AN ECOLOGICAL STUDY OF THE GRASSLANDS OF THE JACK SCOTT NATURE RESERVE, TRANSVAAL, WITH SPECIAL REFERENCE TO PLANT PRODUCTION AND UNGULATE-HABITAT RELATIONSHIPS

by

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Submitted in partial fulfilment of the requirements
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Department of Zoology
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Co-supervisor: Prof J. du P. Bothma

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ABSTRACT

An ecological study of the grasslands of Jack Scott Nature Reserve, in the Krugersdorp District of the Transvaal, was done to investigate phytomass changes and ungulate-habitat relationships over a period of one year. Included in the study are a determination of the botanical composition of the grasslands and estimates of aerial net primary production and productivity rates during the year, as well as notes on the seasonal changes in numbers, activities and distributions of 10 ungulate types in the study area. Some guidelines regarding stocking rates and stock ratios are given, as well as suggestions regarding ecological monitoring and other management considerations for the study area and Jack Scott Nature Reserve as a whole.

ACKNOWLEDGEMENTS

I would like to thank Mr A.J. Vaughan, the former manager of Jack Scott Nature Reserve, for his enthusiastic support of the project, especially regarding logistics in the field. I thank also Mr J. Nash of Tweedsmuir Ranches, and owner of the reserve, for granting me permission to do the project on his land. Tweedsmuir Ranches provided a motorcycle and petrol for fieldwork, as well as domestic gas and gas appliances while I was living on Jack Scott Nature Reserve from April 1986 to April 1987.

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Dr D. Grossman of the Grasslands Research Centre, Pretoria, gave advice during the preparatory stages of the project with respect to the palatability of grass species in the study area. Prof D.A. Scogings and Mrs A. Allardice, both of the Department of Surveying & Mapping, University of Natal, Durban, assisted with the preparation of maps and gave helpful advice in that respect.

Miss G. Brown read a draft of the thesis and gave useful comments, while Miss M.E. Johnston translated the summary into Afrikaans.

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CHAPTER ONE: INTRODUCTION

In an article on Transvaal grasslands, Clinning (1986) stated that "the distribution of arable land in South Africa to a large extent coincides with the distribution of natural grasslands." The grasslands are, in fact, the most productive region of the country in terms of agriculture, mining and industry, and so grassland reserves have usually been situated in marginal, unsettled areas of low economic value. There is a need for private landowners to become aware of their important role in the conservation of the grasslands in South Africa (Clinning 1986).

However, it is not sufficient to only become aware of a conservation need. Conservation involves management, and the successful management of areas of natural vegetation depends on a knowledge of the composition of the vegetation, how it is used, and how it changes in response to environmental factors and patterns of use (Walker 1976). In order to effectively manage ecosystems, it is necessary to develop an understanding of animal-habitat interactions, whether management is profit-oriented or not.

Habitats change with changes in climate, therefore whether these changes are seasonal or annual, obtaining knowledge of habitats and how animals relate to them is not a momentary procedure that can be done once or even on odd occasions: it must be an on-going process. As awareness of the importance of various habitats or elements thereof in a wildlife management area is increased, so standards of management can be improved to meet whatever ends are envisaged.

PAST RESEARCH ON JACK SCOTT NATURE RESERVE

Previous botanical research on Jack Scott Nature Reserve has been largely qualitative. Wells (1964) described the vegetation on a structural and ecological basis, while Coetzee (1972, 1974a) classified the vegetation of Jack Scott Nature Reserve on a phytosociological basis, using association-analysis and Braun-

Blanquet tabulation (Coetzee 1974b).

The only previous studies of ungulates on Jack Scott Nature Reserve were by Mason (1973), who studied rangeland use and population structure of ungulates, Novellie (1975), who did a comparative social behaviour study of blesbok and springbok, and Van Aarde & Skinner (1975), who studied the feeding behaviour of giraffe.

PRESENT RESEARCH OBJECTIVES

The present study was aimed at gaining further insight into the nature of the grasslands of Jack Scott Nature Reserve and how various ungulate types utilise these grasslands. Because previous botanical research on Jack Scott Nature Reserve was qualitative, emphasis was placed on collecting quantitative data for the botanical side of the project. The grassland part of Jack Scott Nature Reserve was selected as the study area , as opposed to the whole reserve, because all but two of the 15 ungulate types that occur in the reserve are grazers or mixed feeders. The grasslands of Jack Scott Nature Reserve make up 60 % of the total reserve area and are thus important to the ungulates in the reserve. Furthermore, the most abundant ungulate type on Jack Scott Nature Reserve, the blesbok Damaliscus dorcas phillipsi, which numbered 400 to 420 the year before the present study began (Scogings 1985), is a grazer of short grass and prefers flat to gently undulating grasslands (Marchant 1983).

The specific objectives of the present study were:

1) To determine the botanical composition and herbage yield of the grasslands of Jack Scott Nature Reserve.
2) To determine the distribution and habitat preferences of ungulates in the said grasslands.

CHAPTER TWO: THE STUDY AREA

Jack Scott Nature Reserve boasts a variety of specialized habitats such as limestone caves and sinkholes, cliffs and freshwater cold springs. The caves provide a winter home for the Natal clinging bat _Miniopterus_ _schreibersi_ _natalensis_ which uses such caves for mating and hibernation (Van der Merwe 1973a,b,c), while the cliffs provide nesting sites for raptors such as the lanner falcon _Falco_ _biarmicus_ and black eagle _Aquila_ _verreauxii_.

Of historical interest is an Iron Age site on Jack Scott Nature Reserve. The site has been excavated by Prof R. Mason and members of the Archeological Research Unit of the University of the Witwatersrand (Brain*, pers. comm.).

LOCALITY

Jack Scott Nature Reserve is situated between latitudes 25° 52' and 25°57' S and between longitudes 27° 43' and 27° 48' E in the Krugersdorp district of the Transvaal (Figure 1). The reserve was started by Colonel Jack Scott in 1947 but has been owned by Mr John Nash** since 1978. The reserve consists of the farm Uitkomst 499 JQ and parts of the farms Hartbeesthoek 498 JQ and Diepkloof 496 JQ to the north and east respectively (Figure 2). The Diepkloof portion was added to the reserve during April 1985 and the whole reserve now covers 3 500 ha. The study area covers the 2 100 ha southern grasslands (Figure 3).

PHYSIOGRAPHY

The rocks in the study area belong to the Transvaal Sequence. From south to north across the study area, the geological

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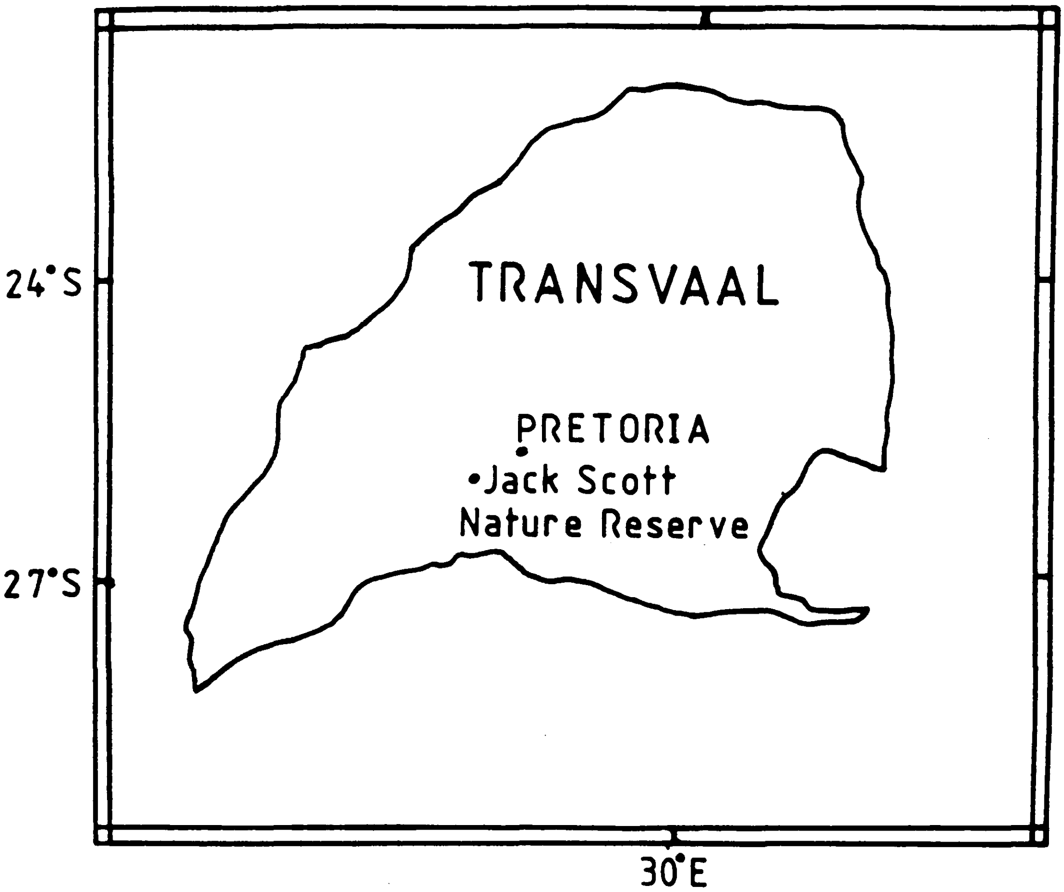

Figure 1 The locality of Jack Scott Nature Reserve in the Transvaal, Republic of South Africa.

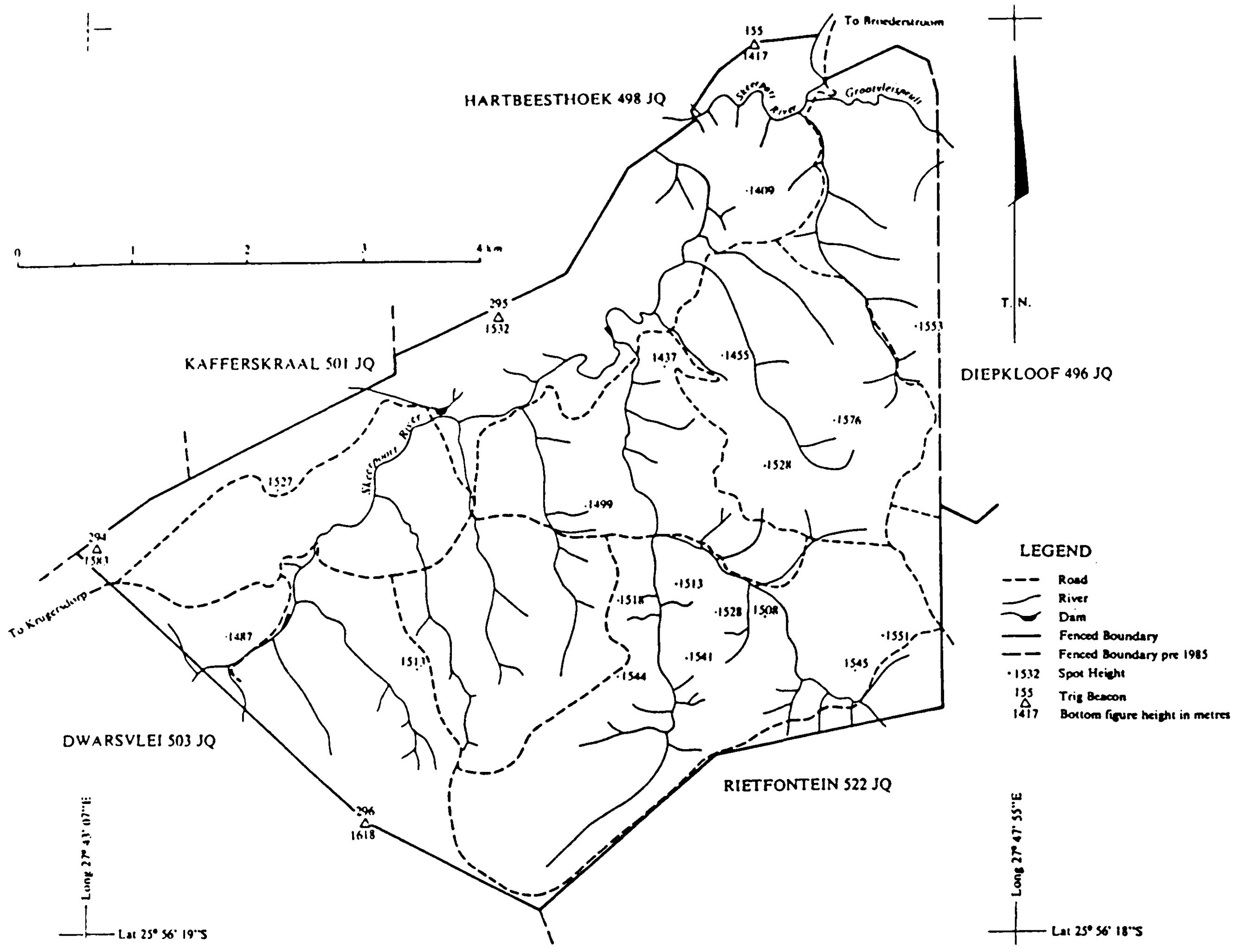

Figure 2 Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as it appeared during the period of field work for the present study (April 1986 to April 1987). The part of Diepkloof 496 JQ which was included in April 1985 is not indicated because of the lack of accurate information regarding the position of the added fence line.

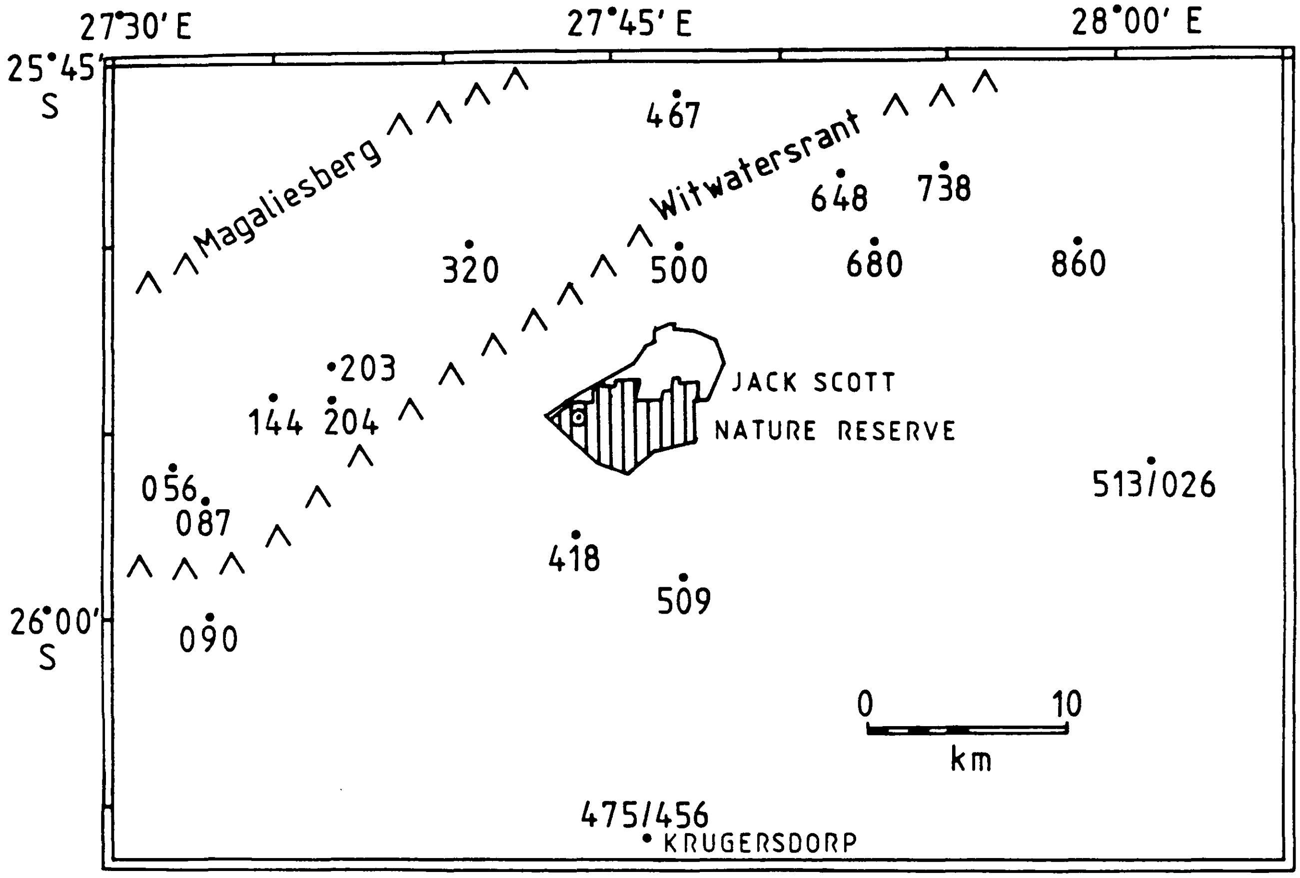

Figure 3 The location of the study area (hatched) on Jack Scott Nature Reserve, Krugersdorp District, Transvaal and surrounding Weather Bureau stations; unprefixed station numbers are in section 512 of the station network (Weather Bureau 1987) and the circle in the study area marks the position of a rain gauge used during the study period.

succession is ascended from the older, dolomite-chert formations of the Malmani Subgroup, Chuniespoort Group, to the younger shale and quartzite units of the Timeball Hill Formation, Pretoria Group (Figure 4).

The altitude of the study area ranges from 1 365 to 1 615 m above sea level and the main river, the Skeerpoort River, flows north-easterly across the study area. Although the course of the Skeerpoort River starts 9 to 10 km south-west of the study area, the first kilometre of the river's course inside Jack Scott Nature Reserve is dry, except during thunderstorms. From the place where the water springs from the ground, namely 1 km inside the south-western boundary, the Skeerpoort River flows perennially for the remainder of its course through Jack Scott Nature Reserve. Most tributaries flow northwards into the Skeerpoort River and are all non-perennial (Figure 2).

CLIMATE

The climate of the study area can be deduced from the climatograms constructed for Krugersdorp and Pelindaba (Figure 5). The data for the climatograms were obtained from the Weather Bureau, Pretoria. The convention used by Walter (1979) for constructing southern hemisphere climate diagrams was used where mean temperature and mean precipitation are plotted at a ratio of 1 °C : 2 mm. Where the rainfall exceeds 100 mm, the vertical scale is reduced 10 times. Where the rainfall exceeds the temperature on such a diagram, a humid period is defined, while a drought period is defined when the rainfall is less than the temperature. The first line of the diagram gives the station name, altitude (m) above sea level, mean annual temperature (°C) and mean annual precipitation (mm), in that order, while the second line indicates, in square brackets, the number of years for which temperature (left-hand figure) and rainfall (right-hand figure) have been recorded. From Figure 5 it is evident that there is a cold, dry season from May to September and a hot, wet season from October to April.

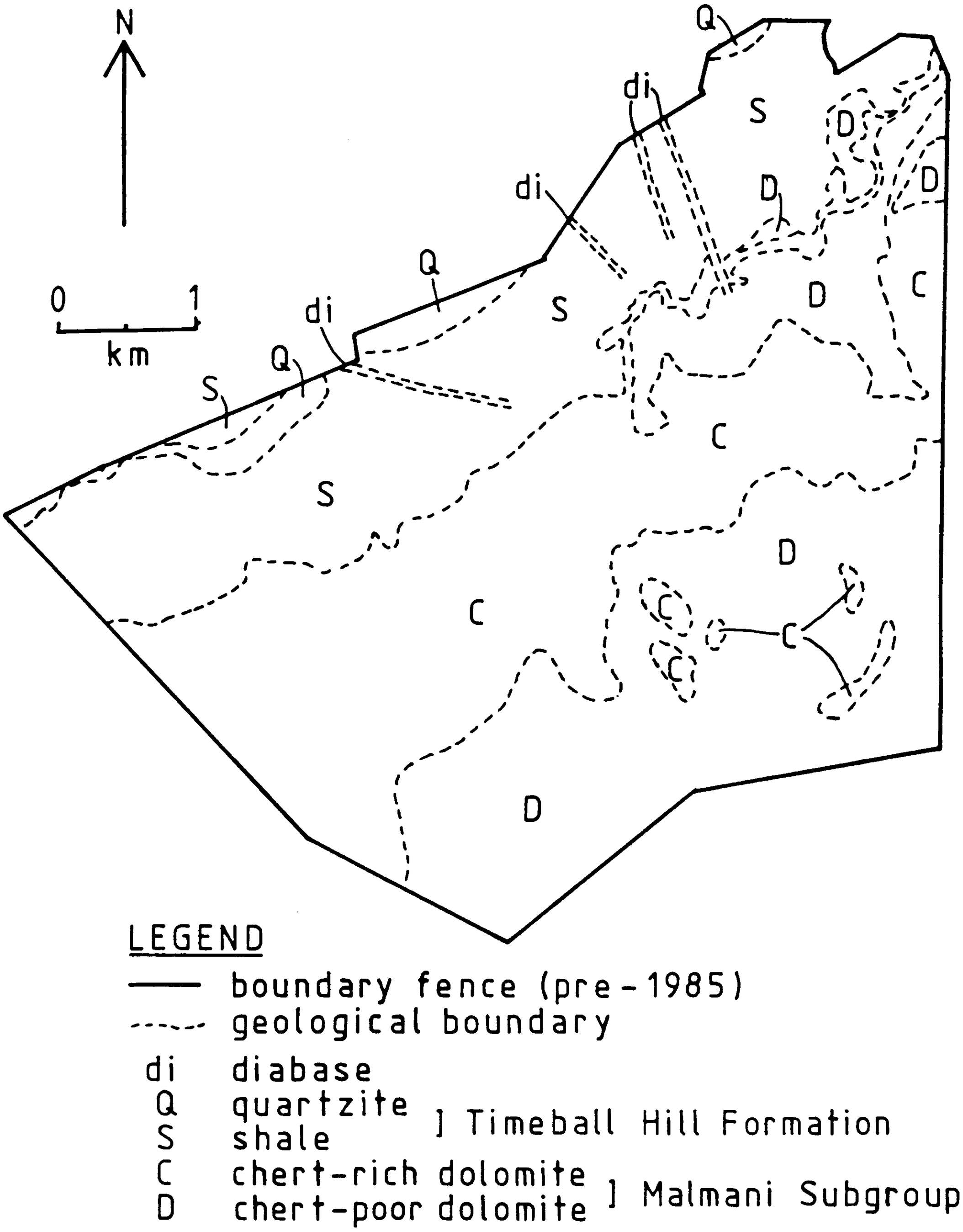

Figure 4 The geology of Jack Scott Nature Reserve, Krugersdorp District, Transvaal (after Mason 1973).

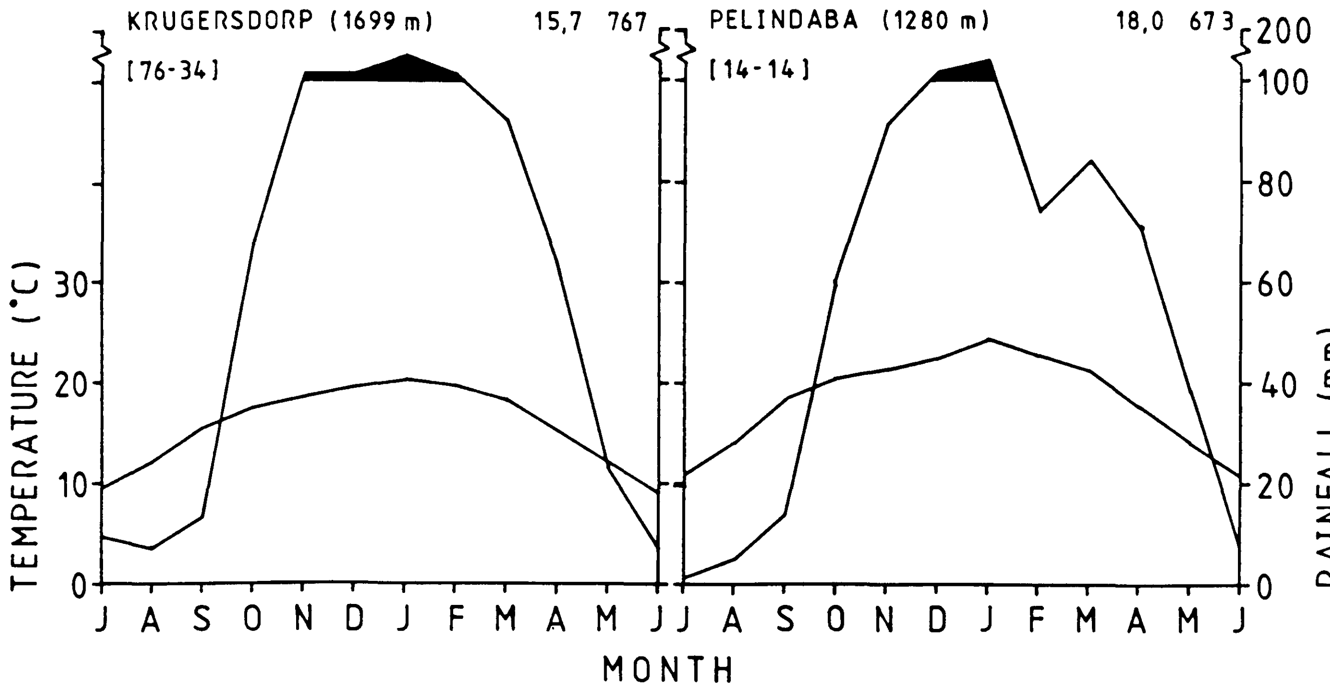

Figure 5 Climatograms for Krugersdorp and Pelindaba in the Transvaal, compiled from data supplied by the Weather Bureau, Department of Environment Affairs, using the convention of Walter (1979). Where the rainfall curve is above the temperature curve, a wet season is defined, and where the rainfall curve is below the temperature curve, a dry season is defined. The shaded area defines a very wet season.

Temperature data for Pelindaba and Krugersdorp are presented in Table 1, while precipitation data for 17 stations in the region (Figure 3) are presented in Table 2. Details of each station may be found in Table 3. All the weather data are by courtesy of the Weather Bureau, Department of Environment Affairs, apart from the rainfall data recorded personally in the study area during the study period. The mean annual precipitation for all 17 stations is 683 mm (Table 2), which may be taken as an approximation of the mean for the study area. It should be noted that the two stations with the lowest mean annual rainfall, namely Bekker Landbouskool (512/087) and Bluebird Farm (512/320), both have records over the shortest period of time (7 years) and for the early 1980's and early 1960's respectively. These periods were relatively dry, as indicated by the decennial dry-wet cycles proposed by Dyer & Tyson (1977). The implication therefore, is that the mean annual rainfall of 683 mm could well be an underestimate.

Table 4 contains rainfall figures for the study area and four neighbouring Weather Bureau stations over the period of study. All the latter stations had rainfall that was above their respective annual means, so the rainfall of 773 mm recorded on Jack Scott Nature Reserve was probably also substantially above the annual mean.

From Table 5 it is evident that relative humidity for Hartbeespoort and Pretoria is highest at the end of the wet season, namely autumn, and lowest at the end of the dry season, namely early spring.

Information supplied by the Weather Bureau indicates that the mean number of days per year on which thunder occurs is 38,6 for Krugersdorp (weather station 475/456) and 26,3 for Hartbeespoort (weather station 512/545), while hail occurs on a mean of 3,9 and 2,0 days per year at these two stations respectively.

The potential sunshine duration for Pretoria is 13,7; 12,2; 10,6 and 11,9 hours per day for December, March, June and September respectively (Coetzee 1972). Mean monthly sunshine duration in Pretoria from 1939 to 1948 was 62 to 75 % of the potential

Table 1 Mean maximum, minimum and daily [(maximum+minimum)/2] temperatures (°C) for Krugersdorp (weather station 475/456) located at 26°06' S; 27°46' E and 1 699 m above sea level, and Pelindaba (weather station 512/738) located at 25°48' S; 27°55' E and 1 280 m above sea level as supplied by the Weather Bureau, Department of Environment Affairs, Pretoria. Data are for 76 and 14 years respectively.

MONTH	KRUGERSDORP			PELINDABA		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
January	26,0	14,2	20,2	28,2	17,4	23,3
February	25,3	14,0	19,8	27,6	16,6	22,5
March	24,2	12,4	18,4	26,6	15,2	21,2
April	21,4	9,0	15,3	23,4	11,6	17,5
May	19,0	5,3	12,2	21,0	6,7	14,0
June	16,4	2,1	9,2	18,2	2,9	10,4
July	16,8	2,3	9,5	19,1	2,5	10,8
August	19,4	4,5	12,0	21,8	5,9	13,9
September	22,9	8,1	15,5	25,9	11,0	18,6
October	24,3	10,8	17,6	26,6	13,6	20,2
November	24,7	12,3	18,6	26,8	15,4	21,3
December	25,6	13,4	19,5	28,1	16,7	22,5

Table 2 Mean annual rainfall for 17 Weather Bureau stations less than 30 km from the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal. Data were supplied by the Weather Bureau, Department of Environment Affairs, Pretoria.

STATION NUMBER	STATION NAME	RAINFALL (mm)	PERIOD OF DATA COLLECTION (YEARS)
475/456	Krugersdorp	767	34
513/026	Diepsloot	657	12
512/056	Seekoeihoek	694	44
512/087	Bekker Landbouskool	608	7
512/090	Magaliesburg	665	17
512/144	Nooitgedacht	700	57
512/203	Hekpoort	682	40
512/204	Hekpoort	662	12
512/320	Bluebird Farm	607	7
512/418	Maryvale Farm	726	20
512/467	Scheerpoort	659	42
512/500	Hartebeesthoek	652	47
512/509	Kromdraai	714	49
512/648	Broederstroom	792	16
512/680	Kalkheuwel	742	45
512/738	Pelindaba	673	14
512/860	Hennopsrivier	614	55
Mean		683	30

Table 3 Details of the rainfall station on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, and of the Weather Bureau stations (Weather Bureau 1987) for which rainfall data were obtained.

STATION NUMBER	STATION NAME	LATITUDE AND LONGITUDE	ALTITUDE ABOVE SEA LEVEL(m)	PERIOD OF RECORDS	DISTANCE FROM STUDY AREA (km)
-	Jack Scott Nature Reserve	2554 2744	1443	1986-87	0
475/456	Krugersdorp	2606 2746	1699	1951-84	21
513/026	Diepsloot	2556 2801	1370	1907-18	29
512/056	Seekoeihoek	2556 2732	1341	1935-78	20
512/087	Bekker Landbouskool	2557 2733	1341	1979-85	17
512/090	Magaliesburg	2600 2733	1480	1969-85	21
512/144	Nooitgedacht	2554 2735	?	1915-71	15
512/203	Hekpoort	2553 2737	1365	1905-44	12
512/204	Hekpoort	2554 2737	1358	1974-85	12
512/320	Bluebird Farm	2550 2741	1220	1960-66	10
512/418	Maryvale Farm	2558 2744	1524	1945-64	6
512/467	Scheerpoort	2547 2746	1219	1907-48	17
512/500	Hartebeesthoek	2550 2747	1372	1907-53	10
512/509	Kromdraai	2559 2747	1463	1905-53	10
512/648	Broederstroom	2548 2752	1250	1923-38	18
512/680	Kalkheuwel	2550 2753	1370	1915-59	16
512/738	Pelindaba	2548 2755	1280	1963-76	22
512/860	Hennopsrivier	2550 2759	1280	1908-62	25

Table 4 Rainfall (mm) recorded in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, and at four Weather Bureau stations during the study period. Data for the latter were supplied by the Weather Bureau, Department of Environment Affairs, Pretoria.

YEAR	MONTH	JACK SCOTT NATURE RESERVE	WEATHER BUREAU STATIONS			
			475/456 Krugersdorp	512/087 Bekker Landbou.	512/090 Magaliesburg	512/204 Hekpoort
1986	April	39	74	34	50	16
	May	0	0	0	0	0
	June	30	26	20	19	32
	July	0	0	0	0	0
	August	13	26	32	35	15
	September	1	2	7	9	0
	October	113	123	144	112	116
	November	88	107	75	72	83
	December	96	184	152	131	139
1987	January	152	213	110	152	100
	February	111	110	22	27	56
	March	130	161	150	100	152
Total		773	1026	746	707	709
Excess over annual mean			259	138	42	47

Table 5 Mean monthly relative humidity (%) derived from dry-bulb and wet-bulb temperatures (°C) at 08h00 and 14h00 at Hartbeespoort (512/545), located at 25°35' S; 27°49' E and 1 158 m above sea level, and Pretoria-Forum (513/314), located at 25°44' S; 28°11' E and 1 330 m above sea level, for the periods 1951-1984 and 1965-1984 respectively, as supplied by the Weather Bureau, Department of Environment Affairs, Pretoria.

MONTH	HARTBEESPOORT			PRETORIA-FORUM		
	08h00	14h00	Mean	08h00	14h00	Mean
January	71	42	57	72	47	60
February	74	42	58	74	47	61
March	76	41	59	76	46	61
April	79	42	61	78	43	61
May	80	37	59	77	36	57
June	79	34	57	76	32	54
July	76	31	54	73	30	52
August	67	27	47	66	28	47
September	58	24	41	60	28	44
October	58	31	45	63	34	49
November	66	40	53	68	42	55
December	70	42	56	69	43	56

duration for October to April and 78 to 88 % for May to September (Coetzee 1972).

The wind direction on Jack Scott Nature Reserve is mainly northerly to easterly in summer and north-westerly to south-westerly in winter (Coetzee 1972). Spring (September to November) is the most windy time of the year, while autumn and early winter (March to July) is the least windy time of the year. The strongest winds are usually the southerly to south-westerly winds associated with thunderstorms (ibid.).

VEGETATION

Jack Scott Nature Reserve is on the northern edge of the Central Variation of the Bankenveld, which is a false grassland maintained at a fire climax while the true climax is thought to be an open savanna of *Acacia caffra* (Acocks 1975). Rocky hills and ridges are dominated by *A. caffra* and *Protea caffra*, representing Bushveld vegetation. In sheltered valleys and sinkholes there are traces of temperate forest, while on flatter parts that were once cultivated, *Hyparrhenia hirta* is abundant. The sour nature of the grass causes the rangeland to be highly unpalatable in the winter months (Acocks 1975). A more detailed discussion of the vegetation of Jack Scott Nature Reserve may be found at the beginning of Chapter Three where previous botanical studies are discussed.

CHAPTER THREE: THE BOTANICAL SURVEY

The grasslands of the study area are tropical, as defined by Misra (1979), because the area is situated between 30° N and 30° S. Using cluster analysis, Lauenroth (1979) classified 52 grassland sites worldwide into six groups based on climatic diagrams. The present site would be included in Group 3 which is characterised by "a single peak in precipitation occurring during the warmest months of the year, preceded and followed by a period of severe drought" (Lauenroth 1979). According to the classification of Trewartha (1968), Group 3 includes both climatically tropical sites and subtropical semi-arid sites.

The first study of the vegetation of Jack Scott Nature Reserve was a description by Wells (1964),followed by a phytosociological classification by Coetzee (1972, 1974a) using association-analysis supplemented by Braun-Blanquet tabulation (Coetzee 1974b). Using a structural and ecological approach, Wells (1964) divided the vegetation into forest patches, tree communities, grasslands and marshy areas. Five tree communities were identified floristically, namely *Protea caffra*-, *Protea roupelliae*-, *Acacia caffra*-, *Acacia karroo*- and *Burkea africana*-communities. The grasslands were divided physiographically into Valley, Rocky and Highland Grasslands. The study by Coetzee (1974a) identified 11 grassland communities in the study area, of which three were on dolomite, three were on chert-rich dolomite, two were on chert, one was on shale and two were on old farmlands. The two old farmlands communities were also situated on shale and were cultivated in the 1920's (Mason 1973). Table 6 lists the prominent plant species occurring in the grassland communities on dolomite, chert and chert-rich dolomite, shale and old farmlands, as recorded by Coetzee (1974a).

The 11 grassland communities described by Coetzee (1974a) in the study area were grouped into four broader communities for the purposes of the present study, based on the map of Coetzee (1974 a). These four grassland communities are presently referred to as the dolomite community (D), the chert community (C), the shale community (S) and the old lands community (F), corresponding to

Table 6 Prominent plant species (those with a Braun-Blanquet cover-abundance value of two or more in at least 25 % of releves representing a community) in the grass layer of communities on dolomite, chert and chert-rich dolomite, shale and old farmlands, as recorded by Coetzee (1974a) on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

PLANT SPECIES	PLANT COMMUNITIES ON:			
	Dolomite	Chert & chert-rich dolomite	Shale	Old farm-lands
Eragrostis curvula	x			x
Heteropogon contortus	x			x
Eustachys paspaloides	x			
Elephantorrhiza elephantina	x			
Tristachya rehmannii		x		
Sporobolus pectinatus		x		
Bulbostylis burchellii		x		
Urelytrum agropyroides		x		
Digitaria monodactyla		x		
Digitaria brazzae		x		
Monocymbium ceresiiforme		x		
Parinari capensis		x		
Sporobolus congoensis		x		
Digitaria tricholaenoides		x		
Cymbopogon excavatus	x			x
Cynodon dactylon				x
Hyparrhenia hirta				x
Sporobolus africanus				x
Trachypogon spicatus	x	x	x	
Elionurus muticus	x	x	x	
Eragrostis racemosa	x	x	x	x
Brachiaria serrata	x	x	x	
Diheteropogon amplectens	x	x	x	
Loudetia simplex		x	x	
Andropogon schirensis		x	x	
Schizachyrium sanguineum	x	x	x	x
Panicum natalense		x		
Bewsia biflora	x	x		
Rhynchelytrum nerviglume	x	x	x	
Themeda triandra	x	x	x	x
Setaria sphacelata	x	x		

Coetzee's (1974a) communities on dolomite and chert-rich dolomite, chert, shale and old farmlands respectively (Figure 6). It should be noted here that Coetzee's (1974a) map combines the communities on dolomite and chert-rich dolomite.

In each of the four communities mentioned above, 10 sample sites were randomly positioned and at each site a 1 m iron stake was erected to mark the intersection of four 100 m long transects at right angles to each other (Figure 7). The first transect was directed down the slope of the land surface and originated from the iron stake, while another transect was directed up the slope from the iron stake and was thus back-to-back with the first transect. The remaining two transects were then placed at right angles to the other two and also originated from the iron stake. There were thus two transects across the contour of the land surface and two transects along the contour of the land surface. The down-slope direction from the stake was measured from true north using a magnetic compass and this direction was recorded as the orientation direction for later reference. The initial sample site placement avoided areas burnt in 1985 as well as water courses and steep, rocky slopes. The latter were avoided because of the nature of the equipment to be used; only one site on dolomite was rejected for this reason during the initial selection of sampling sites. Another site on dolomite had to be excluded from the sampling after it was burnt during the spring burn of 9 October 1986. All data analyses were done using SAS - Statistical Analysis System (SAS Institute Inc. 1982a, b) on the IBM 4341 mainframe of Computer Services, University of Pretoria.

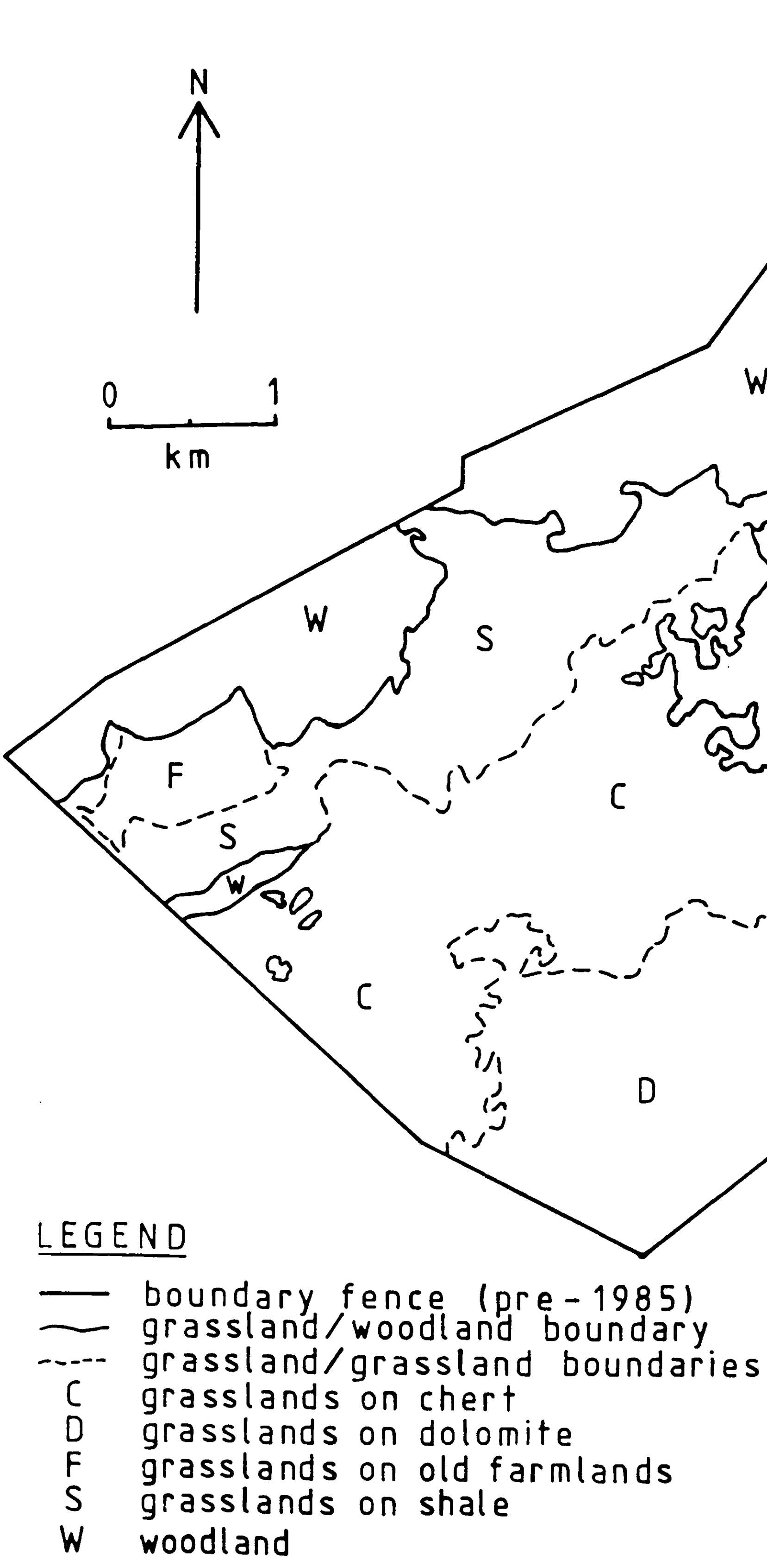

Figure 6 A simplified vegetation map of Jack Scott Nature Reserve, Krugersdorp District, Transvaal, based on the map of Coetzee (1974a), to show the grasslands that make up the study area.

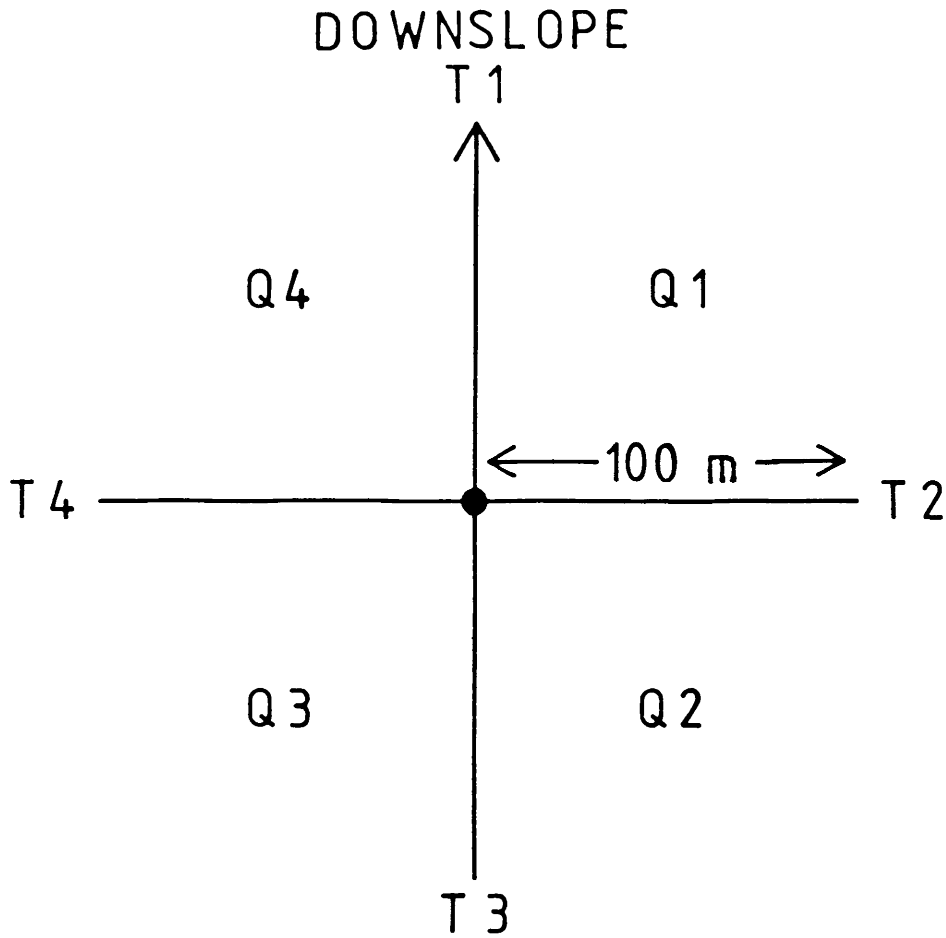

Figure 7 Basic form of each sample site used for the dry-weight ranking ('t Mannetje & Haydock 1963) and disc pasture meter (Bransby & Tainton 1977) surveys of the grassland communities in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, April 1986 to April 1987, where T1 to T4 are basic transects 1 to 4, and Q1 to Q4 are quadrants 1 to 4.

PART ONE

BOTANICAL COMPOSITION

INTRODUCTION

Botanical composition is an important measure of the vegetation in an area, especially when doing pasture research (Jones & Hargreaves 1979). Data on botanical composition are necessary when studying grassland ecology as such data enable the monitoring of grasslands in terms of changes caused by herbivores and fire. The botanical composition of natural rangeland can also affect the productivity of the vegetation in an area, which in turn affects the number of animals that can use the area. One of the aims of the present study was to gather quantitative data on the botanical composition of the grasslands of Jack Scott Nature Reserve.

Measuring botanical composition

Botanical composition may be described either by the absolute measures of number, cover or dry mass, or by the non-absolute measure of frequency (presence/absence). Non-absolute measures are comparable only if the sample size and number are known (Tothill 1978). Absolute data yield frequency data, but the converse is not true. The method used in a study depends on the objectives of the study, but describing botanical composition in terms of the proportional mass of species is most apt for production studies (Shaw, 't Mannetje, Jones & Jones 1976; Tothill 1978).

Brown (1954) distinguished four methodologies for use in the measuring of botanical composition by dry mass. The methods of hand separation and weighing of cut herbage are the most accurate, but most time-consuming, and require drying facilities ('t Mannetje & Haydock 1963). The remaining methodologies are more rapid, but less accurate than the first as they involve either estimates of the percentage mass of cut herbage or <u>in situ</u> herbage, or estimates of the actual mass of herbage in the field ('t Mannetje & Haydock 1963).

The dry-weight rank method was developed by 't Mannetje & Haydock (1963) in order to satisfy the need for an accurate and rapid method for the botanical analysis of pastures in terms of mass. In each quadrat an observer ranks those species that occupy first, second and third place in terms of dry mass. The proportion of quadrats in which each species occurs in the respective ranks is determined and then multiplied by the empirical factors of 70,19; 21,08 and 8,73 for ranks one to three respectively. The resulting products are added for each species, the sum being the percentage dry mass. If some quadrats have less than three species, then the ratios 8,04; 2,41 and 1,00 are used as the multipliers. The sum of products for each species is then expressed as a percentage of the total sum of products, this being the percentage dry mass. The multipliers may vary between sites and vegetation types, but the derivation of new multipliers is unnecessary as the new resultant dry mass percentages are only marginally different from the results obtained using the original multipliers mentioned above (Jones & Hargreaves 1979; Kelly & McNeill 1980; Barnes, Odendaal & Beukes 1982).

There are two problems with dry-weight ranking, but most pastures do not present situations in which these problems arise (Tothill 1978). The first problem arises in a situation in which the vegetation is dominated by one species making up more than 75 % of the dry matter ('t Mannetje & Haydock 1963). This problem can be lessened by assigning more than one rank to the dominant species (Tothill 1978). This solution is referred to as cumulative ranking by Jones & Hargreaves (1979). The second problem arises when there is a consistent relationship between the quadrat yield and the order in which species are ranked, in other words, when one species is always dominant in quadrats with high yield and another species is always dominant in quadrats with low yield. Results biased in this way can be corrected by applying a weighting factor, based on quadrat yield, to the multipliers (Tothill 1978). Such weighting has been found to increase the precision of botanical composition estimates (Jones & Hargreaves 1979; Kelly & McNeill 1980; Barnes et al. 1982).

The size of the quadrat is not critical, as long as a minimum of three species occurs in most quadrats ('t Mannetje & Haydock 1963). Generally, the smaller the quadrat, the fewer the species therein, but the easier it is to rank these species, and the opposite is true. Quadrats of 0,04; 0,09; 0,25 and 0,40 m^2 were used successfully on subtropical pastures by 't Mannetje & Haydock (1963) who recommend quadrats of 0,09 or 0,25 m^2. Walker (1970) used quadrats of 0,81 m^2 on grassland cleared of trees and scrub at the Matopos Research Station, Zimbabwe. In a later publication, Walker (1976) recommends quadrats of 0,25 m^2 or less if "the herbaceous layer is dense and diverse, but the 1 m^2 quadrat is satisfactory for most open swards, particularly in more arid regions". Haydock & Shaw (1975) used quadrats of 0,25 m^2 for the comparative yield method while Kelly & McNeill (1980) also used and recommend quadrats of that size for dry-weight ranking of the herbaceous layer of tree savanna in Zimbabwe. Locally, in the eastern Transvaal grasslands of Nooitgedacht (26° 31' S; 29° 58' E) and Athole (26°36' S; 30° 35' E) research stations, quadrats of 0,04 m^2 were found to be sufficient for dry-weight ranking (Barnes et al. 1982).

Kelly & McNeill (1980) used 240 quadrats with success, but suggest using up to 600 quadrats for greater accuracy. Barnes et al. (1982) recommend that "at least 100 quadrats and preferably many more (be observed), if the area to be sampled is relatively large, or if the pattern of distribution of species or communities is variable."

Multivariate methods

Data are multivariate when various attributes are measured for each of numerous individuals, for example, plant species found in each sample site. Multivariate analysis is used "to treat multivariate data as a whole, summarising the data and revealing their structure" (Gauch 1982). Unlike hypothesis-testing classical statistical methods, multivariate analyses generate hypotheses (Williams 1973). Methods of multivariate analysis aim to reduce noise, summarise redundancy, express relationships and detect outliers (Gauch 1982).

Noise is caused by individuals from identical environmental conditions having different attributes, while redundancy is the opposite of noise. Individual redundancy occurs when many individuals resemble each other in their attributes and attribute redundancy occurs when many attributes resemble each other in their distribution among individuals. Individual redundancy is equivalent to replication, while attribute redundancy is caused by the effects of a few factors on the distribution of numerous attributes. An example of attribute redundancy is when the decrease in one species and increase in another may be caused by one factor, enabling the status of one species to be known by knowing the status of the other. Outliers are individuals with unusual attributes compared with other individuals examined. Disjunction in a data set occurs when a group of individuals is clearly separate from other groups of individuals. The whole data set is then referred to as being disjunct. Outliers and disjunctions occur frequently in community data and are either real or artificial. Real outliers/ disjunctions are caused by community disturbance or heterogeneity, while artificial outliers/disjunctions are caused by incomplete sampling (Gauch 1982).

Whittaker (1978a) defines two broad multivariate analysis methodologies used in community analysis, namely classification and gradient analysis, the latter consisting of direct and indirect gradient analysis. Direct gradient analysis arranges individuals/ attributes along one or more known gradients. Indirect gradient analysis, of which ordination is an essential part, arranges individuals/attributes in terms of abstract axes, after which gradients, if they exist, may be interpreted. The two types of gradient analysis cannot be sharply separated, but represent different approaches, hence their separate treatment by Whittaker (1978b) and Gauch (1982).

Unlike direct gradient analysis, ordination and classification usually require computers for data analysis. Ordination attempts to represent individual and attribute relationships in low-dimensional space in which similar individuals/attributes, or both, are near each other (the converse being true), while classification assigns individuals and attributes to classes which may or may not be hierarchically arranged (Gauch 1982). After organising ecological community data, environmental interpretation is performed. Ordination, like direct gradient analysis, applies to continuous data, while classification applies to discrete, discontinuous data or entities (Kershaw 1973; Whittaker 1978a, b). Despite this difference, classification and ordination may be applied to the same data set in various complementary ways, either in series or in parallel (Goodall 1978; Noy-Meir & Whittaker 1978; Gauch 1982). The application of continuous multivariate analysis methods to discrete data has usually been achieved by ordinating reasonably continuous, preclassified groups of individuals/attributes. However, it has been shown that improved ordination methods, especially non-centred eigenvector methods, can be applied to discontinuous data as a guide to classification (Goodall 1978; Noy-Meir & Whittaker 1978).

Ordination in community ecology

Popular ordination techniques used by ecologists include weighted averaging, polar ordination, principle components analysis, reciprocal averaging and detrended correspondence analysis (Gauch 1982). Weighted averaging is a technique also used in direct gradient analysis and requires an initial knowledge of environmental gradients in order to derive sample/species scores (ibid.). Polar ordination requires all the samples to be compared with each other so as to find the least similar pair. These samples are then used as endpoints or poles of the ordination axis (Cottam, Goff & Whittaker 1978; Gauch 1982). Principle components analysis requires only the data matrix for the derivation of the sample and species ordination scores which, furthermore, can be obtained simultaneously (Gauch 1982).

The subjectivity of selecting weights and endpoints in weighted averaging and polar ordination is removed by using principle components analysis. Reciprocal averaging, also known as correspondence analysis (Hill 1973, 1974), is related conceptually to weighted averaging, while being an eigenvector technique related to principle components analysis, using average sample ordination scores for species ordination scores and vice versa (Gauch, Whittaker & Wentworth 1977; Gauch 1982). Although reciprocal averaging suffers from the arch effect like principle components analysis, the former is not subject to the involution of axis ends as is the case with the latter (Gauch et al. 1977). Detrended correspondence analysis (Hill 1979a; Hill & Gauch 1980) improves upon reciprocal averaging by removing the arch effect while also correcting the second fault of reciprocal averaging, namely the compression of axis ends. The arch effect is removed by a process of detrending, while the compression of axis ends is rectified by rescaling the axes. Locally, detrended correspondence analysis has been used recently for, among other applications, pattern analysis (Theron, Morris & Van Rooyen 1984; Whittaker, Morris & Goodman 1984; Ben-Shahar 1986) and grassland monitoring (Mentis 1984; Brockett & Holton 1986; Mentis 1986).

Classification in community ecology

Three kinds of classification are used by ecologists: Braun-Blanquet tabulation, non-hierarchical classification and hierarchical classification (Gauch 1982). Table arrangement is a non-numerical classification technique which aims to arrange species according to their distribution through samples and, similarly, to arrange samples according to species composition. The result is a table of species and samples, with similar entities arranged together (ibid.). Numerical classification includes non-hierarchical classification which assigns samples or species to clusters without summarising relationships among the samples or species. Non-hierarchical classification is most useful for the initial clustering of relatively large data sets in order to detect noise and redundancy early in the classification process (Gauch 1980, 1982).

Hierarchical classification, like non-hierarchical classification, groups similar entities together, but then arranges the classes into a hierarchy. Hierarchical classification can be either agglomerative or divisive. Agglomerative methods start with separate samples and combine them into clusters of decreasing similarity until all the samples are combined into one cluster. Conversely, divisive methods start with all the samples together and divide them into smaller clusters. Monothetic methods divide the samples according to the presence or absence of one species, while polythetic methods divide the samples according to the presence or absence of all or many of the species (Goodall 1978; Gauch 1982).

A more detailed discussion of the specific ordination and classification techniques, namely detrended correspondence analysis (Hill 1979a) and two-way indicator species analysis (Hill 1979b), used in the present study may be found in the description of methods below.

METHODS

Dry-weight rank analysis

Initially a wheel-point survey (Tidmarsh & Havenga 1955) was to be done to determine the basal cover and species composition of the grasslands making up the study area. Because of the cumbersome equipment and the labour- and time-intensive nature of such a survey, it was decided to use the dry-weight ranking method of 't Mannetje & Haydock (1963). In retrospect, the latter method seemed more appropriate than a point survey because of the emphasis on dry mass, thus linking this part of the botanical survey to the second part (Chapter Three, Part Two).

The botanical composition of the grasslands was determined between 10 February and 6 March 1987. At each randomly selected sample site (10 per community), except the one site on dolomite that was burnt in October 1986, each of the four basic transects (Figure 7) was walked and a 0,5 x 0,5 m quadrat was evaluated every 10 paces. Dry-weight ranking was thus applied to 39 of the 40 sample sites in the study area. Forty quadrats (10 per transect) were examined at each sample site, in other words, 400 in each community, except the dolomite community where 360 quadrats were examined. Non-grass species were ranked as separate species as opposed to treating them together as one 'species'. The species were identified by comparison with Wells' herbarium specimens housed on the reserve and by Prof Theron*, and the species names follow Gibbs Russel, Reid, Van Rooy & Smook (1985) and Gibbs Russel, Welman, Retief, Immelman, Germishuizen, Pienaar, Van Wyk & Nicholas (1987) (Appendix A).

The height (mm) of the tallest plant in each quadrat was measured with a metre rule. Dry-weight ranking was not applied to areas burnt during spring 1985 or 1986 and the calculations of percentage dry mass were done using the original multiplying ratios of 't Mannetje & Haydock (1963), namely 8,04; 2,41 and 1,00.

Multivariate analyses

The botanical composition information from the dry-weight rank analysis ('t Mannetje & Haydock 1963) of the study area was subjected to ordination and classification, with the 39 sample sites as individuals and the plant species as attributes, quantified by percentage dry mass. The main multivariate approach was that of ordination using detrended correspondence analysis (DECORANA) (Hill 1979a), while classification by the polythetic divisive technique of two-way indicator species analysis (TWINSPAN) (Hill 1979b) was done supplementary to the ordination.

Detrended correspondence analysis is an improvement on a simpler ordination method, namely reciprocal averaging or correspondence analysis. One of the two main faults of reciprocal averaging is the arch effect caused by the tendency for the second axis to be non-independent of the first axis, while still being uncorrelated therewith. For separate interpretation of the axes, they need to be independent as well as uncorrelated. While the first axis in detrended correspondence analysis is calculated as for normal reciprocal averaging, the second and subsequent axes are adjusted by a process of detrending described in detail by Hill (1979a) and Hill & Gauch (1980). Detrending essentially aims to equalise the sample scores along the first axis such that the said scores have a mean of zero.

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The other main fault of reciprocal averaging is the compression of axis ends so that sample or species pairs separated by equivalent ecological distances appear closer together at the axis ends than at the axis middles. In other words, the standard deviation of species scores is less at the ends of gradients than in the middle of gradients. This fault is rectified by rescaling the axes so that the within-sample dispersion of the species scores is set to unit standard deviation (1,0 SD). The process of rescaling is described in detail by Hill (1979a) and Hill & Gauch (1980). Generally, a species appears, rises to its mode, and disappears over a distance of 4,0 SD and samples separated by more than 4,0 SD generally have no mutual species. The ordination unit of 1,0 SD is approximately equal to another measure of species turnover (beta-diversity), namely the half-change unit which represents a 50 % change in composition (Hill & Gauch 1980). Apart from dealing with the arch effect and unequal scaling of axes, DECORANA also reduces computing time when dealing with relatively large data sets.

However, there are drawbacks associated with detrended correspondence analysis. The only way to deal with extreme outliers is to exclude them and also the width of large discontinuities may be poorly estimated. Another drawback is that species ordinations are often less satisfactory (and thus more difficult to interpret) than sample ordinations. Species ordinations can also be unreliable if one gradient crosses another at one end but not at the other. As with all ordination methods, environmental interpretation is subject to ecological knowledge of the study area (Hill & Gauch 1980).

Two-way indicator species analysis is a development of indicator species analysis described by Hill, Bunce & Shaw (1975). Unlike its precursor, which classified the samples only, TWINSPAN classifies both the samples and the species. The samples are classified first and this classification is then used to classify the species. The two classifications are then used to construct an ordered two-way table similar to a Braun-Blanquet table (Hill 1979b; Gauch 1982). The classification is done by a dichotomisation process based on reciprocal averaging ordination. The samples are ordinated first (primary ordination) to obtain an initial, rough dichotomy by dividing the ordination at its middle. Differential species that characterise the poles of the ordination are used in a second ordination (the refined ordination) aimed at constructing a refined version of the initial sample division. A third ordination, the indicator ordination, may be carried out using a few of the most strongly differential species to see if the refined ordination dichotomy can be reproduced. The division process is repeated on the two sample clusters to give four, then eight clusters, and so on, until the desired number of clusters is obtained. A corresponding species classification is produced and combined with the sample classification to create the ordered two-way table. The sample and species hierarchies can also be represented as dendrograms, however the nature of a dendrogram prevents the expression of gradients of more than one dimension (Gauch 1982).

Two data sets were examined in the present study: one containing the percentage dry mass values of the 20 plant species (16 grass species and 4 non-grass species) that were recorded in all four communities but not necessarily at all sample sites, while the other set contained the percentage dry mass values of all 127 species recorded. Each data set was examined for all four grassland communities and for the three subclimax communities (excluding the old lands) and standard analyses were applied.

RESULTS

Botanical composition

The botanical composition of each grassland community in the study area is presented in Table 7 while all the recorded plant species are listed taxonomically in Appendix A. Non-grass species made up 5,3; 4,1; 4,6 and 2,6 % of the composition of the chert, dolomite, old lands and shale communities respectively, in terms of dry mass. Such percentages agree with the results in Chapter Three, Part Two (Tables 15 and 22) in that the grasses made up over 94 % of the total phytomass. The number of grass and non-grass species recorded in each community is presented in Table 8, while Table 9 contains information on vegetation heights. The

Table 7 Botanical composition in terms of percentage dry mass for each grassland community of the study area on Jack Scott Nature Reserve, as measured by the dry-weight rank method of 't Mannetje & Haydock (1963) during February/March 1987.

NUMBER	SPECIES	PERCENTAGE DRY MASS Chert	Dolomite	Old land	Shale
001	Cassia mimosoides	0,2	+		
002	Crabbea angustifolia	+	+	+	+
003	Anthericum fasciculatum		+		
004	Kohautia amatymbica	+		0,7	+
005	Oldenlandia herbacea			+	+
006	Conyza podocephala			0,3	
007	Solanum incanum		0,2	0,2	+
008	Hermannia depressa			+	
009	Acanthospermum australe *			0,4	+
010	Vernonia poskeana	+			+
011	Acalypha angustata			+	+
012	Vigna vexilata			+	
013	Solanum panduriforme			0,4	+
014	Helichrysum rugulosum			0,3	
015	Eriosema salignum			0,1	
016	Unknown 1			+	
017	Rhynchosia totta			+	
018	Pentarrhinum insipidum			+	
019	Pollichia campestris	+		0,2	
020	Felicia muricatus		+	+	
021	Acacia ataxacantha			+	
022	Erigeron karvinskianus *			+	
023	Hypoxis rigidula		0,2	+	+
024	Lippia javanica			+	
025	Verbena bonariensis *			+	
026	Osteospermum muricatum			+	
027	Hermannia lancifolia	+	0,2		
028	Solanum supinum		+		
029	Helichrysum callicomum		+		
030	H. cf. oxyphyllum	+	+		
031	Bulbostylis burchellii	0,8	0,2		
032	Sphenostylis angustifolia	0,1	+		+
033	Senecio lydenbergensis		+		
034	Leucas neufliziana	+	+		
035	Polygonum sp.		+		
036	Rhus magalismontana		0,3		
037	Euphorbia sp.		+		
038	Plexipus pinnatifidus		+		
039	Cassine burkeana		+		
040	Barleria sp.		+		
041	Gnidia sericocephala		+		
042	Clutia pulchella		+		
043	Asparagus suaveolens		+		
044	Unknown 2		+		
045	Hermannia transvaalensis		+		
046	Ledebouria revoluta		0,1		
047	Kohautia virgata	+	0,1		
048	Limeum viscosum	+	0,1		

049	Fimbristylis hispidula		0,2		
050	Chaetacanthus costatus		+		
051	Dicoma anomala	+	+		
052	Gnidia splendens	0,4			
053	Pentanisia angustifolia	+			0,2
054	Amaranthus thunbergii	+			
055	Rhynchosia monophylla	0,1			
056	Gnidia capitata				0,2
057	Tephrosia elongata				0,2
058	Walafrida densiflora				+
059	Phyllanthus incurvis				+
060	Justicia sp.				+
061	Blepharis sp.				+
062	Indigofera comosa	+			
063	Pearsonia sesillifolia				+
064	Ziziphus zeyheriana				+
065	Cyperus margaritaceus				+
066	Cassia biensis	+			
067	Sutera palustris	0,2			
068	Helichrysum nudifolium	+			
069	Ipomoea obscura	+			
070	Sida rhombifolia			+	
071	Stoebe vulgaris			0,7	0,2
072	Parinari capensis	0,5	0,5	+	+
073	Elephantorrhiza elephantina	0,1	0,2	0,4	0,3
074	Senecio venosus	1,2	0,6	0,1	0,4
075	Xerophyta retinervis	1,0	0,2		
076	Bidens pilosa *	+			
077	Kalanchoe thyrsiflora		+		
078	Indigofera arrecta				0,5
Subtotal for non-grasses		5,3	4,1	4,6	2,6
079	Andropogon schirensis	7,7	1,2	1,9	10,2
080	Aristida congesta subsp. congesta	0,1	1,3	0,8	+
081	Aristida sp. 1	1,8	1,5		+
082	Aristida sp. 2	0,2	1,8		
083	Bewsia biflora	0,5	0,2		+
084	Brachiaria serrata	3,3	2,8		4,4
085	Cymbopogon excavatus	+		11,0	0,7
086	C. validus			0,4	
087	Cynodon dactylon	0,2	+	2,3	0,5
088	Diheteropogon amplectens	8,6	5,4	0,3	12,3
089	Digitaria brazzae	4,4	0,5		
090	D. diagonalis				0,1
091	D. monodactyla	2,7	5,1		
092	D. tricholaenoides	1,5	1,2	0,2	0,1
093	Elionurus muticus	4,7	5,5	0,8	11,4
094	Eragrostis chloromelas	0,8	5,0	3,2	0,1
095	E. curvula	1,2	5,1	11,9	1,3
096	E. gummiflua	0,4	0,4	3,1	0,7
097	E. racemosa	1,4	1,1	1,0	1,7
098	E. rigidior			+	
099	Eustachys paspaloides		0,4		
100	Fingerhuthia sesleriiformis		1,1		
101	Heteropogon contortus	0,2	0,6	3,1	0,6
102	Hyparrhenia hirta			24,5	
103	Loudetia simplex	5,4	1,7		2,3
104	Microchloa caffra	+	+		

105	Monocymbium ceresiiforme	2,3	1,2		0,5
106	Panicum natalense	0,2	0,4		3,8
107	Paspalum scrobiculatum			2,4	
108	Pogonarthria squarrosa	0,1	+		
109	Rhynchelytrum nerviglume	4,0	0,7	0,6	7,5
110	R. repens	1,0	0,5	+	1,2
111	Schizachyrium sanguineum	10,2	1,9	3,0	10,9
112	S. ursulus	0,3			
113	Setaria sphacelata	13,0	34,8	10,7	2,6
114	Sporobolus africanus			1,0	0,2
115	S. fimbriatus	0,2		11,3	0,8
116	S. pectinatus	0,9	0,5		
117	Stipagrostis zeyheri	0,2	1,1		
118	Themeda triandra	3,7	3,8	1,2	6,4
119	Trachypogon spicatus	3,1	4,3	0,9	14,0
120	Tristachya rehmannii	8,2	3,6		1,0
121	Triraphis andropogonoides	0,4	1,1		
122	Urelytrum agropyroides	1,0	0,8		1,8
123	Trichoneura grandiglumis	0,6			
124	Tragus berteronianus		+		
125	Eragrostis sp. 1			+	
126	Eragrostis sp. 2		+		
127	Hyparrhenia sp. 1			0,2	
Subtotal for grasses		94,7	95,9	95,4	97,4

* = exotic
+ = 0,01 to 0,09 % dry mass

Table 8 Number (n) and percentage (%) of grass and non-grass species recorded while doing dry-weight ranking ('t Mannetje & Haydock 1963) in each grassland community of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal during February/March 1987.

VEGETATION COMPONENT	GRASSLAND COMMUNITY							
	Chert		Dolomite		Old lands		Shale	
	n	%	n	%	n	%	n	%
Non-grasses	27	42	36	49	28	52	25	45
Grasses	37	58	37	51	26	48	30	55
Total	64	100	73	100	54	100	55	100

Table 9 Mean vegetation height recorded in each grassland community of the study area on Jack Scott Nature Reserve in the Krugersdorp District, Transvaal, during February/March 1987.

GRASSLAND COMMUNITY	SAMPLE SIZE	MEAN HEIGHT (mm)	COEFFICIENT OF VARIATION (%)
Chert	399	820	24,2
Dolomite	357	620	30,3
Old lands	400	1090	23,9
Shale	399	870	24,9

chert and dolomite communities both had the highest number of grass species (37) while the old lands community had the lowest number of grass species (26). The shale community had the lowest number of non-grass species (25) while the dolomite community had the highest number of non-grass species (36).

The dry-weight rank method of determining botanical composition does not indicate the distribution pattern of species through a community. For example, Kohautia amatymbica and Stoebe vulgaris both made up 0,7 % of botanical composition in the old lands community but the former was more evenly distributed than the latter; K. amatymbica was recorded at six of the 10 old land sites while S. vulgaris was recorded at only two of the 10 old land sites. Similarly, in the shale community, Indigofera arrecta (0,5 %) occurred in three of the 10 sample sites while Senecio venosus (0,4 %) occurred in six of the 10 sample sites. Because no single species made up more than 75 % of the composition of any community, cumulative ranking was not applied. Perusal of Table 7 makes apparent the differences in botanical composition of the communities, but the ecological differences are better elucidated by the results of the multivariate analyses.

Multivariate analyses

Ordination by DECORANA was the main approach, while classification by TWINSPAN supplemented the ordination. Ordination using the 20 ubiquitous species reflected the main gradients yielded by the alternate ordination using all the species as attributes. The latter ordination yielded more information and so the former is hereafter ignored.

The most noticeable feature indicated by the multivariate analyses was the separation of the old lands community from the other communities, as evident to the right of Figure 8. The application of TWINSPAN to all the data revealed that samples 20 to 29 were separated from the other samples at the first level by Hyparrhenia hirta (Figure 9). The dolomite community was separated from the shale and chert communities at level two by Setaria sphacelata, the latter two communities being characterised by Rhynchelytrum nerviglume and Andropogon

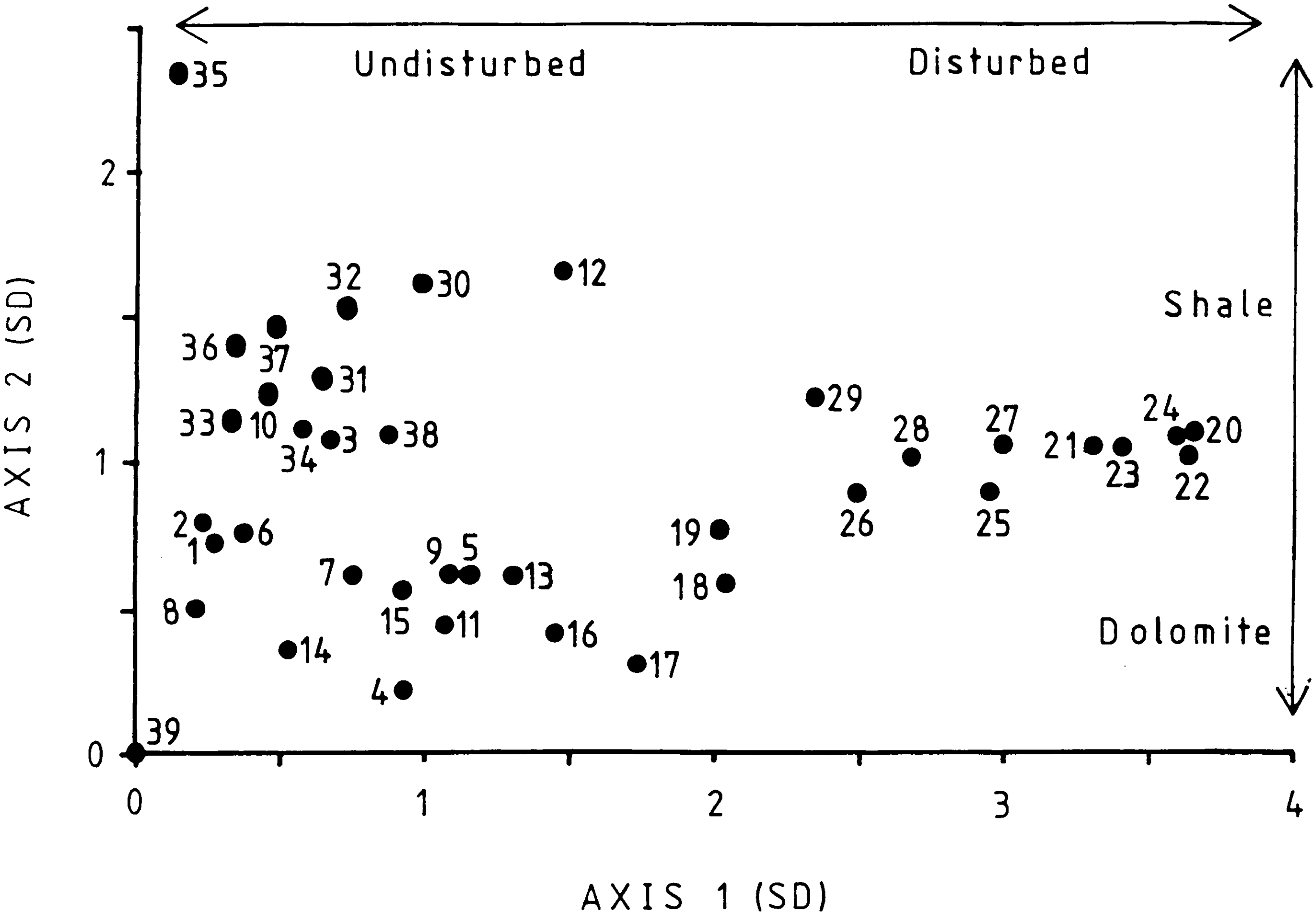

Figure 8 Ordination, by DECORANA, of all vegetation samples (including all species) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/March 1987. Eigenvalues for the first and second axes are 0,673 and 0,230 respectively and sample numbers are as follows:
1 to 10 = samples in the chert community
11 to 19 = samples in the dolomite community
20 to 29 = samples in the old lands community
30 to 39 = samples in the shale community.

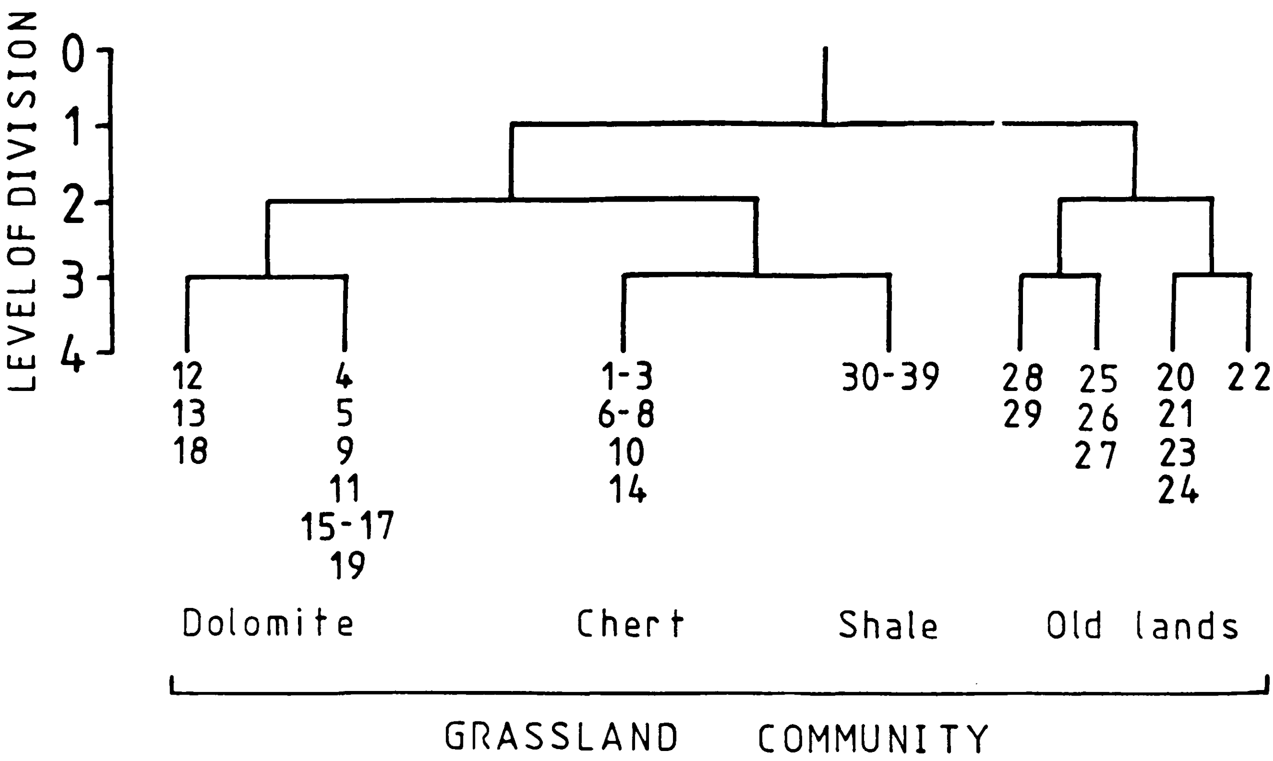

Figure 9 Classification, by TWINSPAN, of all vegetation samples (including all species) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/March 1987. Sample numbers are as follows:

1 to 10 = samples in the chert community
11 to 19 = samples in the dolomite community
20 to 29 = samples in the old lands community
30 to 39 = samples in the shale community.

schirensis, while the chert community was separated from the shale community by Digitaria monodactyla and Tristachya rehmannii at the third level.

Species such as Andropogon schirensis, Rhynchelytrum nerviglume, Schizachyrium sanguineum, Eragrostis racemosa and Themeda triandra, which were common across all the communities, were more abundant in the shale community while Aristida congesta subsp. congesta, Eragrostis chloromelas and E. curvula were more abundant in the dolomite and old lands communities where commoner species were less abundant.

The first sample ordination axis in Figure 8 represents a gradient from natural, undisturbed range to disturbed range. Within the first axis there is a subgradient across the old land samples representing an increase in Cymbopogon excavatus, Paspalum scrobiculatum and Eragrostis chloromelas from left to right. Along the second axis, samples on chert and dolomite (1-19) tend to plot at the lower end except for samples 10 and 12, while samples on shale (20-39), including the old lands (which were on shale), tend to plot at the upper end, except for sample 39.

The shale-chert-dolomite gradient may be explained by scrutinising geochemical analyses of the respective rock types (Table 10). The chert and dolomite formations referred to are, more specifically, chert-rich and chert-poor dolomite formations respectively (Eriksson*, pers. comm.) and are comparable with the limestones of Table 10. Compared with the shale analyses of Table 10, the limestones are poorer in acidic elements such as Si and Al, but richer in the alkali elements Ca and Mg. It may, therefore, be expected that soils derived from the limestones would have higher pH values than soils derived from the shales. As they are more base-rich than the chert- and shale-derived soils, the dolomite-derived soils are also physiologically drier (Werger & Coetzee 1978). Hence the occurrence of species such as the geophytic Anthericum fasciculatum, Hypoxis rigidula and

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Table 10 Chemical composition (mass %) of five limestone samples and two shale samples from the upper part of the Pretoria Group, to show the base-rich nature (CaO and MgO) of limestones and the acid-rich nature (SiO_2 and Al_2O_3) of shales when compared with each other (after Van Biljon 1949).

	DOLOMITE SAMPLES					SHALE SAMPLES	
	I	II	III	IV	V	VI	VII
SiO_2	-	23,58	19,61	-	24,52	57,53	62,35
Al_2O_3	-	2,95	1,30	-	4,67	11,91	15,84
Fe_2O_3	-	0,97	0,80	-	0,80	1,27	4,95
FeO	-	0,28	0,14	-	0,86	3,31	2,30
Cr_2O_3	-	-	0,00	-	-	trace	0,01
MnO	-	trace	0,03	-	0,50	0,05	0,06
CaO	30,91	22,43	28,08	18,05	28,71	6,05	1,01
MgO	9,58	23,95	20,32	27,93	18,11	10,66	3,66
K_2O	-	-	-	-	-	3,43	5,70
Na_2O	-	-	-	-	-	1,58	1,67
P_2O_5	-	0,07	0,00	-	0,11	0,05	0,15
SO_4	-	-	-	-	-	0,13	0,13
H_2O	-	8,33	6,96	-	3,58	1,38	0,58
TiO_2	-	trace	trace	-	0,20	0,75	0,66
CO_2	-	17,61	22,15	-	18,21	1,64	0,75
Total	-	99,81	99,59	-	99,92	99,74	99,84

Ledebouria revoluta, as well as the crassulacean Kalanchoe thyrsiflora, and the succulent Euphorbia sp. and Unknown 2 (species number 44, Table 7) on chert-poor dolomite.

The species ordination reflected the sample ordination, but the gradients were at an angle to the axes. The strongest gradient apparent in Figure 10 is from Increaser I to Increaser II grasses (Appendix B) from upper left to lower right. This gradient corresponds to utilisation of the grasslands by ungulates; the plant species common to the underutilised shale community being on the left and the plant species common to the overutilised/disturbed areas on the right.

The exclusion of the old land samples (20-29) from the detrended correspondence analysis resulted in the most interpretable gradients in both sample and species ordinations. The geological and ungulate utilisation gradients were repeated, while two additional gradients were revealed (Figures 11-13). Both the geological and utilisation gradients were aligned with the first axis; from less-used shale on the left, through chert-rich dolomite, to more-used, chert-poor dolomite on the right (Figures 11 and 12). The second axis of the sample ordination represented a gradient across the dolomitic end of axis one, from sites with less outcrop at the lower end, to sites with more outcrop (samples 12, 13 and 18) at the upper end (Figure 11). The third axis of the sample ordination reflected a gradient across the shale community from the relatively xeric, north-facing sample sites at the lower end to the relatively mesic, south-facing sample 39 at the upper end (Figure 12).

The ungulate utilisation gradient was also well represented by the diagonal axis from upper left (underutilisation) to lower right (overutilisation) of the species ordination (Figure 13). The end of the gradient representing underutilisation by ungulates was characterised by plant species generally common or unique to the shale community, including Increaser I grasses and shrubs, while the end of the gradient representing overutilisation by ungulates was characterised by plant species generally common or unique to the dolomite community, including Increaser II grasses and herbs (see Appendix B). The Increaser I

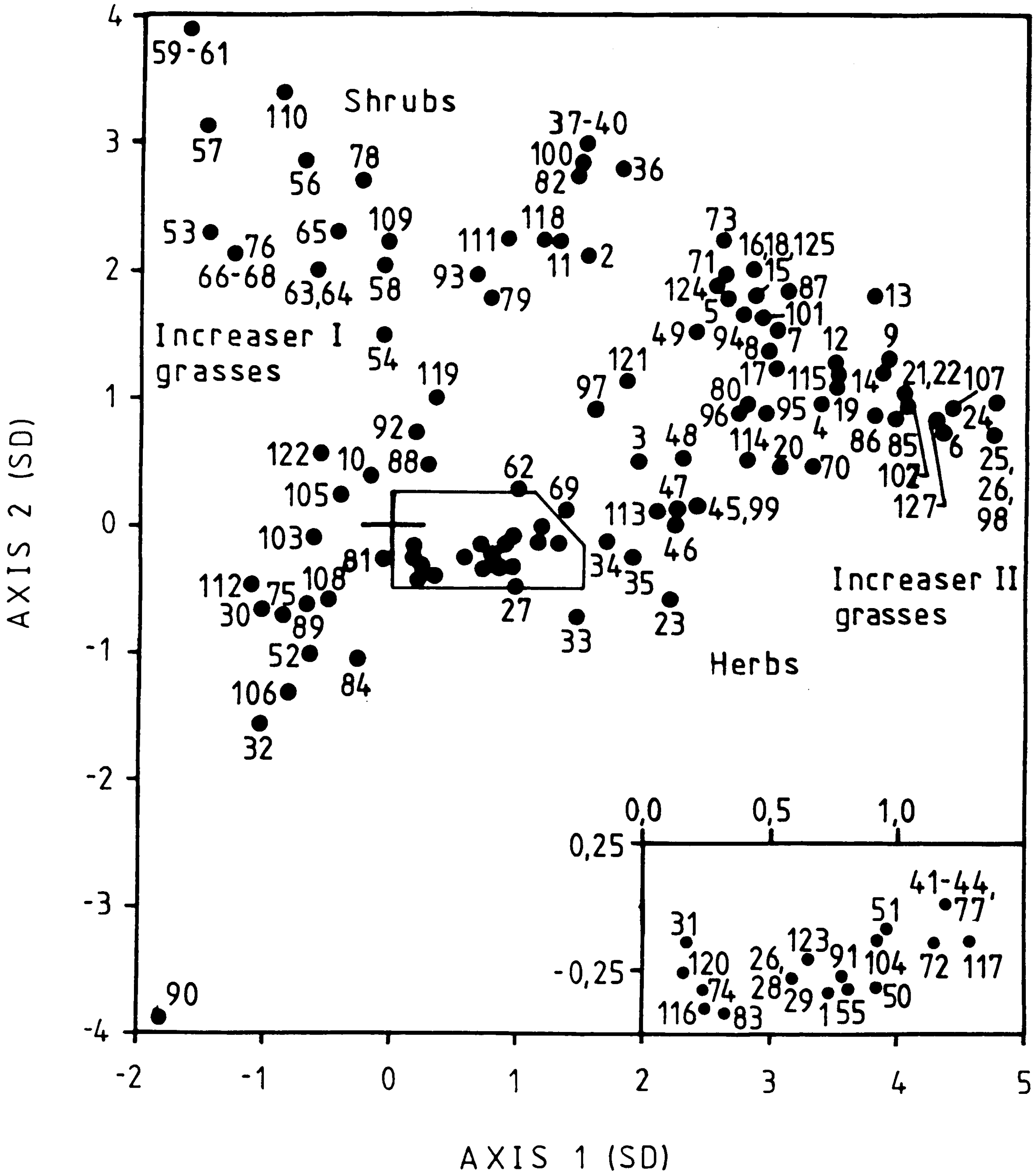

Figure 10 Ordination, by DECORANA, of all plant species from all vegetation samples in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/ March 1987. Eigenvalues for the first and second axes are 0,673 and 0,230 respectively and species numbers relate to Table 7.

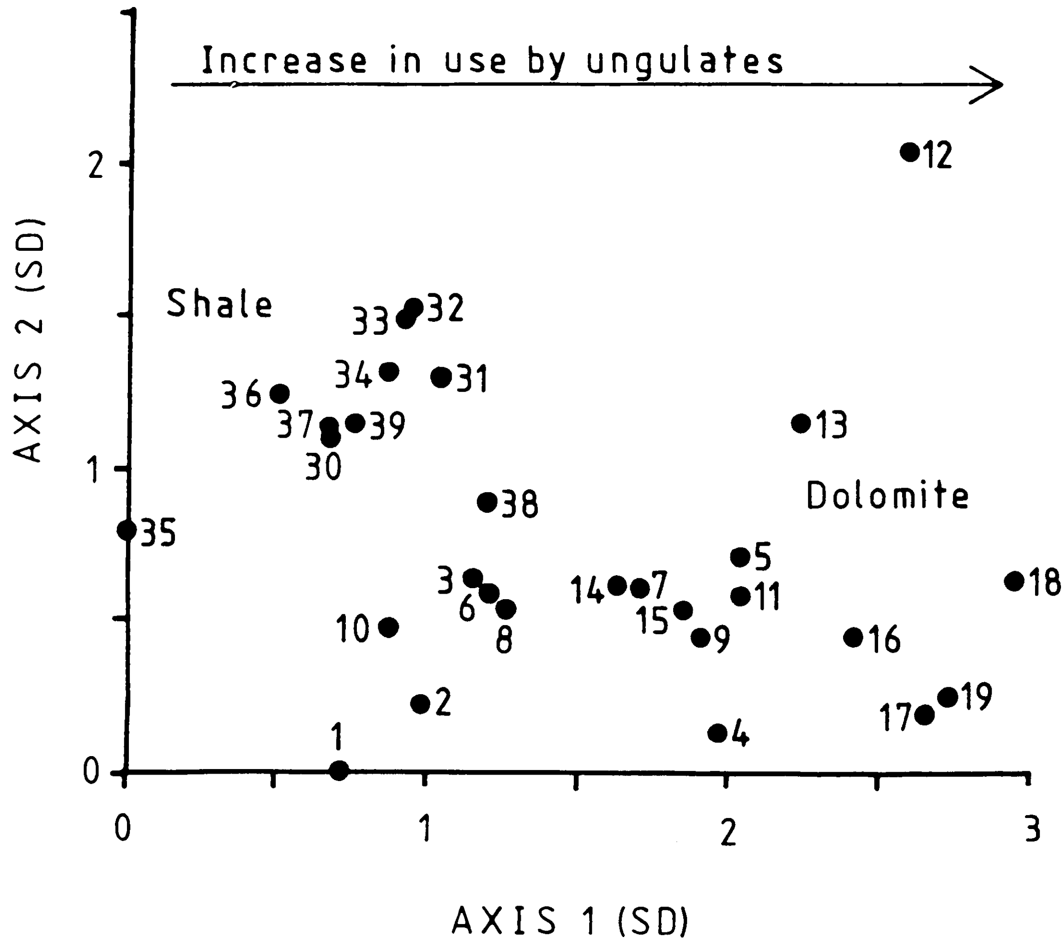

Figure 11 First and second axes of the DECORANA ordination of samples in the three subclimax grassland communities (excluding the old lands community) of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/March 1987. Eigenvalues for the first and second axes are 0,441 and 0,195 respectively and sample numbers are as follows:

1 to 10 = samples in the chert community
11 to 19 = samples in the dolomite community
30 to 39 = samples in the shale community.

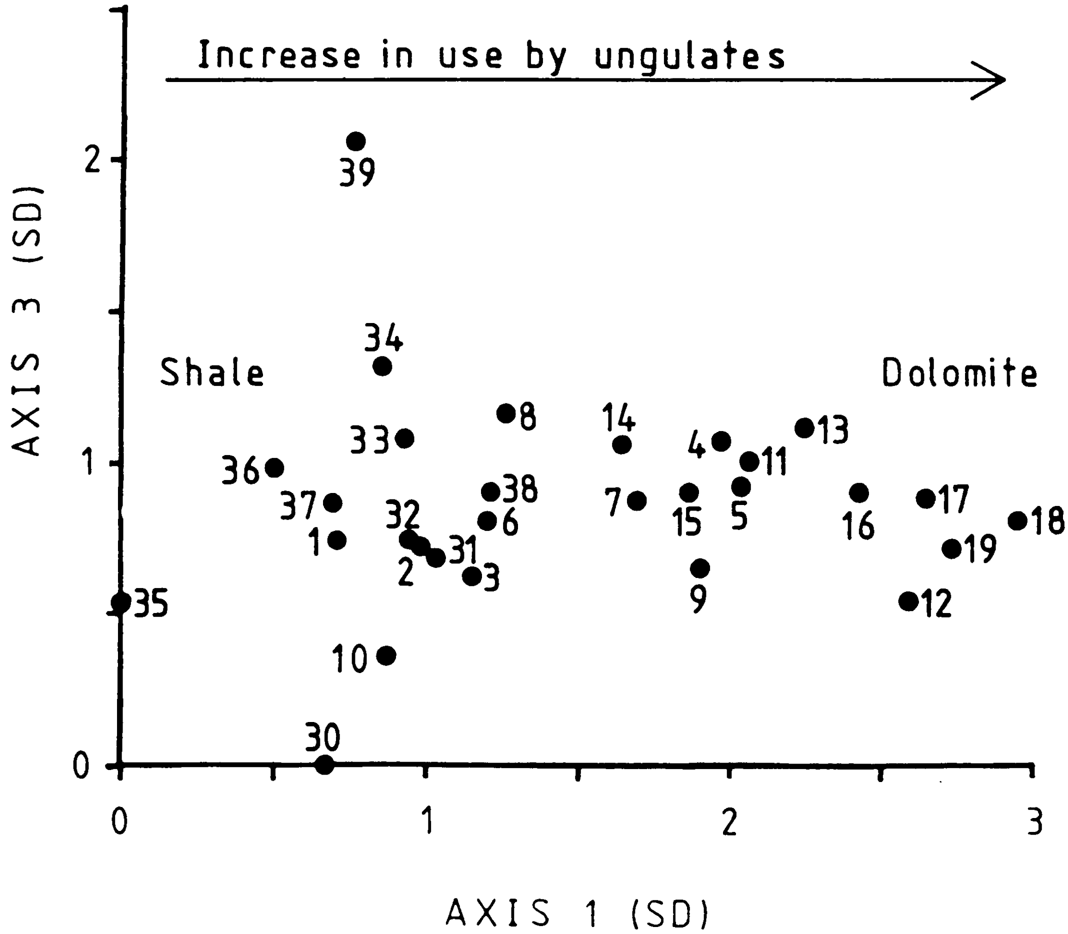

Figure 12 First and third axes of the DECORANA ordination of samples in the three subclimax grassland communities (excluding the old lands community) of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/March 1987. Eigenvalues for the first and third axes are 0,441 and 0,145 respectively and sample numbers are as follows:

1 to 10 = samples in the chert community
11 to 19 = samples in the dolomite community
30 to 39 = samples in the shale community.

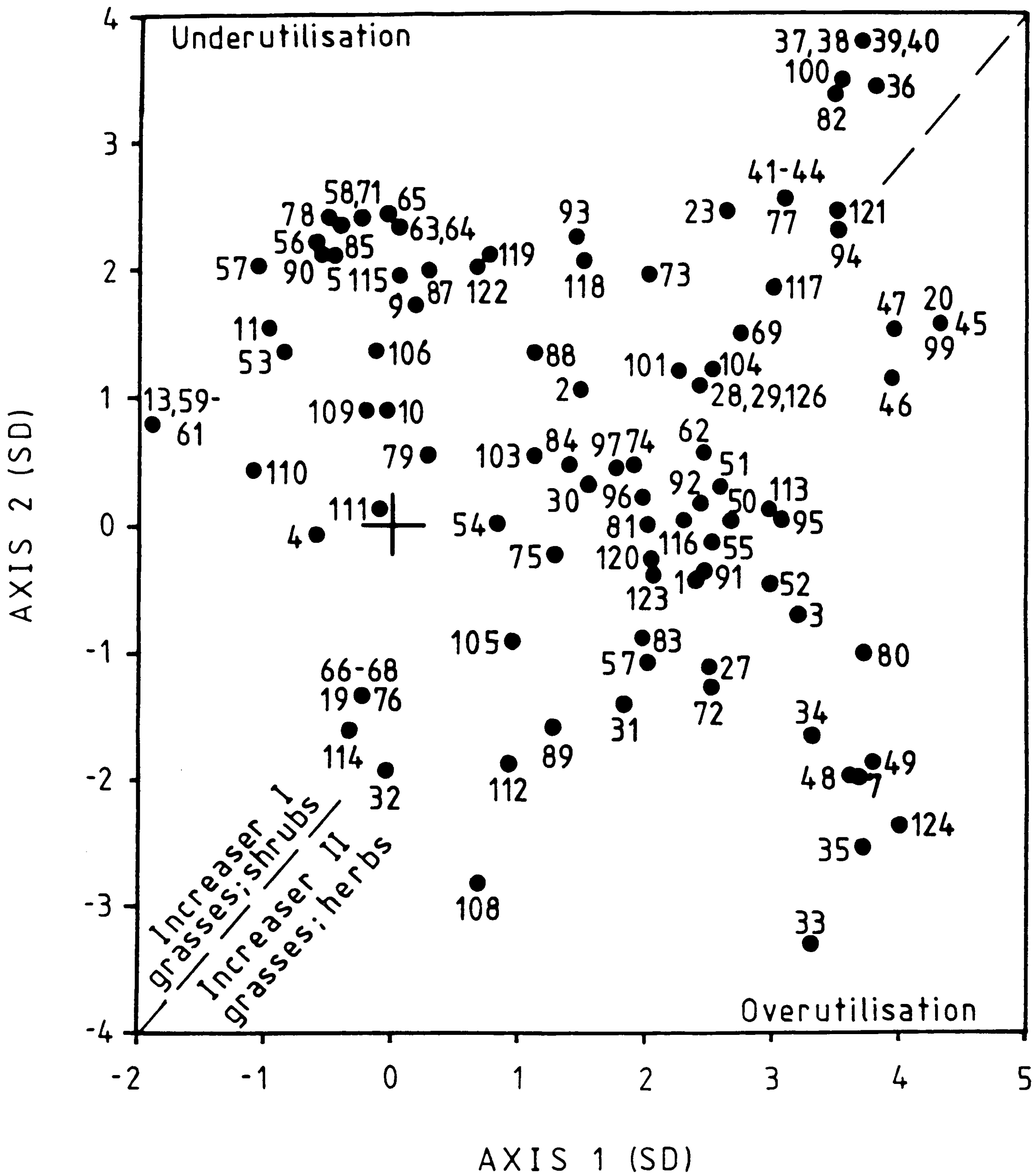

Figure 13 Ordination, by DECORANA, of plant species from samples in the three subclimax grassland communities (excluding the old lands community) of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, using data from the dry-weight ranking ('t Mannetje & Haydock 1963) applied to the samples during February/March 1987. Eigenvalues for the first and second axes are 0,441 and 0,195 respectively and species numbers relate to Table 7.

- Increaser II gradient was repeated in the plot of axes one and three, but the shrub - herb gradient was not as clear as in Figure 13, hence the exclusion of the plot of axes one and three from this discussion of results.

The TWINSPAN classifications of all the samples (Figure 9) and all the samples excluding the old land samples (no Figure here) revealed the dissimilar nature of the four grassland communities. The order of the samples across Figure 9 also reflected the geological gradient of vegetation on chert-poor dolomite to vegetation on shale.

CONCLUSIONS

The four grassland communities found in the study area and which were defined according to Coetzee's (1974a) map, displayed unique features which made them identifiable units, with more or less overlap and definite ecological relationships. The primary dichotomy was the separation of the old lands community from the three subclimax communities. This dichotomy arose from the presence of the strongly differential Hyparrhenia hirta on the old lands. Less strongly differential old land species were Sporobolus fimbriatus and Cymbopogon excavatus.

The individual subclimax communities did not have strongly differential plant species associated with them, however, Brachiaria serrata was strongly affiliated to all three subclimax communities, followed by Diheteropogon amplectens and Senecio venosus. The chert community (on chert-rich dolomite), although geologically intermediate between the shale and dolomite communities (on shale and chert-poor dolomite respectively), was ecologically closer to the dolomite community. This relationship was illustrated by the differential species of more or less strength that typified the chert and dolomite communities. These species were, in decreasing order of differential capability, Sporobolus pectinatus, Bulbostylis burchellii, Digitaria monodactyla, D. tricholaenoides, Parinari capensis and Tristachya rehmannii. On the other hand, the weaker differential species Rhynchelytrum repens, Urelytrum agropyroides and, to a lesser extent, Loudetia simplex were indicative of shale and chert-rich dolomite. Furthermore, Panicum natalense associated the vegetation on shale with the vegetation on chert-poor dolomite.

Of the three subclimax communities, the chert community was more closely allied to the old lands than were either of the other two subclimax communities. This relationship was expressed by the presence in both the chert and old lands communities of Eragrostis curvula, E. chloromelas, Heteropogon contortus and Aristida congesta subsp. congesta, all of which were generally less common in the study area than species such as Andropogon schirensis, Rhynchelytrum nerviglume, Schizachyrium sanguineum, Eragrostis racemosa and Themeda triandra.

Within the old land succession there was a gradient of increasing abundance of Cymbopogon excavatus, Eragrostis chloromelas and Paspalum scrobiculatum and decreasing abundance of Setaria sphacelata, Schizachyrium sanguineum, Andropogon schirensis and Kohautia amatymbica. Other species characteristic of the old lands were the herbaceous exotics Acanthospermum australe, Verbena bonariensis and Erigeron karvinskianus, which occurred in the samples containing higher abundances of Cymbopogon excavatus, Eragrostis chloromelas and Paspalum scrobiculatum; these samples (20-24) were probably at earlier stages of secondary succession than were samples 25 to 29. More evenly distributed through the old lands, and representative thereof, were Hyparrhenia hirta, Eragrostis curvula, Sporobolus fimbriatus, Heteropogon contortus, Cynodon dactylon, Themeda triandra and E. racemosa.

The vegetation on chert-poor dolomite graded into the vegetation on chert-rich dolomite. The chert-poor areas coincided with extensive dolomite outcrop (25-50 % of the land surface) and stone-free, deep soil, while the chert-rich areas tended to lack outcrop (<5 %) and had shallow, stony soil. This geological gradient was reflected in the change of floristics; areas of extreme chert paucity were represented by Fingerhuthia sesleriiformis and numerous uncommon non-grass species adapted to water stress, notably the succulent Kalanchoe thrysiflora, Euphorbia sp. and Unknown 2 (species number 44, Table 7). The geophytic Hypoxis rigidula, Ledebouria revoluta and Anthericum fasciculatum occurred in both the chert-poor areas and the areas of intermediate chert paucity.

With an increase in chert content there was a decrease in the abundance of Aristida sp. 2 (species number 82, Table 7), Triraphis andropogonoides, Stipagrostis zeyheri, Eragrostis curvula, E. chloromelas, Elionurus muticus and Setaria sphacelata. There was a concomitant increase in Digitaria brazzae, Aristida sp. 1 (species number 81, Table 7), Tristachya rehmannii, Monocymbium ceresiiforme, Loudetia simplex, Rhynchelytrum repens, Urelytrum agropyroides, Schizachyrium sanguineum, Andropogon schirensis, R. nerviglume and Brachiaria serrata, while Panicum natalense was most abundant in the middle of the gradient from chert-poor dolomite to chert-rich dolomite. The species common to both the dolomite and the chert communities were Parinari capensis, Digitaria monodactyla, D. tricholaenoides, Bulbostylis burchellii, Sporobolus pectinatus, Bewsia biflora, Diheteropogon amplectens, Trachypogon spicatus, Senecio venosus, Eragrostis racemosa and Themeda triandra.

The underutilised, moribund, shale community which had not been burnt for seven to eight years, was characterised by the generally commoner species such as Diheteropogon amplectens, Elionurus muticus, Trachypogon spicatus, Schizachyrium sanguineum, Andropogon schirensis, Themeda triandra, Rhynchelytrum nerviglume and Eragrostis racemosa which were typically more abundant than in the other communities. Of the less common species, Panicum natalense, Rhynchelytrum repens and Urelytrum agropyroides were typical of the shale community. The shale community also had the lowest number (25) and the lowest percentage dry mass (2,6 %) of non-grass species (Chapter Three, Part Two). A gradient from mesic to xeric conditions existed where the south-facing, relatively mesic sample 39 was characterised by the increased abundance of Brachiaria serrata and Panicum natalense and the singular occurrence of Digitaria diagonalis.

There were thus two important ecological gradients across all four grassland communities. The first was from the undisturbed, natural, subclimax grasslands to the disturbed, subseral, old land succession. The second gradient of note was from the vegetation on shale (including the old lands) to the vegetation on chert-rich dolomite. These two gradients were reflected in the subclimax communities, but along one axis instead of two, where the geological gradient was accompanied by a gradient of ungulate utilisation; the shale community was less utilised while the dolomite community was more utilised, even overutilised in places.

PART TWO

PHYTOMASS AND PRIMARY PRODUCTION

INTRODUCTION

Productivity is perhaps "the most fundamental dimension of an ecosystem" (Whittaker 1970). The importance of primary production is emphasised when productivity and yield are seen in terms of "the total matter available for transformation by livestock" (Koechlin & Menaut 1979). Primary productivity and aerial phytomass determine the amount of fuel present in the community and a measure of the fuel load is a measure of the senescence of the rangeland. Despite the efforts of the International Biological Programme (IBP) from 1964 to 1974, and subsequent work, productivity data for the tropical and subtropical zones of the world, including southern Africa, are lacking in completeness (Rutherford 1978; Grossman 1982). To enable the optimization of animal production in the natural rangelands of southern Africa, reliable primary production estimates are necessary (Grossman 1982).

Definitions

Before discussing phytomass and primary production, certain terms must be defined, and in the present study the following terms were defined according to Grossman (1982): biomass is the oven-dry mass of living plant matter, necromass is the oven-dry mass of dead, attached plant matter and phytomass is biomass plus necromass. Only the component of vegetation available to ungulates, namely the aerial component, was considered in the present study.

The dry mass of vegetation present per unit area at any given time has been described variously as yield, forage yield, herbage yield, herbage mass and dry matter yield. However these terms alone do not imply whether the dry mass of living or dead plant parts, or both, are referred to. Phytomass, by the above definition, implies that both the living and dead plant matter are included. Aerial phytomass in this study refers to the dry mass of living and dead attached plant matter present per unit area above ground level at any given time.

Aerial phytomass determination

Aerial phytomass can be determined by either destructive or non-destructive methods. Direct, destructive methods involve the harvesting of vegetation in numerous square or circular quadrats or rectangular strips, followed by the drying and weighing of the clipped material. Indirect methods include electronic capacitance, visual estimation and height measurement (Bransby, Matches & Krause 1977). Such indirect methods require some harvesting for calibration purposes but more data can be collected per unit time in this way than by the direct methods. This is therefore an advantage if the yield for a large area (of the order of 100+ ha) is to be determined.

One indirect method of determining yield is the disc meter or disc pasture meter. The standard disc recommended, and its operation, is described by Bransby & Tainton (1977). The meter is a disc of 0,458 m diameter (0,16 m^2) and 1,5 kg which slides on a pole. When dropped from a fixed height of 0,60 m above ground level, the disc comes to rest on the sward and the height of the disc above ground level is recorded off the central pole. This procedure is followed as often as is required, but at least 50 of the height readings must be calibrated by clipping all vegetation under the disc. The clipped vegetation is then dried and weighed. From the 50 pairs of height/mass data a linear regression equation of the form Y = a + bX can be calculated where Y is the dry mass (g) per disc, a is the Y-intercept, b is the slope and X is the disc height (mm). By substituting the mean disc height into the equation, the mean dry mass yield per disc can be calculated and the multiplication of Y by six gives a measure of the mean dry mass of vegetation per square metre.

Apart from the application of the disc meter to planted pastures (Phillips & Clarke 1971; Powell 1974; Bransby, et al. 1977) the instrument has been successfully tested and applied in the herbaceous layer of various natural rangeland types in South

Africa (Dankwerts & Trollope 1980; Hardy & Mentis 1985; Trollope & Potgieter 1986). The disc pasture meter is useful for the determination of variables such as the fuel load and yield of large areas of natural rangeland such as in game and nature reserves.

Primary production determination

Gross primary production (GPP) is a measure of the total amount of energy fixed by photosynthesis per unit time and unit area while net primary production (NPP) is a measure of the rate at which energy is stored or incorporated into living tissue. Only a part of the energy that is fixed by plants is converted to biomass, the remainder is lost through respiration (Barbour, Burk & Pitts 1980). Net primary production may thus be defined as the total quantity of fixed photosynthate, less the amount of photosynthate lost through respiration (R): NPP = GPP - R. Whittaker & Marks (1975) discuss in detail various methods for assessing terrestrial plant productivity. Most estimates of aerial net primary production are underestimates because of the difficulty in measuring the loss of photosynthate through the translocation of metabolites below ground level and the removal of biomass by death, decomposition and animal agents, both vertebrate and invertebrate. Animals remove biomass through herbivory, trampling and nest-building.

Because of the difficulty in assessing below-ground productivity, most studies focus on the above-ground component. There are two types of method used for assessing aerial net primary production: non-destructive, non-harvest methods and destructive harvesting. The former tend to be indirect while the latter is the simplest, most commonly used and the most direct approach. Non-destructive methods evaluate net primary production by measuring apparent photosynthesis, usually by the measurement of carbon dioxide (CO_2) uptake, in other words, the measurement of gaseous exchange. A variation of this method is the use of radioisotopes, especially $^{14}CO_2$. Other non-destructive methods used for assessing aerial net primary production are based on the relationship between leaf area index or chlorophyll content of a community and net primary production (Milner & Hughes 1968;

Koechlin & Menaut 1979).

An extensive review by Singh, Lauenroth & Steinhorst (1975) assesses various methods for estimating grassland productivity from harvest data and indicates the dependence of the results upon the methods used. There are two approaches to harvesting aerial plant matter with the purpose of estimating aerial net primary production. Firstly, after initial defoliation by clipping/mowing or burning, herbage regrowth can be recorded by sequential harvesting over the time interval for which a productivity measure is desired. This method is favoured by some, namely Boyd (1949), Du Plessis (1972) and Grossman (1982), as being the most accurate. However, it is well documented that the type, intensity and season of defoliation modifies the structure and production of a community (Tainton 1981a, 1982; Edroma 1984).

The second approach to measuring grassland productivity from harvest data is to measure biomass and/or phytomass at intervals during the year, without initial defoliation. Grossman (1982) defines four basic, measurable parameters of biomass/phytomass that have been used in the past as estimates of aerial net primary production:

1) Peak biomass.
2) Peak phytomass.
3) Biomass increase during a season as determined by either summation of sequential harvest increments or by peak/trough differences.
4) Phytomass increments.

The first two parameters are only applicable to the estimation of annual aerial net primary production, while the last two can be applied to the estimation of aerial net primary production over time periods shorter than one year, such as climatic seasons, months, weeks or even days. Unlike the methods which require initial defoliation, the methods of the second approach to measuring grassland productivity from harvest data (no initial defoliation) have the problem of not accounting for the residual biomass carried over from the previous season (Grossman 1982). Most studies of net primary production in grasslands have been done by the summation of sequential harvest increments and this is the method preferred by Milner & Hughes (1968). This is also the method most used in southern Africa (Rutherford 1978).

Attributes of phytomass and productivity

The changes in biomass during the year follow a similar pattern in all tropical grasslands, with vigorous growth being triggered by the start of the wet season and terminated by severe water stress during the dry season (Singh & Joshi 1979). International Biological Programme (IBP) data from Welgevonden (24°20' S; 26° 51' E) indicate that active growth there starts in October and ends in March when the biomass starts to decline (Singh & Joshi 1979). At Nylsvley (24°29' S; 28°41' E) the growth season is from October to May and the dormant season is from June to September (Grossman 1981). In the tropical grasslands of India, Singh (1973) found that the necromass changes closely follow the changes in biomass during the year. A similar pattern of changes in phytomass may thus also be expected.

As with phytomass, productivity varies markedly during the year. Indian tropical grasslands are characterised by maximum production in the wet growth season and minimum production during the remainder of the year (Singh & Joshi 1979). Primary productivity therefore gives an indication of the vigour of a community or species.

METHODS

Aerial phytomass

Aerial phytomass in the study area was measured using the standard disc pasture meter (Bransby & Tainton 1977) on three occasions, each lasting 30 to 40 days, during the study period:

1) April/May 1986 (late autumn; end of the growth season).
2) September/October 1986 (early spring; end of the dormant season).
3) December/January 1986/87 (early summer; middle of the growth season).

Each sample site (10 per grassland community) was visited once during each of the three harvest periods. On each visit to a site, four transects were positioned such that their intersection was positioned 1 to 1,5 m from the iron stake marking the site, so that the transects were parallel to the basic transects T1 to T4 (Figure 7). The latter were reserved for the dry-weight rank analysis (Chapter Three, Part One). The intersections of these transects marked the positions of the first calibration harvests on each visit. From these central points each of the transects was walked, releasing the disc every three paces until 25 readings of disc height (mm) were obtained in each of the four directions. Disc height was recorded to the nearest 5 mm and vegetation was harvested for calibration purposes half-way along each transect at the thirteenth observation of disc height. Altogether, on each visit to each sample site, 101 disc height readings were taken, of which five were calibrated. A total of 1 010 observations, including 50 harvests, was recorded per grassland community per harvest period. The exception was the dolomite community during summer when only 909 disc readings were made, including 45 calibrations, because one sample site was burnt during October 1986. On each visit to a sample site, it took one-and-a-half to one-and-three-quarter hours to collect 101 disc height readings and five calibration harvests.

A hail storm after noon on 10 December 1986 damaged 17 of the 23 sample sites still to be visited. None of the three remaining old land sites was affected. Three of the four remaining sites on shale were lightly damaged and five of the seven unvisited sites on chert were moderately affected. None of the dolomite sites had been visited and all were heavily damaged. These were left for three weeks until January 1987 while the remaining sites in the other three grassland communities were visited.

The harvested material was clipped at a height of 20 to 40 mm above ground level, placed in paper packets and dried in an oven at 70 to 80 °C for at least 48 hours. The dry mass of the material was then determined to 0,1 g. While in the field, the harvested vegetation was divided into four groups as follows, before being placed in the packets:

HARVESTED VEGETATION

GRASSES — NON-GRASSES

GRASSES: DOMINANT GRASS SPECIES — 'OTHER' GRASS SPECIES

DOMINANT GRASS SPECIES: 'PALATABLE' SPECIES — 'UNPALATABLE' SPECIES

The dominant grasses were defined according to Coetzee (1974a) (Table 6), while the forage values were tentatively based upon various sources, namely Roberts & Fourie (1975), Tainton, Bransby & Booysen (1976), and Grossman (1981; pers. comm.*).

Linear regression analyses were done on the paired disc height/dry mass data for all vegetation, all grasses, 'palatable' grasses, 'unpalatable' grasses, 'other' grasses and non-grasses in each grassland community during each harvest period. The linear regression analyses were done with SAS (SAS Institute Inc. 1982a, b). From these analyses, regression equations were obtained, as well as Pearson's correlation coefficients (r) and coefficients of determination (r^2). The mean dry masses of all vegetation, all grasses, 'palatable' grasses and 'unpalatable' grasses (Y), in g per disc, were calculated by substituting the mean disc height (X), in mm, observed for each grassland community in each harvest period into the relevant equations. Phytomass values, in g per m^2, were obtained by multiplying the Y-values by six. The percentage graminaceous and non-graminaceous phytomass was also determined for each community.

Using the relevant equations, individual disc height values were transformed to total (all vegetation) dry mass values and two tests were done. The first test was done to determine the effect of the number of observations on the resultant mean dry mass

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estimate of all vegetation for each community. This mean was calculated for the following numbers of observations, using the initial regression equations derived from the 50 calibration pairs of each community in each season:

1) 50, being the calibrated observations.
2) 250, 500 and 750, being the observations from one, two and three transects at each sample site, excluding the central points.
3) 1 010, being all observations per community.

A second test was then done to determine the significance of the differences between the communities in each season. The Wilcoxon two-sample test (Sokal & Rohlf 1981) was chosen because there is no assumption of normally distributed data. The test is a non-parametric, rank test that compares the distributions of the samples, the null hypothesis stating that the two samples come from populations having the same distribution (Sokal & Rohlf 1981). The SAS procedure NPAR1WAY performs the Wilcoxon test and gives the probability that the difference in rank sums occurs by chance (Cody & Smith 1985); a low P-value ($P<0,05$) means that the difference is caused less by chance than by reality.

Annual aerial net primary production

The first calibration quadrat of each sample site, which was first harvested during April/May 1986, was subsequently reharvested during September/October 1986, December/January 1986/87 and April 1987. The harvested vegetation was separated in the field into grasses and non-grasses, placed in paper packets and oven-dried at 70 to 80 °C for at least 48 hours. The dry mass of the material was then measured to 0,1 g and annual aerial net primary production was then estimated by summing the three increments. Productivity rates, in g per m^2 per week, during the three interharvest periods, namely winter (April/May 1986 to September/October 1986), late spring (September/October 1986 to December/January 1986/87) and late summer/early autumn (December/January 1986/87 to April 1987), were calculated for each community as well as for all four communities together and the three subclimax communities together (excluding the old lands community). Although this method would yield an inaccurate absolute result because of the small sample number (10 quadrats per community) and the ignorance of biomass losses, the exercise was done purely to detect any changes in productivity during the year and to compare the relative productivity of the different grassland communities.

RESULTS

Aerial phytomass

The linear regression parameters and associated statistics are shown in Tables 11 to 14. Information is given only for the dry mass of all vegetation, all grasses, 'palatable' grasses and 'unpalatable' grasses against disc height because the regressions of the dry mass of 'other' grasses and non-grasses against disc height proved to be consistently non-significant (P>0,05). The regression curves for the dry mass of all vegetation against disc height are shown in Figures 14 to 16. All the r-values for the correlations concerning all vegetation and all grasses were significant (P<0,001) and the coefficients of determination ranged from 0,60 to 0,90 (mean = 0,76) and 0,58 to 0,88 (mean = 0,74) respectively, meaning that 58 to 90 % (mean = 75 %) of both the total phytomass and graminaceous phytomass was explained by disc height (Tables 11 and 12). Although most correlation coefficients obtained for 'palatable' and 'unpalatable' grasses on disc height were significant (P<0,05), the coefficients of determination ranged from 0,01 to 0,63 (mean = 0,32) and 0,04 to 0,73 (mean = 0,28) respectively, meaning that 1 to 73 % (mean = 30 %) of the 'palatable' and 'unpalatable' graminaceous phytomass was explained by disc height (Tables 13 and 14).

From Figure 17, it is apparent that the mean dry mass of all vegetation, as derived from the linear regression equations in late autumn 1986 and early spring 1986, levelled off after 500 readings. In some cases, even 250 readings would have been sufficient. However, in early summer, the estimate of the dry mass of all vegetation only stabilised after 750 disc height readings. The use then of all data collected should give a reliable estimate of phytomass.

Table 11 Parameters and statistics pertaining to the linear regression analysis of dry mass (g) of all vegetation on disc height (mm), using data collected with a standard disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/ January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	LINEAR REGRESSION PARAMETERS AND STATISTICS			
		a	b	r	r^2
Late autumn	Chert	-9,14	0,50	0,89	0,80
	Dolomite	-2,12	0,50	0,86	0,73
	Old lands	5,16	0,34	0,86	0,75
	Shale	3,51	0,44	0,77	0,60
Early spring	Chert	-3,85	0,42	0,82	0,67
	Dolomite	-9,19	0,51	0,95	0,90
	Old lands	-2,14	0,34	0,89	0,80
	Shale	-8,58	0,47	0,88	0,77
Early summer	Chert	-0,97	0,44	0,84	0,71
	Dolomite	-8,64	0,63	0,89 #	0,79
	Old lands	3,94	0,35	0,90	0,82
	Shale	-1,69	0,42	0,88	0,78

+ = P>0,05; * = P<0,05; ** = P<0,01;
otherwise P<0,001

= 43 degrees of freedom;
otherwise degrees of freedom = 48

Table 12 Parameters and statistics pertaining to the linear regression analysis of dry mass (g) of all grasses on disc height (mm), using data collected with a standard disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	LINEAR REGRESSION PARAMETERS AND STATISTICS			
		a	b	r	r^2
Late autumn	Chert	-11,96	0,51	0,89	0,80
	Dolomite	-4,86	0,50	0,85	0,73
	Old lands	3,32	0,35	0,86	0,74
	Shale	2,72	0,43	0,76	0,58
Early spring	Chert	-5,11	0,42	0,82	0,67
	Dolomite	-10,59	0,51	0,94	0,88
	Old lands	-2,89	0,34	0,89	0,80
	Shale	-9,49	0,47	0,88	0,77
Early summer	Chert	-2,42	0,43	0,84	0,71
	Dolomite	-10,37	0,63	0,88 #	0,77
	Old lands	1,59	0,35	0,88	0,78
	Shale	-3,10	0,41	0,88	0,77

+ = P>0,05; * = P<0,05; ** = P<0,01; otherwise P<0,001

= 43 degrees of freedom; otherwise degrees of freedom = 48

Table 13 Parameters and statistics pertaining to the linear regression analysis of dry mass (g) of 'palatable' grasses on disc height (mm), using data collected with a standard disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	LINEAR REGRESSION PARAMETERS AND STATISTICS			
		a	b	r	r^2
Late autumn	Chert	1,47	0,22	0,48	0,24
	Dolomite	-4,70	0,40	0,74	0,54
	Old lands	26,70	-0,02	-0,08 +	0,01
	Shale	3,23	0,22	0,46	0,21
Early spring	Chert	0,25	0,19	0,49	0,24
	Dolomite	-11,14	0,40	0,80	0,63
	Old lands	14,74	0,04	0,15 +	0,02
	Shale	-6,09	0,27	0,61	0,37
Early summer	Chert	-8,60	0,34	0,74	0,54
	Dolomite	-12,46	0,56	0,74 #	0,54
	Old lands	22,51	0,05	0,18 +	0,03
	Shale	-5,10	0,29	0,67	0,45

+ = P>0,05; * = P<0,05; ** = P<0,01; otherwise P<0,001

= 43 degrees of freedom; otherwise degrees of freedom = 48

Table 14 Parameters and statistics pertaining to the linear regression analysis of dry mass (g) of 'unpalatable' grasses on disc height (mm), using data collected with a standard disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	LINEAR REGRESSION PARAMETERS AND STATISTICS			
		a	b	r	r^2
Late autumn	Chert	-15,89	0,28	0,60	0,36
	Dolomite	1,18	0,05	0,24 +	0,06
	Old lands	-25,83	0,36	0,85	0,73
	Shale	-1,45	0,21	0,41 **	0,17
Early spring	Chert	-0,45	0,15	0,39 **	0,15
	Dolomite	0,55	0,09	0,35 *	0,31
	Old lands	-19,06	0,28	0,82	0,66
	Shale	-3,72	0,19	0,40 **	0,16
Early summer	Chert	4,89	0,09	0,26 +	0,07
	Dolomite	0,51	0,03	0,21 +#	0,04
	Old lands	-22,22	0,28	0,76	0,58
	Shale	3,22	0,10	0,29 **	0,09

+ = P>0,05; * = P<0,05; ** = P<0,01;
otherwise P<0,001
= 43 degrees of freedom;
otherwise degrees of freedom = 48

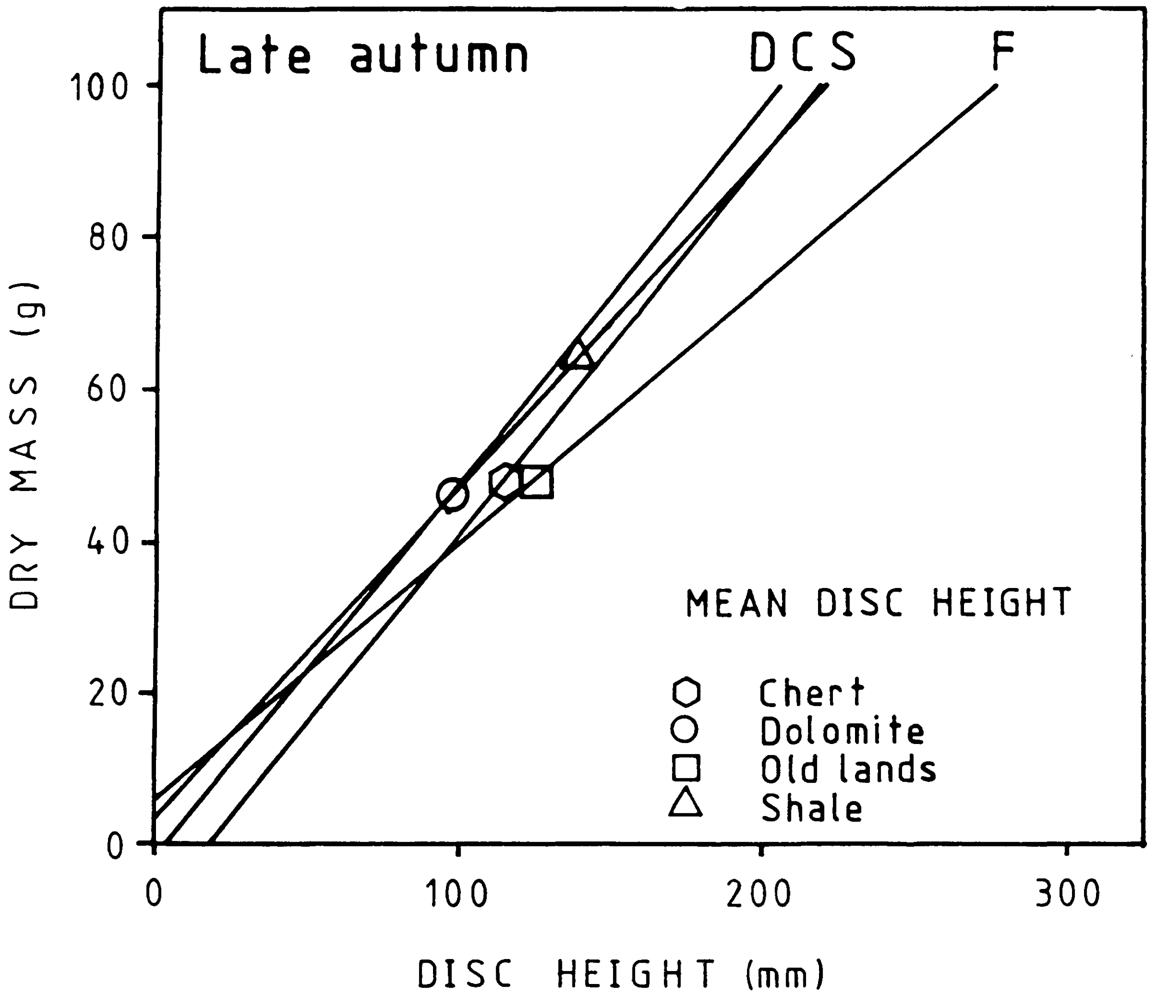

Figure 14 Linear regression curves of dry mass of all vegetation (g) on disc height (mm) for each grassland community (C = chert community, D = dolomite community, F = old lands community, S = shale community) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, derived from the use of the disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986). The position of mean disc height along each curve for each grassland community is indicated by the open symbols. The regression equations are:

for curve D, Y = -9,14 + 0,50X

for curve C, Y = -2,12 + 0,50X

for curve S, Y = 5,16 + 0,34X

for curve F, Y = 3,51 + 0,44X

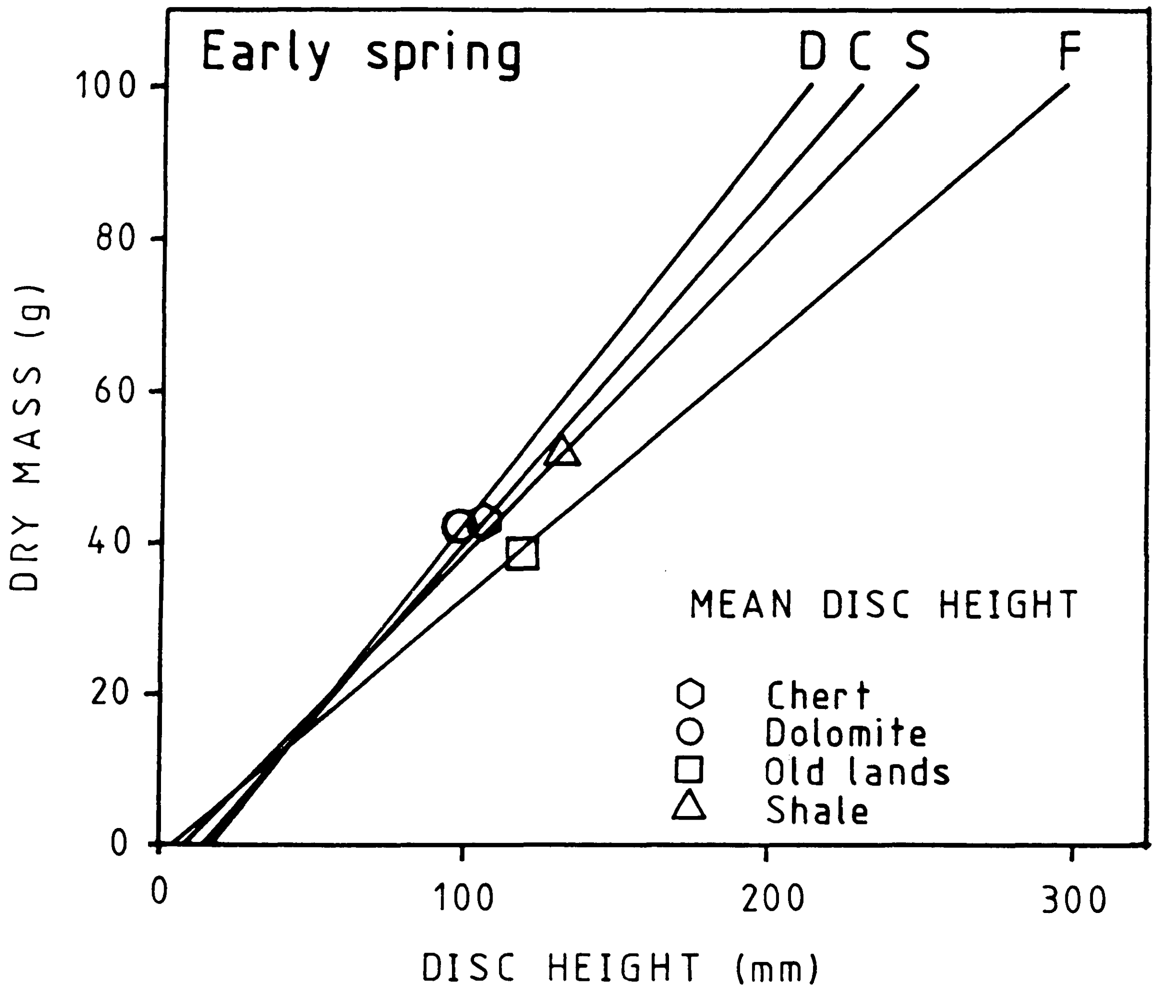

Figure 15 Linear regression curves of dry mass of all vegetation (g) on disc height (mm) for each grassland community (C = chert community, D = dolomite community, F = old lands community, S = shale community) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, derived from the use of the disc pasture meter (Bransby & Tainton 1977) during early spring (September/October 1986). The position of mean disc height along each curve for each grassland community is indicated by the open symbols. The regression equations are: for curve D, $Y = -3,85 + 0,42X$

for curve C, $Y = -9,19 + 0,51X$

for curve S, $Y = -2,14 + 0,34X$

for curve F, $Y = -8,58 + 0,47X$

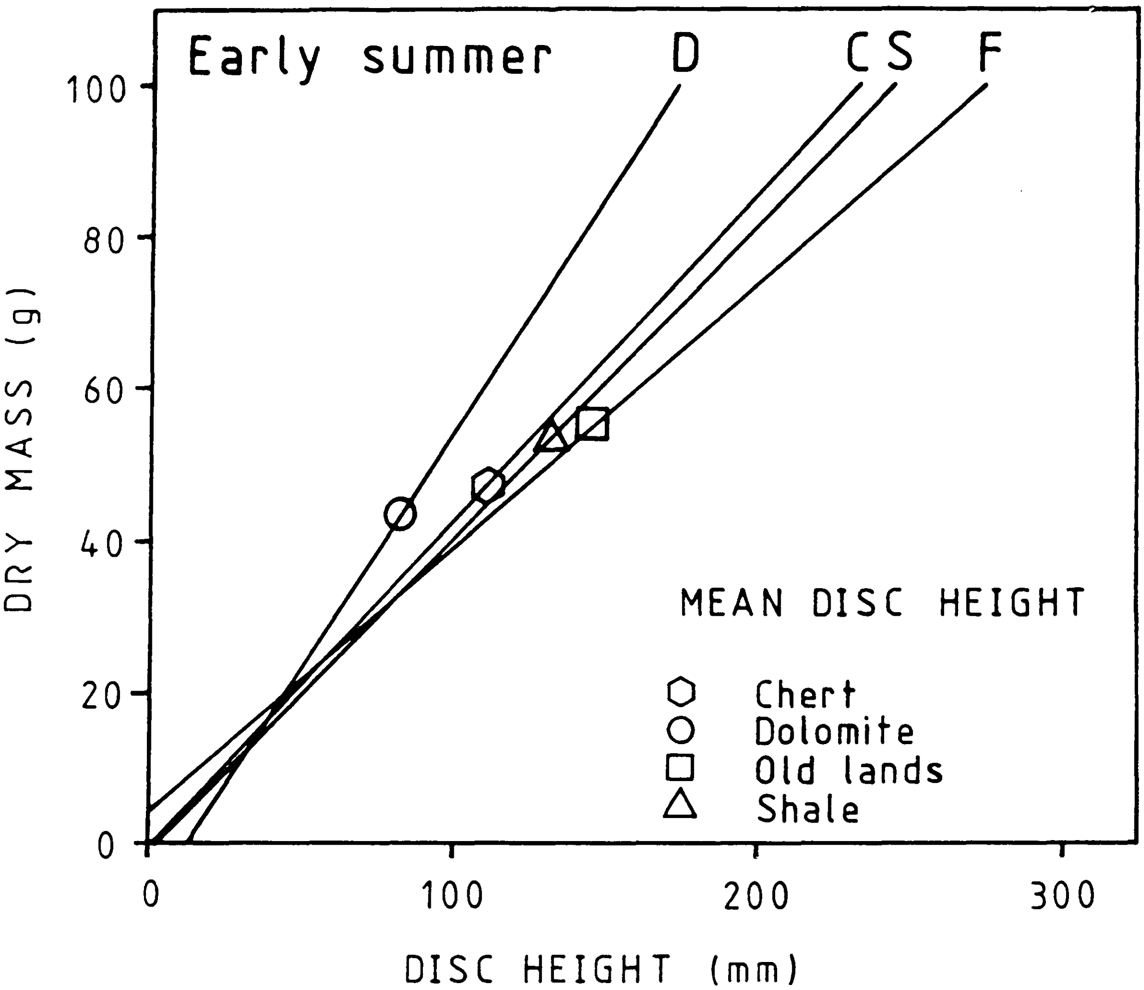

Figure 16 Linear regression curves of dry mass of all vegetation (g) on disc height (mm) for each grassland community (C = chert community, D = dolomite community, F = old lands community, S = shale community) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, derived from the use of the disc pasture meter (Bransby & Tainton 1977) during early summer (December/January 1986/87). The position of mean disc height along each curve for each grassland community is indicated by the open symbols. The regression equations are: for curve D, Y = -0,97 + 0,44X

for curve C, Y = -8,64 + 0,63X

for curve S, Y = 3,94 + 0,35X

for curve F, Y = -1,69 + 0,42X

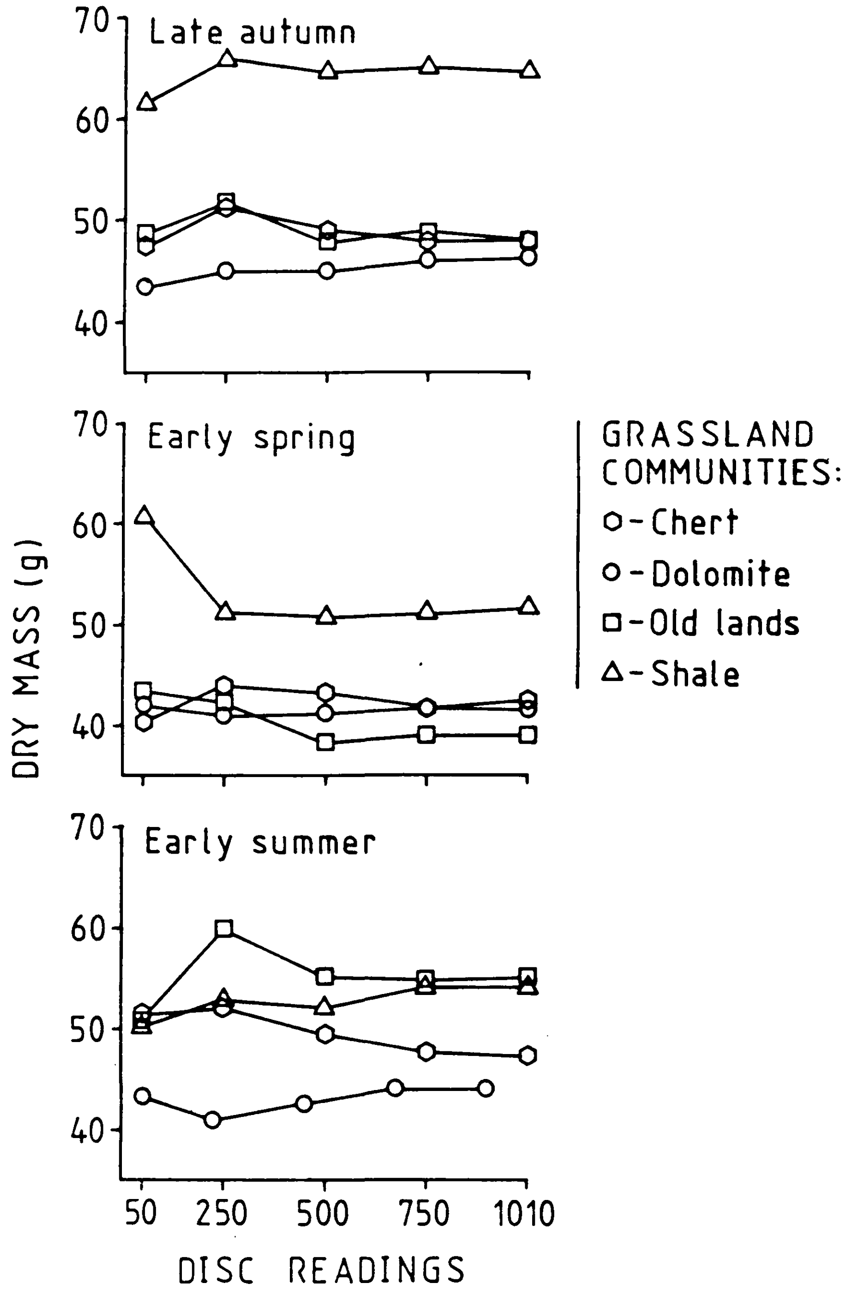

Figure 17 The effect of number of disc readings on mean dry mass of all vegetation (g) derived by the use of the disc pasture meter (Bransby & Tainton 1977) in each grassland community of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87).

The estimates of yield for the different vegetation components (except non-grasses and 'other' grasses) are presented in Tables 15 and 16, while the changes in total phytomass during the year are graphically shown in Figure 18. In all communities, phytomass was lowest in early spring and, except for the old lands, highest in late autumn (Tables 15 and 16). The phytomass of the shale community was generally higher (310-387 $g.m^{-2}$) than the phytomass of the other communities, except in summer when the old lands had the highest phytomass (330 $g.m^{-2}$). The relatively high yield of the shale community was considered to be a result of that vegetation being in a state of senescence, not having been burnt for seven years (Vaughan*, pers. comm.). Unlike the three subclimax communities, the old lands community had more phytomass (+40 $g.m^{-2}$) at the end of the study period than at the beginning and this was possibly due to the harvesting of thatch grass here during 1985. The fact that the dolomite community was the most heavily damaged by hail in December 1986 and was also the most used by ungulates in places (Chapter Four, Part One) probably contributed to the low summer estimate of phytomass here (261 $g.m^{-2}$). Despite the variations in phytomass, grasses consistently made up more than 94 % of the total phytomass in each community (Tables 15 and 16).

The Wilcoxon test was not done on the non-grass and 'other' grass yields because of the non-significant (P>0,05) correlations between dry mass and disc height. Only the differences between the chert and old lands communities during late autumn, and between shale and old lands communities in summer were consistently non-significant (P>0,05). The remainder of the between-community differences were consistently significant (P<0,05) during each season, except for two cases (Tables 17 and 18).

Annual aerial net primary production.

The amount of dry mass produced during the three interharvest periods after the initial harvest in late autumn 1986 is shown in Table 19, while the annual production derived by summing the

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Table 15 Phytomass ($g.m^{-2}$) of all vegetation and of all grasses, and percentage grass by mass as measured with the disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	ALL VEGETATION	ALL GRASSES	PERCENTAGE GRASS
Late autumn	Chert	288	276	96
	Dolomite	278	263	95
	Old lands	287	278	97
	Shale	387	376	97
Early spring	Chert	256	247	97
	Dolomite	251	241	96
	Old lands	230	226	98
	Shale	310	305	98
Early summer	Chert	284	272	96
	Dolomite	261	251	96
	Old lands	330	317	96
	Shale	323	310	96

Table 15 Phytomass ($g.m^{-2}$) of 'palatable' and 'unpalatable' grasses as measured with the disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87) in the four grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HARVEST PERIOD	GRASSLAND COMMUNITY	'PALATABLE' GRASSES	'UNPALATABLE' GRASSES
Late autumn	Chert	161	96
	Dolomite	204	#
	Old lands	#	116
	Shale	206	167
Early spring	Chert	130	95
	Dolomite	173	58
	Old lands	#	86
	Shale	174	126
Early summer	Chert	176	#
	Dolomite	206	#
	Old lands	#	114
	Shale	203	101

= non-significant correlation between dry mass and disc height (P>0,05)

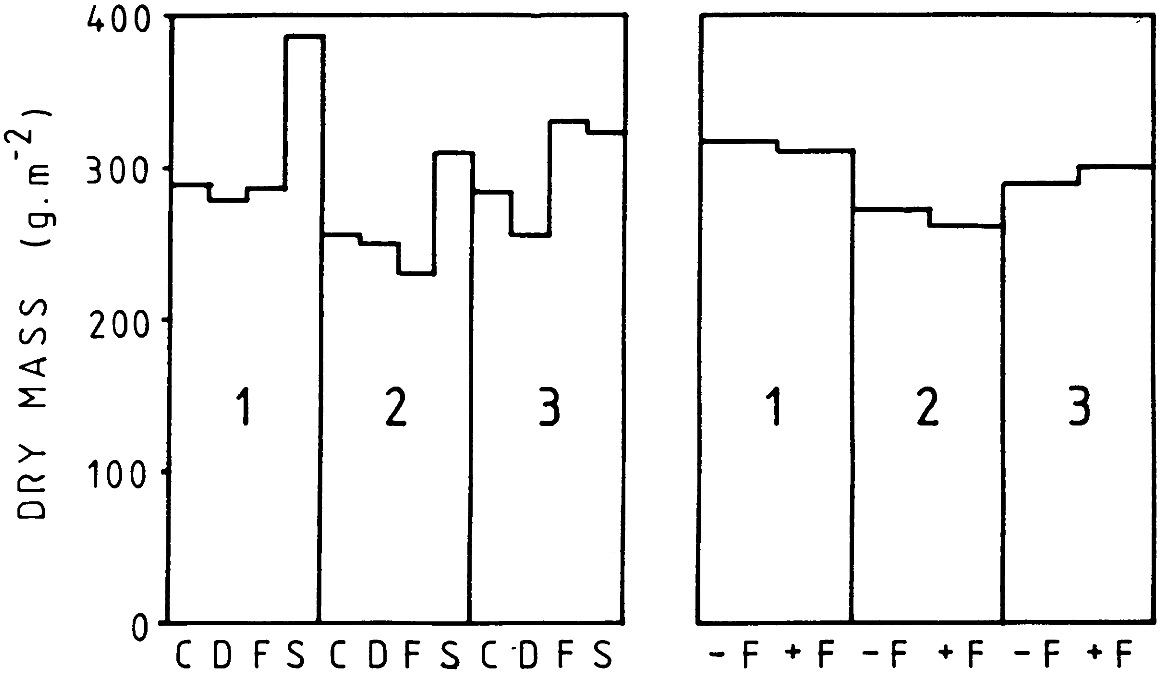


Figure 18 Mean dry mass of all vegetation ($g.m^{-2}$) for each grassland community (C = chert community, D = dolomite community, F = old lands community and S = shale community), all grassland communities including the old lands community (+F) and the three subclimax communities excluding the old lands community (-F) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as determined by the disc pasture meter (Bransby & Tainton 1977) during 1) late autumn (April/May 1986), 2) early spring (September/October 1986) and 3) early summer (December/January 1986/87).

Table 17 Z-values of the Wilcoxon two-sample test (Sokal & Rohlf 1981) done to compare the grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, in terms of phytomass ($g.m^{-2}$) of all vegetation and of all grasses, as determined with the disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87).

HARVEST PERIOD	PAIRS OF GRASSLAND COMMUNITIES COMPARED	VEGETATION COMPONENT IN TERMS OF WHICH COMPARISON WAS MADE	
		All vegetation	All grasses
Late autumn	Chert/dolomite	2,8474 **	2,8474 **
	Chert/old lands	1,2131 +	0,5864 +
	Chert/shale	15,0123 ***	15,2299 ***
	Dolomite/old lands	-1,2744 +	-2,3194 *
	Dolomite/shale	16,1080 ***	16,5641 ***
	Old lands/shale	15,7618 ***	15,7838 ***
Early spring	Chert/dolomite	2,4252 *	2,4376 *
	Chert/old lands	6,1819 ***	5,4089 ***
	Chert/shale	-8,5377 ***	-9,1237 ***
	Dolomite/old lands	3,2557 **	2,8008 **
	Dolomite/shale	-9,5729 ***	-9,9287 ***
	Old lands/shale	12,8228 ***	12,6988 ***
Early summer	Chert/dolomite	-4,0980 ***	-3,9653 ***
	Chert/old lands	-7,5030 ***	-7,1325 ***
	Chert/shale	-6,7656 ***	-6,7656 ***
	Dolomite/old lands	10,2865 ***	-9,9157 ***
	Dolomite/shale	-9,7932 ***	-9,6747 ***
	Old lands/shale	0,6035 +	0,4135 +

+ = P>0,05; * = P<0,05; ** = P<0,01; *** = P<0,001

Table 18 Z-values of the Wilcoxon two-sample test (Sokal & Rohlf 1981) done to compare the grassland communities of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal in terms of phytomass ($g.m^{-2}$) of 'palatable' and of 'unpalatable' grasses, as determined with the disc pasture meter (Bransby & Tainton 1977) during late autumn (April/May 1986), early spring (September/October 1986) and early summer (December/January 1986/87).

HARVEST PERIOD	PAIRS OF GRASSLAND COMMUNITIES COMPARED	VEGETATION COMPONENT IN TERMS OF WHICH COMPARISON WAS MADE	
		'Palatable' grasses	'Unpalatable' grasses
Late autumn	Chert/dolomite	-6,5785 ***	#
	Chert/old lands	#	1,0486 +
	Chert/shale	13,3781 ***	19,9531 ***
	Dolomite/old lands	#	#
	Dolomite/shale	3,3389 ***	#
	Old lands/shale	#	14,4826 ***
Early spring	Chert/dolomite	-7,1863 ***	21,6126 ***
	Chert/old lands	#	7,4370 ***
	Chert/shale	12,1653 ***	11,9174 ***
	Dolomite/old lands	#	-2,5734 *
	Dolomite/shale	-2,3539 *	26,6573 ***
	Old lands/shale	#	13,0711 ***
Early summer	Chert/dolomite	5,0207 ***	#
	Chert/old lands	#	#
	Chert/shale	-6,9803 ***	#
	Dolomite/old lands	#	#
	Dolomite/shale	-0,8602 +	#
	Old lands/shale	#	0,8758 +

= non-significant correlation (P>0,05) between dry mass and disc height in at least one of a pair of grassland communities being compared

+ = P>0,05; * = P<0,05; ** = P<0,01; *** = P<0,001

Table 19 Dry matter plant production ($g.m^{-2}$) of permanent quadrats in each of the four grassland communities, the three subclimax communities (excluding the old lands community) and all four grassland communities together in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during winter (April/May to September/October 1986), late spring (September/October 1986 to December/January 1986/87) and late summer/early autumn (December/January 1986/87 to April 1987), as measured by direct clipping.

INTER-HARVEST PERIOD	GRASSLAND COMMUNITY	NUMBER OF QUADRATS CLIPPED	MEAN INTERVAL BETWEEN HARVESTS (WEEKS)#	MEAN DRY MASS ($g.m^{-2}$)		
				Grasses	Non-grasses	Total
Winter	Chert	10	20,0	5,9	0,6	6,5
	Dolomite	10	20,4	5,6	1,0	6,6
	Old lands	10	19,4	5,1	0,2	5,3
	Shale	10	19,6	5,7	2,6	8,3
	Subclimax	30	20,0	5,7	1,4	7,1
	All	40	19,9	5,6	1,1	6,7
Late spring	Chert	10	12,7	54,2	11,3	65,5
	Dolomite	9	14,0	61,3	10,4	71,7
	Old lands	10	12,6	96,5	18,2	114,7
	Shale	10	12,1	60,4	18,7	79,1
	Subclimax	29	12,9	58,6	13,5	72,1
	All	39	12,9	68,1	14,7	82,8
Late summer/ early autumn	Chert	10	17,9	82,6	12,5	95,1
	Dolomite	9	14,9	68,5	15,1	83,6
	Old lands	10	19,4	180,1	8,8	188,9
	Shale	10	19,6	153,3	13,3	166,6
	Subclimax	29	17,5	101,5	13,6	115,1
	All	39	18,0	121,1	12,4	133,6

= because the interval between consecutive harvests varied among quadrats, a mean interval was calculated for each community

increments appears in Table 20. These values should be taken only as indicators of trends because of the ignorance of biomass loss and small sample numbers (10 per community). The effect of sample number on the phytomass estimate is shown in Table 21, which reveals that the phytomass estimates derived from the direct clipping of the 10 permanent quadrats deviated by up to 17 % from those estimates derived from all data obtained with the disc pasture meter during the initial harvest.

From Table 19, the productivity rates for grasses and non-grasses during each interharvest period were calculated (Figure 19), as well as the proportion of graminaceous and non-graminaceous phytomass present in each grassland community (Figure 20). Because of the inaccuracy of the phytomass estimates based on the permanent quadrats, the estimates of production rates should not be regarded as absolutely representative of each community, but should be regarded only as trend indicators. The proportions of grass to non-grass phytomass can, however, be taken as reliable because the percentages derived from all data and from the permanent quadrats only, are similar (Table 22).

After the first major rainfalls of 23 mm and 34 mm on 16 and 19 October 1986 respectively, one week after completing the early spring harvest, the productivity of all vegetation increased and for the following three months the productivity was estimated to be 5,1 to 9,1 $g.m^{-2}.week^{-1}$ depending on the community (Figure 19). During the five months prior to the early spring harvest, the productivity was only 0,3 to 0,4 $g.m^{-2}.week^{-1}$ and for the rest of the summer and early autumn (mid-January 1987 to the end of April 1987) the production rate was 5,3 to 9,7 $g.m^{-2}.week^{-1}$, although most of this production probably occurred before March 1987. The above productivity rates should be regarded with reservation as no account was taken of biomass loss. However, because the permanent quadrats were small (0,16 m^2) and few (10 per community) there was probably little chance of them being found by ungulates who might have exploited the new growth.

At initial harvesting in late autumn 1986 grasses constituted 94,6 to 97,2 % of the total phytomass in the permanent quadrats, conforming to the grass proportion of 95,5 to 97,0 % derived by

Table 20 Dry matter plant production ($g.m^{-2}$) of permanent quadrats in each of the four grassland communities, the three subclimax communities (excluding the old lands community) and all four grassland communities together in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, from the first harvest in April/May 1986 to the fourth harvest in April 1987, as measured by direct clipping.

GRASSLAND COMMUNITY	NUMBER OF HAR-VESTS	NUMBER OF QUADRATS CLIPPED	MEAN INTERVAL BETWEEN FIRST & LAST HAR-VEST (WEEKS)#	MEAN DRY MASS ($g.m^{-2}$) Grasses	Non-grasses	Total
Chert	4	10	50,6	142,7	24,4	167,1
Dolomite	4	10 *	49,3	135,4	26,5	161,9
Old lands	4	10	51,4	281,7	27,2	308,9
Shale	4	10	51,3	219,4	34,6	254,0
Subclimax	4	30 *	50,4	165,8	28,5	194,3
All	4	40 *	50,8	194,8	28,2	223,0

= because the interval between consecutive harvests varied among quadrats, a mean interval was calculated for each community

* = reduced by one after the second harvest

Table 21 Mean dry mass (g) of all vegetation per quadrat for the permanent quadrats and all quadrats in each grassland community of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as measured during the first harvest in April/May 1986 by direct clipping of the permanent quadrats and by the disc pasture meter (Bransby & Tainton 1977) for all quadrats.

GRASSLAND COMMUNITY	MEAN DRY MASS (g) OF ALL VEGETATION			
	Permanent quadrats (n=10)	All quadrats (n=1 010)	Difference between mean dry masses (g)	Percentage difference between mean dry masses#
Chert	46,3	48,0	-1,7	3,5
Dolomite	42,2	46,3	-4,1	8,9
Old lands	39,8	47,9	-8,1	16,9
Shale	75,8	64,6	11,2	17,3

= difference between mean dry masses * 100 / mean dry mass of all vegetation for all quadrats

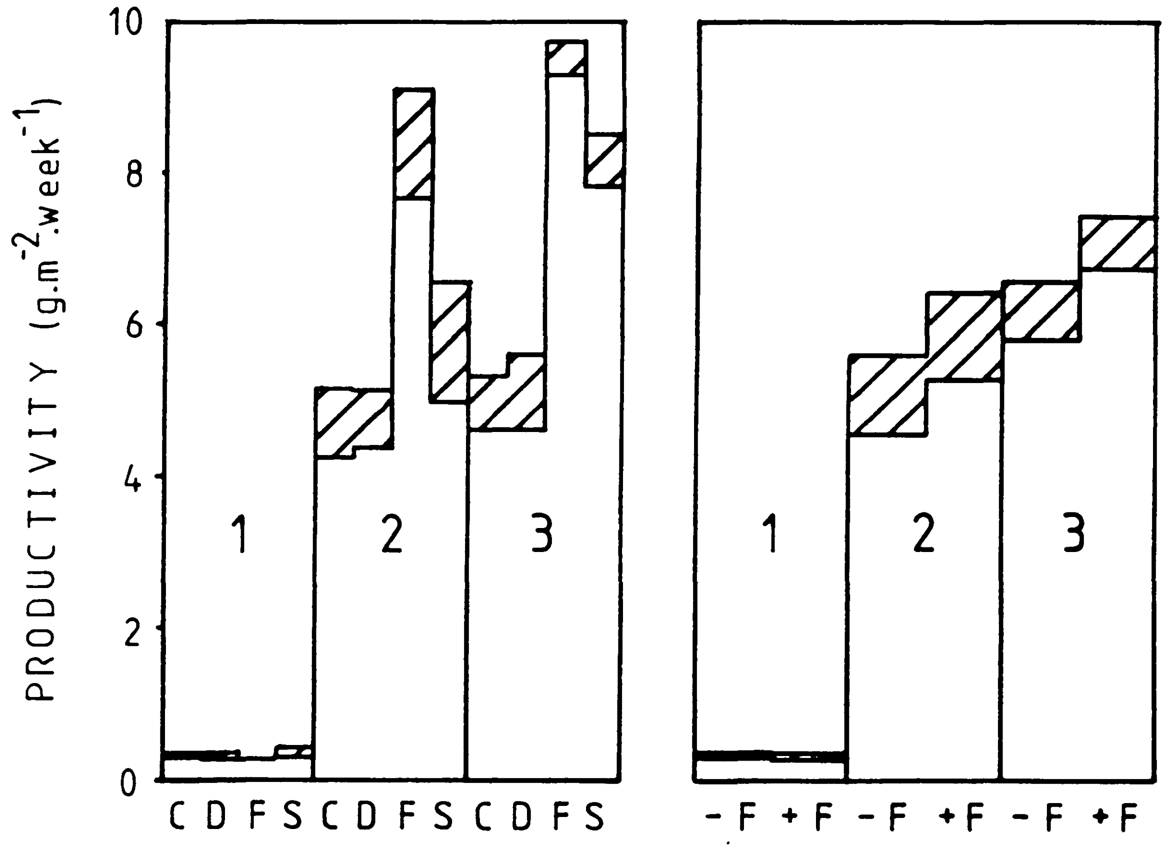


Figure 19 Production rate ($g.m^{-2}$.week) of grasses (open) and non-grasses (hatched) for each grassland community (C = chert community, D = dolomite community, F = old lands community and S = shale community), all grassland communities including the old lands community (+F) and the three subclimax communities excluding the old lands community (-F) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during 1) winter (April/May 1986 to September/October 1986), 2) late spring (September/October 1986 to December/January 1986/87) and 3) late summer/early autumn (December/January 1986/87 to April 1987), as determined by periodic hand-clipping of permanent quadrats.

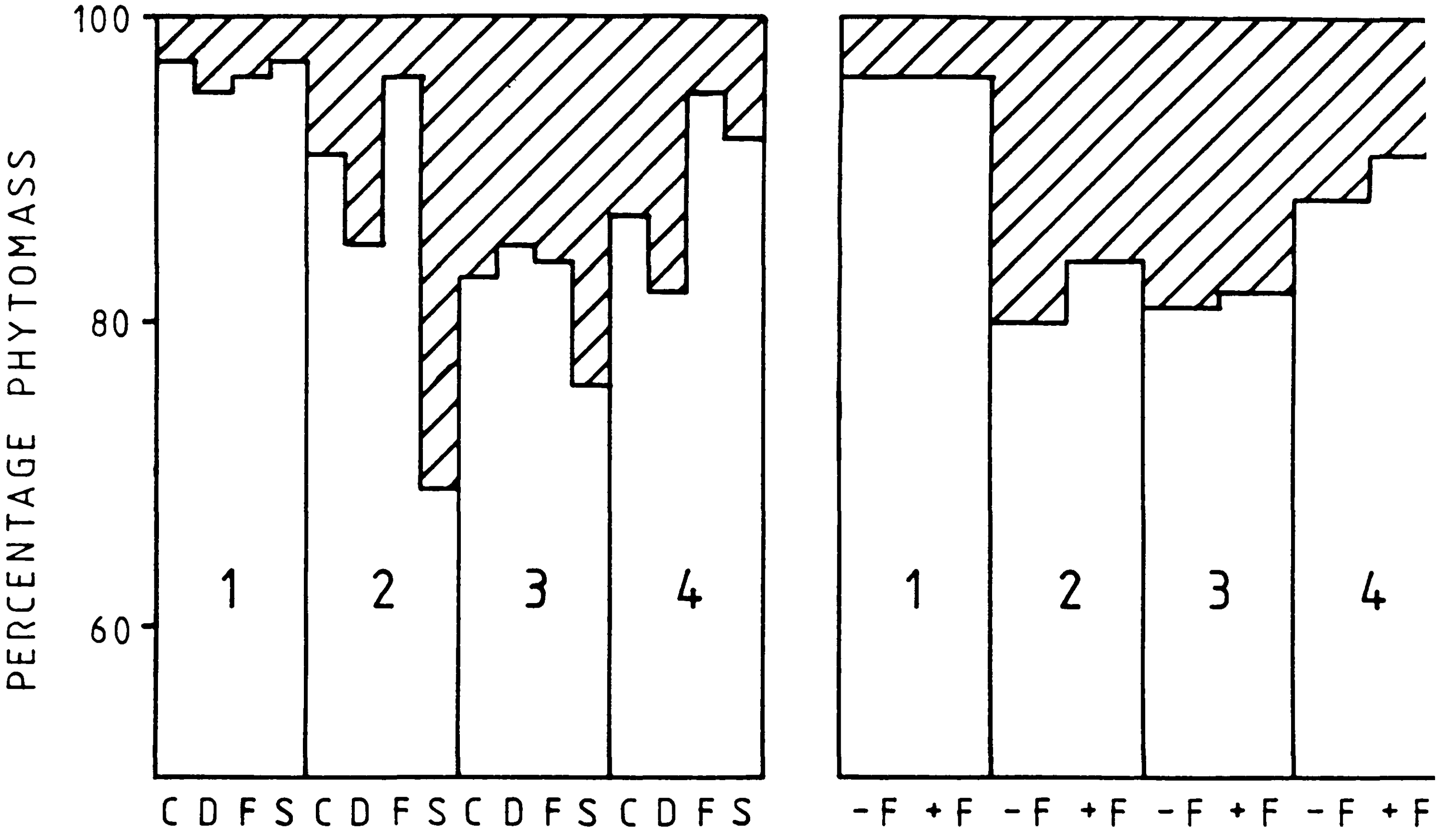


Figure 20 Percentage non-graminaceous (hatched) and graminaceous (open) phytomass present on periodically harvested permanent quadrats in each grassland community (C = chert community, D = dolomite community, F = old lands community and S = shale community), all grassland communities including the old lands community (+F) and the three subclimax communities excluding the old lands community (-F) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during 1) late autumn (April/May 1986), 2) early spring (September/October 1986), 3) early summer (December/January 1986/87) and again in 4) late autumn (April 1987), as determined by hand-clipping.

Table 22 Mean percentage grass by mass for the permanent quadrats and all quadrats in each grassland community of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as measured during the first harvest in April/May 1986 by direct clipping of the permanent quadrats and by the disc pasture meter (Bransby & Tainton 1977) for all quadrats.

GRASSLAND COMMUNITY	MEAN PERCENTAGE GRAMINACEOUS PHYTOMASS	
	Permanent quadrats (n = 10)	All quadrats (n = 1 010)
Chert	97,0	95,8
Dolomite	95,5	94,6
Old lands	96,0	96,9
Shale	96,6	97,2

using the disc pasture meter (Table 22). Whereas during the study period the proportion of grass, as measured by the disc pasture meter, remained relatively constant in each community (Table 15), the periodically harvested permanent quadrats showed a decrease in the percentage grass phytomass to 69 to 96 % (mean = 84 %) of the total phytomass at the first reharvest (or second harvest) during early spring 1986 (Figure 20). Thereafter, the graminaceous phytomass gradually constituted more of the total phytomass until the third reharvest (or fourth harvest) in April 1987 when grasses made up 82 to 92 % (mean = 91 %) of the total phytomass (Figure 20).

CONCLUSIONS

Aerial phytomass

The disc pasture meter proved to be an effective instrument for indirectly assessing the herbaceous phytomass of natural rangeland in the study area. Once the relationships between disc height and dry mass have been determined under various rangeland conditions, the disc meter can be used effectively for assessing the productivity of extensive natural rangeland whenever desired and when more expensive techniques are not feasible. It is suggested from the present data that 500 observations of disc height are required in grasslands, although this minimum may depend on the condition of the vegetation. Previous studies recommend far fewer observations, namely 100 (Hardy & Mentis 1985; Trollope & Potgieter 1986).

The disc pasture meter was really only effective for estimating the phytomass of total herbaceous-layer vegetation as well as the phytomass of grasses only. On the other hand, the disc pasture meter was not useful in determining the phytomass of minor components of the range such as non-grasses and 'other' grasses. Total phytomass ranged from 251 to 387 $g.m^{-2}$ (2 510 - 3 870 $kg.ha^{-1}$) depending on the season and community; the lowest values were recorded in early spring and the highest were recorded in late autumn of the study period. The above-mean annual rainfall of 773 mm recorded in the study area during the study period, should be borne in mind when considering the results of this study and when comparing them with other studies. Singh & Joshi (1979) give an annual phytomass range of 429 to 616 $g.m^{-2}$ for Welgevonden (24° 20' S; 26°51' E), however Rutherford (1978) quotes a value of 350 $g.m^{-2}$ for three years of accumulated production on ungrazed rangeland at Frankenwald, north of Johannesburg where annual rainfall is 750 mm. The observed aerial phytomass figures for the study area therefore appear to be reasonable estimates, according to Rutherford (1978).

The differences in phytomass between communities and within seasons were generally significant ($P<0,05$), however the yields of the chert and old lands communities during autumn 1986 were not significantly different ($P>0,05$), as in the case of the shale and old lands communities in summer 1986/87 (Tables 17 and 18). The senescent nature of the shale community, and thus the higher fuel load, gave the shale community the highest values of total phytomass during late autumn and early spring of 1986 (387 and 310 $g.m^{-2}$ respectively).

Annual aerial net primary production

When converted to daily growth rates in order to compare the productivity figures for the study area with those quoted by Koechlin & Menault (1979), the productivity of 0,7 to 1,4 $g.m^{-2}.day^{-1}$ during the growth season may be compared with the figures of 3,2 to 4,3 $g.m^{-2}.day^{-1}$ during the two to three months of maximum development in Panicum maximum pastures experiencing 560 mm rain per year in Kenya and occassionally high rates of 7,0 $g.m^{-2}.day^{-1}$ for Themeda triandra during maximum growth and under 700 mm annual rainfall. Koechlin & Menault (1979) also give production rates for Upper Volta (1050 mm rain per year) of more than 1,1 $g.m^{-2}.day^{-1}$ in the wet season and 0,3 $g.m^{-2}.day^{-1}$ at the start of the dry season. The relatively low production rates obtained during the present study could well be an effect of the timing of the harvests.

What was emphasised by the exercise however, was the 10- to 20-fold increase in the production rate initiated by, amongst other factors, the spring rains. Another interesting result was the higher rate of plant production of the old lands during the growth season in comparison with the other grassland communities. It is widely known that old-field or early stage successions are characterised by higher productivity than climax, or in the present case subclimax, communities (Barbour, et al. 1980).

From the permanent quadrats, annual aerial net primary production estimates of 162 to 309 (mean = 223) $g.m^{-2}.yr^{-1}$ were obtained, while the use of peak phytomass as an estimate of annual aerial net primary production yielded results of 278 to 387 (mean = 321) $g.m^{-2}.yr^{-1}$. Murphy (1975) quotes total annual net primary production estimates of 520, 150 and 170 $g.m^{-2}.yr^{-1}$ for Namibian grasslands, and grasslands around Pretoria (25°54' S; 28°16' E) and the Springbok Flats (29°35' S; 17°55' E) respectively. These figures were derived from above-ground estimates and include 40 % for the unmeasured, below-ground parts. Lauenroth (1979) gives figures for aerial net primary production of 60 to 550 (mean = 200) $g.m^{-2}.yr^{-1}$ for grassland sites which are climatically similar to the study area. Rutherford (1978) quotes aerial net primary production estimates of 100 to 190 $g.m^{-2}.yr^{-1}$ for grasslands around Pretoria where mean annual rainfall is 700 mm, and 216 $g.m^{-2}.yr^{-1}$ for Frankenwald (750 mm rain per year). In more general terms, Rutherford and Westfall (1986) give an estimate of 100 to 600 $g.m^{-2}.yr^{-1}$ for the drier to wetter areas, respectively, in the grassland biome of southern Africa.

The estimates of annual aerial net primary production derived from the periodic harvesting of permanent quadrats are closer to figures given in the literature than are the estimates derived from peak phytomass. The first estimates mentioned are therefore probably more realistic than the last and the former are, in fact, generally higher than published information for the Pretoria-Johannesburg region, possibly due to the above-mean annual rainfall experienced during the study period.

CHAPTER FOUR: THE UNGULATE SURVEY

The only previous study of range use by ungulates on Jack Scott Nature Reserve was done by Mason (1973) who covered the whole reserve each month during 1971/72. A grid of 200 x 200 m pixels was used by Mason (1973) and all sightings of marked animals were recorded by pixel. The area was classified into habitat types and this variable, together with geology and slope, was recorded for the locality of each sighting. The effect of range burning on ungulate distribution was expressed in terms of the comparative frequency of sightings on burnt and unburnt range and habitat utilisation was defined by the percentage frequency of sightings of each ungulate type in the respective habitat types. All ungulate types present at the time were studied.

Other studies of ungulates on Jack Scott Nature Reserve have been done by Novellie (1975) and Van Aarde & Skinner (1975); both behavioural studies. The former work is a comparative social behaviour study of springbok and blesbok, while the latter is a feeding behaviour study of giraffe.

Of the 10 ungulate types observed during the present study, nine were amongst those observed by Mason (1973). Only the sable antelope were not present at the time of Mason's study. The 10 ungulate types studied are listed below, according to Smithers (1983):

PERISSODACTYLA

EQUIDAE

Equus burchelli (Gray, 1824) - Burchell's zebra

ARTIODACTYLA

GIRAFFIDAE

Giraffa camelopardalis (Linnaeus, 1758) - giraffe

BOVIDAE

Alcelaphinae:

Connochaetes gnou (Zimmerman, 1780) - black wildebeest

Alcelaphus buselaphus (Pallas, 1766) - red hartebeest

Damaliscus dorcas phillipsi Harper, 1939 - blesbok

Antilopinae:

Antidorcas marsupialis (Zimmerman, 1780) - springbok

Aepycerotinae:

Aepyceros melampus (Lichtenstein, 1812) - impala

Hippotraginae:

Hippotragus niger (Harris, 1838) - sable antelope

Oryx gazella (Linnaeus, 1758) - gemsbok

Bovinae:

Taurotragus oryx (Pallas, 1766) - eland

Of the ungulate types studied, the gemsbok is more out of its historical range than the other types which are within or peripheral to their historical ranges (Smithers 1983).

Five other ungulate types were present and seen by the author on Jack Scott Nature Reserve during the study period: oribi Ourebia ourebi, steenbok Raphicerus campestris, kudu Tragelaphus strepsiceros, mountain reedbuck Redunca fulvorufula and waterbuck Kobus ellipsiprymnus.

Three carnivora are known to have occurred in the study area during the study period: brown hyaena Hyaena brunnea, leopard Panthera pardus and black-backed jackal Canis mesomelas. While black-backed jackals were seen and heard by the author, the same saw only the spoor of brown hyaena and leopard.

PART ONE

UNGULATE NUMBERS, ACTIVITY AND HABITAT SELECTION

INTRODUCTION

The maintenance of mixed ungulate populations in an area, without detriment to either habitat or animals, requires insight into habitat needs, habitat use and potential interspecific competition among the animals of the area. Many studies of mammalian herbivores in relation to their environments have been done, especially in the last quarter century. Studies range in complexity from qualitative descriptions of habitat use (for example, Vesey-Fitzgerald 1960, 1965; Lamprey 1963; Bell 1971; Blankenship & Field 1972; Pienaar 1974) to quantitative analyses made possible by recently developed computer methods.

Analysing quantitative animal-habitat data

Simple quantitative studies express habitat preference in terms of the proportion of animals seen in each habitat type, as done by Constan (1972). An extension of this concept is the comparison of observed habitat use with expected habitat use, according to habitat availability (for example, Jarman 1972; Hirst 1975; Singer 1979; Suring & Vos 1979; Cairns & Telfer 1980; Marcum & Loftsgaarden 1980; Rounds 1981; Coppock, Ellis, Detling & Dyer 1983; Kincaid & Bryant 1983; Simpson & Gray 1983; Byers, Steinhorst & Krausman 1984; Hanley 1984; Osborne 1984; Wydeven & Dahlgren 1985). Such studies usually involve classical statistical techniques of hypothesis testing. The null hypothesis tested is that the distribution of animals in an area is random over all habitat types, meaning that the expected occurrence of animals would be in proportion to the relative occurrence of the different habitats in the area. Coefficients of association such as Cole's (1949) coefficient and indices of selection/preference may also be calculated (Hirst 1975; Anthony & Smith 1977; Pettifer & Stumpf 1981).

The second main type of quantitative analysis of animal-habitat relationships is the use of multivariate analysis techniques (for example, Ferrar & Walker 1974; Page & Walker 1978; Pettifer & Stumpf 1981; Braithwaite, Dudzinski & Turner 1983; Rowe-Rowe 1983; Short, Caughley & Grice 1983; Beardall, Joubert & Retief 1984; Brown & Batzli 1984; Davies 1985; Ben-Shahar 1986). Hypothesis-generating multivariate analysis, or pattern analysis, may be distinguished from hypothesis-testing classical statistics (Williams 1973). Studies using multivariate analysis techniques do not require information on the amount of habitat available and a record of habitat variables at each animal location is usually sufficient. Multivariate analyses are more accessable now because of the development of rapid, flexible computer programs such as DECORANA and TWINSPAN (Hill 1979a, b), which are described more fully in Chapter Three, Part One.

METHODS

Enumeration, distribution and activity

A grid of 250 x 250 m (6,25 ha) pixels was constructed on the 1 000 x 1 000 m grid of X and Y National Mapping System coordinates on the four 1:10 000 orthophoto maps covering the study area (2527DC 15 HARTEBEESHOEK, 2527DC 20 WELTEVREDEN, 2527DD 11 SKEERPOORTRIVIER and 2527DD 16 RIETFONTEIN) (Figure 21). This approach was used because of the standard nature of the grid based on the Lo 27 coordinates of the National Mapping System, enabling the grid to be readily redrawn if the original were to become unavailable. For field use, the orthophoto maps were cut into manageable, 200 x 200 mm sheets representing 2 000 x 2 000 m areas of land. The 250 x 250 m grid was marked with permanent ink on each piece of paper, and the rows and columns were identified by letters and numerals respectively. Each sheet was then covered with adhesive, clear plastic and these sheets were used for identifying the locality of ungulates, while data were recorded on separate field forms.

Ungulate counts in the study area were done from May 1986 through April 1987. A fixed route along roads and paths was travelled by

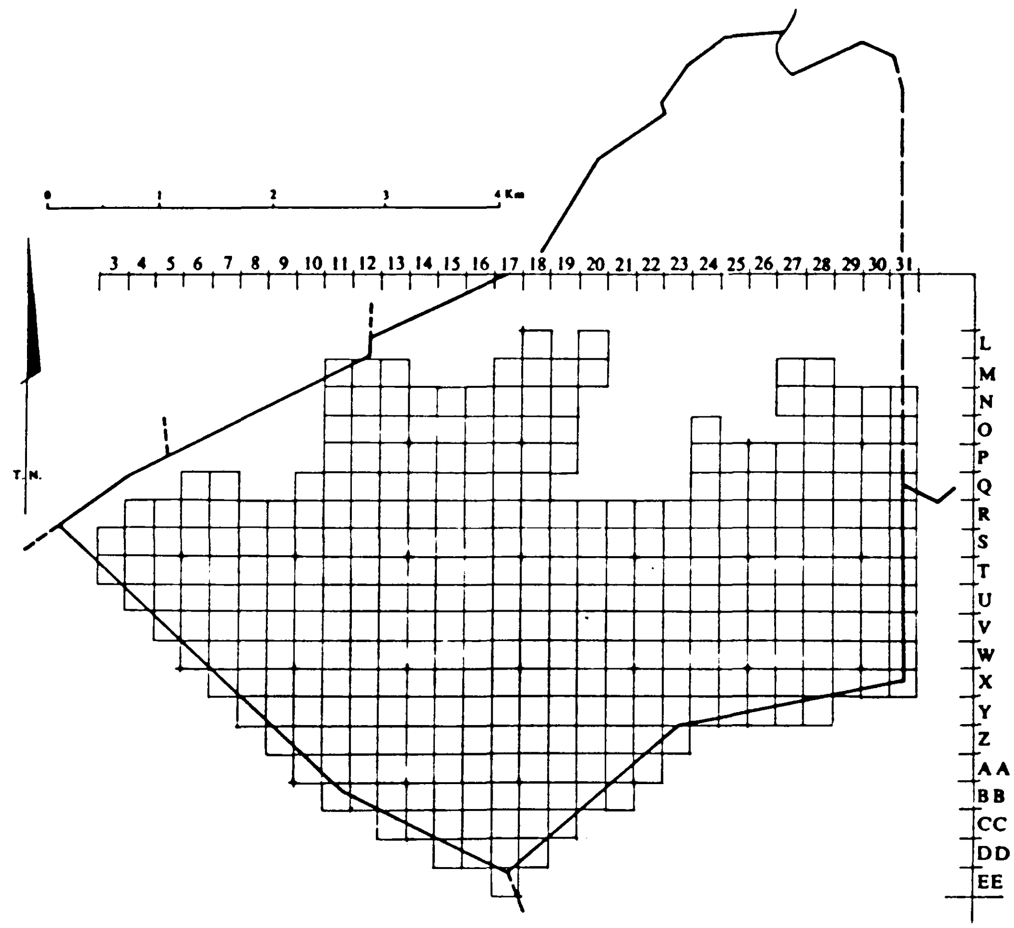


Figure 21 The base grid used in the ungulate-habitat survey of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, from May 1986 to April 1987.

motorcycle and, in parts, on foot during the first 4 to 5 hours after sunrise on two successive days per week. Four starting positions round the census route were used so as to have temporally distributed observations. One census cycle consisted in starting at each of the four starting points on four consecutive counts so that one cycle took two weeks and eight counts (two cycles) could thus be done per month. However, only six to eight counts (mean = 7) per month were actually achieved, with only four in September 1986. During each census, elevated positions were used for scanning sections of the study area with 10 x 50 binoculars. The animals sighted were identified as one of the 10 types mentioned above, and counted and fixed in time and space. The activity of the majority of each ungulate type in a pixel was recorded as disturbed, feeding on natural food, feeding on supplementary food, resting (lying down or standing), in transit or other. The supplementary foods were "Rumevite" game blocks, provided from June to September 1986, and rock salt, provided all year, which were placed at eight permanent sites in the study area. Animals sighted more than once during a count were noted as such because only the first sightings were used in the habitat utilisation analysis, while all sightings were used in the activity analysis. Activity was expressed as the percentage of counted animals involved in each activity class. Natality data were provided by the ranger who patrolled the reserve on horse-back almost daily during the wet season and less frequently during the rest of the year because of other duties.

Ungulate counts by the author were made during the morning only because of the greater visibility of animals at that time. Kutilek (1979) found that peak activity amongst large mammals in Lake Nakuru National Park, Kenya, occurred between 06h00 and 10h00. Jarman (1972) found limited daily movements of large mammals in Mana Pools Game Reserve, Zimbabwe, and these movements only applied to one or two months of the year, depending on species. During December 1986 and January 1987 four of the regular morning counts (done between 05h30 and 10h30 at this time of year) per month in the present study were followed by afternoon counts done between 13h30 and 18h00 for comparison with the same mornings' counts. The Wilcoxon two-sample test described in Chapter Three, Part Two was used on these data.

The twelve-month period over which ungulates were counted was divided into two seasons according to climatograms (Figure 5). The dry season was taken as being May to September 1986 and the wet season was defined as October 1986 to April 1987. An area in the north-east of the study area was deliberately burnt by the manager of Jack Scott Nature Reserve during October 1986 for management reasons.

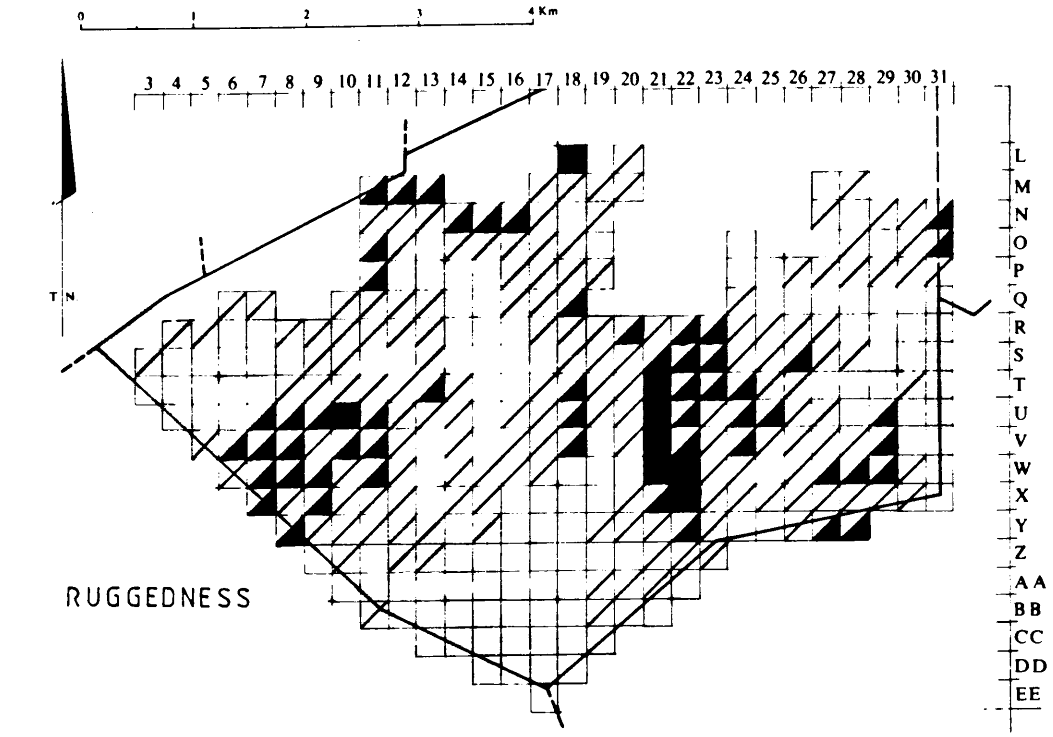
Habitat availability and utilisation

Each pixel was evaluated in terms of 30 habitat categories in eight habitat groups (Table 23; Figures 22-25). Ruggedness was determined according to Beasom, Wiggers & Giardine (1983) and a matrix of 11 x 11 dots, spaced 2,5 mm apart on a piece of transparent plastic film was used. The size of the matrix was therefore 25 x 25 mm, the same size as a 250 x 250 m pixel on a 1:10 000 orthophoto map with contour intervals of 5 m. By placing the dot matrix over each pixel, the number of dot-contour line intercepts could be counted, thus giving an index of land surface ruggedness (LSRI). This method is quicker than measuring the total length of contour lines in each square and the two methods are related (Beasom et al. 1983). To test the relationship, 34 (10%) of the 339 pixels were randomly chosen and treated with both methods and a linear regression analysis of total contour line length on number of dot-contour intercepts (Figure 26) showed a significant correlation ($r=0,990$; $df=32$; $p<0,001$). It was found that when a dot was intercepted by two or more contour lines, that dot should be counted as many times as there were lines passing through it. In this way points representing such dots were moved closer to the linear regression curve in Figure 26 than when such dots were counted once. Problems may also arise when contour lines are roughly parallel in a pixel and some, or all, fall between the dots. In such cases, the dot matrix should be shifted such that it is no longer aligned with the sides of the pixel. A range of contour patterns associated with different LSRI values is shown in Figure 27, traced directly from the orthophoto maps covering the study area.

The mean altitude (m) of each pixel was obtained from the orthophoto maps by calculating the mean of the highest and lowest

Table 23 Habitat categories and their values as used to classify each pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, for the ungulate-habitat investigation from May 1986 to April 1987.

HABITAT GROUP	HABITAT CATEGORY	VALUE OF HABITAT CATEGORY PER PIXEL
Ruggedness	R1	land surface ruggedness index (LSRI) <20
	R2	LSRI = 20 to 39
	R3	LSRI = 40 to 59
	R4	LSRI > 59
Geology	GC	chert-rich dolomite
	GD	chert-poor dolomite
	GS	shale
	GSC	both shale and chert-rich dolomite
	GSD	both shale and chert-poor dolomite
Mean altitude above sea level	A1	<1450 m
	A2	1450-1499 m
	A3	1500-1549 m
	A4	>1549 m
Vegetation	VC	chert community
	VD	dolomite community
	VF	old lands community
	VS	shale community
	VCD	both chert and dolomite communities
	VCS	both chert and shale communities
	VSF	both shale and old lands communities
Woodland	WA	woodland absent from pixel
	WP	woodland present in pixel
Supplementary feed sites	SFSA	supplementary feed site absent from pixel
	SFSP	supplementary feed site present in pixel
Permanent water	PWA	permanent water absent from pixel
	PWP	permanent water present in pixel
Burning history	B4	pixel burnt in spring 1984
	B5	pixel burnt in spring 1985
	B6	pixel burnt in spring 1986
	B0	pixel not burnt in spring 1984/85/86



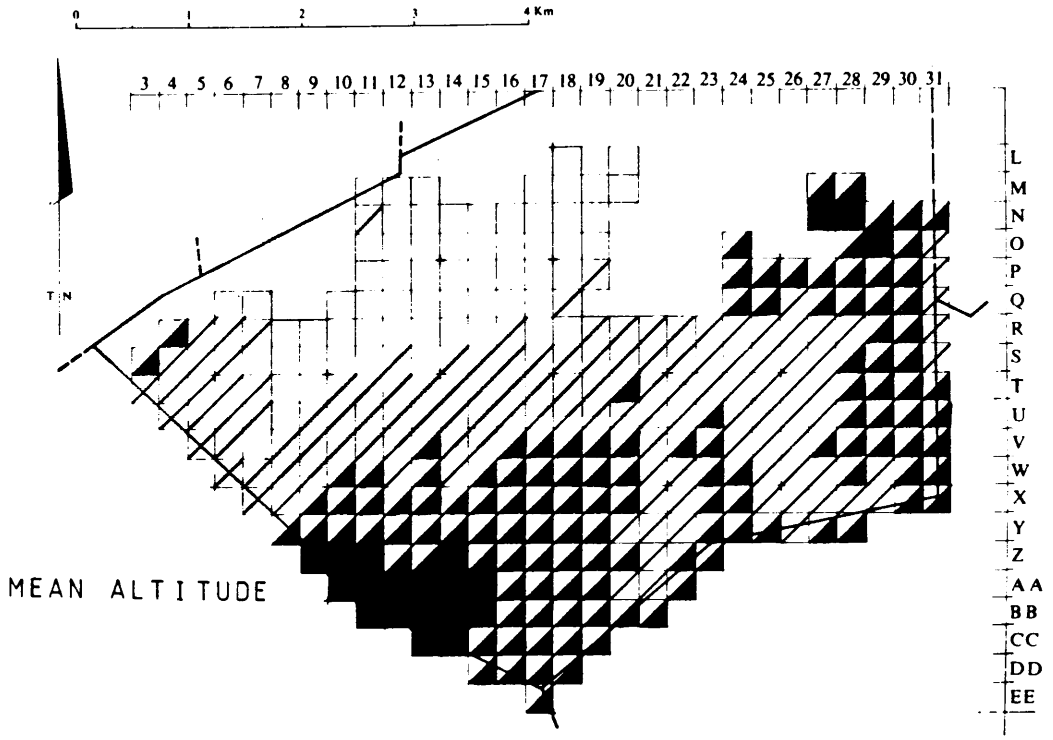
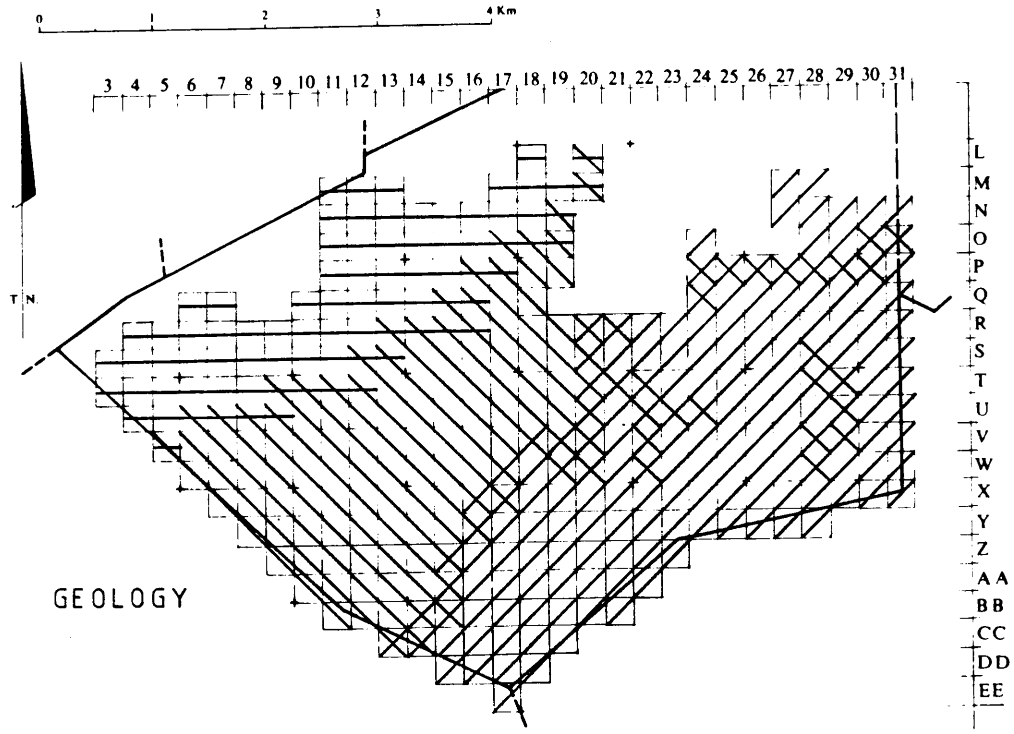


Figure 22 Habitat values per pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, for ruggedness, in terms of the land surface ruggedness index, where open = <20, diagonal line = 20-39, half-solid = 40-59 and solid = >59 and mean altitude above sea level, where open = <1450 m, diagonal line = 1450-1499 m, half-solid = 1500-1549 m and solid = >1549 m.



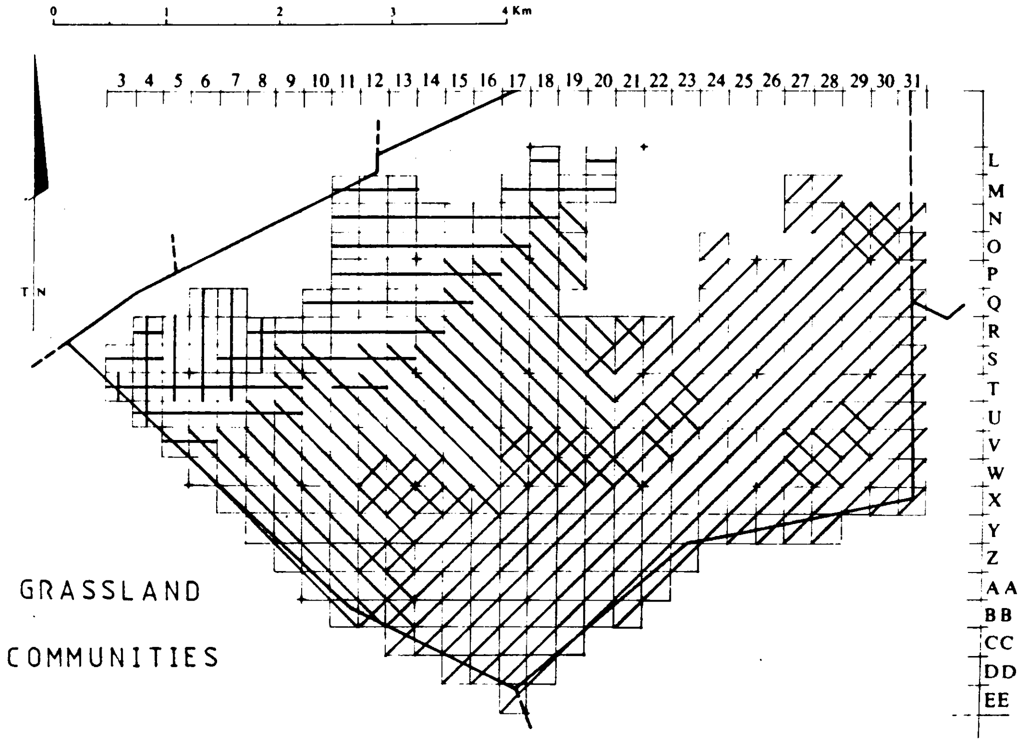


Figure 23 Habitat values per pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, for geology, where — = shale, \\ = chert-rich dolomite and // = chert-poor dolomite and grassland communities, where — = shale community, || = old lands community, \\ = chert community and // = dolomite community.

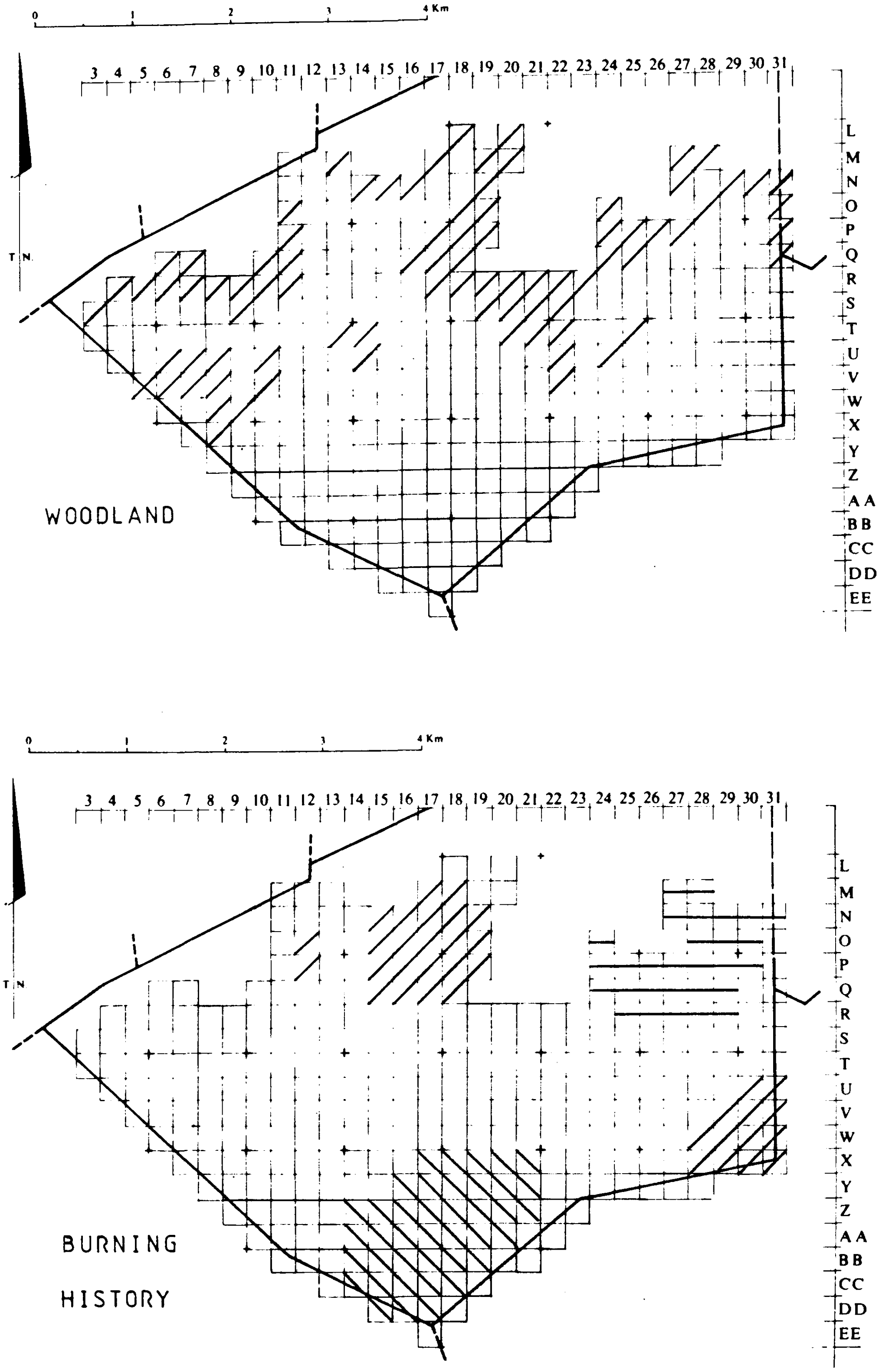
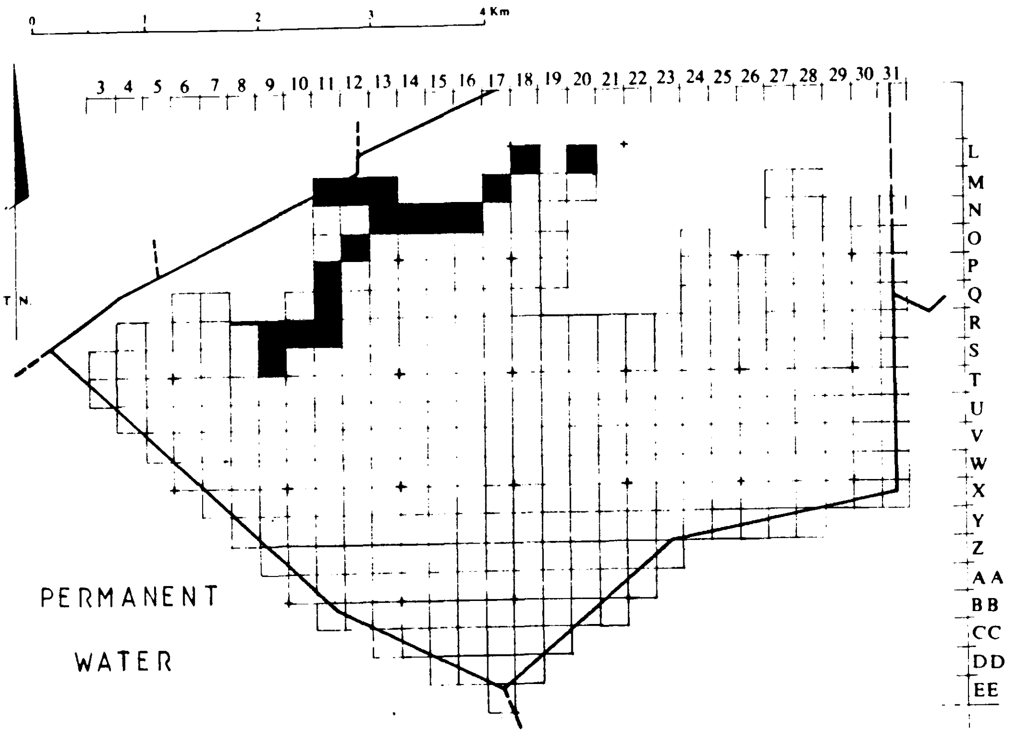


Figure 24 Habitat values per pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, for woodland, where open = woodland absent and a diagonal line = woodland present and burning history, where \ = burnt in spring 1984, / = burnt in spring 1985 and — = burnt in spring 1986.



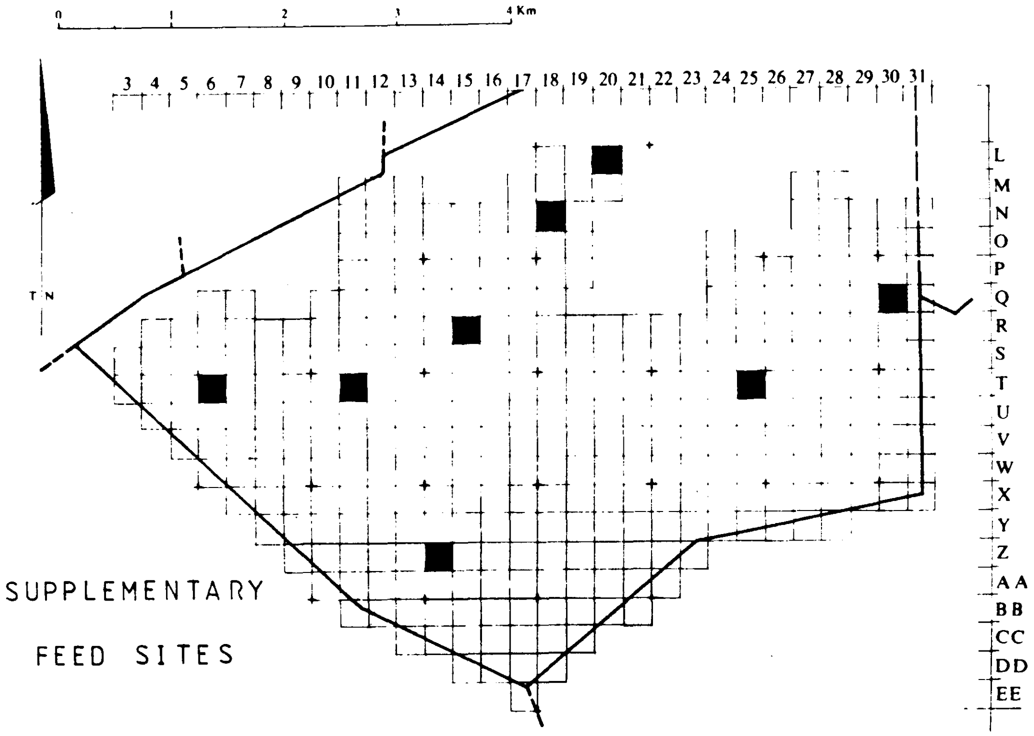


Figure 25 Habitat values per pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, for permanent water, where open = permanent water absent and solid = permanent water present and supplementary feed sites, where open = supplementary feed site absent and solid = supplementary feed site present.

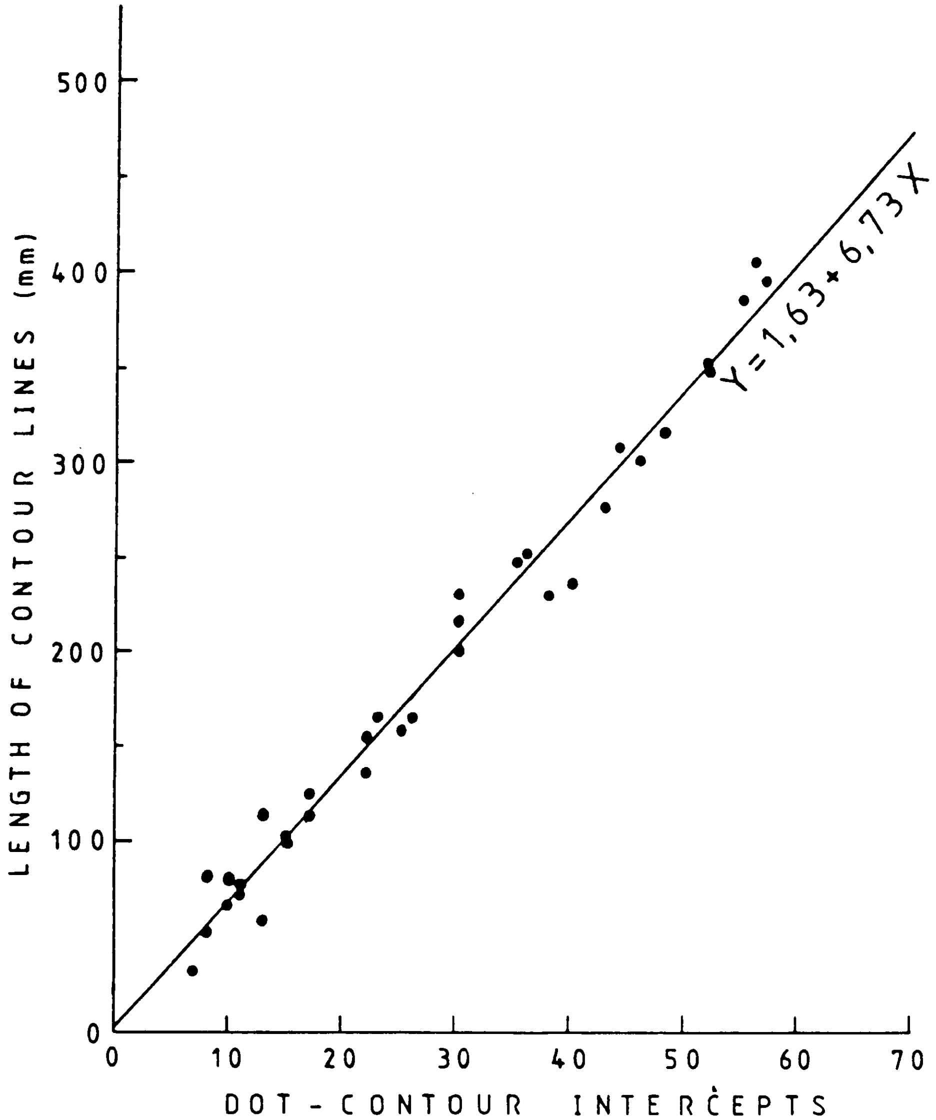


Figure 26 The linear regression curve (r=0,990; df=32; P<0,001) of length of contour lines on number of dot-contour intercepts for 34 randomly selected pixels in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal. Measurements were taken from 25 x 25 mm pixels on 1:10 000 orthophoto maps having 5 m contour intervals.

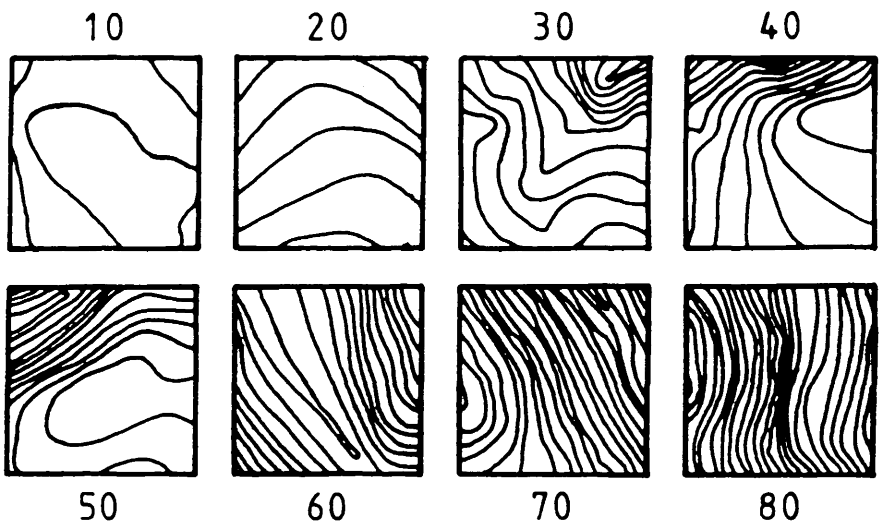


Figure 27 Examples of 25 x 25 mm pixels from the 1:10 000 orthophoto maps of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, to illustrate land surface ruggedness index values of 10, 20, 30, 40, 50, 60, 70 and 80. The contour interval is 5 m.

contour lines in each pixel. The geological classification of the pixels was done from 1:50 000 geological maps and the vegetation classification followed the map of Coetzee (1974a). The remaining habitat categories were assessed by direct observation.

A method described by Byers et al. (1984) was used to compare the expected and observed use of the habitat categories by ungulates in the study area. This use of simultaneous confidence intervals, originally described by Neu, Byers & Peek (1974), uses enumeration data and may be used together with the chi-square goodness-of-fit test. To be sure that the sample size is large enough for the chi-square test, the values of expected use should, generally, be greater than five; to fulfil this requirement, it may be necessary to combine some of the less frequent classes (Byers et al. 1984). Hence the combination of habitat categories R3 and R4 (Table 23), as well as A3 and A4 in the present study. The geological categories were excluded because geology is generally only indirectly effective through vegetation and topography. Further, for the dry season, burning categories B4, B6 and B0 were combined as a new category B>1, being areas burnt more than one year previously; B5 became B<1, being areas burnt less than one year previously. The areas burnt in October 1986 (classed as B6) had not yet been burnt in the dry season and so were classed as B0. Similarly, for the wet season, B4, B5 and B0 were combined as B>1 and B6 became B<1.

When using simultaneous confidence itervals, the chi-square test need not be done and was not done in the present study. The chi-square test only tells whether a particular environmental factor such as vegetation affects animal distribution; the test does not indicate which category of vegetation is preferred by the animals being studied (Byers et al. 1984). If the use (p_i) of a single, preselected category (i) is to be investigated, a straightforward confidence interval is calculated using the formula:

$$p_i - Z_{\alpha/2}\sqrt{p_i(1-p_i)/n} \leqslant p_i \leqslant p_i + Z_{\alpha/2}\sqrt{p_i(1-p_i)/n}$$

where p_i is the observed proportion of use (observed number of animals using category i/total number of animals using all categories), formulated as O_i/n and $Z_{\alpha/2}$ is the upper standard normal table value corresponding to a probability tail of $\alpha/2$ (Byers et al. 1984). Thus, for a 95 % confidence interval: α = 0,05 and $Z_{0,0250}$ = 1,96.

When examining a set of categories such as the three ruggedness categories in the present study, a family of Bonferroni-type simultaneous confidence intervals may be calculated as follows:

$$p_i - Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n} \leqslant p_i \leqslant p_i + Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n}$$

where k is the number of categories (Byers et al. 1984). Thus, when k = 3 and α = 0,05, $Z_{0,0083}$ = 2,39.

Also to be calculated is the expected proportion of use, p_{io}, which is equal to the relative proportion of category i. If p_{io} lies outside the confidence interval, expected use and actual use are significantly different at the stated level of significance, α (ibid.), while p_{io} inside the confidence interval implies chance use of category i by the study animals. To do the chi-square test, expected use, E_i, must also be calculated as np_{io}. However, as mentioned above, the chi-square test is not essential if confidence intervals are calculated.

It is important to note that the effectiveness of the described test depends on the method of data collection. Data collection must be such that the study animals have access to, and opportunity to be observed in, each category. A major assumption involved is that the animals move independently of each other (Byers et al. 1984).

To assess the degree of preference for each category by each species, an affinity index (AI) was calculated in a way similar to that of Cairns & Telfer (1980), where AI = p_i/p_{io} and p_i and p_{io} are as described above. A value of 1,00 in the present study indicates that the observed usage equals the expected usage, while a value different from 1,00 indicates that the observed usage deviates from the expected usage. However, the significance of the deviation is not known, but can be inferred by comparing the affinity index values with the respective simultaneous confidence intervals.

Multivariate analyses

The ungulate distribution data were subjected to DECORANA (Hill 1979a), which is discussed in Chapter Three, Part One. The pixels were individuals and the ungulate types were attributes, quantified by the total number counted per pixel. Multivariate analyses were done for three time periods, namely the wet season, the dry season and the whole study period.

In another application of DECORANA, the individuals were ungulate types and the attributes were habitat categories, quantified by the number of records of each ungulate type in each habitat category. This follows the method of Beardall et al. (1984) and the three abovementioned time periods were again used. This second approach was applied because of the large number of pixels (339) and few ungulate types (10) which made the sample ordination of the previous approach unwieldy and difficult to interpret.

RESULTS

Enumeration

The Wilcoxon two-sample test indicated no significant difference between the morning and afternoon counts of all ungulate types (Z=1,2077; P>0,05). The monthly mean animal numbers derived from six to eight counts per month (four in September) are illustrated in Figures 28 to 31. Because accurate population numbers of the various ungulate types in the study area were not essential to the primary aim of the ungulate study, population numbers are speculative and have not been subjected to rigorous statistical analyses.

The highest number of ungulates counted in the study area during the study period was 590 on 6 February 1987, while the lowest number of ungulates counted was 199 on 22 July 1986.

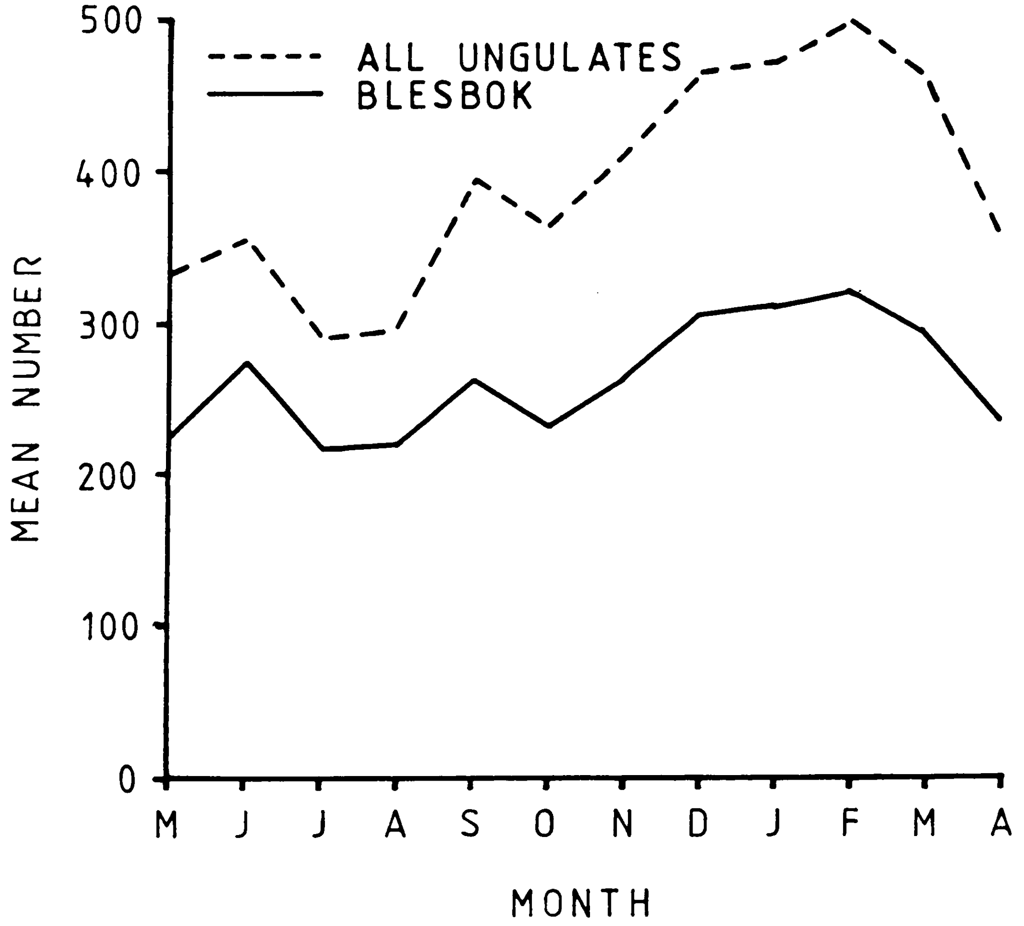


Figure 28 Mean monthly numbers of ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as determined by investigating the whole area six to eight times a month (mean = 7), except for September 1986 (four times), from May 1986 to April 1987. The graph applies to all ungulate types and blesbok.

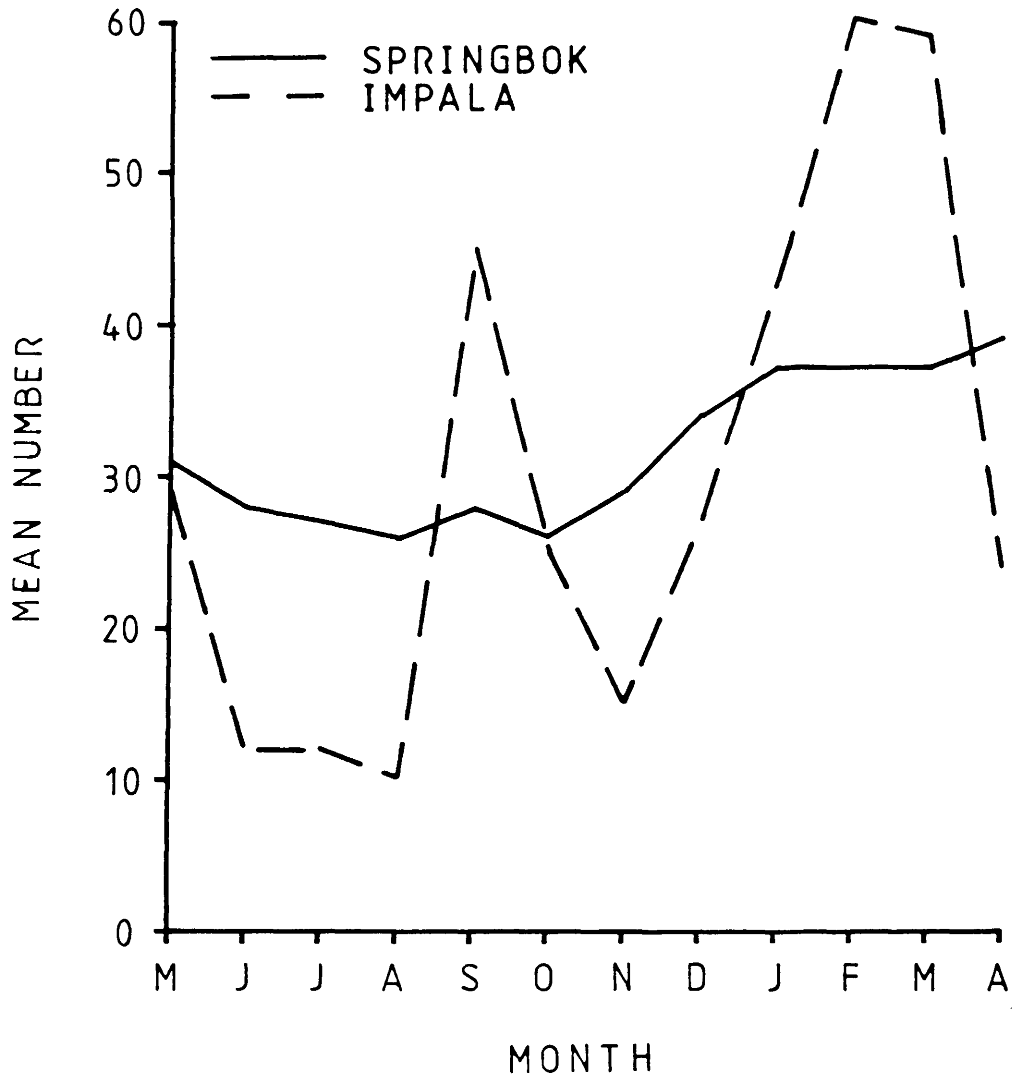


Figure 29 Mean monthly numbers of ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as determined by investigating the whole area six to eight times a month (mean = 7), except for September 1986 (four times), from May 1986 to April 1987. The graph applies to springbok and impala.

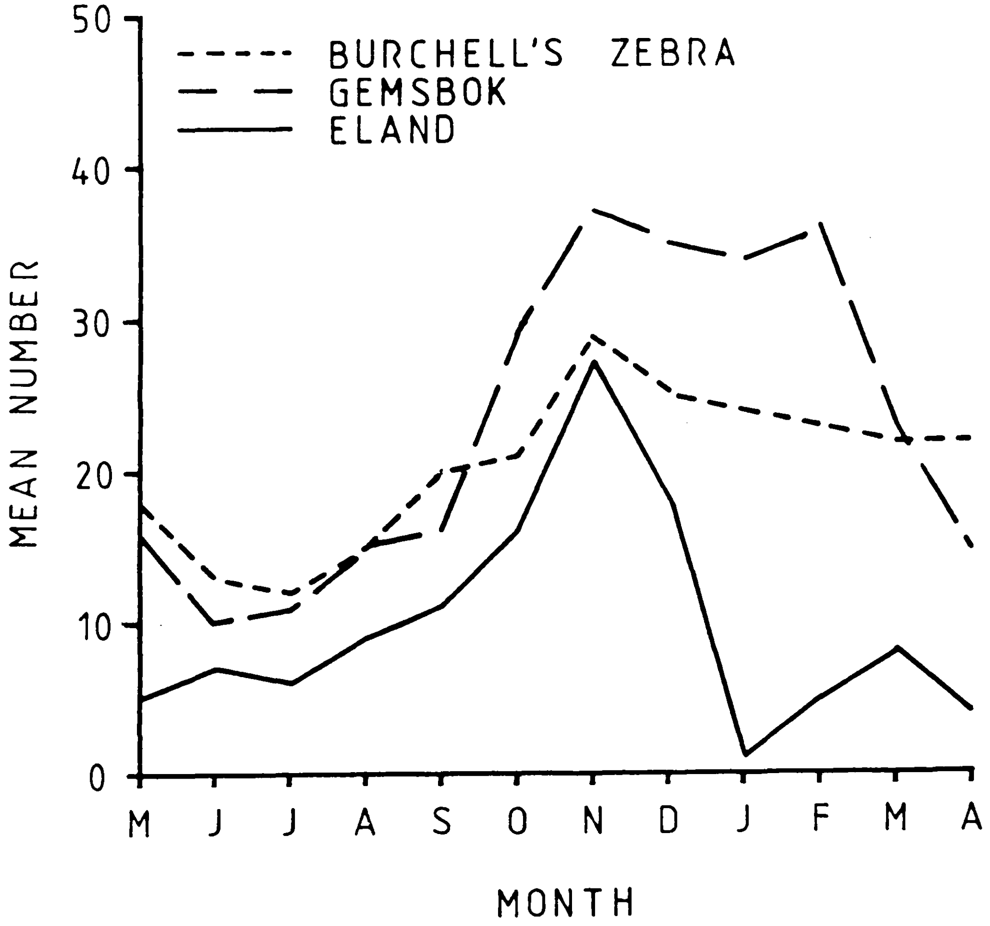


Figure 30 Mean monthly numbers of ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as determined by investigating the whole area six to eight times a month (mean = 7), except for September 1986 (four times), from May 1986 to April 1987. The graph applies to Burchell's zebra, eland and gemsbok.

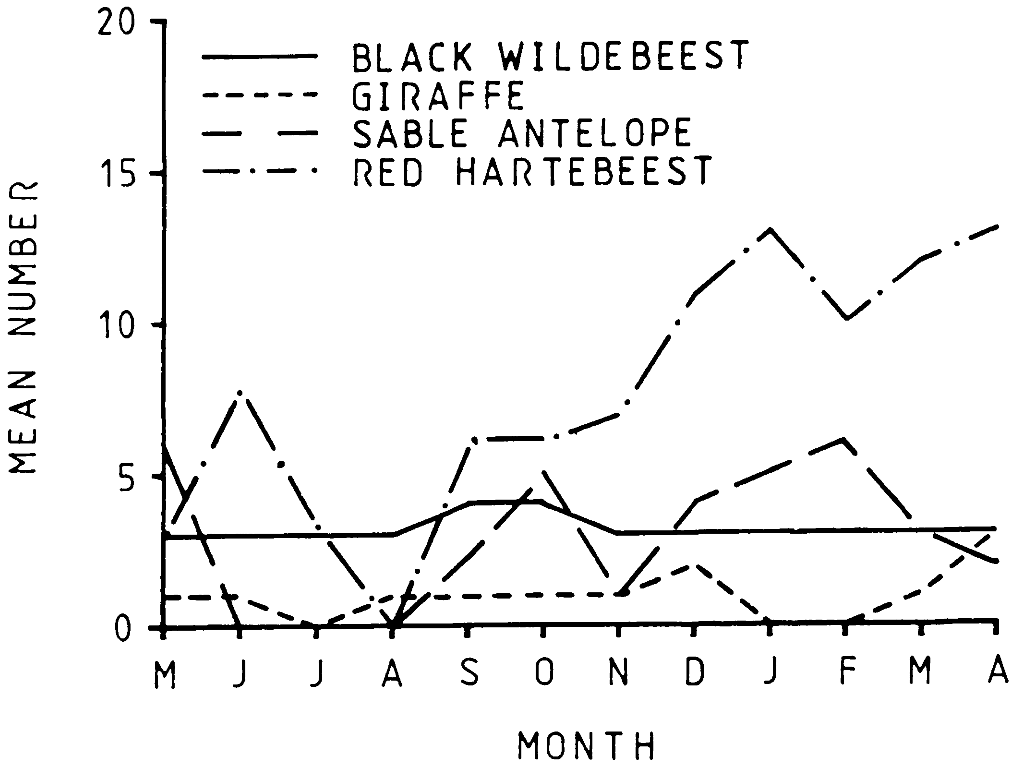


Figure 31 Mean monthly numbers of ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, as determined by investigating the whole area six to eight times a month (mean = 7), except for September 1986 (four times), from May 1986 to April 1987. The graph applies to red hartebeest, sable antelope, black wildebeest and giraffe.

The number of blesbok on Jack Scott Nature Reserve can only be estimated because of their relatively large number. In early 1985 there were 400 to 420 blesbok on the reserve, of which only six were juveniles from the 1984 lambing season (Scogings 1985). The imbalanced age structure would have led to a drop in numbers, but such a drop was restrained by the shooting and killing of at least 18 black-backed jackals Canis mesomelas during late 1985, when over 100 lambs were born (Vaughan*, pers. comm.). Survival amongst the 1985 cohort of young is unknown. From November 1986 to February 1987, 113 blesbok were born, according to the reserve ranger, and a maximum of 382 animals was counted in the study area during February 1987.

Springbok numbered 34 at the beginning of the study period, decreasing to 30 over the dry season, and then increasing to 41 with the birth of 13, of which two died, leaving a net increase of 11. In November 1986, Burchell's zebra numbered 34 including four young and, in the same month, gemsbok numbered 40, including six young. According to the ranger, eland numbered 50 to 60 on the whole reserve and a maximum of 41 eland was counted during November 1986 in the study area, including a herd of variable size (20-30) containing four young. As eland are known to form separate nursery herds and bachelor herds during summer (Smithers 1983), it is possible that there was a bachelor herd of smaller size outside the study area, as well as individuals moving in and out of the study area.

A known group of impala existed in the south-west of the study area, numbering 20 to 30 during the dry season. By early 1987 this group had increased to 35 to 45 with the addition of 14 young. As the young impala on the reserve totalled 38, according to the ranger, a total population for the reserve could be estimated at 95 to 125. Taking into account the known presence of bachelor groups totalling 20 to 30, the estimate could be increased to 120 to 150. A maximum of 95 impala was counted in the study area during February 1987.

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The black wildebeest population consisted of four adult males, three of which remained together, infrequently accompanied by the fourth individual which otherwise resided outside the study area. The lone animal was frequently seen outside the study area during the first half of the study period, but was not seen during the latter half. The said animal was in poor condition and probably died during the study period. The birth of two giraffe and the death of at least one resulted in a population of 13 to 14 on Jack Scott Nature Reserve during the study period. A maximum of 13 giraffe was seen in the study area in December 1986.

At the start of the study period, sable antelope in the study area comprised a breeding herd of seven, consisting of one adult male, two adult females, two subadults and two juveniles. According to the ranger, another two bulls were present outside the study area. During the wet season, the breeding herd frequently changed composition and at least one subadult male left the herd completely while the other subadult male and the subordinate female were not always present in the herd. The adult male also wandered off occassionally, leaving only the dominant female and two juveniles. However, the breeding herd usually numbered four to six during the wet season and one sable antelope was born in March 1987. Red hartebeest numbered 13 at the beginning of the study. Subsequently, one died, and three were born during the study period, resulting in a total of 15 red hartebeest, all of which used the study area. The three young were born in November 1986 and were part of a herd of 13, while two lone males wandered extensively round the study area during the summer months.

Ungulates in the study area showed an increase in abundance during the wet season, to a lesser or greater extent, for various reasons such as births and immigration (Figures 28-31). The decrease in the abundance of blesbok, impala, Burchell's zebra, gemsbok, eland and sable antelope at the end of the wet season indicates a movement out of the study area to woodland areas and other grassland areas. Although there was no such decrease in the abundance of red hartebeest at the end of the wet season in the study area, fewer were seen during the previous dry season and those that were seen were near woodland. Mason (1973) noted seasonal movements of eland, Burchell's zebra and red hartebeest from woodland to grassland during the wet season.

The fact that the abundance of springbok in the study area remained higher in summer than in winter, infers an increase caused by births rather than immigration and the slight winter fall-off was thus probably caused by deaths. Giraffe and black wildebeest were constantly low in abundance during the study period because of the infrequent occurrence of the former and the permanent occurrence of three of the four wildebeest in one part of the study area. In some cases there was also a peak of abundance in the study area during September/October 1986, especially amongst blesbok, springbok, impala, sable antelope and black wildebeest, coinciding with the spring flush of fresh grass (Figures 28-31).

Distribution

The distribution patterns of ungulates in the study area are shown in Figures 32 to 38. With regard to all ungulates, concentrations occurred in the south-centre, north-centre and north-east areas of the study area (Figure 32). These are areas which were burnt in 1984, 1985 and 1986 respectively. The south-centre area around pixels BB16 and BB17 and the area around pixel R15 were favoured in both the dry and wet seasons (Figure 33), whereas the north-eastern area and the area including pixels N18, O18 and P19 were favoured in the wet and dry seasons respectively. The two last-mentioned areas were burnt in spring 1986 and 1985 respectively, while the two first-mentioned areas appear to be historically favoured: "it appears that most of the biomass of grazing animals ... has, for at least several years, been concentrated in the western half of the reserve, largely on a year-round basis. Areas that appear to have been particularly favoured ... (are) the vlei area along Tshepe Stream south of Gravestones Junction, and the grassland area south-east of Wildebeest Junction" (Mason 1973). The vlei area refers to pixel R15 where a supplementary feed site exists and the area south-east of Wildebeest Junction is the south-centre area. Mason (1973) also mentions the old lands in the extreme west as being favoured by ungulates, but this was not apparent during the

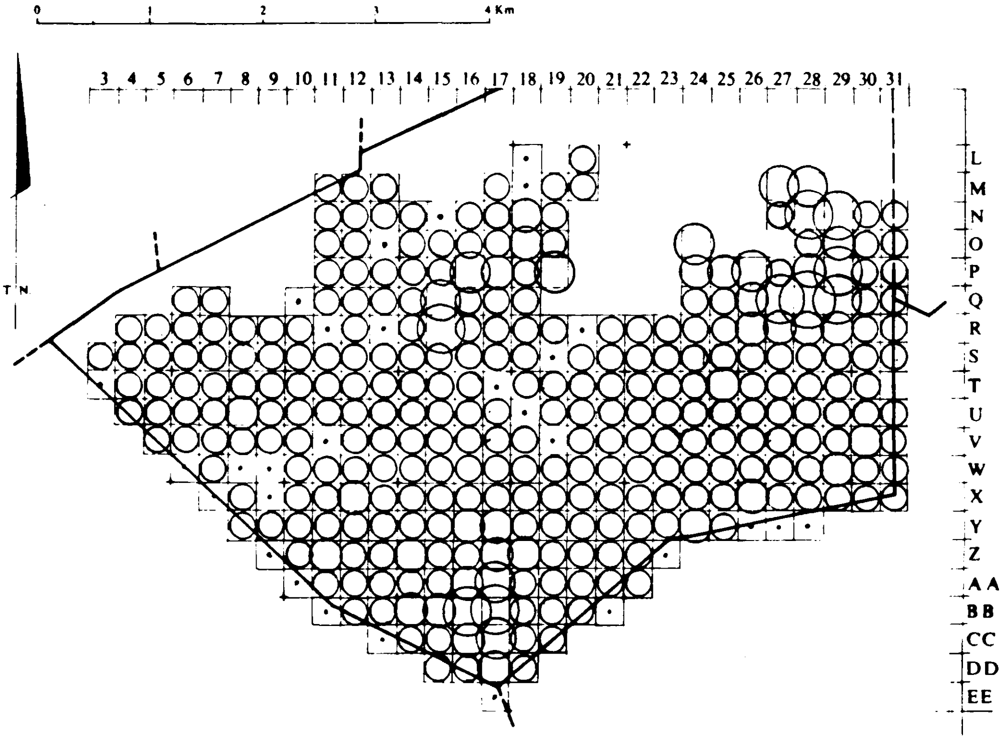


Figure 32 Total number of ungulates counted per pixel in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, from May 1986 to April 1987, during which time the whole study area was investigated 86 times in order to count ungulates.

• = 0 ◯ = 401 to 600
○ = 1 to 200 ◯ = 601 to 800
○ = 201 to 400 ◯ = 801 to 1000

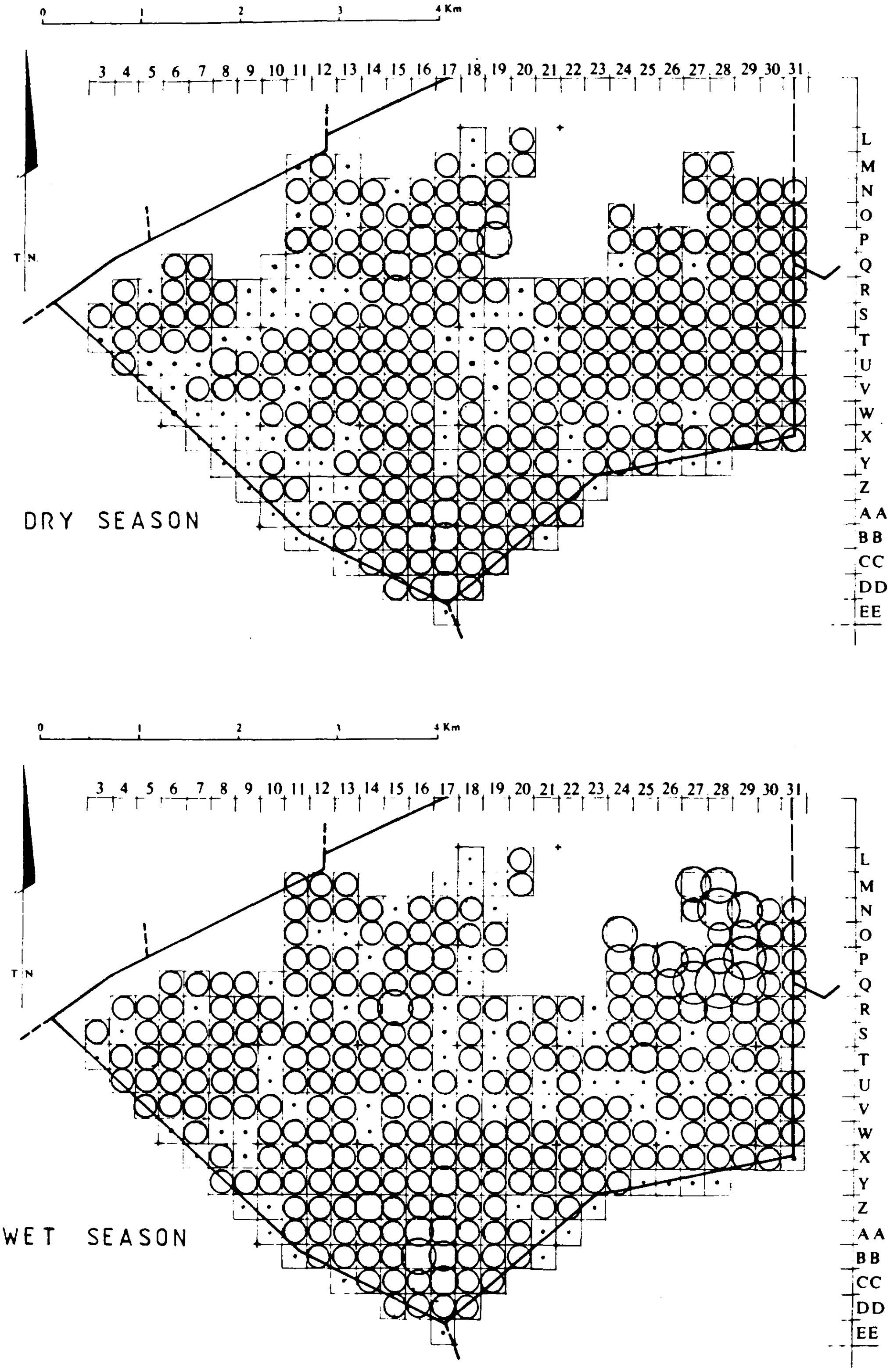


Figure 33 Total number of ungulates counted per pixel in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - 36 counts) and the wet season (October 1986 to April 1987 - 50 counts).

= 0
= 1 to 200
= 201 to 400
= 401 to 600
= 601 to 800
= 801 to 1000

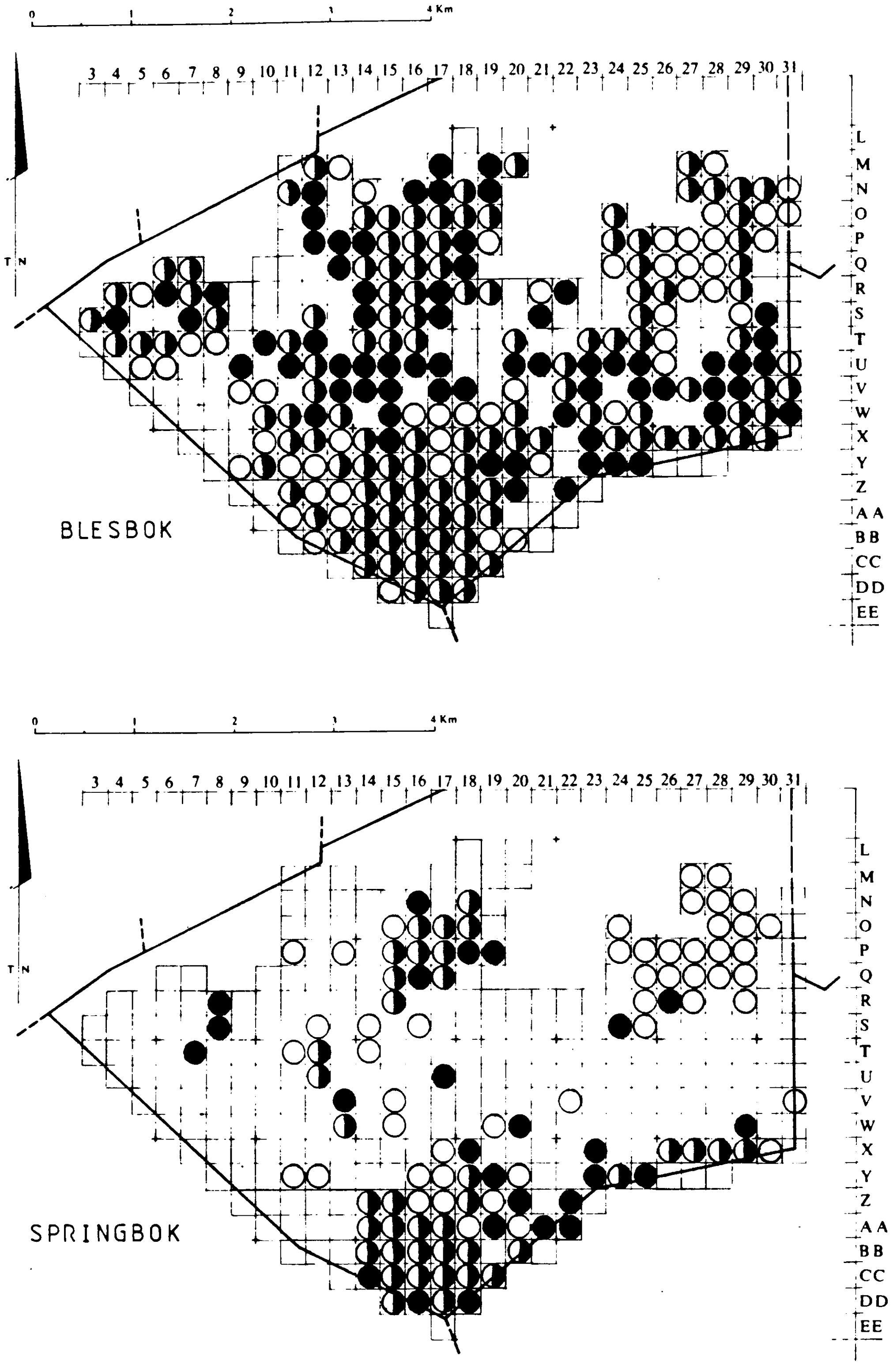
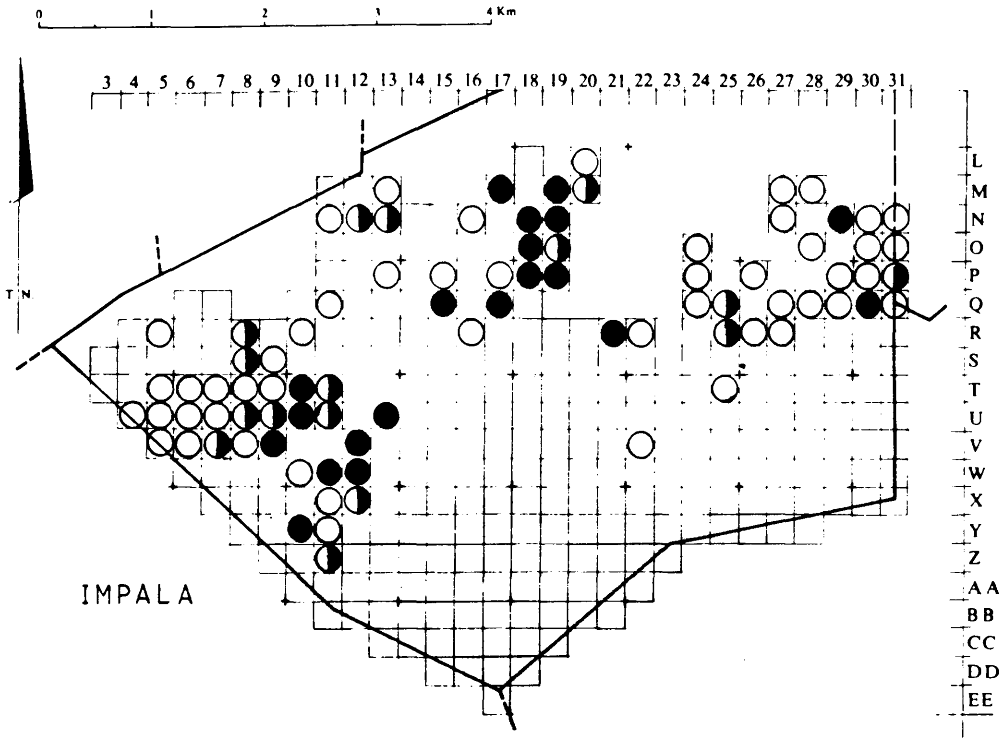


Figure 34 Distribution of sightings in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - solid circle), the wet season (October 1986 to April 1987 - open circle) and both seasons (half-solid circle) for blesbok and springbok.



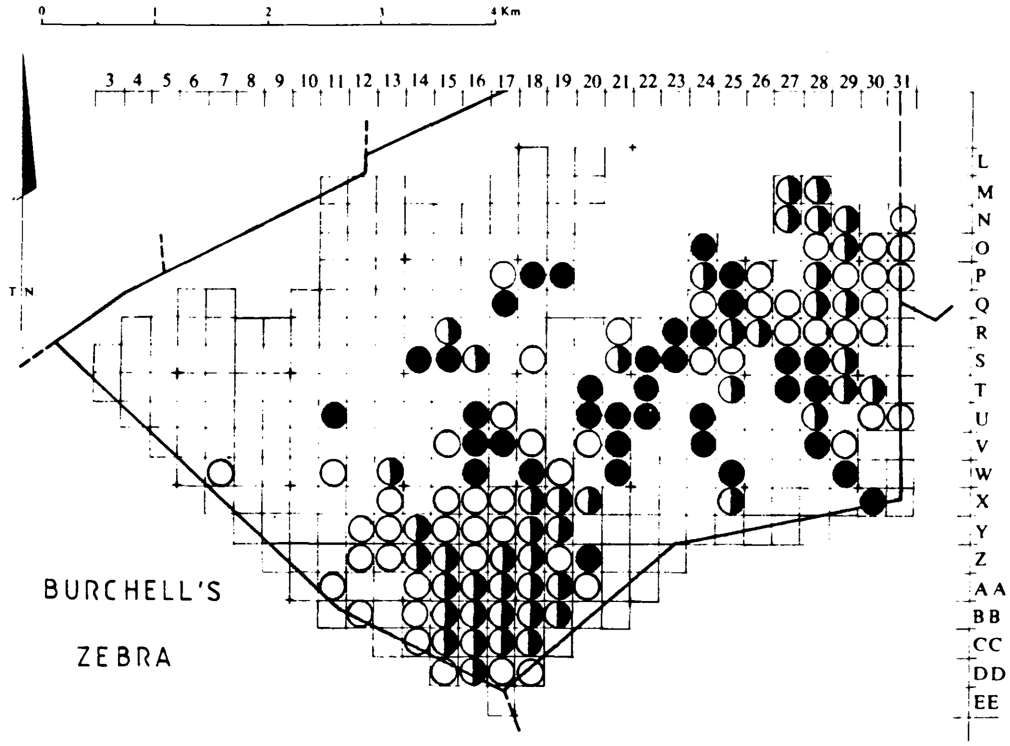
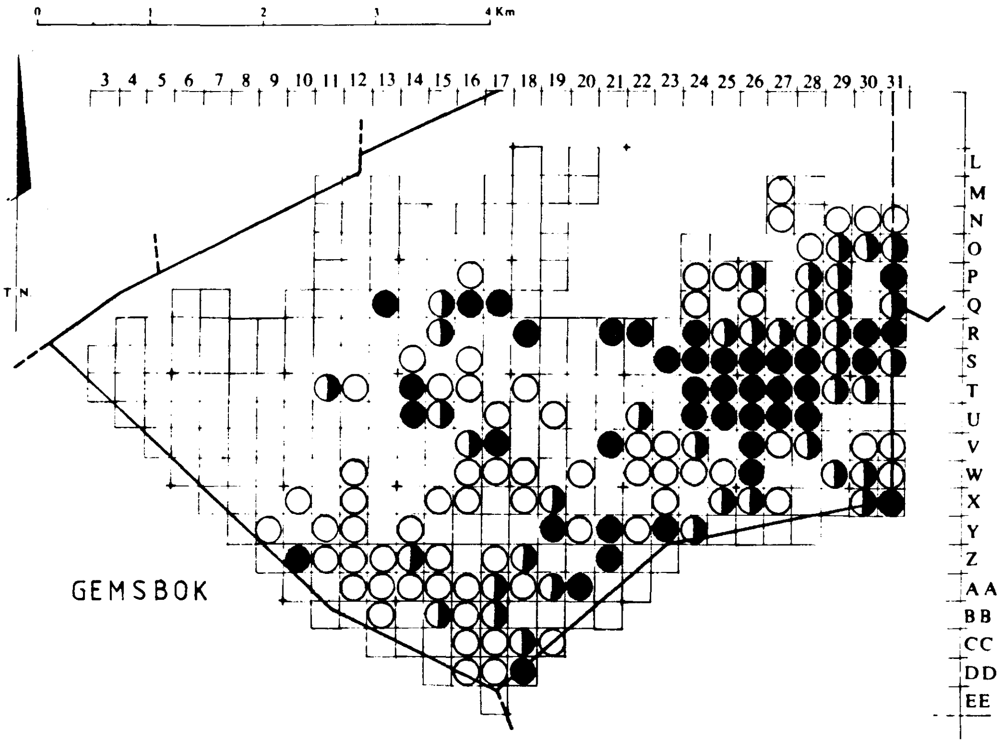


Figure 35 Distribution of sightings in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - solid circle), the wet season (October 1986 to April 1987 - open circle) and both seasons (half-solid circle) for impala and Burchell's zebra.



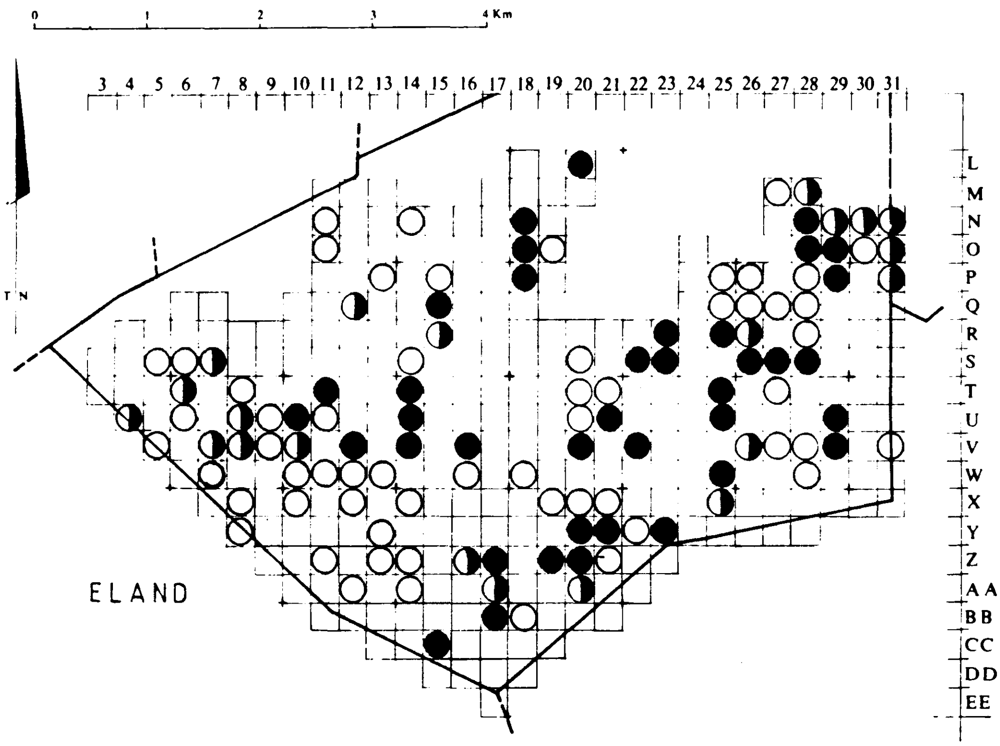


Figure 36 Distribution of sightings in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - solid circle), the wet season (October 1986 to April 1987 - open circle) and both seasons (half-solid circle) for gemsbok and eland.

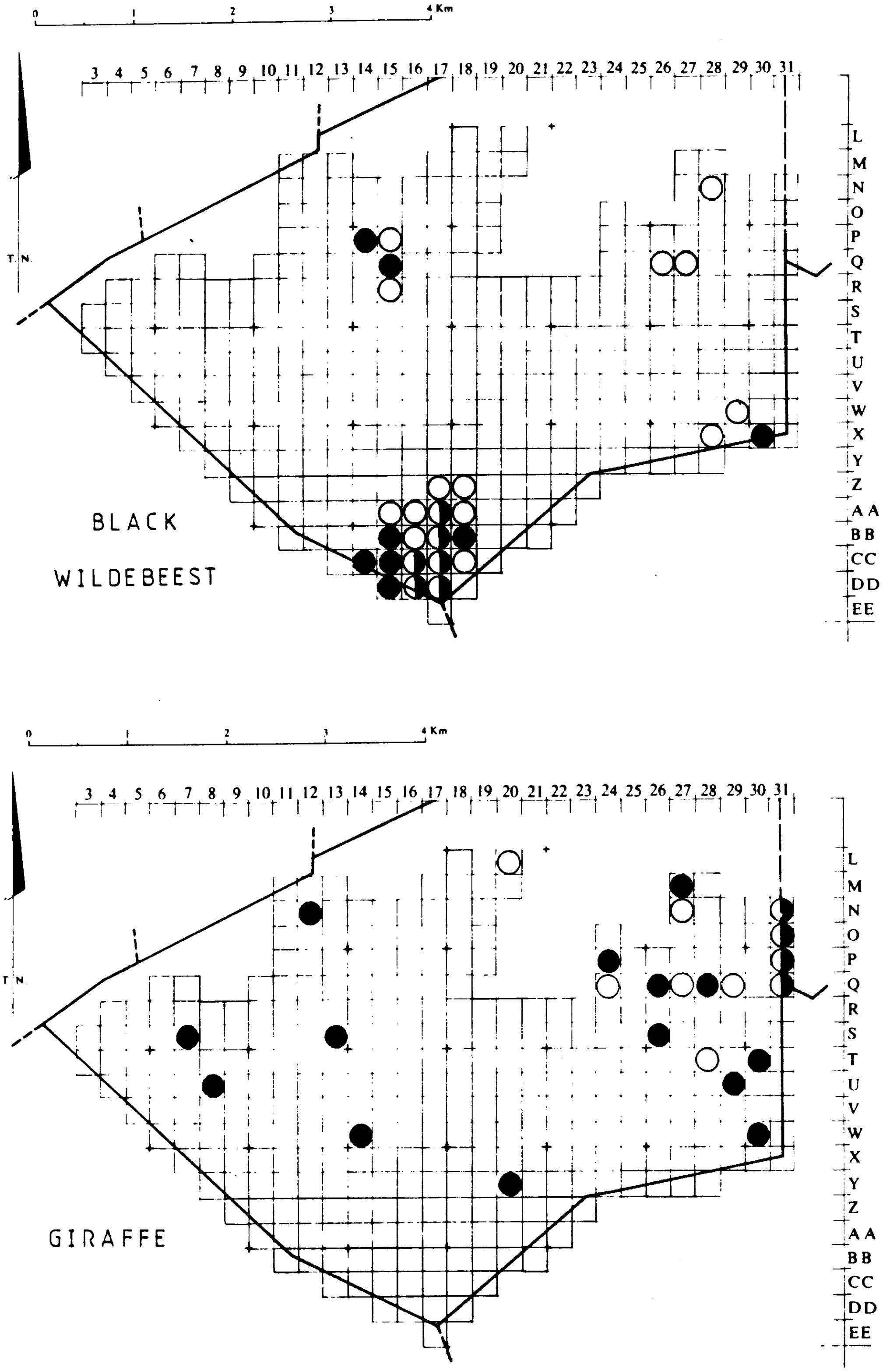
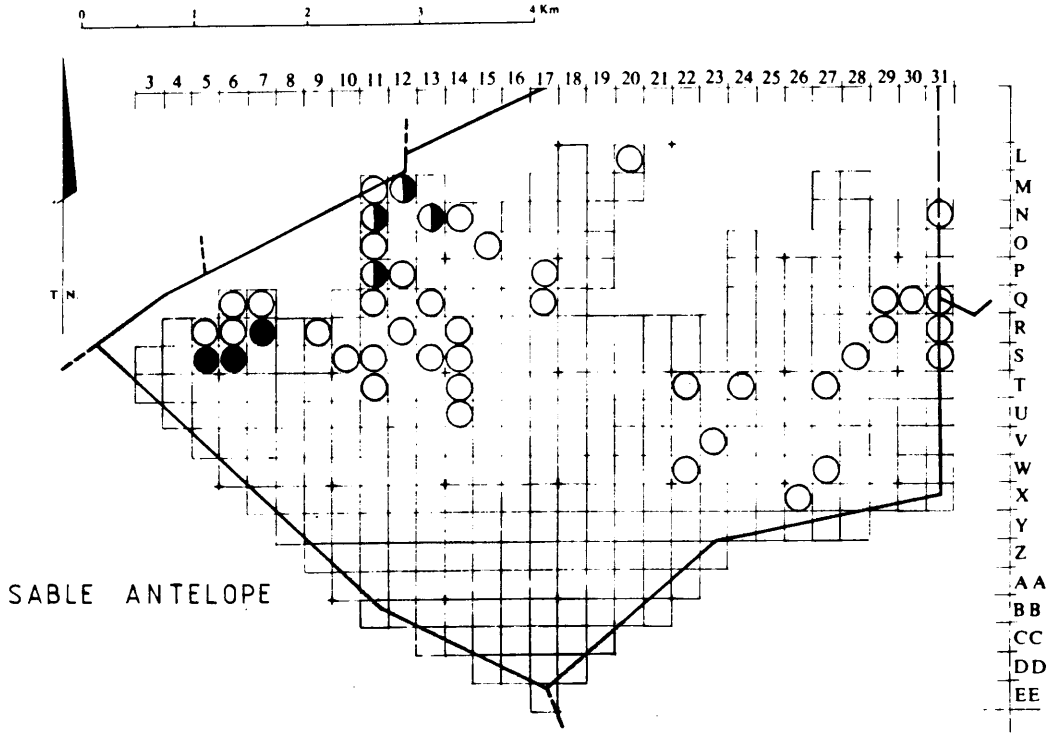


Figure 37 Distribution of sightings in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - solid circle), the wet season (October 1986 to April 1987 - open circle) and both seasons (half-solid circle) for black wildebeest and giraffe.



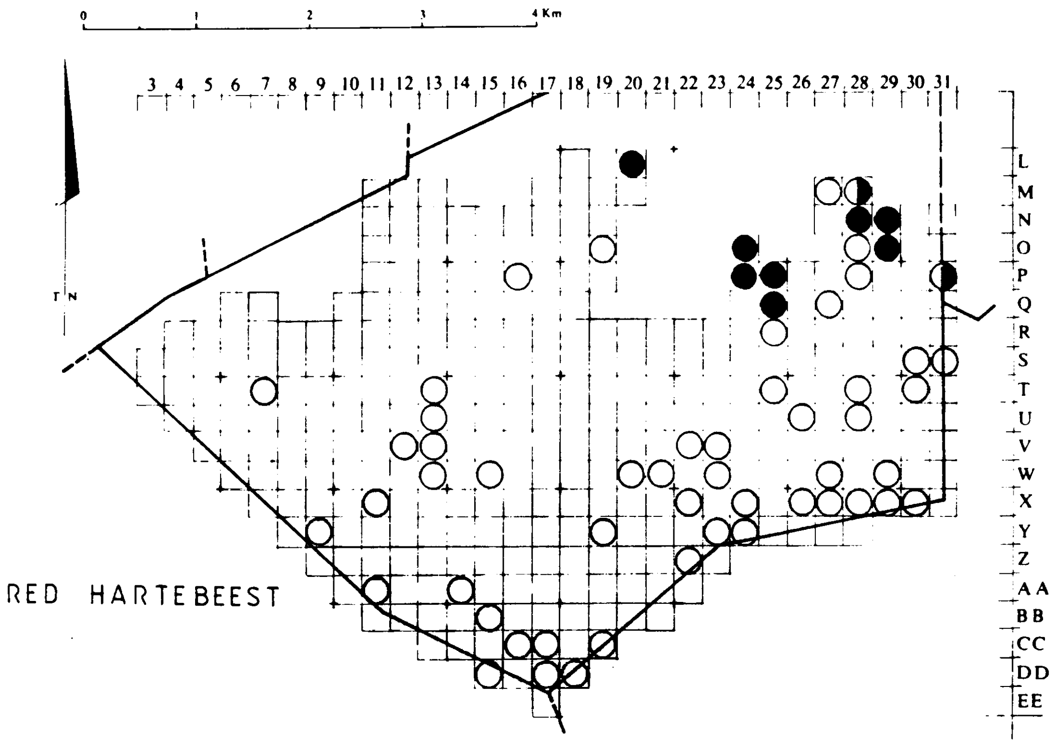


Figure 38 Distribution of sightings in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986 - solid circle), the wet season (October 1986 to April 1987 - open circle) and both seasons (half-solid circle) for sable antelope and red hartebeest.

present study and favouring of the said area was probably due to the burning at that time.

Certain distribution patterns characterised the different ungulate types (Figures 34-38). Blesbok, the most abundant ungulate, occurred most widely, avoiding the most rugged areas and moribund vegetation (Figure 34). Springbok distribution was clustered in the south, north-centre and north-east of the study area where the vegetation was shortly grazed or had been burnt within the previous year to year-and-a-half (Figure 34).

Impala distribution was clustered in the south-west, north-centre and north-east (Figure 35), while the south-western cluster of observations included dry and wet season occurrences of impala and represents a resident herd in that area. The northern and north-eastern groups of observations of impala were predominantly dry-season and wet-season occurrences respectively. The said areas were burnt in spring 1985 and 1986 respectively and the observations of impala there probably represent temporary home range extensions induced by the burning. The south-western herd of impala showed a westward extension from sheltered and wooded valleys to open grassland during the wet season. However this range extension could have resulted from an attraction to the salt that was present in pixel T6 during the wet season. Scattered observations of impala during the wet season also occurred between the three main clusters.

Burchell's zebra, like gemsbok, occurred in the south-eastern two thirds of the study area, the former showing a dry season tendency to enter more rugged areas in the centre, while the latter tended to occupy the low-lying, dolomite area in the east during the dry season (Figures 35 and 36). The low-lying north-west, including the old lands and grasslands on shale, were not visited at all by Burchell's zebra or gemsbok during the study period.

Eland did not show any particular distribution pattern and occurred throughout the study area (Figure 36). Conversely, three of the four black wildebeest occurred constantly in the south of the study area, rarely venturing to other parts (Figure 37), while the fourth black wildebeest appeared in the study area for a while during September and October 1986. Mason (1973) also noted a concentration of black wildebeest in the south, being "seldom sighted elsewhere". Giraffe distribution during the dry season was more widespread than during the wet season (Figure 37) as they apparently utilised scattered trees in the study area during the dry season. Notable amongst the dry-season observations of giraffe were a mother and calf, implying a search by the mother for sufficient nutrition.

Sable antelope were distinctly absent from the study area during the dry season, occurring only in the dense, tall vegetation of the old lands and in the north-east along the perennial Skeerpoort River, while they occurred more widely in the study area during the wet season (Figure 38). The observations in the east were mostly of two bachelors, at least one of which was the one evicted from the breeding herd during the year. Similarly, red hartebeest were located on the north-eastern edge of the study area, near woodland, during the dry season, dispersing through the grasslands during the wet season (Figure 38).

Activity

Ungulate activity information is presented in Tables 24 and 25 and Figure 39, expressed as a percentage of observed animals engaged in each activity. The tendency amongst most ungulate types in the study area was to use available supplementary food more in the dry season than in the wet season. However, the supplements differed between seasons. "Rumevite" game blocks were present in the dry season and salt was present all year. Whether the season or available food type caused the different usage of supplementary food is not possible to tell because no data were collected in this regard.

Concerning feeding on natural vegetation, springbok and impala were observed feeding more often than other ungulates while giraffe and black wildebeest were observed feeding less often than other ungulates. Unlike the black wildebeest, but like eland, more giraffe were observed in transit than were other ungulates. The proportion of giraffe seen feeding on natural

Table 24 Percentage of observed animals engaged in each of five activities in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season, May to September 1986.

UNGULATE TYPE	NUMBER OF UNGULATE OBSERVATIONS	UNGULATE ACTIVITY#				
		1	2	3	4	5
Blesbok	5238	50,6	0,1	43,7	5,5	0,1
Springbok	882	80,7	2,9	8,7	5,1	2,6
Burchell's zebra	447	40,9	0,9	51,7	6,6	-
Impala	458	75,6	1,1	20,5	2,6	0,2
Gemsbok	355	51,0	3,7	26,2	18,0	1,1
Eland	141	49,7	1,4	18,4	30,5	-
Black wildebeest	104	28,8	-	71,2	-	-
Giraffe	25	44,0	-	16,0	24,0	16,0
Sable antelope	50	90,0	-	10,0	-	-
Red hartebeest	124	49,2	10,5	40,3	-	-

# 1 = feeding on natural vegetation
2 = feeding on supplementary food
3 = resting (lying down or standing)
4 = in transit
5 = other

Table 25 Percentage of observed animals engaged in each of five activities in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the wet season, October 1986 to April 1987.

UNGULATE TYPE	NUMBER OF UNGULATE OBSERVATIONS	UNGULATE ACTIVITY#				
		1	2	3	4	5
Blesbok	7145	72,4	-	21,6	5,9	0,1
Springbok	963	84,5	-	9,3	4,5	1,7
Burchell's zebra	791	45,3	-	50,3	4,4	-
Impala	988	90,5	4,9	2,3	1,9	0,4
Gemsbok	1177	54,3	-	30,7	15,0	-
Eland	482	46,5	-	22,8	30,7	-
Black wildebeest	145	49,0	-	49,6	1,4	-
Giraffe	36	27,8	-	36,1	36,1	-
Sable antelope	140	52,9	1,4	40,0	4,3	1,4
Red hartebeest	273	52,7	-	36,3	10,6	0,4

# 1 = feeding on natural vegetation
2 = feeding on supplementary food
3 = resting (lying down or standing)
4 = in transit
5 = other

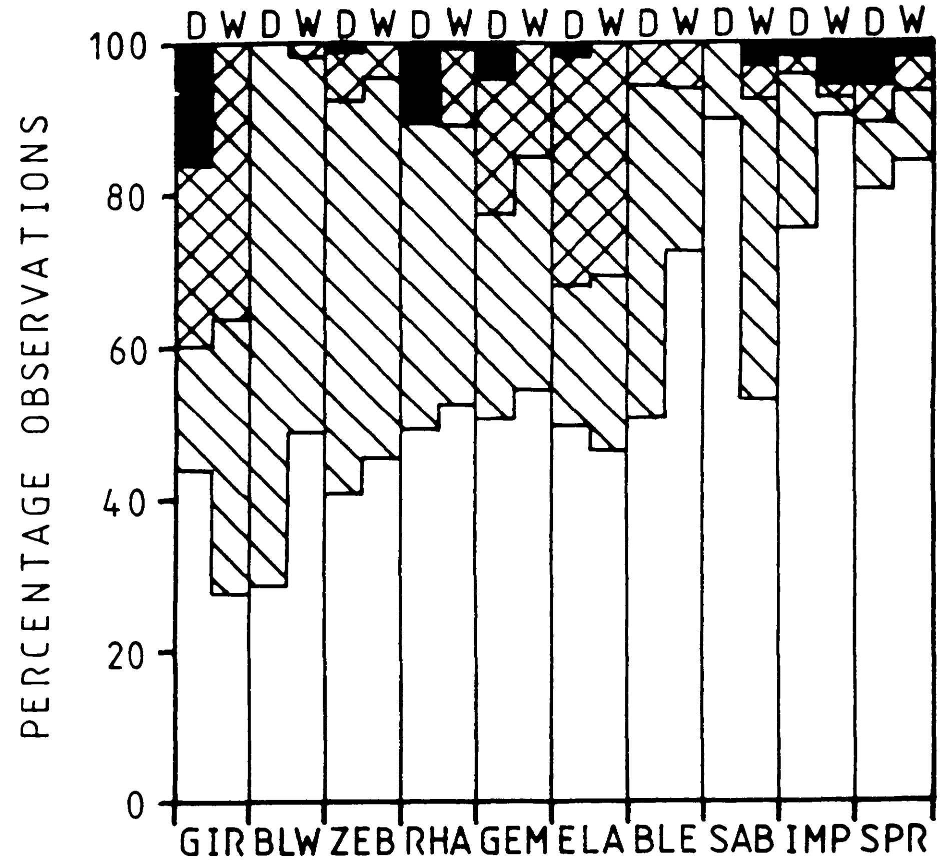


Figure 39 Percentage of observations of giraffe (GIR), black wildebeest (BLW), Burchell's zebra (ZEB), red hartebeest (RHA), gemsbok (GEM), eland (ELA), blesbok (BLE), sable antelope (SAB), impala (IMP) and springbok (SPR) engaged in feeding on natural food (open), resting (single hatching), in transit (double hatching) and other/feeding on supplementary food (solid) during the dry season (May to September 1986 - D) and the wet season (October 1986 to April 1987 - W) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

vegetation in the dry season was greater than in the wet season, indicating the dependence of giraffe on scattered trees in the grasslands of Jack Scott Nature Reserve for additional nutrition during the dry season. Like black wildebeest, blesbok increased their feeding activity and decreased their resting activity during the wet season. However, further comparison of these two ungulate types is meaningless because of the great disparity in their numbers in the study area. Similar proportions of Burchell's zebra, gemsbok and eland were observed feeding on natural food, but proportionally more gemsbok and eland were observed in transit, while proportionally more Burchell's zebra and red hartebeest were observed resting.

Habitat availability and utilisation

Bonferroni simultaneous confidence intervals are presented in Appendix C and are summarised in Tables 26 to 28, while affinity index values appear in Tables 29 to 32.

Blesbok selected areas of lower ruggedness (LSRI<20), higher altitude and dolomitic vegetation throughout the year (Tables 26 and 27). High altitude areas (>1499 m) were also, by nature, dolomitic areas, but the converse is not true. Selection of low altitude (<1450 m) areas of mixed chert and shale vegetation during the dry season (Tables 26 and 27) was possibly an effect of selection for the area burnt during spring 1985. Blesbok also selected year-round for areas around supplementary feed sites (Table 28), the selection of which could be stimulated either by the presence of supplementary food or the short-grass lawns caused by trampling. Areas with permanent water were not selected, while areas burnt less than one year prior to observation were selected all year (Table 28). The selection of wooded areas in the wet season (Table 28) could result either from such areas having been recently burnt or the quest for shade during the summer months.

Like blesbok, springbok selected year-round for low ruggedness, dolomite vegetation and recent burns (less than one year old) (Tables 26-28). Springbok also did not select for permanent water or woodland and supplementary feed sites were selected in the dry

Table 26 Selection of categories of ruggedness and mean altitude (m) by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period, as determined by calculating Bonferroni simultaneous confidence intervals (Byers et al. 1984).

UNGULATE TYPE	SEASON	HABITAT CATEGORY#					
		R1	R2	R3+R4	A1	A2	A3+A4
Blesbok	dry	+	+	-	+	-	+
	wet	+	-	-	-	-	+
Springbok	dry	+	*	-	+	-	*
	wet	+	-	-	-	-	+
Burchell's zebra	dry	+	-	-	-	-	+
	wet	+	-	-	-	-	+
Impala	dry	-	-	+	+	-	-
	wet	-	-	+	+	+	-
Gemsbok	dry	+	-	-	-	+	+
	wet	+	-	-	-	-	+
Eland	dry	-	*	-	+	*	-
	wet	+	*	-	-	-	+
Black wildebeest	dry	+	-	0	-	0	+
	wet	+	-	0	-	-	+
Giraffe	dry	*	*	+	*	*	*
	wet	*	*	-	+	*	*
Sable antelope	dry	*	*	*	*	+	0
	wet	*	*	*	+	*	-
Red hartebeest	dry	+	*	0	-	-	+
	wet	-	+	-	-	+	+

+ = observed use > expected use (α=0,05)
- = observed use < expected use (α=0,05)
* = no significant difference between observed and expected use (α=0,05)
1 = all animals recorded were in this category (equivalent to +)
0 = no animals were recorded in this category (equivalent to -)
# R1 = land surface ruggedness index (LSRI) of <20
R2 = LSRI of 20 to 39
R3+R4 = LSRI of >39
A1 = mean altitude of <1450 m
A2 = mean altitude of 1450 to 1499 m
A3+A4 = mean altitude of >1499 m

Table 27 Selection of categories of vegetation by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period, as determined by calculating Bonferroni simultaneous confidence intervals (Byers et al. 1984).

UNGULATE TYPE	SEASON	HABITAT CATEGORY#						
		VC	VD	VF	VS	VCD	VCS	VSF
Blesbok	dry	*	+	-	-	-	+	*
	wet	-	+	-	-	*	-	-
Springbok	dry	*	+	0	-	-	+	*
	wet	-	+	0	-	-	+	0
Burchell's zebra	dry	-	+	0	0	-	0	0
	wet	-	+	0	-	-	0	0
Impala	dry	+	-	0	-	-	+	+
	wet	-	-	-	+	-	+	+
Gemsbok	dry	-	+	0	-	-	-	0
	wet	-	+	0	0	*	-	0
Eland	dry	-	+	0	-	*	*	*
	wet	-	+	*	-	+	-	*
Black wildebeest	dry	0	+	0	-	0	*	0
	wet	-	+	0	0	0	-	0
Giraffe	dry	0	*	0	-	*	*	*
	wet	0	+	0	+	0	0	0
Sable antelope	dry	0	0	+	+	0	0	0
	wet	-	-	+	+	-	+	0
Red hartebeest	dry	0	+	0	*	*	0	0
	wet	-	+	0	0	-	-	-

+ = observed use > expected use (α=0,05)
- = observed use < expected use (α=0,05)
* = no significant difference between observed and expected use (α=0,05)
1 = all animals recorded were in this category (equivalent to +)
0 = no animals were recorded in this category (equivalent to -)
# VC = vegetation consists of the chert community
VD = vegetation consists of the dolomite community
VF = vegetation consists of the old lands community
VS = vegetation consists of the shale community
VCD = vegetation consists of both the chert and dolomite communities
VCS = vegetation consists of both the chert and shale communities
VSF = vegetation consists of both the shale and old lands communities

Table 28 Selection of categories of woodland, supplementary feed sites, permanent water and burning history by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period, as determined by calculating Bonferroni simultaneous confidence intervals (Byers et al. 1984).

UNGULATE TYPE	SEASON	HABITAT CATEGORY#							
		WA	WP	SFSA	SFSP	PWA	PWP	B<1	B>1
Blesbok	dry	*	*	-	+	+	-	+	-
	wet	-	+	-	+	+	-	+	-
Springbok	dry	+	-	-	+	+	-	+	-
	wet	+	-	+	-	+	-	+	-
Burchell's zebra	dry	+	-	*	*	1	0	-	+
	wet	+	-	-	+	1	0	+	-
Impala	dry	-	+	-	+	*	*	+	-
	wet	-	+	-	+	-	+	+	-
Gemsbok	dry	+	-	-	+	1	0	-	+
	wet	+	-	+	-	1	0	+	-
Eland	dry	-	+	*	*	+	-	-	+
	wet	*	*	-	+	+	-	+	-
Black wildebeest	dry	1	0	1	0	1	0	-	+
	wet	1	0	*	*	1	0	-	+
Giraffe	dry	*	*	1	0	1	0	*	*
	wet	-	+	-	+	-	+	+	-
Sable antelope	dry	-	+	1	0	-	+	0	1
	wet	-	+	*	*	-	+	-	+
Red hartebeest	dry	-	+	-	+	*	*	0	1
	wet	+	-	-	+	1	0	*	*

+ = observed use > expected use (α=0,05)
- = observed use < expected use (α=0,05)
* = no significant difference between observed and expected use (α=0,05)
1 = all animals recorded were in this category (equivalent to +)
0 = no animals were recorded in this category (equivalent to -)
# WA = woodland absent
WP = woodland present
SFSA = supplementary feed site absent
SFSP = supplementary feed site present
PWA = permanent water absent
PWP = permanent water present
B<1 = burnt less than one year ago
B>1 = burnt more than one year ago

Table 29 Affinity index values (observed proportion of use/ expected proportion of use) pertaining to the use of categories of ruggedness and mean altitude (m) by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period.

UNGULATE TYPE	SEASON	HABITAT CATEGORY#					
		R1	R2	R3+R4	A1	A2	A3+A4
Blesbok	dry	1,34	1,06	0,21	1,58	0,65	1,04
	wet	1,68	0,82	0,10	0,35	0,42	1,78
Springbok	dry	1,56	0,96	0,02	2,24	0,30	1,05
	wet	1,97	0,55	0,03	0,72	0,12	1,87
Burchell's zebra	dry	1,82	0,54	0,44	0,09	0,60	1,74
	wet	1,99	0,56	0,08	0,06	0,16	2,13
Impala	dry	0,45	0,79	2,54	3,51	0,63	0,22
	wet	0,71	0,90	1,80	1,45	1,13	0,69
Gemsbok	dry	1,49	0,82	0,46	0,34	1,15	1,16
	wet	1,90	0,60	0,17	0,05	0,49	1,86
Eland	dry	0,73	1,08	1,34	0,48	1,33	0,94
	wet	1,15	1,06	0,57	0,24	0,70	1,58
Black wildebeest	dry	2,66	0,02	0,00	0,14	0,00	2,23
	wet	2,63	0,05	0,00	0,14	0,09	2,16
Giraffe	dry	0,63	0,74	2,30	0,92	1,34	0,74
	wet	0,86	1,37	0,44	1,89	0,63	0,93
Sable antelope	dry	1,16	0,83	1,08	1,71	1,81	0,00
	wet	0,92	1,03	1,09	3,03	0,92	0,17
Red hartebeest	dry	1,75	0,80	0,00	0,49	0,25	1,86
	wet	0,71	1,49	0,44	0,02	1,35	1,13
Mean	dry	1,36	0,76	0,84	1,15	0,81	1,10
	wet	1,45	0,84	0,47	0,80	0,60	1,43

# R1 = land surface ruggedness index (LSRI) of <20
R2 = LSRI of 20 to 39
R3+R4 = LSRI of >39
A1 = mean altitude of <1450 m
A2 = mean altitude of 1450 to 1499 m
A3+A4 = mean altitude of >1499 m

Table 30 Affinity index values (observed proportion of use/ expected proportion of use) pertaining to the use of categories of vegetation by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period.

UNGULATE TYPE	SEASON	HABITAT CATEGORY#						
		VC	VD	VF	VS	VCD	VCS	VSF
Blesbok	dry	0,95	1,14	0,05	0,73	0,46	2,49	0,88
	wet	0,39	1,70	0,14	0,09	0,97	0,45	0,59
Springbok	dry	1,15	1,14	0,00	0,26	0,16	3,79	0,63
	wet	0,22	1,77	0,00	0,28	0,51	1,70	0,00
Burchell's zebra	dry	0,30	1,95	0,00	0,00	0,69	0,00	0,00
	wet	0,16	2,01	0,00	0,01	0,70	0,00	0,00
Impala	dry	1,57	0,06	0,00	0,74	0,25	9,53	1,97
	wet	0,79	0,46	0,05	1,52	0,69	4,96	3,72
Gemsbok	dry	0,36	1,97	0,00	0,03	0,41	0,13	0,00
	wet	0,42	1,70	0,00	0,00	1,13	0,60	0,00
Eland	dry	0,57	1,56	0,00	0,06	0,70	1,47	1,00
	wet	0,76	1,21	0,81	0,51	1,46	0,51	0,78
Black wildebeest	dry	0,00	2,23	0,00	0,07	0,00	0,38	0,00
	wet	0,09	2,23	0,00	0,00	0,00	0,15	0,00
Giraffe	dry	0,00	1,48	0,00	0,23	1,45	1,87	1,84
	wet	0,00	1,46	0,00	2,92	0,00	0,00	0,00
Sable antelope	dry	0,00	0,00	20,52	4,59	0,00	0,00	0,00
	wet	0,64	0,45	5,43	3,22	0,21	2,70	0,00
Red hartebeest	dry	0,00	1,71	0,00	0,76	1,31	0,00	0,00
	wet	0,12	2,05	0,00	0,00	0,62	0,04	0,06
Mean	dry	0,49	1,32	2,06	0,75	0,54	1,97	0,63
	wet	0,36	1,50	0,64	0,86	0,63	1,11	0,52

# VC = vegetation consists of the chert community
VD = vegetation consists of the dolomite community
VF = vegetation consists of the old lands community
VS = vegetation consists of the shale community
VCD = vegetation consists of both the chert and dolomite communities
VCS = vegetation consists of both the chert and shale communities
VSF = vegetation consists of both the shale and old lands communities

Table 31 Affinity index values (observed proportion of use/ expected proportion of use) pertaining to the use of categories of woodland and supplementary feed sites by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period.

UNGULATE TYPE	SEASON	HABITAT CATEGORY#			
		WA	WP	SFSA	SFSP
Blesbok	dry	1,05	0,87	0,95	3,17
	wet	0,99	1,04	0,96	2,71
Springbok	dry	1,09	0,74	0,91	4,46
	wet	1,10	0,72	1,01	0,62
Burchell's zebra	dry	1,17	0,51	1,00	1,17
	wet	1,21	0,40	0,99	1,58
Impala	dry	0,42	2,67	0,92	4,25
	wet	0,64	2,04	0,97	2,33
Gemsbok	dry	1,08	0,77	0,92	4,12
	wet	1,22	0,36	1,01	0,62
Eland	dry	0,89	1,32	0,98	2,00
	wet	0,98	1,07	0,95	2,83
Black wildebeest	dry	1,35	0,00	1,02	0,00
	wet	1,35	0,00	1,00	0,83
Giraffe	dry	0,75	1,72	1,02	0,00
	wet	0,31	2,98	0,65	15,08
Sable antelope	dry	0,60	2,15	1,02	0,00
	wet	0,67	1,95	0,97	2,37
Red hartebeest	dry	0,25	3,16	0,93	3,92
	wet	1,06	0,81	0,97	2,04
Mean	dry	0,87	1,39	0,97	2,31
	wet	0,95	1,14	0,95	3,10

# WA = woodland absent
WP = woodland present
SFSA = supplementary feed site absent
SFSP = supplementary feed site present

Table 32 Affinity index values (observed proportion of use/ expected proportion of use) pertaining to the use of categories of permanent water and burning history by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period.

UNGULATE TYPE	SEASON	HABITAT CATEGORY#			
		PWA	PWP	B<1	B>1
Blesbok	dry	1,03	0,46	3,29	0,73
	wet	1,05	0,12	6,76	0,46
Springbok	dry	1,05	0,08	4,10	0,63
	wet	1,05	0,08	3,85	0,73
Burchell's zebra	dry	1,05	0,00	0,26	1,09
	wet	1,05	0,00	2,29	0,88
Impala	dry	0,98	1,40	1,99	0,88
	wet	0,96	1,78	1,76	0,93
Gemsbok	dry	1,05	0,00	0,45	1,06
	wet	1,05	0,00	2,21	0,89
Eland	dry	1,05	0,08	0,30	1,08
	wet	1,05	0,06	4,40	0,68
Black wildebeest	dry	1,05	0,00	0,25	1,09
	wet	1,05	0,00	0,47	1,05
Giraffe	dry	1,05	0,00	0,56	1,05
	wet	0,67	7,24	2,97	0,82
Sable antelope	dry	0,71	6,56	0,00	1,12
	wet	0,79	5,06	0,51	1,05
Red hartebeest	dry	0,95	1,88	0,00	1,12
	wet	1,05	0,00	0,92	1,01
Mean	dry	1,00	1,05	1,12	0,99
	wet	0,98	1,43	2,61	0,85

# PWA = permanent water absent
PWP = permanent water present
B<1 = burnt less than one year ago
B>1 = burnt more than one year ago

season, but not in the wet season (Table 28). As with blesbok, the use of low altitude areas of mixed shale and chert vegetation was probably caused by the 1985 burn.

Burchell's zebra, like the previous two ungulate types, selected areas of low ruggedness, high altitude and dolomite vegetation throughout the year (Tables 26 and 27). Woodland areas were avoided year-round while supplementary feed sites were selected only in the wet season (Table 28). The non-selection of recently burnt areas in the dry season and the opposite situation in the wet season (Table 28) implies that by the dry season, Burchell's zebra were no longer attracted to areas burnt in the previous spring. No sightings of Burchell's zebra during the day occurred in pixels containing permanent water (Table 28).

Impala selected for higher ruggedness (LSRI>39), low altitude (<1450 m), wooded areas, supplementary feed sites and recent burns throughout the year (Tables 26 and 28). The apparent selection for areas of combined chert/shale and shale/old lands vegetation was possibly caused by the resident herd in the south-west being present in an area containing all three vegetation communities in relatively close proximity to each other (<u>cf</u>. Figures 23 and 35). The selection of shale grasslands in the wet season indicates the movement of impala into open areas as discussed above and permanent water was selected during the wet season only (Tables 27 and 28).

In both the dry and wet seasons, gemsbok selected areas of low ruggedness, high altitude and dolomitic vegetation, as well as areas away from trees and permanent water (Tables 26-28). Supplementary feed sites were selected in the dry season, but not in the wet season and recent burns were selected in the wet season but not in the dry season (Table 28) as with Burchell's zebra, implying an attraction to burnt areas for less time than blesbok and springbok which both selected burnt areas up to one year after burning. In explanation: during the dry season, the previous spring's burn is more than six months old, while in the wet season the most recent spring burn is six months old or less.

The same pattern of attraction to burnt areas appeared to apply as much to eland as to Burchell's zebra and gemsbok. Again, dolomitic vegetation and areas away from water were selected in both the dry and wet seasons (Tables 27 and 28). Noticeable in Tables 26 to 28 is the number of asterisks, which indicates more chance (random) utilisation of the environment than in the case of other ungulates (cf. Figure 36). There was, however, selection for upland dolomite areas of low ruggedness during the wet season when the nursery herd was formed (Tables 26 and 27). The selection of wooded areas in the dry season could be linked to a dietary change, while the selection of supplementary feed sites in the wet season could be for the salt (Table 28).

The black wildebeest showed restricted movements, with little seasonal change. Flat, upland, dolomite areas without trees or water and unburnt for at least one year were selected all year by the black wildebeest in the study area.

Giraffe showed mostly random utilisation in the dry season (cf. Figure 37) as with eland. Recent burns were used in the wet season, but probably because the 1986 burn included woodland, while the wet-season selection of woodland, supplementary feed sites and permanent water could well be an effect of sighting the whole population at one time one day in pixel L20 where all three features occur (Table 28; Figures 24 and 25).

Unlike all other ungulate types studied, sable antelope selected for old lands, shale vegetation, wooded areas and permanent water in both seasons (Tables 27 and 28). The old lands and shale communities were characterised by high phytomass (Chapter Three, Part Two) and had not been burnt for over three years. Land surface ruggedness did not influence the distribution of sable antelope (Table 26).

Red hartebeest selected upland, dolomite areas and supplementary feed sites in both seasons while unburnt, wooded areas were selected in the dry season and wooded areas were avoided in the wet season (Tables 26-28).

Those habitat categories with consistently high mean affinity index values (>1,00) were: less rugged (LSRI<20), high altitude (>1499 m), dolomite vegetation, mixed chert/shale vegetation, wooded areas, supplementary feed sites, areas with permanent water and areas with no more than one season's plant growth (Tables 29-32).

Based on affinity index values above 1,00 for both seasons, less rugged areas and supplementary feed sites were each selected by five of the 10 ungulate types (Tables 29 and 31). Knowing that the higher areas were also dolomitic, seven of the 10 ungulate types selected these categories combined. All together, eight of the 10 ungulate types selected areas of low ruggedness, high altitude, and dolomite vegetation (Tables 29 and 30). The six most abundant ungulate types, namely blesbok, impala, eland, gemsbok, springbok and Burchell's zebra, with two of the four less abundant types, namely red hartebeest and black wildebeest, selected a combination of the categories mentioned above.

Less rugged, upland, dolomite areas occur in the south and north-east, of which the latter was burnt in October 1986. As impala were never seen in the former area, their occurrence on the said habitat categories was probably as a result of the burning. The other seven ungulate types mentioned above were seen in both areas.

The remaining two ungulate types, namely sable antelope and giraffe, favoured wooded areas, while the former selected areas with permanent water as well. Like sable antelope, impala favoured wooded areas, but unlike the former, impala also utilised recent burns.

Multivariate analyses

Detrended correspondence analysis results are plotted in Figures 40 and 41. Because of the large number of samples (339), the sample ordination of the pixel-by-ungulate type approach was unwieldy and is not shown. The second approach of using ungulate types as individuals and habitat categories as attributes proved to yield results no different from the pixel-by-ungulate type

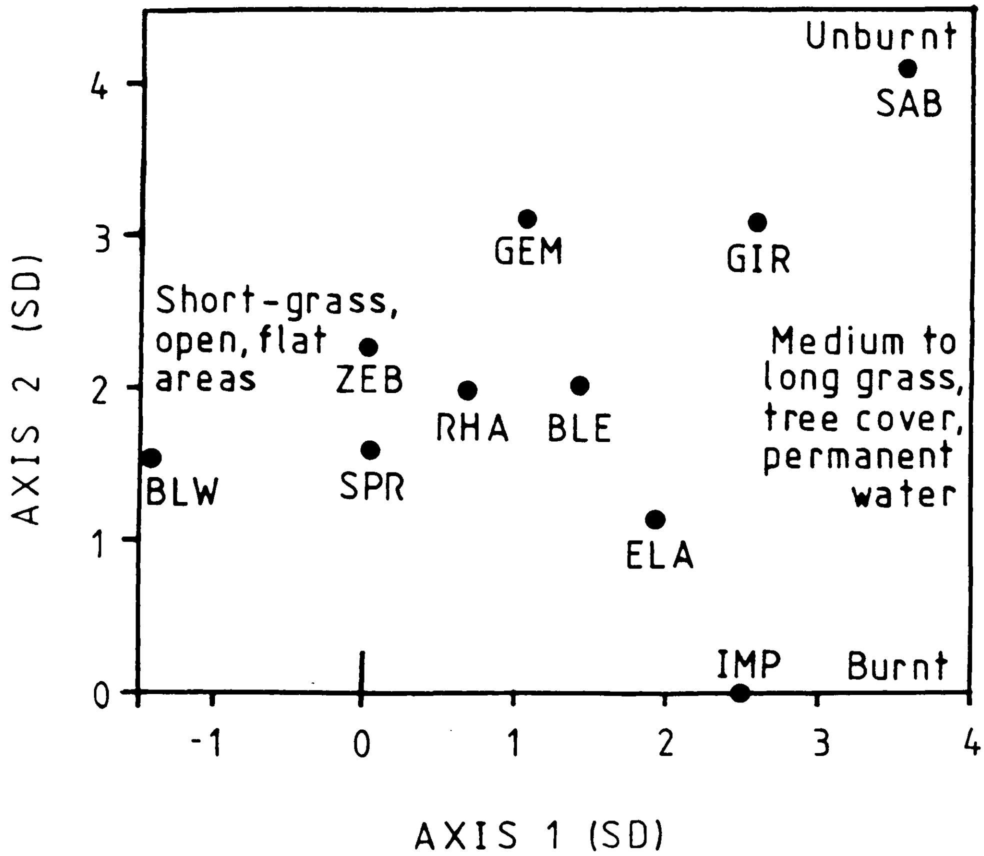


Figure 40 Ordination, by DECORANA, of ungulate types observed in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the period May 1986 to April 1987, based on the number of animals counted per pixel. Eigenvalues for the first and second axes are 0,410 and 0,250 respectively and ungulate types are black wildebeest (BLW), Burchell's zebra (ZEB), springbok (SPR), red hartebeest (RHA), gemsbok (GEM), blesbok (BLE), eland (ELA), impala (IMP), giraffe (GIR) and sable antelope (SAB).

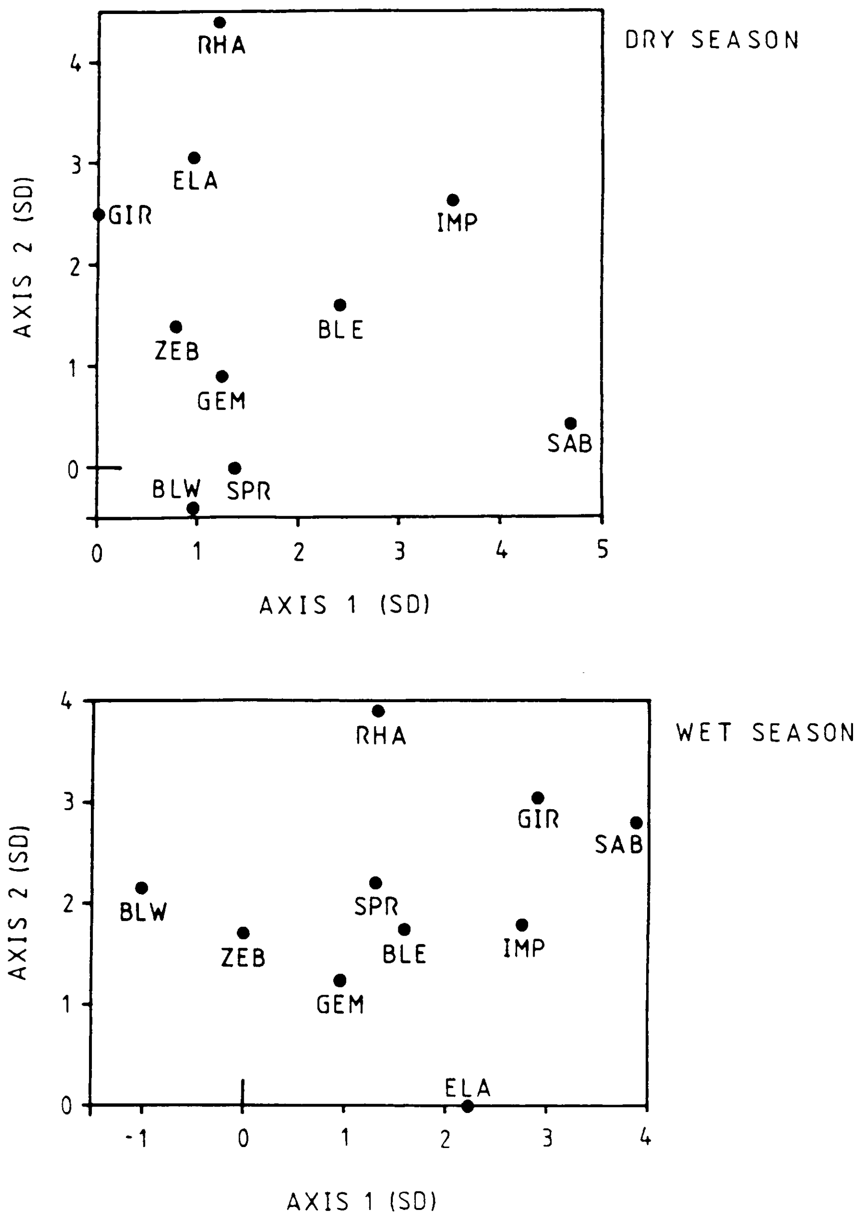


Figure 41 Ordination, by DECORANA, of ungulate types observed in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987), based on the number of animals counted per pixel. Eigenvalues for the first and second axes respectively are 0,653 and 0,388 for the dry season and 0,552 and 0,351 for the wet season, while ungulate types are black wildebeest (BLW), Burchell's zebra (ZEB), springbok (SPR), red hartebeest (RHA), gemsbok (GEM), blesbok (BLE), eland (ELA), impala (IMP), giraffe (GIR) and sable antelope (SAB).

approach. The former results were, in fact, less clear than the latter. Only the attribute ordinations of the first approach (pixel-by-ungulate type), as applied to both seasons and the whole year, are considered here.

The first axis for all three time periods considered, represents, from left to right across Figures 40 and 41, a preference for short-grass, open, flat areas, away from trees, to a preference for medium- to tall-grass areas with tree cover and permanent water. The second axis, especially on the right of Figure 40, separates impala from sable antelope, the former being a selector of recently burnt areas and the latter being a selector of unburnt areas with dense grass cover, as described above.

While most ungulate types remained in relatively the same positions along the first axis between seasons, the point representing giraffe moved from left to right with the wet season (Figure 41). Giraffe sightings in the wet season were on the edge of the study area, not far from the woodland part of the reserve (Figure 37), while in the dry season giraffe occurred more widely through the study area, browsing on singular individuals or clusters of trees scattered through the study area. This observation supports the previous comments on the distribution and activity of giraffe in the study area.

Also of note is the consistent position of blesbok in the middle of the field of points in Figures 40 and 41, blesbok being the most abundant ungulate type and relatively general with respect to habitat use.

CONCLUSIONS

Numbers, distribution and activity

Apart from eland, impala and black wildebeest, all ungulate populations that were studied remained stable or increased in number in the study area during the study period. Changes in the numbers of eland and impala are difficult to assess because of the lack of accurate totals for the whole of Jack Scott nature

Reserve, while it is suspected that one of the four black wildebeest died during the study period.

Most ungulate populations showed increased abundance in the study area during the wet season, caused partly by births and partly by immigration. Only black wildebeest and giraffe failed to display this pattern. Some ungulates, especially blesbok, impala, springbok and sable antelope also became more evident during the spring flush prior to their later peak in summer.

There were distinct differences in distribution among ungulate types in the study area and, in some cases, between the wet and dry seasons. However, ungulates concentrated in the south all year and dispersed to the previous spring's burn during each season. The southern area appeared to be of year-round importance and it is probably subjected to continuous grazing, with some pressure taken off by the burning of other areas.

Just as the distribution reflected the ecological separation of the ungulates, so did the activity patterns. Most of the ungulate types considered used supplementary food more in the dry season than in the wet season. However, "Rumevite" was available only in the former while salt was available all year. Giraffe and eland were seen mostly in transit or feeding as they moved around the study area looking for scattered browse, especially in the dry season. On the other hand, the typical grassland ungulates such as springbok, black wildebeest and blesbok were involved mostly in feeding and resting, with limited movement.

Habitat selection

The methods used in the present study to examine habitat use by ungulates in the study area complemented each other and highlighted the same features affecting habitat use. The primary dichotomy was the separation between open grassland ungulates such as blesbok, springbok and black wildebeest, and woodland ungulates such as impala and sable antelope. Blesbok, springbok and impala utilised burnt areas up to one year after burning, while Burchell's zebra, gemsbok and eland utilised burnt areas only for the first six months after burning. Other ungulates, namely giraffe, black wildebeest, red hartebeest and sable antelope were not particularly selective of any burnt areas.

The present study also empasised the selection of the southern area by most of the ungulate biomass on Jack Scott Nature Reserve. This fact should be remembered when calculating stocking rates, planning burning and positioning supplementary feed sites and water points. The fact that many ungulate types normally dependent on water did not show significant selection of permanent water means that water was not a limiting factor in this case.

PART TWO

CARRYING CAPACITY AND STOCKING RATES

INTRODUCTION

Carrying capacity means different things to different people. For game farmers and domestic stock farmers, economic carrying capacity is the stocking rate which gives maximum sustained yield, in other words, maximum animal production. On the other hand, ecological carrying capacity is "the average density a population assumes over a long period if it is not harvested" (Caughley 1983). In the words of Eltringham (1979), ecological carrying capacity is "the maximum number of animals that can be supported (indefinitely) in a particular area without causing habitat deterioration." Economic carrying capacity usually approximates half of the ecological carrying capacity, in other words, the population density corresponding to the inflection point of the sigmoid population growth curve (Mentis 1977; Baily 1984). Carrying capacity is habitat-related, while stocking rate is management-related.

Because of the different energy requirements of animals, carrying capacity and stocking rate for domestic animals are expressed in terms of metabolic mass ($W^{0,75}$) rather than live mass (W). Smaller ungulates require more energy per unit mass than larger ungulates (Mentis & Duke 1976; Mentis 1977). Different ungulates can be related to each other through the livestock unit (LU) which is equivalent to a steer of 450 kg which gains mass at a rate of 500 g per day on grass pasture with a mean digestible energy concentration of 55 % ; to maintain this, 75 MJ metabolisable energy per day is required (Meissner 1982). The number of individuals of a species (X) equivalent to one livestock unit is calculated by:

$$450^{0,75}/(\text{mean body mass of X})^{0,75}$$

The derived livestock unit equivalent for each species depends on the mean body mass used in the calculation. The concept of livestock unit equivalents is not perfect as the assumption is made that the differences between individuals of a species are only proportional to a particular exponent of body mass, namely 0,75 (Meissner 1982). In other words, the physiological differences between conspecific individuals of equivalent age and mass are not accounted for. Meissner (1982) therefore proposed a method which compares the energy intake of animals of different age and production phase with the livestock unit. However, this approach requires a knowledge of growth rates, basal heat production, composition of growth, efficiency of feed energy utilisation and average nutritional quality of the species' habitat.

When calculating stocking rates (LU.ha^{-1}) for wild ungulates, certain factors must be remembered. Ungulates can be classified into three feeding groups: bulk and roughage eaters, concentrate selectors and intermediate feeders. The bulk and roughage eaters can take in large quantities of fibrous food, mostly grass, and can be further divided into large (200 kg or more) and small (<200 kg) bulk and roughage eaters, according to Mentis & Duke (1976). The concentrate selectors eat mostly the leaves, flowers and fruit of forbs, shrubs and trees as well as fresh grass, while the intermediate feeders adapt according to area or season towards either bulk and roughage eating or concentrate selecting (Hoffman & Stewart 1972). These feeding types are important when relating game to livestock units because the latter is a large bulk and roughage eater which can tolerate fibrous food and thus can occur at higher stocking rates than the former. The other feeding types are more selective than large bulk and roughage eaters such as cattle, zebra, buffalo, roan and white rhinoceros. The food selected by small bulk and roughage eaters, concentrate selectors and intermediate feeders is scarcer than the more fibrous food used by large bulk and roughage eaters (Mentis 1977). The agriculturally determined carrying capacities of different areas are therefore, generally, overestimates of the game carrying capacities. The smaller ruminants, concentrate selectors and intermediate feeders such as blesbok, springbok, impala, red hartebeest, sable antelope, gemsbok, black wildebeest, giraffe and eland require the relatively scarce, concentrate food and should not exceed 40 to 50 % of the recommended carrying capacity (Mentis & Duke 1976). Another reason for stocking game below the agricultural carrying capacity is that game are not usually grazed on a rotational basis as cattle are. The distribution of wild ungulates tends to be uneven because of uncontrolled grazing and because of factors such as topography, water availability and vegetation.

Finally, it should be mentioned that the use of livestock units for determining stocking rates only gives broad guidelines for an area. Stocking rates thus derived should be considered with caution and viewed in the light of an intimate knowledge of the area and animals concerned. As stated by Van Hoven & Ebedes (1986), the use of livestock units can yield a false impression. When applying this approach to wild ungulate populations, the validity can only be tested by constant, long-term monitoring of the ungulate populations' age and sex structures, and the productivity and composition of the rangeland. Alternative methods of determining carrying capacity and stocking rates are: by trial-and-error and through a knowledge of energy availability and utilisation. The latter is probably the most direct and precise method, but requires a knowledge of the amount of food available, the amount of metabolisable energy in the food and the amount of metabolisable energy required by individuals of a species (Van Hoven & Ebedes 1986).

METHOD

Without data on energetics, the only approach in the present situation was to use livestock units for the calculation of stocking rates (Van Hoven*, pers. comm.). Tainton (1981b) combines Tall Grassveld and Bankenveld in the same category of carrying capacity, so the carrying capacity figures for wild ungulates on Tall Grassveld in Natal, as given by Mentis & Duke (1976) were used as a guideline. More specifically, the more conservative estimate of 4,5 $ha.LU^{-1}$ for Dry Tall Grassveld was used to calculate the potential stocking rate of the study area, as opposed to 3,6 $ha.LU^{-1}$ for Moist Tall Grassveld. Livestock

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unit equivalents for the different ungulate types were obtained from a table appended to a letter dated 27 May 1985 from Marchant* to Vaughan** (Table 33). Stocking levels in the study area at the time of the study were calculated on the basis of the maximum number of each ungulate type recorded during the study period.

RESULTS

On the basis of a potential carrying capacity of 4,5 ha.LU^{-1}, the 2100 ha study area has a potential stocking rate of 0,22 LU.ha^{-1}, or a potential stocking level of 465 LU. However, 30 pixels (190 ha) were not used by game during the study period (Figure 32), thereby reducing the potential stocking rate to 0,20 LU.ha^{-1}, or a potential stocking level of 425 LU. The actual stocking levels for the study area at the time of the study are presented in Table 34.

Although the stocking level of 200 LU was less than half the potential stocking level, it must be remembered that most of the ungulates concentrated on a relatively small area in the south and the more rugged areas (land surface ruggedness index [LSRI] >39), making up 20 % of the study area, were not used much. The shale community and old lands, which together make up 14,5 % of the study area and are both relatively flat, were not used much either, except by sable antelope (Chapter Four, Part One).

Considering that vegetation can be managed more readily than topography (for example, through burning) to make it more available to ungulates, topography becomes an important limiting factor to bear in mind. Of all the pixels in the study area, 109 are of low ruggedness (LSRI<20), but of these, six were not used by any ungulates, leaving 103 (645 ha). Such areas of low ruggedness are important as they were significantly selected year-round by ungulate types that made up 60 % of all the

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Table 33 Mean live mass (kg) and number of animals per livestock unit (LU) (Marchant*, pers. comm.) for the ungulate types studied in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal from May 1986 to April 1987.

UNGULATE TYPE	MEAN LIVE MASS	$ANIMALS.LU^{-1}$
Blesbok	55	4,9
Springbok	28	8,1
Burchell's zebra	200	1,8
Impala	40	6,1
Gemsbok	150	2,3
Eland	340	1,2
Black wildebeest	110	2,9
Giraffe	750	0,7
Sable antelope	185	1,9
Red hartebeest	182	2,0

* Mr A.N. Marchant, 1985, Natal Parks, Game and Fish Preservation Board, P.O. Box 662, PIETERMARITZBURG 3200

Table 34 Maximum recorded numbers, converted to stocking levels (in livestock units - LU), for each ungulate type studied in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, from May 1986 to April 1987.

UNGULATE TYPE	MAXIMUM NUMBER	STOCKING LEVEL (LU)
Blesbok	382	78,0
Springbok	41	5,1
Burchell's zebra	34	18,9
Impala	95	15,6
Gemsbok	40	17,4
Eland	41	34,2
Black wildebeest	4	1,4
Giraffe	13	18,6
Sable antelope	7	3,7
Red hartebeest	15	7,5
Total	672	200,4

livestock units (120 livestock units), namely blesbok, springbok, Burchell's zebra, gemsbok and black wildebeest (Chapter Four, Part One). This is important considering that an area of 645 ha has a potential stocking level of 145 LU, based on a carrying capacity of 4,5 $ha.LU^{-1}$ for wild ungulates.

An important feature revealed in Table 34 is the low proportion of large bulk and roughage eaters which, according to Mentis & Duke (1976), should constitute at least 50 % of the total livestock units. The only large bulk and roughage eaters present during the study period were Burchell's zebra, which comprised only 9,5 % of the total livestock units on the study area. Rather than increasing the proportion of large bulk and roughage eaters at the expense of an increased stocking level, the proportion of large bulk and roughage eaters should be increased at the expense of some of the less common or out-of-range ungulate types. The proportion of large bulk and roughage eaters can be increased by adding more zebra and/or cattle as opposed to buffalo, which are subject to strict veterinary restrictions and white rhinoceros, which require strong fencing before release in a wildlife management area. Aesthetically, zebra are obviously better than cattle, but are less readily available. By removing such game as gemsbok, springbok and black wildebeest, a further 42 zebra could, according to the above analysis, be carried while maintaining a stocking level of 200 LU. However, it should be remembered that zebra, being non-ruminants, consume 2,5 times more food on an equal mass basis than do ruminants (Van Hoven*, pers. comm.). Rather than buying a large number of zebra, emphasis should be placed on building up the population by breeding. The careful use of fire can also make up for the deficiency in large bulk and roughage eaters by removing the more fibrous vegetation and making the less fibrous food available to small bulk and roughage eaters and intermediate feeders. Monitoring of the ungulates and vegetation should be carried out to provide a base for future decisions on stocking levels and ratios.

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CONCLUSIONS

Although the stocking level in terms of livestock units was not overly high in the study area during the study period, the stock ratio was balanced against large bulk and roughage eaters and priority should be given to achieving and maintaining a balanced ratio. While correcting this ratio, monitoring of the animals and vegetation should be implemented. To allow for the likelihood that the potential stocking level is overestimated, as is often the case when using agriculturally derived terms of reference, the stocking level in the study area should be maintained at 200 LU - a stocking rate of 0,10 $LU.ha^{-1}$.

CHAPTER FIVE: DISCUSSION AND MANAGEMENT

The following discussion reflects the author's personal views of the various main methods used in the study, based on actual results and personal experience, and reviews the author's conclusions derived from the study. The methods used for the secondary aspects of the study, such as the determination of net primary production and plant production rates, and the determination of numbers and activities of ungulates are not discussed below because such determinations were done supplementary to the main objectives stated in Chapter One. However, the results and conclusions of the secondary aspects are discussed.

THE BOTANICAL SURVEY

From the results of the present study, it appears that the methods used were effective, despite certain drawbacks. The dry-weight rank method of 't Mannetje & Haydock (1963) for analysing the botanical composition of the natural grasslands and old lands was effectively applied using 400 quadrats of 0,25 m^2 per grassland community defined for the study. The application of detrended correspondence analysis (Hill 1979a) and two-way indicator species analysis (Hill 1979b) helped to elucidate the outstanding features of each vegetation unit and the relationships between these units.

The most noticeable fault with dry-weight ranking in the present study was the method's inability to distinguish the plant species widely distributed across the samples, from the species of equal mass contribution but restricted to fewer samples. For example, Kohautia amatymbica and Stoebe vulgaris made up 0,7 % (by dry mass) of the botanical composition of the old lands, but the former occurred in six of the 10 samples, while the latter occurred in only two of the 10 samples.

The primary dichotomy in the grasslands of the study area in terms of botanical compostion, as revealed by detrended correspondence analysis and two-way indicator species analysis, was between the disturbed old lands and the three, undisturbed, subclimax communities. Within the old lands there was a gradient from early- to late-stage secondary succession, while across the three subclimax communities there was a gradient from the vegetation on shale (rich in acid elements), through the vegetation on chert-rich dolomite, to the vegetation on chert-poor dolomite (rich in base elements). The shale community, which was least used by ungulates, was characterised by Increaser I grasses, while the dolomite community (on chert-poor dolomite), which was most used by ungulates, was characterised by Increaser II grasses.

The standard disc pasture meter described by Bransby & Tainton (1977) was successfully used for the determination of total phytomass and graminaceous phytomass in each grassland community in the study area. The use of over 1 000 disc height readings was more than necessary and 500 would have been generally acceptable for such grasslands, however such conclusions require statistical testing. The disc pasture meter was not successful in determining the phytomass of non-grasses, 'palatable' grasses and 'unpalatable' grasses, as indicated by the regression analyses.

Total phytomass during the present study ranged from 251 to 387 $g.m^{-2}$ depending on the season and grassland community. The lowest value of phytomass was recorded during early spring and the highest was recorded in late autumn. This range of phytomass values agrees with the figure of 350 $g.m^{-2}$ quoted by Rutherford (1978) for similar rangeland near Johannesburg. The annual aerial net primary production figures of 162 to 309 $g.m^{-2}.yr^{-1}$, depending on the grassland community and derived from the periodic harvesting of permanent quadrats by clipping, agree with the figures of 150 $g.m^{-2}.yr^{-1}$ (Murphy 1975), 100 to 190 $g.m^{-2}.yr^{-1}$ (Rutherford 1978) and 216 $g.m^{-2}.yr^{-1}$ (ibid.) for grasslands around Pretoria and Johannesburg. Furthermore, Lauenroth (1979) gives a mean aerial net primary production estimate of 200 $g.m^{-2}.yr^{-1}$ for climatically similar grassland sites around the world.

THE UNGULATE SURVEY

The combination of applying Bonferroni simultaneous confidence intervals (Byers et al. 1984) and detrended correspondence analysis to the data of the present study proved to be complementary, with the results of each technique supporting each other as far as the major habitat utilisation patterns were concerned.

All ungulate populations in the study area, except for giraffe and black wildebeest, increased in abundance during the wet season, while blesbok, impala, springbok and sable antelope showed two peaks in abundance: at the time of the spring flush, and again later in summer. The distribution of ungulates in the study area was concentrated in the south all year, extending to the previous spring's burn during the wet and dry seasons. This resulted in a shift in the extension of distributional concentration from season to season while a core concentration was maintained in the south all year. Activity patterns were divided between ungulate types such as giraffe and eland on the one hand, and springbok, blesbok and black wildebeest on the other. The former were mostly seen in transit or feeding as they moved around the study area looking for scattered browse, especially in the dry season. The latter ungulate types, being typical of grasslands, were involved mostly in resting and feeding.

The ecological separation of the 10 ungulate types studied was represented by the separation between the open grassland types such as blesbok, springbok and black wildebeest, and the woodland types such as sable antelope and impala. There was a further separation between those ungulate types that used burnt areas and those that did not use burnt areas. The former include springbok, blesbok and impala, which used areas up to one year after burning, and Burchell's zebra, eland and gemsbok, which used areas up to six months after burning. The ungulate types that did not use burnt areas were giraffe, black wildebeest, red hartebeest and sable antelope.

Finally, it became apparent from the present study that the southern area represented a core area subjected to continuous grazing and that, while the total stocking rate of 0,10 $LU.ha^{-1}$ at the time of the study should be maintained, the stock ratio should be adjusted in favour of large bulk and roughage eaters.

ECOLOGICAL MONITORING

An awareness of ecological processes and how such processes change in a wildlife reserve is necessary, regardless of how much management is applied and regardless of the aims of the management. Ecological monitoring is an important aspect in the management of a wildlife area, but the type of monitoring carried out depends on the management goals (Macdonald & Grimsdell 1983). Monitoring provides feedback on the management techniques used, in terms of the management goals. For the present study, management is assumed to be mainly for the conservation of Jack Scott Nature Reserve as a natural area, as opposed to management for game farming.

No ecological monitoring has been carried out on Jack Scott Nature Reserve in the past. As the present study focussed on the grasslands of the said reserve, only the monitoring of the specific study area can be discussed.

A simple yet automatic weather station, surrounded by a fence, should be constructed at the main entrance to Jack Scott Nature Reserve, namely the south-western entrance. An automatic rain gauge and a Stevenson screen housing a thermograph and hygrograph are all that are required for the basic monitoring of the climate.

Botanical monitoring can be done using the sample sites used in the present study as they have already been located and marked in the field. An annual assessment of the botanical composition of the grasslands should be done during February/March and this can be done in the same way as for the present study (Chapter Three, Part One).

The amount of aerial phytomass should also be determined annually, in order to assess the impact that animals and fire have on the vegetation, and also to assist the planning of spring burns. Aerial phytomass should be measured during August/September, just before the spring burn.

Unlike the technique used in the present study for the determination of aerial phytomass, only two of the four transects at each sample site need to be traversed with a disc pasture meter (Chapter Three, Part Two). Instead of 1 010 disc height readings, 510 will be recorded thus per grassland community (51 readings per sample site: 25 along each transect and one at the stake that marks the site). To get 50 calibrations of the disc pasture meter, one calibration should be done at the end of each transect, in addition to the first one at the iron stake and the one half-way along each transect.

Because the ungulates that use the study area were most abundant there from November to February during the study period, and because the age structures of ungulate populations are best determined during autumn (Baily 1984), the ungulate populations that use the study area should be assessed, in terms of number and structure, during the period from November to April. As in the present study, the study area can be investigated in a morning by travelling a predetermined route that includes elevated positions and facilitates the investigation of valleys and wooded areas. A period of three to four days per month during the wet season should provide sufficient data for the annual estimation of the number and structure of each ungulate population that uses the grasslands of Jack Scott Nature Reserve.

GENERAL MANAGEMENT CONSIDERATIONS

The following comments apply to the general management of Jack Scott Nature Reserve as a whole and should be considered by Management.

- A burning programme should be worked out where one quarter to one third of the grasslands of Jack Scott Nature Reserve is burnt each spring as soon as possible after the first spring rains. Each area should not be burnt more than once in three years and the size of the burnt area must be large enough to withstand the pressure of grazing over the three to four months after the burning. The aims of the burning should be to keep the vegetation in a healthy condition and to attract animals away from the southern core area which is subjected to continuous grazing.

- Fire-breaks should be burnt around the perimeter and along the roads of Jack Scott Nature Reserve every June/July to prevent the spread of accidental fires.

- The present practice of making available supplementary feed in the form of "Rumevite" game blocks during the dry season should be continued.

- The haphazard construction of roads in the past should be rectified and controlled in the future to prevent, or at least reduce, soil erosion.

- A programme should be devised for the control of exotic plant invaders such as the black wattle <u>Acacia</u> <u>mearnsii</u>, prickly pear <u>Opuntia</u> <u>ficus-indica</u> and blackjack <u>Bidens</u> <u>pilosa</u>.

- The economic utilization of the freshwater fish and terrestrial gamebirds on Jack Scott Nature Reserve should be considered.

- The economic utilization of the excess ungulates by hunting for the pot, trophy hunting and live sale should be considered.

- Nature trails of one or two days duration are a further possibility. These trails can either be for walking or horse riding.

AN ECOLOGICAL STUDY OF THE GRASSLANDS OF THE JACK SCOTT NATURE RESERVE, TRANSVAAL, WITH SPECIAL REFERENCE TO PLANT PRODUCTION AND UNGULATE-HABITAT RELATIONSHIPS

by

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SUMMARY

Botanical composition, phytomass and ungulate-habitat relationships were studied on the grasslands of Jack Scott Nature Reserve in order to understand the ecology of the grasslands better, thus enabling more efficient management practises to be decided upon and implemented.

The botanical composition of the grasslands of the study area, as determined by dry-weight ranking and subjected to ordination and classification, appeared to be influenced both by geology and utilisation/disturbance. The vegetation on shale, less used by ungulates and the most moribund of all grassland communities studied, featured Increaser I grasses, while the vegetation on chert-poor dolomite (the dolomite community) was most used by ungulates and featured Increaser II grasses. The subseral old lands community, cultivated in the 1920's and undergoing secondary succession, was separate from the three natural, subclimax grassland communities (the shale, chert and dolomite communities).

Phytomass in the study area, as measured with a standard disc pasture meter, was generally greatest in the moribund shale

community, while an overall peak in phytomass occurred at the end of the growth season and a trough in phytomass occurred at the end of the dormant season. Phytomass ranged between 250 and 390 $g.m^{-2}$ during the study period, depending on the grassland community and time of year. The production rates of vegetation and aerial net primary production were estimated by the periodic harvesting of permanent quadrats by clipping. Production rates in the study area showed a 10- to 20-fold increase during the three months after the first spring rains and ranged between 5,0 and 10,0 $g.m^{-2}.week^{-1}$ during the growth season, depending on the grassland community, while production rates during the dormant season were less than 0,5 $g.m^{-2}.week^{-1}$. Annual aerial net primary production was estimated to be between 160 and 310 $g.m^{-2}.yr^{-1}$, depending on the grassland community.

From the regular game counts twice a week, the distribution patterns of all ungulate types in the study area revealed a year-round concentration in the south where continuous grazing occurred. The concentration in the southern area though, was decreased by the burning of other parts inside and outside the study area.

By using Bonferroni simultaneous confidence intervals and detrended correspondence analysis in a complementary manner, a division between the open grassland ungulate types such as blesbok, springbok and black wildebeest, and the woodland types such as impala and sable antelope, became apparent. A further separation between the users of unburnt areas and the users of burnt areas was revealed. The former include giraffe, black wildebeest, red hartebeest and sable antelope, while the latter include blesbok, springbok and impala which used burnt areas up to one year after burning, and Burchell's zebra, gemsbok and eland which did not use burnt areas for more than six months after burning.

The estimated stocking rate of 0,10 $LU.ha^{-1}$ (a stocking level of 200 LU) for the study area during the study period should be maintained, while adjustments to the stock ratio should be made in favour of large bulk and roughage eaters such as zebra.

'n EKOLOGIESE STUDIE VAN DIE GRASVELDE VAN DIE JACK SCOTT-NATUURRESERVAAT, TRANSVAAL, MET SPESIALE VERWYSING NA PLANTPRODUKSIE EN HOEFDIER-HABITAT VERWANTSKAPPE

deur

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OPSOMMING

Botaniese samestelling, fitomassa en hoefdier-habitat verwantskappe is op die grasvelde van die Jack Scott-natuurreservaat bestudeer om die ekologie van die grasvelde beter te verstaan en op 'n meer doeltreffende manier van bestuur te besluit en dit te implimenteer.

Die botaniese samestelling van die grasvelde van die studiegebied, soos bepaal deur droë-massa rangordening en geanaliseer deur ordening en klassifikasie, is deur geologie en benutting/versteuring beinvloed. Die plantegroei op skalie, minder gebruik deur hoefdiere en die mees sterwend van alle grasveldgemeenskappe bestudeer, het Vermeerderde I grasse vertoon, terwyl die plantegroei op chert-arm dolomiet (die dolomiet-gemeenskap) meer deur hoefdiere gebruik was en het Vermeerderde II grasse vertoon. Die subseraal, ou lande-gemeenskap, in die 1920's gekultiveer en wat sekondêre suksessie ondergaan, was apart van die drie natuurlike, subklimaks grasveldgemeenskappe (die skalie-, chert- en dolomiet-gemeenskappe).

Fitomassa in die studiegebied, soos deur 'n standaard skyfweiveldmeter gemeet, is oor die algemeen die grootste in die sterwende skalie-gemeenskap, terwyl 'n algemene piek in fitomassa

teen die einde van die groeiseisoen en 'n trog in fitomassa teen die einde van die russeisoen het voorgekom. Fitomassa het tussen 250 en 390 $g.m^{-2}$ tydens die studieperiode gewissel, afhangende van die grasveldgemeenskap en tyd van die jaar. Die produksietempo van die plantegroei en bo-grondse netto primêre produksie was bereken deur die periodiese oes van permanente kwadrate deur knipping. Produksietempos in die studiegebied het 'n 10- tot 20-keer verhoging tydens die drie maande na die eerste lentereëns vertoon en het tussen 5,0 en 10,0 $g.m^{-2}.week^{-1}$ gewissel gedurende die groeiseisoen, afhangende van die grasveldgemeenskap, terwyl produksietempos gedeurende die russeisoen minder as 0,5 $g.m^{-2}.week^{-1}$ was. Jaarlikse bo-grondse netto primêre produksie is tussen 160 en 310 $g.m^{-2}.jr^{-1}$ gereken, afhangende van die grasveldgemeenskap.

Van die gereelde wildtellings twee keer elke week, het die verspreidingspatrone van alle hoefdiersoorte in die studiegebied 'n konsentrasie dwarsdeur die jaar in die suidelike gebied vertoon waar aanhoudende weiding voorgekom het. Die konsentrasie in die suidelike gebied was egter deur die branding van ander gedeeltes binne en buite die studiegebied verminder.

Deur die gebruik van Bonferroni se gelyktydige vertroueafstande en ontneigde ooreenstemingsanaliese op 'n komplimentêre manier, het 'n verdeling tussen die oop grasveld hoefdiersoorte soos die blesbok, springbok en swartwildebees, en die boomveld soorte soos die rooibok en swartwitpens, voorgekom. 'n Verdere onderskeid tussen die gebruikers van onverbrande gebiede en die gebruikers van verbrande gebiede het voorgekom. Die eersgenoemde sluit die kameelperd, swartwildebees, rooihartebees en swartwitpens in, terwyl die laasgenoemde sowel die blesbok, springbok en rooibok wat die verbrande gebiede tot een jaar na verbranding gebruik het, as die bontsebra, gemsbok en eland wat die verbrande gebiede vir nie meer as ses maande na ver branding gebruik het nie, insluit.

Die berekende veeladingstempo van 0,10 $GVE.ha^{-1}$ ('n veeladingsvlak van 200 GVE) vir die studiegebied moet bewaar word, terwyl veranderinge in die veeverhouding ten gunste van groot ruvreters soos die sebra gemaak moet word.

REFERENCES*

ACOCKS, J.P.H. 1975. Veld types of South Africa. Mem. Bot. Surv. S. Afr. 40:1-128.

ANTHONY, R.G. & SMITH, N.S. 1977. Ecological relationships between mule deer and white-tailed deer in southeastern Arizona. Ecol. Monogr. 47:255-277.

BAILY, J.A. 1984. Principles of wildlife management. John Wiley & Sons, New York.

BARBOUR, M.G., BURK, J.H. & PITTS, W.D. 1980. Terrestrial plant ecology. Benjamin/Cummings, Menlo Park, Ca.

BARNES, D.L., ODENDAAL, J.J. & BEUKES, B.H. 1982. Use of the dry-weight-rank method of botanical analysis in the Eastern Transvaal highveld. Proc. Grassld. Soc. sth. Afr. 17:79-82.

BEARDALL, G.M., JOUBERT, S.C.J. & RETIEF, P.F. 1984. An evaluation of the use of correspondence analysis for the analysis of herbivore-habitat selection. S. Afr. J. Wildl. Res. 14:79-88.

BEASOM, S.L., WIGGERS, E.P. & GIARDINE, J.R. 1983. A technique for assessing land surface ruggedness. J. Wildl. Manage. 47:1163-1166.

BELL, R.H.V. 1971. A grazing system in the Serengeti. Sci. Am. 225:86-93.

BEN-SHAHAR, R. 1986. The conservation of endangered ungulates in the Waterberg, Transvaal. Unpublished MSc thesis, University of Pretoria.

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* Cited according to the conventions used by the South African Journal of Wildlife Management.

BLANKENSHIP, L. H. & FIELD, C. R. 1972. Factors affecting the distribution of wild ungulates on a ranch in Kenya. Zool. Africana 7:81-302.

BOYD, D.A. 1949. Experiments with leys and permanent grass. J. Brit. Grassld. Soc. 4:1-10.

BRAITHWAITE, L.W., DUDZINSKI, M.L. & TURNER, J. 1983. Studies in the arboreal marsupial fauna of eucalypt forests being harvested for woodpulp at Eden, N. S. W. II. Aust. Wildl. Res. 10:231-247.

BRANSBY, D.I., MATCHES, A.G. & KRAUSE, G.F. 1977. Disk meter for rapid estimation of herbage yield in grazing trials. Agron. J. 69:393-396.

BRANSBY, D.I. & TAINTON, N.M. 1977. The disc pasture meter: possible applications in grazing management. Proc. Grassld. Soc. sth. Afr. 12:115-118.

BROCKETT, B. H. & HOLTON, G.D. 1986. Proposed procedures for monitoring vegetation. In: Monitoring in South African grasslands - workshop no. 2, (Ecosystem Programmes Occ. Rep. 13) (ed.) Mentis, M. T., pp 11-23. Council for Scientific and Industrial Research, Pretoria.

BROWN, B.W. & BATZLI, G.O. 1984. Habitat selection by fox and gray squirrels: a multivariate analysis. J. Wildl. Manage. 48: 616-621.

BROWN, D. 1954. Methods of surveying and measuring vegetation. (Bull. 42, Commonwealth Bureau of Pastures and Field Crops) Commonwealth Agricultural Bureaux, Bucks.

BYERS, C.R., STEINHORST, R.K.& KRAUSMAN, P.R. 1984. Clarification of a technique for analysis of utilisation-availability data. J. Wildl. Manage. 48:1050-1053.

CAIRNS, A. L. & TELFER, E.S. 1980. Habitat use by 4 sympatric ungulates in boreal mixedwood forest. J. Wildl. Manage. 44:849-857.

CAUGHLEY, G. 1983. Dynamics of large mammals and their relevance to culling. In: Management of large mammals in African conservation areas, (ed.) Owen-Smith, R. N., pp 115-126. Haum, Pretoria.

CLINNING, C.F. 1986. Transvaal grasslands. Fauna and Flora 44:3-5.

COETZEE, B. J. 1972. 'n Plantsosiologiese studie van die Jack Scott-natuurreservaat. Unpublished MSc thesis, University of Pretoria.

COETZEE, B.J. 1974a. A phytosociological classification of the vegetation of the Jack Scott Nature Reserve. Bothalia 11:329-347.

COETZEE, B. J. 1974b. Improvement of association-analysis classification by Braun-Blanquet technique. Bothalia 11:365-367.

CODY, R.P. & SMITH, J.K. 1985. Applied statistics and the SAS programming language. Elsevier, New York.

COLE, L.C. 1949. The measurement of interspecific association. Ecology 30:411-424.

CONSTAN, K.J. 1972. Winter foods and range use of three species of ungulates. J. Wildl. Manage. 36:1068-1076.

COPPOCK, D.L., ELLIS, J.E., DETLING, J.K. & DYER, M. I. 1983. Plant-herbivore interactions in a North American mixed-grass prairie. Oecologia 56:10-15.

COTTAM, F., GOFF, G. & WHITTAKER, R.H. 1978. Wisconsin comparative ordination. In: Ordination of plant communities, (ed.) Whittaker, R.H., Ch. 7, W Junk, The Hague.

DANKWERTS, J.E. & TROLLOPE, W.S.W. 1980. Assessment of the disc pasture meter on natural veld in the False Thornveld of the Eastern Province. Proc. Grassld. Soc. sth. Afr. 15:47-52.

DAVIES, R. A. G. 1985. A comparison of springbok Antidorcas marsupialis and Merino sheep Ovis aries on Karoo veld. Unpublished MSc thesis, University of Pretoria.

DU PLESSIS, S.S. 1972. Ecology of blesbok with special reference to productivity. Wildl. Monogr. 30:1-70.

DYER, R.A. 1975. The genera of South African flowering plants, Volume 1, Dicotyledons. Department of Agricultural Technical Services, Pretoria.

DYER , R.A. 1976. The genera of South African flowering plants, Volume 2, Gymnosperms and monocotyledons. Department of Agricultural Technical Services, Pretoria.

DYER, T. G. J. & TYSON, P.D. 1977. Estimating above- and below-normal rainfall periods over South Africa, 1972-2000. J. Appl. Met. 16:145-147.

EDROMA, E. L. 1984. Effects of burning and grazing on the productivity and number of plants in Queen Elizabeth National Park, Uganda. Afr. J. Ecol. 22:165-174.

ELTRINGHAM, S. K. 1979. The ecology and conservation of large African mammals. MacMillan, London.

FERRAR, A. A. & WALKER, B. H. 1974. An analysis of herbivore/habitat relationships in Kyle National Park, Rhodesia. J. sth. Afr. Wildl. Mgmt. Ass. 4:137-147.

GAUCH, H.G. 1980. Rapid initial clustering of large data sets. Vegetatio 42:103-111.

GAUCH, H.G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge.

GAUCH, H.G., WHITTAKER, R.H. & WENTWORTH, T.R. 1977. A comparative study of reciprocal averaging and other ordination techniques. J. Ecol. 65:157-174.

GIBBS RUSSEL, G. E., REID, C., VAN ROOY, J. & SMOOK, L. 1985. List of species of southern African plants. Edition 2, Part 1. Mem. Bot. Surv. S. Afr. 51:1-152.

GIBBS RUSSEL, G. E., WELMAN, W. G., RETIEF, E., IMMELMAN, K. L., GERMISHUIZEN, G., PIENAAR, B.J., VAN WYK, M. & NICHOLAS, A. 1987. List of species of southern African plants. Edition 2, Part 2. Mem. Bot. Surv. S. Afr. 56:1-270.

GOODALL, D.W. 1978. Numerical classification. In: Classification of plant communities, (ed.) Whittaker, R.H., Ch. 9, W Junk, The Hague.

GROSSMAN, D. 1981. Studies in herbaceous layer production in Burkea africana savanna. Unpublished MSc thesis, University of Pretoria.

GROSSMAN, D. 1982. Primary productivity of rangeland: practical and interpretive problems. Proc. Grassld. Soc. sth. Afr. 17:76-78.

HANLEY, T.A. 1984. Habitat patches and their selection by wapiti and black-tailed deer in a coastal montane coniferous forest. J. Appl. Ecol. 21:423-436.

HARDY, M.B. & MENTIS, M.T. 1985. The relative efficiency of three methods of estimating herbage mass in veld. J. Grassld. Soc. sth. Afr. 2:35-58.

HAYDOCK, K.P. & SHAW, N.H. 1975. The comparative yield method for estimating dry matter yield of pasture. Aust. J. exp. Agric. Anim. Husb. 15:663-670.

HILL, M.O. 1973. Reciprocal averaging: an eiegenvector method of ordination. J. Ecol. 61:237-249.

HILL, M.O. 1974. Correspondence analysis:a neglected multivariate method. Appl. Statist. 23:340-354.

HILL, M. O. 1979a. DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Cornell University, Ithaca, NY.

HILL, M. O. 1979b. TWINSPAN - A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Ithaca, NY.

HILL, M.O, BUNCE, R.G.H. & SHAW, M. W. 1975. Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. J. Ecol. 63:597-613.

HILL, M.O. & GAUCH, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio 42:47-58.

HIRST, S. M. 1975. Ungulate-habitat relationships in a South African woodland/savanna ecosystem. Wildl. Monogr. 44:1-60.

HOFFMAN, R. R. & STEWART, D. R. M. 1972. Grazer or browser: a classification based on the stomach-structure and feeding habits of East African ruminants. Mammalia 36:226-240.

JARMAN, P. J. 1972. Seasonal distribution of large mammal populations in the unflooded Middle Zambezi Valley. J. Appl. Ecol. 9:283-299.

JONES, R.M. & HARGREAVES, J.N.G. 1979. Improvements to the dry-weight-rank method for measuring botanical composition. Grass For. Sci. 34:181-189.

KELLY, R.D. & MCNEILL, L. 1980. Tests of two methods for determining hebaceous yield and botanical composition. Proc. Grassld. Soc. sth. Afr. 15:167-171.

KERSHAW, K.A. 1973. Quantitative and dynamic plant ecology. Edward Arnold, London.

KINCAID, W.B. & BRYANT, E.H. 1983. A geometric method for evaluating the null hypothesis of random habitat utilization. Ecology 64:1463-1470.

KOECHLIN, J. & MENAUT, J.C. 1979. Phenology and primary production, In: Tropical grazing land ecosystems, (Natural resources research XVI) UNESCO/UNEP/FAO, Ch. 5, UNESCO, Paris.

KUTILEK, M.J. 1979. Forage-habitat relationships of nonmigratory African ungulates in response to seasonal rainfall. J. Wildl. Manage. 43:899-908.

LAMPREY, H. F. 1963. Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. E. Afr. Wildl. J. 1:63-92.

LAUENROTH, W.K. 1979. Grassland primary production:North American grasslands in perspective. In: Perspectives in grassland ecology, (Ecological Studies 32) (ed.) French, N.R., Ch. 1, Springer-Verlag, Berlin.

MACDONALD, I.A.W. & GRIMSDELL, J. 1983. What causes change? - getting at the facts. In: Guidelines for the management of large mammals in African conservation areas, (S. Afr. nat. Sci. Prog. Rep. 69) (ed.) Ferrar, A.A., Ch. 5, Council for Scientific and Industrial Research.

MARCHANT, A.N. 1983. Management of blesbok on farmland in Natal. (Wildlife management technical guides for farmers, Number 3) Natal Parks Board.

MARCUM, C.L. & LOFTSGAARDEN, D.O. 1980. A non-mapping technique for studying habitat preferences. J. Wildl. Manage. 44:963-968.

MASON, D.R. 1973. Range use and population structure of ungulates in the Jack Scott Nature Reserve. Unpublished MSc thesis, University of Pretoria.

MEISSNER, H. H. 1982. Theory and application of a method to calculate forage intake of wild southern African ungulates for purposes of estimating carrying capacity. S. Afr. J. Wildl. Res. 12:41-47.

MENTIS, M. T. 1977. Stocking rates and carrying capacities for ungulates on African rangelands. S. Afr. J. Wildl. Res. 7:89-98.

MENTIS, M.T. 1984. Monitoring in South African grasslands. (S. Afr. nat. Sci. Prog. Rep. 91) Council for Scientific and Industrial Research, Pretoria.

MENTIS, M.T. 1986. Veld monitoring using permanent plots - a case history. In: Monitoring in South African grasslands - workshop no. 2, (Ecosystem Programmes Occ. Rep. 13) (ed.) Mentis, M. T., pp 2 - 10. Council for Scientific and Industrial Research, Pretoria.

MENTIS, M.T. & DUKE, R.R. 1976. Carrying capacities of natural veld in Natal for large wild herbivores. S. Afr. J. Wildl. Res. 6:65-74.

MILNER, C. & HUGHES, R.E. 1968. Methods for the measurement of the primary production of grassland. (IBP Handbook 6) Blackwell Scientific Publications, London.

MISRA, K.C. 1979. Introduction. In: Grassland ecosystems of the world: analysis of grasslands and their uses, (IBP 18) (ed.) Coupland, R.T., Ch. 16, Cambridge University Press, Cambridge.

MURPHY, P.G. 1975. Net primary productivity in tropical terrestrial ecosystems. In: Primary productivity of the biosphere, (Ecological Studies 14) (eds) Leith, H. & Whittaker, R.H., Ch. 11, Springer-Verlag, Berlin.

NEU, C.W., BYERS, C.R. & PEEK, J.M. 1974. A technique for analysis of utilization-availability data. J. Wildl. Manage. 38: 541-545.

NOVELLIE, P.A. 1975. Comparative social behaviour of springbok, Antidorcas m. marsupialis (Zimmerman, 1780), and blesbok, Damaliscus dorcas phillipsi Harper 1939, on the Jack Scott Nature Reserve, Transvaal. Unpublished MSc thesis, University of Pretoria.

NOY-MEIR, I. & WHITTAKER, R. H. 1978. Recent developments in continuous multivariate techniques. In: Ordination of plant communities, (ed.) Whittaker, R.H., Ch. 11, W Junk, The Hague.

OSBORNE, B.C. 1984. Habitat use by red deer (Cervus elaphus) and hill sheep in the West Highlands. J. Appl. Ecol. 21:497-506.

PAGE, B.R. & WALKER, B.H. 1978. Feeding niches of four large herbivores in the Hluhluwe Game Reserve, Natal. Proc. Grassld. Soc. sth. Afr. 13:117-122.

PETTIFER, H.L. & STUMPF, R.H. 1981. An Approach to the calculation of habitat preference data: impala on Loskop Dam Nature Reserve. S. Afr. J. Wildl. Res. 11:5-13.

PIENAAR, U. de V. 1974. Habitat preference in South African antelope species and its significance in natural and artificial distribution patterns. Koedoe 17:185-195.

PHILLIPS, S.M. & CLARKE, S.E. 1971. The calibration of a weighted disc against pasture dry matter yields. Proc. N.Z. Grassl. Asso. 33:68-75.

POWELL, T.L. 1974. Evaluation of a weighted disc meter for pasture yield estimation on intensively stocked dairy pastures. N.Z. J. Exp. Agric. 2:237-242.

ROBERTS, B.R. & FOURIE, J.H. 1975. General grasses of the Northern Cape. Northern Cape Livestock Co-operative,Bloemfontein.

ROUNDS, R.C. 1981. First approximation of habitat selectivity of ungulates on extensive winter range. J. Wildl. Manage. 45:187-196.

ROWE-ROWE, D. T. 1983. Habitat preferences of five Drakensberg antelopes. S. Afr. J. Wildl. Res. 13:1-8.

RUTHERFORD, M. C. 1978. Primary production ecology in southern Africa. In: Biogeography and ecology of southern Africa, (ed.) Werger, M.J.A., Ch. 15, W. Junk, The Hague.

RUTHERFORD, M.C. & WESTFALL, R.H. 1986. Biomes of southern Africa - an objective classification. Mem. Bot. Sur. S. Afr. 54:1-98.

SAS INSTITUTE INC. 1982a. SAS User's Guide: Basics, 1982 Edition. SAS Institute Inc., Cary, NC.

SAS INSTITUTE INC. 1982b. SAS User's Guide: Statistics, 1982 Edition. SAS Institute Inc., Cary, NC.

SCOGINGS, P. F. 1985. An assessment of the state of the blesbok population on Nash-Scott Nature Reserve. Unpublished BSc (Hons) (Wildl. Mgmt.) thesis, University of Pretoria.

SHAW, N.H., 't MANNETJE, L., JONES, R.M. & JONES, R.J. 1976. Pasture measurement. In: Tropical pasture research, (Bulletin 51, Commonwealth Bureau of Pastures and Field Crops) (eds) Shaw, N.H. & Bryan, W.W., Ch. 4, Commonwealth Agricultural Bureaux, Bucks.

SHORT, J., CAUGHLEY, G., GRICE, D. & BROWN, B. 1983. The distribution and abundance of kangaroos in relation to environment in Western Australia. Aust. Wildl. Res. 10:435-451.

SIMPSON, C.D. & GRAY, G.G. 1983. Topographic and habitat use by sympatric Barbary sheep and mule deer in Palo Duro Canyon, Texas. J. Range Manage. 36:190-194.

SINGER, F.J. 1979. Habitat partioning and wildfire relationships of wild cervids in Glacier National Park, Montana. J. Wildl. Manage. 43:437-444.

SINGH, J.S. 1973. A compartment model of herbage dynamics for Indian tropical grasslands. Oikos 24:367-372.

SINGH, J.S. & JOSHI, M.C. 1979. Primary production. In: Grassland ecosystems of the world: analysis of grasslands and their uses, (IBP 18) (ed.) Coupland, R.T., Ch. 17, Cambridge University Press, Cambridge.

SINGH, J.S., LAUENROTH, W.K. & STEINHORST, R.K. 1975. Review and assessment of various techniques for estimating net aerial primary production in grassland from harvest data. Bot. Rev. 41: 181-232.

SMITHERS, R. H. N. 1983. The mammals of the southern African subregion. University of Pretoria, Pretoria.

SOKAL, R.R. & ROHLF, F.J. 1981. Biometry. W H Freeman, San Francisco.

SURING, L.H. & VOS, P.A. 1979. Habitat use by Columbia white-tailed deer. J. Wildl. Manage. 43:610-619.

TAINTON, N. M. 1981a. The grass plant and its reaction to treatment. In: Veld and pasture management in South Africa, (ed.) Tainton, N.M., Ch. 8, Natal University Press in association with Shuter & Shooter, Pietermaritzburg.

TAINTON, N.M. 1981b. The ecology of the main grazing lands of South Africa. In: Veld and pasture management in South Africa, (ed.) Tainton, N.M., Ch. 2, Natal University Press in association with Shuter & Shooter, Pietermaritzburg.

TAINTON, N.M. 1982. Response of the humid sub-tropical grasslands of South Africa to defoliation. In: The ecology of tropical savannas, (Ecological Studies 42) (eds) Huntley, B.J. & Walker, B.H., Ch. 16, Springer-Verlag, Berlin.

TAINTON, N.M, BRANSBY, D.I. & BOOYSEN, P.de V. 1976. Common veld and pasture grasses of Natal. Shuter & Shooter, Pietermaritzburg.

THERON, G.K., MORRIS, J.W. & VAN ROOYEN, N. 1984. Ordination of the herbaceous stratum of savanna in the Nylsvley Nature Reserve, South Africa. S. Afr. J. Bot. 3:22-32.

TIDMARSH, C.E.M. & HAVENGA, C.M. 1955. The wheelpoint method of survey and measurement of open and semi-open savanna vegetation. Mem. Bot. Surv. S. Afr. 29:1-49.

't MANNETJE, L. & HAYDOCK, K.P. 1963. The dry-weight rank method for the botanical analysis of pasture. J. Brit. Grassld. Soc. 18: 268-275.

TOTHILL, J. C. 1978. Measuring botanical composition. In: Measurement of grassland vegetation and animal production, (Bulletin 52, Commonwealth Bureau of Pastures and Field Crops) (ed.) 't Mannetje, L., Ch. 3, Commonwealth Agricultural Bureaux, Farnham Royal.

TREWARTHA, G. 1968. An introduction to climate. McGraw-Hill, London.

TROLLOPE, W.S.W. & POTGIETER, A.L.F. 1986. Estimating grass fuel loads with a disc pasture meter in the Kruger National Park. J. Grassld. Soc. sth. Afr. 3:148-152.

VAN AARDE, R.J. & SKINNER, J.D. 1975. The food and feeding of the giraffe Giraffa camelopardalis in the Jack Scott Nature Reserve. Publ. Univ. Pretoria, New Series 97:59-68.

VAN BILJON, S. 1949. The transformation of the upper part of the Pretoria Series in the Bushveld Igneous Complex. Trans. geol. Soc. S. Afr. 52:1-197.

VAN DER MERWE, M. 1973a. Aspects of temperature and humidity in preferred hibernation sites of the Natal clinging bat Miniopterus schreibersi natalensis (A.Smith, 1834). Zool. Africana 8:121-134.

VAN DER MERWE, M. 1973b. Aspects of social behaviour of the Natal clinging bat Miniopterus schreibersi natalensis (A.Smith,1834). Mammalia 37:379-389.

VAN DER MERWE, M. 1973c. Aspects of hibernation and winter activity of the Natal clinging bat, Miniopterus schreibersi natalensis (A.Smith,1834), on the Transvaal Highveld. S. Afr. J. Sci. 69:116-118.

VAN HOVEN, W. & EBEDES, H. 1986. Voeding en drakrag. In: Wildplaasbestuur, (ed.) Bothma, J.du P., pp 498-524, J. L. van Schaik, Pretoria.

VESEY-FITZGERALD,D.F. 1960. Grazing succession among East African game animals. J. Mamm. 4:161-172.

VESEY-FITZGERALD, D.F. 1965. The utilization of natural pastures in the Rukwa Valley, Tanganyika. E. Afr. Wildl. J. 3:38-48.

WALKER, B. H. 1970. An evaluation of botanical analysis on grasslands in Rhodesia. J. Appl. Ecol. 7:403-417.

WALKER, B.H. 1976. An approach to the monitoring of changes in the composition and utilization of woodland and savanna vegetation. S. Afr. J. Widl. Res. 6:1-32.

WALTER, H. 1979. Vegetation of the Earth and ecological systems of the geo-biosphere. Springer-Verlag, New York.

WEATHER BUREAU. 1987. Station register - weather observational network. Department of Environment Affairs, Pretoria.

WELLS,M.J. 1964. The vegetation of the Jack Scott Nature Reserve. Fauna and flora. 15:17-25.

WERGER, M.J.A. & COETZEE, B.J. 1978. The Sudano-Zambezian Region. In: Biogeography and ecology of southern Africa, (ed) Werger, M. J.A., Ch. 10, W Junk, The Hague.

WHITTAKER, R.H. 1970. Communities and ecosystems. Macmillan, London.

WHITTAKER, R. H. 1978a. Introduction. In: Ordination of plant communities, (ed.) Whittaker, R.H., Ch. 1, W Junk, The Hague.

WHITTAKER, R.H. (ed.) 1978b. Ordination of plant communities. W Junk, The Hague.

WHITTAKER, R.H. & MARKS, P.L. 1975. Methods of assessing terrestrial productivity. In: Primary productivity of the biosphere, (Ecological Studies 14) (eds) Lieth, H. & Whittaker, R.H., Ch.4, Springer-Verlag, Berlin.

WHITTAKER, R.H., MORRIS, J.W. & GOODMAN,D. 1984. Pattern analysis in savanna-woodlands at Nylsvley, South Africa. Mem. Bot. Surv. S. Afr. 49:1-51.

WILLIAMS, W.T. 1973. Pattern analysis in field experiments. In: Development in field experiment design and analysis, (eds) Bofinger, B.J. & Wheeler, J.L., Ch. 8, Commonwealth Agricultural Bureaux, Melbourne.

WYDEVEN, A.P. & DAHLGREN, R.B. 1985. Ungulate habitat relationships in Wind Cave National Park. J. Wildl. Manage. 49:850-813.

APPENDIX A

TAXONOMIC LIST OF PLANT SPECIES

The following is a list of plant species recorded during a dry-weight rank analysis of the four grassland communities making up a study area in the southern part of Jack Scott Nature Reserve. The communities were originally described by Coetzee (1972) and consist of grassland on chert, grassland on dolomite, grassland on shale and grassland on old lands (also on shale). The analysis was done during February/March 1987 and the following list uses the conventions of Gibbs Russel et al. (1985, 1987). Exotic species are prefixed with an asterisk (*).

MONOCOTYLEDONAE

Poaceae

Urelytrum agropyroides (Hack.) Hack.
Elionurus muticus (Spreng.) Kunth
Schizachyrium sanguineum (Retz.) Alst.
S. ursulus Stapf
Andropogon schirensis A. Rich.
Cymbopogon excavatus (Hochst.) Stapf ex Burtt Davy
C. validus (Stapf) Stapf ex Burtt Davy
Hyparrhenia hirta (L.) Stapf
Hyparrhenia sp.
Monocymbium ceresiiforme (Nees) Stapf
Trachypogon spicatus (L.F.) Kuntze
Heteropogon contortus (L.) Roem. & Schult.
Diheteropogon amplectens (Nees) Clayton
Themeda triandra Forssk.
Digitaria brazzae (Franch.) Stapf
D. diagonalis (Nees) Stapf
D. monodactyla (Nees) Stapf
D. tricholaenoides Stapf
Brachiaria serrata (Thunb.) Stapf
Paspalum scrobiculatum L.
Panicum natalense Hochst.
Setaria sphacelata (Schumach.) Moss
Rhynchelytrum nerviglume (Franch.) Chiov.
R. repens (Willd.) C.E.Hubb.
Tristachya rehmannii Hack.
Loudetia simplex (Nees) C.E.Hubb.
Stipagrostis zeyheri (Nees) de Winter
Aristida congesta Roem. & Schult. subsp. congesta
Aristida spp.
Tragus berteronianus Schult.

Sporobolus africanus (Poir.) Robyns & Tournay
S. fimbriatus (Trin.) Nees
S. pectinatus Hack.
Eragrostis chloromelas Steud.
E. curvula (Schrad.) Nees
E. gummiflua Nees
E. racemosa (Thunb.) Steud.
E. rigidior Pilg.
Eragrostis spp.
Microchloa caffra Nees
Cynodon dactylon (L.) Pers.
Eustachys paspaloides (Vahl) Lanza & Mattei
Pogonarthria squarrosa (Roem. & Schult.) Pilg.
Bewsia biflora (Hack.) Goosens
Triraphis andropogonoides (Steud.) Phill.
Trichoneura grandiglumis (Nees) Ekman
Fingerhuthia sesleriiformis Nees

Cyperaceae

Cyperus margaritaceus Vahl
Fimbristylis hispidula (Vahl) Kunth
Bulbostylis burchellii (Fical. & Hiern) C.B.Cl.

Liliaceae

Anthericum fasciculatum Bak.
Ledebouria revoluta (L.F.) Jessop
Asparagus suaveolens Burch.

Hypoxidaceae

Hypoxis rigidula Bak.

Velloziaceae

Xerophyta retinervis Bak.

DICOTYLEDONAE

Polygonaceae

Polygonum sp.

Amaranthaceae

Amaranthus thunbergii Moq.

Aizoaceae

Limeum viscosum (Gay) Fenzl

Illecebraceae

Pollichia campestris Ait.

Crassulaceae

Kalanchoe thyrsiflora Harv.

Chrysobalanaceae

Parinari capensis Harv.

Fabaceae

Acacia ataxacantha DC.
Elephantorrhiza elephantina (Burch.) Skeels
Cassia biensis (Steyaert) Mendonca & Torre
C. mimosoides L.
Pearsonia sessilifolia (Harv.) Duemmer
Indigofera arrecta Hochst. ex A. Rich
I. comosa N.E. Br.
Tephrosia elongata E. Mey.
Rhynchosia monophylla Schltr.
R. totta (Thunb.) DC.
Eriosema salignum E. Mey.
Vigna vexillata (L.) A. Rich.
Sphenostylis angustifolia Sond.

Euphorbiaceae

Phyllanthus incurvis Thunb.
Acalypha angustata Sond.
Clutia pulchella L.
Euphorbia sp.

Anacardiaceae

Rhus magalismontana Sond.

Celastraceae

Cassine burkeana Kuntze

Rhamnaceae

Ziziphus zeyheriana Sond.

Malvaceae

Sida rhombifolia L.

Sterculiaceae

Hermannia depressa N.E. Br.
H. lancifolia Szyszyl.
H. transvaalensis Schinz

Thymelaeaceae

Gnidia capitata L.F.
G. sericocephala (Meisn.) Gilg ex Engl.
G. splendens Meisn.

Asclepiadaceae

Pentarrhinum insipidum E. Mey.

Convolvulaceae

Ipomoea obscura (L.) Ker-Gawl.

Verbenaceae

*Verbena bonariensis L.
Lippia javanica (Burm. F.) Spreng.
Plexipus pinnatifidus (L.F.) R. Fernandes

Lamiaceae

Leucas neuflizeana Courb.

Solanaceae

Solanum incanum L.
S. panduriforme E. Mey.
S. supinum Dun.

Scrophulariaceae

Sutera palustris Hiern

Selaginaceae

Walafrida densiflora (Rolfe) Rolfe

Acanthaceae

Chaetacanthus costatus Nees
Crabbea angustifolia Nees
Barleria sp.
Blepharis sp.
Justicia sp.

Rubiaceae

Kohautia amatymbica Eckl. & Zeyh.
K. virgata (Willd.) Brem.
Oldenlandia herbacea (L.) Roxb.
Pentanisia angustifolia (Hochst.) Hochst.

Asteraceae

Vernonia poskeana Vatke & Hildebr.
*Erigeron karvinskianus DC.
Felicia muricata (Thunb.) Nees
Conyza podocephala DC.

Helichrysum callicomum Harv.
H. nudifolium (L.) Less.
H. cf. oxyphyllum DC.
H. rugulosum Less.
Stoebe vulgaris Levyns
*Acanthospermun australe (Loefl.) Kuntze
*Bidens pilosa L.
Senecio lydenbergensis Hutch. & Burtt Davy
S. venosus Harv.
Osteospermum muricatum E. Mey. ex DC.
Dicoma anomala Sond.

APPENDIX B

ECOLOGICAL SIGNIFICANCE AND GROWTH FORMS OF PLANT SPECIES

The following list of plant species encountered during the dry-weight rank analysis ('t Mannetje & Haydock 1963) of the grasslands in the study area on Jack Scott Nature Reserve during February/March 1987 indicates the ecological significance of the grass species and the general growth forms of the non-grass species. The grasses were classified as Increaser I (I), Increaser II (II) or Decreaser (D) species (Rethman*, pers. comm.), where Increaser I species increase in abundance with undergrazing, Increaser II species increase in abundance with overgrazing and Decreaser species are dominant in good pasture but decrease in abundance with deterioration of the pasture. The non-grass species were classified with reference to Dyer (1975, 1976) as herbs (H), shrubs (S), geophytes (G) or trees (T). Species are listed and numbered according to Table 7.

NUMBER	SPECIES	GROWTH FORM
001	Cassia mimosoides	S
002	Crabbea angustifolia	S
003	Anthericum fasciculatum	G
004	Kohautia amatymbica	H
005	Oldenlandia herbacea	H
006	Conyza podocephala	H
007	Solanum incanum	S
008	Hermannia depressa	H
009	Acanthospermum australe	H
010	Vernonia poskeana	H
011	Acalypha angustata	H
012	Vigna vexilata	H
013	Solanum panduriforme	S
014	Helichrysum rugulosum	S
015	Eriosema salignum	S
016	Unknown 1	H
017	Rhynchosia totta	H
018	Pentarrhinum insipidum	H
019	Pollichia campestris	S
020	Felicia muricatus	H
021	Acacia ataxacantha	T
022	Erigeron karvinskianus	H
023	Hypoxxis rigidula	G
024	Lippia javanica	S
025	Verbena bonariensis	H

* Prof N.F.G. Rethman, 1987, Department of Plant Production, University of Pretoria, PRETORIA 0002

026	Osteospermum muricatum	H
027	Hermannia lancifolia	H
028	Solanum supinum	S
029	Helichrysum callicomum	S
030	H. cf. oxyphyllum	H
031	Bulbostylis burchellii	H
032	Sphenostylis angustifolia	H
033	Senecio lydenbergensis	H
034	Leucas neufliziana	H
035	Polygonum sp.	H
036	Rhus magalismontana	S
037	Euphorbia sp.	H
038	Plexipus pinnatifidus	H
039	Cassine burkeana	S
040	Barleria sp.	S
041	Gnidia sericocephala	S
042	Clutia pulchella	S
043	Asparagus suaveolens	S
044	Unknown 2	H
045	Hermannia transvaalensis	H
046	Ledebouria revoluta	G
047	Kohautia virgata	H
048	Limeum viscosum	H
049	Fimbristylis hispidula	H
050	Chaetacanthus costatus	S
051	Dicoma anomala	H
052	Gnidia splendens	S
053	Pentanisia angustifolia	H
054	Amaranthus thunbergii	H
055	Rhynchosia monophylla	H
056	Gnidia capitata	S
057	Tephrosia elongata	H
058	Walafrida densiflora	S
059	Phyllanthus incurvis	H
060	Justicia sp.	S
061	Blepharis sp.	H
062	Indigofera comosa	S
063	Pearsonia sesillifolia	S
064	Ziziphus zeyheriana	S
065	Cyperus margaritaceus	H
066	Cassia biensis	S
067	Sutera palustris	S
068	Helichrysum nudifolium	H
069	Ipompoea obscura	H
070	Sida rhombifolia	H
071	Stoebe vulgaris	S
072	Parinari capensis	S
073	Elephantorrhiza elephantina	S
074	Senecio venosus	H
075	Xerophyta retinervis	H
076	Bidens pilosa	H
077	Kalanchoe thyrsiflora	H
078	Indigofera arrecta	S
079	Andropogon schirensis	I
080	Aristida congesta subsp. congesta	II
081	Aristida sp. 1	II
082	Aristida sp. 2	II
083	Bewsia biflora	I
084	Brachiaria serrata	D

085	Cymbopogon excavatus	I
086	C. validus	I
087	Cynodon dactylon	II
088	Diheteropogon amplectens	D
089	Digitaria brazzae	D
090	D. diagonalis	?
091	D. monodactyla	?
092	D. tricholaenoides	D
093	Elionurus muticus	II
094	Eragrostis chloromelas	II
095	E. curvula	II
096	E. gummiflua	II
097	E. racemosa	II
098	E. rigidior	II
099	Eustachys paspaloides	D
100	Fingerhuthia sesleriiformis	?
101	Heteropogon contortus	D
102	Hyparrhenia hirta	D
103	Loudetia simplex	I
104	Microchloa caffra	II
105	Monocymbium ceresiiforme	D
106	Panicum natalense	I
107	Paspalum scrobiculatum	D
108	Pogonarthria squarrosa	II
109	Rhynchelytrum nerviglume	I
110	R. repens	II
111	Schizachyrium sanguineum	I
112	S. ursulus	I
113	Setaria sphacelata	D
114	Sporobolus africanus	II
115	S. fimbriatus	II
116	S. pectinatus	II
117	Stipagrostis zeyheri	?
118	Themeda triandra	D
119	Trachypogon spicatus	I
120	Tristachya rehmannii	I
121	Triraphis andropogonoides	?
122	Urelytrum agropyroides	I
123	Trichoneura grandiglumis	II
124	Tragus berteronianus	II
125	Eragrostis sp. 1	II
126	Eragrostis sp. 2	II
127	Hyparrhenia sp. 1	I

APPENDIX C

BONFERRONI SIMULTANEOUS CONFIDENCE INTERVALS

The following tables present expected and observed habitat use by the 10 ungulate types studied on the grasslands of Jack Scott Nature Reserve from May 1986 to April 1987. Bonferroni simultaneous confidence intervals were calculated after the method described by Byers et al. (1984). Abbreviations are as follows: TYPE = ungulate type, where

1 = blesbok
2 = springbok
3 = Burchell's zebra
4 = impala
5 = gemsbok
6 = eland
7 = black wildebeest
8 = giraffe
9 = sable antelope
10 = red hartebeest

n = number of observations
CAT = habitat category
EXPPRO = expected proportion of use
EXPUSE = expected usage
OBSUSE = observed usage
OBSPRO = observed proportion of use
BSCI = Bonferroni simultaneous confidence intervals

APPENDIX C.1

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of ruggedness categories by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α =0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	8199	1	0,372	3050	4085	0,498	0,485 - 0,511
		2	0,436	3575	3787	0,462	0,449 - 0,475
		3	0,192	1574	327	0,040	0,035 - 0,045
2	978	1	0,372	364	566	0,579	0,541 - 0,617
		2	0,436	426	408	0,417	0,379 - 0,455
		3	0,192	188	4	0.004	-0,001 - 0,009
3	544	1	0,372	202	369	0,678	0,630 - 0,726
		2	0,436	237	129	0,237	0,193 - 0,281
		3	0,192	104	46	0,085	0,056 - 0,114
4	639	1	0,372	238	108	0,169	0,134 - 0,204
		2	0,436	279	219	0,343	0,298 - 0,388
		3	0,192	123	312	0,488	0,441 - 0,535
5	483	1	0,372	180	268	0,555	0,501 - 0,609
		2	0,436	211	172	0,356	0,304 - 0,408
		3	0,192	93	43	0,089	0,058 - 0,120
6	248	1	0,372	92	67	0,270	0,203 - 0,337
		2	0,436	108	117	,472	0,396 - 0,548
		3	0,192	48	64	0,258	0,192 - 0,324
7	110	1	0,372	41	109	0,991	0,969 - 1,013
		2	0,436	48	1	0,009	-0,013 - 0,031
		3	0,192	21	0	0,000	0,000 - 0,000
8	34	1	0,372	13	8	0,235	0,061 - 0,409
		2	0,436	15	11	0,324	0,132 - 0,516
		3	0,192	7	15	0,441	0,237 - 0,645
9	58	1	0,372	22	25	0,431	0,276 - 0,586
		2	0,436	25	21	0,362	0,211 - 0,513
		3	0,192	11	12	0,207	0,080 - 0,334
10	138	1	0,372	51	90	0,652	0,555 - 0,749
		2	0,436	60	48	0,348	0,251 - 0,445
		3	0,192	26	0	0,000	0,000 - 0,000

Habitat categories: 1 = R1 (land surface ruggedness index - LSRI of <20)
2 = R2 (LSRI of 20 to 39)
3 = R3+R4 (LSRI of >39)

APPENDIX C.2

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of ruggedness categories by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,372	5079	8525	0,624	0,614 - 0,634
		2	0,436	5953	4862	0,356	0,346 - 0,366
		3	0,192	2621	266	0,019	0,016 - 0,022
2	1682	1	0,372	626	1229	0,731	0,705 - 0,757
		2	0,436	733	445	0,265	0,239 - 0,290
		3	0,192	323	8	0,005	0,001 - 0,009
3	1160	1	0,372	432	860	0,741	0,711 - 0,772
		2	0,436	506	282	0,243	0,213 - 0,273
		3	0,192	223	18	0,016	0,007 - 0,024
4	1776	1	0.372	661	467	0,263	0,238 - 0,288
		2	0,436	774	696	0,392	0,364 - 0,420
		3	0,192	341	613	0,345	0,318 - 0,372
5	1492	1	0,372	555	1052	0,705	0,677 - 0,733
		2	0,436	651	392	0,263	0,236 - 0,290
		3	0,192	286	48	0,032	0,021 - 0,043
6	592	1	0,372	220	253	0,472	0,379 - 0,476
		2	0,436	258	274	0,463	0,414 - 0,512
		3	0,192	114	65	0,110	0,079 - 0,141
7	151	1	0,372	56	148	0,980	0,953 - 1,007
		2	0,436	66	3	0,020	-0,007 - 0,047
		3	0,192	29	0	0,000	0,000 - 0,000
8	47	1	0,372	17	15	0,319	0,157 - 0,482
		2	0,436	20	28	0,596	0,425 - 0,767
		3	0,192	9	4	0,085	-0,012 - 0,182
9	158	1	0,372	59	54	0,342	0,252 - 0,432
		2	0,436	69	71	0,449	0,355 - 0,544
		3	0,192	30	33	0,209	0,132 - 0,286
10	493	1	0,372	183	130	0,264	0,216 - 0,311
		2	0,436	215	321	0,651	0,600 - 0,702
		3	0,192	95	42	0,085	0,055 - 0,115

Habitat categories: 1 = R1 (land surface ruggedness index - LSRI of <20)
2 = R2 (LSRI of 20 to 39)
3 = R3+R4 (LSRI of >39)

APPENDIX C.3

Bonferroni simultaneous confidence intervals (Byers <u>et</u> <u>al</u>. 1984) for the use of altitude categories by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSPRO	OBSUSE	BSCI
1	8199	1	0,192	1574	2485	0,303	0,335 - 0,361
		2	0,372	3050	1982	0,242	0,230 - 0,253
		3	0,436	3575	3732	0,455	0,442 - 0,468
2	978	1	0,192	188	421	0,430	0,392 - 0,468
		2	0,372	364	108	0,110	0,086 - 0,134
		3	0,436	426	449	0,459	0,421 - 0,497
3	544	1	0,192	104	10	0,018	0,005 - 0,032
		2	0,372	202	122	0,224	0,182 - 0,267
		3	0,436	237	412	0,757	0,713 - 0,801
4	639	1	0,192	123	430	0,673	0,629 - 0,717
		2	0,372	238	149	0,233	0,193 - 0,273
		3	0,436	279	60	0,094	0,066 - 0,121
5	483	1	0,192	93	32	0,066	0,039 - 0,093
		2	0,372	180	206	0,427	0,373 - 0,480
		3	0,436	210	245	0,507	0,453 - 0,562
6	248	1	0,192	48	23	0,093	0,049 - 0,137
		2	0,372	92	123	0,496	0,420 - 0,572
		3	0,436	108	102	0,411	0,337 - 0,468
7	110	1	0,192	21	3	0,027	-0,010 - 0,064
		2	0,372	41	0	0,000	0,000 - 0,000
		3	0,436	48	107	0,973	0,936 - 1,010
8	34	1	0,192	6	6	0,176	0,020 - 0,333
		2	0,372	13	17	0,500	0,295 - 0,705
		3	0,436	15	11	0,324	0,132 - 0,515
9	58	1	0,192	11	19	0,328	0,180 - 0,475
		2	0,372	22	39	0,672	0,525 - 0,820
		3	0,436	25	0	0,000	0,000 - 0,000
10	138	1	0,192	26	13	0,094	0,035 - 0,154
		2	0,372	51	13	0,094	0,035 - 0,154
		3	0,436	60	112	0,812	0,737 - 0,891

Habitat categories: 1 = A1 (mean altitude of <1450 m)
2 = A2 (mean altitude of 1450 to 1499 m)
3 = A3+A4 (mean altitude of >1499 m)

APPENDIX C.4

Bonferroni simultaneous confidence intervals (Byers *et al*. 1984) for the use of altitude categories by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α =0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSPRO	OBSUSE	BSCI
1	13653	1	0,192	2621	918	0,067	0,062 - 0,072
		2	0,372	5079	2130	0,156	0,149 - 0,163
		3	0,436	5953	10605	0,777	0,768 - 0,785
2	1682	1	0,192	323	232	0,138	0,118 - 0,158
		2	0,372	626	78	0,046	0,034 - 0,059
		3	0,436	733	1372	0,816	0,793 - 0,838
3	1160	1	0,192	223	13	0,011	0,004 - 0,019
		2	0,372	431	69	0,059	0,043 - 0,076
		3	0,436	506	1078	0,929	0,911 - 0,947
4	1776	1	0,192	341	495	0,279	0,253 - 0,304
		2	0,372	661	748	0,421	0,393 - 0,449
		3	0,436	774	533	0,300	0,274 - 0,326
5	1492	1	0,192	286	15	0,010	0,004 - 0,016
		2	0,372	555	270	0,181	0,157 - 0,205
		3	0,436	651	1207	0,809	0,785 - 0,833
6	592	1	0,192	114	28	0,047	0,026 - 0,068
		2	0,372	220	155	0,262	0,219 - 0,305
		3	0,436	258	409	0,691	0,645 - 0,736
7	151	1	0,192	29	4	0,026	-0,005 - 0,058
		2	0,372	56	5	0,033	-0,002 - 0,068
		3	0,436	66	142	0,940	0,894 - 0,986
8	47	1	0,192	9	17	0,362	0,194 - 0,529
		2	0,372	17	11	0,234	0,086 - 0,382
		3	0,436	21	19	0,404	0,233 - 0,575
9	158	1	0,192	30	92	0,582	0,489 - 0,676
		2	0,372	59	54	0,342	0,252 - 0,432
		3	0,436	69	12	0,076	0,026 - 0,126
10	493	1	0,192	95	2	0,004	-0,003 - 0,011
		2	0,372	183	248	0,503	0,449 - 0,557
		3	0,436	215	243	0,493	0,439 - 0,547

Habitat categories: 1 = A1 (mean altitude of <1450 m)
2 = A2 (mean altitude of 1450 to 1499 m)
3 = A3+A4 (mean altitude of >1499 m)

APPENDIX C.5

Bonferroni simultaneous confidence intervals (Byers <u>et</u> <u>al</u>. 1984) for the use of vegetation categories by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α =0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSPRO	OBSUSE	BSCI
1	8199	1	0,218	1787	1697	0,207	0,195 - 0,219
		2	0,437	3583	4099	0,500	0,485 - 0,515
		3	0,021	172	5	0,001	0,000 - 0,002
		4	0,124	1017	746	0,091	0,082 - 0,100
		5	0,121	992	463	0,056	0,049 - 0,063
		6	0,047	385	958	0,117	0,107 - 0,126
		7	0,032	262	231	0,028	0,023 - 0,033
2	978	1	0,218	213	245	0,251	0,213 - 0,288
		2	0,437	427	489	0,500	0,457 - 0,543
		3	0,021	21	0	0,000	0,000 - 0,000
		4	0,124	121	31	0,032	0,017 - 0,047
		5	0.121	118	19	0,019	0,008 - 0,031
		6	0,047	46	174	0,178	0,145 - 0,211
		7	0,032	31	20	0,020	0,008 - 0,033
3	544	1	0,218	119	36	0,066	0,038 - 0,095
		2	0,437	238	463	0,851	0,810 - 0,892
		3	0,021	11	0	0,000	0,000 - 0,000
		4	0,124	67	0	0,000	0,000 - 0,000
		5	0,121	66	45	0,083	0,051 - 0,114
		6	0,047	26	0	0,000	0,000 - 0,000
		7	0,032	17	0	0,000	0,000 - 0,000
4	639	1	0,218	139	219	0,343	0,292 - 0,393
		2	0,437	279	16	0,025	0,008 - 0,042
		3	0,021	13	0	0,000	0,000 - 0,000
		4	0,124	79	59	0,092	0,062 - 0,123
		5	0,121	77	19	0,030	0,012 - 0,048
		6	0,047	30	286	0,448	0,395 - 0,500
		7	0,032	20	40	0,063	0,037 - 0,088
5	483	1	0,218	105	38	0,079	0,046 - 0,112
		2	0,437	211	416	0,861	0,819 - 0,904
		3	0,021	10	0	0,000	0,000 - 0,000
		4	0,124	60	2	0,004	-0,004 - 0,012
		5	0,121	58	24	0,050	0,023 - 0,076
		6	0,047	23	3	0,006	-0,003 - 0,016
		7	0,032	15	0	0,000	0,000 - 0,000

6	248	1	0,218	54	31	0,125	0,069 - 0,181
		2	0,437	108	169	0,681	0,602 - 0,761
		3	0,021	5	0	0,000	0,000 - 0,000
		4	0,124	31	2	0,008	-0,007 - 0,023
		5	0,121	30	21	0,085	0,037 - 0,132
		6	0,047	12	17	0,069	0,025 - 0,112
		7	0,032	8	8	0,032	0,002 - 0,062
7	110	1	0,218	24	0	0,000	0,000 - 0,000
		2	0,437	48	107	0,973	0,931 - 1,015
		3	0,021	2	0	0,000	0,000 - 0,000
		4	0,124	14	1	0,009	-0,015 - 0,033
		5	0,121	13	0	0,000	0,000 - 0,000
		6	0,047	5	2	0,018	-0,016 - 0,052
		7	0,032	4	0	0,000	0,000 - 0,000
8	34	1	0,218	7	0	0,000	0,000 - 0,000
		2	0,437	15	22	0,647	0,427 - 0,868
		3	0,021	1	0	0,000	0,000 - 0,000
		4	0,124	4	1	0,029	-0,049 - 0,107
		5	0,121	4	6	0,176	0,001 - 0,352
		6	0,047	2	3	0,088	-0,043 - 0,219
		7	0,032	1	2	0,059	-0,050 - 0,167
9	58	1	0,218	13	0	0,000	0,000 - 0,000
		2	0,437	25	0	0,000	0,000 - 0,000
		3	0,021	1	25	0,431	0,256 - 0,606
		4	0,124	7	33	0,569	0,394 - 0,744
		5	0,121	7	0	0,000	0,000 - 0,000
		6	0,047	3	0	0,000	0,000 - 0,000
		7	0,032	2	0	0,000	0,000 - 0,000
10	138	1	0,218	30	0	0,000	0,000 - 0,000
		2	0,437	60	103	0,746	0,647 - 0,846
		3	0,021	3	0	0,000	0,000 - 0,000
		4	0,124	17	13	0,094	0,027 - 0,161
		5	0,121	17	22	0,159	0,076 - 0,243
		6	0,047	6	0	0,000	0,000 - 0,000
		7	0,032	4	0	0,000	0,000 - 0,000

Habitat categories:
1 = VC (vegetation consists of the chert community)
2 = VD (vegetation consists of the dolomite community)
3 = VF (vegetation consists of the old lands community)
4 = VS (vegetation consists of the shale community)
5 = VCD (vegetation consists of both the chert and dolomite communities)
6 = VCS (vegetation consists of both the chert and shale communities)
7 = VSF (vegetation consists of both the shale and old lands communities)

APPENDIX C.6

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of vegetation categories by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α =0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,218	2976	1162	0,085	0,079 - 0,092
		2	0,437	5966	10153	0,744	0,734 - 0,754
		3	0,021	287	46	0,003	0,002 - 0,005
		4	0,124	1693	144	0,011	0,008 - 0,013
		5	0,121	1652	1597	0,117	0,110 - 0,124
		6	0,047	642	292	0,021	0,018 - 0,025
		7	0,032	437	259	0,019	0,016 - 0,022
2	1682	1	0,218	367	83	0,049	0,035 - 0,064
		2	0,437	735	1302	0,774	0,747 - 0,802
		3	0,021	35	0	0,000	0,000 - 0,000
		4	0,124	209	59	0,035	0,023 - 0,047
		5	0,121	204	104	0,062	0,046 - 0,078
		6	0,047	79	134	0,080	0,062 - 0,097
		7	0,032	54	0	0,000	0,000 - 0,000
3	1160	1	0,218	253	40	0,034	0,020 - 0,049
		2	0,437	507	1020	0,879	0,854 - 0,905
		3	0,021	24	0	0,000	0,000 - 0,000
		4	0,124	144	1	0,001	-0.001 - 0,003
		5	0,121	144	99	0,085	0,063 - 0,107
		6	0,047	55	0	0,000	0,000 - 0,000
		7	0,032	37	0	0,000	0,000 - 0,000
4	1776	1	0,218	387	307	0,173	0,149 - 0,197
		2	0,437	776	360	0,203	0,177 - 0,228
		3	0,021	37	2	0,001	-0,001 - 0,003
		4	0,124	220	334	0,188	0,163 - 0,213
		5	0,121	215	148	0,083	0,066 - 0,101
		6	0,047	83	413	0,233	0,206 - 0,260
		7	0,032	57	212	0,119	0,099 - 0,140
5	1492	1	0,218	325	137	0,092	0,072 - 0,112
		2	0,437	652	1108	0,743	0,712 - 0,773
		3	0,021	31	0	0,000	0,000 - 0,000
		4	0,124	185	0	0,000	0,000 - 0,000
		5	0,121	181	205	0,137	0,113 - 0,161
		6	0,047	70	42	0,028	0,017 - 0,040
		7	0,032	48	0	0,000	0,000 - 0,000

6	592	1	0,218	129	98	0,166	0,124 - 0,207
		2	0,437	259	313	0,529	0,474 - 0,584
		3	0,021	12	10	0,017	0,003 - 0,031
		4	0,124	73	37	0,063	0,036 - 0,089
		5	0,121	73	105	0,177	0,135 - 0,220
		6	0,047	28	14	0,024	0,007 - 0,040
		7	0,032	19	15	0,025	0,008 - 0,043
7	151	1	0,218	33	3	0,020	-0,011 - 0,050
		2	0,437	66	147	0,974	0,938 - 1,009
		3	0,021	3	0	0,000	0,000 - 0,000
		4	0,124	19	0	0,000	0,000 - 0,000
		5	0,121	18	0	0,000	0,000 - 0,000
		6	0,047	7	1	0,007	-0,011 - 0,024
		7	0,032	5	0	0,000	0,000 - 0,000
8	47	1	0,218	10	0	0,000	0,000 - 0,000
		2	0,437	21	30	0,638	0,450 - 0,827
		3	0,021	1	0	0,000	0,000 - 0,000
		4	0,124	6	17	0,362	0,173 - 0,550
		5	0,121	6	0	0,000	0,000 - 0,000
		6	0,047	2	0	0,000	0,000 - 0,000
		7	0,032	2	0	0,000	0,000 - 0,000
9	158	1	0,218	34	22	0,139	0,065 - 0,213
		2	0,437	69	31	0,196	0,111 - 0,281
		3	0,021	3	18	0,144	0,046 - 0,182
		4	0,124	20	63	0,399	0,294 - 0,504
		5	0,121	19	4	0,025	-0,008 - 0,059
		6	0,047	7	20	0,127	0,055 - 0,198
		7	0,032	5	0	0,000	0,000 - 0,000
10	493	1	0,218	107	13	0,026	0,007 - 0,046
		2	0,437	215	441	0,895	0,857 - 0,932
		3	0,021	10	0	0,000	0,000 - 0,000
		4	0,124	61	0	0,000	0,000 - 0,000
		5	0,121	60	37	0,075	0,043 - 0,107
		6	0,047	23	1	0,002	-0.003 - 0.007
		7	0,032	16	1	0,002	-0,003 - 0,007

Habitat categories: 1 = VC (vegetation consists of the chert community)
2 = VD (vegetation consists of the dolomite community)
3 = VF (vegetation consists of the old lands community)
4 = VS (vegetation consists of the shale community)
5 = VCD (vegetation consists of both the chert and dolomite communities)
6 = VCS (vegetation consists of both the chert and shale communities)
7 = VSF (vegetation consists of both the shale and old lands communities)

APPENDIX C.7

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of woodland categories by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	8199	1	0,743	6092	6368	0,777	0,737 - 0,817
		2	0,252	2107	1831	0,223	0,183 - 0,263
2	978	1	0,743	727	793	0,811	0,773 - 0,849
		2	0,257	251	185	0,189	0,151 - 0,227
3	544	1	0,743	404	472	0,868	0,835 - 0,900
		2	0,257	140	72	0,132	0,100 - 0,165
4	639	1	0,743	475	200	0,313	0,272 - 0,354
		2	0,257	164	439	0,687	0,646 - 0,728
5	483	1	0,743	359	387	0,801	0,761 - 0,842
		2	0,257	124	96	0,199	0,158 - 0,239
6	248	1	0,743	184	164	0,661	0,594 - 0,729
		2	0,257	64	84	0,339	0,271 - 0,406
7	110	1	0,743	82	110	1,000	1,000 - 1,000
		2	0,257	28	0	0,000	0,000 - 0,000
8	34	1	0,743	25	19	0,559	0,368 - 0,750
		2	0,257	9	15	0,441	0,250 - 0,632
9	58	1	0,743	43	26	0,448	0,302 - 0,595
		2	0,257	15	32	0,552	0,405 - 0,698
10	138	1	0,743	103	26	0,188	0,114 - 0,263
		2	0,257	35	112	0,812	0,737 - 0,886

Habitat categories: 1 = WA (woodland absent)
2 = WP (woodland present)

APPENDIX C.8

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of woodland categories by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,743	10144	9992	0,732	0,723 - 0,740
		2	0,257	3509	3661	0,268	0,260 - 0,277
2	1682	1	0,743	1250	1373	0,816	0,795 - 0,837
		2	0,257	432	309	0,184	0,163 - 0,205
3	1160	1	0,743	862	1041	0,897	0,877 - 0,917
		2	0,257	298	119	0,103	0,083 - 0,123
4	1776	1	0,743	1320	844	0,475	0,449 - 0,502
		2	0,257	456	932	0,525	0,498 - 0,551
5	1492	1	0,743	1109	1355	0,908	0,891 - 0,925
		2	0,257	383	137	0,092	0,075 - 0,109
6	592	1	0,743	440	429	0,725	0,684 - 0,766
		2	0,257	152	163	0,275	0,234 - 0,316
7	151	1	0,743	112	151	1,000	1,000 - 1,000
		2	0,257	39	0	0,000	0,000 - 0,000
8	47	1	0,743	35	11	0,234	0,096 - 0,372
		2	0,257	12	36	0,766	0,628 - 0,904
9	158	1	0,743	117	79	0,500	0,411 - 0,589
		2	0,257	41	79	0,500	0,411 - 0,589
10	493	1	0,743	366	390	0,791	0,750 - 0,832
		2	0,257	127	103	0,209	0,168 - 0,250

Habitat categories: 1 = WA (woodland absent)
2 = WP (woodland present)

APPENDIX C.9

Bonferroni simultaneous confidence intervals (Byers _et al_. 1984) for the use of supplementary feed sites by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSPRO	OBSUSE	BSCI
1	8199	1	0,976	8002	7577	0,924	0,918 - 0,931
		2	0,024	197	622	0,076	0,069 - 0,082
2	978	1	0,976	955	873	0,893	0,870 - 0,915
		2	0,024	23	105	0,107	0,085 - 0,130
3	544	1	0,976	531	529	0,972	0,957 - 0,988
		2	0,024	13	15	0,028	0,012 - 0,043
4	639	1	0,976	624	574	0,898	0,871 - 0,925
		2	0,024	15	65	0,102	0,075 - 0,129
5	483	1	0,976	471	435	0,901	0,870 - 0,931
		2	0,024	12	48	0,099	0,069 - 0,130
6	248	1	0,976	242	236	0,952	0,921 - 0,982
		2	0,024	6	12	0,048	0,018 - 0,079
7	110	1	0,976	107	110	1,000	1,000 - 1,000
		2	0,024	3	0	0,000	0,000 - 0,000
8	34	1	0,976	33	34	1,000	1,000 - 1,000
		2	0,024	1	0	0,000	0,000 - 0,000
9	58	1	0,976	57	58	1,000	1,000 - 1,000
		2	0,024	1	0	0,000	0,000 - 0,000
10	138	1	0,976	135	125	0,906	0,850 - 0,961
		2	0,024	3	13	0,094	0,039 - 0,150

Habitat categories: 1 = SFSA (supplementary feed site absent)
2 = SFSP (supplementary feed site present)

APPENDIX C.10

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of supplementary feed sites by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,976	13325	12761	0,935	0,930 - 0,939
		2	0,024	328	892	0,065	0,061 - 0,070
2	1682	1	0,976	1642	1657	0,985	0,979 - 0,992
		2	0,024	40	25	0,015	0,008 - 0,021
3	1160	1	0,976	1132	1116	0,962	0,950 - 0,975
		2	0,024	28	44	0,038	0,025 - 0,050
4	1776	1	0,976	1733	1676	0,944	0,931 - 0,956
		2	0,024	43	100	0,056	0,044 - 0,069
5	1492	1	0,976	1456	1470	0,985	0,978 - 0,992
		2	0,024	36	22	0,015	0,008 - 0,022
6	592	1	0,976	578	552	0,932	0,909 - 0,956
		2	0,024	14	40	0,068	0,044 - 0,091
7	151	1	0,976	147	148	0,980	0,955 - 1,006
		2	0,024	4	3	0,020	-0,006 - 0,045
8	47	1	0,976	46	30	0,638	0,481 - 0,795
		2	0,024	1	17	0,362	0,205 - 0,519
9	158	1	0,976	154	149	0,943	0,902 - 0,984
		2	0,024	4	9	0,057	0,016 - 0,098
10	493	1	0,976	481	469	0,951	0,930 - 0,973
		2	0,024	12	24	0,049	0,027 - 0,070

Habitat categories: 1 = SFSA (supplementary feed site absent)
2 = SFSP (supplementary feed site present)

APPENDIX C.11

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of permanent water by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSPRO	OBSUSE	BSCI
1	8199	1	0,950	7789	8007	0,977	0,973 - 0,980
		2	0,050	410	192	0,023	0,020 - 0,027
2	978	1	0,950	929	974	0,996	0,991 - 1,000
		2	0,050	49	4	0,004	0,000 - 0,009
3	544	1	0,950	517	544	1,000	1,000 - 1,000
		2	0,050	27	0	0,000	0,000 - 0,000
4	639	1	0,950	607	594	0,930	0,907 - 0,952
		2	0,050	32	45	0,070	0,048 - 0,093
5	483	1	0,950	459	483	1,000	1,000 - 1,000
		2	0,050	24	0	0,000	0,000 - 0,000
6	248	1	0,950	236	247	0,996	0,987 - 1,005
		2	0,050	12	1	0,004	-0,005 - 0,013
7	110	1	0,950	105	110	1,000	1,000 - 1,000
		2	0,050	5	0	0,000	0,000 - 0,000
8	34	1	0,950	32	34	1,000	1,000 - 1,000
		2	0,050	2	0	0,000	0,000 - 0,000
9	58	1	0,950	55	39	0,672	0,534 - 0,810
		2	0,050	3	19	0,328	0,190 - 0,466
10	138	1	0,950	131	125	0,906	0,850 - 0,961
		2	0,050	7	13	0,094	0,039 - 0,150

Habitat categories: 1 = PWA (permanent water absent)
2 = PWP (permanent water present)

APPENDIX C.12

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of permanent water by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,950	12970	13576	0,994	0,993 - 0,996
		2	0,050	683	77	0,006	0,004 - 0,007
2	1682	1	0,950	1598	1675	0,996	0,992 - 0,999
		2	0,050	84	7	0,004	0,001 - 0,008
3	1160	1	0,950	1102	1160	1,000	1,000 - 1,000
		2	0,050	58	0	0,000	0,000 - 0,000
4	1776	1	0,950	1687	1618	0,911	0,896 - 0,926
		2	0,050	89	158	0,089	0,074 - 0,104
5	1492	1	0,950	1417	1492	1,000	1,000 - 1,000
		2	0,050	75	0	0,000	0,000 - 0,000
6	592	1	0,950	562	590	0,997	0,991 - 1,002
		2	0,050	30	2	0,003	-0,002 - 0,008
7	151	1	0,950	143	151	1,000	1,000 - 1,000
		2	0,050	8	0	0,000	0,000 - 0,000
8	47	1	0,950	45	30	0,638	0,481 - 0,795
		2	0,050	2	17	0,362	0,205 - 0,519
9	158	1	0,950	150	118	0,747	0,669 - 0,824
		2	0,050	8	40	0,253	0,176 - 0,331
10	493	1	0,950	468	493	1,000	1,000 - 1,000
		2	0,050	25	0	0,000	0,000 - 0,000

Habitat categories: 1 = PWA (permanent water absent)
2 = PWP (permanent water present)

APPENDIX C.13

Bonferroni simultaneous confidence intervals (Byers et al. 1984) for the use of burning categories by ungulate types during the dry season (May to September 1986) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	8199	1	0,106	869	2859	0,349	0,337 - 0,360
		2	0,894	7330	5340	0,651	0,640 - 0,663
2	978	1	0,106	104	425	0,435	0,399 - 0,470
		2	0,894	874	553	0,565	0,530 - 0,601
3	544	1	0,106	58	15	0,028	0,012 - 0,043
		2	0,894	486	529	0,972	0,957 - 0,988
4	639	1	0,106	68	135	0,211	0,175 - 0,247
		2	0,894	571	504	0,789	0,753 - 0,825
5	483	1	0,106	51	23	0,048	0,026 - 0,069
		2	0,894	432	460	0,952	0,931 - 0,974
6	248	1	0,106	26	8	0,032	0,007 - 0,057
		2	0,894	222	240	0,968	0,943 - 0,993
7	110	1	0,106	12	3	0,027	-0,008 - 0,062
		2	0,894	98	107	0,973	0,938 - 1,008
8	34	1	0,106	4	2	0,059	-0,032 - 0,149
		2	0,894	30	32	0,941	0,851 - 1,032
9	58	1	0,106	6	0	0,000	0,000 - 0,000
		2	0,894	52	58	1,000	1,000 - 1,000
10	138	1	0,106	15	0	0,000	0,000 - 0,000
		2	0,894	123	138	1,000	1,000 - 1,000

Habitat categories: 1 = B<1 (burnt less than one year ago)
2 = B>1 (burnt more than one year ago)

APPENDIX C.14

Bonferroni simultaneous confidence intervals (Byers <u>et</u> <u>al</u>. 1984) for the use of burning categories by ungulate types during the wet season (October 1986 to April 1987) in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, (α=0,05).

TYPE	n	CAT	EXPPRO	EXPUSE	OBSUSE	OBSPRO	BSCI
1	13653	1	0,086	1174	7935	0,581	0,572 - 0,591
		2	0,914	12479	5718	0,419	0,409 - 0,428
2	1682	1	0,086	145	556	0,331	0,305 - 0,356
		2	0,914	1537	1126	0,669	0,644 - 0,695
3	1160	1	0,086	100	229	0,197	0,171 - 0,224
		2	0,914	1060	931	0,803	0,776 - 0,829
4	1776	1	0,086	153	269	0,151	0,132 - 0,171
		2	0,914	1623	1507	0,849	0,829 - 0,868
5	1492	1	0,086	128	284	0,190	0,168 - 0,213
		2	0,914	1364	1208	0,810	0,787 - 0,832
6	592	1	0,086	51	224	0,378	0,334 - 0,423
		2	0,914	541	368	0,622	0,577 - 0,666
7	151	1	0,086	13	6	0,040	0,004 - 0,075
		2	0,914	138	145	0,960	0,925 - 0,996
8	47	1	0,086	4	12	0,255	0,113 - 0,398
		2	0,914	43	35	0,745	0,602 - 0,887
9	158	1	0,086	14	7	0,044	0,008 - 0,081
		2	0,914	144	151	0,956	0,919 - 0,992
10	493	1	0,086	42	39	0,079	0,052 - 0,106
		2	0,914	451	454	0,921	0,894 - 0,948

Habitat categories: 1 = B<1 (burnt less than one year ago)
2 = B>1 (burnt more than one year ago)

Scogings, P.F.

Two quantitative methods of analysing ungulate-habitat data*

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Ungulate-habitat data for 10 ungulate types that use the grasslands of Jack Scott Nature Reserve were quantitatively analysed using simultaneous confidence intervals and detrended correspondence analysis. The first method is an hypothesis-testing statistical method while the second method is an hypothesis-generating multivariate method. The two methods complemented each other and both revealed the same major habitat selection patterns.

Hoefdier-habitat gegewens is vir 10 wildsoorte wat die grasvelde van die Jack Scott-natuurreservaat gebruik, kwantitatief geanaliseer. Gelyktydige vertroubaarheids-intervalle en ontneigde ooreenstemmingsanalise is gebruik. Die eerste metode is 'n statistiese metode wat 'n hipotese toets en die tweede metode is 'n meervoudige metode wat hipotese ontwikkel. Die twee metodes was

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komplimentêr en albei het dieselfde hoof habitat-seleksiepatrone onthul.

Keywords: Habitat selection, ungulates, grasslands, simultaneous confidence intervals, DECORANA

Introduction

The maintenance of mixed ungulate populations in an area, without detriment to either habitat or animals, requires insight into habitat needs, habitat use and potential interspecific competition among the animals of the area. Many studies of mammalian herbivores in relation to their environments have been done, especially in the last 25 years. Studies range in complexity from qualitative descriptions of habitat use (for example, Lamprey 1963) to quantitative analyses made possible by advanced computer methods such as detrended correspondence analysis (Hill & Gauch 1980).

Analysing quantitative animal-habitat data

Simple quantitative studies express habitat preference in terms of the proportion of animals seen in each habitat type. An extension of this concept is the comparison of observed habitat use with expected habitat use, according to habitat availability (for example, Hirst 1975). Such studies usually involve classical statistical techniques of hypothesis testing (Williams 1973). The null hypothesis tested is that the distribution of animals in an area is random over all habitat types, meaning that the expected occurrence of animals would be in proportion to the relative occurrence of the different habitats in the area.

Coefficients of association and indices of selection/ preference may also be calculated.

The second main type of quantitative analysis of animal-habitat relationships is the use of multivariate analysis techniques (for example, Beardall, Joubert & Retief 1984). Hypothesis-generating multivariate analysis, or pattern analysis, may be distinguished from hypothesis-testing classical statistics (Williams 1973). Studies using multivariate analysis techniques do not require information on the amount of habitat available and a record of habitat variables at each animal location is usually sufficient. Multivariate analyses are more accessable now because of the development of rapid, flexible computer programs such as DECORANA (Hill 1979).

Study area

Jack Scott Nature Reserve is situated between latitudes 25° 52' and 25°57' S and between longitudes 27° 43' and 27° 48' E in the Krugersdorp District of the Transvaal. The reserve is located on the northern edge of Acocks' (1975) Central Variation of the Bankenveld which is a false grassland maintained at a fire climax while the true climax is thought to be an open savanna.

The actual study area covers only 2 100 ha of Jack Scott Nature Reserve, namely the southern grasslands and ranges in altitude from 1 365 to 1 615 m above sea level. The northern 1 400 ha consists of Acacia caffra and Protea caffra woodlands.

The mean annual rainfall for 17 weather stations within 30 km of the study area is 683 mm and there is a cold, dry season from May to September and a hot, wet season from October to April.

Methods

A grid of 250 x 250 m (6,25 ha) pixels was constructed on the 1 000 x 1 000 m grid of X and Y National Mapping System coordinates on the four 1:10 000 orthophoto maps covering the study area (2527DC 15 HARTEBEESHOEK, 2527DC 20 WELTEVREDEN, 2527DD 11 SKEERPOORTRIVIER and 2527DD 16 RIETFONTEIN).

Ungulate counts in the study area were done from May 1986 through April 1987. Ten ungulate types were observed (the maximum number counted in the study area during the study period is in brackets): Burchell's zebra Equus burchelli (34), giraffe Giraffa camelopardalis (13), black wildebeest Connochaetes gnou (4), red hartebeest Alcelaphus buselaphus (15), blesbok Damaliscus dorcas phillipsi (382), springbok Antidorcas marsupialis (41), impala Aepyceros melampus (95), sable antelope Hippotragus niger (7), gemsbok Oryx gazella (40) and eland Taurotragus oryx (41). The twelve-month period over which ungulates were counted was divided into two seasons. The dry season was defined as May to September 1986 and the wet season was defined as October 1986 to April 1987.

A fixed route along roads and paths was travelled by motorcycle and, in parts, on foot during the first 4 to 5 hours after sunrise on two successive days per week. Four starting positions round the census route were used so as to have temporally distributed observations. One census cycle consisted in starting at each of the four starting points on four consecutive counts so that one census cycle took two weeks and eight counts (two census cycles) could thus be done per month. However, only six to eight counts (mean = 7) per month were actually achieved, with only four in September 1986. During each census, elevated positions were used for scanning sections of the study area with 10 x 50 binoculars. The animals sighted were identified as one of the 10 types mentioned above, and counted and fixed in time and space. Animals sighted more than once during a count were noted as such because only the first sightings were used in the habitat utilisation analysis.

Ungulate counts were done by the senior author during the morning only because of the greater visibility of animals at that time. During December 1986 and January 1987 four of the regular morning counts (done between 05h30 and 10h30 at this time of year) per month in the present study were followed by afternoon counts done between 13h30 and 18h00 for comparison with the same mornings' counts. The Wilcoxon two-sample test (Sokal & Rohlf 1981) was used to compare the number of animals counted in the mornings with the number of animals counted in the afternoons.

An area in the north-east of the study area was deliberately burnt during October 1986 for management reasons. "Rumevite" game blocks were available to the ungulates during the dry season and rock salt was available throughout the year. Both supplements were placed at eight permanent sites in the study area as part of the normal management of the reserve.

Habitat availability and utilisation

Each pixel was evaluated in terms of 21 habitat categories in seven habitat groups (Table 1). Ruggedness was determined according to Beasom, Wiggers & Giardine (1983) and a matrix of 11 x 11 dots, spaced 2,5 mm apart on a piece of transparent plastic film was used. The size of the matrix was therefore 25 x 25 mm, the same size as a 250 x 250 m pixel on a 1:10 000 orthophoto map with contour intervals of 5 m. By placing the dot matrix over each pixel, the number of dot-contour line intercepts could be counted, thus giving an index of land surface ruggedness (LSRI). This method is quicker than measuring the total length of contour lines in each square and the two methods are related (Beasom et al. 1983). A linear regression analysis of total contour line length on number of dot-contour intercepts for 34 random pixels in the study area showed a significant correlation ($r=0,990$; $df=32$; $p<0,001$).

The mean altitude (m) of each pixel was obtained from the orthophoto maps by calculating the mean of the highest and lowest contour lines in each pixel. The vegetation classification followed the map of Coetzee (1974) and the remaining habitat categories were assessed by direct observation.

A method described by Byers, Steinhorst & Krausman (1984) was used to compare the expected and observed use of the habitat categories by ungulates in the study area. This method uses enumeration data for the calculation of simultaneous confidence intervals and may be used together with the chi-square goodness-of-fit test. The values of expected use should generally be greater than five, so it might be necessary to combine some of the less frequent classes (Byers et al. 1984).

When examining a set of categories such as the three ruggedness categories in the present study, a family of Bonferroni-type simultaneous confidence intervals may be calculated as follows:

$$p_i - Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n} \leqslant p_i \leqslant p_i + Z_{\alpha/2k}\sqrt{p_i(1-p_i)/n}$$

where p_i is the observed proportion of use (observed number of animals using category i / total number of animals using all categories), n is the total number of animals using all categories, α is the stated level of significance, k is the number of categories, and $Z_{\alpha/2k}$ is the upper standard normal table value corresponding to a probability tail of $\alpha/2k$ (Byers et al. 1984). Thus, when k = 3 and $\alpha = 0,05$, $Z_{0,0083} = 2,39$.

Also to be calculated is the expected proportion of use, p_{io}, which is equal to the relative proportion of category i. If p_{io} lies outside the confidence interval, expected use and actual use are significantly different at the stated level of significance (Byers et al. 1984), while p_{io} inside the confidence interval implies chance use of category i by the study animals.

It is important to note that the effectiveness of the described test depends on the method of data collection. Data collection must be such that the study animals have access to, and opportunity to be observed in, each category. A major assumption involved is that the animals move independently of each other (Byers _et al_. 1984).

Multivariate analyses

The ungulate census data were subjected to DECORANA (Hill 1979), a FORTRAN program for detrended correspondence analysis. The pixels were the individuals and the ungulate types were the attributes, quantified by the total number counted per pixel. Multivariate analyses were done for three time periods, namely the wet season, the dry season and the whole study period.

In another application of DECORANA, the individuals were ungulate types and the attributes were habitat categories, quantified by the number of records of each ungulate type in each habitat category. The three abovementioned time periods were again used. This second approach was applied because of the large number of pixels (339) and few ungulate types (10) which made the ordination of individuals by the previous approach unwieldy and difficult to interpret.

Results

The Wilcoxon two-sample test indicated no significant difference between the morning and afternoon counts of all ungulate types ($Z=1,2077$; $P>0,05$).

The highest number of ungulates counted in the study area during the study period was 590 on 6 February 1987, while the lowest number of ungulates counted was 199 on 22 July 1986.

Habitat selection

Habitat selection by ungulates in the study area, as determined by the calculation of simultaneous confidence intervals, is presented in Table 2.

Areas of low ruggedness (LSRI<20) were selected consistently (all year) by blesbok, springbok, Burchell's zebra, gemsbok and black wildebeest. Impala were the only consistent selectors of low altitude areas (<1 450 m) of high ruggedness (LSRI>39). Blesbok, Burchell's zebra, gemsbok, black wildebeest and red hartebeest consistently selected high altitude areas (>1 499 m) and the same ungulate types, as well as springbok and eland, consistently selected the grasslands on dolomite, which were generally also of high altitude and low ruggedness.

Sable antelope were the only consistent selectors of the old lands and shale grasslands, which had the greatest phytomass and tallest grass (Scogings 1988).

Springbok, Burchell's zebra, gemsbok and black wildebeest consistently selected areas without trees, while impala and sable antelope consistently selected areas with trees in the study area. Burchell's zebra and gemsbok were, however, observed using the woodlands outside the study area.

Supplementary feed sites were selected consistently by blesbok, impala and red hartebeest, while springbok and gemsbok selected areas around supplementary feed sites in the dry season, but not in the wet season. Conversely, Burchell's zebra and eland selected areas around supplementary feed sites in the wet season, but not in the dry season.

Permanent water was selected consistently by sable antelope only, while areas without permanent water were selected consistently by blesbok, springbok, Burchell's zebra, gemsbok, eland and black wildebeest. The fact that ungulate types such as blesbok, Burchell's zebra and black wildebeest, which are considered to be dependent on free water (Smithers 1983), did not select areas with permanent water, indicates that permanent water was not a limiting factor in the study area. Ungulates in the study area were generally never more than 4 km from permanent water because of the size of the study area.

Only sable antelope and black wildebeest consistently selected areas that had not been burnt within the last year. Blesbok, springbok and impala, however, consistently selected areas that had been burnt within the last year. Burchell's zebra, gemsbok and eland selected areas which had been burnt within the last year during the wet season only. This implies that by the dry season, in other words six months after the previous spring's burn, these ungulate types were no longer attracted to that burnt area.

The number of asterisks associated with eland and giraffe in Table 2 indicates a largely random use of the habitats in the study area. These two ungulate types were mostly observed in transit as they moved from tree to tree in the study area (Scogings 1988).

Multivariate analyses

The first axis of the attribute ordination represented the same gradient for all three time periods considered. Because of the large number of pixels (339), the individual ordination of the pixel-by-ungulate type approach was unwieldy and is not shown.

The second approach of using ungulate types as individuals and habitat categories as attributes proved to yield results no different from the pixel-by-ungulate type approach. The former results were, in fact, less clear than the latter and are not dealt with here.

The first axis in Figure 1 represents, from left to right, a preference for short-grass, open, flat areas, away from trees, to a preference for medium- to tall-grass areas with tree cover and permanent water. The second axis, especially on the right of Figure 1, separates impala from sable antelope, The former selected recently burnt areas and the latter selected unburnt areas with dense grass cover, as described above.

While most ungulate types remained in relatively the same positions along the first axis between seasons, the point representing giraffe was at the left end of the axis in the dry season and moved to the right end of the axis in the wet season. Giraffe sightings in the wet season were on the edge of the study area, not far from the woodland part of the reserve, while in the dry season giraffe occurred more widely through the study area, browsing on singular individuals or clusters of trees scattered through the study area.

Also of note is the position of blesbok in the middle of the field of points in Figure 1. Blesbok were the most abundant ungulate type in the study area during the study period and are relatively general with respect to habitat use.

Conclusions

The methods used in the present study to examine habitat use by ungulates in the study area complemented each other and highlighted the same main features affecting habitat use. The primary dichotomy was the separation between open grassland ungulates such as blesbok, springbok and black wildebeest, and woodland ungulates such as impala and sable antelope. Blesbok, springbok and impala utilised burnt areas up to one year after burning, while Burchell's zebra, gemsbok and eland utilised burnt areas only for the first six months after burning. Other ungulates, namely giraffe, black wildebeest, red hartebeest and sable antelope were not particularly selective of any burnt areas.

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References

ACOCKS, J.P.H. 1975. Veld types of South Africa. Mem. Bot. Surv. S. Afr. 40:1-28.

BEARDALL, G.M., JOUBERT, S.C.J. & RETIEF, P.F. 1984. An evaluation of the use of correspondence analysis for the analysis of herbivore-habitat selection. S. Afr. J. Wildl. Res. 14:79-88.

BEASOM, S.L., WIGGERS, E.P. & GIARDINE, J.R. 1983. A technique for assessing land surface ruggedness. J. Wildl. Manage. 47:1163-1166.

BYERS, C.R., STEINHORST, R.K. & KRAUSMAN, P.R. 1984. Clarification of a technique for analysis of utilisation-availablity data. J. Wildl. Manage. 48: 1050-1053.

COETZEE, B.J. 1974. A phytosociological classification of the vegetation of the Jack Scott Nature Reserve. Bothalia. 11:329-347.

HILL, M.O. 1979. DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Cornell University, Ithaca, NY.

HILL, M.O. & GAUCH, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio. 42:47-58.

HIRST, S.M. 1975. Ungulate-habitat relationships in a South African woodland/savanna ecosystem. Wildl. Monogr. 44:1-60.

LAMPREY, H.F. 1963. Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. E. Afr. Wildl. J. 1:63-92.

SCOGINGS, P.F. 1988. An ecological study of the grasslands of the Jack Scott Nature Reserve, Transvaal, with special reference to plant production and ungulate-habitat relationships. Unpublished MSc thesis, University of Pretoria, Pretoria.

SMITHERS, R.H.N. 1983. The mammals of the southern African subregion. University of Pretoria, Pretoria.

SOKAL, R.R. & ROHLF, F.J. 1981. Biometry. W H Freeman, San Francisco.

WILLIAMS, W.T. 1973. Pattern analysis in field experiments. In: Development in field experiment design and analysis, (eds) Bofinger, B.J. & Wheeler, J.L., Ch. 8, Commonwealth Agricultural Bureaux, Melborne.

Table 1 Habitat categories and their values as used to classify each pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal.

HABITAT GROUP	HABITAT CATEGORY	VALUE OF HABITAT CATEGORY PER PIXEL
Ruggedness	R1	land surface ruggedness index (LSRI) < 20
	R2	LSRI = 20 to 39
	R3	LSRI > 39
Mean altitude above sea level	A1	< 1 450 m
	A2	1 450 - 1 499 m
	A3	> 1 499 m
Vegetation (grassland community)	VC	only chert community in pixel
	VD	only dolomite community in pixel
	VF	only old lands community in pixel
	VS	only shale community in pixel
	VCD	both chert and dolomite communities in pixel
	VCS	both chert and shale communities in pixel
	VSF	both shale and old lands communities in pixel
Woodland	WA	woodland absent from pixel
	WP	woodland present in pixel
Supplementary feed sites	FSA	supplementary feed site absent from pixel
	FSP	supplementary feed site present in pixel
Permanent water	PWA	permanent water absent from pixel
	PWP	permanent water present in pixel
Burning history	B<1	pixel burnt less than one year ago
	B>1	pixel burnt more than one year ago

Scogings, P.F.

Table 2 Selection of habitat categories by ungulate types in the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, during the dry season (May to September 1986) and the wet season (October 1986 to April 1987) of the study period, as determined by calculating Bonferroni simultaneous confidence intervals (Byers et al. 1984).

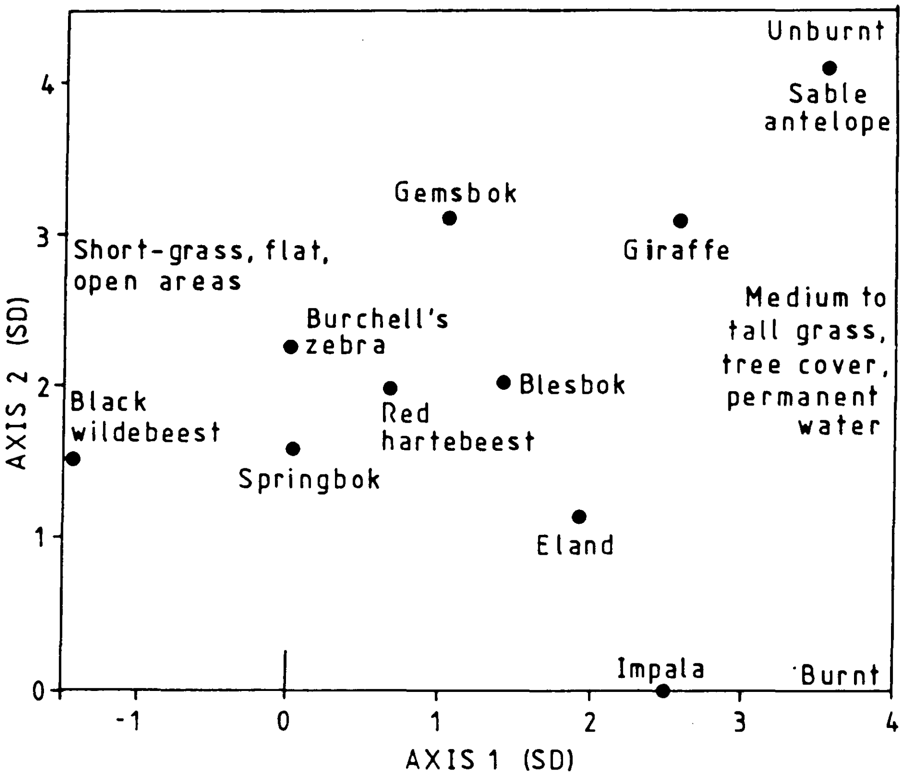
UNGULATE TYPE	SEASON	HABITAT CATEGORY#																				
		R1	R2	R3	A1	A2	A3	VC	VD	VF	VS	VCD	VCS	VSF	WA	WP	FSA	FSP	PWA	PWP	B<1	B>1
Blesbok	dry	+	+	-	+	-	+	*	+	-	-	-	+	*	*	*	-	+	+	-	+	-
	wet	+	-	-	-	-	+	-	+	-	-	*	-	-	-	+	-	+	+	-	+	-
Springbok	dry	+	*	-	+	-	*	*	+	-	-	-	+	*	+	-	-	+	+	-	+	-
	wet	+	-	-	-	-	+	-	+	-	-	-	+	-	+	-	+	-	+	-	+	-
Burchell's zebra	dry	+	-	-	-	-	+	-	+	-	-	-	-	-	+	-	*	*	+	-	-	+
	wet	+	-	-	-	-	+	-	+	-	-	-	-	-	+	-	-	+	+	-	+	-
Impala	dry	-	-	+	+	-	-	+	-	-	-	-	+	+	-	+	-	+	*	*	+	-
	wet	-	-	+	+	+	-	-	-	-	+	-	+	+	-	+	-	+	-	+	+	-
Gemsbok	dry	+	-	-	-	+	+	-	+	-	-	-	-	-	+	-	-	+	+	-	-	+
	wet	+	-	-	-	-	+	-	+	-	-	*	-	-	+	-	+	-	+	-	+	-
Eland	dry	-	*	-	+	*	-	-	+	-	-	*	*	*	-	+	*	*	+	-	-	+
	wet	+	*	-	-	-	+	-	+	*	-	+	-	*	*	*	-	+	+	-	+	-
Black wildebeest	dry	+	-	-	-	-	+	-	+	-	-	-	*	-	+	-	+	-	+	-	-	+
	wet	+	-	-	-	-	+	-	+	-	-	-	-	-	+	-	*	*	+	-	-	+
Giraffe	dry	*	*	+	*	*	*	-	*	-	-	*	*	*	*	*	+	-	+	-	*	*
	wet	*	*	-	+	*	*	-	+	-	+	-	-	-	-	+	-	+	-	+	+	-
Sable antelope	dry	*	*	*	*	+	-	-	-	+	+	-	-	-	-	+	+	-	-	+	-	+
	wet	*	*	*	+	*	-	-	-	+	+	-	+	-	-	+	*	*	-	+	-	+
Red hartebeest	dry	+	*	-	-	-	+	-	+	-	*	*	-	-	-	+	-	+	*	*	-	+
	wet	-	+	-	-	+	+	-	+	-	-	-	-	-	+	-	-	+	+	-	*	*

+ = observed use > expected use (α=0,05)
- = observed use < expected use (α=0,05)
* = no significant difference between observed and expected use (α=0,05)
# see Table 1

Scogings, P.F.

Caption for Figure

Figure 1 DECORANA ordination of the number of animals of each ungulate type counted in each pixel of the study area on Jack Scott Nature Reserve, Krugersdorp District, Transvaal, from May 1986 to April 1987.



Unburnt
Sable antelope
Gemsbok
Giraffe
Short-grass, flat, open areas
Medium to tall grass, tree cover, permanent water
Burchell's zebra
Blesbok
Black wildebeest
Red hartebeest
Springbok
Eland
Impala
Burnt
AXIS 2 (SD)
AXIS 1 (SD)
4
3
2
1
0
-1