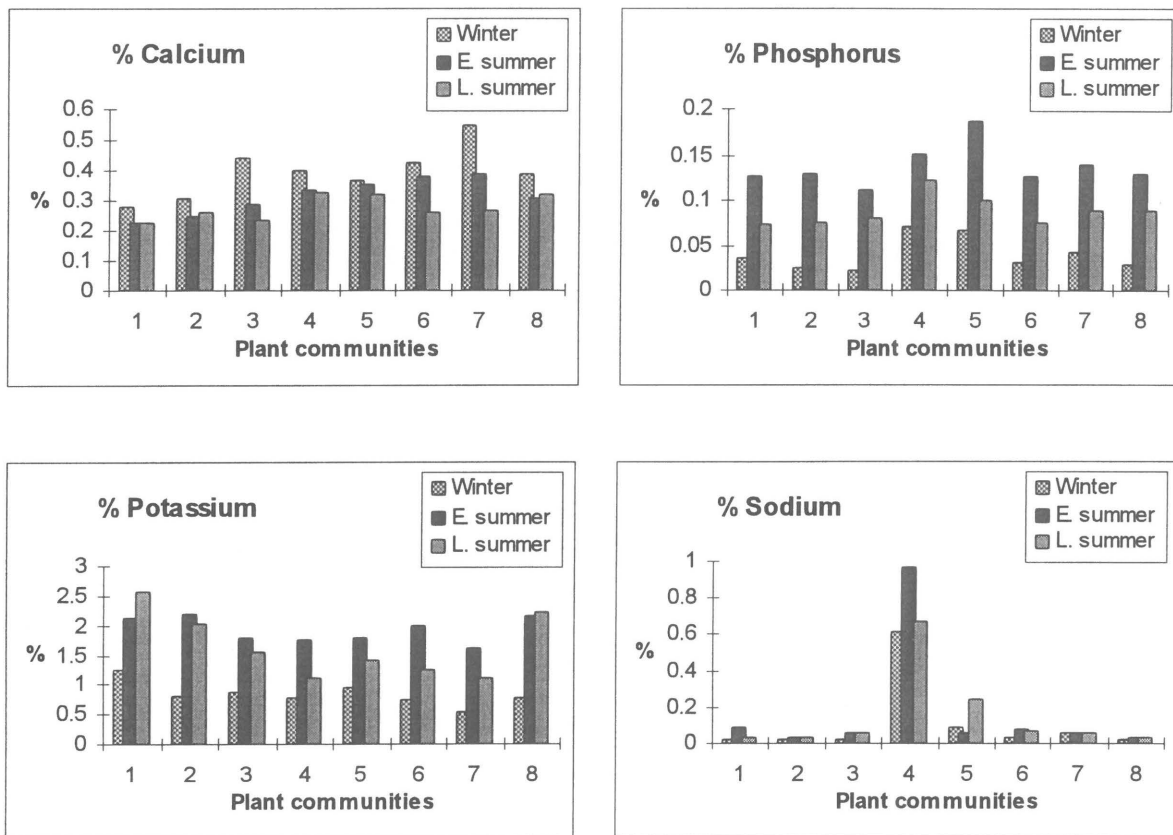
Fig. 10.1: Mean seasonal changes in chemical composition, expressed as a percentage in non-burnt plant communities. Plant communities 5 and 8 contain missing data for % moisture during winter and late summer respectively. Numbers of plant communities depict 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl River and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, and 8) *Eragrostis pallens - Burkea africana* Savanna. In the latter plant community no moisture was measured during late summer.

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Differences in forage quality between burnt plant communities

Significant differences ($p < 0.03$) in the chemical composition were found between burnt plant communities during late summer excluding the minerals % P ($p = 0.3499$), % K ($p = 0.2349$) and % Na ($p = 0.3143$). There were generally no statistical differences ($p > 0.05$) in the chemical composition between the burnt *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation, or between the burnt *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations. These similarities in forage quality were also found when the above plant communities were in a non-burnt state.

Although measurements were taken for three months only, the Nyl river and floodplain had the highest % N and % IVOMD (Fig. 10.2, Table 7.3, Appendix 7). This plant community also had the lowest percentage fibres (% NDF and % ADF). Forages in the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation, and the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations had high fibre and organic matter contents (Fig. 10.2, Table 7.3, Appendix 7). Specific mineral concentrations were highest in the *Cymbopogon plurinodis - Combretum apiculatum* Variation (% K), the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations (% Ca) and the *Tristachya rehmannii - Digitaria monodactyla* Variation (% P) (Fig. 10.2, Table 7.3, Appendix 7).

Differences between burnt and non-burnt plant communities

The forage quality increased after burning but generally did not differ ($p > 0.05$) from non-burnt areas (Fig. 10.2). Of importance was only the % IVOMD that increased significantly in the burnt *Eragrostis nindensis - Digitaria monodactyla* Variation ($p = 0.0029$), and both the *Aristida bipartita - Setaria sphacelata* Savanna ($p = 0.0003$) and Grassland Variations ($p = 0.0005$). The mineral data was too little ($n = 6$) for statistical analysis but burnt forages showed a decrease in % Ca and an increase in % P and % K (Fig. 10.2, Table 7.2 and 7.3, Appendix 7)
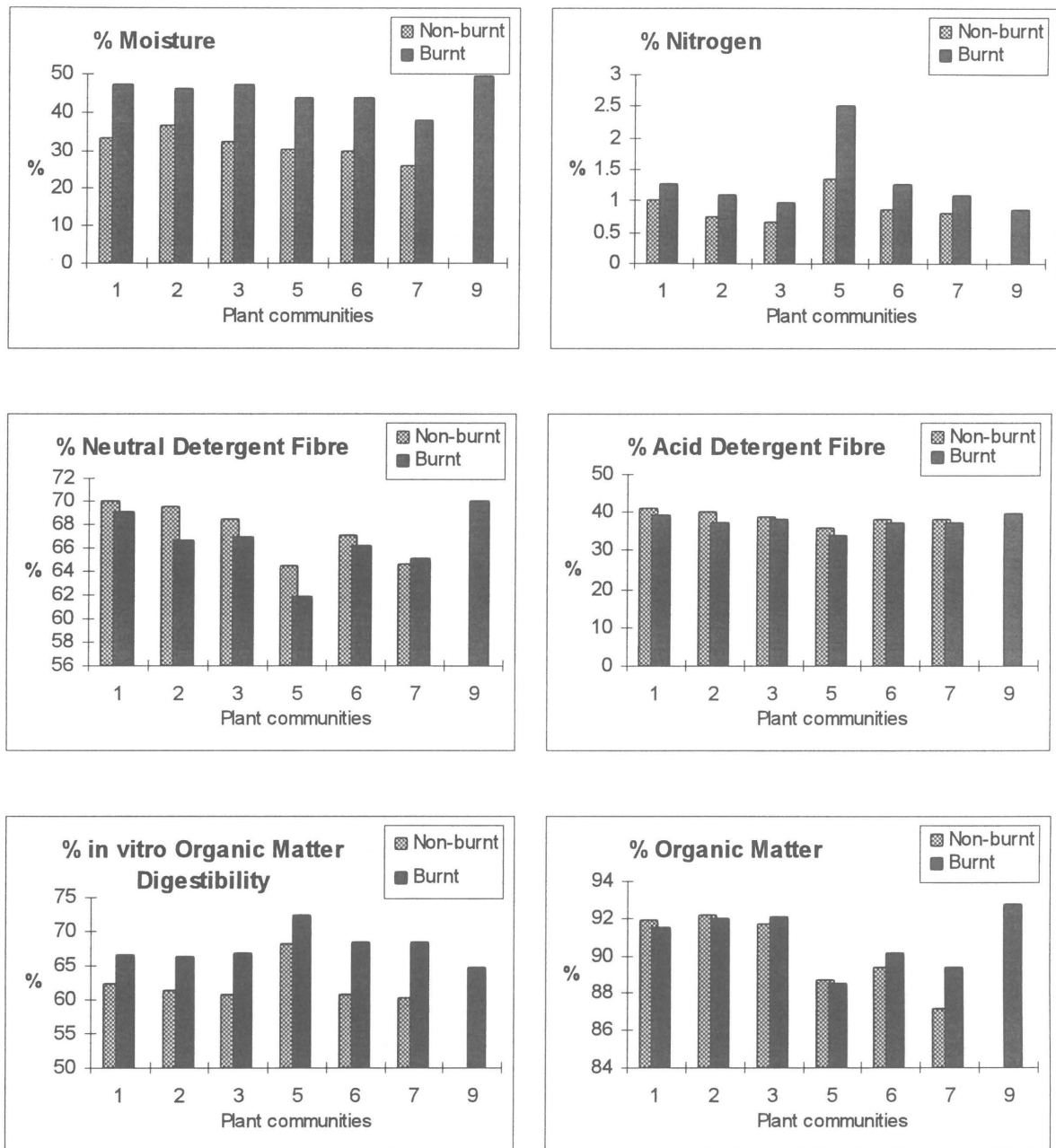
Fig. 10.2 (for title see next page)

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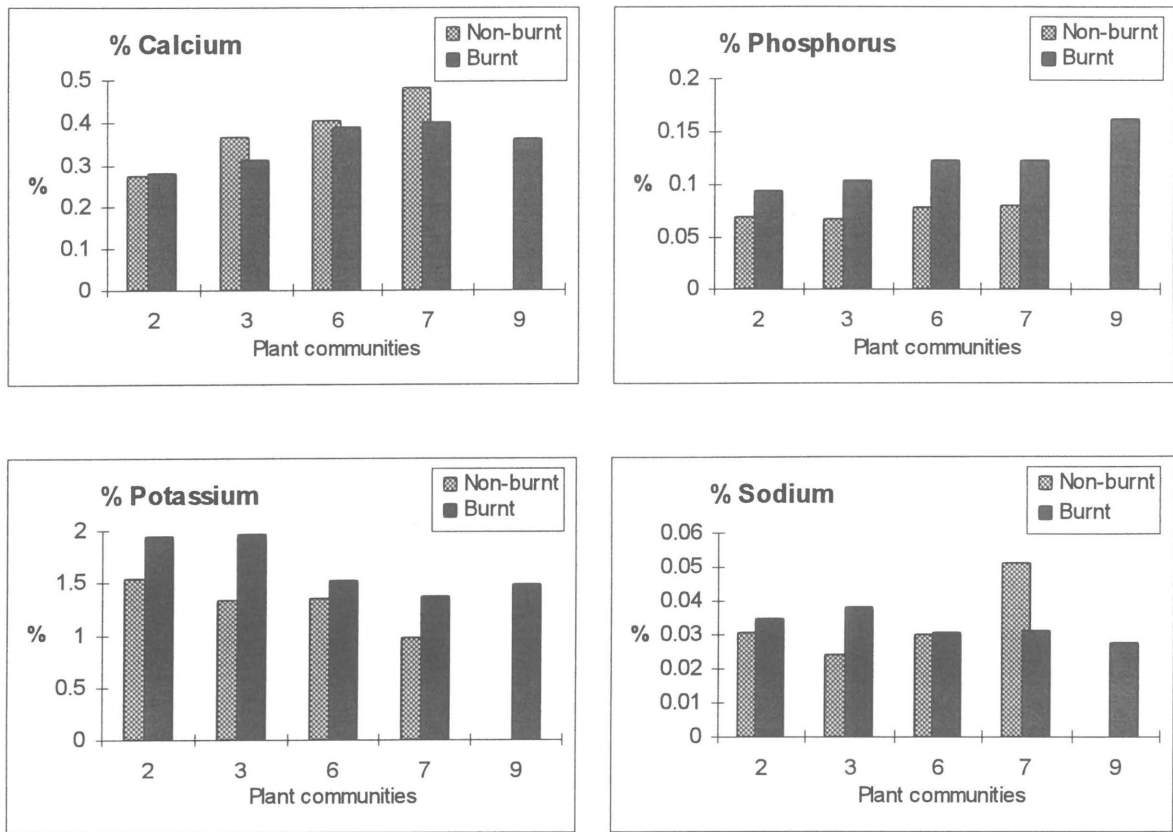
Fig. 10.2: Chemical components, expressed as a percentage in non-burnt and burnt plant communities. Not all the plant communities were burnt or sampled for macro minerals. Numbers of plant communities are the same as in Fig. 10.1. Plant community 9 is the *Tristachya rehmannii - Digitaria monodactyla* Variation.

Differences in mineral ratios between plant communities

There were no significant differences ($p > 0.33$) in Ca:P ratios between non-burnt plant communities throughout the year. However there were differences ($p < 0.0003$) in the K:Na ratio between plant communities. The low K:Na ratio in the *Sporobolus ioclados - Acacia tortilis* Savanna differed significantly ($p < 0.03$) from all other plant communities during all seasons (Fig. 10.3, Table 7.4, Appendix 7) except from the floodplain during late summer ($p = 0.0719$). Differences in the Ca:P ($p = 0.9839$) and K:Na ($p = 0.8560$) ratios between burnt plant communities were not significant during late summer.

Seasonal differences in mineral ratios within each plant community, and differences between burnt and non-burnt plant communities could not be analysed statistically because of limited data ($n < 10$) (Table 7.5, Appendix 7).
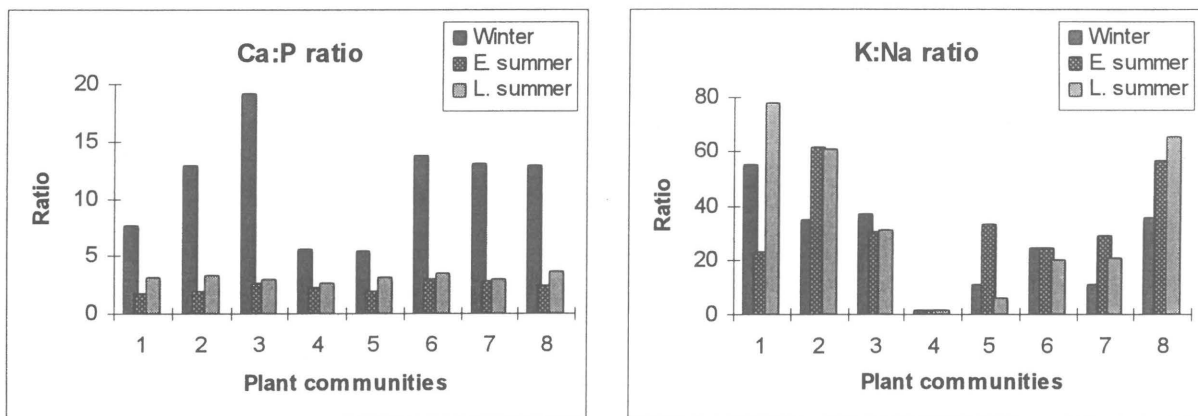
Fig. 10.3: Seasonal mineral ratios in the non-burnt 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl River and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, and the 8) *Eragrostis pallens - Burkea africana* Savanna.

Differences in forage quality of principal grass species between the floodplain and the Eragrostis pallens - Burkea africana Savanna

Significant differences in forage quality [% NDF ($p = 0.0189$), % ADF ($p = 0.0001$), % IVOMD ($p = 0.0178$), % Ca ($p = 0.0312$) and % Na ($p = 0.0055$)] of the principal grass species were

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found between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna during winter (winter and early summer). All chemicals except % NDF were higher in the floodplain (Table 7.6, Appendix 7). The Na concentration in the floodplain was more than twice as high as in the *Eragrostis pallens - Burkea africana* Savanna. During late summer percentage moisture ($p = 0.0036$), % NDF ($p = 0.0043$) and % ADF ($p = 0.0114$) were significantly higher in the *Eragrostis pallens - Burkea africana* Savanna (Table 7.6, Appendix 7).

On an annual basis the principle grasses in the floodplain were of higher quality than those in the *Eragrostis pallens - Burkea africana* Savanna. The % N, % IVOMD and % Na were higher while the fibre content (% NDF and % ADF) of the grasses was lower (Table 7.6, Appendix 7). Macrominerals other than % Na were higher in the *Eragrostis pallens - Burkea africana* Savanna.

When comparing the quality of principle grass species utilized by roan between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna, the Ca:P ratios did not differ significantly during winter ($p = 0.6947$) and late summer ($p = 0.1233$). The K:Na ratios were however significantly higher ($p \leq 0.0052$) in the floodplain throughout the year (Table 7.6, Appendix 7).

Discussion

Forage quality in non-burnt areas

In non-burnt plant communities leaf samples were collected from mainly mature grass plants. This is reflected in the results which show a generally low nitrogen levels ranging from 0.6667 to 1.8233 % N (4.17 % to 11.40 % protein) over the study period (Fig. 10.1, Table 7.2, Appendix 7). Young shoots of grass, forbs and browse can have 20-30 % protein on a dry-weight basis which declines to 3-4 % in mature plants (Robbins, 1993).

The average winter dietary protein content in the NNR of 4.10 % (0.656 % N) (1.98 % to 7.94 % protein) was below 5 % for most plant communities. It, therefore, appears that animals in the NNR face a protein shortage which is especially serious in roan when females are lactating. Mungall & Sheffield (1994) mentioned that grasses preferred by sable and roan decline to 2-5 % protein during the dry season in sourveld areas. Wilson & Hirst (1977) found that forage protein and phosphorus levels in the Percy Fyfe Nature Reserve were too low to provide adequate

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nutrition during the critical weaning period which often coincides with the end of the dry season. Protein requirements for white-tailed deer are estimated as 6 to 7 % crude protein level for maintenance (Soper *et al.*, 1993) or a minimum of 5 % for survival (Mungall & Sheffield, 1994). Dietary protein requirements for growth in weaned mammals is 13 to 20 % for deer and other ruminants, and 5 to 9 % for maintenance of adult wild ruminants (Robbins, 1993). These minimum dietary protein requirements differ between 4.5 % for grazers and 6.0 % for browsers.

A minimum of 50 % DMD of the forage is required by ruminants (Child *et al.*, 1984 in Kinyamario & Macharia, 1992). The *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and *Eragrostis nindensis - Digitaria monodactyla* Variation, and the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations had the lowest % IVOMD. Digestibility of grasses is influenced by leaf/stem ratios (McDonald *et al.*, 1995) and the phenological stage of the plant ([*]Meissner, H.H. 1994. pers. comm.). Forages with a low digestibility have low amounts of available nutrients, require a longer digestion time, and decrease the daily intake rate (Westenskow-Wall *et al.*, 1994). Many of the above-mentioned areas with low forage digestibilities (Table 7.2, Appendix 7) were avoided by roan (Chapter 16). Plant communities with a higher overall % IVOMD for example the floodplain (p = 0.0001 for late summer), were sought out by roan during summer. This plant community was often water-logged during summer.

Macrominerals of non-burnt plant communities

In a survey of the forage quality in a number of nature reserves, Wilson & Hirst (1977) found that the basic deficiencies in sourveld areas of the Percy Fyfe Nature Reserve and other nature reserves were P, selenium and protein. Sodium, Ca, Mg and K were linked to these deficiencies but in themselves were not deficient. High levels of macrominerals in the soil are reflected in the plants and increased uptake and body reserves in the animals (Wilson & Hirst, 1977).

The Ca and P concentration in the NNR was generally lower (Table 7.2, Appendix 7) than the requirements for growing mammals which are 0.4 to 1.2 % Ca, and 0.3 to 0.6 % P (Robbins, 1993). Pregnant wintering cattle require 0.18 % for both Ca and P (NRC, 1984 in Westenskow-Wall *et al.*, 1994) and a dietary P intake of less than 0.16 % may adversely affect deer production (Howery & Pfister, 1990).

[*] Meissner, H.H. pers comm. Agricultural Research Council, Animal Nutrition and Products Institute, Private Bag X2, Irene 1675.

Approximately 99 % of Ca in the body is stored in the skeleton and teeth where it occurs in a ratio of about 2:1 with P in the bone (Pond *et al.*, 1995). According to Robbins (1993) and Westenskow-Wall *et al.* (1994) a ratio of Ca to P of 1:1 to 2:1 is needed for optimum absorption of both minerals while Soares (1995b) quotes a ratio of dietary calcium to P of approximately 2.2:1 as optimal, but ruminants can tolerate a Ca to P ratio of 1:1 to 1:7 without adverse affects (Simesen, 1980 in Westenskow-Wall *et al.*, 1994). An inadequacy of dietary Ca may be an important determinant of productivity in free-ranging wildlife (Robbins, 1993).

The most advantageous Ca:P ratios based on the average over the entire study period were measured in the *Sporobolus ioclados - Acacia tortilis* Savanna (3.49:1), the floodplain (3.49:1) and the *Rhus leptodictya - Combretum apiculatum* Variation (4.21:1). The Ca:P ratios may play some role in area selection as roan selected the floodplain during summer (Chapter 16).

Potassium deficiencies in wildlife are rare due to the very high K contents in growing plants, usually in excess of animal requirements (Robbins, 1993). This appears to be the situation in the NNR (Fig. 10.2, Table 7.2, Appendix 7) where K concentrations are considerably higher than those of Na.

Sodium deficiency is a frequent problem in grazing ruminants with no access to Na supplementation (Henry, 1995). Limited availability of Na in certain areas may restrict animal distribution and productivity (Robbins, 1993). In general the Na content of plants was lowest during winter; also recorded by Delgiudice, Singer & Seal (1991). High Na contents are found in aquatic vegetation along streams (Delgiudice *et al.*, 1991) which may explain the selection of aquatic plants by roan in the Nyika National Park (Malawi) (Gewalt, 1987) and in the NNR (personal observation). It is well known that moose select aquatic plants having 50 to 500 times higher Na concentrations than terrestrial plants (Robbins, 1993).

Most estimates of the Na requirements are based on domestic or laboratory animals. These requirements range from 0.05 to 0.4 % of the dry diet with a minimum intake necessary for Na balance calculated as 9.0 mg/kg/day for wild animals (Robbins, 1993). Subtle stressors, such as overcrowding, may increase the Na requirement (Robbins, 1993). Minimum necessary dietary concentrations were calculated as 9.0 mg/kg/day multiplied by the average body weight and divided by the average daily dry matter intake. Average body weight of roan was taken as 260 kg and average daily dry matter intake as 28 g/kg (Heitkönig, 1993). The necessary dietary concentration for roan was calculated as 0.0836 % Na. Based on this calculation it appears that roan in the NNR experience a sodium shortage in all but the *Sporobolus ioclados - Acacia tortilis*

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Savanna and the floodplain. Although a high correlation between roan distribution and Na concentrations was found it cannot be interpreted as indicating that Na is the element being sought.

Burnt areas

Burning does not affect the mineral content to a large extent, especially if the soil is phophorus deficient (Wilson & Hirst, 1977). However, sprouting grasses have been found to contain higher amounts of protein (75-100 % increase), Ca and P compared with unburnt leaves (Moe, Wegge & Kapela, 1990). As plants grow and mature the main structural carbohydrates (cellulose and hemicellulose) and lignin increase, and the protein concentration and digestibility decreases (McDonald *et al.*, 1995). Young and rapidly growing forages frequently contain K concentrations well in excess of the ruminant's requirements (Miller, 1995). Fig.10.2 shows that the forage quality increased after burning and confirms the findings in other areas.

Conclusion

Differences in chemical components were found between plant communities throughout the year. During winter the forage quality in the floodplain was higher than in the *Eragrostis pallens - Burkea africana* Savanna. In general no differences in forage quality occurred between these two plant communities during late summer. The *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation had a low forage quality. Similar forage qualities were found when these plant communities were burnt or non-burnt. Similarities in forage quality were also found in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations when burnt and non-burnt.

A comparison of the forage quality of the preferred grasses between the floodplain and the *Eragrostis pallens - Burkea africana* Savanna showed a slightly higher forage quality in the former area during winter and late summer. Where % Ca and % P were higher in the *Eragrostis pallens - Burkea africana* Savanna, the Na concentration was (> 2 x) higher in the floodplain along the Nyl River.

Forage quality increased after burning and confirms the results found in other savanna ecosystems. Comparing the burnt plant communities, the floodplain had the highest % N and % IVOMD three months after they were burnt. In general only % IVOMD differed between burnt and non-burnt plant communities.

The highest macromineral concentrations occurred in the *Eragrostis pallens - Burkea africana* Savanna (Ca and P), the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation (K), and Na in the *Sporobolus ioclados - Acacia tortilis* Savanna and floodplain. The high % Na in the floodplain could be ascribed to the semi-aquatic vegetation. Aquatic vegetation along streams has a high Na content (Delgiudice *et al.*, 1991). It is possible that these minerals Ca, P and Na may play a role in habitat selection as is suggested by the distribution of roan.

The lower Ca:P ratios (< 2:1) were found in the *Sporobolus ioclados - Acacia tortilis* Savanna, the floodplain, and *Rhus leptodictya - Combretum apiculatum* Variation to a lesser extent. The Ca:P ratio of the preferred grasses in the *Eragrostis pallens - Burkea africana* Savanna was more advantageous for nutrition compared to those in the floodplain. In non-burnt areas the lowest K:Na ratio was found in the *Sporobolus ioclados - Acacia tortilis* Savanna. In newly burnt plant communities no differences in mineral ratios were found. Preferred grasses in the floodplain had a consistently lower K:Na ratio than those in the *Eragrostis pallens - Burkea africana* Savanna.

Management implications

A protein shortage during winter and a general shortage of macrominerals (with the exeption of K) may put animals under nutritional stress for most of the dry period. Artificial licks high in protein levels and minerals such as Ca, P and Na should be supplied to animals particularly during winter. Other management practices such as burning should change the phenological stage of grasses into an actively growing, vegetative stage in order to maximize forage quality, specifically protein content and digestibility, and therefore intake rate. This could be achieved by burning patches at different times during the dry season which among other things would increase dietary

mineral concentrations. Nutritious forage would then be available throughout the dry season especially at the end when many roan cows are lactating or calves are being weaned.

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CHAPTER 11

Intra-plant community differences

Introduction

Habitat selection may include the selection of specific geographical regions, vegetation types, plant communities or even areas within plant communities. Monthly observations showed that roan selected certain areas within some plant communities (Chapter 16). These were the eastern section of the *Rhus leptodictya - Combretum apiculatum* Variation, the lower section of the floodplain and the eastern part of the *Eragrostis pallens - Burkea africana* Savanna. For example the western or main section of the *Rhus leptodictya - Combretum apiculatum* Variation was avoided by roan. The aim of these statistical analyses were therefore to determine if there were any significant intra-specific differences in plant communities most commonly selected by roan.

Methods

Sites compared with each other were sites 1 and 2 against 3 in the *Rhus leptodictya - Combretum apiculatum* Variation, sites 1 and 2 against 3 in the floodplain, and site 1 against 2 and 3 in the *Eragrostis pallens - Burkea africana* Savanna. Within each plant community these sites were compared with each other in terms of percentage species composition (Chapter 3), percentage dry-weight (Chapter 3), grass density (Chapter 3), total grass height (Chapter 5), grass tuft height (Chapter 5), above-ground standing crop (Chapter 7), biomass concentration (Chapter 8), woody plant density (Chapter 6), woody plant canopy cover (Chapter 6), and 10 chemical components (Chapter 10). The same data set was analysed as was used before for each variable. Methods are described in each respective chapter.

Differences within plant communities were tested with genral linear modelling (PROC GLM) (SAS Institute, 1990) at a 95 % confidence level.

Results

Rhus leptodictya - Combretum apiculatum Variation

Total grass height (p = 0.0091), above-ground standing biomass (p = 0.0001) and biomass concentration (p = 0.0005) were significantly higher at site 3 (selected by roan) than at sites 1 and 2. Other parameters did not differ significantly (p > 0.05) or had insufficient data for statistical analysis (n < 20). The % species composition (p = 0.3506), % dry-weight per ecological group (p = 0.7891), grass tuft height (p = 0.1826), % N, % OM and % Na were marginally higher at site 3. Grass density, woody plant density and canopy cover was lower at site 3.

Nyl River and floodplain

The lower percentage moisture (p = 0.0345) and % Na (p = 0.0076) at site 3 (lower floodplain) differed significantly from sites 1 and 2. Grass density could not be analysed statistically because of insufficient data (n = 15) but it was considerably higher (221.2 plants/m²) at site 3 than at sites 1 and 2 (92.1 plants/m²). Other parameters did not differ significantly (p > 0.05) between the sites. However the % species composition (p = 0.5034), % dry-weight per ecological group (p = 0.7425), % N (p = 0.9837), % IVOMD (p = 0.2829), % OM (p = 0.0560), % Ca (p = 0.3109) was higher at site 3. The marginally lower above-ground standing biomass (p = 0.9787), biomass concentration (p = 0.7207), grass tuft height (p = 0.6437), total grass height(p = 0.3764), % NDF (p = 0.4997), % ADF (p = 0.0656), % P (p = 0.6456), % K (p = 0.7671) at site 3 did not differ from the other sites.

Eragrostis pallens - Burkea africana Savanna

Significantly higher total grass height (p = 0.0002), grass tuft height (p = 0.0006) and above-ground standing crop (p = 0.0001) occurred at sites 2 and 3. Percentage species composition (p = 0.9371) and % dry-weight per ecological group (p = 0.8464) did not differ significantly (p > 0.05) between sites. Insufficient data (n < 20) of grass density, woody plant density and canopy cover did not justify any statistical analysis of the data but these were lower at sites 2 and 3.

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Discussion

It appears that a tall grass height and a high above-ground standing crop are important factors influencing the distribution of roan in the *Rhus leptodictya - Combretum apiculatum* Variation and the *Eragrostis pallens - Burkea africana* Savanna. A well developed grass stratum with a low tree density played an important role in habitat selection by roan in the KNP (Joubert, 1976).

Percentage moisture and % Na were significantly lower at site 3 (lower region) of the floodplain. Although the floods arrive later in the lower floodplain it is flooded for longer periods of the year. Sodium deficiency is a frequent problem in grazing ruminants (Henry, 1995) and limited availability of sodium may restrict animal distribution and productivity (Robbins, 1993) to certain areas.

In conclusion, the results indicated variability within plant communities. It is therefore important to take these variances into account in any vegetation survey. Habitat parameters, which differed significantly within plant communities, confirmed those found by Joubert (1976) that grass height with corresponding high biomass are critical factors affecting habitat preferences of roan. Grass density, tree density and percentage tree canopy cover were lower in the preferred areas, although they did not differ significantly.

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CHAPTER 12

Population composition, natality and mortality of roan antelope

Introduction

The individual animal is an easily recognisable and well-defined unit providing the basic information required for population analysis (Delany & Happold, 1979). Population dynamics are determined by its age-specific fecundity and mortality rates which interact with its age distribution and sex ratio (Shaw, 1985; Caughley & Sinclair, 1994). Changes in these parameters result in changes in population size (Bailey, 1984) the speed of which is measured as the rate of increase (Caughley & Sinclair, 1994).

Birth and death rates change in relation to population density (Shaw, 1985). Factors affecting birth rates are a decline in the frequency of births and a reduction in the quality and quantity of food per individual animal in the population (Shaw, 1985). Nutritional stress may lead to decreases in pregnancy rate, rebreeding frequency and implantation success (Lochmiller, Hellgren & Grant, 1987 in Hellgren, Synatzske, Oldenburg & Guthery, 1995). It is suggested that reductions in reproduction and juvenile survival are the main mechanisms of population regulation (Bissonette, 1982 in Hellgren *et al.*, 1995). Survival rate is commonly measured indirectly from recruitment and gross population changes (Janz, 1989 in McNay & Voller, 1995).

The aim of this survey was to assess the population composition and estimate the age specific mortality rate of the roan population in the Nylsvlei Nature Reserve (NNR).

Methods

Sex and age

The sex and age ratio of non-seasonal breeders should be determined at least once a year, or more frequently during the most suitable periods (Riney, 1982). Roan breed all year round (Joubert,

1976; Skinner & Smithers, 1990), although more calves are born from March to June (Joubert, 1976). Calves are concealed for about six weeks (Skinner & Smithers, 1990).

The shyness and unapproachability of roan in the NNR, and the type of vegetation made it difficult to find the entire population for observation. In general large numbers of roan could be observed only during summer in the open marshy areas and on newly burnt areas. Population data of age and sex were acquired during monthly surveys from July 1994 to June 1996 while estimating animal distribution (Chapter 16).

The age classes used by Joubert (1976) were modified to be able to classify animals more accurately in the field. Eight age classes were selected based on the development of horn growth and from photographs:

1) **0-2 months** (no horns visible)

2) **> 2-6 months** (short spikes; few centimeters)

3) **> 6-12 months** (straight spikes; between 10 and 12 ridges appear on the anterior surface; spikes project slightly above the ears, up to 14 to 18 cm long)

4) **> 1-2 years** (horns start to curve backwards; ridges are more prominent; about three ridges; darker coloured than adults)

5) **> 2-3 years** (horns curved slightly backwards and attain full curvature at the end of three years; annular rings appear at the base of the horns and are clearly distinguishable from one another by marked depressions; rings are far apart; about 10 rings; body about ¾ size of adults)

6) **> 3-4 years** (young adult - horns curved fully backwards; annular rings are closer together and still clearly visible but are less well defined; 16-17 rings cover about ¾ of horn length)

7) **> 4 years** (adult - depressions between successive rings are less visible; inner sides of horns become almost flat)

8) **old** (approximately 10 years and older, lower parts of horns are completely flat, run-down appearance and generally poor condition, loss of hair on some parts of the skin)

Sex ratios were calculated from population data collected over two years since these do not change over time.

Natality and recruitment

Population performance is expressed as the reproductive success rate (Riney, 1982) or annual birth rate (calf/adult cow ratio) (Beudels, Durant & Harwood, 1992). Calves were taken as less than 12 months old and adult females as > 2 years of age. Recruitment rate (sexually mature animals/adult) as defined by Bailey (1984) was calculated from the population data. Natality, recruitment and survival were calculated from January 1995 data only when 49 animals were classified. This number of animals included the largest proportion of the total population.

Survival and mortality

The Chapman-Robson equation was used to calculate survival rate. This method can be applied when a population is stable and experiences constant mortality rates for several years (Shaw, 1985). This roan population showed a rate of increase close to zero for a number of years (Dörgeloh, Van Hoven & Rethman, 1996). For this analysis the juvenile age class (< 12 months) was further subdivided into the first six months of their lives and a six to 12 month age class. The age structure was used to calculate the finite annual survival rate with the Chapman-Robson equation (Shaw, 1985; Krebs, 1989):

$$S = \frac{T}{R + T - 1}$$

where S = Finite annual survival rate

$\quad\quad T = N_l$

$\quad\quad R = \sum_{t=0}^{\infty} N_t$

$\quad\quad N_t = \%$ composition of individuals in age group X

The variance of survival was estimated as:

$$\text{var}(\hat{S}) = S[S - (\frac{T-1}{R+T-2})]$$

Mortality was calculated as the complementary of the survival rate.

Results and discussion

Population structure

The population male:female ratio for the entire study period was 1:1.89 (Table 12.2). This appears to be within the general sex ratio of the species. For example, Joubert (1976) working in the Kruger National Park (KNP) recorded the total population male to female ratios of calves 1:1.129, yearlings 1:1.578 and adults 1:1.8 while Munthali & Banda (1992) recorded a sex ratio of 1:0.83 for the total population in the Nyika National Park (Malawi).

Sexually mature adult cows (> 2 years) formed 53.06 % of the total population (Table 12.1). This is slightly higher than found by Joubert (1976) for the KNP where adult cows formed on average 41.66 % of the total population. The age structure of the total Nylsvlei population (Table 12.1) was similar to that of the breeding herds in the KNP with 22.4 % (0-12 months), 13.12 % (13-18 months), 9.09 % (19-24 months) and 55.39 % of 25+ months old animals (Joubert, 1976).

Table 12.1: Population structure of the Nylsvlei roan population based on the January 1995 survey alone.

Age class	Age	Male	Female	Sex unknown	Total	%
1	0-2 months					
2	> 2-6 months	1	1	6	8	17.39
3	> 6-12 months	1		2	3	6.52
4	> 1-2 years	1	1		2	4.26
5	> 2-3 years	1	8		9	19.15
6	> 3-4 years	1	4		5	10.64
7	> 4 years	5	12		17	36.17
8	Old		2		2	4.26
	Age unknown	1	2		3	
	TOTAL	11	30		49	

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Table 12.2: Annual sex ratios of the roan population calculated from all data collected over that year.

Year	Sex ratio
1994	1 m : 2.19 f
1995	1 m : 1.98 f
1996	1 m : 1.14 f
Mean	1 m : 1.89 f

Natality and recruitment

In the NNR the percentage calves (<12 months) of the roan population was 23.91 % (Table 12.1). Roan in the Nyika National Park (Malawi) had a similar proportion of young (21.2 %) (Munthali & Banda, 1992) and in the KNP the calf percentage to total population varied between 9.09 and 25.61 % (Joubert, 1976).

The average number of calves per 100 adult females was 42.31 (Table 12.1) which compares with the KNP population of 0.39 calves/cow (Joubert, 1976). Factors affecting birth rates are a decline in the quality and quantity of food per individual animal in the population (e.g. when the population approaches carrying capacity) (Shaw, 1985).

The recruitment rate as defined by Bailey (1984) was 0.3750 sexually mature animals (2-3 years) per adult animal (> 3 years). If compared to the KNP population where the annual sexually maturing females entering the breeding segment of the population was 12.20 % (Joubert, 1976), the recruitment in the Nylsvlei population of 0.3333 females (2-3 years) per breeding adult (> 3 years) (Table 12.1) was considerably higher. This may indicate that mortalities are higher in the younger age classes than in sub-adult animals.

Mortality and survival

The limited data collected from the Nylsvlei roan population and the possibility that their ages could have been misidentified made it difficult to calculate the survival rate accurately. However the mortality rates of 76.90 % for 0-6 month old calves and 69.67 % for 6-12 months old calves (Table 12.3) compared with those found by Joubert (1976). He calculated a mortality of 80.74 %

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within the first 12 months for the KNP population. He also found no sex differentiated mortality during the first two years.

Because the birth rate could not be assessed accurately, unrecorded mortalities in the first two months of their lives may increase the actual calf mortalities. Wilson, Bartsch, Bigalke & Thomas (1974) recorded an 80 % mortality of roan calves within the first 12 weeks after birth in the Percy Fyfe Nature Reserve. These authors found similar mortality rates on other provincial reserves. Joubert (1976) recorded a calf mortality of 67.5 % within the first few weeks after birth.

The predator diversity and density as found in the KNP is absent in the NNR and it is probable that they do not play as an important role in calf mortality in the NNR. The relatively high roan density may be a contributing factor to the calf mortality (Dörgeloh *et al.*, 1996) since birth and death rates change in relation to population density (Shaw, 1985). Mortality may be caused by nutritional stress (Hellgren *et al.*, 1995) during winter when many calves are born.

Calf mortality may also be disease related. The high calf mortalities found by Wilson *et al.* (1974) and Wilson & Hirst (1977) in the Percy Fyfe Nature Reserve were mainly contributed to the disease cytauxinosis. This disease is caused by the blood parasite *Cytauxzoon* which contributes to high mortalities among stressed roan (Wilson & Hirst, 1977; Mungall & Sheffield, 1994), sable, tsessebe and possibly eland. This parasite is widespread in Africa and is easily carried between areas by the hosts. Kudu and maybe waterbuck can carry the parasite without showing symptoms (Mungall & Sheffield, 1994).

Table 12.3: Finite survival and mortality rate of the roan population.

Age	Survival rate	Variance	Mortality rate
0-6 months	0.2310	0.0065	0.7690
> 6-12 months	0.3033	0.0162	0.6967
> 1-2 years	0.4608	0.0061	0.5392
> 2-3 years	0.2698	0.0051	0.7302
> 3-4 years	0.4412	0.0030	0.5588
> 4 years	0.0974	0.0021	0.9026

Conclusion

The age structure, sex ratio and natality of the Nylsvlei population compared with those of other populations. Recruitment was higher than in the KNP population. Calf mortality was marginally lower compared to the KNP population but may be higher if calf mortalities within the first two months were to be added. Factors that may play a role in calf mortality in the NNR are nutritional stress and disease. Since the population may have reached carrying capacity and experiences a negative rate of increase Dörgeloh *et al.* (1996) the population may be controlled by mortalities in the younger age classes. However, to substantiate this more detailed investigations of age specific mortalities are needed.

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CHAPTER 13

Population growth of roan antelope under different management systems.

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Roan antelope (*Hippotragus equinus equinus*) is an endangered species in southern Africa. Appropriate management strategies, under intensive systems, may be to the advantage of roan populations. The exponential rate of increase of roan populations under various degrees of intensive management systems was investigated. A one-way analysis of variance was used to test the null hypothesis that there is no difference in the rate of increase between roan populations. The roan population on the Nylsvlei Nature Reserve had a negative rate of increase. The high exponential rate of increase (0.2574) of the small Rooipoort population differed significantly (p < 0.05) from all other populations. This population grazed on planted pastures and was fed during the dry period with at least 0.5 kg of supplementary food per day (mixture of lucerne, antelope cubes and lick). It also had the highest sex ratio. Under intensive management, animals may be stocked at a density of up to 20 animals/km². The Spearman's rank correlation coefficient showed that the rate of increase was correlated with the amount of supplementary feeding. For these populations no correlation was found with % females, % calving rate, population size and density.

Key words: conservation areas, sex ratio, calving rate, population size and density, supplementary feeding

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Introduction

Roan antelope (*Hippotragus equinus equinus*) are distributed widely throughout Africa (Skinner & Smithers, 1990), but are found only in low densities. The highest densities are found in areas with an average rainfall close to 1 000 mm/annum (East, 1984 in Heitkönig, 1993). Roan antelope (hereafter referred to as roan) used to occur in the northern areas of South Africa, although never abundantly (Joubert, 1976). At present roan are listed as endangered in southern Africa (Smithers, 1986; Skinner & Smithers, 1990). In past decades their numbers decreased dramatically. For example, the roan population in the Kruger National Park (extensive management) has decreased by 90 % over eight years ([*]Viljoen, P. 1995. pers. comm.) From 1991 to 1994 this was a negative exponential rate of increase of -0.3705. In contrast, the population in the Percy Fyfe Nature Reserve (under intensive management) has increased over the past 25 years. It appears that intensive management is an option for endangered species management.

The aim of this study was to investigate population growth of roan antelope under different intensive management systems in small conservation areas (< 3 000 ha). Two null hypotheses were tested:

H_o: there is no significant difference (p = 0.05) in the rate of increase between roan populations

H_o: rate of increase is not correlated with % females, % calving rate, population size, density or the amount of supplementary feeding

Methods

Five small conservation areas (Table 13.1), less than 3 000 ha in size, were investigated. Data on population size and composition, and the amount, frequency and duration of artificial feeding was obtained from landowners for each population. Data of population composition was obtained during winter of 1995. Large stock units were calculated for roan from the mean standard basal metabolism equation as described by Meissner (1982) and Mentis (1977).

[*] Viljoen, P. 1994. Kruger National Park, Private bag X402, Skukuza, 1350

Table 13.1: Topographical information of the study areas (Acocks, 1988; Land Type Survey Staff, 1987, 1988 & in press).

	Nylsvlei N.R.	Percy Fyfe N.R.	Le Grange Farm	Sable Ranch	Rooipoort Farm
Province	Northern	Northern	Northern Cape	North West	Northern
Veld type	Mixed Bushveld	North east mountain sourveld; mountain sourveld mixed with Pietersburg plateau false grassveld	Kalahari Thornveld	Sourish Mixed Bushveld	Turf Thornveld
Altitide of lowest point	1 103 m	1 205 m	1 000 m	1 040 m	985 m
Mean annual rainfall	594.7 mm	544.4 mm	383.1 mm	619.0 mm	596.3 mm

Statistical analysis

The exponential rate of increase (r) for each population, based on total numbers, was calculated as described in Shaw (1985), Caughley & Sinclair (1994) and Bothma (1995). Growth data was tested for homogeneity of variances between populations with Cochran's test, Bartlett's test and Hartley's test at a significance level of $p = 0.05$ using Statgraphics. Variances between populations were equal allowing the use of the one-way analysis of variance to test for differences in the exponential rate of increase between populations. Differences between populations were tested with Scheffe averages and are presented graphically with Box and Whisker plots (Fig. 13.2) (Miller, Freund & Johnson, 1990).

The Spearman's rank correlation coefficient (SAS Institute, 1990) was used to test the relationship between growth rate and sex ratio as % females, % calving rate as % calves per adult breeding female, population size, density and the amount of supplementary feeding. Correlation analysis was done with % females based on the total population and on sexually mature animals only. The calving rate was based on two month-old calves, since roan calves do not join the herd for the first six to eight weeks after birth (Joubert, 1976). Confidence intervals of the correlation coefficient were calculated with Z statistic.

Results

The roan population in Nylsvlei Nature Reserve (NNR) showed a negative rate of increase (Fig. 13.1) and was therefore not included in the analysis of variance for comparing rate of increase between populations. No harvest rate was calculated. This population had a low % breeding females and a low % calving rate compared to other populations (Table 13.2).

The large population in Percy Fyfe Nature Reserve was stocked at a relatively high density (Table 13.2) and showed a low rate of increase (Fig. 13.1). The rate of increase of this population differed significantly ($p < 0.05$) from all other populations, except from the Sable Ranch population (Fig. 13.2). The % harvest rate was also low (Fig. 13.1). Although the % breeding females was high the % calving rate was low (Table 13.2).

The mean exponential rate of increase of the Le Grange Farm population was high (Fig. 13.1) and differed significantly ($p < 0.05$) from all other populations except from the Sable Ranch population (Fig. 13.2). The % harvest rate was high. The sex ratio and % calving rate was similar to other populations (Table 13.2).

Sable Ranch had the largest population, stocked at a high density (Table 13.2). This population had a slightly higher mean exponential rate of increase than the population on Le Grange Farm with a potential harvest rate of 16.48 % (Fig. 13.1). The rate of increase of the Sable Ranch population differed significantly ($p < 0.05$) from that of the Rooipoort population but not from the other populations (Fig. 13.2). The sex ratio and % calving rate (Table 13.2) was similar to that on Le Grange Farm (Table 13.2).

The highest mean exponential rate of increase was recorded from the population on Rooipoort Farm (Fig. 13.1), which differed significantly ($p < 0.05$) from all other populations (Fig. 13.2). This population could be harvested at a rate of 22.69 %, (Fig. 13.1). The % breeding females was high with an average % calving rate of 68.75 % (Table 13.2).

The Spearman's rank correlation coefficient showed that the rate of increase was correlated with the amount of supplementary feeding {$r = 0.90$; $p = 0.0374$; ρ ($0.085 < \rho < 0.993$)}. There was no correlation with sex ratio, calving rate, roan numbers and density.
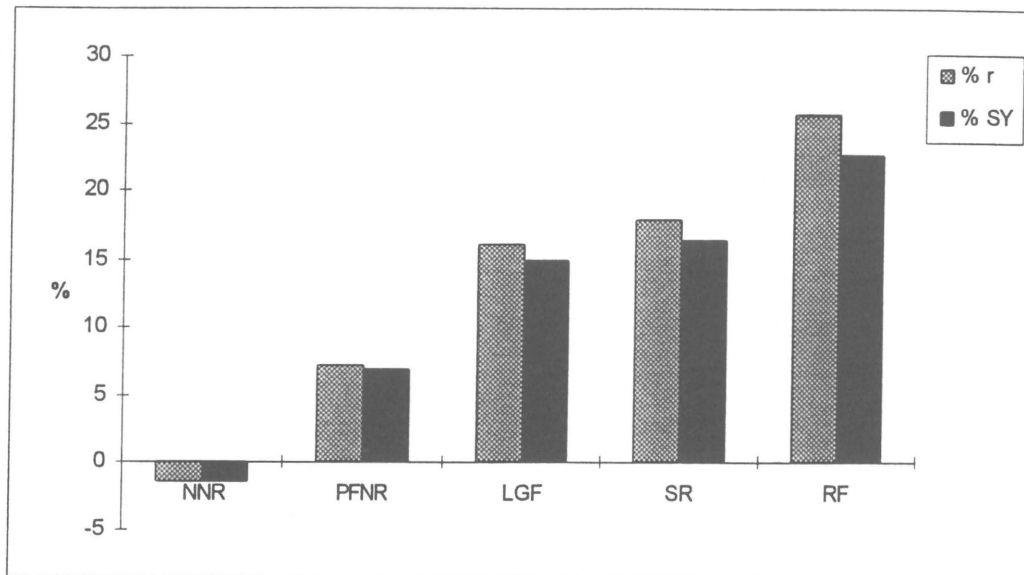
Fig. 13.1: Mean exponential rate of increase (% r) and percentage sustained yield (% SY) of the Nylsvlei Nature Reserve (NNR), Percy Fyfe Nature Reserve (PFNR), Le Grange Farm (LGF), Sable Ranch (SR) and Rooipoort Farm (RF) roan populations.
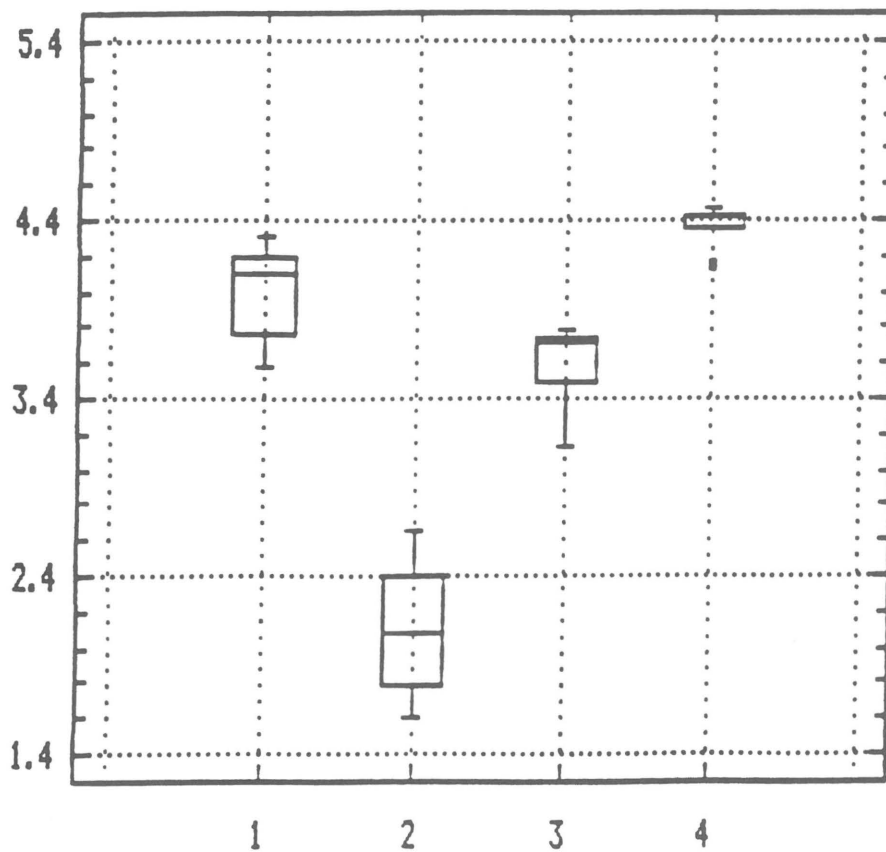
Fig. 13.2: Box and Whisker plots to indicate differences in the exponential rate of increase of the 1) Sable Ranch, 2) Rooipoort Farm, 3) Le Grange Farm and 4) Percy Fyfe Nature Reserve roan populations.

Table 13.2: Population size and density was based on the 1995 survey. Demographics of the five roan populations were calculated from data of the entire study period (Nylsvlei Nature Reserve and Percy Fyfe Nature Reserve) and from 1992 to 1995 for the remaining populations. Sex ratios are based on breeding animals. Calving rate was calculated for juveniles from 2 to 12 months and adult breeding females from age > 3 years (Joubert, 1976; Wilson & Hirst, 1977).

	Nylsvlei N.R.	Percy Fyfe N.R.	Le Grange Farm	Sable Ranch	Rooipoort Farm
Area size (ha)	2 779	1 649	1 600	400	370
Population size of roan and total animals on farm (in brackets)	46 (736)	84 (251)	44 (268)	81(150)	14 (240)
Total no./ha	0.2648	0.1522	0.1675	0.375	0.6486
Roan no./ha	0.0166	0.0509	0.0275	0.2025	0.0378
Roan: % of total no.	6.25	33.47	16.42	54.0	5.83
Total LSU/ha	0.0650	0.0883	0.0674	0.1774	0.3054
Roan LSU/ha	0.0109	0.0334	0.0180	0.1329	0.0248
Roan: % of total LSU	16.70	37.87	26.79	74.89	8.13
Sex ratio (male : female)	1 : 1.89	1 : 2.82	1 : 1.77	1 : 1.73	1 : 4.0
% juveniles per 100 females	90.00 %	68.37 %	75.93 %	78.75 %	68.75 %

Table 13.3: Feeding program of roan in the study areas. Salt was given *ad libitum* in all areas. Year for a specific food item given is indicated in brackets.

	Nylsvlei N.R.	Percy Fyfe N.R.	Le Grange Farm	Sable Ranch	Rooipoort Farm
External parasite treatment	no	yes	at random	yes	no
Months feeding	4 (1994)	5	4	12	4
Epol antelope cubes (kg/feeding period) (kg/animal/day)	750 0.1563	189 0.015		29 200 0.9877	1 680 1.0
Lick (kg/feeding period) (kg/animal/day)		17 0.0013	*ad libidum* *ad libidum*		
Lucerne (kg/feeding period) (kg/animal/day)	460 0.0958	7475 0.5933	2760 0.5227	13800 (5) 1.1358	1200 0.7143
Grass (*Cenchrus ciliaris*) (kg/feeding period) (kg/animal/day)					2400 1.4286
Total intake (kg/animal/day)	**0.2521**	**0.5961**	**>0.5227**	**2.1235**	**3.1429**

Discussion

For these populations the amount of supplementary feeding resulted in the greatest change in the rate of increase. The amount of supplementary feeding may have an indirect effect on the rate of increase through improving the condition of animals, especially during the dry winter period, thereby enhancing calf survival. Sex ratio, calving rate, population size and density were not correlated with rate of increase probably as a result of the small sample used in the analysis. The small sample size resulted in large confidence intervals.

The negative exponential rate of increase of the NNR population (Fig. 13.1) suggests that the population has probably reached optimum stocking rate. Calf mortality through food limitations during winter and some predation could limit population growth. However this calving

rate was slightly higher than that found in a natural population in the Kruger National Park. Its adult ratio of 1.94 females per male (65.99 % females) and mean cow/calf ratio of 1 : 0.3922 (39.22 % calves per female) was reported by Joubert (1976).

Indications are that the Percy Fyfe Nature Reserve population has probably exceeded optimum stocking rate reflected by a low rate of increase (Fig. 13.1). Wilson & Hirst (1977) recommended a maximum population size of 60 because of the poor quality of vegetation in the area which is approximately 25 % lower than the present population size. The relatively low % calving rate (Table 13.2) and the high disease related calf mortality in this area as was found by Wilson & Hirst (1977) may further influence population growth negatively.

The high population increase on Le Grange Farm may be related to the high % calving rate, the annual winter feeding programme (Table 13.3) and the absence of many parasites in the area (*Kriek, J.C. 1995. pers. comm.). Despite the high population density (Table 13.2), roan on Sable Ranch had one of the highest rates of increase. The intensive feeding programme in which animals had access to artificial food 12 months of the year (Table 13.3), parasite and predator control would enhance calf survival thereby positively influencing population growth. The small population size on Rooipoort Farm (Table 13.2), high sex ratio, the winter feeding programme (Table 13.3) and the high quality grazing (adapted planted pastures) contributed to the highest growth rate of all populations surveyed.

Conclusion

Rates of increase were correlated to the amount of winter supplementary feeding and no correlation was found with sex ratio, calving rate, population size and density. The small population sample may have influenced these results. The Nylsvlei population which is not fed during winter had a negative rate of increase. The highest rates of increase were found on Sable Ranch and Rooipoort Farm which fed the roan intensively. These populations had a high and low density respectively. Population density does not seem to play a major role at the density levels investigated provided supplementary feeding is introduced during winter.

* Kriek, J.C. 1995. Long Str. 25, Kimberley 8301.

Management recommendations

Since roan is an endangered species, the aim should be to increase its numbers by maintaining a positive growth rate. Supplementary feeding was correlated significantly with growth rate and it should be implemented during winter to keep animals in a good condition. In this study, populations with the highest rate of increase were fed during winter with at least 0.5 kg/animal/day of a combination of lucerne, antelope cubes and lick. In addition, animals could be grazed on adapted planted pastures such as *Cenchrus ciliaris*. A high percentage of breeding females within the population may also influence population growth. Animals should be treated for parasites and predators should be controlled when and where necessary. Under intensive management, animals may be stocked at a density of up to 20 animals/km². Numbers of potential competitors for food resources such as buffalo, zebra and blue wildebeest should also be limited (Joubert, 1976).

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CHAPTER 14

Population viability analysis

Introduction

Conservation has traditionally concentrated on ecosystem management and on protection. Protection can control deterministic problems such as habitat degradation, unsustainable utilization etc. However conservation should be increasingly based on population management to mitigate stochastic problems (Foose, de Boer, Seal & Lande, 1995).

Roan were once widespread in southern Africa but have been reduced to a few small, isolated populations in South Africa (Skinner & Smithers, 1990). The causes were mainly over-harvesting followed by the introduction of exotic animals such as livestock, and habitat destruction. Fragmented habitats and isolated populations are common problems for endangered species (Doak, 1989), which not only reduces the distribution of animals, but also densities to levels where demographic and genetic constraints threaten the existence of populations (Murphy, Freas & Weiss, 1990). Once a population is small the influence of stochastic processes such as demographic stochasticity, environmental variation, catastrophic variation and genetic drift become more significant and they are more vulnerable to extinction than large populations (Berger, 1990; Lacy, 1995). Variations of these stochastic events place such populations at high risk of extinction (Lacy & Clark, 1990). Furthermore the fate of small populations is often determined by random chance than by the mean birth and death rates that reflect adaptations to their environment (Lacy, 1995). These factors are, however, less important in populations of more than 100 animals (Lacy & Clark, 1990; Ballou, 1995).

Demographic stochasticity is the variation in population reproduction, mortality and imbalances in the age structure and sex ratio that will lead to unpredictable oscillations between population growth and decline (Lacy & Clark, 1990; Stewart & Hutchings, 1996). Even in a constant environment, mortality and fecundity vary annually due to variations between individuals (Durant & Harwood, 1992). Genetic stochasticity is the random genetic change in sexually reproducing, diploid organisms. As allele frequencies change at random with each generation

(genetic drift) genetic variants are lost from the population with a resulting decreased genetic variance (Lacy & Clark, 1990; Stewart & Hutchings, 1996). This increased homozygosity reduces fecundity, survival, viability, and adaptation to changing environments, therefore to decreased fitness (Lacy & Clark, 1990; Ballou, 1992 & 1995; Possingham, 1996). Environmental stochasticity is the variation in population birth and death rates caused by random environmental fluctuations (Lacy & Clark, 1990; Durant & Harwood, 1992). Catastrophic events such as droughts, floods, fire, predation and habitat destruction fall into this category.

Individuals with a low genetic variation often have lower reproductive rates and higher mortality rates than those which are more heterozygous (Ballou, 1992 & 1995). The Nylsvlei founder population originated from the Percy Fyfe Nature Reserve population (Environmental Affairs Northern Province) when 12 animals were released into the reserve in 1977. Grobler & Nel (1996) found that the Percy Fyfe population has a low level of genetic diversity. However, if more tissue samples were used and other molecular genetic tools such as protein sequencing and DNA fingerprinting were used for testing genetic diversity, some allozyme heterogeneity could probably be found in the Percy Fyfe population (Grobler & Nel, 1996). Grobler & Van der Bank (1993) found a similar low heterozygosity of 1.86 % in roan from the Njika National Park, Malawi. Although that population consisted of approximately 1 000 animals the authors suggested that the population experienced a bottleneck in the past or that it originated from a small founder population.

A process that has been developed over recent years to address conservation strategies and population management of small, endangered populations is population viability analysis (PVA) (Lacy & Clark, 1990; Lindenmayer, Clark, Lacy & Thomas, 1993). The general goal of a PVA is to understand the factors and their interactions that are involved in the extinction process (Ralls, Garrott, Siniff & Starfield, 1992). PVA is a tool (Lacy & Clark, 1990) to quantify the effects of stochastic events on the extinction risks. In a comprehensive PVA it is necessary to include demographic, genetic and environmental stochasticity (Ralls *et al.*, 1992; Ruggiero, Hayward & Squires, 1994; Song, 1996). A PVA is the systematic evaluation of the relative importance of factors and processes that have the highest influence on species extinction probabilities and loss of genetic diversity (Lindenmayer *et al.*, 1993; Lacy, 1995; Soulé, 1987 in Lacy, Hughes & Miller, 1995; Bustamante, 1996). PVA is also used to indicate where further field work is necessary to increase our understanding of population persistence, and to evaluate various management actions on the survival of a population (Lacy & Clark, 1990; Lindenmayer *et al.*, 1993; Ballou, 1995;

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Bustamante, 1996; Possingham, 1996; Song, 1996). A summary of further applications and limitations of PVAs is given by Lindenmayer *et al.* (1993). The development of PVAs has not yet reached the stage where it can be said, with certainty, that a population has a 95 % probability of surviving *x* number of years (Murphy *et al.*, 1990). To achieve this extinction risk, probabilities should be parameterized. In spite of this PVA has been used extensively in the management of threatened species (Ralls *et al.*, 1992; Lindenmayer *et al.*, 1993; Lacy, 1995; Bustamante, 1996; Mills, Hayes, Baldwin, Wisdom, Citta, Mattson & Murphy, 1996; Moehlman, Amato & Runyoro, 1996; Song, 1996) and small populations (Somers, 1997).

The roan population in the Nylsvlei Nature Reserve (NNR) of approximately 50 animals has been protected against deterministic problems in the past. However the conservation of this population did not involve population management to alleviate stochastic problems. The aim of this preliminary PVA was to identify those critical demographic parameters that have the greatest effect on the probability of survival. These demographic characteristics could be used as predictors of extinction and to design a monitoring and management plan for this population.

Methods

Individuals were assigned to age-classes which covered one calendar year. The age-classes were 0 (0-1 year), 1 (> 1-2 years), 2 (> 2-3 years), 4 (> 3-4 years), 5 (> 4 years) (Chapter 12). Other parameters were varied during simulations such as calf sex ratio (0.25-0.75 males), age structure (stable and non-stable), age specific mortality (20-80 %), number of animals harvested (15-62 %) and supplemented (20-60 %). Sex specific mortality was regarded the same during the first two years after birth as was found by Joubert (1976).

Default population parameters incorporated into the stochastic simulation model were obtained from the literature (Huntley, 1971; Poché, 1974; Joubert, 1976; Wilson & Hirst, 1977; Lacy *et al.*, 1995) and some from the Nylsvlei population itself. A carrying capacity of 50 roan for the NNR was assumed based on the negative growth rate at a population size of approximately 46 in 1995 (Dörgeloh, Van Hoven & Rethman, 1996). The default population parameters and other variables were:

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Carrying capacity of the Nylsvlei Nature Reserve	50
Trend projected in carrying capacity	No
Initial population size (1996)	48
Mating system	Polygynous
Age when females begin breeding (time when first offspring are born)	3 years
Age when males begin breeding (time when first offspring are born)	8 years
Maximum age beyond which all animals stop breeding	12
Males in breeding pool	10 %
Is reproduction density dependent?	Yes
Exponential steepness (B)	2
Allee parameter (A)	1
Breeding females that produce litter size 1	80 %
litter size 2	20 %
Mean litter sizes for the average year	1
Maximum number of young/litter	2
Environmental variation (reproduction) correlated with environmental variation (survival)	Yes
Are good years for reproduction also good years for survival?	Yes
Incorporate inbreeding depression?	Yes
Apply the heterosis model?	Yes
No. of lethal equivalents per diploid genome in the population	3.14
If harvesting was included in the simulations, then:	
First year of harvest	2
Last year of harvest	10
Harvest interval	2
If supplementing was included in the simulations, then:	
First year of supplementation	0
Last year of supplementation	10
Supplement interval	5

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A PVA was conducted with the VORTEX programme. The VORTEX computer programme is a Monte Carlo simulation of the effects of demographic, environmental, and genetic stochastic events on wildlife populations. It models population dynamics as discrete, sequential events (e.g. births, deaths, and catastrophes) according to defined probabilities (Lacy *et al.*, 1995). Ballou (1995) suggested that only one or two factors should be examined at a time since interactions between these many factors would be too complex. Critical factors that have an impact on the population should be chosen and others that don't should be ignored. Various population parameters and environmental variations, and some combinations thereof, were analysed in 92 iterations (each had 100 simulations).

Results

The simulation results predicted the survival probability given the mean population parameters and the simulated stochasticity. In the majority of simulations (73 %), populations became extinct within 40 to 50 years. Demographic parameters and management strategies that increased the population persistence to more than 50 years were selected for future population monitoring.

Of all simulations conducted the single most important parameter to increase the probability of population survival to 80 years was a female calf (age 0-1 year) mortality of less than 20 % (Fig. 14.1). A mortality of less than 40 % increased the survival to 70 years. The probability of extinction within 70-80 years was 0.60 (Table 8.1, Appendix 8). A low female calf mortality improved the probability of population survival by approximately 60 % compared to most other factors. Other important factors that improved the probability of survival by approximately 20 %, were new born male calf mortality of less than 20 % (population persistence to 60 years) and a 2-3 year old female mortality of less than 20 % (population persistence to 60 years) (Fig. 14.1). Even a mortality rate of less than 40 % of 2-3 year old females increased population persistence to 60 years. The populations went extinct within 50-60 years at a probability of 0.88 and 0.71 respectively (Table 8.1, Appendix 8).

The harvesting of animals and supplementing the population with genetically different animals in similar numbers improved the survival probability. The greatest improvement in population persistence of 20 % was found when some adult females (age > 4 years) were harvested and supplemented with females of 2-3 years of age (first time breeders) in equal

numbers (Fig. 14.1), or when age 3-4 year old males (after they have been evicted from the breeding herds) were harvested and supplemented. Under this harvesting/supplementing strategy populations persisted up to 60 years with a probability of extinction of 0.89 for the female and 0.92 for male section (Table 8.1, Appendix 8).

Simulations were conducted of the worst and the best scenarios. Of the various combinations of simulations done the best scenario had a population size of 25 with a stable age distribution, a sex ratio at birth of 25 % males, which was harvested every second year and supplemented every five years with genetically different animals (Fig. 14.2). This population went extinct before 70 years at a probability of 0.92 (Table 8.2, Appendix 8). In contrast populations under the worst scenarios were not harvested and supplemented with other animals, irrespective of size and age distribution to some extent. Their sex ratios at birth were 75 % males. All these populations went extinct within 20 years (Table 8.2, Appendix 8).

Discussion

In general most simulations predicted that the Nylsvlei population (based on 48 animals) will persist for only 40 to 50 years. Results usually underestimate a population's probability of extinction because not all the population, environmental and genetic factors are taken into account (Ballou, 1995). Berger (1990) also predicted extinctions of bighorn sheep (south-western North America) within 50 years if populations were fewer than 50 animals. Local extinctions could not be "stopped" because 50 animals was not a minimum viable population. He suggested that population size should be used as a marker of persistence.

Beudels, Durant & Harwood (1992) found that population size and the number and sex of calves born each year should be monitored. Concerning population size these authors monitored a meta-population consisting of six stable herds (minimum 144 animals) in a large protected area. They came to the conclusion that perhaps only the number of herds rather then the total population size should be monitored. This would not apply to NNR where there is only one herd confined in a small area. In the NNR, the total population size should rather be monitored.
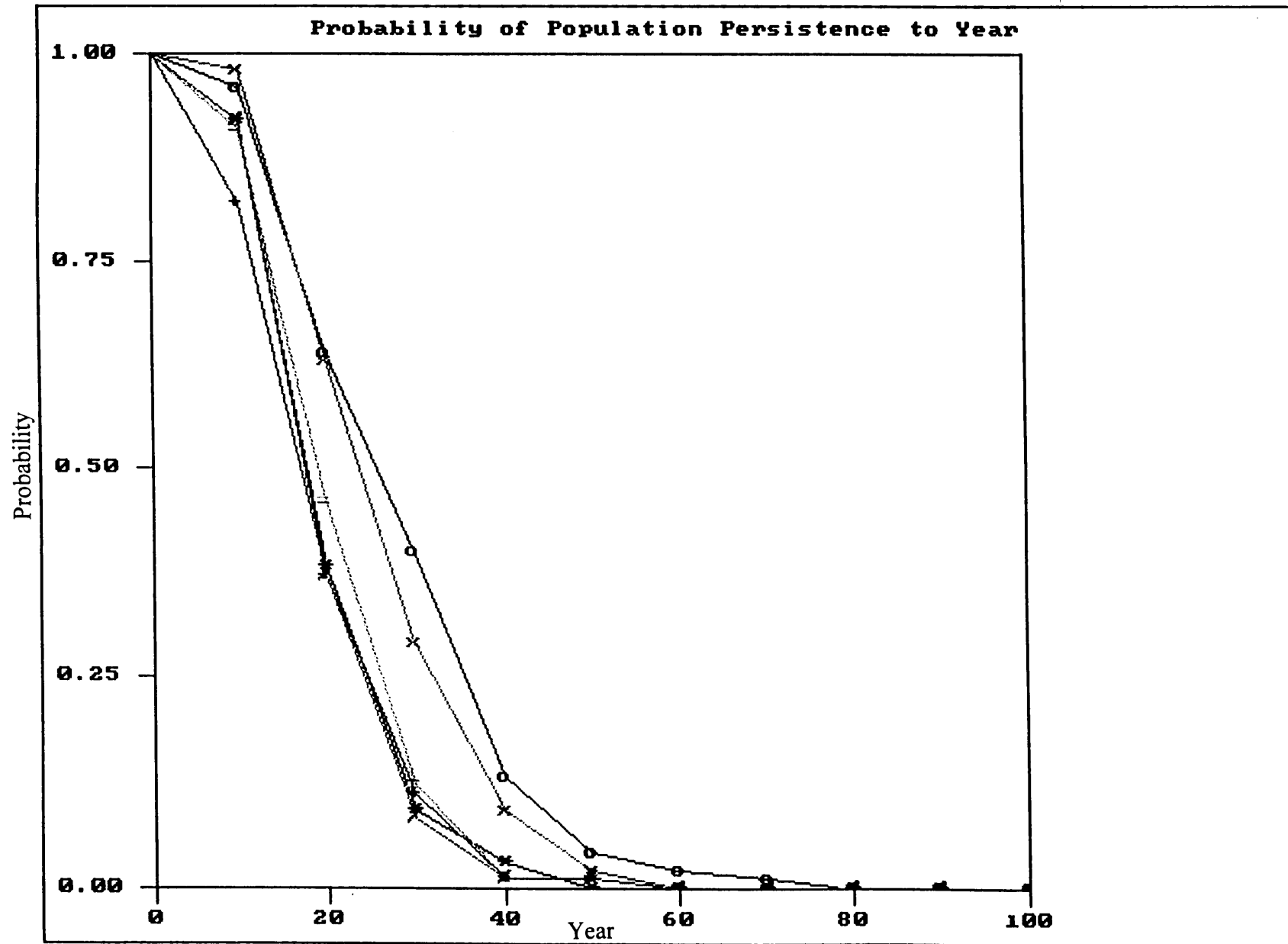
Fig. 14.1: Probabilities of persistence of simulated populations (n = 48): + (harvest adult females, n =6 and supplement with females age 2-3 years, n = 6), = (male mortality age 0-1 year is 20 %), / (harvest males age 3-4 years, n =6 and supplement with males age 3-4 years, n = 6),* (calf sex ratio is 25 % males), x (female mortality age 2-3 years is 20 %), o (female mortality age 0-1 year is 20 %).

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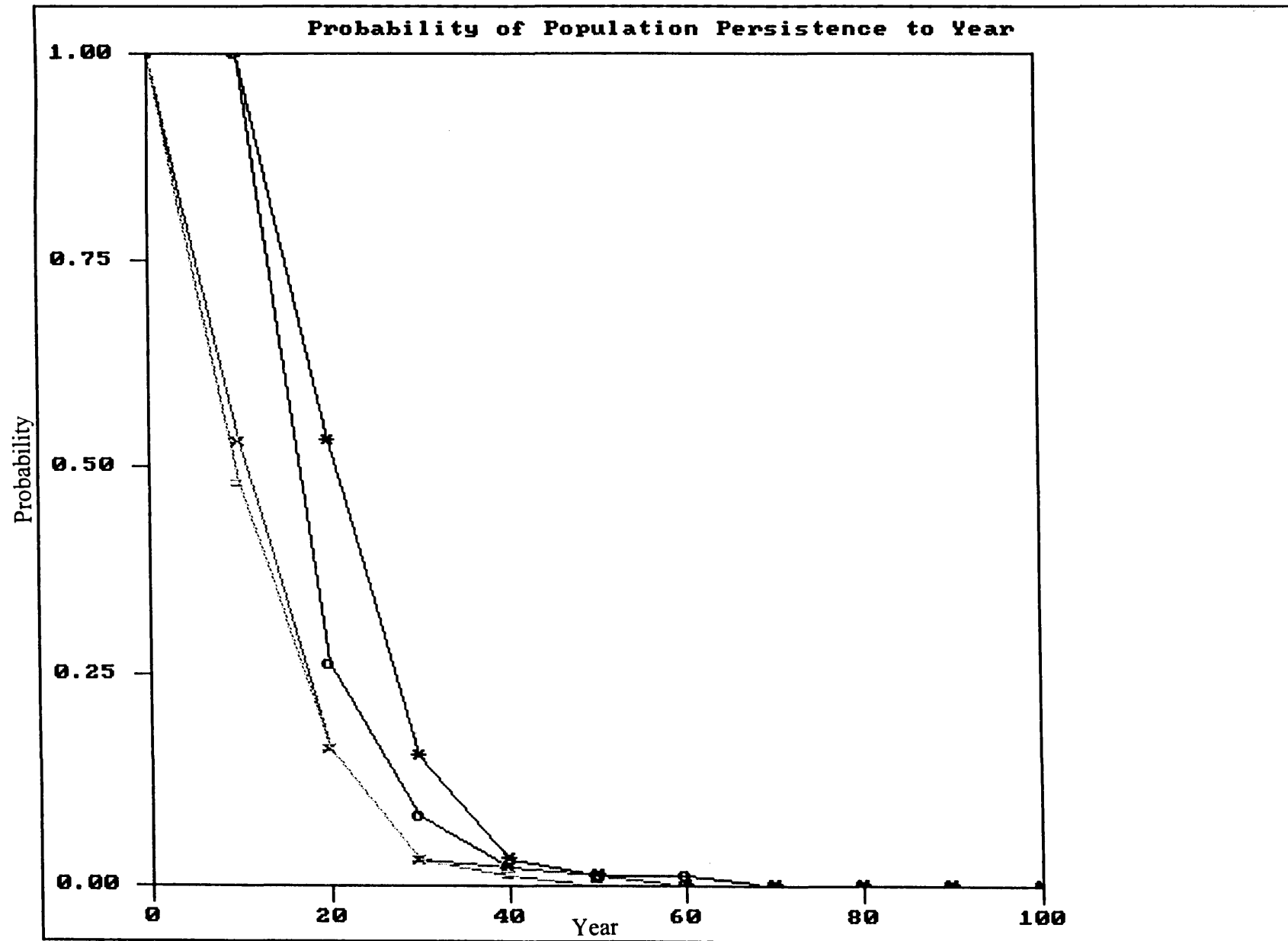
Fig. 14.2: Probabilities of persistence of simulated populations: = (population size is 25, non-stable age distribution, harvested and supplemented), **x** (population size is 48, non-stable age distribution, not harvested and supplemented), **o** (population size is 25, stable age distribution, harvested and supplemented), * (population size is 48, non-stable age distribution, harvested and supplemented).

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Simulations with a smaller population size did increase population persistence but the growth rate was reduced in comparison with a larger population. Dörgeloh *et al.* (1996) pointed out that a smaller population size than at present would probably increase the growth rate. This is because the present population is near carrying capacity.

Roan could be regarded as a prolific breeder based on the reproductive potential such as a high conception and birth rate (Joubert, 1976). Therefore demographic stochasticity limiting population growth should rather be sought in post-natal stages than in reproductive deficiencies (Joubert, 1976). This was shown in the PVA conducted on the roan population of the NNR. The most critical population parameter influencing extinction risk was new born calf mortality, especially that of female calves. If this mortality rate exceeded approximately 40 % it would negatively influence the probability of population survival in the long term. Sub-adult female (2-3 years old) mortality of more than 40 % also had a negative influence on population survival.

A biased sex ratio in favour of males may influence population growth rate. When the proportion of males at birth was reduced to 0.25 the probability of survival was improved by approximately 40 %. However the population still became extinct after 40 to 50 years (Table 8.1, Appendix 8). It was, therefore, not regarded as an important indicator of extinction for this population, but due to its effect on survival it is advisable to monitor the sex ratio at birth.

The harvesting and supplementation of individuals had a greater effect on population survival compared to the present no-harvest strategy. This is expected from a population which originated from a small, probably genetically poor, founder population. The Nylsvlei population originated from the Percy Fyfe Nature Reserve when 12 roan (3 males and 9 females) were introduced in 1977 (* Environmental Affairs Northern Province, 1996. pers. comm.). It is well known that inbreeding affects the fecundity and mortality of animals. Inbred bighorn sheep have been reported to suffer higher juvenile mortality than those from less inbred populations (Berger, 1990).

Ginzburg, Ferson & Akçakaya (1990) stated that data sets of 10 to 20 years are insufficient to precisely estimate extinction risks or to reconstruct reliable measurements of density dependence. This data set of two years is, therefore, insufficient to reliably assess extinction. For a comprehensive PVA more accurate population data on sex ratios at birth, age and sex specific mortality and its variation, and the effect of catastrophes on reproduction and survival rates collected over a longer period is needed.

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Management recommendations

Managing small populations of rare species should aim to prevent population extinction. To maximize population viability effective management intervention is, therefore, necessary. Mortality rates of especially female calves of the Nylsvlei population should be monitored. In addition, Beudels *et al.* (1992) suggested that calf production and birth rate should be monitored annually. In the NNR measures to reduce calf mortality have to be taken to increase population viability. A possible practical solution, would be to implement a supplementary feeding programme during winter when calves could be more closely observed. It may also improve the condition of females during winter and, therefore, calf survival (Dörgeloh *et al.*, 1996). Another option would be to patch burn during the dry period to increase forage quality and productivity.

To improve population growth and genetic variation in this potential genetically poor population, harvesting and supplementing this population would be advisable. It is, therefore, recommended that a harvesting strategy be implemented similar to the one tested in this PVA, to reduce the population size. This may increase the population growth rate as was suggested by Dörgeloh *et al.* (1996). A higher growth rate would produce a regular offtake of animals for restocking other conservation areas. In addition genetically different breeding stock should be introduced to enhance the genetic variability. A greater genetic diversity may increase the chances of survival (Berger, 1990).

Genetic management of the Percy Fyfe population (Grobler & Nel, 1996) and, therefore, of all its other progeny populations such as those in the NNR and the Skuinsdraai Nature Reserve would be advisable. A similar management strategy should be applied to roan originating from Malawi which were also found to be genetically poor (Grobler & Nel, 1996). Those roan were found on Rooipoort Farm, Le Grange Farm and some on Sable Ranch.

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CHAPTER 15

Faecal analysis

Introduction

Nutrient levels of collected forages are generally an unreliable method to determine the diet quality of wild herbivores (Howery & Pfister, 1990). Animals are able to select the most nutritious plant parts (Howery & Pfister, 1990), thereby ingesting higher quality foods than found in indiscriminately collected forage samples (Irwin, Cook, McWhirter, Smith & Arnett, 1993).

A noninvasive method for assessing dietary nutrient levels in wild ruminants is to determine faecal nitrogen (FN) (Howery & Pfister, 1990; Jenks, Soper, Lochmiller & Leslie, 1990; Irwin *et al.*, 1993; Robbins, 1993). This method applies to animals feeding mainly on grasses. In general grasses contain virtually no tannins or proanthocyanidins, particularly when they are cured (Chesselet, Wolfson & Ellis, 1992; Irwin *et al.*, 1993) as during the dry season. If browse forms a large proportion of the diet then the relationship between dietary and faecal protein content is less close (Mould & Robbins, 1981 in Novellie, Fourie, Kok & Van der Westhuizen, 1988). Forages containing soluble digestion inhibitors such as phenolics (e.g. tannins) can adversely affect FN correlations (Howery & Pfister, 1990) by increasing the faecal nitrogen concentration (Irwin *et al.*, 1993). Heitkönig (1993) showed that roan feed mainly on grasses (84 % of the year-round diet) which implied that faecal protein could be used for roan as an indicator of dietary quality.

Many different faecal components such as N, crude fibre, chromogen, normal-acid fibre, acid detergent fibre (ADF), neutral detergent fibre (NDF), and methoxyl have been used to indirectly predict forage digestibilities, lignin and dietary protein with regression analyses (Erasmus, Penzhorn & Fairall, 1978; Howery & Pfister, 1990; Minson, 1990; Irwin *et al.*, 1993). Faecal N is the most common parameter to assess forage quality (Irwin *et al.*, 1993). It should, however, be used only as a very general indicator of protein intake (Robbins, 1993) and other quality measures such as digestibility. Faecal N can be used to assess the nutritional status of free-ranging ungulates and the seasonal relationships between habitats and populations (Irwin *et al.*, 1993). Grant, Meissner & Schultheiss (1995) used FN and FP (faecal phosphorus) as indicators of

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the nutritive quality of veld and of the condition of animals. These nutrients differed between species, areas, forage types, seasons and soil types.

Poor nutrition (usually energy and N) and a low mineral intake may lead to poor lactation and may limit the ability of females to raise their off-spring (Freeland & Choquenot, 1990). This limiting demographic parameter may reduce population growth in addition to predation, parasitism and genetic causes. Information obtained from faecal analysis could be used to determine the time of initiating or discontinuing a supplementary feeding programme.

Objectives of this investigation were to determine if feacal quality changes seasonally and to estimate the winter nutritional status of roan populations in different areas under different management systems. The null hypotheses were tested that faecal quality does not change seasonally, and that it does not differ among roan populations in winter residing in different areas.

Methods

Nylsvlei Nature Reserve (NNR)
Faecal samples exposed to field conditions, provided they have not been attacked by insects, can be collected up to 7 days (Leite & Stuth, 1994), 14 days (Pearce, Lyons & Stuth, 1993) or less than 24 days (Jenks *et al.*, 1990) after defaecation for nutritional quality analysis to estimate FN, faecal neutral detergent fibre and acid detergent fibre. For this study, a minimum of five fresh faecal piles (collected immediately after defaecation or when still wet), with the assumption that these represented five different individuals, were sampled monthly from July 1994 to June 1996. A minimum of 30 whole pellets from each faecal pile were collected. Faecal samples were kept in open plastic bottles in a cool, dry place before being frozen within five hours after collection for storage.

Faecal samples were dried at 80 °C for 48 hours and ground with a Knifetech Mill to a grain size of 1 mm (Minson, 1990). Each of the five samples collected per month was analysed separately. Samples were analysed with wet chemical analysis for total nitrogen with the Kjeldahl method (A.O.A.C., 1980), neutral detergent fibre and acid detergent fibre (Goering & Van Soest, 1970), and for the macrominerals Ca, P, K, and Na (Nana, 1971; Hambledon, 1976; Zasoski & Burau, 1977; Bessinger, 1988). Further descriptions of the above methods are also found in Zacharias (1986), Van Soest (1987), Gauthier, Huot & Picard (1991) and Robbins (1993). The

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protein content of forages was measured by multiplying the nitrogen content by a factor of 6.25 (Cheeke, 1991; McDonald, Edwards, Greenhalgh & Morgan, 1995).

Other populations

Faecal samples from other populations in the Percy Fyfe Nature Reserve, Rooipoort Farm, Sable Ranch, Le Grange Farm and the Skuinsdraai Nature Reserve (Chapter 2) were collected during July/August 1995 only. Approximately 30 whole pellets from five different faecal piles were collected of each population. Samples were prepared and analysed as described for the NNR.

Statistical analyses

Seasonal differences in faecal chemical concentrations for the Nylsvlei population, and differences between various populations were tested with general linear modelling (PROC GLM) (SAS Institute, 1990).

Results

Seasonal differences in faecal nutritive concentrations

Differences were found in faecal nitrogen (FN) ($p = 0.0001$), % NDF ($p = 0.0040$), and % ADF ($p = 0.0022$), between winter and summer. During summer the FN was higher and faecal fibres were lower, compared to winter. This corresponded with seasonal dietary trends. No significant differences between seasons were found for minerals, % Ca ($p = 0.4148$), % P ($p = 0.0910$), % K ($p = 0.0936$), and % Na ($p = 0.2069$) (Fig. 15.1, Table 15.1).

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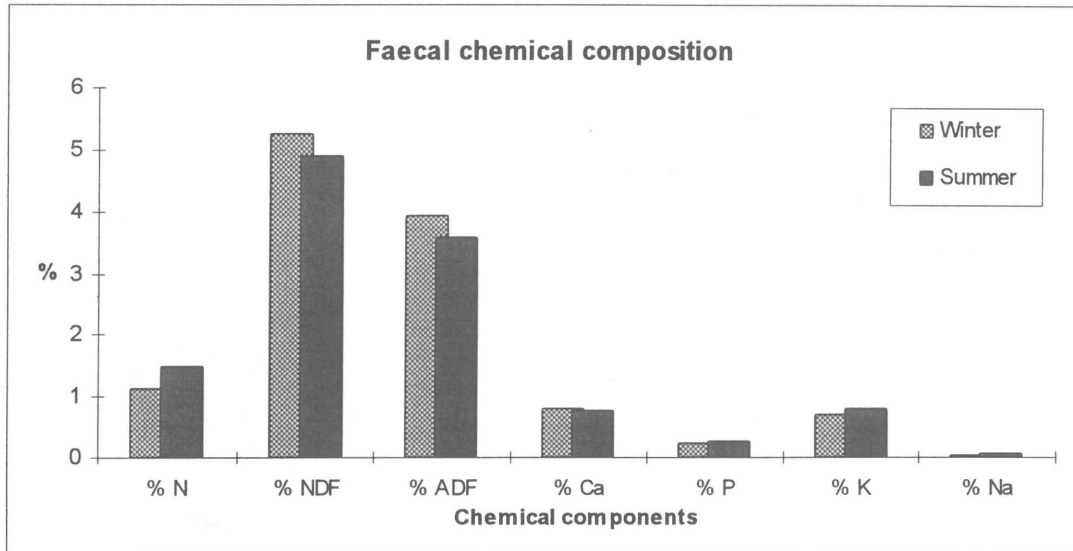
Fig. 15.1: Faecal chemical composition of roan in the NNR during winter (May to September) and summer (October to April). Values of fibres (% NDF and % ADF) are 10^{-1}.

Table 15.1 Faecal chemical composition of different populations. In the NNR data was pooled for winter (May to September) and summer (October to April). Faecal samples from other populations were collected in July/August 1995 only.

	% N	CP	% NDF	% ADF	% Ca	% P	% K	% Na
Nylsvlei N.R.								
Winter								
Mean	1.0990	6.8690	52.5619	39.2247	0.7963	0.2340	0.6726	0.0371
SD	0.2326	1.4540	3.8564	4.6194	0.0927	0.1282	0.2026	0.0182
Summer								
Mean	1.4733	9.2081	48.7161	35.8961	0.7556	0.2776	0.7974	0.0652
SD	0.2684	1.6773	5.0155	4.7209	0.2192	0.0569	0.3079	0.1041
Percy Fyfe N.R.	1.5000	9.3750	50.3496	38.9424	2.4480	0.6380	0.3925	0.0793
SD	0.1839	1.1494	4.9951	4.0540	0.8398	0.2616	0.1212	0.0612
Rooipoort Farm	1.1172	6.9825	55.8000	38.6516	1.4180	0.4674	0.5320	0.0418
SD	0.0712	0.4448	2.4999	1.9982	0.1997	0.1653	0.1130	0.0183
Sable Ranch	1.5904	9.9400	56.7012	45.6738	0.9702	0.2736	0.5040	0.0282
SD	0.3036	1.8975	2.5715	2.1972	0.1365	0.0441	0.1792	0.0109
Le Grange	1.1964	7.4775	52.9014	39.6146	1.3300	0.1884	0.5700	0.0456
SD	0.1228	0.7674	4.8841	2.7198	0.1521	0.0178	0.1414	0.0244
Skuinsdraai N.R.	1.3590	8.4938	51.7967	43.3937	1.3737	0.2383	0.3533	0.0160
SD	0.0448	0.2800	1.9783	3.2573	0.4101	0.0446	0.0569	0.0035

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Differences in faecal nutritive concentrations between populations

Faecal nitrogen in the NNR was significantly lower than those in Percy Fyfe N.R. (p = 0.0001), Sable Ranch (p = 0.0001), and Skuinsdraai N.R. (p = 0.0073), during winter. The lower % NDF from NNR differed (p < 0.05) from Rooipoort Farm (p = 0.0206) and Sable Ranch (p = 0.0063), and the lower % ADF from Sable Ranch (p = 0.0001) and Skuinsdraai N.R. (p = 0.0128) (Fig. 15.2, Table 15.1).

Macrominerals differed significantly (p < 0.05) between some of these areas. Percentage Ca from the NNR did not differ from Sable Ranch (p = 0.5344) but was lower (p < 0.03) compared to the other areas. Percentage P from the NNR was significantly lower than that from Percy Fyfe N.R. (p = 0.0008) and Rooipoort Farm (p = 0.0385); % K was significantly higher than that from Percy Fyfe N.R. (p = 0.0062), Sable Ranch (p = 0.0422) and Skuinsdraai N.R. (p = 0.0058), and % Na was lower (p = 0.0032) than on Percy Fyfe N.R. (Fig. 15.2, Table 15.1).
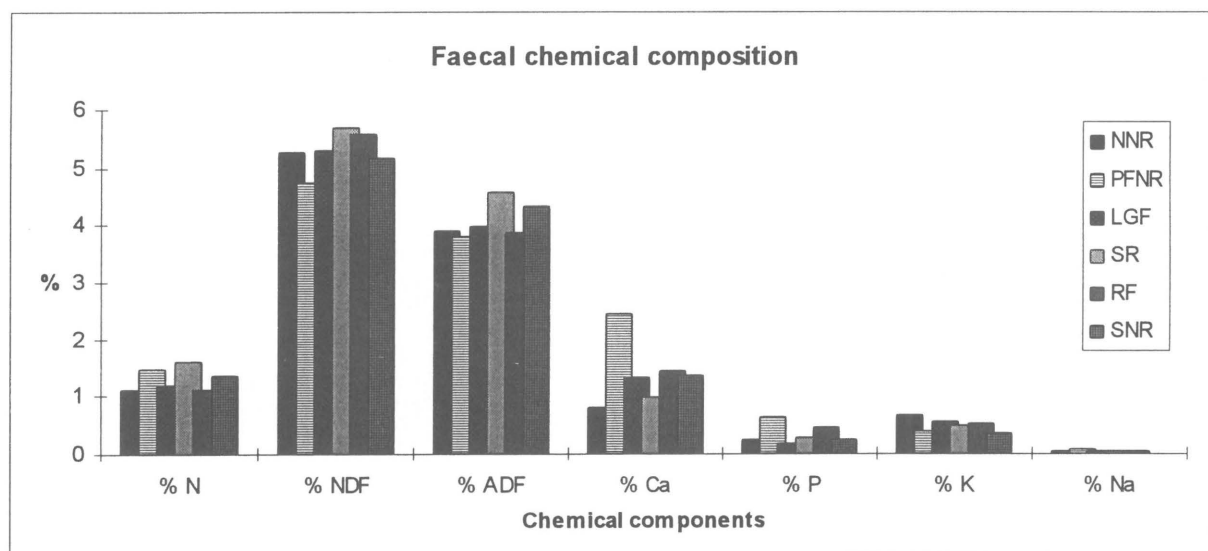
Fig. 15.2: Winter faecal chemical composition of roan populations in the NNR (Nylsvlei Nature Reserve), PFNR (Percy Fyfe Nature Reserve), LGF (Le Grange Farm), SR (Sable Ranch), RF (Rooipoort Farm), and SNR (Skuinsdraai Nature Reserve). Values of fibres (% NDF and % ADF) are 10^{-1}.

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Discussion

Grant *et al.* (1995) analysed faecal samples from five ruminants [buffalo (*Syncerus caffer*), blue wildebeest (*Connochaetus taurinus*), impala (*Aepyceros melampus*), kudu (*Tragelaphus strepsiceros*) and giraffe (*Giraffa camelopardalis*)] in eight different lanscapes representing the major plant and soil types in the Kruger National Park. They found the lowest faecal concentrations of N and P to be in July-September. Highest dietary N concentrations were in January-March and highest P concentrations from October to December. In the NNR the highest FN and FP were found in summer which related to the dietary concentrations. Seasonal differences in protein and fibre concentrations are related to the variations in forage quality and could be used as indicators of seasonal forage quality. Faecal N is an indication of the digestibility of grasses (Grant *et al.*, 1995). However, diet composition may influence the predictability of faecal nitrogen for identifying nutritional deficiency among ungulates (Irwin *et al*, 1993). Faecal nitrogen-dietary quality associations deteriorate when dietary nitrogen levels exceed 2.4 % nitrogen (15 % crude protein) (Irwin *et al.*, 1993). A high-fibre diet also produces a higher metabolic faecal nitrogen (MFN) (Robbins, 1993) and consequently a higher total faecal nitrogen.

In contrast macrominerals did not change significantly across seasons but would probably change across plant communities. This could not be measured since roan were feeding across plant communities. Faecal macrominerals could not, therefore, be used as an indicator of seasonal forage quality, but only to compare the mineral content between areas.

Significant differences in winter faecal quality estimates between the different populations reflects a difference in dietary quality. The low FN of the Nylsvlei population may be an indication of a nutrient deficiency during winter. Wilson & Hirst (1977) stated that roan on reserves in the former Transvaal province suffered severe nutritional deficiencies and that the nutritional status of these roan was a primary limiting factor. The basic deficiences in the sourveld areas (e.g. Percy Fyfe N.R.) were protein, phophorus and selenium (Wilson & Hirst, 1977). Sodium, calcium, magnesium and potassium were also deficient.

A low faecal nitrogen concentration would indicate potential nutritional deficiency via a reduced forage intake (Irwin *et al.*, 1993). Ruminants, including wild ungulates, need a minimum of 5 % crude protein (0.8 % nitrogen) in their food to maintain body weight (Liversidge & Berry, 1995; Kinyamario & Macharia, 1992). For example blue wildebeest require about 5-6 % dietary protein for maintenance (Sinclair, 1975 in Kinyamario & Macharia 1992). If dietary protein levels

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fall below 5 %, food intake in ruminants increases to compensate for the low protein intake. The microbe activity is inhibited so that nitrogen excretion exceeds nitrogen intake (Kinyamario & Macharia, 1992). A minimum N concentration of 1.1 to 1.2 % is required to maintain rumen fermentation (Grant *et al.*, 1995).

It appears that P becomes a limiting nutrient below 0.2 % faecal phosphorus (FP) when FN increases due to an enhanced endogenous N excretion (Grant *et al.*, 1995). Howery & Pfister (1990) found FN and FP to be independent of physiological condition for deer. This was confirmed by Grant *et al.* (1995) who found a non-significant correlation between the condition of grazers and faecal N. Both FN and FP concentrations should be considered when interpreting results on forage quality because their excretion is linked (Grant *et al.*, 1995).

Signs of sodium deficiency is indicated by decreased faecal sodium concentrations (Henry, 1995). Faecal sodium concentrations in the NNR appeared to be average.

Conclusion

The seasonal variation in faecal nitrogen and fibres, with a higher quality in summer (high protein and low fibres) is a reflection of the changing forage quality. Nutritional deficiencies usually occur in winter or the dry period of the year. Seasonal changes in macrominerals were not significant but differences were found between populations residing in different geographical areas. Since all populations other than that of the NNR were artificially fed during winter, a generally higher faecal quality was found in these populations. It appeared that artificial feeding during winter is advantageous for animals by increasing its nutritive status. Wilson & Hirst (1977) stated that the management of roan must take their susceptibility to nutritional deficiencies and resultant diseases into account.

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CHAPTER 16

Habitat selection

Introduction

The maintenance of wildlife populations through effective management requires an understanding and prediction of their habitat requirements (Scogings, Theron & Bothma, 1990; Clark, Dunn & Smith, 1993). Ecological habitat selection theory suggests that population densities are an indication of habitat quality (Fagen, 1988). Habitat features and requirements of herbivores may change with time and space. For African ungulates the main determinants of local migrations are forage availability, forage quality in terms of mineral nutrition, water availability (Ben-Shahar & Coe 1992) and certain landscape types and features such as topography, soil types, vegetation composition and structure (Ben-Shahar, 1995). Seasonal movements of animals may be attributed to climatic conditions, the seasonal phenological development of forage and after fire (Munthali & Banda, 1992). To determine which habitat features are important to a species a classification based on human perceptions has to be implemented initially. This can be modified and adapted according to results from statistical analysis indicating which features are important for the species.

Simple statistical techniques may not adequately assess the multidimensional nature of habitat use by wildlife (Clark *et al.*, 1993). While the Chi-square analysis is a hypothesis-testing technique, multivariate analysis is a hypothesis-generating technique (Scogings *et al.*, 1990). Multivariate analysis is commonly used to determine habitat selection by ungulates (Morrison, Marcot & Mannan, 1992; Clark *et al.*, 1993; Pauley, Peek & Zager, 1993; Schooley, 1994; Ben-Shahar, 1995). Multivariate models help identify significant habitat parameters that account for observed variation in the distribution and abundance of widlife species (Morrison *et al.*, 1992). They are an efficient way of testing for temporal variation in habitat selectivity (Schooley, 1994). The null hypothesis that the distribution of roan is random over all plant communities and that the utilization of plant communities is in proportion to their availability, was tested with the Chi-square goodness-of-fit test. Other null hypotheses tested were:

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1) there is no difference in plant community selection between breeding herds and bachelor males,

2) there is no difference in selection between newly burnt areas and non-burnt areas.

To test these null hypotheses a few assumptions had to be made as recommended by Fagen (1988):

1) Animal locations are representative of the population segment (breeding herd) or character (habitat use).

2) Animals move freely to preferred habitats.

3) Animals prefer the available habitats that offer the highest per capita resource availability.

4) Resource availability is predictable.

5) Moving between habitats costs little.

6) Moving within each habitat costs the same.

Methods

When studying resource selection a study design must be chosen that is cost effective and realistic given labor limitations. It is also important to know if the investigation will be at the population level or at the individual level, and the type of statistical analysis to be used. This study investigated selectivity and followed Design 1 as described by Thomas & Taylor (1990) where availabilities and utilization for the habitat resource were estimated for all roan (individuals were not identified). Observations of roan were assumed to be independent and the availability and utilization of the resource (plant communities) was assumed equal for all individuals. The area covered by each plant community was measured with a digital planimeter (Placom KP-80). Availability of the resources is presented as a percentage of area (Chapter 2).

The distribution of roan (630 roan were observed over the study period) in the Nylsvlei Nature Reserve (NNR) was monitored on a monthly basis from May 1994 to April 1996. A standard route of 59 km (90 % of the road system) within the reserve was covered by vehicle at an average speed of 20 km/h. The same route and two experienced observers were used each

time. The census was conducted from 06:00 to 11:30 in summer and from 07:00 to 12:30 in winter.

Statistical analysis

Small numbers of individuals cause unacceptably high Type II error rates (Thomas & Taylor, 1990) when the statistical tests predict absence although the species is actually present. Alldredge & Ratti, 1986 in Thomas & Taylor (1990) suggested at least 50 observations on ≥ 20 animals are required for adequate hypothesis testing. This level of observation intensity could not be achieved during this study and data was therefore pooled across years.

Annual variation in habitat utilization should be taken into account necessitating the analysis of habitat selection data for each year separately (Schooley, 1994). Pooled data does not provide an average or typical pattern of habitat selection. If combined data over years has to be used, a test for annual variation or data for individual years should be presented (Schooley, 1994).

The Chi-square goodness-of-fit test is the most commonly used method of statistically comparing resource use and availability (Thomas & Taylor, 1990). It requires the assumption that resource availabilities are known constants (percentage availability) and not estimated quantities (Thomas & Taylor, 1990). Another assumption is that a relationship exists between density and relative preference. The power of the Chi-square goodness-of-fit test to detect habitat selection is decreased by an increasing habitat complexity (Clark *et al.*, 1993). It also is sensitive to the subjective inclusion or exclusion of resources if a resource is rarely used but commonly available. The Chi-square test will most likely indicate resource selectivity. A similar problem is found with preference ratios (Thomas & Taylor, 1990). The roan distribution data was subjected to a Chi-square test with PROC CHISQ (SAS Institute, 1990) to detect habitat selection and to compare the results with those of multivariate analysis for investigating roan-habitat relationships.

To substantiate the Chi-square test the data was further subjected to multiple correspondence analysis (PROC CORRESP) (SAS Institute, 1990) to establish the relationships between habitats selected by roan. This is an interdependence technique with the ability to accommodate both nonmetric data and nonlinear relationships, and providing a multivariate representation of interdependence data (Hair, Anderson, Tatham & Black, 1995). Analyses were conducted with PROC CORRESP (SAS Institute, 1990).

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Results

Seasonal breeding herd distribution in non-burnt areas

Winter

During winter, breeding herds selected (p < 0.0001) the *Aristida bipartita - Setaria sphacelata* Grassland Variation and the adjacent *Tristachya rehmannii - Digitaria monodactyla* Variation (near the *Burkea* Savanna) (Table 16.1). The eastern pocket of the *Rhus leptodictya - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation were also selected (Fig. 16.1, Table 9.1, Appendix 9). The *Eragrostis pallens - Burkea africana* Savanna (mainly the eastern section) was utilized to a large extent but it was not statistically significant.

The correspondence analysis showed similar results where the positive values of the selected plant communities *Aristida bipartita - Setaria sphacelata* Grassland Variation (7), *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna) (9) and lower floodplain (11) indicated some degree of correspondence between them (Fig. 16.2A). The *Aristida bipartita - Setaria sphacelata* Savanna Variation (6) showed a dissimilarity with the other plant communities. The relatively high total inertia of 1.0005 (χ^2 = 63.0301, df = 88) indicates some dispersion of the row profiles, i.e. the higher is the row-column association (Greenacre, 1993).

Summer

In summer, areas that were selected to a significantly greater degree than their availabilities (p < 0.0005) were the lower floodplain and the *Eragrostis pallens - Burkea africana* Savanna (Table 16.1). The upper floodplain, the *Aristida bipartita - Setaria sphacelata* Grassland Variation (7) and the *Eragrostis nindensis - Digitaria monodactyla* Variation were selected at random. The *Sporobolus ioclados - Acacia tortilis* Savanna was avoided (p < 0.0001) throughout the year (Fig. 16.1, Table 9.1, Appendix 9).

The lower floodplain (11) and the *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna) (9) were similar as shown by their high positive values in the correspondence analysis (Fig. 16.2B). Although the *Aristida bipartita - Setaria sphacelata* Grassland Variation (7) had a positive value it was low and was therefore more associated with the other plant communities. The dissimilarity of the *Cymbopogon plurinodis - Combretum apiculatum* Variation (2) was shown by the high negative value (Fig. 16.2B). The dispersion of

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the row profiles was shown by the high total inertia of 1.0642 (χ^2 = 45.7594; df = 50) when the row profiles lie closer to the column vertices (Greenacre, 1993).

Table 16.1: Utilization of plant communities by breeding herds during winter and summer.

	Plant community	Total size (ha)	% Observations
WINTER	*Aristida bipartita - Setaria sphacelata* Grassland Variation *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna) *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket) *Eragrostis nindensis - Digitaria monodactyla* Variation	502.14 ha	65.86 %
SUMMER	Floodplain (lower section) *Eragrostis pallens - Burkea africana* Savanna (eastern section)	435.06 ha	56.63 %

Seasonal bachelor male distribution in non-burnt areas

Winter

The *Cymbopogon plurinodis - Combretum apiculatum* Variation, and the entire floodplain (upper and lower sections) were selected significantly (p < 0.005) by bachelor males during winter (Fig. 16.1, Table 9.2, Appendix 9). Male roan selected the *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket), *Eragrostis nindensis - Digitaria monodactyla* Variation, the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variations, and the *Tristachya rehmannii - Digitaria monodactyla* Variation at random (Table 9.2, Appendix 9).

Correspondence analysis showed that only the lower floodplain (11) and the *Tristachya rehmannii - Digitaria monodactyla* Variation (12) were not associated with other plant communities (Fig. 16.2C). The high χ^2 value (row coordinate = 1.4706) of the latter plant community indicates a strong degree of "correspondence" (Hair *et al.*, 1995) between the plant community (row attribute) and the male distribution (column). The total inertia was 0.8355 (χ^2 = 40.1039; df = 35) showing some row-column association (Greenacre, 1993).

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Summer

In summer males were found mainly in the Nyl River and surrounding floodplain ($p < 0.0001$). The *Sporobolus ioclados - Acacia tortilis* Savanna and the *Eragrostis pallens - Burkea africana* Savanna were avoided during all seasons (Fig. 16.1, Table 9.2, Appendix 9). Most other plant communities were utilized at random during summer.

According to the correspondence analysis the *Cymbopogon plurinodis - Combretum apiculatum* Variation (2) was not associated with the other plant communities and had a high positive value (row coordinate = 1.8804). This shows a strong "correspondence" between the plant community and male distribution (Hair *et al.*, 1995). The upper (5) and lower (11) sections of the Nyl River and floodplain were similar (Fig.16.2D). The total inertia of 0.5522 ($\chi^2 = 19.8795$; df = 24) showed some dispersion of the row profiles.

Selection of burnt and non-burnt habitats by the total roan population

Newly burnt areas were significantly selected ($p < 0.02$) by roan (Table 9.4, Appendix 9) except for the *Rhus leptodictya - Combretum apiculatum* Variation which was avoided. However the spatial segregation generally found between breeding herds and males (Fig. 16.1) still applied under these conditions.

The non-burnt *Aristida bipartita - Setaria sphacelata* Savanna (6) and Grassland Variation (7), the *Tristachya rehmannii - Digitaria monodactyla* (adjacent to the *Burkea* Savanna) (9) and the lower floodplain (11) had positive values showing some correspondence between plant communities and animal distribution (Fig. 16.3A). The total inertia was 0.3953 ($\chi^2 = 83.8103$; df = 88).

The two burnt plant communities that were not associated with the others were the *Aristida bipartita - Setaria sphacelata* Grassland Variation (7) and the *Tristachya rehmannii - Digitaria monodactyla* between the lithosol areas (12) in the north west (Fig. 16.3B). These plant communities were selected respectively by the breeding herds and bachelor males. The *Aristida bipartita - Setaria sphacelata* Grassland Variation (7) had a high χ^2 value of 1.0540 indicating a strong degree of "correspondence" between the plant community and roan distribution (Hair *et al.*, 1995). The total inertia was 0.5903 ($\chi^2 = 51.359$; df = 64).

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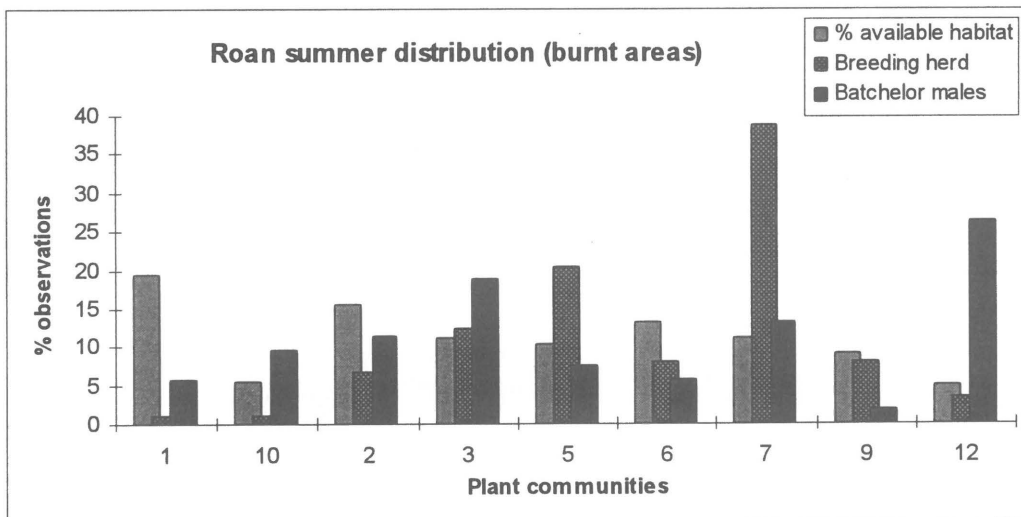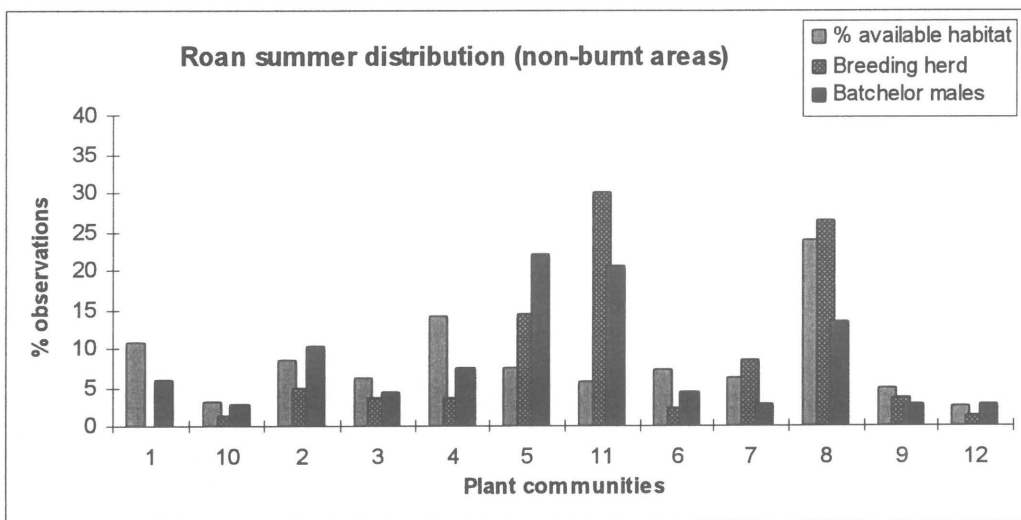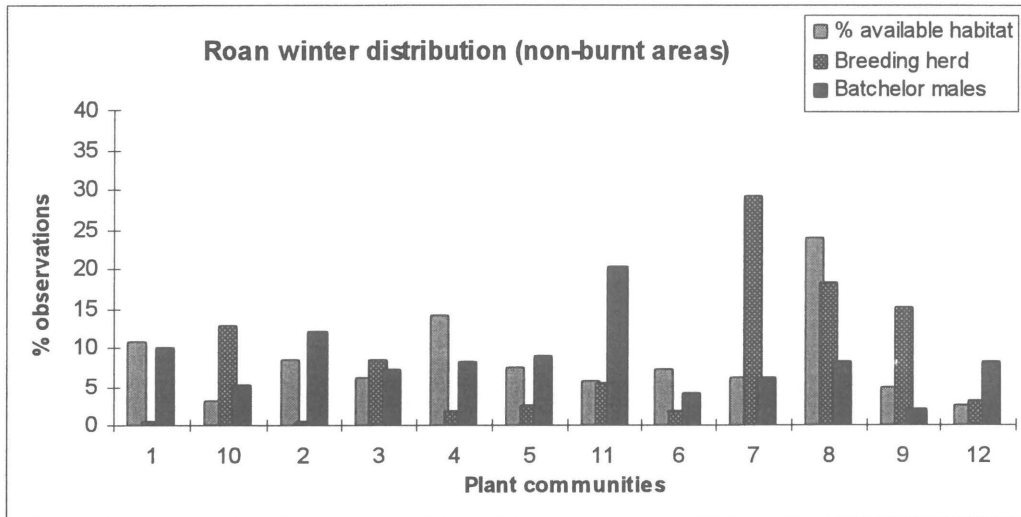
Fig. 16.1 (for title see overleaf)

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Fig. 16.1: Distribution of roan during winter and summer, when burnt and non-burnt. The available habitat is based on the size (ha) of each plant community expressed as a percentage of the total of these plant communities. The plant communities are: 1) *Rhus leptodictya - Combretum apiculatum* Variation, 10) eastern pocket of *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) upper and middle Nyl River and floodplain, 11) lower Nyl River and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, 8) *Eragrostis pallens - Burkea africana* Savanna, 9) *Tristachya rehmannii - Digitaria monodactyla* Variation adjacent to the *Burkea* Savanna (south east), and 12) *Tristachya rehmannii - Digitaria monodactyla* Variation between the lithosol areas (north west).

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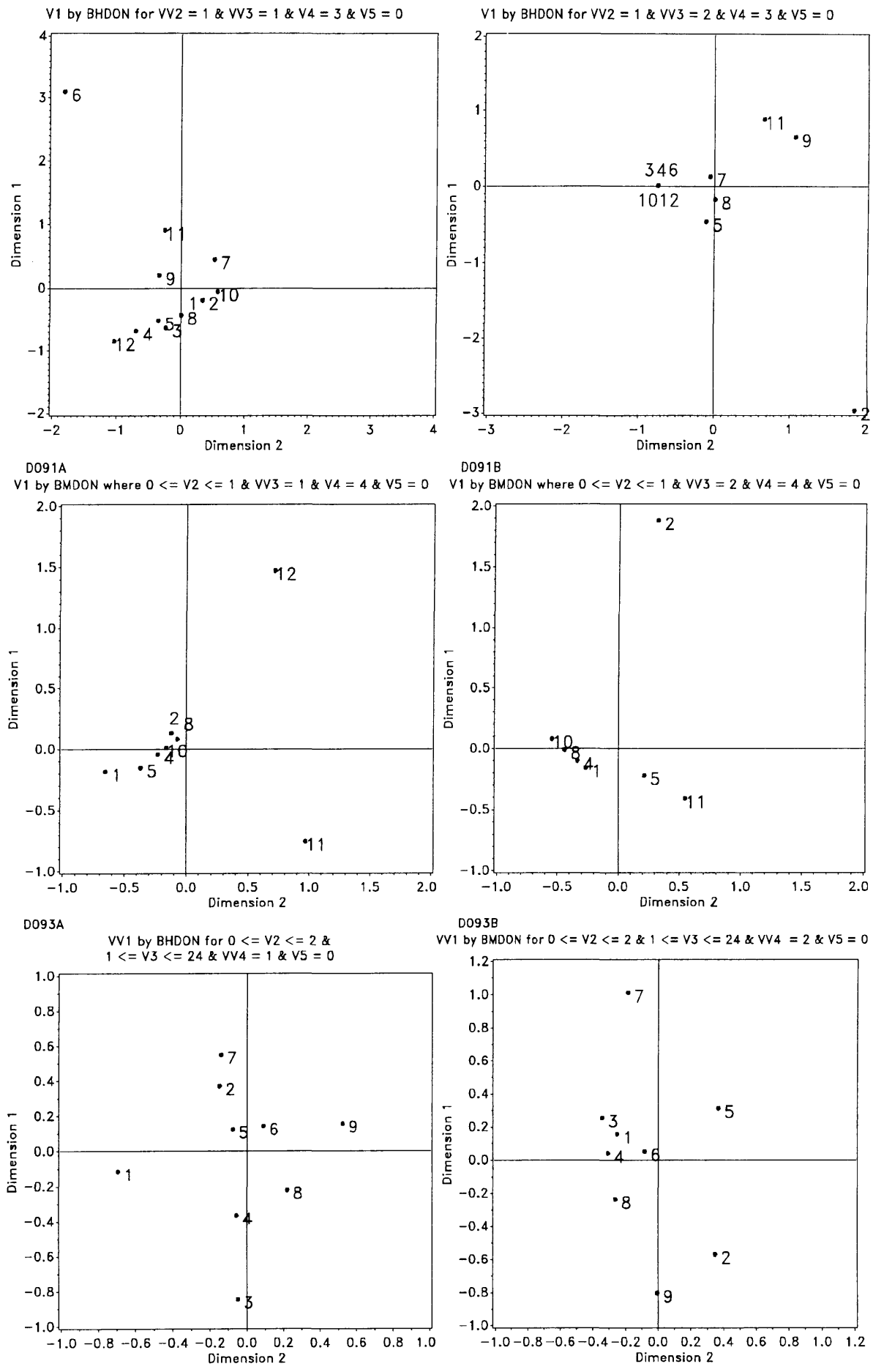
Fig. 16.2: Correspondence analysis of the distribution of (A, top left) breeding herds in non-burnt areas in winter, (B, top right) breeding herds in non-burnt areas in summer, (C, middle left) bachelor males in non-burnt areas in winter, and (D, middle right) bachelor males in non-burnt areas in summer. Plant communities are explained in text.

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V1 by BHDON and BMDON for VV2 = 1 &
1 <= V3 < = 24 & 3 <= V4 <= 4 & V5 = 0
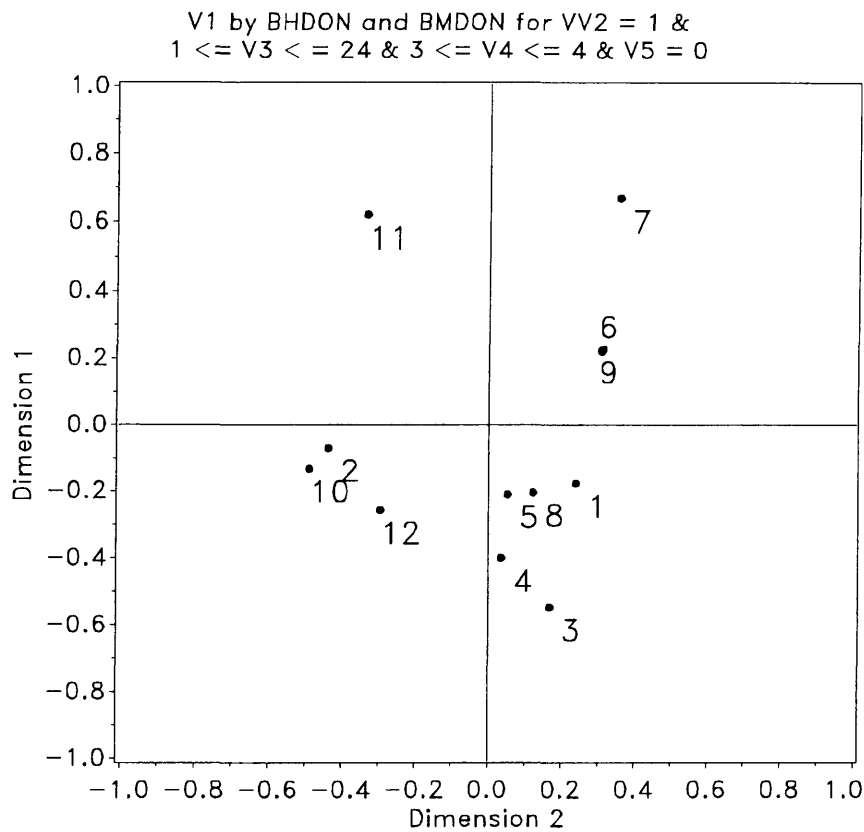
D092A

V1 by BHDON and BMDON for VV2 = 2 & 1 <= V3 < = 24 &
2 <= V4 <= 4 & V5 = 0
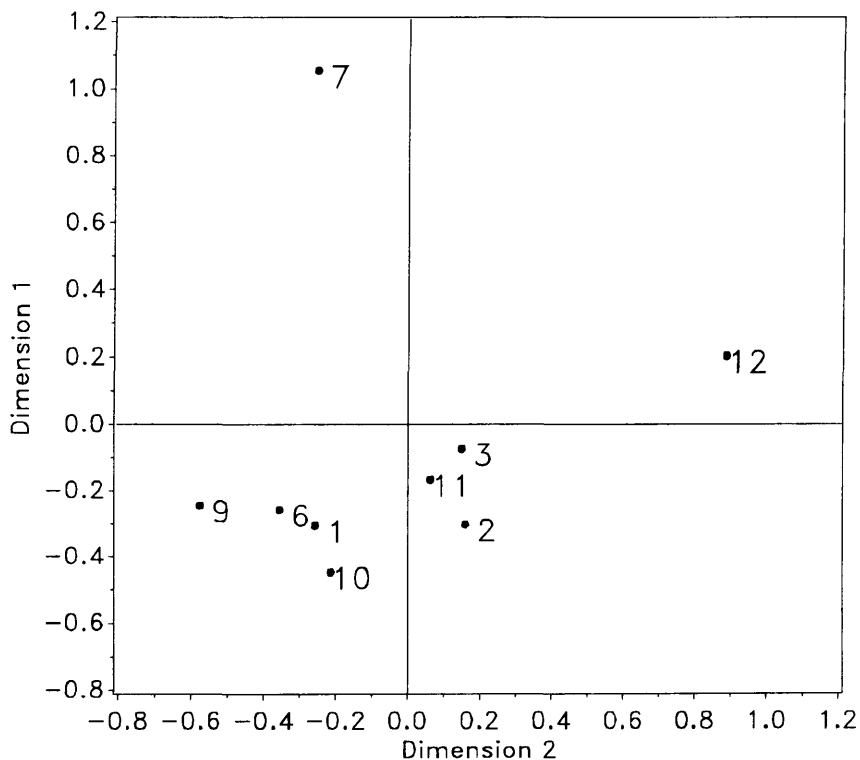
D092B

Fig. 16.3: Correspondence analysis of the total roan population distribution in (A, top) non-burnt plant communities and (B, bottom) burnt plant communities in summer for the entire study period. Plant communities are explained in text.

Discussion

Breeding herd distribution in non-burnt areas
Winter

The lower floodplain was selected in summer. As winter approached the disintegration of the grass layer due to dessication and reduced forage quality (Chapter 10) forced the breeding herds out of these areas. In the Dinder National Park, Sudan roan also used meadows extensively, where they were dependent on riparian forage along meadows during the dry season. Meadow grasses included *Echinocloa* spp., *Sorghum* spp. and *Oryza longistaminata*. At the end of the dry season the amount of forage became limiting and roan moved out of these areas (Hashim, 1987). During winter the areas selected in the NNR were mainly the *Aristida bipartita - Setaria sphacelata* Grassland Variation, *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna), *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket) and the *Eragrostis nindensis - Digitaria monodactyla* Variation to a smaller extent (Fig. 16.1). Although the *Eragrostis pallens - Burkea africana* Savanna was not selected significantly it was utilized to some extent. Poché (1974) reported that roan used to be a common species in the Park W in Dahomey, Upper Volta and Niger which consisted of 90 % shrub savanna, 7 % wooded savanna and 3 % grassland.

These local movements to other areas were also found in the Nyika National Park (Malawi) where low temperatures, and reduced forage quality and palatability during winter force roan to lower altitudes. Many animals remain on the central plateau where highly nutritive forage is maintained through dry season patch burning. Some will feed in the miombo woodlands and valleys (Munthali & Banda, 1992).

Winter is the time when many female roan, calve and lactate. Therefore breeding herds have to find the best quality areas where they can maximize their intake of quality food. This would comply with the optimal foraging theory where animal responses can be predicted by changes in food resources and other environmental factors (Owen-Smith, 1991). It is possible that breeding females select areas high in Ca because Ca was the only variable that correlated significantly (r = 0.7175) with breeding herd distribution in winter. Kreulen (1975) in Freeland & Choquenot (1990) reported that for example lactating blue wildebeest select pastures growing on calcium-rich soils. Pregnant and lactating wintering cattle require more dietary Ca and P than other animals, up to 0.18 % for both Ca and P (McDowell, 1985; NRC, 1984 in Westenskow-Wall,

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Krueger, Bryant & Thomas, 1994). The Ca and P concentrations in the NNR were generally lower (Chapter 10) than the requirements for growing mammals which are 0.4 to 1.2 % Ca, and 0.3 to 0.6 % P (Robbins, 1993). An inadequacy of dietary calcium may be an important determinant of productivity in free-ranging wildlife (Robbins, 1993).

The habitat sought by the breeding groups was mainly the *Aristida bipartita - Setaria sphacelata* Grassland Variation. This plant community had the highest forage Ca content (0.549 %) which differed significantly (p < 0.05) from all other plant communities (Chapter 10). The forage Ca content in the *Eragrostis pallens - Burkea africana* Savanna was also high (0.384 %). The % Ca and % P of the preferred grass species, identified by Heitkönig (1993) in the *Eragrostis pallens - Burkea africana* Savanna (0.4662 % Ca; 0.1629 %P) were also significantly higher than those in the floodplain (0.3963 % Ca; 0.0724 % P) (Chapter 10). The breeding herds may, therefore, search for food high in Ca in these two plant communities.

Calving females may utilize the *Eragrostis pallens - Burkea africana* Savanna where the long grass (mean = 48.30 cm) and woody plant cover (mean = 1 985 woody plants/ha and 45.40 % woody plant cover) provide shelter for the newly-born calves. Sheppe & Osborne (1971) in Heitkönig (1993) reported that roan moved to tall grass upland areas for calving in the Kafue Flats (Zambia). Tree canopy provides a measure of thermal cover for wildlife species (Patton, 1992). Allsopp (1979) observed roan calves along the edge of riverine vegetation or in tall grass areas where they would lie in concealment.

Summer

Summer areas that were selected to a significantly greater degree than their availability by the breeding herds were the lower floodplain and the *Eragrostis pallens - Burkea africana* Savanna. Breeding herds were mainly observed in the lower floodplain while bachelor males utilized the entire floodplain. In summer the mean grass height in the floodplain (45.27 cm) was higher compared to other plant communities. Joubert (1976) also found that roan do select open long grass areas. The floodplain is also virtually treeless, a condition preferred by roan (Joubert, 1976). The structure of vegetation plays an important role in determining the selection of a habitat by wildlife (Van Rooyen, Bredenkamp & Theron, 1995). Roan selected *Terminalia laxiflora* wooded savanna in the Bouba Ndjida National Park (Cameroon) with the grass cover consisting mainly of Andropogoneae and growing up to 3 m high during the rainy season (Van Lavieren & Esser, 1979).

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Sward structure such as the amount of leaf and grass tuft height may influence food selection (O'Reagain, 1990; O'Connor, 1992). Species selection is possibly a consequence of selection for plant structure to optimize forage intake (O'Connor, 1992). Biomass concentration is related to grass structure. It is an important parameter in optimizing forage intake, and was significantly higher in the floodplain (mean summer biomass concentration was 7.754 kg/m³) than in other areas. Only in the *Sporobolus ioclados - Acacia tortilis* Savanna did the biomass concentration not differ from the floodplain. Roan experience a bite size limitation on very short swards (Heitkönig, 1993) as were found in the *Sporobolus ioclados - Acacia tortilis* Savanna (mean summer total height of 8.72 cm).

Sodium deficiency is a frequent problem in grazing ruminants with no access to Na supplementation (Henry, 1995). Aquatic vegetation along streams has a high Na content (Delgiudice, Singer & Seal, 1991). The Na content was higher in the floodplain (0.146 % Na) than in other plant communities except for the *Sporobolus ioclados - Acacia tortilis* Savanna (0.8167 % Na). Although the % Na in the latter plant community was more than four times higher than in other plant communities, it was avoided by roan.

From the above it appears that the Nyl River with its floodplain is the most important plant community during summer. Roan antelope is an ecotonal species which is particularly selective of open "dambo-like" grasslands (Pienaar, 1974) within typical *Brachystegia* spp. woodlands with closed canopies (Joubert, 1976) and meadows, e.g. in the Dinder National Park, Sudan (Hashim 1987).

Bachelor male distribution in non-burnt areas

Winter and summer

Roan have a territorial social system (Joubert, 1996) where one bull protects the herd and other males are usually forced into less optimal areas. Batchelor males were spatially segregated from the breeding herds by selecting the *Cymbopogon plurinodis - Combretum apiculatum* Variation and the floodplain during winter. The *Tristachya rehmannii - Digitaria monodactyla* Variation was selected at random which is adjacent to the above plant community but a few kilometers from that selected by the breeding herds (Fig. 2.1, Chapter 2). These plant communities were generally of a low forage quality. Some of these areas may be unsuitable for the breeding herds or roan in general due to the high woody plant densities (*Rhus leptodictya - Combretum apiculatum* Variation = 3 992 woody plants/ha, *Cymbopogon plurinodis - Combretum apiculatum* Variation

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= 2 358 woody plants/ha). Esser (1980) found small groups of roan (4.0) in savanna woodland, woodland savanna, fringing forest and dense woodland in the Benoue National Park (northern Cameroon), suggesting that these habitats were probably sub-optimal. In the Lambwe Valley (Kenya) breeding herds occupied the open *Themeda/Setaria* grassland and were never observed in the *Hyparrhenia* grassland which was selected by bachelor males (Allsopp, 1979).

In summer the Nyl River and surrounding floodplain was selected while other plant communities were utilized at random. In general male roan utilized the western part of the NNR to a larger extent.

Burnt areas

Roan (both social groups) were highly selective of burnt areas. However the spatial segregation between social groups could still be observed to some extent even when sub-optimal habitats (e.g. the *Cymbopogon plurinodis - Combretum apiculatum* Variation) were burnt. Some areas such as the *Rhus leptodictya - Combretum apiculatum* Variation were avoided when in a non-burnt state but also when it was burnt. Newly burnt areas with a regrowth of grass of 1-10 cm are selected by large herbivores (Moe, Wegge & Kapela, 1990) with a decline in utilization with aging of the sward (Shackleton, 1992). This drop in the number of herbivores was observed when green grass shoots reached a height of 10 cm above ground (Moe *et al.*, 1990). They also found that recently burnt areas with no regrowth and areas not burnt were avoided. Burnt areas with regrowth less than 5 cm had the highest attraction of herbivores compared to other regrowth stages (Moe *et al.*, 1990).

Roan selected mainly the floodplain and the *Aristida bipartita - Setaria sphacelata* Grassland Variation when newly burnt. The floodplain showed the highest increase in % N (from 1.6900 % to 2.5067 %) and % IVOMD (from 69.4165 % to 72.3967 %), while the *Aristida bipartita - Setaria sphacelata* Savanna Variation and the *Aristida bipartita - Setaria sphacelata* Grassland Variation had the highest increase in % Ca (from 0.3254 % to 0.3975 %) and % P (from 0.1005 % to 0.1240 %) respectively when burnt. Moe *et al.* (1990) also reported that ash from newly burnt grass and woody vegetation is high in Ca, P, potash and trace minerals. Fast growing, immature grasses have a high quality (Dunham, 1990) as found on newly burnt areas. Sprouting grasses have been found to contain higher amounts of protein (75-100 % increase), Ca and P compared with unburnt leaves (Moe *et al.*, 1990).

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Conclusion

The Chi-square tests and correspondence analyses indicated a similar selection of plant communities by roan. Roan exhibited differential utilization of plant communities on a seasonal basis and between social groups. The breeding herd concentrated mainly in *Aristida bipartita - Setaria sphacelata* Grassland Variation, the *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna) and the eastern pocket of the *Rhus leptodictya - Combretum apiculatum* Variation during winter.

The high dietary Ca in the *Aristida bipartita - Setaria sphacelata* Grassland Variation may play a role in habitat selection for pregnant and lactating females during winter. Shelter in terms of long grass provided by these plant communities may be favoured by calving females. Also the high woody plant cover (45.4 %) in the nearby *Eragrostis pallens - Burkea africana* Savanna may supply some shelter.

In summer the most important areas for the breeding herds were the lower floodplain and the *Eragrostis pallens - Burkea africana* Savanna (eastern section). The long grass in the treeless floodplain had a very high Na content. The biomass concentration, an indication of forage availability, was also high in this plant community. On a year round basis the lower floodplain, the *Aristida bipartita - Setaria sphacelata* Grassland Variation and the *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna) were most selected by the breeding herds.

Bachelor males were spatially segregated from the breeding herds, where they selected less optimal areas such as the *Cymbopogon plurinodis - Combretum apiculatum* Variation, and the floodplain during winter. In summer the entire floodplain was selected. The year round areas of importance for bachelor males were the *Cymbopogon plurinodis - Combretum apiculatum* Variation and the floodplain.

Newly burnt areas were attractive for roan mainly because of increased levels of % N, % IVOMD, % Ca and % P. Plant communities that were burnt in spring were selected in a similar sequence by each social group as in a non-burnt state. This implies that even when plant communities were burnt there could still be a similar spatial segregation found as in a non-burnt state.

Management implications

The important winter habitats, that is the *Aristida bipartita - Setaria sphacelata* Grassland Variation, *Tristachya rehmannii - Digitaria monodactyla* Variation (adjacent to the *Burkea* Savanna), *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket) and the *Eragrostis nindensis - Digitaria monodactyla* Variation to some extent comprised approximately 502 ha. A conservative calculation of roan density (breeding herds only) for these winter habitats would be 6.77 roan per km². This is considerably higher than that described by Dörgeloh, Van Hoven & Rethman (1996) for natural areas where no artificial feeding is applied. The effect of this can be seen in the poor condition of animals from the onset of winter (casual observations). Especially during winter it would be important for females and their young to be in good condition. Since the breeding herds do not utilize other areas to any large extent it can be assumed that roan have reached the carrying capacity of the NNR. Hence their negative growth rate as shown by Dörgeloh *et al.* (1996).

The summer habitat of 435 ha consisted mainly of the lower floodplain and the eastern section of the *Eragrostis pallens - Burkea africana* Savanna. The roan density during summer was 7.82 roan per km². This range was marginally smaller than the winter range. Since roan is an endangered species the habitat in the NNR should be improved and managed to benefit roan. For example the *Aristida bipartita - Setaria sphacelata* Grassland Variation is being invaded by *Acacia karroo* (casual observation) making this plant community unsuitable for roan.

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CHAPTER 17

Habitat parameter selection for model construction

Introduction

An *a priori* approach to develop a wildlife-habitat model uses forecasting data, where important habitat variables are predetermined (Morrison, Marcot & Mannan, 1992). For roan these would be a generally accepted low tree density, or cover, and long grass. However, this may not adequately explain or predict roan presence or absence. By measuring only two or three predetermined variables, vital parameters that affect animal presence or absence may be excluded. This may cause a Type II error when the model predicts absence and the species is actually present (Morrison *et al.*, 1992).

Predictive models are often based on hindcasting, where data on a number of variables is collected first, then analysed, and key environmental variables identified that account for observed variation in species variables (Morrison *et al.*, 1992). With this *a posteriori* approach Type II error would be avoided to a larger extent. Hindcasting is used to explain patterns in species presence or absence and abundance (Morrison *et al.*, 1992). The results of hindcasting were obtained with multivariate techniques such as correspondence analysis and logistic regression analysis.

Correspondence analysis is a powerful tool for gaining an insight into the relative positions of plant communities and the attributes (habitat variables) associated with those positions (Hair, Anderson, Tatham & Black, 1995). It provides a means for directly comparing the similarity or dissimilarity of plant communities and the associated attributes (Hair *et al.*, 1995).

Logistic regression analysis has only recently been used in wildlife-habitat studies (Morrison *et al.*, 1992, Pauley, Peek & Zager, 1993). Logistic regression analysis, or logit analysis in short, is a combination of multiple regression and multiple discriminant function (Hair *et al.*, 1995). Logistic regression is a robust alternative to discriminant analysis (Dattalo, 1994) where one or several independent or predictor variables are used to predict a single dependent variable (Dattalo, 1994; Hair *et al.*, 1995; Lottes, Adler & DeMaris, 1996). It is a probability model which not only

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predicts whether an event occurred or not, but also the probability of an event (Hair *et al.*, 1995). Logistic regression is more appropriate to use when the outcome of interest is dichotomous (Hall & Round, 1994; Gallo, 1996). It accounts for some of the non-linearity between predictor (independent) and response (dependent) variables (Morrison *et al.*, 1992).

Multivariate analysis was used to investigate the variation among plant communities (correspondence analysis) and to test the predictive significance of the independent habitat variables (logistic regression analysis). These significant predictor variables were then used for further model construction for the Habitat Suitability Model (Chapter 18).

Methods

Twenty three habitat parameters, as described in the previous chapters (Chapters 3 to 10), were used for further analyses. Since the methods, sample sizes and sampling frequencies used, differed between various habitat parameters, the entire data set could not be analysed at once with correspondence analysis and logistic regression. Also not all measurements were taken for the same number of seasons and burnt and non-burnt areas. Therefore the variables that could be paired off according to plant community, state of burn and season were grouped together (Table 17.1) and a new database created for multivariate analysis. Species diversity and veld condition had one value only per plant community and were therefore not included in the logistic regression analysis.

A multivariate approach was used to construct empirical models derived from hindcasting data from field observations. The relationship between plant communities in terms of these 23 habitat variables was investigated with multiple correspondence analysis (PROC CORRESP) (SAS Institute, 1990). It was used to identify the variables that summarized the variation among plant communities (Pauley *et al.*, 1993). However, correspondence analysis by itself is not sufficient to explain variation among plant communties because it is an explorative technique and need to be supported by further, more formal analysis ([*]Groeneveld, H. 1997. pers. comm.).

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[*] Groeneveld, H. 1997. Department Statistics, University of Pretoria, Pretoria 0002.

Logistic regression analysis was performed with PROC LOGIT (SAS Institute, 1990) to identify those habitat variables which best describe the plant communities. Habitat parameters were taken as the independent predictor variables. Plant communities as the dependent variable were treated as binary where the independent variables of each plant community were measured against the other plant communities. A binary function requires that the dependent variable can be any value between zero and one (Hair *et al.*, 1995).

Table 17.1: Groups of habitat parameters that could be paired off and were used in correspondence analysis and logistic regression analysis.

Group	Habitat parameters	Abbreviations
1	Species density Grass density	SPDEN GRDEN
2	% Composition % Dry weight	PCOMP PDWGT
3	Grass canopy cover Woody plant density Woody plant canopy cover	MPGRCCO MTRDEN MPTCCO
4A Correspondence analysis only	Total grass height Grass tuft height Above-ground standing crop Biomass concentration	TH GH BM BMCON
4B Logistic regression only	Total grass height Grass tuft height Above-ground standing crop	TH GH BM
4C Logistic regression only	Grass tuft height Biomass concentration	GH BMCON
5	% Moisture % Nitrogen % Neutral Detergent Fibre % Acid Detergent Fibre % *in vitro* organic matter digestibility % Organic matter	PMOIS PNITR PNDFI PADFI PIVOM PORMA
6	% Calcium % Phosphorus % Potassium % Sodium	PCALC PPHOS PPOTA PSODI

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The basic logistic model (Ely, Dawson, Mehr & Burns, 1996) applied was:

Logit (p) = log $(p / 1\text{-}p)$ = α + β'x

where α = intercept parameter

$\quad$ β' = row vector of slope parameter

$\quad$ x $\quad$ = column vector of explanatory variables

A logistic model was developed for each group of independent variables as described by Hall & Round (1994), Ely *et al.* (1996) and Lottes *et al.* (1996):

Power (P) = $\alpha + \beta_1 x_1 + \beta_2 x_2 \ldots \beta_n x_n$

where $\quad$ α = intercept parameter

$\quad$ β = row vector which contains the slopes associated with the vector of explanatory

$\quad\quad$ variables (log weighting coefficient for a variable)

$\quad$ x = column vector of explanatory variables

The parameters of the standard logit model can be interpreted directly or indirectly after transformation to an odds ratio, to a probability, or to a difference in probability. These differences in probability are due to differences in observed independent variables (McArdle & Hamagami, 1996).

The power value or log of odds (Hall & Round, 1994) for each plant community (dependent variable) was calculated based on the mean value of each habitat variable (Table 10.1, Appendix 10). Probabilities (p) were calculated from the antilog of the power value or odds described as $e^{(\beta 0 + \beta 1 x)}$ (Ely *et al.*, 1996) with the equation:

$p = e^{(\beta 0 + \beta 1 x)} / [1 + e^{(\beta 0 + \beta 1 x)}]$

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Probabilities were used to identify the habitat variables which best described the variation between plant communities. If the predicted probability was greater than 0.50, then the prediction was taken as positive, otherwise negative (Hair *et al.*, 1995). At very low levels of the independent variable (habitat parameter), the probability approaches zero and *vice versa*. At high levels the probability will approach one but never exceeds it (Hair *et al.*, 1995).

Results based on mean values of the predictor variables were not satisfactory due to the similar p values between plant communities (Table 10.2, Appendix 10). It was therefore difficult to isolate significant predictor variables. Further analyses were conducted with a combination of high and low values of the habitat variables.

Effects and statistical significance of the independent variables (mean values only) was further evaluated with the Wald Chi-square statistic which tests the null hypothesis that the β coefficient equals zero (Pauley *et al.*, 1993; Dattalo, 1994, Hair *et al.*, 1995). Therefore a significant Wald statistic (α = 0.05) indicates that an independent variable is a significant predictor of the dependent variable (Lottes *et al.*, 1996). The Wald statistic is also used to evaluate whether the parameters in a model are necessary in a statistical sense by indicating which parameter should be discarded from the model (Schumacker & Lomax, 1996).

The suitability of the logistic models was tested with a Chi-square goodness-of-fit test under the null hypothesis that the data may be modelled with logistic regression (SAS Institute, 1990). Non-significance ($p > 0.25$) suggested that the model was suitable (Pauley *et al.*, 1993).

Results

Table 17.2: Plant communities used in the analysis and their respective numbers.

No.	Plant community
1	*Rhus leptodictya - Combretum apiculatum* Variation
2	*Cymbopogon plurinodis - Combretum apiculatum* Variation
3	*Eragrostis nindensis - Digitaria monodactyla* Variation
4	*Sporobolus ioclados - Acacia tortilis* Savanna
5	Nyl River and floodplain
6	*Aristida bipartita - Setaria sphacelata* Savanna Variation
7	*Aristida bipartita - Setaria sphacelata* Grassland Variation
8	*Eragrostis pallens - Burkea africana* Savanna

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<u>Correspondence analysis</u>

Species density, Species diversity (Simpson's index), Veld condition value, Grass density

Two clusters were identified, those of plant communities 1, 2, 3, 5 and 8, and that of plant communities 6 and 7 (Fig. 17.1). The high positive Chi-square value of plant community 4 indicates a strong degree of "correspondence" between the variables (row attributes) and the plant community (column) (Hair *et al.*, 1995). The floodplain (5) and plant community 8 had similar positive values and were associated with the plant communities on the lithosols (1, 2 and 3) (Fig. 17.1). The plant communities on the vertisols (6 and 7) were closely associated. The total inertia of 5.8639 ($\chi^2 = 2814.67$, df = 777) indicates a dispersion of the row profiles and a high row-column association (Greenacre, 1993).

% Grass composition, % Dry-weight of grass species

Plant communities 2 and 3 were similar. They "corresponded" to a high degree with the variables. Another cluster was formed by plant communities 4, 5, 6, 7 and 8 (Fig. 17.1). Plant community 1 was dissimilar from the other plant communities (Fig. 17.1). The total inertia was 5.7377 ($\chi^2 =$ 1377.04, df = 1 323).

Grass canopy cover, Woody plant density, Woody plant canopy cover

Plant communities 1, 2, 4, 5, 6, and 7 were closely associated as seen by the distinctive cluster (Fig. 17.2). The *Eragrostis pallens - Burkea africana* Savanna (8) showed a strong degree of "correspondence" between the variables and plant community (row coordinate = 2.6458) (Hair *et al.*, 1995). Plant community 3 was dissimiar from the other plant communities. The total inertia was 6.2222 ($\chi^2 = 448$, df = 413).

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Total grass height, Grass tuft height, Above-ground standing crop, Biomass concentration

Non-burnt winter

Plant communities for the non-burnt winter grass layer had a similar pattern to the overall mean annual grass layer (Fig. 17.1). Plant communities 1, 2, 3, 5, 7 and 8 formed a distinctive cluster.

Plant communities 4 and 6 were not associated with the other plant communities. The former plant community had a high row coordinate of 2.7634. The high total inertia of 6.4792 (χ^2 = 2462.08, df = 2 401) indicates that the row profiles lie close to the column vertices (Greenacre, 1993).

Non-burnt summer

In summer the non-burnt grass layer showed three clusters. Plant communities 1 and 2, 3 and 5, and 7 and 8 formed separate clusters (Fig 17.1). The first cluster corresponded to a stronger degree with the variables than the other clusters due to the positive values. The *Sporobolus ioclados - Acacia tortilis* Savanna (4) corresponded strongly with the habitat variables (row coordinate = 2.1689). The total inertia was 6.3512 (χ^2 = 2946.97, df = 2 912). The *Aristida bipartita - Setaria sphacelata* Savanna Variation (6) was dissimilar from the other plant communities.

Burnt summer

When burnt in summer one cluster of plant communities 2, 3 and 7 could be identified (Fig 17.1). The lower floodplain (5) was not associated with the other plant communities (row coordinate = 2.2206). Plant communities 3 and 6 also had positive values indicating some "correspondence" between habitat variables and plant community (Fig. 17.1). The total inertia was 4.2204 (χ^2 = 3308.8, df = 3 235).

Irrespective of burn and season

When the data was combined most plant communities (1, 2, 3, 5, 7 and 8) were associated and formed a cluster (Fig. 17.1). The high total inertia of 5.3569 (χ^2 = 8720.96, df = 8 526) indicates a high row-column association (Greenacre, 1993). The *Sporobolus ioclados - Acacia tortilis* Savanna (4) with a high row coordinate of 2.7182 showed a strong degree of "correspondence"

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between the habitat variables and plant community (Hair *et al.*, 1995). The *Aristida bipartita - Setaria sphacelata* Savanna Variation (6) was dissimilar from the other plant communities.

% Moisture, % Nitrogen, % Neutral Detergent Fibre, % Acid Detergent Fibre, % in vitro organic matter digestibility, % Organic matter

Non-burnt winter

The chemical composition of the grass layer in winter (non-burnt) showed that plant communities 2, 3, 4, 6 and 7 were very similar (Fig 17.2). Plant communities 1 and 8 were dissimilar from the other plant communities (Fig. 17.2). The high positive Chi-square value (2.4495) of the latter plant community indicated a strong degree of "correspondence" between the chemicals (row attribute) and plant community (column) (Hair *et al.*, 1995). The other plant communities were closely associated. The total inertia was 5.9444 ($\chi^2 = 749$, df = 744).

Non-burnt summer

The summer non-burnt plant communities 1, 2, 3, 6 and 7 were closely associated (Fig. 17.2). The floodplain (5) and the *Eragrostis pallens - Burkea africana* Savanna (8) did not form part of the cluster although they had the same row coordinate of 0.3922. The *Sporobolus ioclados - Acacia tortilis* Savanna (4) was dissimilar to the others with a high negative Chi-square value. The total inertia was 6.7083 ($\chi^2 = 1811.25$, df = 1 813).

Burnt summer

In summer the burnt plant communities were more dispersed (Fig. 17.2). Plant communities 3, 6 and 7 were similar. Plant community 2 was associated with forage quality. The floodplain (5) had a high positive Chi-square value of 4.2091 indicating a strong "correspondence" between forage quality and plant community (Hair *et* al., 1995). The total inertia was 4.5636 ($\chi^2 = 2601.23$, df = 2 560).

Irrespective of burn or season

When all values were combined irrespective of burn or season one distinctive cluster was formed by the closely associated plant communities 1, 2, 3, 5, 6 and 7 (Fig. 17.2). The *Eragrostis pallens*

- *Burkea africana* Savanna (8) "corresponded" strongly (Chi-square value = 4.2837) with the row attributes (chemicals) (Fig. 17.2). Plant community 4 was dissimilar from all other plant communities. The remaining plant communities were similar to each other (Fig. 17.2). The total inertia was 6.3070 (χ^2 = 6092.52, df = 6 006).

% Calcium, % Phophorus, % Potassium, % Sodium

Non-burnt winter

During winter plant communities 3, 6 and 8 were similar and "corresponded" with the mineral content of the forage. Plant communities 1 and 2 also had positive values. The other plant communities were dissimilar from all other areas (Fig. 17.3). The row profiles were dispersed as shown by the high total inertia of 5.7361 (χ^2 = 527.722, df = 511).

Non-burnt summer

In summer plant communities 6 and 7, and 1 and 2 were respectively closely associated and formed separate clusters (Fig. 17.3). The *Sporobolus ioclados - Acacia tortilis* Savanna (4) and plant communities on the vertisols (turf soils) (6 and 7) were closely associated with the mineral content shown by their high row coordinates (Fig. 17.3). Plant communities (row coordinates) were widely dispersed, indicated by the high total inertia of 5.8792 (χ^2 = 799.567, df = 791).

Burnt summer

For the burnt areas in summer, limited data was available. Plant communities 3 and 7 were similar, with positive values (Fig. 17.3). Plant community 2 showed a strong correspondence between row attributes (minerals) and column (plant community) (Hair *et al.*, 1995) indicated by the high Chi-square value of 1.2243. The total inertia was 2.7181 (χ^2 = 206.572, df = 195).

Irrespective of burn or season

When all values were combined irrespective of burn or season plant communities 3, 7 and 8 were closely associated (Fig. 17.3). Plant community 6 was positively associated with macrominerals. Plant communities 1 and 2 had high positive values of 1.6449 and 1.0371 respectively (Fig. 17.3).This indicates a strong degree of "correspondence" between the row attributes (mineral

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variables) and the column (plant community) (Hair *et al.*, 1995). The total inertia of 5.4709 (χ^2 = 1663.16, df = 1 596) showed a dispersion of the row coordinates.

Logistic regression analysis

A logistic regression analysis was conducted with mean values of the predictor variables (Table 10.2, Appendix 10). A second analysis with combinations of high and low values (Table 10.4, Appendix 10) did not improve the output (i.e. reduce the number of predicted plant communities). The latter output is not discussed any further. Instead the results described below are from the logistic output based on mean values and the corresponding Wald Chi-square statistic (Table 10.3, Appendix 10).

Species density, Grass density

The probability was high ($p > 0.5$) that the measured species densities and grass densities are found in plant communities 2, 3, 6, 7 and 8 (Table 10.2, Appendix 10). The Wald statistic indicated that species density was a significant predictor ($\alpha < 0.05$) in more plant communities than in the case of grass density (Table 10.3, Appendix 10).

% Composition, % Dry weight

The probability of finding % composition and % dry-weight in certain plant communities was equal for all plant communities (Table 10.2, Appendix 10). The Wald Chi-square statistic showed these variables not to be important.

Grass canopy cover, Woody plant density, Woody plant canopy cover

The probabilities that the measured grass canopy cover, woody plant density or woody plant canopy cover are found in any of the plant communities were not significant (Table 10.2, Appendix 10) (logistic $p < 0.5$, Wald $\alpha > 0.05$).

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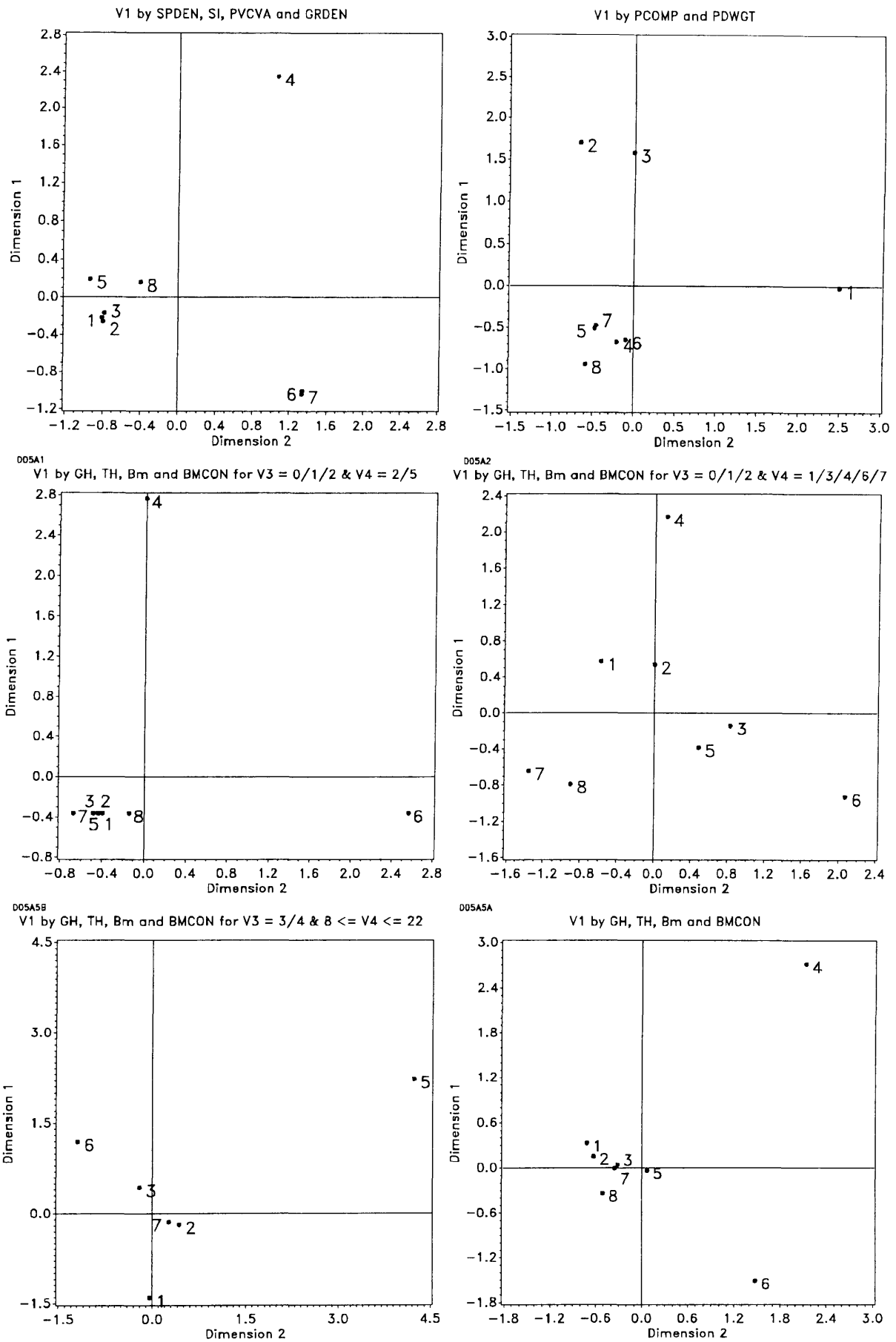
Fig. 17.1: Correspondence analysis of plant communities with respect to species density, Simpson's index, veld condition value and grass density (top left); % composition and % dry-weight (top right); total grass height, grass tuft height, above-ground standing crop and biomass concentration in non-burnt areas in winter (middle left); total grass height, grass tuft height, above-ground standing crop and biomass concentration in non-burnt areas in summer (middle right); total grass height, grass tuft height, above-ground standing crop and biomass concentration in burnt areas in summer (bottom left); and total grass height, grass tuft height, above-ground standing crop and biomass concentration throughout the year irrespective of burn or season (bottom right).

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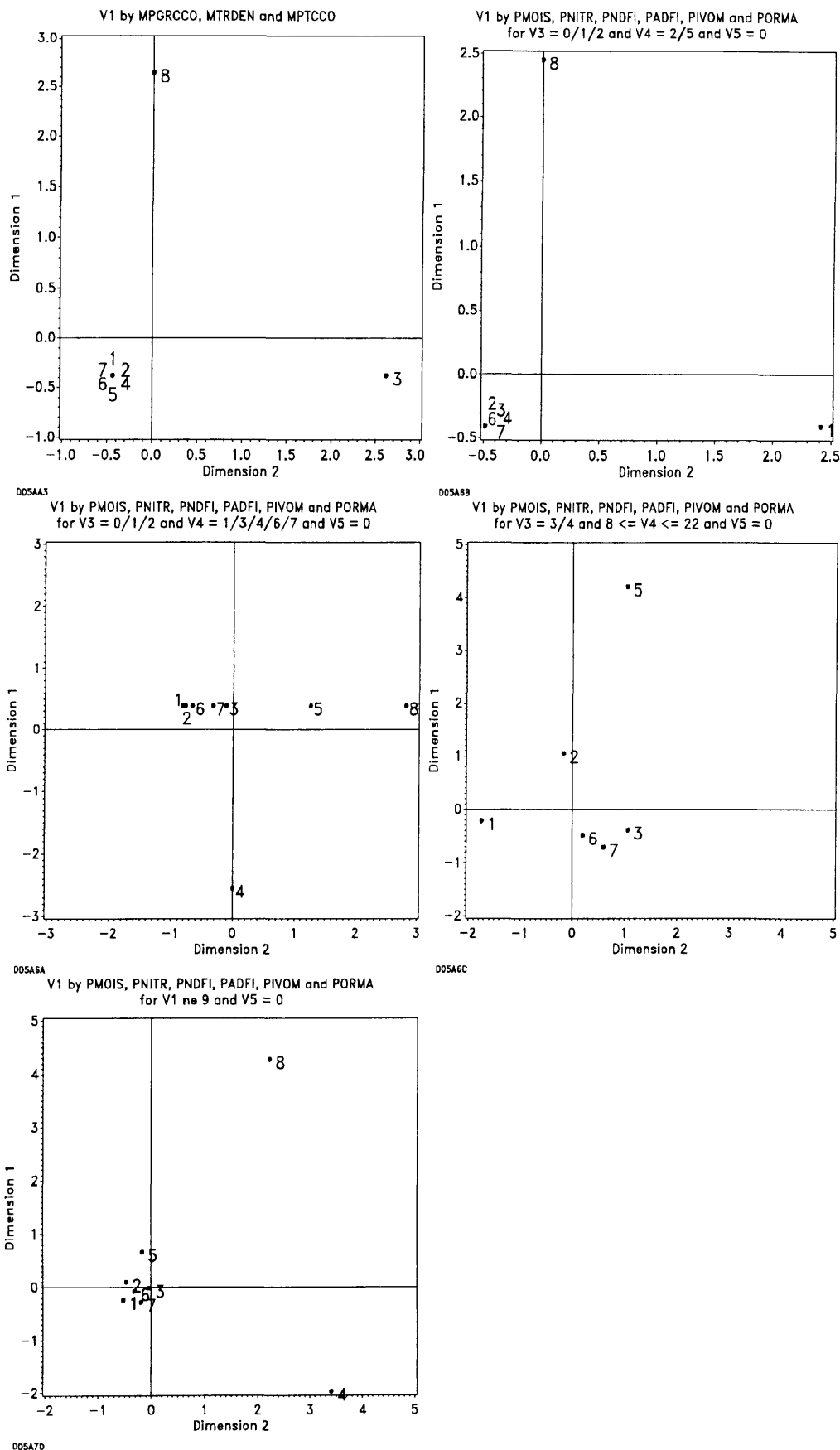
Fig. 17.2: Correspondence analysis of plant communities with respect to grass canopy cover, woody plant density and canopy cover (top left); chemical parameters (% moisture, % N, % NDF, % ADF, % IVOMD, % OM) for non-burnt areas in winter (top right); chemical parameters for non-burnt areas in summer (middle left); chemical parameters for burnt areas in summer (middle right); and chemical parameters irrespective of burn or season (bottom left).

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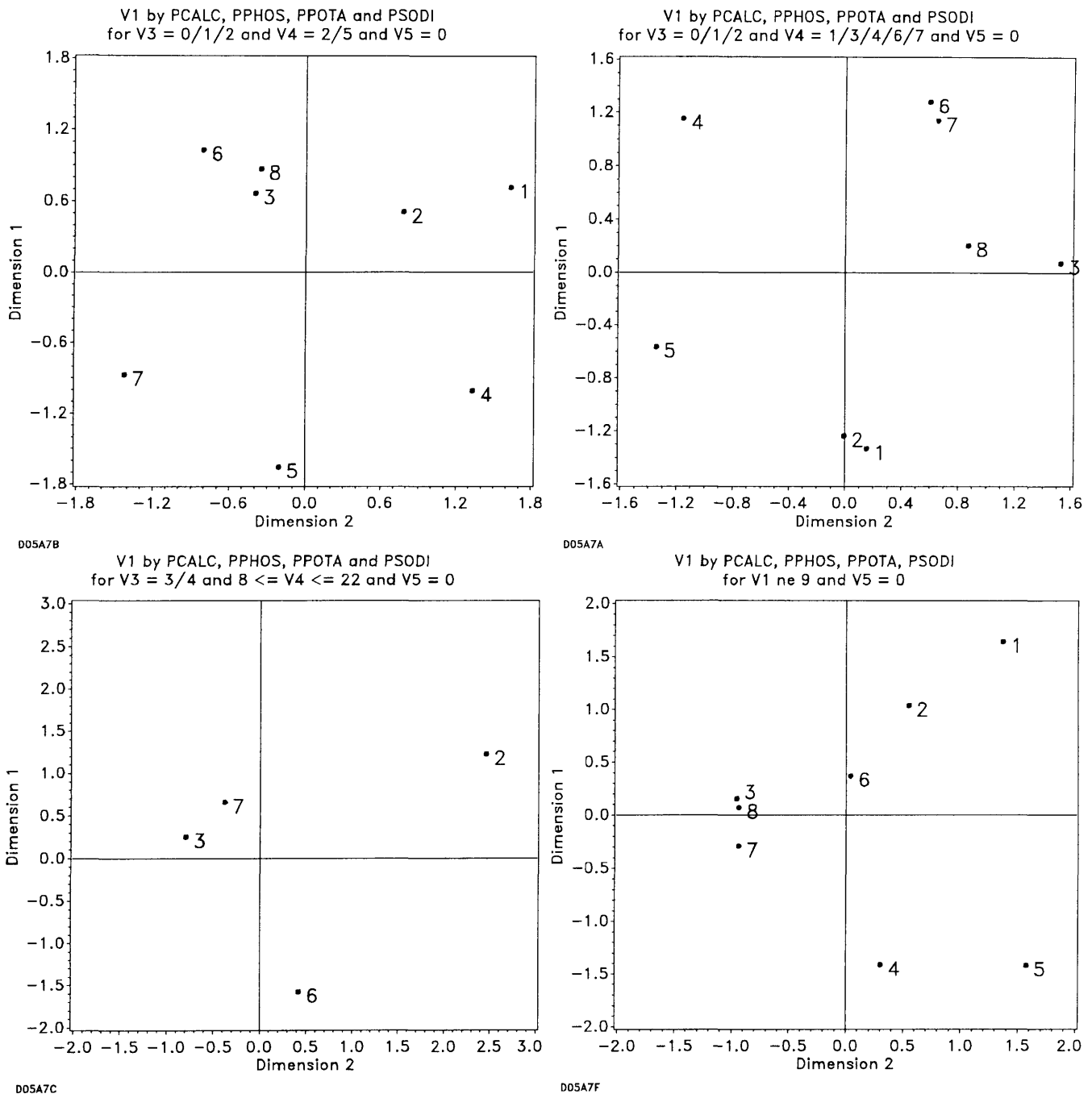
Fig. 17.3: Correspondence analysis of plant communities with respect to macromineral contents (% Ca, % P, % K, % Na) when non-burnt in winter (top left), non-burnt in summer (top right), burnt in summer (bottom left) and throughout the year irrespective of burn and season (bottom right). Plant communities are explained in text.

Total grass height, Grass tuft height, Above-ground standing crop, Biomass concentration

Non-burnt winter

In winter (non-burnt) the probability was high that the mean total grass height, grass tuft height and above-ground standing crop is found in the plant communities on the lithosols (plant communities 1, 2 and 3) and in plant community 7 (Table 10.2, Appendix 10). The Wald statistic showed that grass height and above-ground standing crop was significant for plant communities 6 and 8 (Table 10.3, Appendix 10).

The total grass height and biomass concentration during winter (non-burnt) were generally significant (high probability) for the plant communities on the lithosols (1, 2 and 3) and 5, 7 and 8 (Table 10.2, Appendix 10). The Wald Chi-square test showed that these two variables were generally significant for the plant communities on the lithosols (1, 2 and 3) and the vertisols (6 and 7) (Table 10.3, Appendix 10).

Non-burnt summer

When not burnt during summer the probability was significantly higher that total grass height, grass tuft height and above-ground standing crop are found in the plant communities on the lithosols (felsite) and the vertisols (turf) (Table 10.2, Appendix 10). These variables were significant for plant communities 1, 4 and 8 as shown by the Wald statistic (Table 10.3, Appendix 10).

In summer (non-burnt) the measured total grass height and biomass concentration had a high probability that they occurred in plant communities 1, 2, 3, 5, 6 and 7 (Table 10.2, Appendix 10). The Wald statistic indicated grass tuft height to be significant for plant communities 1, 4, 6 and 7. Biomass concentration was significant in plant communities 1, 5 and 8 (Table 10.3, Appendix 10).

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% Moisture, % Nitrogen, % Neutral Detergent Fibre, % Acid Detergent Fibre, % in vitro organic matter digestibility, % Organic matter

Non-burnt winter

In winter the probability was significant ($p > 0.5$) that the measured forage quality is found in plant community 1 (Table 10.2, Appendix 10). The Wald statistic showed that none of the chemical parameters were significant (Table 10.3, Appendix 10).

Non-burnt summer

In summer (non-burnt) the measured chemical parameters had a high probability that they are found in plant communities 1, 6 and 8 (Table 10.2, Appendix 10). The Wald statistic showed that only % OM was significant for plant community 2 (Table 10.3, Appendix 10).

% Calcium, % Phophorus, % Potassium, % Sodium

Non-burnt winter

In winter (non-burnt) the probability was high that the measured mineral contents occurred in plant community 6 (Table 10.2, Appendix 10). The Wald statistic showed non-significance ($\alpha > 0.05$) for all minerals.

Non-burnt summer

The probability was high that the mean mineral contents are found in plant communities 2, 3, 5 and 6 during summer (Table 10.2, Appendix 10). According to the Wald statistic no minerals were significant for any plant communities.

Discussion

<u>Correspondence analysis</u>

In terms of many habitat parameters the three plant communities on the lithosols (1, 2 and 3) were closely associated. A similar pattern was also found for plant communities 6 and 7. This supports the grouping of certain plant communities into Relative Homogenous Grazing Araes (RHGA) as found with detrended correspondence analysis (ISPD programme) and described in Chapter 4. The general dissimilarity of the plant communities on the lithosols (1, 2 and 3) with the other plant communities may be due to the high percentage Decreasers and Increaser I grasses indicative of a low grazing pressure. The high grass density, low grass height and above-ground standing crop, and low veld condition of plant community 4 made it dissimilar to the other plant communities.

With respect to many habitat parameters the important plant communities for the breeding herds namely 5, 7, and 8 were often similar. The morphological, structural and chemical composition of the variables in these plant communities probably comply with the roan's habitat requirements under the set of conditions. Plant communities 5 and 7 were open areas with long grass and virtually no trees. They also had high concentrations of Na and Ca respectively.

<u>Logistic regression analysis</u>

The probabilities of the logistic regression, based on mean, and high and low values, were used to isolate those habitat variables which best predict the plant communities. However the predictions were not satisfactory since all variables could be found in most plant communities (dependent variable) (Table 10.2 and 10.4, Appendix 10). For further modelling only a few variables should be used to make it less dependent on the observed data and more stable (O'Neil, Roberts, Wakeley & Teaford, 1988; Dattalo, 1994). The Wald statistic indicating if an independent variable is a significant predictor of the dependent variable (Lottes *et al.*, 1996) was used to support the probabilities of the logistic regression. It indicated fewer variables to be significant predictors of plant communities (Table 10.3, Appendix 10). These isolated habitat parameters were supported with general linear modelling (PROC GLM) (see previous chapters) where only habitat variables

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in selected plant communities (by roan) that differed significantly from other plant communities were used (Table 10.5, Appendix 10).

In total 17 variables were isolated, 16 variables for winter and 12 for late summer (Table 10.6, Appendix 10). From the logistic analysis it appeared that the most important habitat variables had a significantly high probability of being found in the *Rhus leptodictya - Combretum apiculatum* Variation, *Cymbopogon plurinodis - Combretum apiculatum* Variation and the *Eragrostis nindensis - Digitaria monodactyla* Variation (1, 2 and 3), and in the *Aristida bipartita - Setaria sphacelata* Savanna and Grassland Variation (6 and 7). The probability was also high that grass tuft height, biomass concentration, chemical parameters and minerals are being found in the floodplain (5) and *Eragrostis pallens -Burkea africana* Savanna (8).

Significantly high probabilities of finding habitat parameters in certain plant communities were less in winter (n = 12) than in summer (n = 18). This may indicate that during summer plant communities are more similar with respect to habitat parameters than during winter. The effect of this would be that breeding herds are confined to fewer plant communities in winter than in summer.

Conclusion

The correspondence results indicated which plant communities are similar by forming clusters and which plant communities have a strong "correspondence" with certain combinations of habitat variables. However, this did not isolate the important variables that summarized the variation among plant communities. A similar situation was found with logistic analysis.

Since the probability (p) of the logistic analysis is a prediction that a specific combination of habitat variables is found in one or more plant communities, it did not isolate individual variables satisfactory. The grouping of variables may have resulted in all habitat parameters being found with a high probability in the majority of plant communities. Maybe logistic regressions should have been done on single variables rather than groups of variables.

The Wald Chi-square statistic limited the number of significant variables. In combination with general linear modelling the number of important variables was further reduced.

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CHAPTER 18

Habitat suitability model

Introduction

Effective management of wildlife populations depends largely upon understanding and predicting their habitat requirements (Clark, Dunn & Smith, 1993) and assessing habitat quality accurately (Van Horne, 1983). Habitat suitability, defined as the potential to support a species (Clark *et al.*, 1993), is a measure of the presence of important environmental parameters. It relates to abiotic and biotic conditions (Cox, 1997). Modelling is an aid to predict the habitat requirements and habitat suitability. There is also a need for habitat models to predict wildlife responses to habitat changes (Fagen, 1988). Joubert (1976) recommended the development of quick, easy methods to measure roan habitat. He suggested identifying those factors that exert the most influence on roan and to investigate a burning regime to maintain medium to tall grass conditions.

Habitat Suitability Index (HSI) models are a popular approach to modelling habitat suitability of a species based on those habitat variables which most affect species presence, distribution or abundance (Morrison, Marcot & Mannan, 1992). They help in predicting species presence or abundance, and have been used for predicting how well a species should do in a particular area (Emlen, Freeman, Bain & Li, 1992). HSI models have also been used for comparing habitat values, evaluate the effect of various habitat management options on habitat potential, and for identifying suitable habitat (Cook & Irwin, 1985) by evaluating the quality of habitat (O'Neil, Roberts, Wakeley & Teaford, 1988). HSI models are intended to provide a standard basis for evaluating species-habitat interactions and to provide a quantitative assessment of a habitat's quality (Johnson, Hammond, McDonald, Nustad & Schwartz, 1989). They are useful for representing these significant habitat variables in a simple and understandable form (Morrison *et al.*, 1992).

The general approach to formulate HSI models is *a priori* or *a posteriori* (Fabricius & Mentis, 1992). In the *a priori* approach perceived important habitat parameters may be obtained from expert opinion. For roan the known important habitat parameters are long grass and a low

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tree density (Joubert, 1976). However this may not adequately explain or predict roan presence or absence. A similar problem was also found by Fabricius (1989) when he used a draft model to predict kudu occurence. By measuring only two or three predetermined variables, vital parameters that affect animal presence or absence may be excluded. This may cause a Type II error when the model predicts absence and the species is actually present (Morrison *et al.*, 1992). The *a posteriori* approach was, therefore, followed where data on a number of variables was collected first and then analysed. The models constructed included aspects of both forage and cover.

A simplified model that incorporates only two or three of the most important variables should be developed. The rationale for minimizing the number of variables is that the resultant model is more likely to be stable, is more easily generalized, has a smaller standard error, and is less dependent on the observed data (Dattalo, 1994). In general, the larger the number of variables, the less responsive the model is to changes in any equation (O'Neil *et al.*, 1988). HSI models can be improved by conducting studies at the appropriate scale, constructing seasonal submodels and by using functional plant attributes rather than species names as model variables (Fabricius & Mentis, 1992).

The objective of this study was to develop a habitat suitability model for roan in the Nylsvlei Nature Reserve (NNR) to predict the suitability of habitats and habitat utilization.

Model construction

Model objectives

The underlying assumption in developing these models was that plant communities with a higher suitability should support a higher density of roan. Although Van Horne (1983) cautioned against this assumption the mobility of roan, small size of the plant communities (a few hundred hectares) short time span of the project (24 months), and the ease of monitoring density made it more suitable for this study than monitoring reproduction or mortality which could not be linked to a specific plant community. The objective was to develop a wildlife-habitat model that:

a)   predicts habitat use, defined as density of the roan breeding herd

b)   applies to the Nylsvlei Nature Reserve situated in the Mixed Bushveld (Northern Province)

c)   applies to winter (May to September) and late summer (January to April) respectively

Habitat variables

The habitat variables used in a model had to meet three criteria as recommended by the U.S. Fish and Wildlife Service (1981):

a)   the variable is related to the capacity of the habitat to support the species

b)   there is a basic understanding of the variable/habitat relationship

c)   the variable is practical to measure within the constraints of the model application

It should also be possible to quantitatively describe these variables with some degree of replicability using standard field sampling techniques (U.S. Fish and Wildlife Service, 1981). The scale at which data of habitat variables and roan distribution was collected was at the plant community level. The relationship between roan density and habitat variables, in non-burnt areas only, was investigated with simple correlation (Table 18.1). Density data of only the breeding herd was used since social interactions may prevent subordinate animals in this case bachelor males from utilizing high-quality habitat (Van Horne 1983). The spatial separation between the breeding herd and bachelor males was described in Chapter 16.

Breeding herd density (no./ha) correlated significantly with % Ca during winter ($r = 0.7175$). Other variables did not correlate significantly with density. Variables isolated with the Wald statistic and verified with general linear modelling (Chapter 17) were therefore used to construct the HSI model.

However the variables isolated with the Wald statistic and general linear modelling numbered 17 which is far above the recommended number of only two to three variables for HSI models (O'Neil *et al.*, 1988). These were: species density, grass density, percentage grass canopy cover, total grass height, grass tuft height, above-ground standing crop, biomass concentration, woody plant density, percentage woody plant canopy cover, % N, % NDF, % ADF, % IVOMD, % OM, % Ca, % K and % Na.

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Table 18.1: Correlations between breeding herd density and independent habitat variables. Significant correlation coefficients (r) (p ≤ 0.05) are indicated with an *.

	Winter	Late Summer
Habitat variable	r	r
Species density	-0.2716	-0.4496
Grass density	-0.0873	-0.0044
Grass canopy cover	-0.0026	0.6377
Total grass height	0.2886	0.3180
Grass tuft height	0.3805	0.1113
Above-ground standing crop	0.2671	0.4558
Biomass concentration	-0.1740	0.1100
Woody plant density	-0.2702	-0.3556
Woody plant canopy cover	-0.3487	-0.4933
% Moisture	-0.0254	0.1083
% N	-0.2156	-0.1890
% NDF	-0.4313	-0.3941
% ADF	0.0227	0.0275
% IVOMD	-0.1461	0.0721
% OM	-0.5017	-0.0904
% Ca	0.7175*	0.3628
% P	0.0017	0.2239
% K	-0.4753	-0.1386
% Na	-0.1774	0.0201

Some of these variables were discarded to reduce their number for constructing a model. Species density was not included in the winter model since it is difficult to identify grass species accurately during winter. Since grass canopy cover is not an accurate measure of cover but rather basal cover, canopy cover was not used in the models. Grass tuft height can be used to predict above-ground standing crop ($r^2 = 0.6089$) and biomass concentration ($r^2 = 0.8856$) (Chapter 8).

Grass tuft height was therefore used in the HSI model as an indirect measure for above-ground standing crop and biomass concentration. Indirect measures may be used where necessary to stay within the constraints of the intended applications of the model (U.S. Fish and Wildlife Service, 1981).

Of the fibres only % NDF was used as it describes the total cell wall fraction of the forage (Minson, 1990; McDonald, Edwards, Greenhalgh & Morgan, 1995). Because % NDF partly regulates forage intake through rumen fill, it is probably the best estimator of forage quality (Cheeke, 1991). Percentage OM was omitted from the HSI model because the digestibility of forage OM is estimated when applying the rumen fluid-pepsien technique (Minson, 1990). Instead % IVOMD was used as an important measure of the nutritional value of forages in ruminants (Pehrson & Faber, 1994). Potassium is seldom a limiting mineral for animals due to the very high K contents in growing plants, usually in excess of animal requirements (Robbins, 1993). Potassium was therefore not used for the HSI models.

This subjective selection of the habitat parameters resulted in 11 variables being used for the HSI model construction. These were: species density (V_1), grass density (V_2), total grass height (V_3), grass tuft height (V_4), woody plant density (V_5), percentage woody plant canopy cover (V_6), % N (V_7), % NDF (V_8), % IVOMD (V_9), % Ca (V_{10}), and % Na (V_{11}).

Relationship between variables

The habitat was separated into less complex components with tree diagrams to facilitate the understanding of the relationship between variables (U.S. Fish and Wildlife Service, 1981). The life requisite components considered to be critical for roan were forage and cover since these affect reproduction, mortality and survival (Van Horne & Wiens, 1991). The forage value was inferred from forage availability and quality. Each component consists of a number of related and measurable variables (Fig. 18.1). Because the patterns in habitat utilization shifted seasonally the variables were separated into a winter (May to September) and a late summer season (January to April).

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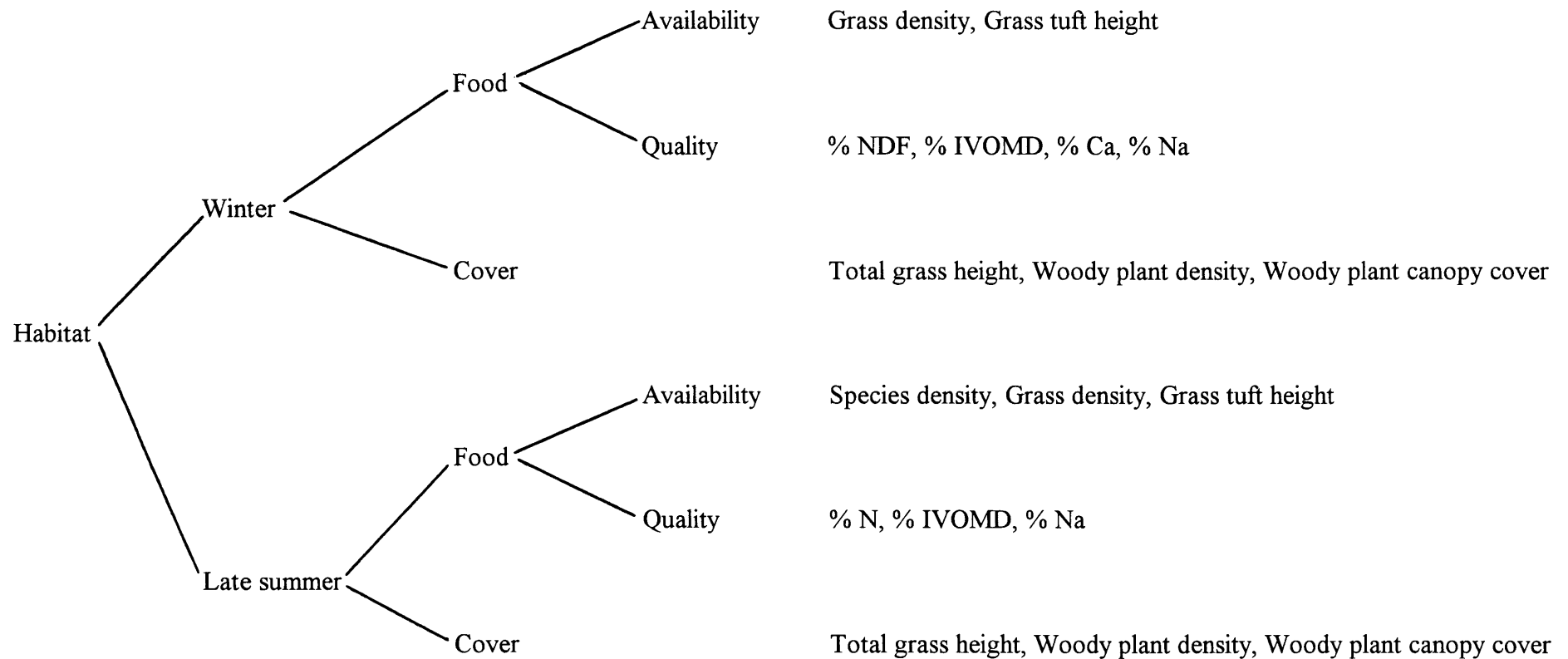
Fig. 18.1: Relationship of life requisite components and their variables of seasonal habitats for the roan breeding herd.

Suitability of variables

Developing a HSI model involves two processes (U.S. Fish and Wildlife Service, 1981; Allen & Armbruster, 1982): 1) determination of a suitability index for each variable and 2) the aggregation of suitability indices into a component suitability index. The relationship between the variable and the index of suitability was described with a suitability index graph. This relationship between habitat suitability and a variable is assumed to be independent of other variables (U.S. Fish and Wildlife Service, 1981).

Suitability index graphs were constructed by assigning a suitability score of 1.0 to the range of variable measurements corresponding to the maximum observed density. Measures of variables found in areas avoided or less frequently utilized by the breeding herd were assigned a suitability score of 0.0 for unsuitable conditions (U.S. Fish and Wildlife Service, 1981). These were then connected by a straight line. Suitability index (SI) curves were drawn for each variable by plotting the values against their corresponding suitability indices (Fig. 18.2). Numerical SI values were obtained by comparing variable measurements with the relationship depicted by the suitability curve. The SI values were correlated with breeding herd density (Table 18.2).

Table 18.2: Correlations (r) of SI values of variables with breeding herd densities (no/ha). Significant correlation coefficients (r) ($p \leq 0.05$) are indicated with an *.

WINTER		LATE SUMMER	
Variable	r	Variable	r
		Species density	0.7686*
Grass density	0.2592	Grass density	0.1972
Grass tuft height	0.3106	Grass tuft height	0.3342
% NDF	0.3813	% N	0.0294
% IVOMD	0.1168	% IVOMD	0.0193
% Ca	0.1888		
% Na	0.0313	% Na	0.3303
Total grass height	0.4329	Total grass height	0.0479
Woody plant density	0.0967	Woody plant density	0.3064
Woody plant canopy cover	0.0912	Woody plant canopy cover	0.0954

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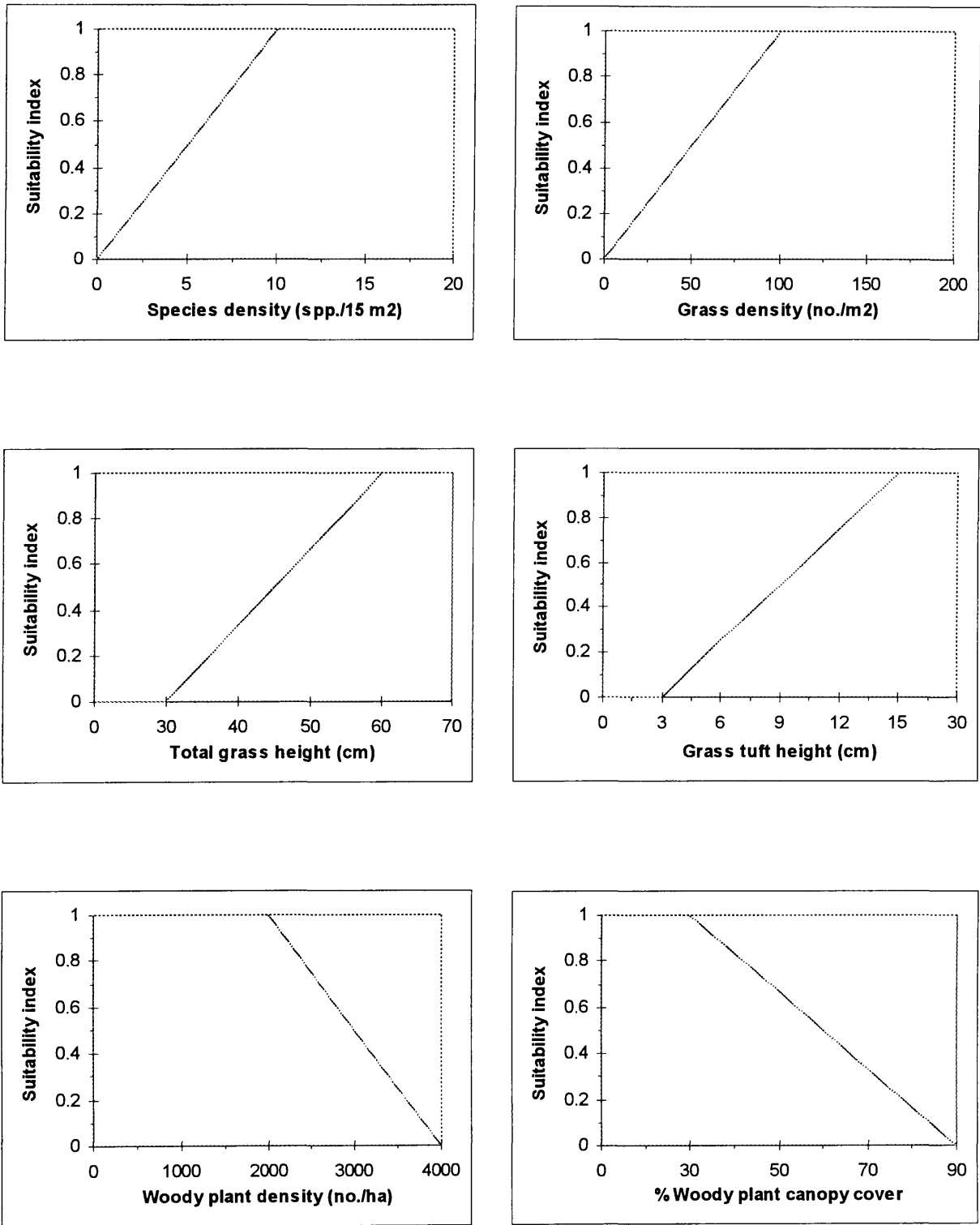
Fig. 18.2: Suitability index (SI) graphs of variables used in the HSI models.
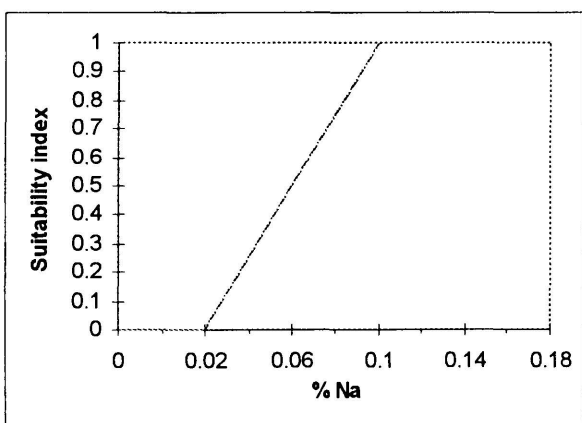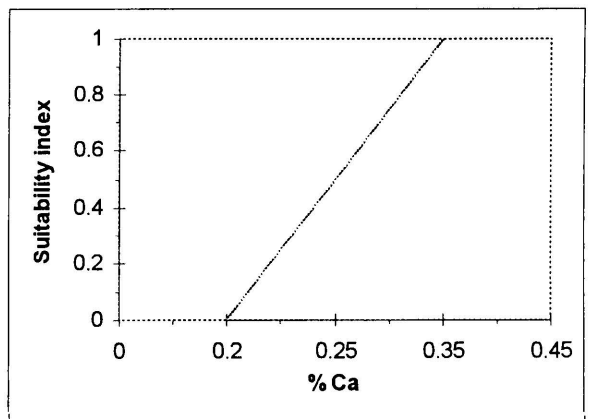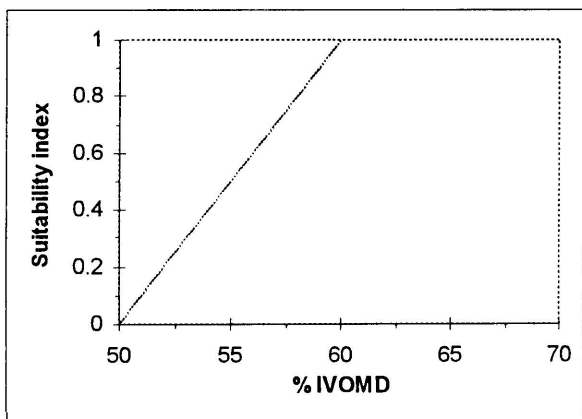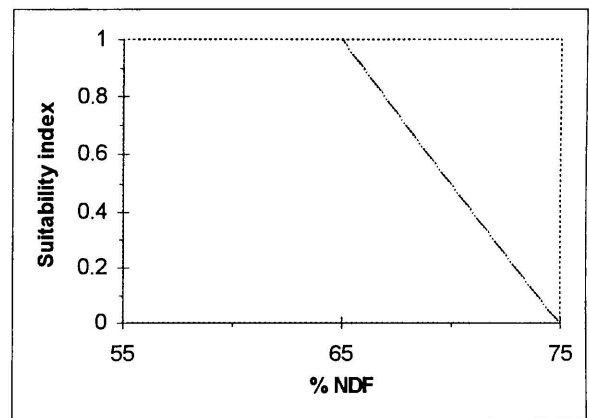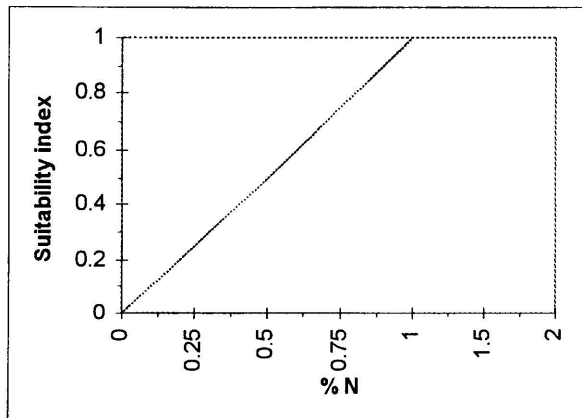
Fig. 18.2 (cont.): Suitability index (SI) graphs of variables used in the HSI models.

Habitat suitability model

The seasonality in habitat selection became apparent with the analyses of the distribution data (Chapter 16). The decision to develop seasonal sub-models simulated habitat selection more realistically. Seasonal sub-models were also used by various other authors e.g. Cook & Irwin (1985) and Fabricius & Mentis (1992). Two seasonal habitat models were developed, a winter HSI model (May to September) and a late summer HSI model (January to April). The late summer model did not include data from early summer because many early summer habitat parameters did not differ from the winter data (Chapters 3 to 10). The variables (n = 11) identified with the Wald statistic and general linear modelling were used for each respective HSI model as shown in Fig. 18.1. Variables in each seasonal model were separated into the life requisites forage and cover (Fig. 18.1), similar to those described by Cook & Irwin (1985), O'Neil *et al.* (1988) and Morrison *et al.* (1992). The forage value was inferred from forage availability and quality.

Based on the literature (Joubert, 1976; Heitkönig, 1993), it was assumed that roan are limited by grass tuft heights < 5 cm, low total grass heights and high tree densities. These variables may partially be compensated for by higher values of other variables. In this case a geometric mean would be used as the overall value is also weighted by the smallest value (U.S. Fish and Wildlife Service, 1981; Van Horne & Wiens, 1991). Variables with low suitabilities such as low grass tuft heights and high woody plant densities would have a greater influence on the HSI value. If one SI score is 0.0 then a geometric mean gives a score of zero (U.S. Fish and Wildlife Service, 1981). Geometric means are commonly used in HSI models (Allen & Armbruster, 1982; Cook & Irwin, 1985; Krohn & Owen, 1988; O'Neil *et al.*, 1988; Johnson *et al.*, 1989; Schroeder, 1990). The life requisites forage availability, forage quality and cover were calculated with the geometric mean. An averaging function was not applied since it tends to become insensitive to extremely low or high values where four or more variables are used (U.S. Fish and Wildlife Service, 1981).

There was generally a poor correlation between values of life requisites and breeding herd density (Fig. 18.3).

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Table 18.3: Correlations (r) of life requisites with breeding herd densities (no/ha). All correlations were non-significant (p > 0.05).

Winter		Late summer	
Life requisite	r	Life requisite	r
Favail	0.3357	Favail	0.3430
Fqual	0.2258	Fqual	0.3293
Cover	0.3151	Cover	0.3364

Calcium appeared to be an important component in winter where it correlated significantly (r = 0.7175) with breeding herd density. An increased influence of % Ca was therefore allowed in the winter model by multiplying it with the geometric mean of the other chemical components as described by Cook & Irwin (1985).

The Wald statistic and the general linear modelling showed that % Na was not an important parameter in summer. A draft late summer model was constructed without % Na being in the life requisite forage quality equation. This draft model showed a poor correlation with density (r = 0.3713). The model was improved by including % Na into the life requisite forage quality. The rationale was that roan do select the floodplain in summer which had a mean forage Na content of 0.1257 %. This is considerably higher than in most other plant communities (0.0247 - 0.0510 %), except for the *Sporobolus ioclados - Acacia tortilis* Savanna (0.7488 %). The correlation obtained with this final version of the late summer model was r = 0.6522. This suggests that % Na may be an important variable for roan during late summer.

The SI values for each variable were substituted in each life requisite equation to obtain a value for food availability (Favail), food quality (Fqual) and cover. The overall HSI value was calculated as the product of the life requisite values. This allows individual variables with low values to have a large influence on depressing HSI values (Van Horne & Wiens, 1991).

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The seasonal HSI models were:

WINTER

HSI = Favail x Fqual x Cover

where $\text{Favail} = (SIV_2 \times SIV_4)^{1/2}$

$\text{Fqual} = SIV_{10} (SIV_8 \times SIV_9 \times \% \, SIV_{11})^{1/3}$

$\text{Cover} = (SIV_3 \times SIV_5 \times SIV_6)^{1/3}$

LATE SUMMER

HSI = Favail x Fqual x Cover

where $\text{Favail} = (SIV_1 \times SIV_2 \times SIV_4)^{1/3}$

$\text{Fqual} = V_{11} (SIV_7 \times SIV_9)^{1/2}$

$\text{Cover} = (SIV_3 \times SIV_5 \times SIV_6)^{1/3}$

HSI scores range from 0.0 to 1.0, representing unsuitable and optimum habitats respectively (Cook & Irwin 1985; Bender, Roloff & Haufler 1996). The calculated HSI values are given in Table 18.4.

Table 18.4: HSI values for the winter and late summer sub-models.

Plant community	Winter	Late summer
Rhus leptodictya - Combretum apiculatum Variation	0.0000	0.0000
Cymbopogon plurinodis - Combretum apiculatum Variation	0.0942	0.0932
Eragrostis nindensis - Digitaria monodactyla Variation	0.2478	0.2699
Sporobolus ioclados - Acacia tortilis Savanna	0.0000	0.0000
Nyl River and flooplain	0.5679	0.8159
Aristida bipartita - Setaria sphacelata Savanna Variation	0.4433	0.6201
Aristida bipartita - Setaria sphacelata Grassland Variation	0.7194	0.4300
Eragrostis pallens - Burkea africana Savanna	0.0810	0.1112

Linear regressions of HSI values and breeding herd densities produced the following models to predict densities:

WINTER

$$Y = -0.06 + 3.2564x \quad (r^2 = 0.4011)$$

where Y = roan breeding herd density

$x =$ HSI value

LATE SUMMER

$$Y = 0.0338 + 0.7235x \quad (r^2 = 0.4254)$$

where Y = roan breeding herd density

$x =$ HSI value

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Model validation

Validating models is a multifaceted problem. Different criteria are used to test various aspects of model prediction such as the robustness of the model, the sensitivity of predictions, the precision of input variables, and the accuracy of predictions of species' abundance (Morrison *et al.*, 1992). These seasonal sub-models were validated by correlating roan density (dependent variable) with the HSI values (independent variable) as suggested by Cook & Irwin (1985), Krohn & Owen (1988), Morrison *et al.* (1992) and Bender *et al.* (1996). Krohn & Owen (1988) suggested that the use of abundance as the standard of comparison is a more meaningful test of HSI models.

Validation of the HSI models showed that the HSI scores poorly correlate with population indicators (breeding herd density) of habitat quality. Correlations between HSI values (predictor variable) and breeding herd densities (dependent variable) were $r = 0.6333$ during winter and $r = 0.6522$ during late summer.

An important aspect of testing HSI models is to compare the model output to a maximum standard of comparison (Schroeder, 1990) which should be the same population variable as was used in constructing the model. In this test the linear regression model output was compared with actual breeding herd densities because the population was close to carrying capacity (Dörgeloh, Van Hoven & Rethman, 1996). The winter regression model overestimated breeding herd density (mean 6.53/ha) by 2.44 times that of the actual densities (2.68/ha) during winter. The late summer model approximated expected population densities (mean 1.96/ha) more closely.

Discussion

The number of variables used in the development of the sub-models was still relatively high compared to the recommended number of variables in HSI models. They measure typically three to five habitat parameters, mainly plant density and cover (Cook & Irwin, 1985; O'Neil *et al.*, 1988; Fabricius & Mentis, 1992; Bender *et al.*, 1996; Nelson & Buech, 1996). As was mentioned earlier, by excluding other variables the HSI model may not adequately avoid Type II errors. Furthermore, by including more variables the models may be applicable in a greater variety of conditions, than a simplified version.

The HSI output showed that the *Aristida bipartita - Setaria sphacelata* Grassland Variation and the Nyl River and floodplain were most important during winter and late summer

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respectively. The poor correlation between the SI scores and HSI scores, and breeding herd densities reflects a deficiency in the models. It may also show that animal density is not necessarily indicative of habitat suitability (U.S. Fish and Wildlife Service, 1981; Van Horne & Wiens, 1991). The models did not predict density adequately but probably predict the potential of a habitat to support roan. The standard of comparison (breeding herd density) may also have been inadequate because certain criteria were not met. These are a large sample size, long-term data and the elimination of unreliable data (Krohn & Owen, 1988). Other criteria such as consistent field methods and data from the same geographical area were met. The number of plant communities (n = 8) may have also inadequately covered the variety of habitat conditions used in these models. Most HSI models can be expected to account for approximately half of the variation in animal density or abundance (U.S. Fish and Wildlife Service, 1981). The reason is that most models predicting species presence or population density capture only a portion of environmental variables. This implies that environmental conditions cannot be managed alone or to expect a population response with a high degree of certainty (Morrison *et al.*, 1992).

The late summer regression model had some predictive power to explain breeding herd densities. The predicted densities were close to the observed densities indicating that the model fits the data (Gallo, 1996). The winter model did not predict density adequately but probably predicts the potential of a habitat to support roan. It should not be used to predict densities.

Model application and refinement

The models ability to rate habitat quality does not include abnormal years such as droughts. The seasonal sub-models have not been evaluated against an independent data set either from a different time series, or from another area and population.

A draft model has to be validated with independent data (Cook & Irwin, 1985; Johnson *et al.*, 1989) to determine if they incorporate appropriate habitat variables shown to limit populations (Irwin and Cook 1985), and to assess their predictive capabilities of animal presence or absence. Model validation should also address the appropriateness of the objectives, reliability and accuracy of the model (Cook & Irwin, 1985), and focus on the use of SI values to calculate overall HSI values, and the application of manipulative field experiments (Van Horne & Wiens,1991). The closer the predicted outcomes are to the observed findings, the better the

model fits the data (Gallo, 1996). To field test these models and to fully understand their behaviour more long-term data in additional geographic areas covering a large diversity of habitats and with a wider range of environmental conditions should be collected. Regional rather than local data should be collected to improve the reliability of these models (Irwin & Cook, 1985). This may require modification to perform adequately in other areas being evaluated (Cook & Irwin 1985, O'Neil *et al.*, 1988).

Sensitivity analyses should be performed (Van Horne & Wiens, 1991) to assess the relative importance of variables. With this knowledge these models could be improved by applying weighted means. Confidence intervals for the mean HSI scores should be calculated. These can be used to test for differences in HSI scores by applying the bootstrapping technique or Monte Carlo simulations (Bender *et al.*, 1996).

Model predictions combined with true roan densities will indicate if the model is correct or if Type I or Type II errors have occurred (Morrison *et al.*, 1992). If the objective of the model's intended use is to identify environmental parameters for purchasing habitats or restoring or enhancing environmental conditions for reintroductions of a species then the model must accurately predict species presence. Therefore frequencies of Type I errors should be minimized because of the high costs involved. These models should also be tested for avoiding Type I and Type II errors. The degree to which a model avoids Type I errors is given by the confidence coefficient P where $P = 1 - \alpha$ (Morrison *et al.*, 1992). The power $(1 - \beta)$ of a model tests the degree to which a model avoids Type II errors.

Because the models were based on a case study, it is therefore risky to extend the models to a broader geographical area or another set of conditions. Therefore some caution has to be exercised when applying these models as a predictive management tool until further testing and modifications have been made.

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CHAPTER 19

Management

Habitat

Being at the fringe of its geographical range, roan are more susceptible to disruptive pressures especially in confined areas where they cannot escape harmful ecological factors. Wilson & Hirst (1977) reported that the existing provincial reserves (in the former Transvaal) are inadequate for rare species such as roan and that those reserves hosting rare species are either too small or of poor quality. They also considered the nutritional status of roan antelope in these areas to be a primary limiting factor. Nutritional factors are a precipitating force operating on various aspects such as diseases (e.g. *Cytauxzonosis*) causing mortality (Wilson & Hirst, 1977). In their report they did not mention the Nylsvlei Nature Reserve (NNR) which is situated approximately in the middle of its former South African distribution.

Small enclosed areas where seasonal rotation of grazing pressures resulting from migrations (Novellie, Fourie, Kok & Van der Westhuizen, 1988) has been limited or effectively stopped cannot support high densities of animals on a continual basis. At the most seasonal local movements between plant communities could be maintained. It would be advantageous to the vegetation and for the animals if conservation areas could be planned to encourage some form of rotational grazing (Novellie *et al.*, 1988). Local seasonal movements were found with the roan population and appeared to be influenced by changes in forage quality and availability. Selections for certain areas were further enhanced when the vegetation was burnt thereby improving the forage base.

In wild animals in general, the breeding female population is the most important component in a population (Caughley & Sinclair, 1994). Often they would select the best grazing areas while bachelor males are forced into sub-optimal areas by the dominant herd male. Habitat selection of the breeding herds would, therefore, be a good indicator of optimal habitats within the confines of an area. This study showed that the breeding herds were highly selective of the lower part of the Nyl River and floodplain during summer. This reserve is transected by this seasonal floodplain and

according to literature such plains are important habitat for roan throughout Africa. The *Eragrostis pallens - Burkea africana* Savanna was also selected during summer. The present vegetation found in the floodplain appears to be suitable but a limiting factor in this plant community seems to be the lack of water during winter when the grasses dry out, forcing the roan out of these areas. Maintaining the water balance of the floodplain may extend the feeding period in this important summer feeding area.

In winter they favoured the *Aristida bipartita - Setaria sphacelata* Grassland Variation, *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket) and the *Tristachya rehmannii - Digitaria monodactyla* Variation near the *Eragrostis pallens - Burkea africana* Savanna. The *Eragrostis nindensis - Digitaria monodactyla* Variation was selected to some extent. Although it was shown that the *Eragrostis pallens - Burkea africana* Savanna was avoided during winter roan utilized this plant community to some extent. The *Aristida bipartita - Setaria sphacelata* Grassland Variation and the *Eragrostis pallens - Burkea africana* Savanna may play an important role for grazing and cover for the breeding herds during winter. Roan prefer open grassland while cover in the form of trees and shrubs is also essential (Joubert, 1974). Especially the *Aristida bipartita - Setaria sphacelata* Grassland Variation should be maintained as a grass plain. The present bush encroachment onto this plain (personal observation) should be counteracted as it reduces the size and suitability of this plant community for roan during winter.

To optimize the NNR for roan the vegetation should be managed specifically to suit the needs of roan. Wilson & Hirst (1977) proposed that habitats should be monitored for structural and nutritional adequacy. The management of roan must take their susceptibility to nutritional deficiencies and resultant diseases into account (Wilson & Hirst, 1977). An enlargement of the floodplain along the Nyl River for summer grazing and the *Aristida bipartita - Setaria sphacelata* Grassland Variation and the *Eragrostis pallens - Burkea africana* Savanna as a winter habitat should be considered to increase the carrying capacity of the NNR for roan, thereby overcoming the nutritional problems.

If the above recommendation cannot be met due to financial or other constraints, the implementation of an artificial feeding programme or a reduction of the population size should be considered. Patch burning throughout winter would also improve the forage quality during the critical dry period. This is when females are in most need of high quality food.

It is further suggested that the present monitoring programme of roan distribution should be terminated; the seasonal distribution of roan and the utilization of different plant communities has

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been well documented in this and other studies. Instead monitoring efforts should rather concentrate on population dynamics such as age specific fecundity and mortality. This would enhance the understanding of long-term demographic processes and improve population mangement.

Population dynamics

A population viability analysis (PVA) of this population showed that a low calf and sub-adult female mortality (2-3 years old) is important for long-term population survival. Calf sex ratio should also be monitored. However, these parameters are difficult, if not impossible, to monitor in the field. An option would be to attract the breeding herds to an artificial feeding site during winter of each year. Here age specific sex ratios, fecundities and mortalities could be monitored. In this way a more comprehensive and accurate population composition could be compiled. This data base could be used for further analysing the population dynamics and to conduct a detailed PVA.

Joubert (1976) found that a reduction in roan population size in the Kruger National Park was mainly caused by calf mortality within the first few months after birth. This was affected by various factors such as predation, diseases and food shortage. Other mortality factors were an increased male mortality during their eviction from the nursery herd and the higher mortality among adult males. Roan could be regarded as the most prolific breeder of all larger antelope in the Kruger National Park based on the reproductive potential and the high conception and birth rate (Joubert, 1976). Therefore demographic stochasticity limiting population growth should rather be sought in post-natal stages than in reproductive deficiencies (Joubert, 1976). Although no calf mortalities were recorded in the NNR the average calving rate and a negative growth rate (Dörgeloh, Van Hoven & Rethman, 1996) suggest that this population also experiences a high calf mortality.

The PVA also showed that this population should be harvested. Dörgeloh *et al.* (1996) suggested that the population should be reduced to improve its growth rate. Replacements of some animals with unrelated sub-adult females (2-3 years old) to maintain the demographic balance and genetic variation should be implemented.

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The goals of managing an endangered species should include a population size that is self sustaining with minimal intervention (Lacy & Clark, 1990). The NNR is too small to hold a self sustaining population. Therefore this small population has to be managed demographically and genetically for long term population persistence. Apart from being managed as a separate population, it should form part of a larger meta-population and be managed as such. This would imply the exchange of different genetic stock from other populations.

Behaviour and other species

Although the behaviour and effects of parasites on the roan population were not investigated in this study, these two aspects are briefly discussed in relation to population density and growth. The considerable intraspecific aggression by roan is of major importance in the maintenance of herds in relatively small, fenced areas (Wilson & Hirst, 1977). When sufficient space is not available to accomodate all social groups, it can be expected that young maturing males will be killed by the dominant herd bull (Wilson & Hirst, 1977).

The maintenance of healthy roan populations should include the control in numbers of other competing species, since roan are always at disadvantage in a competitive situation (Joubert, 1976; Wilson & Hirst, 1977).

Parasites

The PVA identified calf mortality as an important limiting factor for population persistence (Chapter 14). Ebedes (1992) reported that the brown ear tick *Rhipicephalus appendiculatus* was found to be an important cause of calf mortality in Percy Fyfe N.R.. He also suggested that ticks may limit the roan population in the NNR ([*]Ebedes, H. 1997. pers. comm.). Infection with the blood parasite *Cytauxzoon* can contribute to high losses among stressed roan. This parasite can be carried by kudu without any obvious effects. (Wilson & Hirst, 1977; Mungall & Sheffield, 1994). Roan are also sensitive to anthrax (Skinner & Smithers, 1990).

[*] Ebedes, H, 1997. Onderstepoort Veterinary Institute, Private bag X5, Onderstepoort, 0110

It is recommended that the roan population in the NNR should receive nutritional supplementation during winter. The daily food quantities given do not have to be the amounts as suggested by Dörgeloh *et al.* (1996). In this case the artificial feeding should mainly serve as a mechanism to attract the roan to a device (e.g. Duncan applicator or Tickoff) where they can be treated with a chemical to control parasites. The feeding programme and parasite control may improve the general condition of the females which are pregnant or lactating during this time.

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CHAPTER 20

Conclusion

The most suitable area for wildlife in general, in terms of forage quality and optimal forage intake would be the *Sporobolus ioclados - Acacia tortilis* Savanna. It had a very high Na concentration of 0.7488 % (annual mean). This was on average 16.5 times higher than in other plant communities. The other chemical components were also high with moisture being 37.40 % (highest), 1.82 % N (highest), and 67.71 % IVOMD (second highest). The minerals Ca and P were second highest with 0.3549 % and 0.1152 % respectively. Fibres had the lowest concentrations with 30.34 % ADF and 62.20 % NDF. Biomass concentration plays an important role in forage intake and at 4.58 kg/m³ was the second highest. Tree density, an important parameter in roan habitat, was less than 1 000 woody plants/ha. While these conditions would probably be suitable for roan, the grass layer of < 5 cm grass tuft height (mean of 2.32 cm) could not be utilized by roan and is therefore not available to them as roan feed at a height between 5 and 30 cm (Heitkönig, 1993).

High quality forage was also found in the Nyl River and floodplain where the Na content was 0.1257 % (2.76 times higher than in other plant communities). The N content was 1.36 % (second highest), and IVOMD and P were highest with 68.1 % and 0.1186 % respectively. Fibre components had the second lowest year round concentrations of 64.52 % NDF and 35.75 % ADF. This plant community had the highest mean annual biomass concentration of 6.44 kg/m³. In other plant communities it ranged between 1.36 and 2.00 kg/m³. Woody plant density was less than one woody plant/ha. Although the floodplain had the lowest grass species density of 10 species per 15 m² many of these species are favoured by roan. The high quality and availability of forage in this plant community may make it an important summer feeding area for roan. Grasses in the floodplain stayed green for the longest period (casual observation) because of flooding during summer. As the water recedes towards winter the grasses dry out and senescede. The grass tuft height is reduced to 15.54 cm from a summer high of 30.4 cm. The reduction in food quantity and quality probably forces roan out of the floodplain into other areas.

Other areas which may be potentially suitable, based on a high grass species diversity with a Simpson's index of 0.8252 and a grass species density of 29 species per 15 m², are the *Rhus leptodictya - Combretum apiculatum* Variation and the *Cymbopogon plurinodis - Combretum apiculatum* Variation. Most of these grasses are Decreaser and Increaser I species. However, the chemical composition of the forage (low protein, digestibility and minerals, high fibre content) and biomass concentrations (1.5126 and 1.6857 kg/m³) were low. Also areas with high densities of woody plants such as the *Rhus leptodictya - Combretum apiculatum* Variation (3 630 woody plants/ha) and the *Cymbopogon plurinodis - Combretum apiculatum* Variation (2 357 woody plants/ha) are avoided by roan, which prefer more open areas (Joubert, 1976).

In winter roan selected mainly the *Aristida bipartita - Setaria sphacelata* Grassland Variation which had the highest Ca content of 0.549 %. Forage high in Ca may be important for pregnant and lactating females (Robbins, 1993). The above-ground standing crop and grass height were still high in winter with a biomass of > 4 000 kg/ha and a grass tuft height of 25.03 cm. This plant community also has a woody plant density of less than one woody plant/ha. The adjacent *Tristachya rehmannii - Digitaria monodactyla* Variation and the *Rhus leptodictya - Combretum apiculatum* Variation (eastern pocket) were utilized to some extent in winter. The *Eragrostis pallens - Burkea africana* Savanna was not selected significantly but it was utilized to some extent by the breeding herd in winter. The % Ca and % P of the preferred grass species, identified by Heitkönig (1993) in the *Eragrostis pallens - Burkea africana* Savanna were 0.4662 % Ca and 0.1629 % P respectively. These were also significantly higher than those in the floodplain (0.3963 % Ca; 0.0724 % P). The long grass (total grass height of 48.30 cm) and cover provided from trees (1 985 woody plants/ha) in the *Eragrostis pallens - Burkea africana* Savanna may provide the necessary shelter needed for new-born calves. Tree canopy provides a measure of thermal cover for wildlife species (Patton, 1992).

The areas most utilized when newly burnt were the Nyl River and floodplain, and the *Aristida bipartita - Setaria sphacelata* Grassland Variation. The latter plant community was utilized to a larger extent than in a non-burnt state. This increased utilization of newly burnt areas was the result of an increased forage quality and forage availability. Forage availability in terms of biomass concentration increased by 30.00 % and 35.21 % respectively although it was not statistically significant. Increased levels of % N, % IVOMD, % Ca and % P were not significant except for % IVOMD. An increased forage quality and forage availability will lead to an optimal quality forage intake. In comparison the *Rhus leptodictya - Combretum apiculatum* Variation was

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not utilized when burnt. The high woody plant density probably limited its utilization by the breeding herds.

The most important habitat parameters determining the distribution of the roan breeding herd in the Nylsvlei Nature Reserve (NNR) were identified with logistic regression analysis. These were: species density, grass density, percentage grass canopy cover, total grass height, grass tuft height, above-ground standing crop, biomass concentration, woody plant density and canopy cover, % N, % NDF, % ADF, % IVOMD, % OM, % Ca, % K and % Na. These were reduced subjectively by comparing the results with general linear modelling and roan distribution. The remaining 11 variables were then used for developing seasonal draft Habitat Suitability Index (HSI) sub-models. Regression analysis between HSI output and breeding herd observations indicated high correlations, suggesting some validity of these models. The importance of the floodplain (summer) and the *Aristida bipartita - Setaria sphacelata* Grassland Variation (winter) predicted by the models confirmed earlier analysis with the Chi-square test and correspondence analysis. However these draft HSI models need further testing with independent field data.

The negative rate of increase of the roan population in the NNR may be the result of the population having reached carrying capacity (Dörgeloh, Van Hoven & Rethman, 1996). This may further lead to high calf mortalities due to poor lactation and parasite infections. The general density of roan in this reserve was higher compared to natural areas. If calculated according to their preferred winter and summer ranges only, the densities are four to seven times higher. It is recommended that the population is reduced by approximately 50 % to increase the growth rate. Other options would be to introduce an artificial feeding programme or to plant a section with suitable grass pastures, thereby increasing the carrying capacity artificially. This may also help in maintaining the condition of animals during the dry winter months.

A population viability analysis (PVA) of the roan population in the NNR showed that the most critical population parameter influencing extinction risk was new born calf mortality, especially that of female calves. If this mortality rate exceeded approximately 40 % it would negatively influence the probability of population survival in the long term. Measures to reduce calf mortality have to be taken to increase population viability. Other population parameters of importance for population viability were sub-adult female (2-3 years old) mortality, proportion of males at birth, and the harvesting and supplementation of individuals to increase the genetic variation. In general most simulations of the present population size (based on 48 animals) and composition predicted that the Nylsvlei population will persist for only 40 to 50 years. This low

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population survival rate has been found by other workers (e.g. Berger, 1990) where populations are smaller than 50 animals. This appears to be in contrast with the above recommendation to even further reduce the population size. Since the Nylsvlei population is not viable in the long term anyway it must form part of a larger meta-population and be managed as such. This would include the exchange of genetic stock.

Further research

The HSI models were based on a few of the habitat parameters tested. To increase the predictive accuracy of the models additional environmental parameters such as the intermediate stratum (1.5 to 4.0 m) of woody vegetation as suggested by Joubert (1976) should also be tested. Also the distance from water, availability of vleis and floodplains, numbers and density of competitors and predators, generally found in large natural areas such as the Kruger National Park, should be included.

Although the NNR lies within the natural distribution of roan in South Africa, the habitat requirements displayed may not necessarily apply to the species in general. The draft HSI models must be validated by field testing with independent data (Cook & Irwin, 1985). Independent data of the same population in a different time series or of other populations in geographically different areas and with other habitat conditions should be collected. This data should be used to validate and if necessary modify the existing draft models. Models should be modified when applied in other areas to perform adequately in the area being evaluated (Cook & Irwin, 1985, O'Neil, Roberts, Wakeley, & Teaford, 1988).

The models developed were based on linearity. However, in nature most systems are functioning non-linearly but non-linear mathematical models are more difficult to develop. A new mathematical field of research to overcome this problem is neural networking and fuzzy logic where combinations of a number of factors can be tested (*Van Wyk, A., 1997. pers.comm.). Model development in this field could be used to refine wildlife-habitat models and to increase their predictive accuracy.

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* Van Wyk, A. 1997. Mining and Engineering, Technikon SA, Private bag X6, Florida, 1710

More detailed studies of the processes playing a role in the important population parameters identified in the PVA should be conducted. Other aspects of the population dynamics and social behaviour of this roan population should also be collected over the long term to refine, and to be able to conduct, a reliable PVA. Especially age specific birth and death rates and their variation below and at carrying capacity, calf sex ratio, the contribution of bachelor males to breeding, variability in carrying capacity, and the probability and severity of catastrophes are important to monitor.

Genetic studies should be conducted on roan in general to determine the degree of inbreeding and genetic variation. This detailed data should be included into a PVA to predict the viability of the many small populations found on small conservation areas. A PVA should not only be conducted for other roan populations but also for other rare and endangered species.

A PVA can also be used to define "minimum critical areas". This would imply a knowledge of (1) the habitat and area requirements of the species, (2) the spatial and temporal variability of suitable habitats, and (3) the effectiveness of remaining habitats in contributing to minimum critical areas (Lindenmayer, Clark, Lacy & Thomas, 1993). Some of this information was collected during this study but was not used to calculate a minimum critical area to support a minimum viable population.

When implementing an artificial feeding programme the effect of protein and mineral supplementation on natality and calf survival should be investigated. Only then can its effectiveness be measured and a cost/benefit analysis be done.

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SUMMARY

The aim of this study was to model the roan-habitat relationships and the demography of the roan population in the Nylsvlei Nature Reserve. Habitat variables were measured in eight plant communities over 24 months. There were three sites per plant community. Species composition, dry weight contribution per species and grass density were measured with a small quadrat method. Species composition was used to calculate species diversity, species density and veld condition. Above-ground standing crop was measured with a disc pasture meter. Total grass height and grass tuft height were ranked according to height classes. Biomass concentration was calculated from the above-ground standing crop and grass tuft height. Grass canopy cover was measured with the step-point method. Belt transects were used to measure woody plant density and woody plant canopy cover was measured with the line intercept method. Grass leaves at a height between five and 30 cm were collected and analysed for nutritional quality. Forage quality described as % moisture, % N, % NDF, % ADF, % IVOMD, % OM, % Ca, % P, % K and % Na was measured with wet chemical methods and near-infrared reflectance spectroscopy. Differences in habitat variables between seasons and between plant communities were tested with general linear modelling. They were further analysed with correspondence analysis and logistic regression analysis to identify those variables that are most important in a plant community.

Seventeen habitat parameters were isolated with logistic regression analysis of which only 11 were used for constructing seasonal Habitat Suitability Index models. These models predict the suitability of habitats and the roan densities in each plant community. Regression analysis between HSI output and breeding herd observations indicated high correlations, suggesting some validity of these models. These models need further testing with independent field data.

The roan population and its distribution were monitored monthly for 24 months. Distribution data was compared with habitat variables. A spatial segregation was found between the roan breeding herd and bachelor males. The floodplain with its high forage quality (mainly Na) and availability (high biomass concentration) is an important summer feeding area utilized by both social groups. The drying of the floodplain in autumn with a corresponding decrease in forage quality and availability forces roan out of this plant community and into more suitable areas. During winter the breeding herd selected the *Aristida bipartita - Setaria sphacelata*

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Grassland Variation probably because of the high Ca content and the large amounts of available forage. The adjacent *Tristachya rehmannii - Digitaria monodactyla* and the *Rhus leptodictya - Combretum apiculatum* Variation were selected to a lesser extent. The *Eragrostis pallens - Burkea africana* Savanna was also uitilized to a large extent and may serve as a calving area in winter because of the cover provided.

The high density and negative rate of increase of this population indicates that they have probably reached carrying capacity. The demography of the roan population was analysed with a Population Viability Analysis (PVA) to identify those population parameters that negatively influence population growth and to predict its persistence. The PVA revealed that female calf mortality is an important parameter influencing the population viability. This aspect needs to be monitored and controlled to ensure population persistence. Other important parameters identified were sub-adult female mortality and calf sex ratio. The roan population should be harvested and supplemented to increase its genetic variation.

A management plan was compiled with recommendations for improving the habitat for roan and to apply population management to ensure maximum population persistence. Management recommendations include the maintenance of the important plant communities, mainly the floodplain and the *Aristida bipartita - Setaria sphacelata* Grassland Variation. The hydrology of the floodplain should be maintained to supply sufficient quality forage throughout the summer. Bush encroachment onto the latter plant community should be controlled. Patch burning throughout winter will increase the forage quality for roan. The carrying capacity can be increased by enlarging the reserve. It can also be increased artificially by introducing an artificial feeding programme. This should enhance the condition of animals during winter and control their parasite load. At the same time the population can be monitored more closely. Another option could be to reduce the population size which will improve the population growth rate. This may also improve calf survival and the condition of animals.

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OPSOMMING

Die doel van hierdie studie was om die bastergemsbok-habitatverhoudings en die demografie van die bastergemsbokbevolking in die Nylsvlei Natuurreservaat te modelleer. Habitatveranderlikes is gemeet in agt plantgemeenskappe oor 'n tydperk van 24 maande. Daar was drie moniteringspunte per plantgemeenskap. Spesiesamestelling, droëgewigbydrae per spesies en grasdigtheid is gemeet met 'n kleinkwadraatmetode. Spesiesamestelling is gebruik om spesiedigtheid, spesiediversiteit en veldtoestand te bereken. Die biomassa van die bogrondse graslaag is gemeet met 'n skyfweiveldmeter. Totale grashoogte en graspolhoogte is gegradeer volgens hoogte-klasse. Die biomassakonsentrasie is bereken vanaf die bogrondse graslaag en graspolhoogte. Graskroondekking is gemeet met die stap-puntmetode. Strooktransekte is gebruik om die digtheid van houtagtige plante te meet en die kroondekking is gemeet met die lynintersepmetode. Grasblare op 'n hoogte van tussen vyf en 30 cm is versamel en ontleed vir voedingswaarde. Voergehalte beskryf as % vogtigheid, % N, % NDF, % IVOMD, % OM, % Ca, % P, % K en % Na is gemeet met natchemiesemetodes en naby-infrarooi-reflektansspektroskopie. Verskille in habitatveranderlikes tussen seisoene en tussen plantgemeenskappe is getoets met algemene lineêre modellering. Dit is verder geanaliseer met korrespondensieanalise en logistiese regressieanalise, om die belangrikste veranderlikes in 'n plantgemeenskap te identifiseer.

Sewentien habitat-parameters is geïsoleer met logistiese-regressieanalise, waarvan slegs 11 gebruik is om seisoenale Habitatgeskiktheidsmodelle (HGI) mee te konstrueer. Hierdie modelle voorspel die geskiktheid van habitats en die bastergemsbokdigtheid in elke plantgemeenskap. Regressieanalise tussen die HGI-uitset en teeltropwaarnemings het hoë korrelasies getoon, wat dui op 'n mate van geldigheid van hierdie modelle. Dié modelle benodig verdere toetsing met onafhanklike velddata.

Die bastergemsbokpopulasie en sy verspreiding is maandeliks 24 maande lank getoets. Verspreidingsdata is vergelyk met habitatveranderlikes. 'n Ruimtelike skeiding is aangetref tussen die teeltrop en die enkelbulle. Die vloedvlakte met sy hoë voedingskwaliteit (hoofsaaklik Na) en -beskikbaarheid (hoë biomassakonsentrasie) is 'n belangrike somervoedingsarea, benut deur beide sosiale groepe. Die uitdroging van die vloedvlakte in die herfs, met ooreenstemmende

afname in voedingskwaliteit en -beskikbaarheid dwing die bastergemsbok uit hierdie plantgemeenskap, na meer geskikte areas. In die winter selekteer die teeltrop die *Aristida bipartita- Setaria sphacelata* grasplantgemeenskap, waarskynlik weens die hoë Ca-inhoud en die groot hoeveelhede beskikbare weiding. Die aangrensende *Tristachya rehmannii - Digitaria monodactyla* en die *Rhus leptodictya - Combretum apiculatum*-variasie is in 'n mindere mate geselekteer. Die *Eragrostis pallens - Burkea africana*-savanne is ook in 'n groot mate benut en kan dien as 'n kalwingsarea in die winter, weens die dekking wat dit verskaf.

Die negatiewe groeikoers van hierdie populasie dui daarop dat hulle moontlik die drakapasiteit van die gebied bereik het. Digtheid is hoër bevind as in natuurlike areas. Die demografie van die bastergemsbokpopulasie is geanaliseer met 'n Populasielewensvatbaarheids-analise (PLA) is gedoen om die populasieparameters wat 'n negatiewe invloed het op die populasiegroei te identifiseer en om die volhouding daarvan te voorspel. Die PLA het aan die lig gebring dat vroulike kalfvrektes 'n belangrike parameter is wat die populasie se lewensvatbaaarheid beïnvloed. Hierdie aspek moet gemonitor en beheer word om die populasie se voortbestaan te verseker. Ander belangrike parameters wat geïdentifiseer is, is subvolwasse ooivrektes en kalwergeslagskoers. Die bastergemsbokpopulaise behoort geoes en aangevul te word om die genetiese variasie te verbeter.

'n Bestuursplan is opgestel met aanbevelings vir die verbetering van die habitat vir bastergemsbokke, om die maksimum populasie-voortbestaan te verseker. Bestuursaanbevelings sluit in die instandhouding van die belangrike plantgemeenskappe, hoofsaaklik die vloedvlakte en die *Aristida bipartita - Setaria sphacelata* grasplantgemenskap. Die hidrologie van die vloedvlakte moet in stand gehou word om voldoende kwaliteit voeding in die somer te verskaf. Bosindringing in laasgenoemde plantgemeenskap moet beheer word. Die brand van klein areas dwarsdeur die winter sal die weidingskwaliteit vir die bastergemsbok vermeerder. Die drakapasiteit kan verhoog word deur die reservaat te vergroot. Dit kan ook kunsmatig verhoog word deur 'n kunsmatige voedingsprogram te begin. Dit behoort die diere se kondisie in die winter te verbeter en hul parasietlading te beheer. Terselfdertyd kan die populasie beter gemonitor word. 'n Ander opsie sou wees om die populasiegrootte te verminder en daardeur die groeikoers te verbeter. Dit sal moontlik ook kalfoorlewing en die kondisie van die diere verbeter.

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Table 1.1: Climatic data of Roedtan, 39.8 km from the Nylsvlei Nature Reserve. Longterm rainfall was measured at the Nylsvlei N.R..

Months	Total rainfall (mm)					Average air temperature (°C)				Average wind (km/day)			
	1993	1994	1995	1996	Longterm (20 yrs)	1994	1995	1996	Longterm (13 yrs)	1994	1995	1996	Longterm (13 yrs)
Jan		34.0	35.5	219.0	106.0	23.4	25.5	24.3	24.5	147.8	164.4	152.4	165.9
Feb		141.0	82.0	111.0	82.0	23.6	24.9	22.8	24.3	129.6	162.7	133.8	157.6
March		40.0	98.1	106.0	78.5	22.3	23.1	21.3	22.9	114.6	135.8	101.4	126.8
April		2.0	138.0	2.5	23.7	19.7	20.2	18.5	19.7	106.9	116.8	116.2	111.6
May		0.0	4.0		6.2	15.7	16.3		16.2	89.4	92.8		94.3
June		0.0	0.0		4.8	11.9	12.5		12.7	112.0	92.3		105.3
July		0.0	0.0		1.0	10.5	13.2		12.8	109.3	103.7		108.6
Aug		0.0	0.0		6.1	15.2	16.6		15.8	165.7	128.2		151.7
Sept	1.0	1.1	0.0		16.2	19.3	20.1		20.1	188.0	150.6		199.6
Oct	45.0	21.2	36.5		54.6	21.6	24.9		22.4	242.6	159.2		238.2
Nov	69.5	53.5	129.5		106.2	24.1	24.0		23.3	219.9	184.8		222.8
Dec	148.0	83.0	107.0		104.4	24.7	22.8		23.9	225.3	172.8		190.9
Total		375.8	630.6		589.7	232	244.1		238.6	1851.1	1664.1		1873.3
Mean						19.33	20.34		19.88	154.258	138.675		156.108
S.D.		41.9067	52.5050		42.0577	4.6896	4.4545		4.2442	50.7513	30.5087		46.4624
% below or above long-term mean		-36.27 %	6.94 %			-2.77 %	2.31 %			-1.19 %	-11.17 %		

Table 1.2: Geographical information of the land type maps of the Nylsvlei Nature Reserve (Land Type Survey Staff, 1988).

Land type	Fa266a	Ca90a	Ab88c
Terrain type	B3	A1	C4
Terrain unit	3	5	3
Altitude of the lowest point in the land type	1 090 m	1 070 m	1 150 m
Difference between the highest and lowest points in the landscape	90-150 m	0-30 m	150-300m
Slope	2-6 %	1-3 %	6-20 %
Geology	rhyolite quartzite granite	alluvium	Waterberg Group Swaershoek Formation sandstone, greywacke siltstone, shale conglomerate
Soil series	Rock 10 % Williamson 30 % Platt 5 % Klipfontein 20 % Southwold 18 % Msinga,Doveton 15 % Erfdeel 2 %	Phoenix, Rensburg 36 % Arniston 4 % Lindley 10 % Arcadia 5 % Jozini 2 % Koedoesvlei 2 % Limpopo, Mutale 2 % Katspruit 13 % Dundee 5 % Suurbrak 3 % Longlands 3 % Albany 3 % Leksand 2 %	Rock 18 % Bontberg 65 % Shorrocks 5 % Mispah 12 %
Mean annual rainfall	603.1 mm	562.1 mm	619.0 mm
Mean daily temperature for each month maximum for the year minimum for the year	 29.3 °C 6.1 °C	 n.a. n.a.	 29.8 °C 1.8 °C
Mean number of frost days	n.a.	n.a.	32.1

Table 1.3: Positions of vegetation monitoring sites measured with a GPS.

Plant community	Site no.	Position
Rhus leptodictya - Combretum apiculatum Variation	1	S 24° 38' 41.1"
		E 28° 40' 33.2"
	2	S 24° 38' 39.0"
		E 28° 40' 44.9"
	3	S 24° 38' 36.1"
		E 28° 42' 48.7"
Cymbopogon plurinodis - Combretum apiculatum Variation	1	S 24° 38' 18.4"
		E 28° 40' 48.0"
	2	S 24° 38' 20.6"
		E 28° 40' 47.8"
	3	S 24° 37' 31.4"
		E 28° 40' 35.6"
Eragrostis nindensis - Digitaria monodactyla Variation	1	S 24° 37' 04.8"
		E 28° 40' 30.5"
	2	S 24° 37' 11.7"
		E 28° 40' 37.4"
	3	S 24° 37' 17.1"
		E 28° 41' 04.5"
Sporobolus ioclados - Acacia tortilis Savanna	1	S 24° 39' 19.8"
		E 28° 40' 36.8"
	2	S 24° 39' 14.2"
		E 28° 41' 25.0"
	3	S 24° 37' 59.6"
		E 28° 41' 25.7"
Nyl River and floodplain	1	S 24° 39' 37.8"
		E 28° 41' 11.3"
	2	S 24° 38' 39.0"
		E 28° 41' 58.9"
	3	S 24° 37' 29.2"
		E 28° 41' 33.8"
Aristida bipartita - Setaria sphacelata Savanna Variation	1	S 24° 39' 36.0"
		E 28° 41' 29.8"
	2	S 24° 38' 50.4"
		E 28° 42' 17.9"
	3	S 24° 38' 29.2"
		E 28° 42' 29.5"
Aristida bipartita - Setaria sphacelata Grassland Variation	1	S 24° 40' 10.8"
		E 28° 41' 26.5"
	2	S 24° 39' 50.5"
		E 28° 41' 31.1"
	3	S 24° 39' 00.3"
		E 28° 42' 32.0"
Eragrostis pallens - Burkea africana Savanna	1	S 24° 40' 15.0"
		E 38° 41' 36.5"
	2	S 24° 39' 25.2"
		E 28° 42' 46.2"
	3	S 24° 39' 22.9"
		E 28° 43' 16.4"

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Table 1.4: Geographical information of the land types of the study areas (Land Type Survey Staff, 1988).

	PERCY FYFE NATURE RESERVE	ROOIPOORT FARM
Land type	Ab91a	Ae224a
Terrain type	A4	A2
Terrain unit	1	4
Altitude of the lowest point in the land type	1 205 m	985 m
Difference between the highest and lowest points in the landscape	150-300 m	30-90 m
Slope	3-10 %	1-3 %
Geology	Geyser granite leucocratic grey biotite granite-gneiss, granite, pegmatite, Pietersburg Group acid to intermediate lava, pyroclasts	granite, granophyre, ferrogabbro, gabbro, norite & anorthosite of the Bushveld Complex; hornfels, shale, quartzite, & conglomerate of the Pretoria Group; basalt and sandstone of the Karoo Sequence; river alluvium
Soil series	Bontberg 22 % Msinga 15 % Platt, Glenrosa 30 % Paardeberg 4 % Mispah 14 % Springfield 10 % Sebakwe 5 %	Msinga, Shorrocks 35 % Doveton, Makatini 35 % Sunvalley 15 % Arniston 10 % Nyoka 5 %
Mean annual rainfall	544.4 mm	596.3 mm
Mean daily temperature for each month maximum for the year minimum for the year	 26.8 °C 4.2 °C	 29.7 °C 5.0 °C
Mean number of frost days	6.7	n.a.

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Table 1.5: Geographical information of the land types of the study areas (Land Type Survey Staff, 1987 & in press).

	SABLE RANCH	LE GRANGE FARM
Land type	Fa4c	Ac44a
Terrain type	A3	A2
Terrain unit	3	4
Altitude of the lowest point in the land type	1 040 m	1 000 m
Difference between the highest and lowest points in the landscape	90-150 m	1 000-2 000 m
Slope	2-6 %	0-2 %
Geology	Predominantly red granite of the Bushveld Complex; occasional dykes of diabase and syenite	Andrasitic to basaltic lavas of the Ventersdorp Supergroup sometimes overlain by calcrete. Dwyka tillite occurs in places.
Soil series	Rock 17 % Paardeberg 27 % Paleisheuwel 26 % Clansthal 9 % Msinga, Shorrocks 8 % Sandvlei, Wasbank 9 % Rossdale 2 % Vaalsand 2 %	Shorrocks (-) 60 % Zwartfontein 15 % Shorrocks (+) 5 % Kalkbank 20 %
Mean annual rainfall	619.0 mm	383.1 mm
Mean daily temperature for each month maximum for the year minimum for the year	 29.8 °C 1.8 °C	 33.3 °C 1.2 °C
Mean number of frost days	32.1 days	n.a.

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APPENDIX 2

Table 2.1: Mean calculated sample size (using 0.25 m² quadrats) and range of all sites at each plant community.

Plant community	Mean	Range
Rhus leptodictya - Combretum apiculatum Variation	24.28	12.09 - 37.65
Cymbopogon plurinodis - Combretum apiculatum Variation	28.24	23.62 - 32.19
Eragrostis nindensis - Digitaria monodactyla Variation	31.07	15.97 - 52.53
Sporobolus ioclados - Acacia tortilis Savanna	10.28	5.01 - 13.71
Nyl River and floodplain	10.92	4.65 - 20.22
Aristida bipartita - Setaria sphacelata Savanna Variation	13.14	7.28 - 16.82
Aristida bipartita - Setaria sphacelata Grassland Variation	11.04	7.44 - 15.33
Eragrostis pallens - Burkea africana Savanna	16.32	13.59 - 20.18

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Table 2.2: Grass species found during the surveys. Forbs were treated as a group. Species were grouped into ecological groups according to Van Oudtshoorn (1992). Species with ecological groups in brackets were regrouped with ordination modelling (Chapter 4).

DECREASER	*Andropogon shirensis*	INCREASER	*Aristida canescens - canescens*
	Andropogon chinensis	III	*Aristida congesta - barbicollis*
	Brachiaria serrata		*Aristida congesta - congesta*
	Digitaria eriantha (Inc. II)		*Aristida diffusa - burkei*
	Diheteropogon amplectens		*Aristida junciformis - junciformis*
	Eustachys paspaloides		*Aristida meridionalis*
	Ischaeum afrum (Inc. I)		*Aristida mollissima-argentea*
	Panicum coloratum - coloratum		*Aristida rhiniocloa*
	Panicum dregeanum		*Aristida stipitata - graciliflora*
	Panicum maximum		*Aristida stipitata - stipitata*
	Panicum natalense		*Brachiaria eruciformis*
	Schmidtia pappaphoroides		*Chloris virgata*
	Setaria incrassata		*Dactyloctenium aegyptium*
	Setaria nigrirostris		*Eragrostis gummiflua*
	Setaria sphacelata - sericea (Inc. I)		*Eragrostis nindensis*
	Setaria sphacelata - sphacelata (Inc. I)		*Eragrostis trichophora*
	Sporobolus ioclados (Inc. III)		*Leersia hexandra (Inc. III)*
	Themeda triandra		*Melinis repens - repens*
			Microchloa caffra
INCREASER I	*Bothriocloa bladhii*		*Paspalum scrobiculatum*
	Cymbopogon excavatus		*Perotis patens*
	Cymbopogon plurinodes		*Pogonarthria squarrosa*
	Forbs (all species) (Inc. I)		*Setaria pallide-fusca*
	Hyperthelia dissoluta		*Sporobolus pyramidalis (Inc. III)*
	Loudetia simplex		*Tragus racemosus*
	Oryza longistaminata (Inc. I)		*Trichoneura grandiglumis*
	Schizachyrium jeffreysii		*Urochloa mosambicensis*
	Schizachyrium sanguinum		
	Trachypogon spicatus	VARIABLE	*Heteropogon contortus*
	Trystachya leucothrix (rehmannii)		*Setaria sphacelata - torta (Inc. I)*
	Urelytrum agropyroides		*Aristida sciurus*
INCREASER	*Bothriocloa insculpta*	STATUS	*Bewsia biflora*
II	*Cynodon dactylon (Inc. III)*	UNKNOWN	*Brachiaria brizantha*
	Digitaria monodactyla		*Dactyloctenium giganteum*
	Elionurus muticus		*Echinochloa colona*
	Enneapogon scoparius		*Eragrostis biflora*
	Eragrostis chloromelas		*Eragrostis heteromera*
	Eragrostis curvula		*Panicum schinzii* (Decreaser)
	Eragrostis lehmanniana		*Panicum volutans*
	Eragrostis pallens		
	Eragrostis rigidor		

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Table 2.3: Relative % composition (% C), % frequency (% F) and % dry-weight (% DW) of the herbaceous layer of each plant community in the Nylsvlei Nature Reserve. For generic names refer toTable 3.2 (Appendix 3).

Rhus leptodictya - Combretum apiculatum Variation.

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	A. chinensis	0.77	15	4.56							0.28	5	1.82
	A. schirensis	1.54	5	0	0.44	5	1.49	2.3	5	0.44	0.75	3	0.59
	D. amplectens	2.56	10	1.49							0.94	3	0.59
	D. eriantha	1.03	15	0.44	10.48	60	2.98	6.45	25	0.44	6.2	33	1.24
	P. maximum	1.03	10	0.44	2.62	35	5.43				1.5	15	2.26
	S. incrassata				3.28	15	6.49				1.41	5	2.29
	T. triandra	2.31	20	8.94	0.44	5	3.51	3.23	25	2.55	1.69	17	5.00
Total		9.24		15.87	17.26		19.9	11.98		3.43	12.77		13.79
INCREASER I	L. simplex	2.82	20	8.94				2.76	10	1.05	1.6	10	3
	S. jeffreysii	1.28	10	0							0.94	5	0.17
	S. sphacelata-s	47.18	90	58.6	29.26	90	37.99				29.86	60	32.13
	T. spicatus	0.26	5	3.51							0.09	2	1.4
Total		51.54		71.05	29.26		37.99	2.76		1.05	32.49		36.70
INCREASER II	E. chloromelas				0.44	10	3.51				0.19	3	1.4
	E. lehmanniana				1.97	25	0				0.85	8	0
	E. muticus	0.51	10	0.44							0.19	3	0.17
	E. scoparius							53.92	95	84.65	10.99	32	28.25
	H. contortus	3.85	30	11.58	6.11	60	20.53	5.07	20	1.49	5.07	37	11.04
Total		4.36		12.02	8.52		24.04	58.99		86.14	17.29		40.86
INCREASER III	A. congesta-b.				0.66	10	7.02				0.28	3	2.11
	A. congesta-c.	0.77	15	0	1.31	20	0				0.85	12	0
	A. diffusa-b.	1.54	15	1.05				8.29	45	7.46	2.25	20	2.7
	A. mollissima-a.				1.53	10	0				0.66	3	0
	C. dactylon				13.32	20	1.05				5.73	7	0.42
	E. gummiflua							0.46	5	0.44	0.09	2	0.17
	E. nindensis	0.51	10	0							0.19	3	0
	M. caffra							1.38	5	0.44	0.28	2	0.17
	M. repens-r.	0.51	5	0	0.66	10	0				0.47	5	0
	S. pyramidalis				0.66	10	4.56				0.28	3	1.82
	T. grandiglumis							0.46	5	0	0.09	2	0
	T. racemosus				2.84	30	0				1.22	10	0
Total		3.33		1.05	20.98		12.63	10.59		8.34	12.39		7.39
	Forbs	31.54	85	0	23.58	100	5.43	15.67	70	1.05	24.88	85	2.29

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Cymbopogon plurinodis - Combretum apiculatum Variation

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	A. schirensis	1.31	5	3.51	1.02	10	0.44	0.47	10	1.05	0.88	8	1.99
	B. serrata	0.33	5	0							0.10	2	0
	D. amplectens	0.66	5	0	1.71	20	5.00	2.60	35	8.07	1.76	20	4.31
	D. eriantha	5.57	25	0.44	0.68	10					1.86	12	0.17
	E. paspaloides							4.96	15	0.44	2.05	5	0.17
	T. triandra	3.93	30	9.57	1.71	20	0.44	0.71	15	3.95	1.96	22	4.58
Total		11.80		13.52	5.12		5.88	8.74		13.51	8.61		11.22
INCREASER I	H. dissoluta	0.33	5	0.44	4.44	40	15.53	4.73	50	17.46	3.33	32	10.87
	L. simplex	1.64	20	6.06	13.99	85	35.1	1.65	10	0	5.19	38	13.76
	S. jeffreysii	0.33	5	3.51	1.02	15	7.02	2.6	25	7.89	1.47	15	5.88
	S. sanguineum							0.47	10	7.02	0.20	3	2.11
	S. sphacelata-s.	56.07	85	50.53	35.84	80	32.2	39.01	75	20.17	43.15	80	34.00
	S. sphacelata-t.							0.95	10	0	0.39	3	0
	T. spicatus				0.34	5	0	0.95	10	4.56	0.49	5	1.82
	U. agropyroides							0.47	5	4.56	0.20	2	1.82
Total		58.37		60.54	55.63		89.85	50.83		61.66	54.42		70.26
INCREASER II	D. monodactyla	1.64	5	0				6.86	45	6.06	3.33	17	2.20
	E. chloromelas							0.47	10	0	0.2	3	0
	E. muticus	0.66	10	3.95	0.34	5	0.44	4.49	25	7.46	2.15	13	3.95
	E. rigidior							1.18	5	1.05	0.49	2	0.42
	H. contortus	2.30	30	7.46	2.73	25	0.44	0.47	5	0	1.66	20	2.37
Total		4.6		11.41	3.07		0.88	13.47		14.57	7.83		8.94
INCREASER III	A. canescens-c.	0.98		4.56				1.18		2.11	1.17		2.45
	A. congesta-c.	0.66	10	0				0.47	10				
	E. gummiflua							0.24	5	0	0.1	2	0
	E. nindensis	4.92	35	0	0.34	5	0	1.65	20	0.44	2.25	20	0.17
	M. repens-r.	1.97	10	5	2.05	20	1.31	0.24	5		1.27	12	2.43
	P. squarrosa	0.33	5	0				0.24	5	0	0.2	3	0
	T. grandiglumis				1.71	10	0				0.49	3	0
Total		8.86		9.56	4.1		1.31	4.02		2.55	5.48		5.05
	Forbs	15.74	75	5	31.06	95	2.11	12.06	75	5.62	18.59	82	3.97
Status unknown	B. biflora				0.34	5	0	9.93	55	2.11	4.31	22	0.63

Eragrostis nindensis - Digitaria monodactyla Variation

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	A. chinensis				2.60	25	12.45	0.23	5	0	0.98	10	4.19
	A. schirensis	2.10	30	4.56							0.68	10	1.82
	B. serrata							1.84	25	10.53	0.60	8	3.51
	D. amplectens	5.36	65	10.7	0.22	5	1.05	4.61	40	1.92	3.32	37	4.75
	D. eriantha							5.30	50	0	1.74	17	0
	T. triandra	1.86	15	1.05				0.92	5	0	0.91	7	0.42
Total		9.32		16.31	2.82		13.5	12.90		12.45	8.23		14.69
INCREASER I	H. dissoluta	10.49	70	28.08	3.69	45	9.04	1.15	20	1.05	5.06	45	13.05
	L. simplex	1.17	5	3.95				7.37	50	18.95	2.79	18	7.37
	S. jeffreysii	1.40	15	3.95	2.39	30	9.57	0.69	10	0	1.51	18	4.40
	S. sphacelata-s.	20.51	70	8.94	63.12	95	40.96	34.33	95	28.42	39.85	87	25.95
	T. spicatus	1.17	20	7.02	1.74	20	1.05				0.98	13	2.53
	U. agropyroides				4.12	20	11.40	0.92	10	3.51	1.74	10	5.17
Total		34.74		51.94	75.06		72.02	44.46		51.93	51.93		58.47
INCREASER II	D. monodactyla	10.96	50	5.87	1.3	15	0	6.22	40	1.49	6.04	35	2.64
	E. chloromelas	1.17	10	0							0.38	3	0
	E. muticus	7.69	40	17.46	0.22	5	0	4.61	30	8.60	4.08	25	8.43
	H. contortus				0.87	15	10.97	1.84	30	3.95	0.91	15	5.17
Total		19.82		23.33	2.39		10.97	12.67		14.04	11.41		16.24
INCREASER III	A. congesta-c.							1.15	20	2.11	0.38	7	0.63
	A. diffusa-b.	1.86	15	0.44				1.15	15	0	0.98	10	0.17
	A. junciformis-j.	0.47	5	0.44	0.43	5	0				0.3	3	0.17
	E. nindensis	5.83	25	0	3.69	20	0	2.76	20	0	4.08	22	0
	M. repens-r.				0.22	5	3.51	1.61	30	0	0.6	12	1.4
	P. squarrosa							0.46	10	0	0.15	3	0
	T. grandiglumis	1.4	25	0				2.30	25	0	1.21	17	0
Total		9.56		0.88	4.34		3.51	9.43		2.11	7.70		2.37
	Forbs	20.51	80	3.16	14.97	75	0	18.43	100	17.55	17.89	85	6.67
Status unknown	B. biflora	5.13	30	4.38	0.22	5	0	2.07	15	1.92	2.42	17	2.43

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Sporobolus ioclados - Acacia tortilis Savanna

ECOLOGICAL		SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
GROUP	SPECIES	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	*E. paspaloides*	2.15	25	1.05							1.19	8	0.42
	P. maximum				0.14	5	0				0.03	2	0
	P. schinzii	2.15	30	5.43							1.19	10	2.08
Total		**4.30**		**6.48**	**0.14**		**0.00**	**0.00**		**0.00**	**2.41**		**2.50**
INCREASER I													
Total		**0.00**		**0.00**	**0.00**		**0.00**	**0.00**		**0.00**	**0.00**		**0.00**
INCREASER II	*C. dactylon*				0.42	5	0				0.09	2	0
	E. lehmanniana-l.	2.65	70	0	0.99	15	0				1.67	28	0
Total		**2.65**		**0.00**	**1.41**		**0.00**	**0.00**		**0.00**	**1.76**		**0.00**
INCREASER III	*C. virgata*	0.44	10	0	4.23	30	0				1.16	13	0
	D. aegyptium	0.22	10	0	2.16	25	5	11.08	65	1.93	3.16	33	2.46
	E. trichophora	21.98	90	18.15	27.22	70	17.9	6.65	30	0	19.53	63	11.74
	S. ioclados	32.80	100	49.75	36.39	75	39.39	43.68	85	33.95	36.11	87	41.23
	T. racemosus				0.71	10	0	0.78	10	0	0.33	7	0
	U. mosambicensis	5.96	70	16.06	7.76	55	17.11				4.96	42	11.05
Total		**61.40**		**83.96**	**78.47**		**79.40**	**62.19**		**35.88**	**65.25**		**66.48**
	Forbs	**31.64**	**100**	**9.57**	**20.03**	**75**	**20.62**	**37.81**	**100**	**64.12**	**30.57**	**92**	**31.60**

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Nyl River and floodplain

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	P. schinzii	32.15	90	54.12	3.78	35	12.02	16.11	95	88.69	15.25	73	51.61
	T. triandra				5.67	50	29.56				1.63	17	9.83
Total		32.15		54.12	9.45		41.58	16.11		88.69	16.88		61.44
INCREASER I	B. bladhii				1.72	20	13.08				0.49	7	4.31
	O. longistaminata	41.00	95	18.86	0.17	5	0	11.40	70	6.49	13.13	57	8.75
Total		41.00		18.86	1.89		13.08	11.40		6.49	13.62		13.06
INCREASER II													
	C. dactylon				25.26	70	0				7.26	23	0
Total		0.00		0.00	25.26		0.00	0.00		0.00	7.26		0.00
INCREASER III	A. congesta-c.				0.52	5	0				0.15	2	0
	L. hexandra	12.09	45	0	13.92	40	0	58.82	100	1.31	38.10	62	0.44
	P. scrobiculatum	2.65	20	15.09	9.97	65	31.84	0.09	5	0	3.36	28	16.27
	S. pallide-fusca				14.78	70	2.55				4.24	23	0.80
Total		14.74		15.09	39.19		34.39	58.91		1.31	45.85		17.51
	Forbs	12.09	65	11.93	23.71	75	10.96	13.57	65	3.51	16.24	68	8.96

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Aristida bipartita - Setaria sphacelata Savanna Variation

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	D. eriantha	5.08	25	8.94				2.41	15	0	2.47	13	2.79
	P. dregeanum							1.09	5	0.44	0.26	2	0.17
	P. maximum	0.28	5	0							0.11	2	0
	P. natalense				0.14	5	0	15.10	60	1.49	3.68	22	0.59
	S. incrassata	0.42	15	2.55	1.63	35	23.61				0.79	17	8.76
	S. nigrirostris				9.08	30	8.07	14.22	40	1.05	6.93	23	2.74
	T. triandra	4.23	40	25.72	3.12	25	15	14.44	90	59.65	6.25	52	33.62
Total		10.01		37.21	13.97		46.68	47.26		62.63	20.49		48.67
INCREASER I	B. bladhii							4.16	30	12.02	1	10	4.10
	C. excavatus							6.78	60	11.49	1.63	20	3.60
	I. afrum	80.82	100	59.28	68.16	100	51.40				56.51	67	36.59
Total		80.82		59.28	68.16		51.40	10.94		23.51	59.14		44.29
INCREASE R II	B. insculpta							0.44	5	0	0.11	2	0
	E. chloromelas							0.66	15	1.05	0.16	5	0.42
	E. curvula	0.14	5	0	0.81	5	0				0.37	3	0
Total		0.14		0	0.81		0	1.10		1.05	0.64		0.42
INCREASER III	A. congesta-c.	0.42	5	0							0.16	2	0
	A. diffusa-b.	0.14	5	0	0.14	5	0				0.11	3	0
	C. virgata	0.14	5	0							0.05	2	0
	S. pyramidalis	0.85	25	0				8.1	75	11.49	2.26	33	3.6
Total		1.55		0	0.14		0	8.1		11.49	2.58		3.60
	Forbs	6.77	50	3.51	15.72	40	0	29.1	95	0.87	15.6	62	1.66
Status unknown	E. biflora				0.14	5	0				0.05	2	0
	E. heteromera							1.75	25	0.44	0.42	8	0.17
	E. colona	0.42	5	0	1.08	15	1.92				0.58	7	0.68
Total		0.42		0.00	1.22		1.92	1.75		0.44	1.05		0.85

Aristida bipartita - Setaria sphacelata Grassland Variation

ECOLOGICAL GROUP	SPECIES	SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
		% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	S. incrassata	8.14	70	15.87	9.13	85	45.10				6.37	52	20.59
	S. nigrirostris							15.33	40	0	4.07	13	0
	S. sphacelata-t.	0.25	5	0							0.13	2	0
	T. triandra	11.25	70	53.94	1.71	25	8.07	32.91	95	92.02	13.60	63	51.21
Total		**19.64**		**69.81**	**10.84**		**53.17**	**48.24**		**92.02**	**24.17**		**71.80**
INCREASER I													
	I. afrum	39.8	90	7.54	70.15	100	26.74	13.32	20	0	43.30	70	11.73
Total		**39.80**		**7.54**	**70.15**		**26.74**	**13.32**		**0.00**	**43.30**		**11.73**
INCREASER II	B. insculpta	0.67	10	3.51							0.26	3	1.40
	C. dactylon	8.14	25	0				2.01	5	0	3.74	10	0
	E. curvula	11.75	55	1.49							4.60	18	0.59
Total		**20.56**		**5.00**	**0**		**0**	**2.01**		**0.00**	**8.60**		**1.99**
INCREASER III	A. meridionalis							3.77	15	3.51	0.99	5	1.40
	E. trichophora	0.76	15	0							0.33	5	0
	S. pallide-fusca	0.25	5	0				0.25	45	0.44	0.06	15	0.17
Total		**1.01**		**0.00**	**0.00**		**0.00**	**4.02**		**3.95**	**1.38**		**1.57**
	Forbs	**16.37**	**70**	**13.08**	**19.01**	**70**	**20.10**	**4.52**	**45**	**3.60**	**14.19**	**45**	**12.09**
Status unknown	E. biflora	2.52	35	4.56				0.50	5	0	1.12	13	1.82
	E. heteromera	0.25	5	0							0.13	2	0
	L. hexandra							27.39	55	0	7.16	18	0
Total		**2.77**		**4.56**	**0.00**		**0.00**	**27.89**		**0.00**	**8.41**		**1.82**

Eragrostis pallens - Burkea africana Savanna

ECOLOGICAL		SITE 1			SITE 2			SITE 3			PLANT COMMUNITY		
GROUP	SPECIES	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW	% C	% F	% DW
DECREASER	*D. amplectens*	0	0	0	0.91	5	3.95	2.01	15	4.56	0.88	6.67	2.84
	P. maximum	0.61	10	4.56	2.73	20	6.05	0.00	0	0.00	1.01	10	3.54
	S. sphacelata-s.	16.51	50	16.10	15.45	40	9.29	20.48	45	23.07	17.46	45	16.17
	T. triandra	0	0	0	0.45	5	3.51	0.00	0	0.00	0.13	1.67	1.17
Total		**17.12**	0	**20.66**	**19.54**	0	**22.80**	**22.49**	0	**27.63**	**19.48**	0	**23.72**
INCREASER I	*C. plurinoides*	1.53	15	7.02	0	0	0.00	0.00	0	0.00	0.63	5	2.34
	S. jeffreysii	0.31	5	3.51	0	0	0.00	2.01	20	0.87	0.75	8.33	1.46
Total		**1.83**	0	**10.53**	**0.00**	0	**0.00**	**2.01**	0	**0.87**	**1.38**	0	**3.80**
INCREASER II	*D. eriantha*	37.92	90	22.62	45.91	90	38.16	33.73	80	11.93	38.82	86.67	24.24
	E. muticus	4.59	20	10.62	0	0	0.00	3.21	15	1.31	2.89	11.67	3.98
	E. pallens	5.20	40	25.53	11.82	55	30.09	8.84	45	32.20	8.17	46.67	29.27
	H. contortus	0.31	5	3.51	0.45	5	0.00	3.21	30	3.51	1.26	13.33	2.34
	E. lehmanniana	0	0	0	1.82	5	0.00	0.00	0	0.00	0.51	1.67	0
Total		**48.02**	0	**62.28**	**60.00**	0	**68.25**	**48.99**	0	**48.95**	**51.65**	0	**59.83**
INCREASER III	*A. congesta-c.*	0.31	5	0	0.45	5	0.00	0.80	10	0.00	0.50	6.67	0
	A. canescens	0	0	0	2.73	20	0.44	0.00	0	7.46	0.75	6.67	2.63
	A. mollissima-a.	0.61	10	0	0.00	0	0.00	6.43	30	0.00	2.26	13.33	0
	A. stipitat-g.	0	0	0	2.73	15	1.49	3.21	10	4.56	1.76	8.33	2.02
	P. patens	0	0	0	0	0	0.00	1.20	15	3.51	0.38	5.00	1.17
Total		**0.92**	0	**0**	**5.91**	0	**1.93**	**11.65**	0	**15.53**	**5.65**	0	**5.82**
	Forbs	**32.11**	**85**	**6.49**	**14.55**	**80**	**7.02**	**14.86**	**60**	**7.02**	**21.86**	**75.00**	**6.84**

Table 2.4: Total percentage composition (% C) and percentage dry-weight (% DW) of each ecological group and plant community.

Plant community		DECR.	INC. I	INC. II	INC. III	FORBS	STATUS UNKNOWN
Rhus leptodictya - Combretum apiculatum Variation	% C	12.77	32.49	17.29	12.39	24.88	
	% DW	13.79	36.70	40.86	7.39	2.29	
Cymbopogon plurinodis - Combretum apiculatum Variation	% C	8.61	54.42	7.83	5.48	18.59	4.31
	% DW	11.22	70.26	8.94	5.05	3.97	0.63
Eragrostis nindensis - Digitaria monodactyla Variation	% C	8.23	51.93	11.41	7.70	17.89	2.42
	% DW	14.69	58.47	16.24	2.37	6.67	2.43
Sporobolus ioclados - Acacia tortilis Savanna	% C	2.41	0.00	1.76	65.25	30.57	
	% DW	2.50	0.00	0.00	66.48	31.60	
Nyl River and floodplain	% C	16.88	13.62	7.26	45.85	16.24	
	% DW	61.44	13.06	0.00	17.51	8.96	
Aristida bipartita - Setaria sphacelata Savanna Variation	% C	20.49	59.14	0.64	2.58	15.60	1.05
	% DW	48.67	44.29	0.42	3.60	1.66	0.85
Aristida bipartita - Setaria sphacelata Grassland Variation	% C	24.17	43.30	8.60	1.38	14.19	8.41
	% DW	71.80	11.73	1.99	1.57	12.09	1.82
Eragrostis pallens - Burkea africana Savanna	% C	19.48	1.38	51.65	5.65	21.86	
	% DW	23.72	3.80	59.83	5.82	6.84	

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Table 2.5: Species density (species/15 m²) and Simpson's index as the bootstrap estimate of the mean with the SE in brackets.

Plant community	Species density	Simpson's index (D)	Simpson's index (1 - D)
Rhus leptodictya - Combretum apiculatum Variation	29	0.1638	0.8362 (0.00045)
Cymbopogon plurinodis - Combretum apiculatum Variation	27	0.1865	0.8135 (0.00074)
Eragrostis nindensis - Digitaria monodactyla Variation	25	0.1694	0.8306 (0.00062)
Sporobolus ioclados - Acacia tortilis Savanna	12	0.2727	0.7273 (0.00093)
Nyl River and floodplain	10	0.2079	0.7921 (0.00054)
Aristida bipartita - Setaria sphacelata Savanna Variation	21	0.2779	0.7221 (0.00117)
Aristida bipartita - Setaria sphacelata Grassland Variation	15	0.2083	0.7917 (0.00066)
Eragrostis pallens - Burkea africana Savanna	17	0.2275	0.7725 (0.00071)

Table 2.6: Statistical analysis of species diversity showing no significant differences between plant communities.

	Mean value for 10 000 iterations	S.D.	97.5th percentile for 10 000 iterations
Rhus leptodictya - *Combretum apiculatum* Variation	0.8362	0.0449	0.9158
Cymbopogon plurinodis - *Combretum apiculatum* Variation	0.8135	0.0738	0.9430
Eragrostis nindensis - *Digitaria monodactyla* Variation	0.8306	0.0616	0.9373
Sporobolus ioclados - *Acacia tortilis* Savanna	0.7273	0.0928	0.8569
Nyl River and floodplain	0.7921	0.0539	0.8661
Aristida bipartita - Setaria sphacelata Savanna Variation	0.7221	0.1171	0.8892
Aristida bipartita - Setaria sphacelata Grassland Variation	0.7917	0.0661	0.8864
Eragrostis pallens - *Burkea africana* Savanna	0.7725	0.0710	0.8725

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Table 2.7: An example of a general linear model (PROC GLM) output for differences in grass density between plant communities. The overall p value of $p = 0.0001$ indicated that there are differences between plant communities. Where $p < 0.05$ the null hypothesis is not accepted indicating that there are differences between plant communities. Where $p > 0.05$ there are no differences between plant communities. All other PROC GLM outputs are similar but were not included in the appendices. These outputs are available from the author.

Plant community	1	2	3	4	5	6	7	8
1		0.9063	0.4872	0.0001	0.0112	0.0265	0.0025	0.4723
2			0.4168	0.0001	0.0081	0.0196	0.0018	0.5476
3				0.0001	0.0624	0.1234	0.0185	0.1589
4					0.0010	0.0003	0.0049	0.0001
5						0.7422	0.6115	0.0013
6							0.4032	0.0036
7								0.0002
8								

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Table 2.8: Species and grass density per square (0.25 m²), site (20 x 0.25 m²) and plant community (60 x 0.25 m²) except where otherwise indicated.

Rhus leptodictya - Combretum apiculatum Variation

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	17	17	11	28
MEAN NO. OF SPP./0.25 m²	3.75	5.20	3.15	4.03
% ≥3 SPP.	90.0 %	100.0 %	80.0 %	90.0 %
NO. OF PLANTS	390	458	217	355 (1 065)
PLANTS/m²	78.0	91.6	43.4	71.0

Cymbopogon plurinodis - Combretum apiculatum Variation

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	18	16	25	27
MEAN NO. OF SPP./0.25 m²	3.70	4.60	5.50	4.6
% ≥3 SPP.	85.0 %	100.0 %	100.0 %	95.0 %
NO. OF PLANTS	305	293	423	340.33 (1 021)
PLANTS/m²	61.0	58.6	84.6	68.07

Eragrostis nindensis - Digitaria monodactyla Variation

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	17	15	21	25
MEAN NO. OF SPP./0.25 m²	5.85	3.85	6.55	5.42
% ≥3 SPP.	100.0 %	75.0 %	100.0 %	91.67 %
NO. OF PLANTS	429	462	434	441.67 (1 325)
PLANTS/m²	85.8	92.4	86.6	88.33

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Table 2.8 (cont.)

Sporobolus ioclados - Acacia tortilis Savanna

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	9	10	6	11
MEAN NO. OF SPP./0.25 m²	5.05	3.65	2.90	3.87
% ≥3 SPP.	100.0%	85.0%	65.0%	85.0%
NO. OF PLANTS	1 811	709	767	1 095.67 (3 287)
PLANTS/m²	362.2	141.8	153.4	219.13

Nyl River and floodplain

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	5	10	5	10
MEAN NO. OF SPP./0.25 m²	3.15	4.40	3.35	3.63
% ≥3 SPP.	65.0 %	95.0 %	90.0 %	85.0 %
NO. OF PLANTS	339	582	1 106	675.67 (2 027)
PLANTS/m²	67.8	116.4	221.2	135.13

Aristida bipartita - Setaria sphacelata Savanna Variation

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	10	9	12	21
MEAN NO. OF SPP./0.25 m²	2.75	2.60	5.15	3.50
% ≥3 SPP.	70.0 %	55.0 %	100.0 %	75.0 %
NO. OF PLANTS	709	738	457	634.67 (1 904)
PLANTS/m²	141.8	147.6	91.4	126.93

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Table 2.8 (cont.)

Aristida bipartita - Setaria sphacelata Grassland Variation

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	11	4	8	14
MEAN NO. OF SPP./0.25 m²	4.50	2.85	2.85	3.40
% ≥3 SPP.	100.0 %	75.0 %	60.0 %	78.33 %
NO. OF PLANTS	596	526	500	540.67 (1 622)
PLANTS/m²	119.2	105.2	100.0	108.13

Eragrostis pallens - Burkea africana Savanna

	SITE 1	SITE 2	SITE 3	PLANT COMMUNITY
NO. OF SPP.	11	12	12	17
MEAN NO. OF SPP./0.25 m²	3.35	3.55	3.75	3.55
% ≥3 SPP.	75.0 %	85.0 %	85.0 %	81.67 %
NO. OF PLANTS	327	220	249	265.33 (796)
PLANTS/m²	65.4	44.0	49.8	53.07

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APPENDIX 3

Table 3.1: Seasonal mean grass height (cm) with standard deviations in brackets for different non-burnt plant communities. Empty cells indicate newly burnt plant communities (data is presented in Table 4.2, Appendix 4).

Plant community	Grass height	1994 Winter	1994 Early summer	1995 Late summer	1995 Winter	1995 Early summer	1996 Late summer	Mean cm per season Winter	Mean cm per season Early summer	Mean cm per season Late summer
Rhus leptodictya - Combretum apiculatum Variation	Total	37.53	34.27	38.2	31.33			34.43 (7.96)	35.42 (19.46)	38.20 (10.78)
	Tuft	11.08	12	14.77	8.82			9.95 (2.20)	12.00 (3.48)	14.77 (1.64)
Cymbopogon plurinodis - Combretum apiculatum Variation	Total	49.87	45.9	48	46.8	16.85	70.4	48.33 (12.41)	36.22 (16.56)	55.47 (13.66)
	Tuft	13.65	15	16.88	12.75	6.2	15.25	13.20 (2.52)	12.07 (5.06)	16.33 (1.58)
Eragrostis nindensis - Digitaria monodactyla Variation	Total	55.47			42.87	20.87	70.93	49.17 (9.8)	23.42 (5.99)	70.93 (9.28)
	Tuft	15.50			11.55	9.13	17.1	13.53 (2.62)	9.13 (1.30)	17.10 (1.33)
Sporobolus ioclados - Acacia tortilis Savanna	Total	12.57	2.95	8.17	8.72	3.87	19.88	10.76 (4.75)	4.38 (4.00)	18.32 (11.20)
	Tuft	1.98	1.35	1.37	0.98	2	6.25	1.49 (1.38)	0.61 (2.75)	4.56 (3.24)
Nyl River and floodplain	Total	44.67	16.8	67.2	29.67	13.48	83.6	37.29 (12.22)	23.49 (13.55)	71.30 (16.49)
	Tuft	16.65	13.15	21.8	14.43	2.08	39	15.54 (1.97)	9.72 (5.56)	27.34 (11.00)
Aristida bipartita - Setaria sphacelata Savanna Variation	Total	79.33			65.73	63.53	88.13	72.53 (10.72)	63.53 (7.90)	88.13 (4.23)
	Tuft	45.47			18.05	17.38	48.2	32.83 (20.16)	17.38 (2.26)	48.20 (4.96)
Aristida bipartita - Setaria sphacelata Grassland Variation	Total	65.80			52.2	48.27	89.47	59.00 (15.84)	48.27 (9.93)	89.47 (7.28)
	Tuft	35.27			14.8	14.43	50.27	26.51 (17.72)	14.43 (2.61)	50.27 (9.80)
Eragrostis pallens - Burkea africana Savanna	Total	49.20	61	52.8	47.4	40.47	71.33	49.68 (21.04)	50.73 (14.92)	62.07 (12.67)
	Tuft	8.88	14.82	13.77	8.98	8.2	14.15	8.93 (3.66)	11.51 (4.00)	13.96 (1.77)

Table 3.2: Mean monthly grass height in newly burnt areas. Values shown in brackets are from plant communities which were burnt in September 1995. Other plant communities were burnt in October 1994. The *Cymbopogon plurinodis - Combretum apiculatum* Variation plant community was burnt in October 1994 (site 3) and in September 1995 (site 1 & 2).

Plant community	Grass height	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Rhus leptodictya - Combretum apiculatum Variation	Total	burnt 1995	1.8	5.28	14.43	43.33	54.33	44.07	39.93
	Tuft					10.67	13.33	12.23	11.87
Cymbopogon plurinodis - Combretum apiculatum Variation	Total	burnt 1995	burnt 1994 (2.33)	13.1 (3.9)	18.05 (14.38)	19.9 (50.1)	36.8 (53.6)	45.6 (56.4)	39 (51.1)
	Tuft			0.77	9.2	8.7 (11.05)	14.3 (14.18)	14.5 (16.05)	11.2 (14.28)
Eragrostis nindensis - Digitaria monodactyla Variation	Total		burnt 1994	12.97	15.12	17.83	33.2	48.8	43.27
	Tuft				5.38	9.45	13.22	14.47	11.87
Lower Nyl River and floodplain	Total	burnt 1995	(2.95)	(3.8)	(10.15)	flooded			
	Tuft								
Aristida bipartita - Setaria sphacelata Savanna variation	Total		burnt 1994	11.57	14.17	28.67	51.13	63.8	63.27
	Tuft			4.10	6.63	14.4	17.25	19.65	17.28
Aristida bipartita - Setaria sphacelata Grassland Variation	Total		burnt 1994	9.70	13.18	18.57	46.53	54.33	54.73
	Tuft			2.97	5.5	10.97	16.02	16.48	15
Tristachya rehmannii - Digitaria monodactyla Variation	Total		burnt 1994	12.45	16.28	22.33	41.93	49.6	43.13
	Tuft			4.38	7.53	11.48	12	11.98	7.3

APPENDIX 4

Table 4.1: Alphabetical order of the woody species found during surveys in the Nylsvlei Nature Reserve.

1	*Acacia ataxacantha*	32	*Lanea discolor*
2	*Acacia caffra*	33	*Lippia javanica*
3	*Acacia karroo*	34	*Maytenus heterophyla*
4	*Acacia mellifera*	35	*Maytenus polyacantha*
5	*Acacia nilotica*	36	*Maytenus tenuispina*
6	*Acacia tortilis*	37	*Mundulea sericea*
7	*Bauhinia galpinii*	38	*Ochna pulchra*
8	*Boscia albitrunca*	39	*Ozoroa paniculosa*
9	*Burkea africana*	40	*Pappea capensis*
10	*Canthium gilfilani*	41	*Pavetta gardenifolia*
11	*Carissa bispinosa*	42	*Peltophorum africanum*
12	*Cassine parvifolia*	43	*Protea caffra*
13	*Cassine transvaalensis*	44	*Protea welwitschii*
14	*Combretum apiculatum*	45	*Rhus lancea*
15	*Combretum hereroense*	46	*Rhus leptodictya*
16	*Combretum imberbe*	47	*Rhus pyroides*
17	*Combretum molle*	48	*Securidaca longepedunculata*
18	*Combretum zeyheri*	49	*Securinega virosa*
19	*Dicrostachys cinerea*	50	*Spirostachys africana*
20	*Diospyros lycioides*	51	*Strychnos pungens*
21	*Dombeya autumnalis*	52	*Stychnos madagascariensis*
22	*Dombeya rotundifolia*	53	*Tarchonanthus camphoratus*
23	*Ehretia rigida*	54	*Terminalia brachystemma*
24	*Euclea crispa*	55	*Terminalia sericea*
25	*Euclea linearis*	56	*Vitex poara*
26	*Euclea natalensis*	57	*Vitex rehmanii*
27	*Euclea schimperii*	58	*Ximenia americana*
28	*Euclea undulata*	59	*Ziziphus mucronata*
29	*Grewia flava*		
30	*Grewia flavescens*		
31	*Grewia bicolor*		

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Table 4.2: Woody plant density (woody plants/ha) and % canopy cover with 95 % confidence intervals (CI) per plant community.

Plant community	Woody plants/ha	CI	% Canopy cover	CI
Rhus leptodictya - Combretum apiculatum Variation	3 816	1 173.39	31.62	11.35
Cymbopogon plurinodis - Combretum apiculatum Variation	2 183	702.61	8.05	6.45
Eragrostis nindensis - Digitaria monodactyla Variation	242	49.11	5.43	4.00
Sporobolus ioclados - Acacia tortilis Savanna	517	381.27	22.60	17.55
Aristida bipartita - Setaria sphacelata Savanna variation	192	96.94	18.03	4.78
Eragrostis pallens - Burkea africana Savanna	2 100	796.06	44.20	10.63
Mean for the Nylsvlei Nature Reserve	1 508	601.24	21.66	6.75

Table 5.1: Seasonal above-ground standing crop (ASC) (kg/ha) in non-burnt plant communities. Empty cells indicate newly burnt plant communities (data is presented in Table 6.2, Appendix 6).

Plant community	1994	1994	1995	1995	1995	1996	Mean ASC per season		
	Winter	Early summer	Late summer	Winter	Early summer	Late summer	Winter	Early summer	Late summer
Rhus leptodictya - Combretum apiculatum Variation	1 572.57	1 671.03	1 997.61	1 664.09			1 618.33 (556.08)	1 671.03 (593.21)	1 997.61 (645.25)
Cymbopogon plurinodis - Combretum apiculatum Variation	2 241.02	2 156.47	2 669.16	1 904.07	1 519.45	2 301.82	2 072.55 (317.58)	1 944.13 (399.33)	2 546.70 (226.52)
Eragrostis nindensis - Digitaria monodactyla Variation	2 534.03			1 634.33	1 811.79	3 062.84	2 084.18 (531.77)	1 811.79 (193.59)	3 062.87 (604.42)
Sporobolus ioclados - Acacia tortilis Savanna	616.18	641.80	1 046.49	540.92	729.66	1 775.61	578.55 (206.33)	685.73 (312.41)	1 411.03 (734.28)
Nyl River and floodplain	6 311.98	5 577.92	8 576.84	5 554.58	4 325.78	7 968.34	5 933.28 (616.25)	5 271.08 (939.80)	8 424.70 (1005.31)
Aristida bipartita - Setaria sphacelata Savanna Variation	5 566.54			3 954.45	4 347.01	7 696.18	4 760.50 (1126.04)	4 347.01 (256.11)	7 696.17 (405.30)
Aristida bipartita - Setaria sphacelata Grassland Variation	4 936.92			3 469.07	3 794.31	8 154.96	4 202.99 (935.17)	3 794.31 (892.17)	8 154.97 (1231.08)
Eragrostis pallens - Burkea africana Savanna	1 250.45	1 311.45	1 699.51	1 361.69	1 495.58	1 815.12	1 306.07 (335.56)	1 403.52 (487.41)	1 757.32 (451.97)

Table 5.2: Monthly post-burn ASC (kg/ha). Values in brackets are from *Cymbopogon plurinodis - Combretum apiculatum* Variation (site 3; 1994/95 season) and those without are from sites 1 and 2 (1995/96 season).

Plant community	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
Rhus leptodictya - Combretum apiculatum Variation	889.04	957.52	1 102.46	1 105.45	1 217.41	1 465.15	1 589.35	1 579.43
Cymbopogon plurinodis - Combretum apiculatum Variation	1 062.93	(1 062.93) 951.26	(1 350.49) 1 077.36	(1 153.11) 1 144.83	(1 281.12) 1 364.82	(1 375.11) 1 768.98	(1 472.01) 1 906.27	(1 666.26) 1 888.03
Eragrostis nindensis - Digitaria monodactyla Variation		1 062.93	1 283.66	1 289.77	1 313.64	1 548.69	1 725.34	1 857.07
Nyl River and floodplain	964.4	1 609.85	2 173.97	2 111.28				
Aristida bipartita - Setaria sphacelata Savanna Variation		1 251.56	1 751.23	1 754.52	2 583.44	3 237.11	3 586.99	3 889.67
Aristida bipartita - Setaria sphacelata Grassland Variation		1 251.56	1 602.46	1 738.34	2 331.75	2 992.72	3 690.53	3 699.7
Tristachya rehmannii - Digitaria monodactyla Variation		193.47	934.73	1 311.45	956.33	1 370.12	1652.54	1 488.24

APPENDIX 6

Table 6.1: Linear regression equations of mean grass tuft height (cm) to
predict above-ground standing crop (kg/ha).

Plant community	Intercept a	Slope b	Coefficient of determination r^2
Rhus leptodictya - Combretum apiculatum Variation	743.4905	84.2431	0.2165
Cymbopogon plurinodis - Combretum apiculatum Variation	1082.9129	81.4727	0.7189
Eragrostis nindensis - Digitaria monodactyla Variation	424.8583	146.9832	0.7613
Sporobolus ioclados - Acacia tortilis Savanna	476.0870	182.1729	0.7889
Nyl river and floodplain	4036.7119	139.7418	0.6766
Aristida bipartita - Setaria sphacelata Savanna Variation	3433.9749	65.4235	0.6337
Aristida bipartita - Setaria sphacelata Grassland Variation	2685.7936	85.78859	0.6264
Eragrostis pallens - Burkea africana Savanna	773.7897	62.3701	0.2761
Nylsvlei Nature Reserve	853.4407	145.2934	0.6089

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Table 6.2: Seasonal biomass concentrations (kg/m³) for non-burnt plant communities. Plant communities are 1) *Rhus leptodictya - Combretum apiculatum* Variation, 2) *Cymbopogon plurinodis - Combretum apiculatum* Variation, 3) *Eragrostis nindensis - Digitaria monodactyla* Variation, 4) *Sporobolus ioclados - Acacia tortilis* Savanna, 5) Nyl River and floodplain, 6) *Aristida bipartita - Setaria sphacelata* Savanna Variation, 7) *Aristida bipartita - Setaria sphacelata* Grassland Variation, and 8) *Eragrostis pallens - Burkea africana* Savanna. Data of burnt areas (empty cells) was not included (see Table 7.3, Appendix 7).

Plant community	Winter 1994	Early summer 1994	Late summer 1995	Winter 1995	Early summer 1995	Late summer 1996	MEAN	S.D.
1	1.419	1.393	1.352	1.887			1.5126	0.2508
2	1.642	1.438	1.581	1.493	2.451	1.509	1.6856	0.3814
3	1.635			1.415	1.984	1.791	1.7063	0.2411
4	3.107	4.754	7.639	5.519	3.648	2.841	4.5847	1.8072
5	3.791	4.242	3.934	3.849	20.797	2.043	6.4427	7.0752
6	1.224			2.191	2.501	1.597	1.8782	0.5752
7	1.400			2.344	2.629	1.622	1.9988	0.5823
8	1.408	0.885	1.234	1.516	1.824	1.283	1.3582	0.3128
MEAN	1.9531	2.5421	3.1481	2.5268	5.1192	1.8123		
S.D.	0.9507	1.8075	2.7443	1.4435	6.9380	0.5109		

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Table 6.3: Biomass concentrations (kg/m³) in newly burnt areas. Plant communities are the same as in Table 7.2. Plant community 9 is the *Tristachya rehmannii - Digitaria monodactyla* Variation.

Plant community	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
1				1.141	1.099	1.299	1.331
2				1.235	1.248	1.188	1.322
3			2.397	1.390	1.171	1.192	1.565
5	5.457	5.721	2.080				
6		4.271	2.646	1.794	1.877	1.825	2.251
7		5.395	3.161	2.126	1.868	2.239	2.466
9		2.134	1.742	0.833	1.142	1.379	2.039

Table 7.1: Total number of samples analysed with the near-infrared reflectance spectroscopy (NIRS) procedure. The accuracy of the method is indicated by the coefficient of determination. Calibrations were based on 130 samples analysed with wet chemical procedures.

Variables	Number of samples	Coefficient of determination (r^2)	Standard error of calibration (SEC)	Number of wavelengths
% nitrogen	210	0.99	0.05	171
% neutral detergent fibre	213	0.95	1.17	171
% acid detergent fibre	209	0.92	1.05	171
% *in vitro* organic matter digestibility	214	0.97	1.60	169
% organic matter	218	0.94	0.71	169

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Table 7.2: Chemical components of the non-burnt herbaceous layer per plant community (names described in Fig. 10.1). The mean (n = 72) was calculated across all seasons. Missing values of standard deviation could not be calculated due to one reading only. Highest values are shown in bold.

Plant community		1	2	3	4	5	6	7	8
% Moisture	Mean	33.3714	36.4187	32.3737	**37.4023**	30.2048	29.9867	25.8916	30.3938
	S.D.	14.3983	17.3336	17.3232	19.3322	15.9597	9.64666	10.6689	15.7927
% N	Mean	0.9978	0.7433	0.6667	**1.8233**	1.3613	0.8678	0.7944	1.2157
	S.D.	0.4058	0.3832	0.3207	0.6050	0.7999	0.3388	0.3196	0.5046
% NDF	Mean	**70.0244**	69.5166	68.4733	62.1977	64.5153	67.0430	64.5900	68.0148
	S.D.	2.8018	3.2305	2.0765	2.2728	3.6098	4.1466	4.7254	5.1396
% ADF	Mean	**40.8766**	40.3033	38.5544	30.3377	35.7546	38.4422	38.2811	38.9763
	S.D.	1.0813	3.2068	2.4153	1.7482	4.1085	4.2902	3.6447	3.3374
% IVOMD	Mean	62.3099	61.4433	60.6888	67.7111	**68.1000**	60.8422	60.3633	64.4701
	S.D.	8.0107	5.6024	2.6390	6.8850	6.7367	3.9862	4.4783	8.4517
% OM	Mean	91.8466	**92.1377**	91.7199	88.6166	88.6891	89.4202	87.1644	91.9789
	S.D.	1.5588	1.4609	0.7432	1.5831	2.9778	2.4967	3.5483	0.8037
% Ca	Mean	0.2440	0.2761	0.364	0.3549	0.3717	0.4025	**0.4828**	0.4457
	S.D.	0.0526	0.0615	0.0879	0.06	0.0642	0.0684	0.1025	0.1741
% P	Mean	0.0784	0.069	0.0672	0.1152	0.1181	0.0782	0.0812	**0.1904**
	S.D.	0.0403	0.0479	0.0483	0.0395	0.0511	0.0554	0.057	0.2294
% K	Mean	**2.0000**	1.5414	1.3337	1.2211	1.2861	1.355	0.9708	1.5344
	S.D.	0.7582	0.7639	0.5531	0.4604	0.598	0.7492	0.5933	0.7635
% Na	Mean	0.0496	0.0305	0.0247	**0.7488**	0.1257	0.0300	0.0510	0.0314
	S.D.	0.0377	0.0066		0.1919	0.0985			0.0084

Table 7.3: Chemical components of the burnt herbaceous layer per plant community (names described in Fig. 10.1). Plant community 9) is the *Tristachya rehmannii - Digitaria monodactyla* Variation. Values were averaged (n = 108) over the six month period following a burn. Samples in the Nyl River and floodplain were collected for three months only due to flooding. Macromineral samples of the *Rhus leptodictya - Combretum apiculatum* Variation (1) and the Nyl river and floodplain (5) were missing. Highest values are indicated in bold.

Plant community		1	2	3	5	6	7	9
% Moisture	Mean	46.9043	46.3136	47.2946	43.6929	43.8399	38.2014	**49.3368**
	S.D.	11.0813	7.9486	12.2207	15.8483	6.5523	8.4659	5.5036
% N	Mean	1.2679	1.0945	0.9711	**2.5067**	1.2744	1.1039	0.8593
	S.D.	0.5881	0.4482	0.2885	0.5093	0.2804	0.1974	0.1399
% NDF	Mean	69.02	66.636	66.896	61.887	66.182	65.099	**70.032**
	S.D.	4.7972	4.4344	2.0106	1.7237	1.6649	1.9391	1.801
% ADF	Mean	39.346	37.371	38.262	33.89	37.376	37.256	**39.523**
	S.D.	3.9886	3.3004	1.6251	1.8539	2.3534	1.563	1.2808
% IVOMD	Mean	66.486	66.373	66.856	**72.397**	68.533	68.387	64.797
	S.D.	5.6832	3.9228	3.2112	4.2039	2.6658	2.8378	3.5413
% OM	Mean	91.481	91.959	92.046	88.517	90.179	89.407	**92.742**
	S.D.	1.527	0.7639	1.138	0.3931	1.4031	1.9223	1.0951
% Ca	Mean		0.281	0.3147		0.391	**0.3975**	0.3627
	S.D.		0.0028	0.0221		0.0536	0.0482	0.0759
% P	Mean		0.095	0.1038		0.124	0.1228	**0.1622**
	S.D.		0.0566	0.045		0.0463	0.0318	0.0749
% K	Mean		1.95	**1.97**		1.5217	1.3667	1.4933
	S.D.		0.495	0.6992		0.3418	0.3277	0.5237
% Na	Mean		0.0345	**0.0382**		0.0308	0.0312	0.0275
	S.D.		0.0050	0.0109		0.0079	0.0074	0.0084

Table 7.4: Seasonal mean mineral ratios in non-burnt plant communities (names described in Fig. 10.1).

Plant communities	1	2	3	4	5	6	7	8
Ca : P								
Winter	7.72	12.83	19.09	5.57	5.46	13.77	13.07	12.8
Early summer	1.81	1.9	2.6	2.22	1.86	3	2.74	2.37
Late summer	3.1	3.38	2.94	2.69	3.15	3.44	3.01	3.66
K : Na								
Winter	54.78	34.48	36.79	1.29	11.02	24.57	10.73	35.14
Early summer	22.8	61.83	30.24	1.81	33.24	24.45	28.44	56.48
Late summer	77.89	60.91	31.13	1.68	5.92	19.63	20.86	65

Table 7.5: Mean mineral ratios of Ca:P and K:Na in non-burnt (early and late summer) and burnt plant communities (names described in Fig. 10.1).

Plant community	1	2	3	4	5	6	7	8
Ca : 1P								
Non-burnt	3.11	4.00	5.42	3.08	3.15	5.15	5.95	2.34
Burnt		2.96	3.03			3.15	3.24	
K : 1Na								
Non-burnt	54.79	10.06	54.00	30.23	20.88	28.23	19.69	53.84
Burnt		56.52	51.62			49.35	43.85	

Table 7.6: Mean (n = 36) forage quality (across seasons) of the principal grass species in the floodplain and the *Eragrostis pallens - Burkea africana* Savanna. Species names are given in the text (Chapter 10) in the same order.

Grass species		Oryz. long.	Pani. schi.	Pasp. scro.	Leer. hexa.	**Mean**	**SD**	Cenc. cilia.	Digi.. eria.	Erag.. lehm.	Erag.. pall.	Hete. cont.	Hype. diss.	Pani. maxi.	Schm. papp.	**Mean**	**SD**
% Moist.	Mean	27.56	38.96	30.32	24.94	30.45	6.09	36.10	41.52	32.49	28.09	29.17	34.86	36.49	30.16	33.61	4.50
	SD	13.24	23.35	14.20	13.21			18.61	19.12	15.33	14.30	12.25	16.57	17.42	14.77		
% N	Mean	1.5700	1.5222	0.9756	1.3956	1.3658	0.2704	1.4867	1.4744	1.3744	0.9122	0.9511	0.8500	1.4689	1.3400	1.2322	0.2774
	SD	1.041	0.9601	0.3776	0.6436			0.5892	0.6518	0.4811	0.3895	0.4230	0.2642	0.4142	0.3078		
% NDF	Mean	64.10	62.07	64.50	65.79	64.12	1.54	60.64	62.78	67.15	77.69	72.54	68.07	65.91	67.95	67.84	5.36
	SD	3.29	5.96	1.33	2.13			2.42	1.87	1.60	2.18	2.79	2.25	1.24	1.11		
% ADF	Mean	35.75	32.38	34.21	37.40	34.94	2.15	34.47	37.98	38.61	42.69	41.13	38.01	38.09	39.63	38.83	2.45
	SD	3.10	7.01	0.69	1.01			3.66	2.90	2.03	3.29	2.82	1.82	1.97	1.85		
% IVOMD	Mean	67.48	68.49	67.20	71.66	68.71	2.04	68.81	66.60	68.37	52.72	60.79	62.48	67.24	70.01	64.63	5.76
	SD	7.49	9.17	2.83	6.27			6.99	4.66	6.78	10.82	8.53	5.56	5.15	4.18		
% OM	Mean	86.06	88.54	93.10	88.45	89.04	2.94	84.07	89.66	88.44	94.57	93.52	91.52	88.99	92.06	90.35	3.33
	SD	1.56	1.91	0.57	2.11			1.46	1.27	1.73	0.84	0.83	2.79	0.75	0.58		
% Ca	Mean	0.3530	0.3839	0.4024	0.3733	0.3782	0.0206	0.4959	0.4646	0.7446	0.2490	0.2786	0.3757	0.5088	0.5393	0.4571	0.1583
	SD	0.0735	0.0950	0.0478	0.0458			0.0844	0.0851	0.1032	0.0737	0.0483	0.1092	0.1222	0.1661		
% P	Mean	0.1147	0.1144	0.1307	0.1122	0.1180	0.0085	0.7816	0.1140	0.3020	0.0511	0.0618	0.0650	0.0898	0.1658	0.2039	0.2475
	SD	0.0436	0.0745	0.0375	0.0413			0.1406	0.0287	0.0223	0.0283	0.0309	0.0205	0.0197	0.0606		
% K	Mean	1.2289	1.6478	1.0700	1.1600	1.2767	0.2558	2.3367	2.0922	1.2233	0.7622	1.2522	1.0678	1.9800	1.3600	1.5093	0.5567
	SD	0.3760	1.0787	0.2644	0.4349			1.1110	0.3970	0.5012	0.4485	0.4471	0.2209	0.6694	0.4649		
% Na	Mean	0.0356	0.1426	0.0244	0.0320	0.0587	0.0561	0.0418	0.0446	0.0273	0.0231	0.0277	0.0293	0.0422	0.0336	0.0337	0.0081
	SD	0.0057	0.1076	0.0024	0.0054			0.0183	0.0131	0.0064	0.0085	0.0079	0.0069	0.0119	0.0093		

Table 8.1: Simulation results which were used to identify important population parameters and management strategies to increase population persistence. The probability of survival after 30 years was compared between populations since all were extinct before 80 years. Population viability is shown as extinction probability (P[E]) and survival probability (P[S]). SD = standard deviation.

Parameter	Amount	Extinct in years	P[E]	P[S]	Mean growth rate (r)	SD of growth rate
Female mortality age 0-1 year	40 %	60-70	0.76	0.24	-0.1252	0.3391
Female mortality age 0-1 year	20 %	70-80	0.60	0.40	-0.1053	-0.3475
Female mortality age 2-3 years	40 %	50-60	0.85	0.15	-0.1529	0.3300
Female mortality age 2-3 years	20 %	50-60	0.71	0.29	-0.1214	0.3082
Male mortality age 0-1 year	20 %	50-60	0.88	0.12	-0.1356	0.3110
Harvest adult females Supplement females age 3 (2-3 yrs)	6 6	50-60	0.89	0.11	-0.2641	0.4830
Harvest males age 4 (3-4 yrs) Supplement males age 4 (3-4 yrs)	6 6	50-60	0.92	0.08	-0.0561	0.3557

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Table 8.2: Simulation results of various combinations of the worst and best scenarios. The probability of survival after 30 years was compared between populations since most were extinct before 50 years. Population viability is shown as extinction probability (P[E]) and survival probability (P[S]).

Scenario	Population size	Proportion males at birth	Age distribution	Harvest/ Supplement	Extinct in years	P[E]	P[S]	Mean growth rate (r)	SD of growth rate
Best	48	0.25	Non-stable	Yes	50-60	0.85	0.15	-0.1961	0.7224
"	48	0.25	Stable	Yes	30-40	0.93	0.07	-0.2343	0.8058
"	48	0.25	Non-stable	No	50-60	0.97	0.03	-0.1552	0.4832
"	25	0.25	Non-stable	Yes	40-50	0.92	0.08	-0.2364	0.6474
"	25	0.25	Stable	Yes	60-70	0.92	0.08	-0.2391	0.6649
"	25	0.25	Stable	No	40-50	0.97	0.03	-0.1717	0.4653
Worst	48	0.75	Non-stable	No	0-10	1.000	0.000	-1.0409	0.7287
"	48	0.75	Stable	No	0-10	1.000	0.000	-1.2893	0.6326
"	48	0.75	Stable	Yes	10-20	1.000	0.000	-1.6256	0.6850
"	25	0.75	Non-stable	No	0-10	1.000	0.000	-1.0350	0.7075
"	25	0.75	Stable	No	0-10	1.000	0.000	-1.1853	0.6312
"	25	0.75	Stable	Yes	10-20	1.000	0.000	-1.3484	0.5353

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Table 9.1: Chi-square analysis of non-burnt plant community selection by breeding herds during winter (n = 164 observations) and summer (n = 83 observations). Abbreviations are select (s), avoid (a) and random selection (r). Some plant communities contained insufficient data (df = 0) for a complete Chi-square analysis.

	Winter				Summer			
	χ^2	df	p		χ^2	df	p	
Rhus leptodictya - Combretum apiculatum Variation	15.55	0		a				
Rhus leptodictya - Combretum apiculatum Variation (eastern pocket)	58.81	9	< 0.0001	s	0.92	0		a
Cymbopogon plurinodis - Combretum apiculatum Variation	11.98	0		a	1.31	0		a
Eragrostis nindensis - Digitaria monodactyla Variation	27.69	4	< 0.0001	s	5.95	2	0.0510	r
Sporobolus ioclados - Acacia tortilis Savanna	34.92	1	< 0.0001	a	19.34	2	< 0.0001	a
Nyl River and floodplain (upper)	16.81	2	0.0002	a	8.31	6	0.21637	r
Nyl River and floodplain (lower)	37.96	3	< 0.0001	a	331.89	7	< 0.0001	s
Aristida bipartita - Setaria sphacelata Savanna Variation	6.56	0		a	8.27	1	0.0040	a
Aristida bipartita - Setaria sphacelata Grassland Variation	176.78	11	< 0.0001	s	3.61	3	0.30736	r
Eragrostis pallens - Burkea africana Savanna	208.05	10	< 0.0001	a	33.57	11	0.00043	s
Tristachya rehmannii - Digitaria monodactyla Variation (adjacent to *Burkea* Savanna)	73.02	9	< 0.0001	s	0.31	0		a
Tristachya rehmannii - Digitaria monodactyla Variation (between the lithosol areas)	5.31	2	0.07033	r	0.67	0		a

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Table 9.2: Chi-square analysis of non-burnt plant community selection by bachelor males during winter (n = 99 observations) and summer (n = 68 observations). Abbreviations are select (s), avoid (a) and random selection (r). Missing p value indicates insufficient data for statistical analysis.

	Winter				Summer			
	χ^2	df	p		χ^2	df	p	
Rhus leptodictya - Combretum apiculatum Variation	32.13	5	< 0.0001	a	4.38	2	0.11212	r
Rhus leptodictya - Combretum apiculatum Variation (eastern pocket)	4.34	3	0.22730	r	0.004	1	0.94896	r
Cymbopogon plurinodis - Combretum apiculatum Variation	20.28	7	0.00500	s	0.79	2	0.67286	r
Eragrostis nindensis - Digitaria monodactyla Variation	4.83	3	0.18464	r	0.10	2	0.60680	r
Sporobolus ioclados - Acacia tortilis Savanna	38.44	5	< 0.0001	a	8.72	3	0.03331	a
Nyl River and floodplain (upper)	26.61	5	< 0.0001	s	75.43	8	< 0.0001	s
Nyl River and floodplain (lower)	66.68	6	< 0.0001	s	150.44	6	< 0.0001	s
Aristida bipartita - Setaria sphacelata Savanna Variation	3.75	1	0.05279	r	5.43	2	0.06617	r
Aristida bipartita - Setaria sphacelata Grassland Variation	5.31	2	0.07016	r	1.09	0		a
Eragrostis pallens - Burkea africana Savanna	89.91	6	< 0.0001	a	46.61	7	< 0.0001	a
Tristachya rehmannii - Digitaria monodactyla Variation (adjacent to *Burkea* Savanna)	6.22	1	0.01262	a	3.33	1	0.06786	r
Tristachya rehmannii - Digitaria monodactyla Variation (between the lithosol areas)	7.08	3	0.06949	r	0.74	1	0.39121	r

Table 9.3: Chi-square analysis of non-burnt (n = 414 observations) and burnt (n = 178) plant community selection by the total roan population during summer. Abbreviations are select (s), avoid (a) and random selection (r). Empty cells are plant communities that were never burnt.

	Non-burnt				Burnt			
	χ^2	df	p		χ^2	df	p	
Rhus leptodictya - Combretum apiculatum Variation	412.17	9	< 0.0001	a	96.81	5	< 0.0001	a
Rhus leptodictya - Combretum apiculatum Variation (eastern pocket)	162.33	16	< 0.0001	s	23.69	6	< 0.0001	s
Cymbopogon plurinodis - Combretum apiculatum Variation	410.35	12	< 0.0001	a	122.67	12	< 0.0001	s
Eragrostis nindensis - Digitaria monodactyla Variation	305.17	14	< 0.0001	s	88.60	11	< 0.0001	s
Sporobolus ioclados - Acacia tortilis Savanna	836.01	14	< 0.0001	a				
Nyl River and floodplain (upper)	684.67	24	< 0.0001	s				
Nyl River and floodplain (lower)	480.31	25	< 0.0001	s	84.77	12	< 0.0001	s
Aristida bipartita - Setaria sphacelata Savanna Variation	214.99	7	< 0.0001	a	78.52	7	< 0.0001	s
Aristida bipartita - Setaria sphacelata Grassland Variation	346.05	19	< 0.0001	s	72.37	12	< 0.0001	s
Eragrostis pallens - Burkea africana Savanna	3602.43	37	< 0.0001	a				
Tristachya rehmannii - Digitaria monodactyla Variation (adjacent to *Burkea* Savanna)	247.31	14	< 0.0001	s	35.43	5	< 0.0001	s
Tristachya rehmannii - Digitaria monodactyla Variation (between the lithosol areas)	56.96	9	< 0.0001	s	19.11	8	0.01426	s

Table 10.1: Values of predictor variables and the corresponding slope vectors as determined with logistic regression analysis. The intercept applies to that specific group of variables.

Group 1, Irrespective of burn and season

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
Species density	1	28	28	28	618.781	-22.4834
per 5 m²	2	27	27	27	11.851	-0.4617
	3	25	25	25	7.032	-0.2166
	4	11	11	11	-3.679	0.5130
	5	10	10	10	-233.384	22.1446
	6	21	21	21	4.070	-0.0796
	7	14	14	14	-0.536	0.1531
	8	17	17	17	-6.235	0.1657
Grass density	1	31	71.00	123		-0.0091
per m²	2	43	68.07	116		0.0172
	3	65	88.33	112		-0.0029
	4	54	219.13	640		-0.0084
	5	47	135.13	296		0.0045
	6	62	126.93	237		-0.0045
	7	46	147.80	344		-0.0006
	8	27	53.06	83		0.0707

Group 2, Irrespective of burn and season

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Composition	1	2.76	19.97	59.45	1.9718	-0.0005
	2	2.13	19.85	58.37	1.9545	-0.0007
	3	0.65	19.92	75.06	1.9609	-0.0008
	4	0.14	19.85	55.54	1.9468	-0.0012
	5	1.89	19.96	64.45	1.9596	-0.0012
	6	0.14	19.47	81.24	1.9358	0.0005
	7	2.26	18.15	70.15	1.8763	0.0056
	8	0.92	20.00	60.00	1.9612	-0.0013
% Dry weight	1	1.05	20.53	86.58		-0.0008
	2	0.88	20.00	89.85		0.0003
	3	0.88	20.14	72.02		0.00008
	4	1.05	19.64	65.81		0.0012
	5	1.31	20.00	88.69		0.0005
	6	0.87	19.93	62.63		-0.000008
	7	0.44	19.97	92.02		-0.0018
	8	0.87	20.00	68.25		0.0005

Table 10.1 (cont.) Group 3, Irrespective of burn and season.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Grass canopy cover	1	74.67	81.06	86.67	-724.28	12.4698
	2	88.00	91.00	92.83	73.07	-0.6453
	3	90.67	94.11	96.17	34.48	-0.3611
	4	59.00	70.06	78.33	-2636.20	32.3528
	5	92.33	94.61	97.00	305.86	-3.4471
	6	82.83	83.89	85.00	1891.86	-19.4223
	7	81.83	83.06	85.33	-309.27	3.4674
	8	75.17	80.28	83.50	538.59	-3.6403
Woody plant density / 200m²	1	57.25	70.41	94.50		-6.112
	2	33.50	47.17	60.50		-1.302
	3	4.25	4.88	5.25		0.065
	4	1.50	16.28	30.33		11.802
	5	0.10	0.10	0.10		0.672
	6	3.25	4.17	6.00		237.058
	7	0.10	0.10	0.10		-1.355
	8	28.00	39.42	61.00		0.668
% Woody plant canopy cover	1	20.85	31.82	38.20		1.174
	2	6.30	8.60	12.10		3.076
	3	2.43	5.30	8.35		-0.084
	4	8.80	24.36	35.45		-3.127
	5	0.10	0.10	0.10		6.724
	6	13.53	17.62	22.43		-123.753
	7	0.10	0.10	0.10		13.712
	8	37.65	45.40	57.25		-7.164

Table 10.1 (cont.) Group 4B, Non-burnt Winter.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
Total grass height (cm)	1	26.4	34.43	51.6	0.312	0.0120
	2	26.8	48.29	67.6	2.189	-0.0360
	3	38.8	49.17	66.8	2.292	-0.0389
	4	2.3	10.66	15.7	-181.353	4.9694
	5	20.4	37.19	55.9	28.160	0.0886
	6	55.6	72.53	86.8	19.856	-0.2573
	7	35.6	59.00	85.2	4.256	-0.0217
	8	16.9	49.41	78.4	4.054	-0.4392
Grass tuft height (cm)	1	6.0	9.95	13.7		-0.0520
	2	10.2	13.19	16.5		0.0105
	3	10.5	13.53	18.1		0.0065
	4	0.1	1.63	3.5		0.4240
	5	13.6	15.54	18.8		6.6790
	6	14.5	32.63	64.0		0.1551
	7	9.6	26.51	59.6		-0.0098
	8	2.5	8.94	13.7		1.6865
Above-ground standing crop (kg/ha)	1	1172.36	1618.33	2443.47		0.0007
	2	1456.57	2072.55	2444.37		0.0005
	3	1488.79	2084.18	2770.65		0.0006
	4	299.35	578.55	902.18		0.0997
	5	4887.32	5933.28	6972.99		-0.0273
	6	3321.23	4760.50	6490.10		-0.0014
	7	2973.50	4203.00	5350.40		-0.0003
	8	816.69	1300.69	2143.03		-0.0001

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Table 10.1 (cont.) Group 4B, Non-burnt Summer.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
Total grass height (cm)	1	18.2	36.68	62.0	0.39	0.0699
	2	16.3	45.84	71.2	1.84	-0.0025
	3	17.8	47.25	80.8	2.27	-0.0258
	4	2.1	12.47	37.6	-3.94	0.0040
	5	10.4	44.91	90.0	1805.67	-7.3944
	6	53.2	75.83	93.2	5.88	-0.0500
	7	35.2	68.87	97.2	3.84	0.0052
	8	23.2	56.40	82.8	0.09	-0.2627
Grass tuft height (cm)	1	9.0	13.38	17.3		-0.4194
	2	6.1	14.20	18.5		-0.0838
	3	7.5	13.12	19.2		0.0436
	4	0.5	2.95	9.5		0.4558
	5	2.6	17.56	47.6		64.0552
	6	14.1	32.79	51.6		-0.0069
	7	11.6	32.35	58.0		-0.0604
	8	4.9	12.74	16.9		0.3218
Above-ground standing crop (kg/ha)	1	1225.62	1834.32	3143.48		0.0022
	2	1492.82	2245.42	3024.43		0.0007
	3	1583.23	2437.32	3702.06		0.0002
	4	289.75	1096.72	2666.24		0.0009
	5	3744.31	6672.69	9493.03		-0.5070
	6	3988.27	6021.59	8264.66		-0.0001
	7	3139.35	5974.63	9492.17		-0.0001
	8	769.97	1561.58	2796.88		0.0051

Table 10.1 (cont.) Group 4C, Non-burnt Winter.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
Total grass height (cm)	1	26.4	34.43	51.6	-5.086	0.0914
	2	26.8	48.29	67.6	-1.141	0.0197
	3	38.8	49.17	66.8	-1.399	0.0192
	4	2.3	10.66	15.7	-275.197	18.5631
	5	20.4	37.19	55.9	1.295	0.0188
	6	55.6	72.53	86.8	10.898	-0.1413
	7	35.6	59.00	85.2	4.232	-0.0425
	8	16.9	49.41	78.4	0.611	0.0050
Biomass concentration (kg/m²)	1	0.9139	1.7112	2.8412		1.6660
	2	1.2473	1.5888	1.8971		1.1304
	3	1.2533	1.5312	1.8377		1.3063
	4	1.8072	6.5411	29.9353		-7.0002
	5	3.4160	3.8404	4.3707		-0.0516
	6	0.9883	1.7908	2.3345		-0.2660
	7	0.8919	2.0286	3.0974		-0.0489
	8	0.9459	1.7923	4.7503		0.5296

Group 4C, Non-burnt Summer

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
Total grass height (cm)	1	18.2	36.68	62.0	-4.6140	0.0632
	2	16.3	45.84	71.2	-0.1933	0.0186
	3	17.8	47.25	80.8	0.7947	0.0119
	4	2.7	12.47	37.6	-1.2623	0.1089
	5	10.4	44.91	90.0	4.6696	-0.0261
	6	53.2	75.83	93.2	7.0106	-0.0698
	7	35.2	68.87	97.2	4.9572	-0.0435
	8	23.2	56.40	82.8	-3.6345	-0.0037
Biomass concentration (kg/m²)	1	0.9473	1.3677	1.8491		2.3772
	2	1.1647	1.6779	2.5346		0.7338
	3	1.4114	1.8957	2.3076		0.3634
	4	1.5668	5.0296	13.4324		-0.0552
	5	1.7405	4.7859	14.4012		-0.5232
	6	1.4555	2.0637	2.9463		-0.2132
	7	1.4987	2.1388	3.1321		-0.1096
	8	0.5725	1.2741	2.4678		3.1779

Table 10.1 (cont.) Group 5, Non-burnt Winter.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Moisture	1	8.82	15.74	24.14	-16.00	-0.0512
	2	11.83	15.78	21.17	1069.35	4.7328
	3	9.35	13.25	19.09	548.49	-2.1090
	4	10.11	13.46	18.39	-125.69	0.5158
	5	10..994	19.68	27.27	38.46	-0.8383
	6	11.89	13.70	15.22	-1394.55	0.3995
	7	8.86	17.38	24.51	863.47	0.1724
	8				78.2895	
% N	1	0.44	0.5500	0.65		-0.597
	2	0.29	0.3167	0.35		30.573
	3	0.28	0.3167	0.36		185.185
	4	1.13	1.2700	1.44		-23.741
	5	0.54	0.4667	0.70		2.435
	6	0.45	0.4300	0.48		100.255
	7	0.38	0.5400	0.50		-87.925
	8	0.42	0.6400	0.67		-5.5131
% NDF	1	68.64	71.00	72.24		-0.5967
	2	68.86	72.58	75.36		-46.3398
	3	68.01	68.42	68.79		20.0197
	4	60.11	62.57	65.95		-3.0049
	5	64.83	66.52	66.92		-2.0707
	6	65.18	63.21	68.36		43.8608
	7	61.59	71.10	66.06		16.6060
	8	68.72	66.22	73.03		0.1848
% ADF	1	40.03	41.13	42.05		0.4450
	2	39.49	42.85	45.39		3.0199
	3	39.40	39.83	40.32		-3.0946
	4	28.20	30.64	32.61		4.3140
	5	37.90	39.84	40.52		-0.5693
	6	38.03	39.22	41.02		-12.4406
	7	38.14	43.63	40.91		-19.0519
	8	43.00	39.57	44.54		-1.1017
% IVOMD	1	47.66	52.67	56.66		0.3726
	2	52.51	54.78	57.19		-13.8805
	3	56.99	57.42	58.13		-2.0128
	4	57.41	59.09	61.56		0.2217
	5	57.32	56.59	59.66		-2.8784
	6	55.86	55.38	57.17		14.8366
	7	55.00	52.38	55.65		-0.9919
	8	50.00	58.20	55.59		-1.4405
% OM	1	90.31	92.16	93.35		0.2432
	2	90.72	92.45	93.94		29.9390
	3	90.37	91.18	91.60		-18.9331
	4	86.50	87.62	89.53		1.9179
	5	82.38	87.75	87.87		3.3855
	6	85.80	84.85	90.67		-21.4577
	7	83.22	92.82	87.41		-12.3626
	8	91.77	85.67	93.54		0.4583

Table 10.1 (cont.) Group 5, Non-burnt Summer.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Moisture	1	37.10	42.19	48.86	121.30	0.0660
	2	30.51	46.73	58.38	154.69	-0.2062
	3	27.36	41.93	55.91	32.12	0.0057
	4	40.44	49.37	63.25	-242.02	-1.2532
	5	39.74	45.45	52.12	-33.71	-0.0891
	6	28.37	35.14	42.43	-59.05	0.0979
	7	21.03	31.99	40.35	-38.71	0.1844
	8	31.52	39.02	48.78	19029.50	7.9758
% N	1	0.82	1.2217	1.60		1.840
	2	0.64	0.9567	1.30		2.192
	3	0.62	0.8417	1.25		16.162
	4	1.45	2.1000	2.99		10.587
	5	0.84	1.6900	2.92		-5.316
	6	0.87	1.0683	1.39		-2.270
	7	0.72	0.9767	1.24		1.914
	8	0.91	1.3550	1.76		765.723
% NDF	1	65.17	69.54	73.67		0.604
	2	64.68	67.98	69.95		1.579
	3	65.50	68.50	71.63		-3.326
	4	59.91	62.01	65.61		-0.903
	5	60.49	66.06	70.11		1.954
	6	61.08	67.31	74.24		-1.172
	7	56.83	65.28	71.34		-0.115
	8	67.36	68.54	69.97		-171.606
% ADF	1	38.78	40.75	42.08		-1.3341
	2	33.97	39.03	41.04		-0.9328
	3	34.19	37.92	41.06		4.2224
	4	27.77	30.18	32.68		5.2798
	5	36.02	38.75	40.29		-2.9421
	6	30.90	37.74	44.37		1.0941
	7	33.70	37.81	43.39		-0.0747
	8	37.43	38.46	39.30		96.5543
% IVOMD	1	63.60	67.13	72.10		-0.565
	2	61.89	64.78	68.91		0.044
	3	60.65	62.32	63.97		1.928
	4	68.37	72.02	75.81		-5.457
	5	65.74	69.42	73.76		-0.267
	6	60.42	62.97	68.67		0.687
	7	58.08	62.86	67.34		-0.062
	8	66.31	68.63	70.75		-149.506
% OM	1	89.39	91.69	93.85		-0.8258
	2	89.92	91.98	93.43		-2.4107
	3	91.07	91.99	92.52		-1.0906
	4	87.14	89.12	90.42		6.1032
	5	85.30	88.10	89.84		0.5490
	6	87.46	90.25	92.31		0.5891
	7	81.23	88.32	91.20		0.5115
	8	90.39	91.56	92.31		-21.8639

Table 10.1 (cont.) Group 6, Non-burnt Winter.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Ca	1	0.232	0.2783	0.360	28.332	114.278
	2	0.255	0.3083	0.415	-845.731	472.380
	3	0.412	0.4390	0.493	-16.951	-57.235
	4	0.373	0.4010	0.437	41.075	-11.935
	5	0.330	0.3660	0.395	-1.337	18.596
	6	0.350	0.4270	0.483	0.110	-3.689
	7	0.503	0.5487	0.617	-3.555	-279.146
	8	0.331	0.3843	0.468	-9.629	-20.672
% P	1	0.026	0.0363	0.050		156.28
	2	0.021	0.0237	0.026		20067.75
	3	0.021	0.0233	0.025		1102.95
	4	0.060	0.0723	0.080		64.08
	5	0.043	0.0667	0.113		-143.29
	6	0.025	0.0307	0.035		24.60
	7	0.023	0.0420	0.065		-1167.82
	8	0.027	0.0303	0.034		-243.54
% K	1	1.10	1.2600	1.42		-65.285
	2	0.66	0.7933	1.00		81.360
	3	0.61	0.8833	1.02		11.256
	4	0.69	0.7900	0.96		-7.829
	5	0.76	0.9367	1.12		1.853
	6	0.62	0.7367	0.82		2.060
	7	0.44	0.5467	0.61		324.500
	8	0.64	0.7733	1.02		-6.303
% Na	1	0.017	0.0233	0.029		-9.04
	2	0.021	0.0227	0.024		5646.18
	3	0.020	0.0243	0.028		217.81
	4	0.608	0.6133	0.618		-100.65
	5	0.081	0.0853	0.088		9.66
	6	0.026	0.0303	0.037		22.10
	7	0.032	0.0510	0.088		16.71
	8	0.020	0.0220	0.026		1349.09

Table 10.1 (cont.) Group 6, Non-burnt Summer.

Habitat variable	Plant community	Low value	Mean value	High value	Intercept	Slope vector (β)
% Ca	1	0.189	0.2268	0.281	-15.99	104.09
	2	0.241	0.2520	0.258	-12.62	19.57
	3	0.272	0.2890	0.302	-3.83	6.01
	4	0.257	0.3318	0.406	2605.48	-1074.69
	5	0.274	0.3358	0.374	-0.17	-5.89
	6	0.297	0.3780	0.433	12.59	-24.75
	7	0.351	0.3840	0.417	171.97	-1057.85
	8	0.272	0.3127	0.400	22.62	-84.48
% P	1	0.064	0.0995	0.134		-10.09
	2	0.072	0.1030	0.133		-16.12
	3	0.102	0.1110	0.119		3.13
	4	0.101	0.1367	0.168		-7478.59
	5	0.087	0.1443	0.219		-18.59
	6	0.098	0.1257	0.157		-11.22
	7	0.123	0.1400	0.157		-490.41
	8	0.081	0.1082	0.149		-62.28
% K	1	1.090	2.2960	2.710		-3.889
	2	1.630	2.1025	2.490		-0.705
	3	1.578	1.7840	2.149		1.736
	4	0.800	1.4367	1.940		-446.650
	5	1.250	1.5640	1.810		3.187
	6	1.463	1.9733	2.452		-0.482
	7	1.463	1.6070	1.751		147.241
	8	1.920	2.1867	2.490		-6.035
% Na	1	0.037	0.0628	0.195		-0.56
	2	0.029	0.0343	0.037		329.76
	3	0.051	0.0590	0.074		8.36
	4	0.577	0.8167	1.320		-1667.38
	5	0.029	0.1646	0.577		3.41
	6	0.069	0.807	0.103		3.72
	7	0.051	0.565	0.062		968.82
	8	0.032	0.362	0.041		582.73

Table 10.2: Combinations of habitat variables (mean values) as predictors of plant communities at probabilities $p > 0.5$ as identified with logistic regression.

Habitat variables	State of burn/ season	Plant community	Probability (p)
Species density Grass density	irrespective	2 3 6 7 8	0.6354 0.7961 0.8615 0.8215 0.5823
% Composition % Dry-weight	irrespective	1-8	0.8750
Total grass height Grass tuft height Above-ground standing crop	Non-burnt Winter	1 2 3 7	0.8281 0.8424 0.8385 0.8123
Total grass height Grass tuft height Above-ground standing crop	Non-burnt Summer	1 2 3 6 7	0.7893 0.8810 0.8891 0.7792 0.8055
Total grass height Biomass concentration	Non-burnt Winter	1 2 3 5 7 8	0.7137 0.8330 0.8244 0.8576 0.8358 0.8593
Total grass height Biomass concentration	Non-burnt Summer	1 2 3 5 6 7	0.7222 0.8691 0.8854 0.7300 0.7820 0.8487
% Moisture % N % NDF % ADF % IVOMD % OM	Non-burnt Winter	1	0.6998
% Moisture % N % NDF % ADF % IVOMD % OM	Non-burnt Summer	1 6 8	0.5823 0.7002 1.0000
% Ca % P % K % Na	Non-burnt Winter	6	0.8141
% Ca % P % K % Na	Non-burnt Summer	2 3 5 6	0.6145 0.8638 0.6708 0.7633

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Table 10.3: Wald statistic to test the effects and significance of the independent habitat variables (based on mean values). A variable was significant if $\alpha < 0.05$.

Habitat variable	State of burn/ season	Plant community	Wald Chi-square	α
Species density	irrespective	2	6.5925	0.0102
		3	8.1061	0.0044
		4	6.7002	0.0096
		7	6.9735	0.0083
		8	8.1226	0.0044
Grass density		4	4.4272	0.0354
		8	12.0291	0.0005
Total grass height	Non-burnt Winter	6	5.0400	0.0248
		8	7.0577	0.0079
Grass tuft height		6	8.7365	0.0031
		8	9.0879	0.0026
Above-ground standing crop		6	6.4493	0.0111
Total grass height	Non-burnt Summer	1	8.9849	0.0027
		4	6.3764	0.0116
Grass tuft height		1	5.3614	0.0206
		8	13.5271	0.0002
Above-ground standing crop		1	9.2620	0.0023
		8	10.6742	0.0011
Total grass height	Non-burnt Winter	1	10.6918	0.0011
		6	14.0174	0.0002
		7	5.1019	0.0239
Biomass concentration		1	8.1802	0.0042
		2	4.3018	0.0381
		3	4.7480	0.0293
		6	3.9025	0.0482
Total grass height	Non-burnt Summer	1	8.4900	0.0036
		4	11.1923	0.0008
		6	11.4069	0.0007
		7	7.0628	0.0079
Biomass concentration		1	9.3896	0.0022
		5	11.5575	0.0007
		8	15.2616	0.0001
% Moisture % N % NDF % ADF % IVOMD % OM	Non-burnt Summer	2	4.0159	0.0451

Table 10.4: Logistic regression analysis of high and low values of combinations of habitat variables. Predictors of plant communities were significant at $p > 0.5$. Most p values were > 0.95.

Combinations of habitat variables	State of burn/ Season	Plant communities
Species density Grass density	irrespective	2, 3, 4, 6, 7, 8
% Composition % Dry weight	irrespective	1, 2, 3, 4, 5, 6, 7, 8
Grass canopy cover Woody plant density Woody plant canopy cover	irrespective	2, 3, 5, 6, 8
Total grass height Grass tuft height Above-ground standing crop	Non-burnt Winter	1, 5
Total grass height Grass tuft height Above-ground standing crop	Non-burnt Summer	1, 2, 4, 8
Total grass height Biomass concentration	Non-burnt Winter	1, 2, 3, 4, 5, 6, 7, 8
Total grass height Biomass concentration	Non-burnt Summer	1, 2, 3, 4, 5, 6, 7, 8
% moisture, % N, % NDF, % ADF, % IVOMD, % OM	Non-burnt Winter	1, 2, 8
% moisture, % N, % NDF, % ADF, % IVOMD, % OM	Non-burnt Summer	1, 4, 5, 8
% Ca, % P, % K, % Na	Non-burnt Winter	1, 3, 6, 7, 8
% Ca, % P, % K, % Na	Non-burnt Summer	5
% moisture, % N, % NDF, % ADF, % IVOMD, % OM	irrespective	5, 8
% Ca, % P, % K, % Na	irrespective	8

Table 10.5: Comparison of seasonal (non-burnt areas) breeding herd distribution with habitat parameters identified with various analyses. All areas were non-burnt.

Plant community selection by roan	General Linear Modelling (PROC GLM)	Correspondence analysis	Logistic analysis (*p*) Mean values	Wald statistic Mean values	Logistic analysis (*p*) High & low values
WINTER					
7 *Aristida bipartita - Setaria sphacelata* Grassland Variation	Grass density Total grass height Grass tuft height Biomass Woody plant density Woody plant canopy cover % NDF, % OM % Ca, % Na		Species density Grass density Total grass height Grass tuft height Biomass Biomass concentration	Species density Grass tuft height	Species density Grass density Total grass height Biomass concentration % Ca, % P, % K, % Na
8 *Eragrostis pallens - Burkea africana* Savanna	Grass density Total grass height Biomass Woody plant density Woody plant canopy cover % NDF, % ADF, %IVOMD, %OM	Species density Species diversity Veld condition Grass density Grass canopy cover Woody plant density Woody plant canopy cover % moisture, % N, % NDF, % ADF, % IVOMD, % OM % Ca, % P, % K, % Na	Species density Grass density Grass tuft height Biomass concentration	Species density Grass density Total grass height Grass tuft height	Species density Grass density Grass canopy cover Woody plant density Woody plant canopy cover Total grass height Biomass concentration % moisture, % N, % NDF, % ADF, % IVOMD, % OM % Ca, % P, % K, % Na
1 *Rhus leptodictya - Combretum apiculatum* Variation	Grass density Total grass height Biomass Woody plant density Woody plant canopy cover % NDF, % IVOMD, % OM % Ca, %K	% Ca, % P, % K, % Na	Total grass height Grass tuft height Biomass Biomass concentration % moisture, % N, % NDF, % ADF, % IVOMD, % OM	Grass tuft height Biomass concentration	Total grass height Grass tuft height Biomass Biomass concentration % moisture, % N, % NDF, % ADF, % IVOMD, % OM % Ca, % P, % K, % Na

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Table 10.5 (cont.)

Plant community selection by roan	General Linear Modelling (PROC GLM)	Correspondence analysis	Logistic analysis (*p*) Mean values	Wald statistic Mean values	Logistic analysis (*p*) High & low values
SUMMER					
5 Nyl River and floodplain	Grass density Total grass height Grass tuft height Biomass Biomass concentration Grass canopy cover Woody plant density Woody plant canopy cover % N, % IVOMD, % OM	Species density Species diversity Veld condition Grass density % moisture, % N, % NDF, % ADF, % IVOMD, % OM	Grass tuft height Biomass concentration Minerals	Biomass concentration	% Composition % Dry weight Grass canopy cover Woody plant density Woody plant canopy cover Total grass height Biomass concentration % moisture, % N, % NDF, % ADF, % IVOMD, % OM % Ca, % P, % K, % Na
8 *Eragrostis pallens - Burkea africana* Savanna	Grass density Total grass height Grass tuft height Biomass Woody plant density Woody plant canopy cover % IVOMD	Species density Species diversity Veld condition Grass density Grass canopy cover Woody plant density Woody plant canopy cover % moisture, % N, % NDF, % ADF, % IVOMD, % OM % Ca, % P, % K, % Na	Species density Grass density Chemicals	Species density Grass density Grass tuft height Biomass Biomass concentration	Species density Grass density % Composition % Dry weight Grass canopy cover Woody plant density Woody plant canopy cover Total grass height Grass tuft height Biomass Biomass concentration % moisture, % N, % NDF, % ADF, % IVOMD, % OM

Table 10.6: Important habitat variables of the most selected non-burnt
plant communities as isolated with general linear modelling analysis
and Wald Chi-square statistic.

WINTER	SUMMER
Species density	Species density
Grass density	Grass density
Grass canopy cover	Grass canopy cover
Total grass height	Total grass height
Grass tuft height	Grass tuft height
Above-ground standing crop	Above-ground standing crop
Biomass concentration	Biomass concentration
Woody plant density	Woody plant density
Woody plant canopy cover	Woody plant canopy cover
% NDF	% N
% ADF	% IVOMD
%IVOMD	% OM
% OM	
% Ca	
% K	
% Na	

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