ECOLOGICAL IMPACT OF LARGE HERBIVORES ON WOODY VEGETATION AT SELECTED WATERING POINTS IN THE KRUGER NATIONAL PARK

by

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Dedicated to my wife,
Letitia

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ABSTRACT

The impact of large herbivores on woody vegetation structure around watering points in the Kruger National Park, necessitated an in depth study. The logistic curve successfully modelled the impact of large herbivores on the woody vegetation around artificial watering points in the KNP. The trends found in biomass around most artificial watering points, indicate that a browsing gradient does exist around artificial watering points in the KNP. Browsing intensity is greatest closer to the watering point and decreases with distance from the watering point. The impact on biomass, extending between 500 m and 2 300 m from the watering point. This means that, on average 3 % of the total area of the KNP is affected by large herbivores congregating around artificial watering points. The eastern basaltic soils showed a trend of low shrub density close to the watering points with increasing density away from the watering point. The western granitic soils showed shrub encroachment close to the watering points on the crestal areas and trends on the footslope areas depended on woody species composition. From the results, it can not be concluded that the provision of artificial water and the accompanying grazing and browsing gradients, play a major role in the decline of large trees in the KNP.

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CHAPTER 1

INTRODUCTION

Water provision programmes were initiated on many properties in the Lowveld of Mpumalanga and the Northern Province, after perceived declines in the water resources of the area. In the Kruger National Park (KNP), a water-for-game programme was implemented in five phases between 1929 and 1990 (Brynard 1969; Pienaar 1985). Reasons given for the stabilization of the water supply included: making the more arid areas accessible to game in order to spread the animals more evenly over the whole KNP; discouraging the emigration of animals out of the KNP before it was fenced; blocking of migration routes after it was fenced; prolonged droughts; and the deteriorating state of perennial rivers (Pienaar *et al.* 1998). This programme led to a situation where in the Kruger National Park, there are at present 283 artificial watering points where drinking water for large herbivores is supplied in troughs, 42 concrete dams and 51 earthen dams, giving a density of artificial watering points of about one per 5 000 ha. This implies that over 96 % of the KNP, the average distance between permanent surface water is about 7 km (Pienaar *et al.* 1998).

According to Walker (1979), African herbivores have adapted to the seasonal availability of water by highly irregular and unpredictable migration between forage resources. Thus, the natural grazing system in southern Africa was one of relatively light vegetation utilization with short periods of fairly intensive utilization. Artificial permanent watering points and the fencing of small areas cause indigenous large herbivores to become sedentary and therefore result in year-round grazing and browsing of rangeland with consequent increased utilization pressure.

Water-dependent herbivores are forced to congregate within walking distance from the watering points in the dry season (Young 1970). This range has been estimated as 10 to 15 km in the Amboseli ecosystem (Western 1975) and 12 to 16 km in the Kruger National Park (Van der Schijff 1957). Most of the rangeland in the Kruger National Park is approximately 7 km from water and is therefore within reach of mobile water-dependent herbivores. Ecological carrying capacity for these animals is thus no longer affected by water availability, but is solely determined by the productivity of the vegetation (Zambatis 1985). Underutilized rangeland is an agricultural rather than a conservation concept. Although it is not desirable that underutilized rangeland dominates a conservation area it should be viewed as habitat that should be preserved (Collinson 1983). However, since few areas in the KNP are now farther than 10 km away from water, these underutilized habitats, with the herbivores and plants that are adapted to them, are now disappearing (Thrash 1993).

Lange (1969) used the word piosphere to describe the area of rangeland which surrounds a permanent watering point. His definition of a piosphere is " an ecological system of interactions between a watering point, its surrounding vegetation and the grazing animal". According to Graetz & Ludwig (1978), a piosphere develops as a result of the interaction of the maintenance and social behaviour patterns of herbivores with the vegetated landscape in which the watering point has been established. In the simplest hypothetical case of an isolated watering point in a uniform rangeland type a gradient of stocking pressure develops which is greatest near the watering point and decreases as a function of distance from it (Graetz & Ludwig 1978).

The zone directly adjacent to the watering point is impacted highly by trampling and utilization and is often referred to as the sacrifice area (Graetz & Ludwig 1978). Conversely, areas at distances exceeding that normally travelled by herbivores from water, experience the lowest utilization pressure (Van Wyk & Fairall 1969; Graetz & Ludwig 1978). Perkins & Thomas (1993a) found an exponential increase in available grazing with increasing distance from water.

Van der Schijff (1959) examined rangeland surrounding watering points in the KNP and distinguished five zones according to degree of utilization by game. The first was a zone adjacent to the watering point up to 91 m away, that was trampled to dust. Child *et al.* (1971) reported significantly less grass cover at 46 m and 229 m than at 0.8 km from watering points in the Kalahari. Senzota & Mtahko (1990) found significantly less grass cover within the first 100 m around a dam than in any other outer region. These results support the concept of a sacrifice area of Graetz & Ludwig (1978). The second zone distinguished by Van der Schijff (1959) extended to 1.6 km from the watering points and was grazed short and trampled. The third zone extended to 5 km from the watering point and was evenly grazed, with the fourth zone extending up to 8 km from the watering point and was grazed lightly and selectively. The range in the fifth zone, further than 8 km from the watering point, was utilized little or not at all by game during the dry season and accumulation of unpalatable material occurred. Perkins & Thomas (1993) identified similar zones as Van der Schijff (1959) on cattle ranches in the Kalahari of Botswana. They divided the sacrifice zone into two zones. The first zone (0-50 m from the watering point) was a zone of irreversible degradation caused by nutrient enrichment to the point of toxicity. The second zone (>50-400 m from the watering point) is an area of negligible herbaceous cover and corresponds with the 91 m zone of Van der Schijff (1959).

Several studies have been conducted on the structure and composition of savanna woody vegetation (Walker 1976; Coetzee & Gertenbach 1977; Dayton 1978; Peel 1989). However, few studies have investigated the impact of water provision on the woody vegetation, especially where high densities of large herbivores occur.

Using aerial photographs, Viljoen (1988), conducted a preliminary survey of changes in the density of large trees in two areas of the *Sclerocarya birrea / Acacia nigrescens* Savanna landscape (Gertenbach 1983) in the Kruger National Park. Between 1944 and 1981 (37 years) there was a 93.4% decline in large trees (> 5 m) in this landscape. Trollope *et al.* (1998) also showed a decline of large trees in this landscape between 1960 and 1989 (30 years). However, these studies were done on the landscape as a whole and not specifically around artificial watering points. The driving forces behind these changes were deemed to be the presence of artificial watering points along with increasing elephant numbers and the previous burning policy (Trollope *et al.* 1998).

In general, studies on grazing gradients away from watering points, indicate that woody plants that are vulnerable to browsing suffer increased mortality (Andrew & Lange 1986b) and tend to be replaced by plants adapted to withstand browsing near the watering point where browsing pressure is highest. For example, it has been claimed that the *Sclerocarya birrea / Acacia nigrescens* Savanna in the central Kruger National Park is currently gradually being replaced by a browsing resistant *Acacia tortilis / Dichrostachys cinerea* Savanna under the existing high browsing pressures around watering points (Coetzee 1983; Du Toit *et al.* 1990). Friedel (1988) found that the relative abundance of *Dichrostachys cinerea* is inversely proportional to distance from watering points and the relative abundances of *Acacia tortilis* and *Acacia karroo* are directly proportional to distance from watering points.

According to Joubert (1986) a sustained high elephant density in the Wik-en-Weeg dam area in the Kruger National Park, has led to high utilization of the woody vegetation and excessive destruction of *Combretum apiculatum* trees. Thrash *et al.* (1991) gave a quantitative description of the impact of water provision on the woody vegetation at the Wik-en-Weeg dam. Over a 17 year period they found no impact on the woody plant community as a whole. However, evidence of an effect on the density and canopy cover of *Combretum apiculatum* was demonstrated.

Elephants are the primary agents of woody stratum change near surface water (Du Toit *et al.* 1990) and the greatest damage to the habitat by elephants is in the vicinity of rivers and permanent watering points (Anderson & Walker 1974). According to the findings of Van Wyk & Fairall (1969), the utilization of woody plants by elephants in the Kruger National Park is inversely proportional to distance from water and the state of the grass cover. Woody plant destruction by elephants is usually species selective and favoured species tend to decline in abundance when the vegetation is heavily utilized by these animals (Van Wyk & Fairall 1969). This results in a decrease in tree density near watering points (Van Wyk & Fairall 1969; Thrash *et al.* 1991) and an increase in shrub growth near watering points (Van Wyk & Fairall 1969; Smuts 1972; Thrash *et al.* 1991).

The lack of quantitative data, on the impact of large herbivores on woody vegetation structure around watering points in the KNP, necessitated an in depth study. The purpose of this study was twofold, firstly to collect baseline data and secondly to model the impact of large herbivores on the woody vegetation around artificial permanent watering points. This information can then be used to determine whether the piosphere concept and sacrifice area are applicable to the woody vegetation around artificial watering points in the KNP.

The study consisted of three phases:

- testing different sampling techniques on different soil types;
- applying the selected technique at various watering points; and
- testing for relationships between selected structural parameters and distance from water.

CHAPTER 2

STUDY AREA

2.1 LOCATION

The Kruger National Park (KNP) is situated in the Lowveld of Mpumalanga and the Northern Province, along the north-eastern boundary of South Africa (Figure 2.1). It measures approximately 350 km in length from north to south and 65 km from east to west and covers an area of 1 948 528 ha.

The KNP is fenced along all its boundaries except for a short distance along the Luvuvhu River in the north-west. The fence prevents movement of most of the larger herbivore species across the boundary.

2.2 GEOLOGY

A diverse assemblage of igneous, sedimentary and metamorphic rocks, which covers a timescale of more than 3 000 million years, occurs within the borders of the KNP. This diversity in parent materials has found manifestation in the large variety of soils, plant communities and animal populations, which make the KNP ecologically one of the most unique national parks in the world (Venter 1990).

2.3 LAND SYSTEMS

Venter (1990) used a land classification system to serve as a basis for management planning and other ecological studies in the KNP. This classification system is based on morphological properties such as landform, soil and the dominant woody vegetation. It is a detailed description of the recurring patterns of the soils, landforms and dominant woody vegetation of the area. The delineated units of land were shown on a map of relatively small scale (1:250 000) to make it practical and usable for the overall

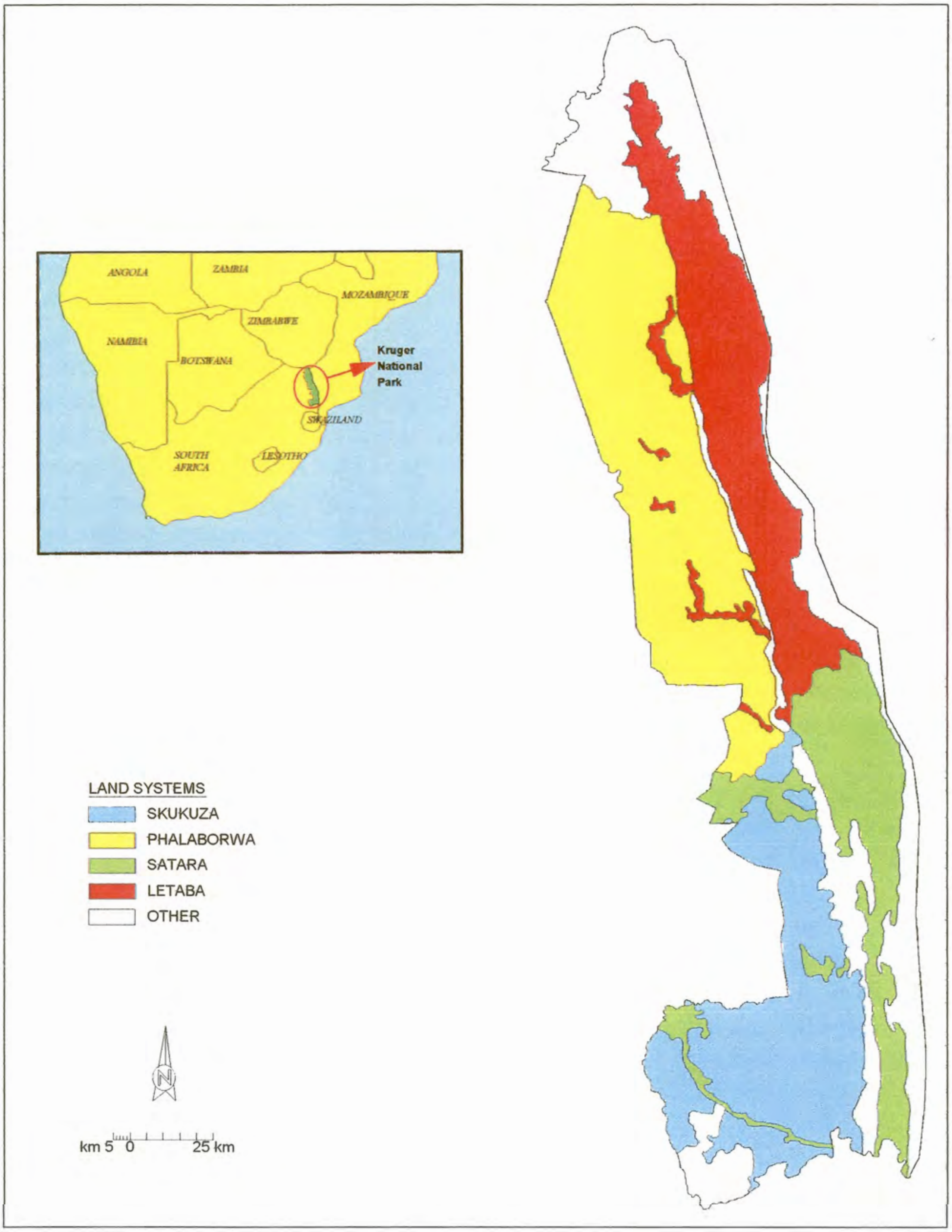

Figure 2.1 The Kruger National Park, Republic of South Africa, showing the four main land systems (after Venter 1990).

interpretation of ecological data and the compilation of management plans, but the characteristic patterns in each unit were described in detail (Venter 1990). The KNP was subdivided into 56 land types on the basis of soil and vegetation patterns and landform characteristics. The land types were included in 11 land systems on the basis of geological, geomorphological and climatic characteristics. The four largest land systems were chosen for this study (Figure 2.1). These land systems represent the major management areas of the KNP (Gertenbach 1983) and are therefore regarded as representative of the whole KNP.

The four largest land systems in the KNP are the Skukuza, Phalaborwa, Satara and Letaba land systems (Figure 2.1). Table 2.1 summarizes the relative size and rainfall of each of these land systems.

Table 2.1

Features of the four major land systems (after Venter 1990)

Land System	Area (ha)	% of KNP	Rainfall (mm)
Skukuza	382 045	19.6	500 - 750
Phalaborwa	518 266	26.6	450 - 600
Satara	275 867	14.2	500 - 650
Letaba	356 664	18.3	450 - 500
TOTAL	1 532 842	78.7	

2.3.1 Skukuza Land System

The geology of the area consists mainly of granite, gneiss, migmatite, amphibolite and schist, of which the former three are dominant (Venter 1990).

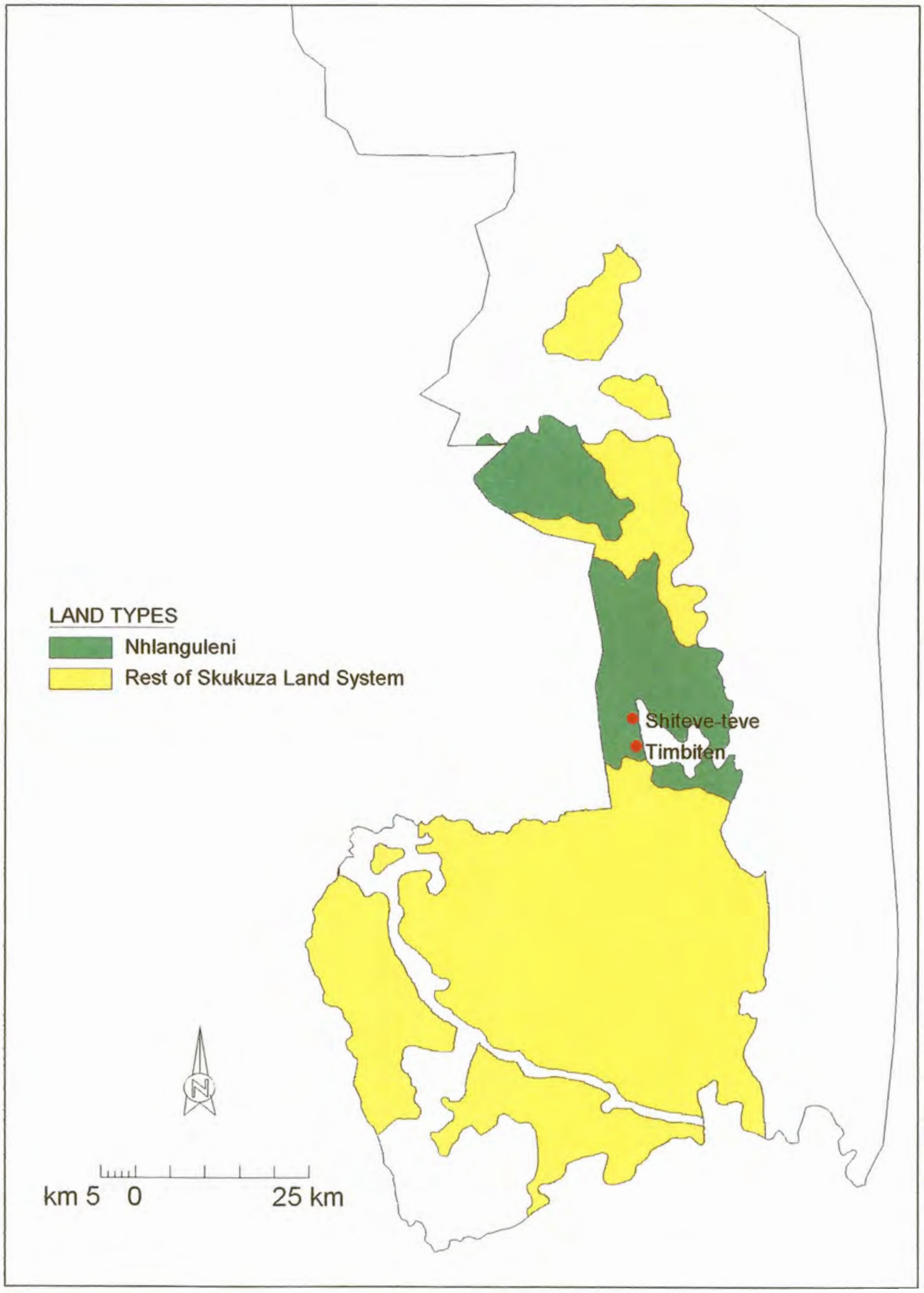

Figure 2.2 The Skukuza Land System and watering points sampled in the Nhlanguleni Land Type (after Venter 1990).

The Skukuza Land System was subdivided into 11 land types on the basis of differences in soil, vegetation and landform characteristics. The two watering points sampled in this land system (Timbiteni & Shiteve-teve) both occur in the Nhlanguleni Land Type (Figure 2.2).

Nhlanguleni Land Type

The Nhlanguleni Land Type comprises a large area north of the Sabie River and is associated with the watershed areas between the Sabie, Nwaswitsontso and Timbavati Rivers. It is characterized by well-defined land units and a very typical catenary sequence of soils. Crests are dominated by deep (> 1 m), red and yellow, apedal sand (Hutton and Clovelly forms); midslopes by moderately deep (0.5 -1 m), grey, hydromorphic sand (Cartref and Fernwood forms); and footslopes by duplex soils (Escourt and Sterkspruit forms) of which the A-horizons vary in depth. Crests tend to be large and relatively flat with *Combretum zeyheri* and *Combretum apiculatum* as the dominant trees. *Strychnos madagascariensis* occasionally forms dense stands where soils are very deep. Midslopes are dominated by a belt of *Terminalia sericea*. Footslopes consist of wide and well defined, shrubby grassland (Venter 1990).

The crest and footslope areas cover 40 % and 37 % respectively of this land type and are the most prominent hillslope units (Venter 1990).

2.3.2 The Phalaborwa Land System

The geology of the area consists mainly of granitoid rocks (gneiss, migmatite, granite) and remnants of greenstone belt rocks (predominantly amphibolite and schist). The whole area has been intruded by numerous dolerite dykes (Venter 1990).

The Phalaborwa Land System was subdivided into 12 different land types. The two watering points chosen in this land system occur in the Phalaborwa (Shivulani watering point) and Malopeni (Ledeboer watering point) land types (Figure 2.3).

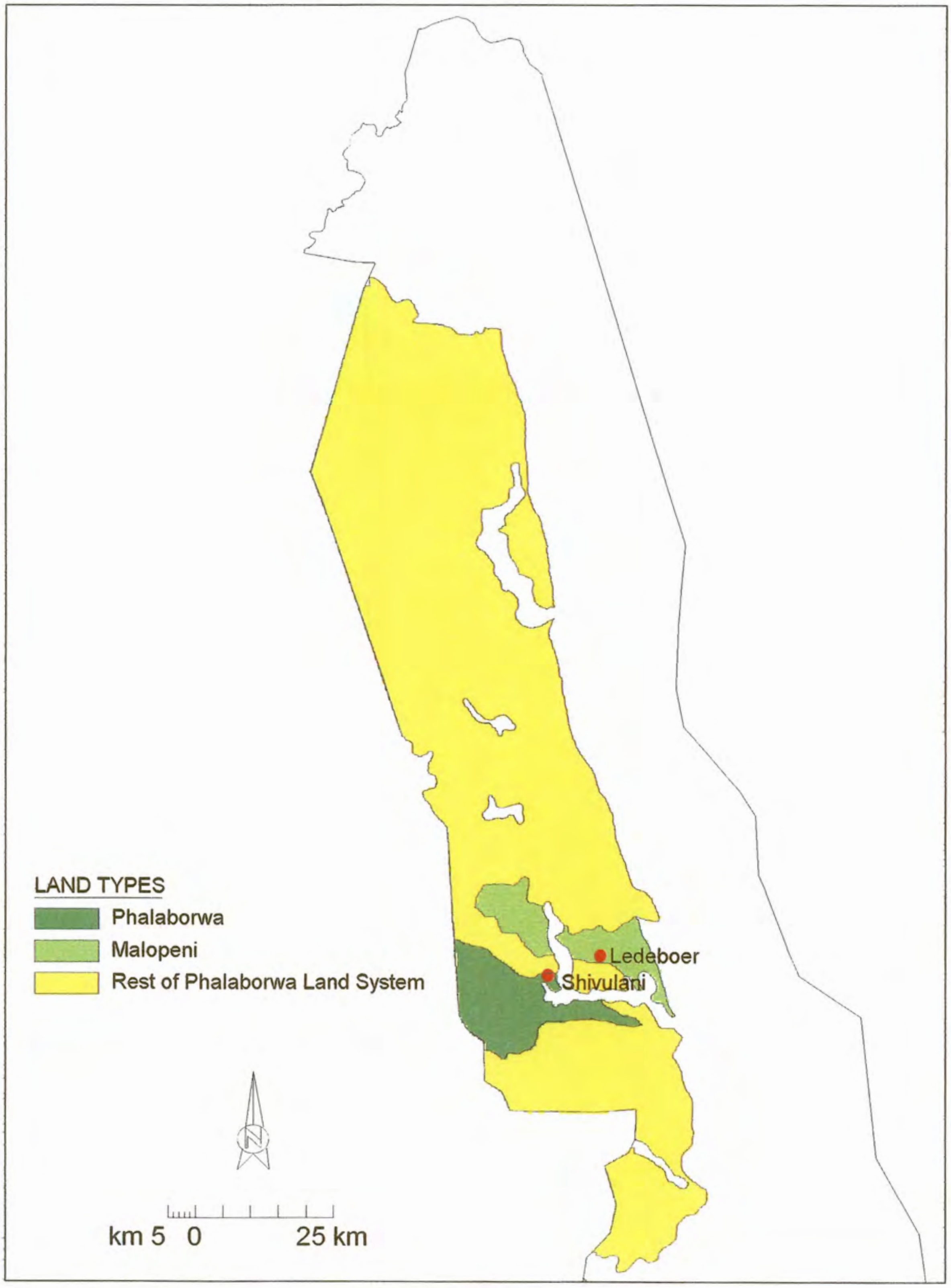

Figure 2.3 The Phalaborwa Land System indicating the watering points sampled in the Phalaborwa - and Malopeni Land Types (after Venter 1990).

Phalaborwa Land Type

The Phalaborwa Land Type is associated with the main watershed between the Olifants and Letaba Rivers. It has a moderately to slightly undulating landform and scattered solitary koppies or inselbergs, consisting of syenite plugs of the Phalaborwa igneous complex, occur. The land type is underlain by granitoid rocks of Makhutswi gneiss (Schutte 1986). The eastern half of this land type is characterized by relatively low densities of dolerite dykes.

Moderately deep, yellow and grey coarse sand (Clovelly form) is dominant on crests, while moderately deep to shallow, grey, coarse sand (Cartref form) is found on the midslopes. Duplex soils (Escourt and Sterkspruit forms with thin A-horizons) occur along the footslopes. In the western half of the area a high density of dolerite dykes occurs. The result is that the soils consist mainly of moderately deep to shallow red and brown loam to clay, especially along the footslopes. *Terminalia sericea* is a very conspicuous tree species of this land type and is closely associated with sandy soils, preferring the grey hydromorphic sand of the midslopes. *Colophospermum mopane* and *Combretum apiculatum* are the dominant trees on loam and clay soils, the latter preferring the shallow soils (Venter 1990).

The crests and footslopes, dominate this land type and cover 44 % and 34 % respectively of the area (Venter 1990).

Malopeni Land Type

The Malopeni Land Type is associated with greenstone belt rock of the Gravelotte group, which occurs as a large east-west orientated xenolith south of the Letaba River (Figure 2.3). The Malopeni Land Type is mainly associated with amphibolite (Venter 1990).

The area has a slightly undulating landform. Hillslopes are long and straight, gently sloping down to the small, seasonal, drainage channels. The soils consist mostly of

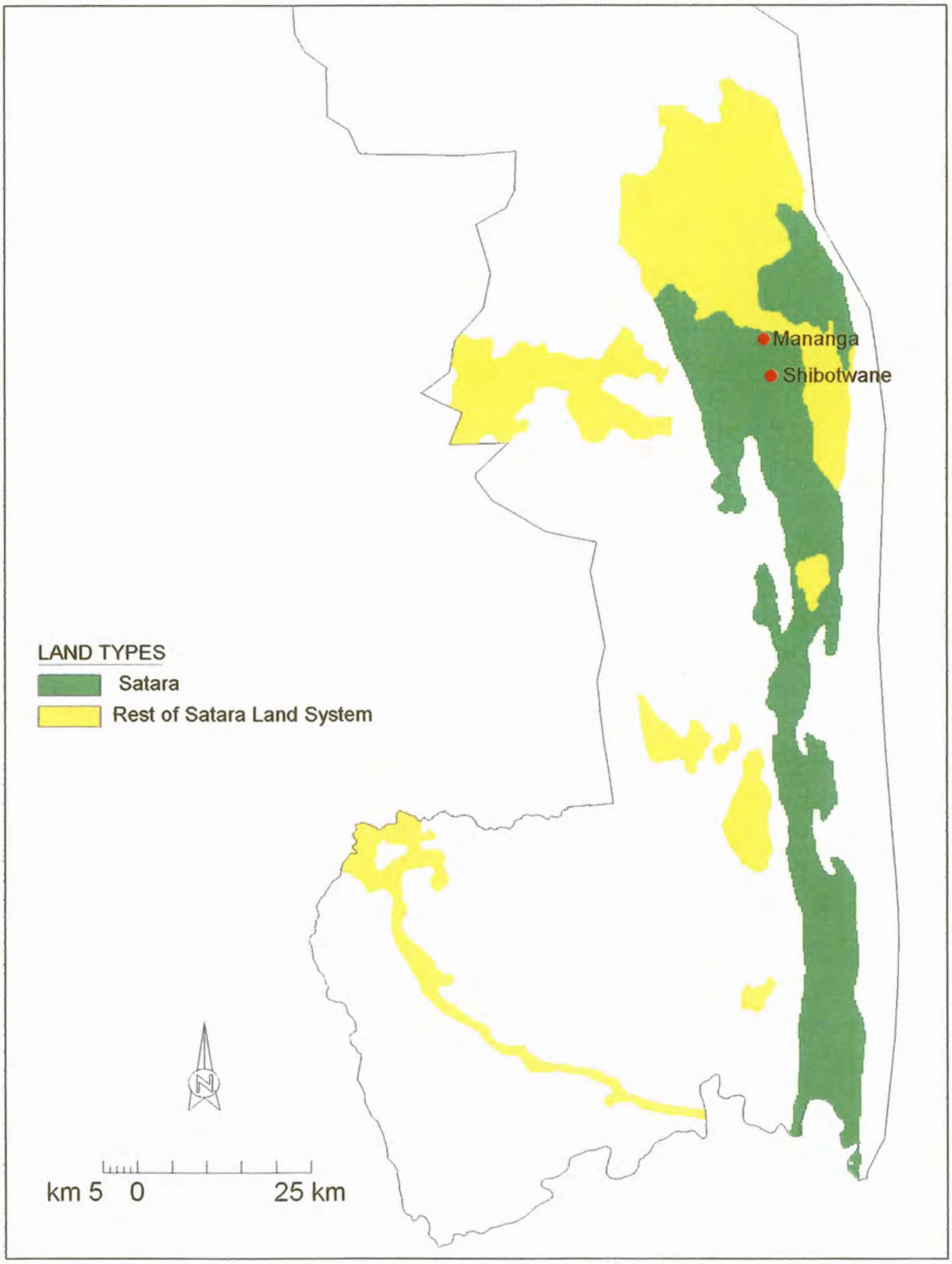

Figure 2.4 The Satara Land System and watering points sampled in the Satara Land Type (after Venter 1990).

moderately deep to shallow, red, apedal soils (Hutton form) and structured clay (Shortlands form). The vegetation is dominated by an open *Colophospermum mopane* Bush Savanna (Gertenbach 1983) in which mopani often occurs as stunted shrubs of 2 m in height. *Combretum apiculatum*, *Acacia exuvialis* and *Acacia nigrescens* are some of the other common trees in this land type.

2.3.3 Satara Land System

The Satara Land System is associated with volcanic rocks of the Sabie River basalt formation, which consists mainly of olivine-poor lavas (Bristow & Venter 1986), as well as gabbro of the Timbavati gabbro (Schutte 1986). The lavas have been intruded by numerous north-south trending dolerite dykes. The dykes are usually inconspicuous due to the similarity between the soils of the dolerite and gabbro lavas, but they can occasionally be seen as elongated rocky outcrops or low ridges (Venter 1990). The Satara Land System was subdivided into six land types. Both the watering points sampled (Mananga and Shibotwane) occur in the Satara Land Type (Figure 2.4).

Satara Land Type

The Satara Land Type includes the basaltic plains, which are characterized by olivine-poor lavas around Satara and southward to Crocodile Bridge. The area has a flat landform and is mainly characterized by moderately deep to shallow, red and brown, structured soils (Shortland form) and paraduplex clay (Swartland form) and an open *Sclerocarya birrea / Acacia nigrescens* Tree Savanna (Gertenbach 1983).

A relatively high density of dolerite dykes occurs in the area directly north and east of Satara Rest Camp, resulting in the more frequent occurrence of shallow soils (Glenrosa and Mayo forms) and rocky areas. This is reflected in the vegetation in that *Grewia bicolor* occurs more frequently in this area (Venter 1990).

2.3.4 Letaba Land System

The mafic volcanic rocks, which underlie the Letaba Land System, consist of three formations (Bristow & Venter 1986), namely nephelinite lavas of the Mashikiri nephelinite formation, which crop out as thin intermittent flows at the base of the volcanic succession; picrite (olivine-rich) lavas of the Letaba basalt formation, which occur in the middle of the mafic volcanic succession and represent the dominant rock type of the Letaba Land System; and olivine-poor lavas (basalt and andesite) of the Sabie River basalt formation, which represent the top of the volcanic succession of mafic rocks in the KNP (Venter 1990).

Numerous dolerite dykes have intruded the lavas and often lead to the formation of north-south trending lines of shallow and rocky soils (Venter 1990).

The area was subdivided into seven land types and all three the watering points sampled (Tihongonyen, Hartbeesbult and Nkolobeni-South) occur in the Mooiplaas land type (Figure 2.5).

Mooiplaas Land Type

This land type is associated with interfluvial areas which are underlain by olivine-rich lavas of the Letaba formation. It is characterized by relatively large, flat and level plains with a low relief and stream frequency. It is drained mainly by shallow grassy vleis.

The soils of this land type consist mainly of shallow to moderately deep, calcareous, melanic and vertic clay (Mayo, Bonheim and Arcadia forms). The soil layer usually overlies a thick (up to 2 m) layer of soft $CaCO_3$ concretions, which gradually become harder with depth and eventually grade into hard calcrete. The calcrete is often exposed along lower midslopes, as is occasionally also the case with rock. The soils of the northern part of the land type, i.e. roughly north of Nkulumbeni Central windmill, are deeper than those in the southern part of the land type, and vertic soils occur more frequently in crestal positions.

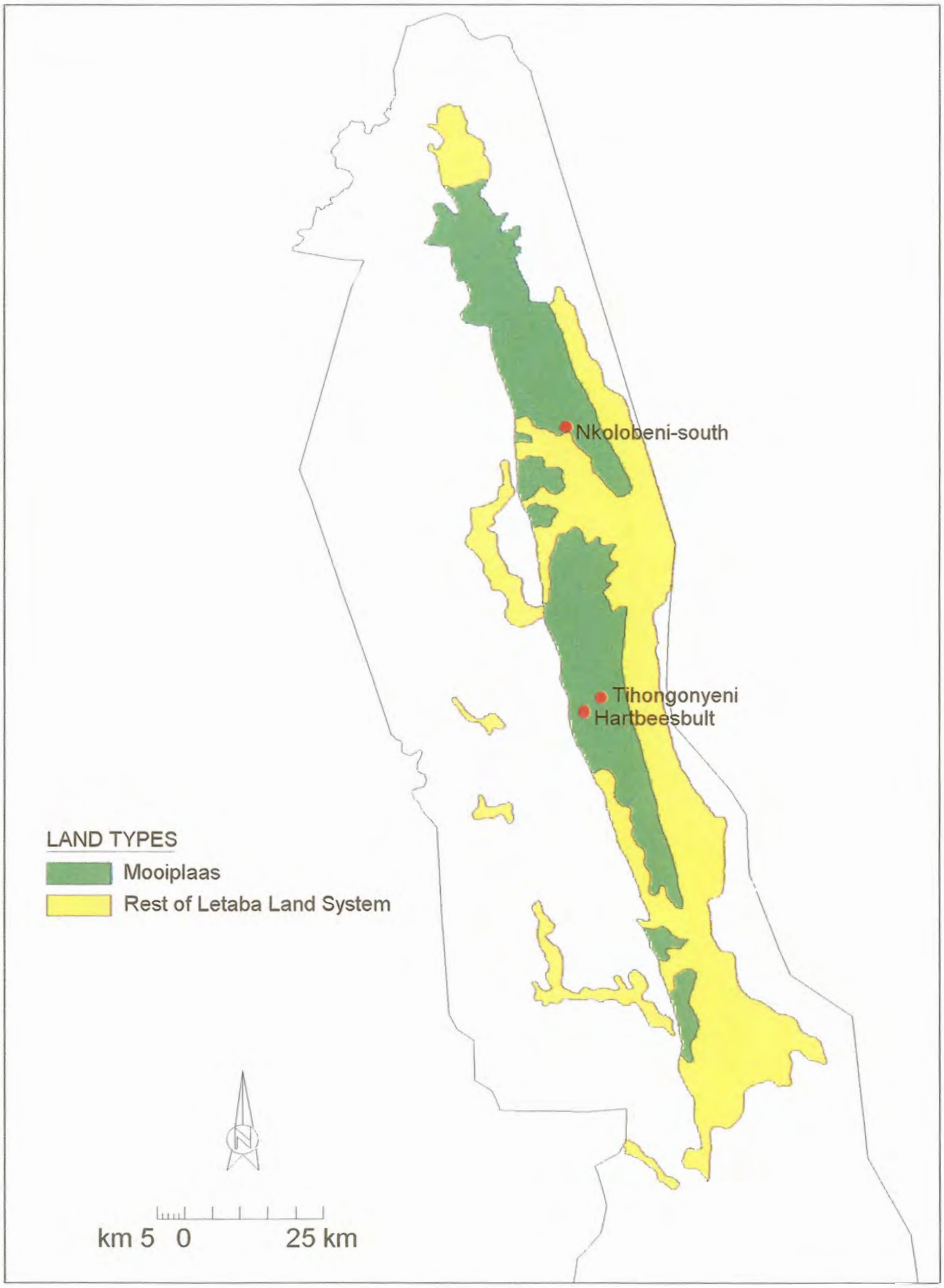

Figure 2.5 The Letaba Land System and watering points sampled in the Mooiplaas Land Type (after Venter 1990).

The vegetation of the crestal areas of this land type is completely dominated by moderately dense to dense *Colophospermum mopane* Shrub Savanna (Gertenbach 1983), which in large areas is devoid of large trees. *Acacia nigrescens* and *Combretum imberbe* tend to be more prominent on vertic soils, while *C. mopane* has lower densities on these soils (Venter 1990).

2.4 RAINFALL

The mean annual precipitation of the KNP decreases from south to north and from west to east (Gertenbach 1978, 1980). The mean annual precipitation of the area varies from approximately 740 mm at Pretoriuskop in the south to about 440 mm at Pafuri in the north. Most of this rain occurs in the form of thunderstorms between November and March with a peak in January and February. Little rain occurs in the period June to August. The mean annual and mean monthly rainfall figures of four stations in the four main Land Systems are presented in Table 2.2. The long term rainfall of the KNP oscillates through periods of above and below normal rainfall. The difference between the mean annual precipitation in wet and dry cycles is about 26% (Gertenbach 1980). The phenomenon of high and low rainfall cycles results in cyclic changes in grass height and production, and consequently also in the population trends and distribution patterns of many animals (Joubert 1986).

Table 2.2

Mean annual and monthly rainfall for four stations in the Kruger National Park

		Mean Monthly Rainfall (mm)			
Station		Skukuza	Satara	Letaba	Shingwedzi
Month	January	94	79	78	59
	February	96	64	58	71
	March	66	73	27	38
	April	38	26	31	29
	May	14	08	10	09
	June	11	11	05	04
	July	11	13	06	03
	August	08	14	08	05
	September	28	13	12	12
	October	40	50	39	35
	November	63	58	54	51
	December	92	93	76	84
Mean Annual	Rainfall (mm)	561	502	404	400

Station	Altitude (m)	Duration	Location
Skukuza	263	29 years	24° 59' S 31° 36' E
Satara	275	12 years	24° 24' S 31° 46' E
Letaba	215	18 years	23° 51' S 31° 35' E
Shingwedzi	215	18 years	23° 6' S 31° 26' E

Duration = Number of years of measurement

2.5 TEMPERATURE

The Lowveld, with a subtropical climate, experiences warm to hot summers and mild winters. Temperatures may reach 44°C in the summer and seldom fall below freezing in winter. Frost is therefore a rarity in the KNP. Mean daily temperatures, as well as maximum and minimum temperatures for four stations in the KNP are presented in

Table 2.3.

Table 2.3

Mean daily temperatures of four stations in the Kruger National Park

		Mean Daily Temperature (° C)			
Station		Skukuza	Satara	Letaba	Shingwedzi
Month	January	26.6	27.4	28.0	27.8
	February	26.2	26.7	27.5	26.9
	March	25.2	25.5	26.5	26.2
	April	22.4	23.4	23.8	23.7
	May	19.0	20.7	20.3	20.0
	June	15.7	17.6	17.1	16.8
	July	15.8	18.0	17.4	17.0
	August	18.0	19.6	19.5	19.1
	September	21.0	21.6	22.5	22.2
	October	22.9	23.1	24.2	24.1
	November	24.3	24.6	25.7	26.1
	December	25.8	26.1	27.2	27.1
	Max (° C)	43.6	43.3	44.4	43.9
	Min (° C)	-4.4	0.2	-3.5	-0.8

Station	Altitude (m)	Duration	Location
Skukuza	263	29 years	24° 59' S 31° 36' E
Satara	275	12 years	24° 24' S 31° 46' E
Letaba	215	18 years	23° 51' S 31° 35' E
Shingwedzi	215	18 years	23° 6' S 31° 26' E

Max = Maximum temperature measured for station

Min = Minimum temperature measured for station

Duration = Number of years of measurement

CHAPTER 3

METHODS

3.1 INTRODUCTION

In impact study design, data collection, data analysis and interpretation of results are all geared to testing hypotheses. The best impact study design is an areas-by-times factorial experiment (Green 1979). This entails the collection of data before and after the impact has occurred, near and at a distance from the point of impact. In this design there are both temporal and spatial controls.

However, the study of impacts often only begins once the disturbance has already occurred and in these cases the impact must be inferred from spatial patterns alone (Green 1979).

Since the present study involved only windmills where no baseline data were collected beforehand, the approach that had to be followed for the major part of the study was one of inferring the impact from the spatial pattern alone.

A balanced design of four combinations of high and low rainfall and two rock types was used. These areas represent the largest land systems of the Kruger National Park (Figure 2.1). The four largest land systems classified by Venter (1990) are the Skukuza, Satara, Letaba and Phalaborwa Land Systems. The Skukuza Land System has a relatively high mean annual rainfall (550 mm) and lies on granitic rock; the Satara Land system also has a relatively high mean annual rainfall (550 mm), and lies on basaltic rock; the Phalaborwa Land System has a lower mean annual rainfall (491 mm) and lies on granitic rock whereas the Letaba Land System has an intermediate mean annual rainfall (530 mm) and lies on basaltic rock.

The watering points studied were chosen in conjunction with the South African National

Parks scientists. For possible comparative purposes, it was attempted to use the same watering points used by Thrash (1993) who investigated the impact of large herbivores on forage and fuel production potential, standing crop, and plant community composition of the herbaceous vegetation around artificial watering points in the KNP.

To position the transects, the area around the watering point was assessed using stereoscopic aerial photographs and the area within the landscape where the least possible changes in soil types would occur was selected. The area chosen was classified according to the Taxonomical Soil Classification System (MacVicar *et al.* 1991). The transects were then placed on the same soil type, as well as within the same burning block to keep the past and present effect of fire intensity and frequency, constant (Kennan 1971; Trollope 1983; Trollope & Potgieter 1985; Trollope *et al.* 1995).

A rope was used to mark out each transect. A woody individual was recorded, when its main stem was inside the transect, but not when only part of the canopy covered the transect. Every woody plant in the transect was identified and the following dimensions of each individual measured:

A - Tree height
B - Height of maximum canopy diameter
C - Height of lowest leaves
D - Maximum canopy diameter
E - Base diameter of foliage at height C

Figure 3.1 shows the illustration of an ideal tree according to Smit (1989) and the dimensions that were measured. Measurements D and E were taken in two directions perpendicular to each other so as to get a better indication of the shape of the canopy (Figure 3.1).

The measurements, together with the exact location of the transect, were noted on a predesigned field form. The measurements were entered into the BECVOL (Biomass

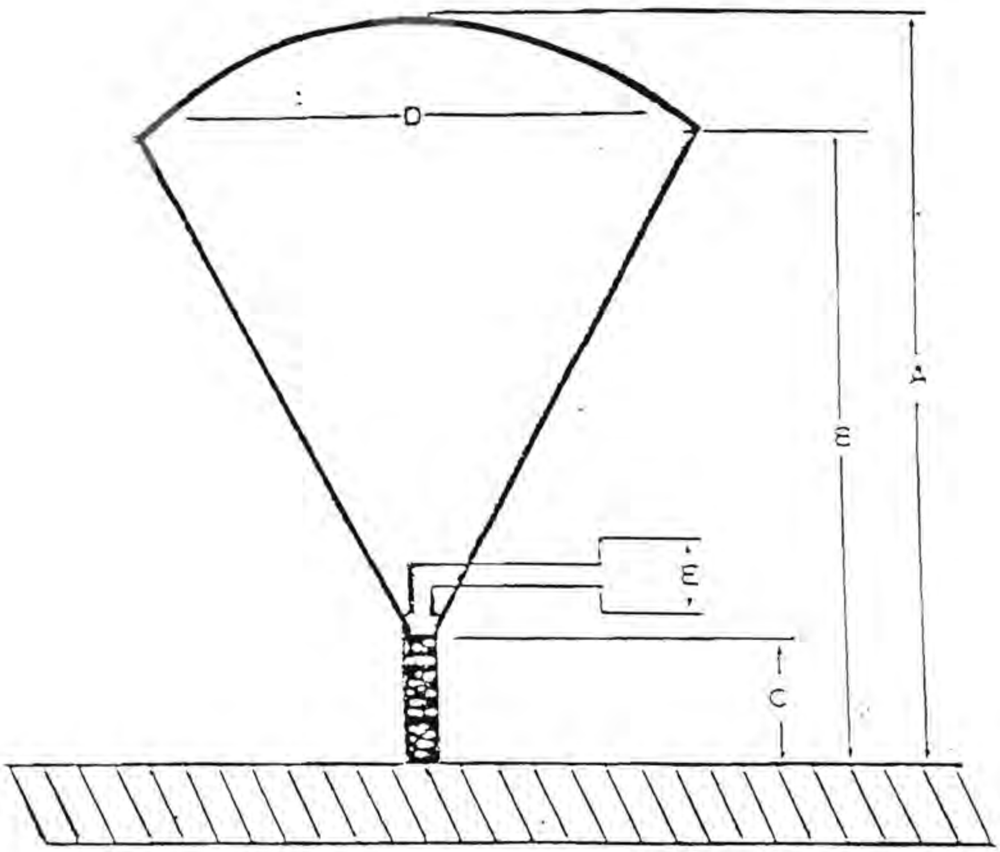

Figure 3.1 The measurements taken of every tree, shown as the perfect tree (after Smit 1989).

Estimates for Canopy VOLume) computer programme (Smit 1989). The measurements were done using a measuring stick marked at 0.5 m intervals. The minimum length that was used was 0.5 m.

By means of the BECVOL computer programme (Smit 1989), certain variables related to woody structure could be calculated. The structural variables chosen were total density (all woody individuals), tree density (woody individuals > 2 m), shrub density (woody individuals $\leq$ 2 m) (Walker 1976) and ETTE (Evapotranspiration Tree Equivalents) (Smit 1989).

ETTE is defined as the leaf volume equivalent of a 1.5 m high single stemmed tree (*Acacia karroo* or *C. mopane*) and was proposed by Smit (1989) as an index of potential tree competitiveness. ETTE-values are a function of both tree height and canopy diameter. Tree Equivalents (TE) (Teague *et al.* 1981), are calculated for each tree by dividing the tree height by 1.5 m, therefore TE is a function only of tree height (Smit 1994). TE is widely used as an index of the phytomass of bush (Trollope *et al.* 1990). Canopy diameter and tree height explain most of the variation found in leaf volume (Smit 1994). ETTE, incorporating both, is therefore a more accurate estimate of tree biomass (leaves) than TE or any of the other descriptive units (Smit 1994).

The data was transferred to the Statgraphics 7 computer programme (Statgraphics 1993). The logistic curve and a third order polynomial curve were fitted to the data using non-linear regression analysis. The aim of fitting these curves was to find a model to describe impact of large herbivores on the structure of the woody vegetation at artificial watering points. The best model was chosen on the criterion of highest r^2 value.

An additional term (z) was included in the logistic equation to correct for situations where the lower asymptote of the curve was not zero. This new equation ($y = z + a / \{1 + e^{b - cx}\}$) was fitted to the data using non-linear regression analysis. The same was done with the polynomial equation where a constant C_0 was added to the equation ($y = C_0 + C_1x + C_2x^2 + C_3x^3$).

Community ecology data are usually rather noisy and some form of smoothing is a common aspect of direct gradient analysis methods (Gauch 1982). To make the graphs simpler to inspect, Friedel (1988) successfully used a 10 m window at 5 m intervals to smooth woody vegetation data around a watering point. A five point moving average (Statgraphics 1993) was calculated from all the data whereafter the logistic and polynomial curves were fitted to the smoothed data. In this manuscript the data reflecting the five point moving average, will be referred to as the smoothed data.

Structural variables were tested for relationships with distance from water using linear regression analysis. It was accepted that the data were normally distributed. Only the original data were used for these analyses.

In the first phase of this study, two different sampling techniques were tested on the basaltic soils. These comparisons were done to determine whether different sampling techniques would give different results and to determine which of the fitted curves modelled the impact of large herbivores at watering points the best. In the second phase of the study the technique shown to be the most suitable, was applied to collect data at the selected watering points. In the third phase of the study the data analysis was done. The final phase included the interpretation and evaluation of the results.

3.2 TECHNIQUE TESTING ON BASALTIC SOILS

The techniques were first tested on the eastern basalt plains. The Satara Land System occurs on the eastern side of the Kruger National Park (Figure 2.4) and has a relatively high mean annual rainfall (550 mm). Since changes in soil type and depth have a major influence on woody structure (Gertenbach 1987; Venter 1990), it was deemed a good place to start, because both parameters could be kept constant along the transect away from the watering point.

3.2.1 Procedure

In the first instance, a four metre wide continuous transect, starting at the watering point and following a directional line away from the watering point using a GPS (Global Positioning System), was sampled (Figure 3.2). This will be referred to as the continuous sampling technique.

Secondly, consecutive 10 m x 50 m transects at 100 m intervals were sampled perpendicular to and on the same directional line and soil type used for the previous technique (Figure 3.2). This will be referred to as the interval sampling technique.

For the continuous sampling technique the transects ended at 3 000 m because of the presence of a dolerite dyke, making further continuous and homogeneous sampling impossible. With the interval sampling technique the dolerite dyke could be avoided and the transects ended when the sphere of influence of the nearest neighbouring watering point was reached at 4 000 m.

In the continuous transect, the mean of a variable in every consecutive 100 m interval away from water, was calculated and compared to the mean of that variable in the 10 m x 50 m transects at the same distance interval.

The two data sets were compared using multifactor analysis of variance (Statgraphics 1993) to determine whether there was any significant difference between the means at the same distance intervals. Only the first 3 000 m from the watering point were compared.

Both logistic and polynomial curves were fitted to the data and compared.

3.2.2 Results

The densities of all woody individuals (total), the shrubs($\leq$ 2 m), trees (> 2 m) and ETTE were determined for both the continuous and interval sampling techniques. Multifactor analysis of variance showed that there was no significant difference ($P >$ 0.05) between results obtained from the two sampling techniques. None of the variables differed significantly at the same distance interval.

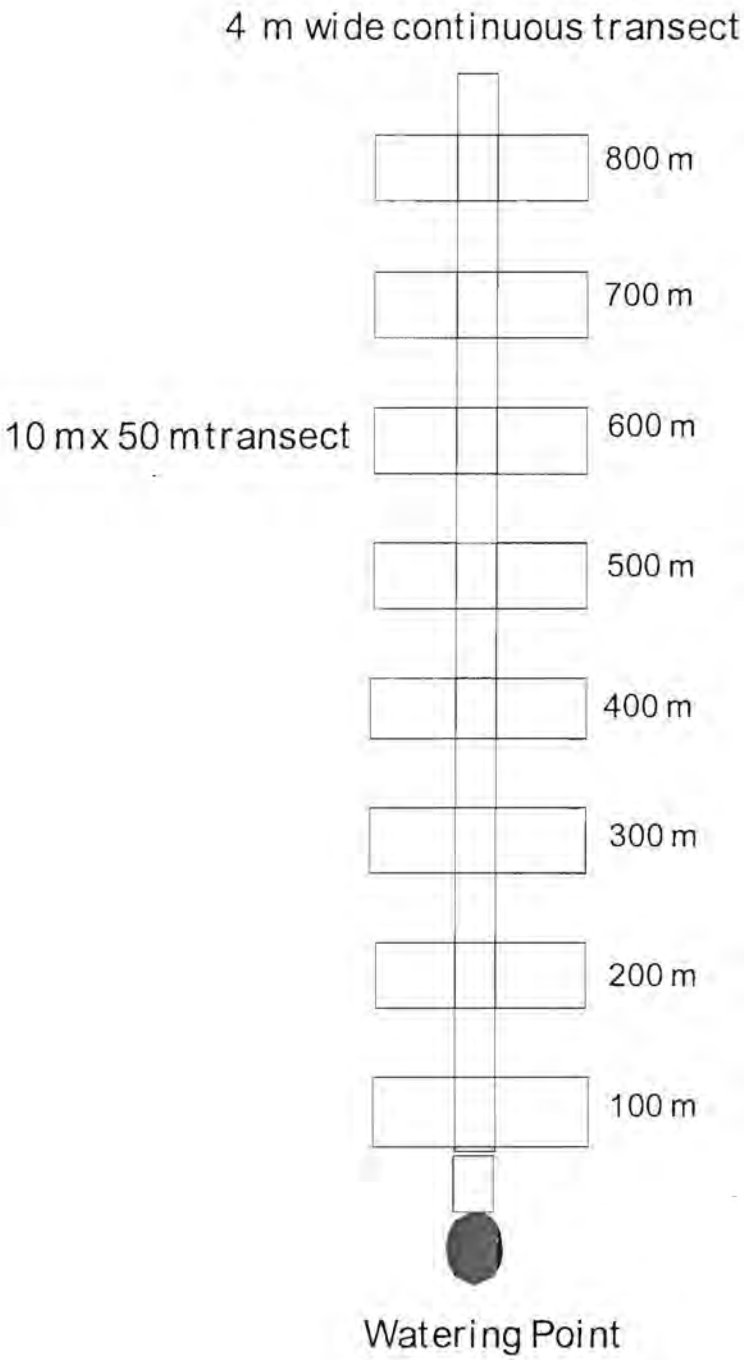

Figure 3.2 Placement of the transects around watering points.

When the logistic and polynomial curves were fitted to the data, variable results were obtained. The smoothed data gave a better fit in all cases (Figures 3.3 - 3.6; Tables 3.1 - 3.4). Both the logistic and polynomial curves from the smoothed data modelled the impact around water well, with r^2 values of up to 0.97 recorded (Tables 3.1 - 3.4). The highest r^2 values were obtained with the continuous sampling technique (Tables 3.1 & 3.3). In both the continuous and interval sampling data sets, total and shrub density gave the highest r^2 values (Tables 3.1 - 3.4).

The continuous and interval sampling techniques did not give the same fit to the data (Figures 3.3 - 3.6). The major difference being that the continuous sampling showed an upper asymptote for total and shrub density on 2 000 m while the interval sampling did not show a threshold (Figure 3.3 - 3.6). From the smoothed data, it can be seen that the techniques gave different results over the first 1 000 m from the watering point, after this the distribution of points are very similar. The interval sample giving higher total and shrub densities and lower tree and ETTE densities than the continuous sampling technique (Figures 3.3 - 3.6).

3.2.3 Discussion

The fact that there was no significant difference between the means of variables at the same distance from the watering point, indicated that the continuous and interval sampling techniques gave similar results. The sampling sizes of both these techniques comply with the suggested sample size of a 10 m x 50 m transect by Walker (1976) and 2 m x 50 m transect used by Smit (1989). Both sampling techniques are therefore suitable to sample the woody vegetation around watering points.

Although the multifactor analysis of variance indicated no significant differences at distance intervals, differences became apparent when the curves were fitted to the data. These differences might be due to the different positioning of the transects (Figure 3.2), causing different areas per distance interval to be sampled. The sampling started at 200 m due to the impact of a road passing within 80 m from the trough. It was also

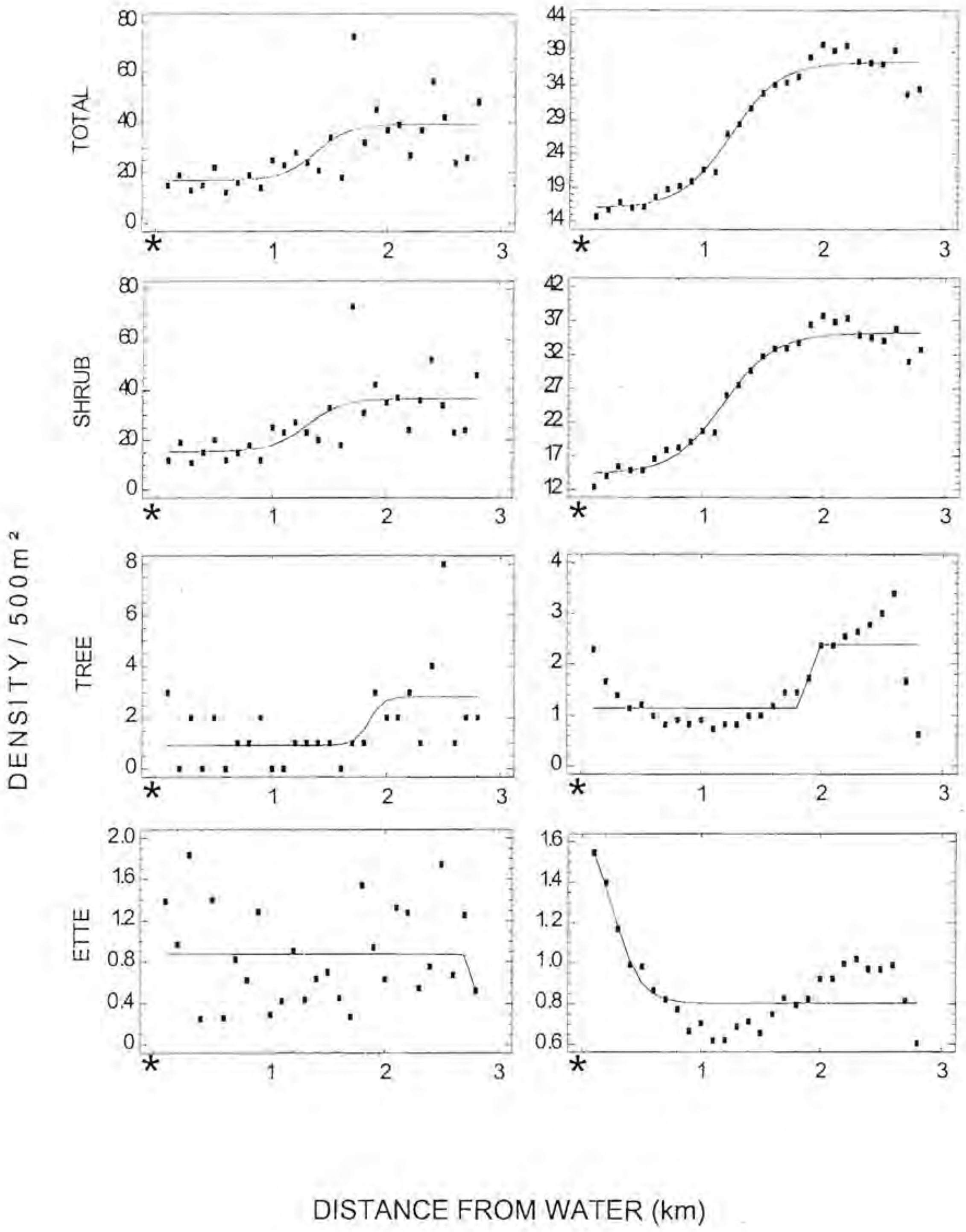

Figure 3.3 Structural variables as a logistic function of distance from water, using the continuous sampling technique on basaltic soils. The original data are on the left and the smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 3.1

Summary of the relationships between structural variables and distance from water using the logistic equation on the Satara Land System in the Kruger National Park

CONTINUOUS SAMPLING	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 39.2 - 22.25 / (1 + e^{-9.7 + 0.71x})$	0.49
	Shrub Density	$y = 36.6 - 21.1 / (1 + e^{-8.5 + 0.64x})$	0.46
	Tree Density	$y = 0.9 + 1.9 / (1 + e^{31.9 - 1.7x})$	0.30
	ETTE Density	$y = -12.1 + 13.0 / (1 + e^{-96.6 + 3.32x})$	0.02
Smoothed data	Total Density	$y = 37.4 - 21.4 / (1 + e^{-5.9 + 0.48x})$	0.97
	Shrub Density	$y = 35.2 - 20.8 / (1 + e^{-5.5 + 0.47x})$	0.97
	Tree Density	$y = 1.14 + 1.2 / (1 + e^{142 - 7.4x})$	0.54
	ETTE Density	$y = 0.8 + 0.9 / (1 + e^{-2.1 + 0.8x})$	0.71

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

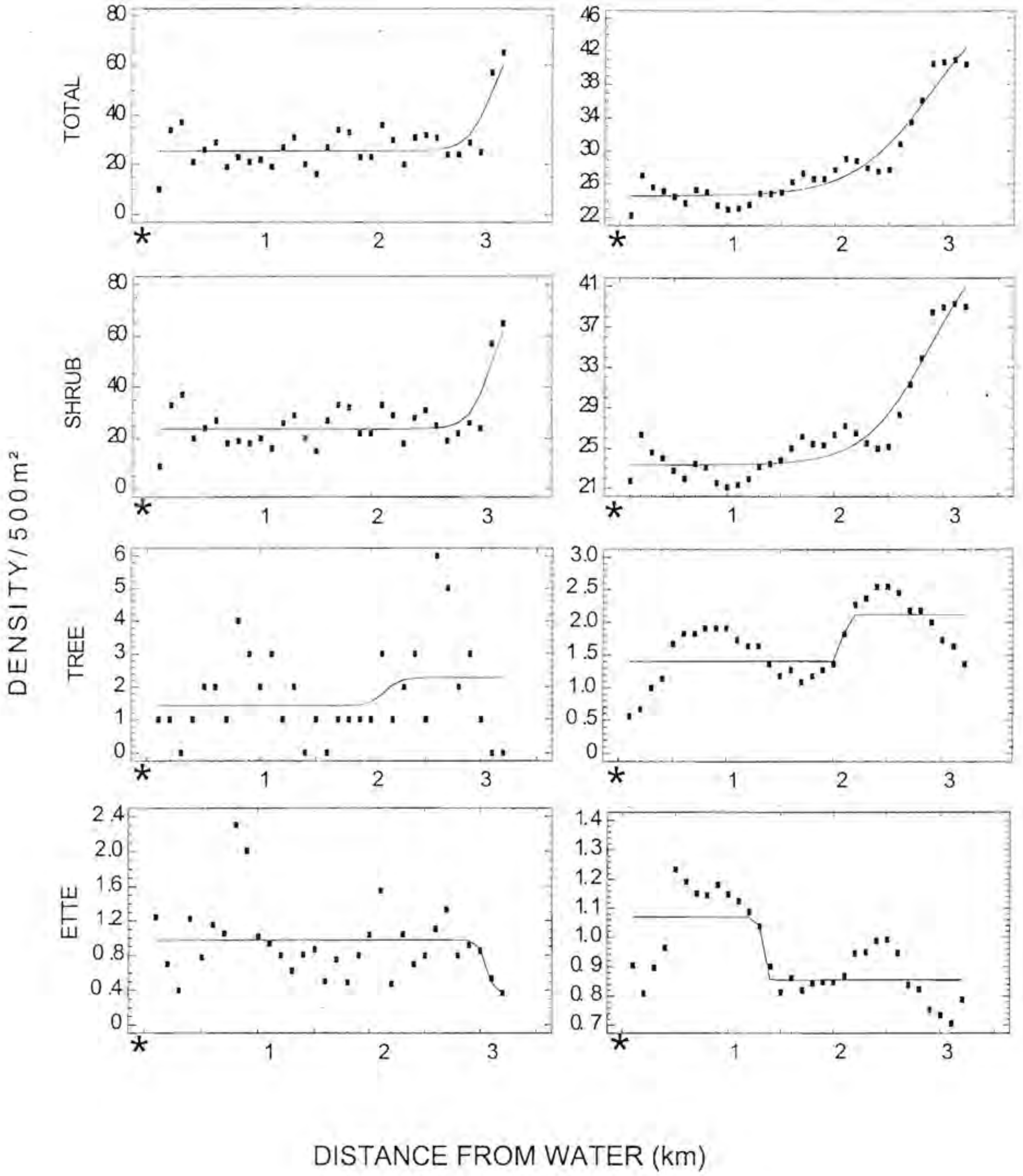

Figure 3.4 Structural variables as a logistic function of distance from water using interval sampling. The original data are on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 3.2

Summary of the relationships between structural variables and distance from water using the logistic equation on the Satara Land System in the Kruger National Park

INTERVAL SAMPLING	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 75.4 - 49.6 / (1 + e^{-27.4 + 0.8x})$	0.58
	Shrub density	$y = 77.9 - 54.6 / (1 + e^{-30.2 + 0.8x})$	0.61
	Tree density	$y = 1.4 + 0.8 / (1 + e^{30.9 - 1.4x})$	0.07
	ETTE Density	$y = 0.3 + 0.6 / (1 + e^{-89.1 + 2.7x})$	0.09
Smoothed Data	Total Density	$y = 49.6 - 25 / (1 + e^{-8.2 + 0.2x})$	0.93
	Shrub Density	$y = 46.9 -23.6 / (1 + e^{-9.7 + 0.3x})$	0.91
	Tree Density	$y = 1.4 + 0.7 / (1 + e^{156.2 - 7.2x})$	0.44
	ETTE Density	$y = 0.8 + 0.2 / (1 + e^{-110 + 8.3x})$	0.51

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

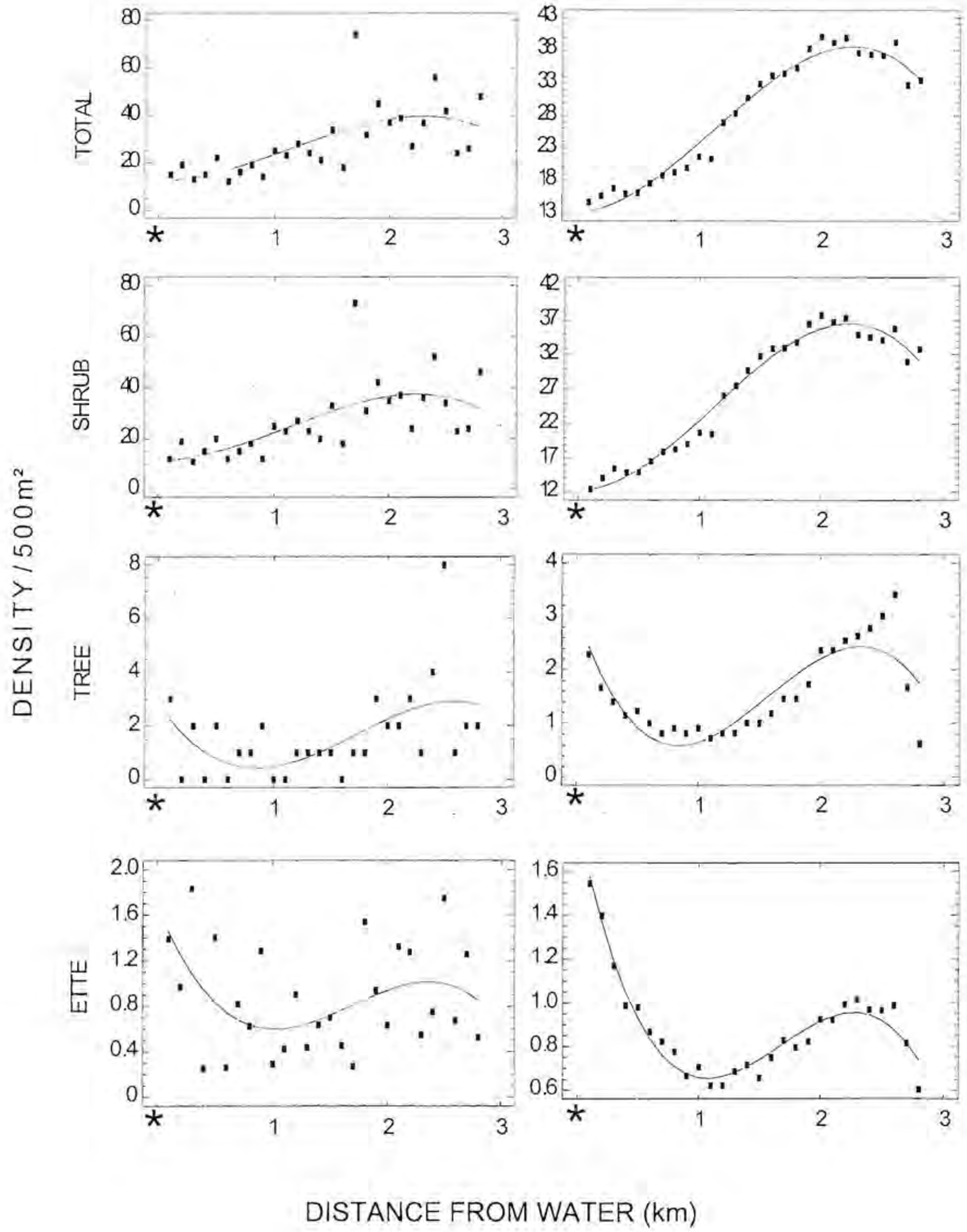

Figure 3.5 Structural variables as a polynomial function of distance from water using the continuous sampling technique on basalt soils. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 3.3

Summary of relationships between structural variables and distance from water using the polynomial equation on the Satara Land System in the Kruger National Park

CONTINUOUS SAMPLING	VARIABLE	POLYNOMIAL EQUATION	r^2
Original Data	Total Density	$y = 12.3 + 0.002x + 6.1x^2 - 0.02x^3$	0.46
	Shrub Density	$y = 11.4 + 0.02x + 5.4x^2 - 0.02x^3$	0.44
	Tree Density	$y = 2.8 - 0.6x - 0.07x^2 - 0.01x^3$	0.30
	ETTE Density	$y = 1.69 - 0.25x - 0.06x^2 - 0.01x^3$	0.20
Smoothed Data	Total Density	$y = 13 + 0.009x + 14.8x^2 - 0.02x^3$	0.97
	Shrub Density	$y = 12 + 0.015x + 9.3x^2 - 0.02x^3$	0.97
	Tree Density	$y = 3.1 - 0.66x - 0.08x^2 - 0.02x^3$	0.73
	ETTE Density	$y = 1.8 - 0.25x - 0.06x^2 - 0.01x^3$	0.94

y = Density of variable / 500 m^2
x = Distance from water (m)
ETTE = Evapotranspiration Tree Equivalents

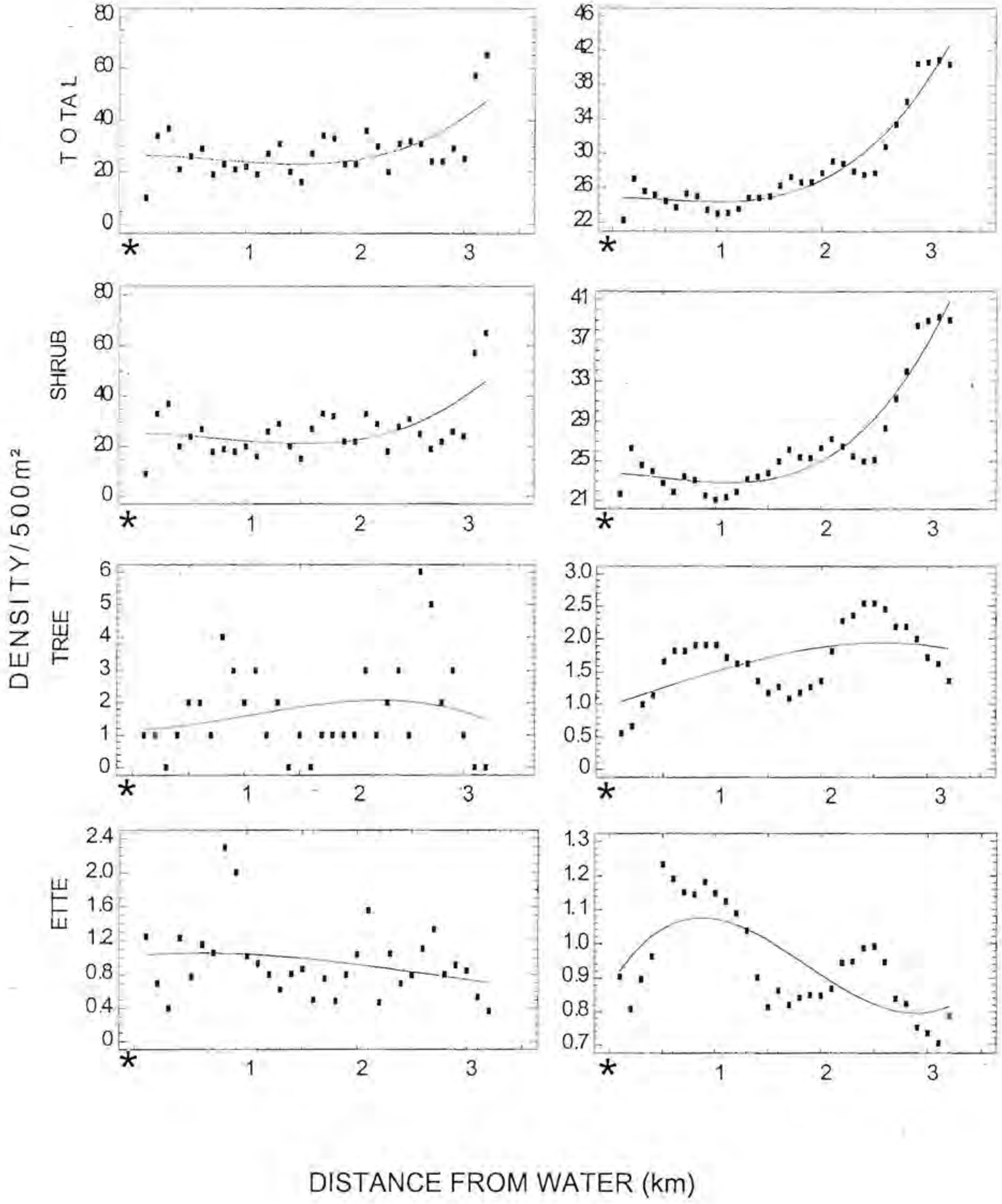

Figure 3.6 Structural variables as a polynomial function away from water using interval sampling on basalt soils. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 3.4

Summary of relationships between structural variables and distance from water using the polynomial equation on the Satara Land System in the Kruger National Park

INTERVAL SAMPLING	VARIABLE	POLYNOMIAL EQUATION	r^2
Original Data	Total Density	$y = 26.5 - 0.02x + 1.4x^2 - 0.06x^3$	0.38
	Shrub Density	$y = 25.3 - 0.03x + 1.5x^2 - 0.06x^3$	0.36
	Tree Density	$y = 1.15 + 0.01x + 0.3x^2 - 0.01x^3$	0.04
	ETTE Density	$y = 1.01 + 0.01x - 0.09x^2 + 0.001x^3$	0.07
Smoothed Data	Total Density	$y = 24.8 + 0.01x - 1.5x^2 + 0.09x^3$	0.92
	Shrub Density	$y = 23.7 - 0.03x + 0.8x^2 - 0.03x^3$	0.90
	Tree Density	$y = 0.98 + 0.05x + 0.001x^2 - 0.0005x^3$	0.32
	ETTE Density	$y = 0.84 + 0.05x - 0.07x^2 + 0.001x^3$	0.48

y = Density of variable / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

decided to sample at every 50 m interval over the first 200 m sampled, to make sure any significant changes in the expected sacrifice area were picked up. Thus, it can be argued that the 500 m² interval sample, would have given a more representative sample of the woody vegetation over the first 1 000 m, than the 400 m² elongated continuous sample. It is thus interesting that more shrubs and less trees were sampled close to the water with the interval sample compared to the continuous sample. However, these differences were not significant.

In a study of this magnitude it can become very difficult to keep all the environmental factors constant and this causes noise in the data. It has been suggested that smoothing of the data helps to reduce noise in a data set (Gauch 1982). The high r^2 values obtained by the smoothed data (Tables 3.1 - 3.4) is due to the number and effect of outlying points being lessened to some degree. Changes in vegetation structure due to small changes in soil depth therefore become less obvious.

Thrash (1993) found that herbaceous basal cover, forage and fuel production potential and standing crop in the vicinity of watering points in the KNP can be modelled satisfactorily by the logistic equation. Graetz & Ludwig (1978) also found that the response to the piosphere grazing pressure gradient around watering points can be quantitively described with logistic equations. Piospheres are dynamic (Heady & Heady 1982; Andrew 1988), the curves varying in shape with time under the influence of grazing pressure and rainfall.

Schmidt (1992) used the polynomial equation to model the change in grass species composition on vegetational gradients. Because of its flexible nature, the polynomial equation was tested and it was thought that if any interesting or complicated model of impact existed, the polynomial equation would show it. No unexpected or complicated fit was seen and to a large extent the polynomial curve followed the shape of the logistic curve (Figure 3.3 - 3.6).

3.3 TECHNIQUE TESTING ON GRANITIC SOILS

3.3.1 Procedure

The same two sampling techniques that were tested on the Satara Land System were also applied on the Skukuza Land System, which lies on rock of granitic origin and has a mean annual rainfall of 550 mm. The undulating terrain on granitic rock results in continual change in soil types. The deep sandy soils of the crest area grade into the well leached soils of the midslope and then to the duplex soils on the footslope areas (Venter 1990). The two landforms that cover the largest part of the landscape are the crest (47%) and footslope (37%) (Venter 1990). The midslope and valleybottom consitute only a small part and only the crown and footslope areas were therefore sampled.

Because of the undulating terrain and soil changes, it became apparent with the application of the continuous transect that the technique was not suited for sampling the granitic soils of the Skukuza Land System.

The interval sampling technique, where the 10 m x 50 m transects were used, could be applied to some extent. The problem being, that on a particular directional line away from the watering point, the same soil type could not be found at every 100 m interval. If sampling was done in all directions though, a particular soil type could always be found within every 100 m interval. This necessitated the lumping of transects of different directions to compile an imaginary representative sample away from the watering point.

On the same soil type, vegetation structure could differ, depending on direction. It was therefore decided to test whether structural variables, at the same distance intervals, differed significantly in direction.

The same distance was sampled in four different directions on both crestal and footslope areas. Four structural variables were compared, namely : ETTE, total density, tree density and shrub density. Variables at the same distance intervals in different directions on both the crest and footslope areas, were tested for significant difference using multifactor analysis of variance.

3.3.2 Results and discussion

It was found that there was no significant difference ($P > 0.05$) in direction for all the structural variables on both the crestal and footslope areas. This means that direction does not influence structural variables at the same distance interval. Therefore the lumping of 10 m x 50 m transects, from different directions, to attain a representative sample away from the watering point, was an acceptable practice.

The curves fitted to the data of the basaltic soils (see Figures 3.3 - 3.6) were also fitted to the data obtained from this pilot study. The results will be discussed later in Chapter 6 with the rest of the watering points (Figures 6.1 & 6.3; Tables 6.1 & 6.4).

3.4 CONCLUSIONS

The continuous sampling technique gave good results on the basaltic soils of the Satara Land System where soil type remains constant. However, on the granitic soils of the Skukuza Land System the regular changes in soil type make this sampling technique unsuitable to apply.

The interval sampling technique gave good results on both the basaltic and granitic soils and was especially suited to the changes found in soil type on the granitic soils.

Therefore the interval sampling technique (10 m x 50 m transect) was used to sample the woody vegetation around watering points in the KNP. This sampling technique makes it possible to stratify for homogeneous soil type at distance away from watering points.

The area sampled (500 m^2), at 100 m intervals seemed to provide a representative sample of the woody structure at that distance interval. Comparative tests that were done on the granitic soils using the 10 m x 50 m transect, showed that at the same distance interval, even in different directions, similar results were obtained. Therefore the assumption can be made that, within a homogeneous landform, only one direction needs to be sampled to give a representative sample of the woody vegetation found around the watering point, on a specific soil type.

In general, the logistic equation described the relationships between structural variables and distance from water better than the polynomial equation (for all data sets). The relationships found were not strong (using original data) in this case, but warrant further investigation. On the grounds of previous studies (Graetz & Ludwig 1978; Thrash 1993) and the fact that the logistic equation gave better results using smoothed data, it was decided to fit the logistic equation to all the data.

CHAPTER 4

SATARA LAND SYSTEM

The Satara Land Type includes the basaltic plains around Satara and southward to Crocodile Bridge. The area has a flat landform and is mainly characterized by an open *Sclerocarya birrea / Acacia nigrescens* Tree Savanna (Gertenbach 1983). Two windmills on the Satara Land System were sampled, namely Mananga and Shibotwane (Figure 2.5). The woody vegetation around these watering points were sampled using the interval sampling technique (Figure 3.2) and the logistic curve was fitted to the data. The species and their densities recorded within each 100 m interval are indicated in the Appendix (Table 1.1 & 1.2).

4.1 RESULTS

Total, shrub, tree and ETTE densities were the structural data that were calculated from the survey data sets. The relationship between structural variables and distance from water was described well by the logistic equation, specifically when the smoothed data were used (Tables 4.1 & 4.2)

At Mananga total density and shrub density showed the same trend along a gradient from the watering point. A low density was recorded from the watering point up to a distance of 2 400 m, an upper asymptote was reached at 2 800 m, after which a constant higher density occurred until the end of the transects (Figure 4.1). Tree density and ETTE density did not show strong relationships with distance from water, with only 29 % and 17 % of the variation respectively, explained by the logistic model (Table 4.1). When the points in the smoothed graphs were assessed, the overall distribution in tree density was one of a low density close to the water and a high density furthest from water with an undulating effect in between (Figure 4.1).

Vegetation structure at Shibotwane showed an increase in total density and shrub

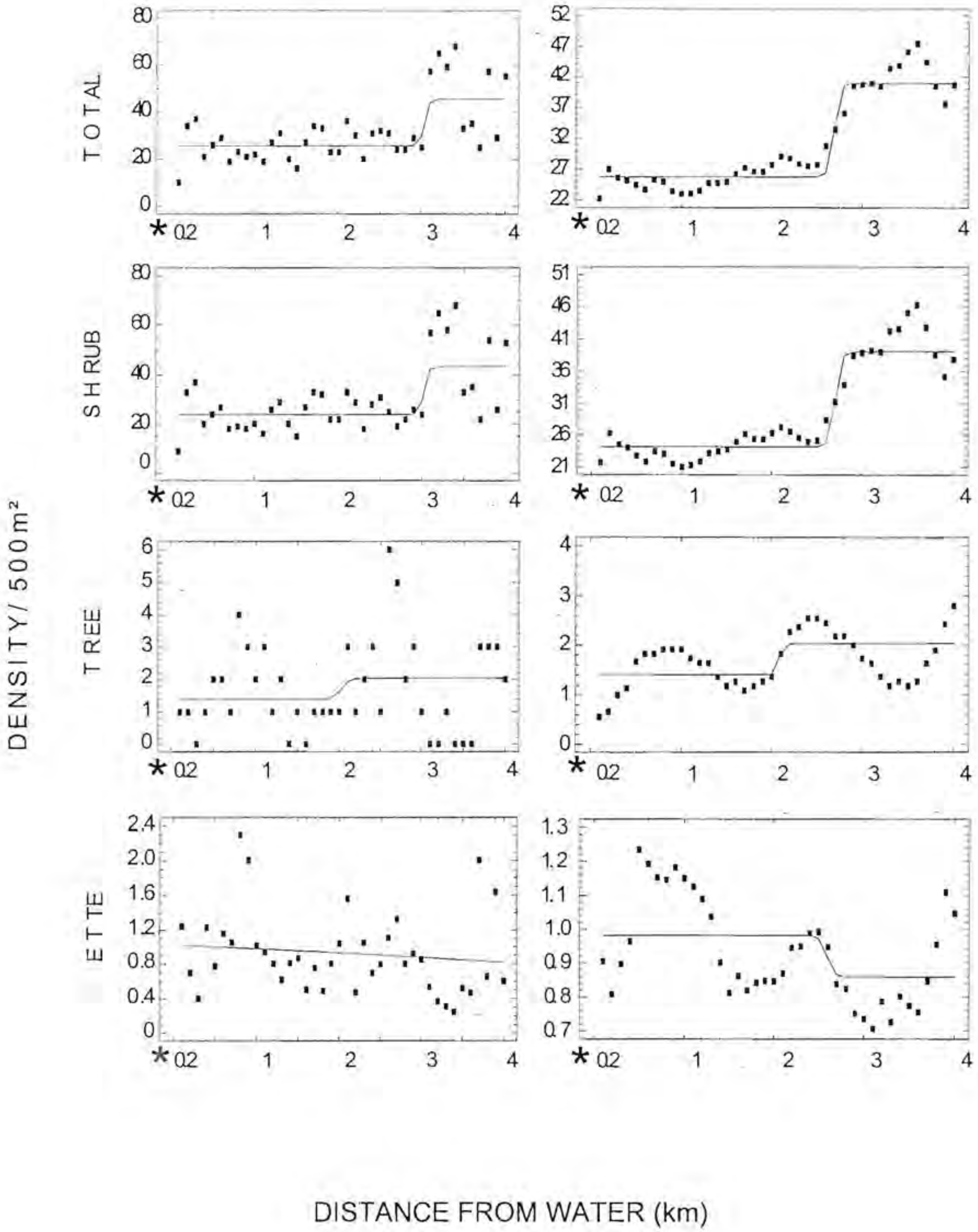

Figure 4.1 Structural variables as a logistic function of distance from water, at Mananga. Original data on the left and smoothed data on the right.
ETTE = Evapotranspiration Tree Equivalents
* = Watering Point

Table 4.1

Summary of relationships between structural variables and distance from water using the logistic equation on the Satara Land System at Mananga in the Kruger National Park

MANANGA	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 45.4 - 19.6 / (1 + e^{-118.4 + 3.9x})$	0.43
	Shrub Density	$y = 43.5 - 19.6 / (1 + e^{-116.2 + 3.8x})$	0.42
	Tree density	$y = 1.4 + 0.6 / (1 + e^{46.2 - 2.2x})$	0.05
	ETTE Density	$y = -12.5 + 14.2 / (1 + e^{-3.1 + 0.007x})$	0.02
Smoothed Data	Total Density	$y = 40.9 - 15 / (1 + e^{-89 + 3.3x})$	0.87
	Shrub Density	$y = 39.1 - 14.9 / (1 + e^{-87.3 + 3.2x})$	0.85
	Tree Density	$y = 2 - 0.6 / (1 + e^{-110.2 + 5.2x})$	0.29
	ETTE Density	$y = 0.8 + 0.12 / (1 + e^{-71 + 2.7x})$	0.17

y = Density of variable / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

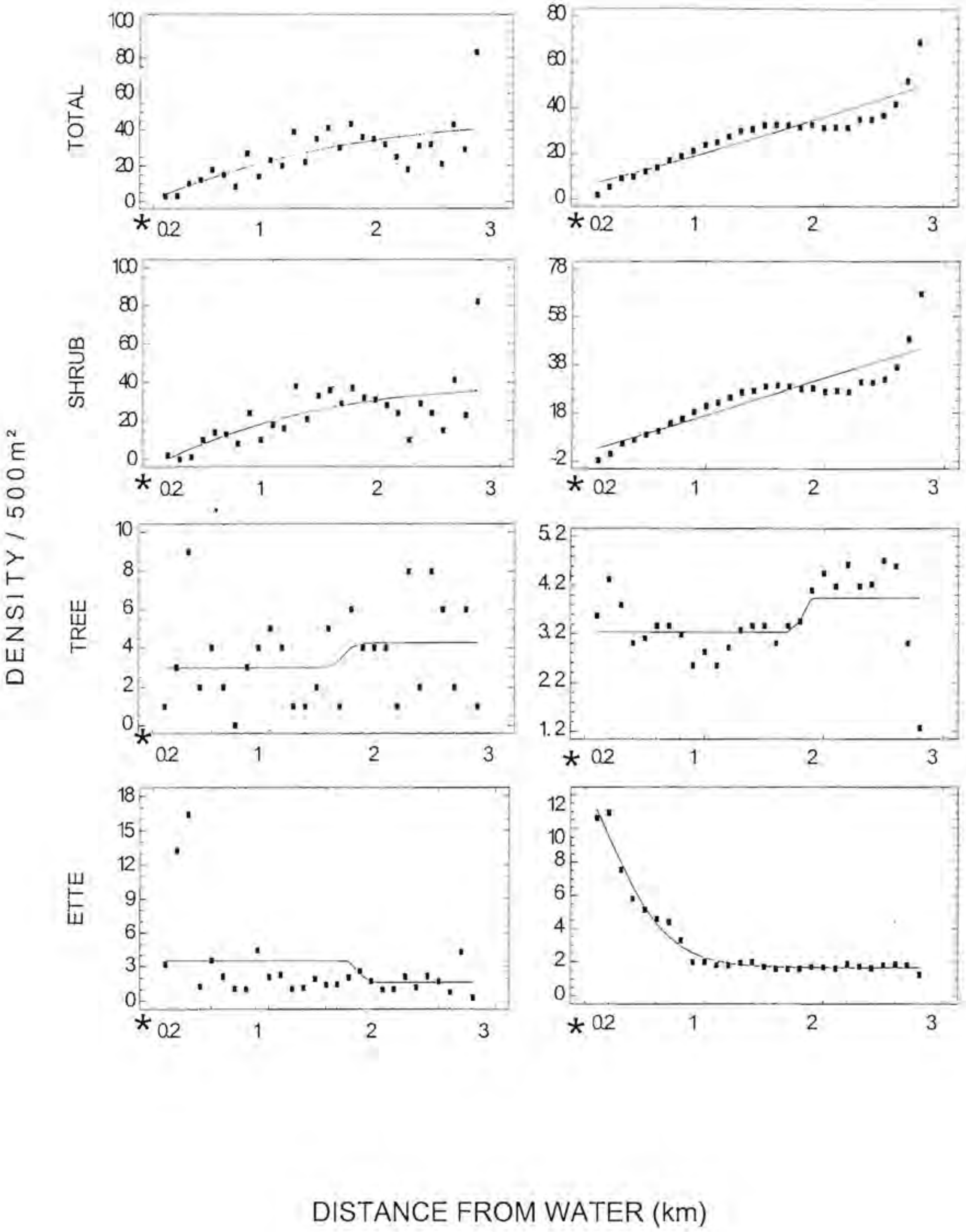

Figure 4.2 Structural variables as a logistic function of distance from water at Shibotwane. Original data on the left and smoothed data on the right. ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 4.2

Summary of relationships between structural variables and distance from water using the logistic equation on the Satara Land System at Shibotwane in the Kruger National Park

SHIBOTWANE	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = -99.7 + 146.1 / (1 + e^{-0.81 - 0.08x})$	0.48
	Shrub Density	$y = -88.5 + 127.4 / (1 + e^{-0.7 - 0.1x})$	0.43
	Tree density	$y = 2.9 - 1.8 / (1 + e^{39 - 2.3x})$	0.07
	ETTE Density	$y = 3.5 -1.8 / (1 + e^{71.1 - 3.9x})$	0.07
Smoothed Data	Total Density	$y = -31.7 + 134.4 / (1 + e^{0.9 - 0.04x})$	0.83
	Shrub Density	$y = -58.9 + 162.3 / (1 + e^{0.5 - 0.04x})$	0.80
	Tree Density	$y = 3.2 + 0.7 / (1 + e^{100.6 - 0.03x})$	0.20
	ETTE Density	$y = 17.4 - 15.8 / (1 + e^{0.8 - 0.4x})$	0.98

y = Density of variable / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

Table 4.3

Linear regression analysis of structural variables on distance from water on the Satara Land System in the Kruger National Park

Watering Point	Variable	Equation	P- value	r^2
Mananga	Total Density	$y = 19.34 + 0.56x$	0.0004	0.27
	Shrub Density	$y = 17.96 + 0.54x$	0.001	0.24
Shibotwane	Total Density	$y = 7.31 + 1.33x$	0.00005	0.47
	Shrub Density	$y = 4.52 + 1.33x$	0.0002	0.42
	ETTE Density	$y = 5.6 - 0.19x$	0.016	0.20

y = Structural Variable Density / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

density with distance from the water. The curve that was fitted did not show any upper asymptote being reached (Figure 4.2). Tree density at Shibotwane did not show much change away from the watering point, with only 20 % of the variation explained by the model. ETTE density ($r^2 = 0.98$) on the other hand showed a high density close to water with a sharp decline up to 1 000 m where the curve reached the lower asymptote (Figure 4.2). This can be explained by the presence of *Acacia tortilis* trees (Appendix: Table 1.2) close to the watering point, which cause an increase in ETTE estimates close to the watering point (Table 4.4). The possibility of the more browse resistant *A. tortilis* replacing less resistant species close to water, was noted by Du Toit *et al.* (1990).

There was a significant but weak relationship between total density and shrub density and distance from water at Mananga when tested with linear regression analysis. At Shibotwane a strong significant relationship was found between these two variables and distance from water (Table 4.3). The ETTE density showed a significant but weak negative relationship with distance from water at Shibotwane (Table 4.3).

4.2 DISCUSSION

Woody structure can be described as canopy regime at different height levels, total canopy cover or density (Coetzee & Gertenbach 1977). Smit (1994) agrees that structure can be described through density but states that density data alone are inadequate to quantify biomass. Biomass was quantified by Teague *et al.* (1981) as tree equivalents (TE), using an *Acacia karroo* tree of 1,5 m high as reference. This estimate was redefined by Smit (1989, 1994) as ETTE (Evapotranspiration Tree Equivalents) which is defined as the leaf volume equivalent of a 1,5 m high single stemmed tree. ETTE gives an index of potential tree competitiveness and is a function of both tree height and canopy cover (Smit 1989, 1994). Therefore ETTE reflects both biomass and structure.

The calculation of ETTE is based on tree height and canopy diameter. When shrub dominated veld is sampled, in this case the *Sclerocarya birrea / Acacia nigrescens* landscape (Gertenbach 1983), very few large trees are taken up in the transect. When a tree does occur in a transect dominated by shrubs, it has a major influence on the ETTE estimate. Therefore, when tree density is compared to ETTE density in shrub dominated veld, both these variables follow the same trend (Figure 4.1). In shrub dominated veld, two large trees could give the same ETTE value as would ten shrubs. The presence of large trees in transects can influence the ETTE estimate to such an extend that it becomes difficult to draw conclusions.

Structure of shrubs (woody individuals ≤ 2 m) is influenced by browsers both in terms of shrub biomass and density. Most browsers will take off, at the most, a few branches when feeding, with elephants being the only browser that can uproot a whole shrub. In general, large herbivores have a bigger impact on biomass than on density. A decrease in density close to the watering point is not necessarily reflected in the biomass (ETTE) (Figures 4.1 & 4.2) if larger, more browse resistant plant species replace smaller species (Du Toit *et al.* 1990), giving the same biomass, but through less individuals. The decrease in shrub density closer to the watering point is therefore of specific interest.

The significant relationship of total density and shrub density with distance from water at both watering points on the Satara Land System indicates that in this case, density data can be of value in assessing structural change. The total density and shrub density followed the same trend away from the watering point (Figure 4.1 & 4.2). This could be attributed to the fact that the area sampled was dominated by *Acacia nigrescens, Cordia monoica* and *Dichrostachys cinerea* shrubs. Thus the total density estimates were greatly influenced by the shrub density. Shrub density at Mananga reached an upper asymptote at 2 800 m from the watering point (Figure 4.1), while at Shibotwane no asymptote was reached, but a constant increase away from the watering point occurred (Figure 4.2). These are two neighbouring watering points (Figure 2.4) and almost the whole distance (8 km) between the two watering points was sampled. The shrub density at both watering points were very similar at 2 800 m (Figure 4.1 & 4.2) and judging from what happened at Mananga (compare Figures 3.4 & 4.1), one could assume that if further sampling at Shibotwane was possible, the shrub density would have shown a threshold at about 3 000 m. Thus, it can be argued that the impact on shrub density occurred in the first 2 800 m from the watering point, and the natural density only occurred from there onwards. Therefore, the change in woody vegetation as a result of the presence of the watering point was manifested in the changes in shrub density.

Evidence, for the existence of a sacrifice area up to 250 m from the watering point in the herbaceous vegetation at watering points in the KNP was given by Thrash *et al.* (1993) and Thrash (1998). The basal cover estimates and forage and fuel production scores close to the watering point all show that the area should be more susceptible to bush encroachment. The first transect at both watering points was placed at 200 m from the trough and the sampling at Mananga was done at 50 m intervals up to 400 m from the trough. In the direction of sampling, in both cases, a road traversed the area within 100 m from the trough, and there were almost no woody individuals in this radius which correlates with the sacrifice area found by Thrash *et al.* (1993). However, no woody plant encroachment occurred within the first 2 800 m from the watering points. This is contradictory to what is often reported for livestock areas (Friedel & Blackmore 1988; Perkins & Thomas 1993a; Perkins 1996) and in some cases also large conservation areas (Van Wyk & Fairall 1969; Smuts 1972; Thrash *et al.* 1991), where bush encroachment close to the watering points was found. Other studies in large conservation areas however do not show increased woody plant density around watering points (Van der Schijff 1959; Child *et al.* 1971; Van Rooyen *et al.* 1991; 1994).

Trollope (1983), studying the effect of fire frequency on woody vegetation in the eastern Cape, showed that over time there was a decrease in woody phytomass, expressed as tree equivalents (Teague *et al.* 1981), rather than density. Trollope *et al.* (1998) confirmed these results in the KNP where vegetation inside exclosure plots was compared over time to the area outside subjected to fire and elephant impact.

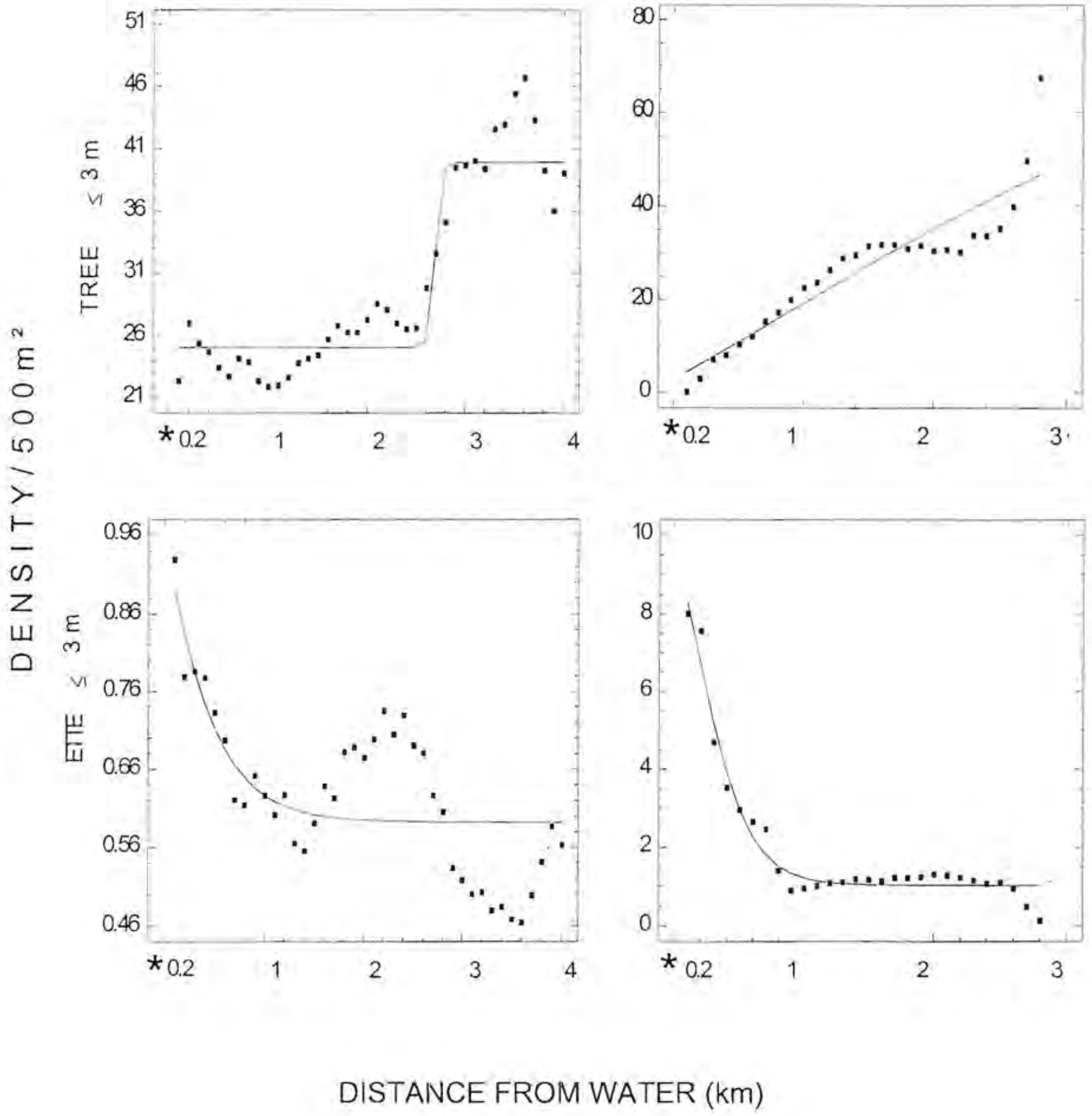

Figure 4.3 Density data for Mananga (left) and Shibotwane (right) as a logistic function of distance from water.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 4.4

Summary of relationships between structural variables of woody plants ≤ 3 m and distance from watering points using the logistic equation on the Satara Land System in the Kruger National Park

WATERING POINT	VARIABLE (≤ 3 m)	LOGISTIC EQUATION	r^2
Mananga	Density	$y = 39.9 - 14.7 / (1 + e^{-89.7 + 3.3x})$	0.85
	ETTE Density	$y = 0.6 + 1.8 / (1 + e^{1.3 + 0.2x})$	0.48
Shibotwane	Density	$y = -85 + 190 / (1 + e^{0.1 - 0.03x})$	0.84
	ETTE Density	$y = 13.8 - 12.8 / (1 + e^{0.7 - 0.4x})$	0.96

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

All the studies where changes in biomass, rather than density, were recorded, were where temporal data were available (Trollope 1983; Trollope *et al.* 1998). In this study, only spatial data were available. It appears, that where spatial data (distance from water) is collected and no temporal data are available, it is advisable to determine density data of different height classes. Along with biomass (ETTE) this additional information can be used to pinpoint the structural changes occurring in the woody vegetation around watering points.

Figure 4.3 shows the density and biomass (ETTE) of woody plants up to 3 m in height at Mananga and Shibotwane. This height class includes most of the woody plants at both watering points. Despite a low density of plants close to the watering point, these plants have the highest biomass (Figure 4.3), while the opposite becomes true as distance from water increases. This means that there are fewer but larger (canopy diameter and height) individuals closer to the watering point and more individuals with smaller canopies further from the watering point.

The trampling effect due to increased herbivore numbers around watering points, has a negative impact on the survival of seedlings of all woody plants. The fact that soils of basaltic origin have a high clay content (Venter 1990), means that water stays in the top soil layers longer and is more available to herbaceous vegetation and favours the fast growth of herbaceous vegetation compared to that of woody plants. As a result the herbaceous vegetation (especially annuals) establish quicker after the dry season than the woody shrubs. Therefore, there is always competition from the herbaceous layer, which makes it difficult for woody seedlings to establish (Trollope *et al.* 1989; 1998). The trampling effect, however, causes lower basal cover estimates, forage and fuel production scores close to the watering point (Senzota & Mthako 1990; Thrash *et al.* 1993). The trampled area thus has a lower fire intensity compared to the surrounding area, meaning that the woody plants that do survive in this trampled area would be less influenced by fire especially in the more susceptible height class of less than 3 m high (Trollope *et al.* 1995). Woody plants closer to water are probably influenced more by browsing than by fire.

According to Du Toit *et al.* (1990), *A. nigrescens* trees close to watering points, in the *Sclerocarya birrea / Acacia nigrescens* landscape (Gertenbach 1983), despite being browsed significantly more, achieved net annual growth increments equivalent to those at control sites away from watering points. He postulated that close to watering points, woody plants are not negatively influenced by fire, but positively through browsing feedback loops (Du Toit *et al.* 1990) which enable the plant to keep a constant canopy volume. More browse resistant species like *A. tortilis* may also replace less resistant species close to water and the reduced fire intensity enables these plants to grow taller, giving higher biomass values closer to watering points (Figure 4.3).

Plants in the below 3 m height class, beyond the sacrifice area at watering points are influenced more severely by fire intensity and frequency (Trollope *et al.* 1995). These plants were burned back by fire in the triennial (three yearly) burning program implemented in the KNP since 1957. The effect of fire accompanied by the lack of stimulation through browsing cause a reduction in canopy cover and consequently a lower biomass away from watering points.

The browsing-regrowth feedback loops proposed by Du Toit *et al.* (1990) were probably initiated when the dominant shrub, *Acacia nigrescens*, became less abundant around surface water due to trampling, especially at older watering points. This meant that there were fewer trees around the watering points for browsers to feed on, leading to higher utilization of individual trees and resulting in browsing-regrowth feedback loops. The presence of the watering point and the resulting grazing gradient was the underlying cause.

These results therefore show that the effects of herbivore use-intensity on woody vegetation around watering points extend further away from watering points, than indicated by Thrash (1993), who studied the effects on the herbaceous layer. This can be seen in the influence on shrub density, extending up to 2 800 m from the water after which the natural density occurs (Figures 4.1, 4.2 & 4.3).

CHAPTER 5

LETABA LAND SYSTEM

The Letaba Land System has an intermediate mean annual rainfall (530 mm) and occurs on basaltic rock (Venter 1990) with *Colophospermum mopane* the dominant woody species throughout the area (Gertenbach 1983).

Three watering points (Tihongonyen, Hartbeesbult and Nkolobeni-South) (Figure 2.5) on the Letaba Land System were sampled and four structural variables (total-, shrub-, tree- and ETTE density) were calculated from the data. The species and their densities recorded are indicated in the Appendix (Table 1.3 - 1.5).

5.1 RESULTS

The smoothed data at Tihongonyen showed that a lower total density, shrub density and ETTE density occurred close to the watering point and the curves reached the upper asymptote at 400 m for total and shrub density and 600 m for ETTE density (Figure 5.1). When the points in the graph of tree density are assessed the same trend is illustrated, with lower densities over the first 500 m. However, due to the decrease in tree density further away from the watering point, the logistic curve gave the opposite fit (Figure 5.1).

Tree density and ETTE density at Hartbeesbult showed a low density close to the watering point with increased density and an upper asymptote being reached at 700 m for tree density and 500 m for ETTE density (Figure 5.2). The shrub density showed the opposite trend with a high density up to 1 500 m from the watering point, then declining and a lower asymptote being reached at 1 900 m. Total density incorporated tree and shrub density. The initial low tree density over the first 600 m is not modelled by the logistic curve for total density. The lower asymptote of total density was reached at approximately 1 800 m (Figure 5.2).

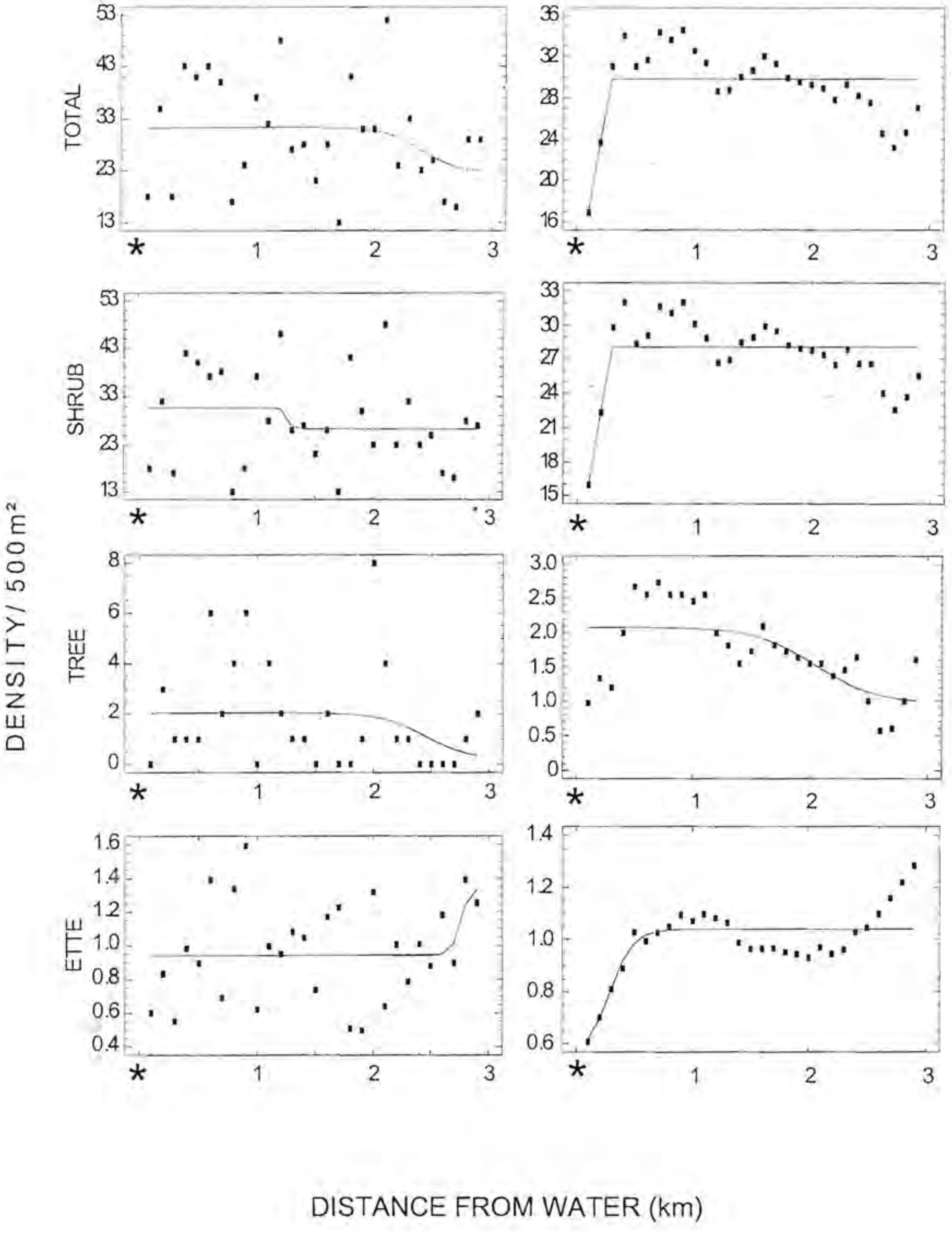

Figure 5.1 Structural variables as a logistic function of distance from water at Tihongonyen. Original data on the left and smoothed data on the right. ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 5.1

Summary of the relationships between structural variables and distance from water using the logistic equation at Tihongonyen on the Letaba Land System in the Kruger National Park

TIHONGONYEN	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 31.3 - 8.6 / (1 + e^{15.7 - 0.6x})$	0.09
	Shrub Density	$y = 30.6 - 4.3 / (1 + e^{63.7 - 5.02x})$	0.05
	Tree Density	$y = 2 - 1.8 / (1 + e^{12.5 - 0.5x})$	0.07
	ETTE Density	$y = 0.9 + 0.4 / (1 + e^{72.6 - 2.6x})$	0.10
Smoothed Data	Total Density	$y = 29.8 - 12.9 / (1 + e^{-22.2 + 11.1x})$	0.47
	Shrub Density	$y = 28 - 12 / (1 + e^{-21.9 + 11x})$	0.53
	Tree Density	$y = 2.1 - 1.1 / (1 + e^{8.1 - 0.39x})$	0.44
	ETTE Density	$y = 0.5 + 0.4 / (1 + e^{2.8 - 0.9x})$	0.62

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

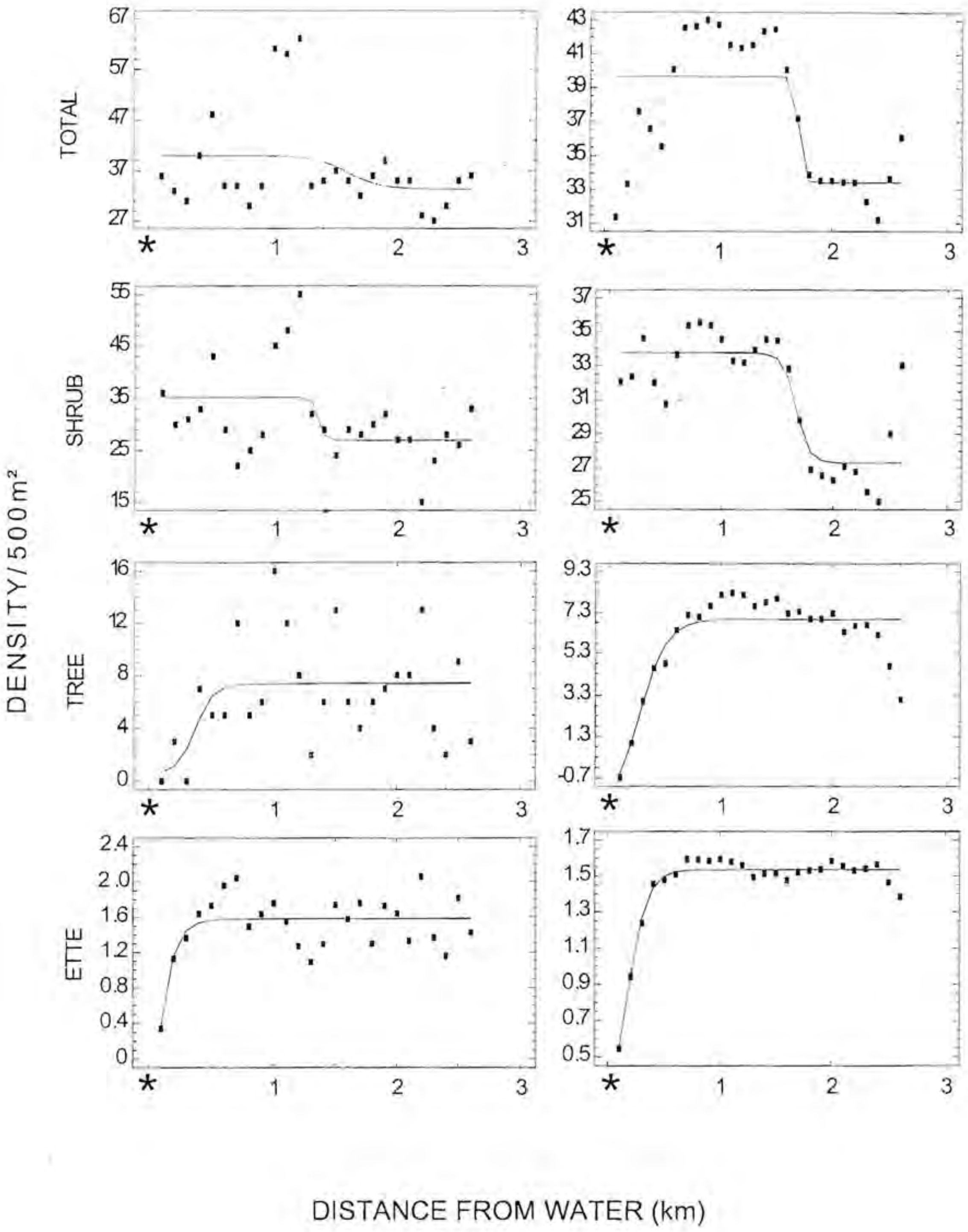

Figure 5.2 Structural variables as a logistic function of distance from water at Hartbeesbult. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 5.2

Summary of the relationships between structural variables and distance from water using the logistic equation at Hartbeesbult on the Letaba Land System in the Kruger National Park

HARTBEESBULT	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 6.6 - 13.3 / (1 + e^{20.6 - 0.75x})$	0.05
	Shrub Density	$y = 29.7 + 1.3 / (1 + e^{-10.9 - 6.5x})$	0.00
	Tree Density	$y = 7.3 - 38.7 / (1 + e^{0.5 + 0.7x})$	0.06
	ETTE Density	$y = 1.5 - 8.6 / (1 + e^{0.6 + 1.1x})$	0.50
Smoothed Data	Total Density	$y = 39.6 - 6.2 / (1 + e^{77.5 - 4.5x})$	0.51
	Shrub Density	$y = 33.7 - 6.4 / (1 + e^{28.7 - 1.7x})$	0.75
	Tree Density	$y = 6.7 - 9.3 / (1 + e^{-2.2 + 0.8x})$	0.77
	ETTE Density	$y = 1.5 - 1.4 / (1 + e^{-1.8 + 1.1x})$	0.96

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

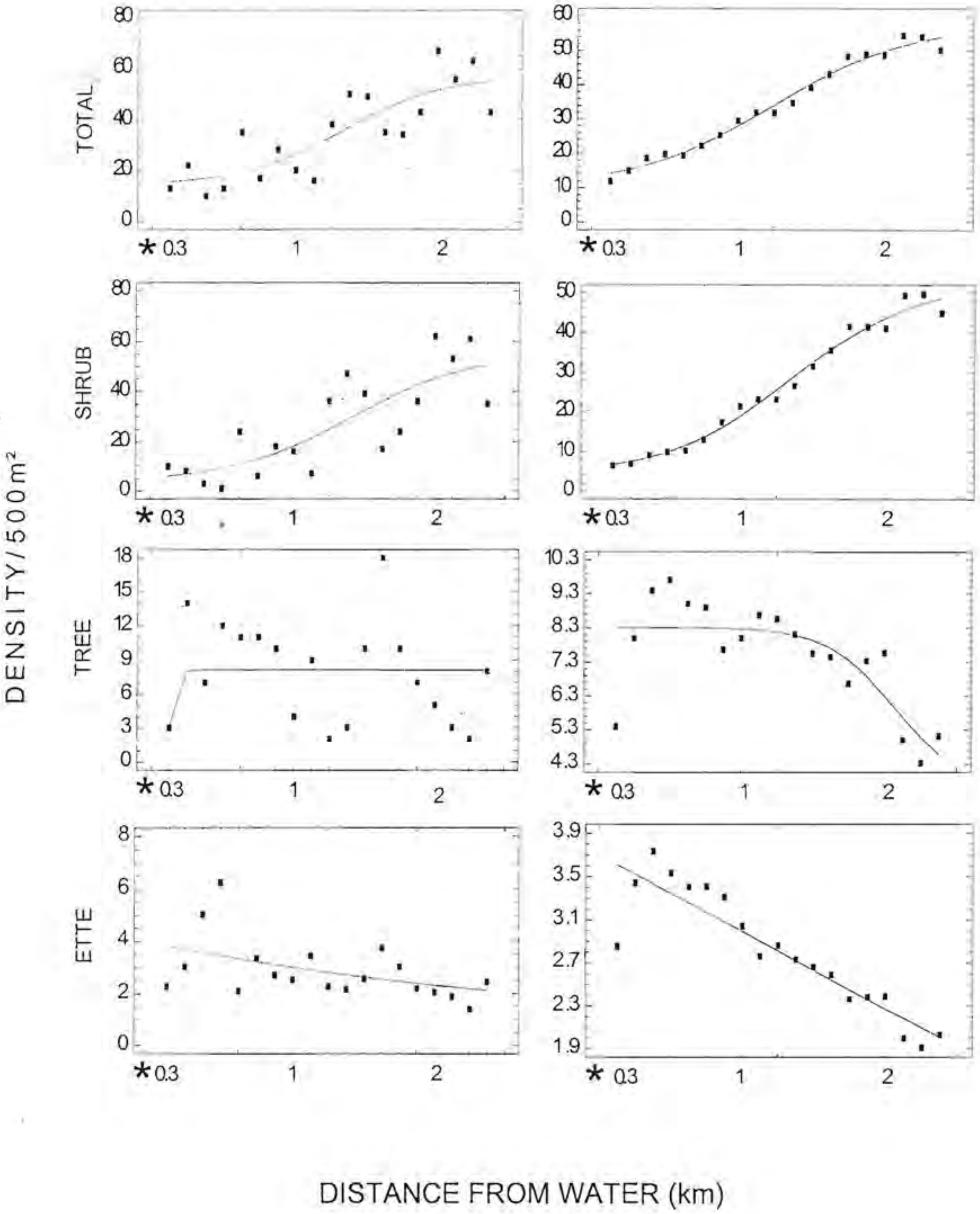

Figure 5.3 Structural variables as a logistic function of distance from water at Nkolobeni-South. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 5.3

Summary of the relationships between structural variables and distance from water using the logistic equation at Nkolobeni-South on the Letaba Land System in the Kruger National Park

NKOLOBENI-SOUTH	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 56.9 - 42.4 / (1 + e^{-3.8 + 0.36x})$	0.70
	Shrub Density	$y = 54.9 - 51.3 / (1 + e^{-3.3 + 0.2x})$	0.65
	Tree Density	$y = 8.1 - 56.8 / (1 + e^{-2.2 + 4.5x})$	0.07
	ETTE Density	$y = 1.2 + 9.3 / (1 + e^{0.8 + 0.07x})$	0.23
Smoothed Data	Total Density	$y = 57.7 - 47.7 / (1 + e^{-2.6 + 0.2x})$	0.98
	Shrub Density	$y = 52.8 - 48.9 / (1 + e^{-3.1 + 0.2x})$	0.98
	Tree Density	$y = 3.6 + 4.6 / (1 + e^{-9.1 + 0.5x})$	0.60
	ETTE Density	$y = -1.2 + 8.1 / (1 + e^{-0.47 + 0.04x})$	0.83

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

Table 5.4

Linear regression analysis of structural variables on distance from water on the northern basalt soils of the Kruger National Park

Watering Point	Variable	Equation	*P*- value	r^2
Nkolobeni - South	Total Density	$y = 8.61 + 2.57x$	0.00001	0.68
	Shrub Density	$y = -1.24 + 2.77x$	0.00004	0.63
	ETTE Density	$y = 3.87 - 0.1x$	0.03	0.24

y = Structural Variable Density / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

Total density and shrub density at Nkolobeni-South showed a low density close to the watering point, increasing with distance from the water and no upper asymptote being reached. When the points of tree and ETTE density are assessed, an initial increase is evident over the first 500 m (Figure 5.3). Whereafter tree and ETTE density show a trend of decreasing density away from the watering point and no lower asymptote being reached.

In most cases the logistic curve fitted the smoothed data well with between 44 % and 98 % of the variation being explained by the model (Tables 5.1 5.3).

Total density, shrub density and ETTE density at Nkolobeni-south showed significant relationships with distance from water when tested with linear regression analysis (Table 5.4).

5.2 DISCUSSION

The northern basalt plains are dominated by shallow soils with a very high clay content and are dominated by a moderately dense *Colophospermum mopane* shrub savanna (Gertenbach 1983). The shrubby nature of the woody vegetation is caused by an impenetrable layer of $CaCO_3$ concretions, which inhibit root development and causes plants to remain in shrub form (Gertenbach & Potgieter 1979; Venter 1990).

Colophospermum mopane is a recognized encroaching woody species, with shrubs ≤ 0.5 m forming dense stands in cattle production (Smit 1994) and wildlife areas (Swart 1995). *Colophospermum mopane* has a high potential to compete with herbaceous plants due to a root biomass that exceeds that of leaf biomass and which is concentrated in the upper soil layer (Ellis 1950; Smit 1994). Where over-utilization of the herbaceous layer occurs one would expect an increase in *C. mopane* shrubs, because of its superior ability to settle and compete with shallow rooted herbaceous plants (Shackleton *et al.* 1988; Moore 1989a). This encroaching ability of *C. mopane* should be evident around watering points in the KNP where sacrifice areas have been

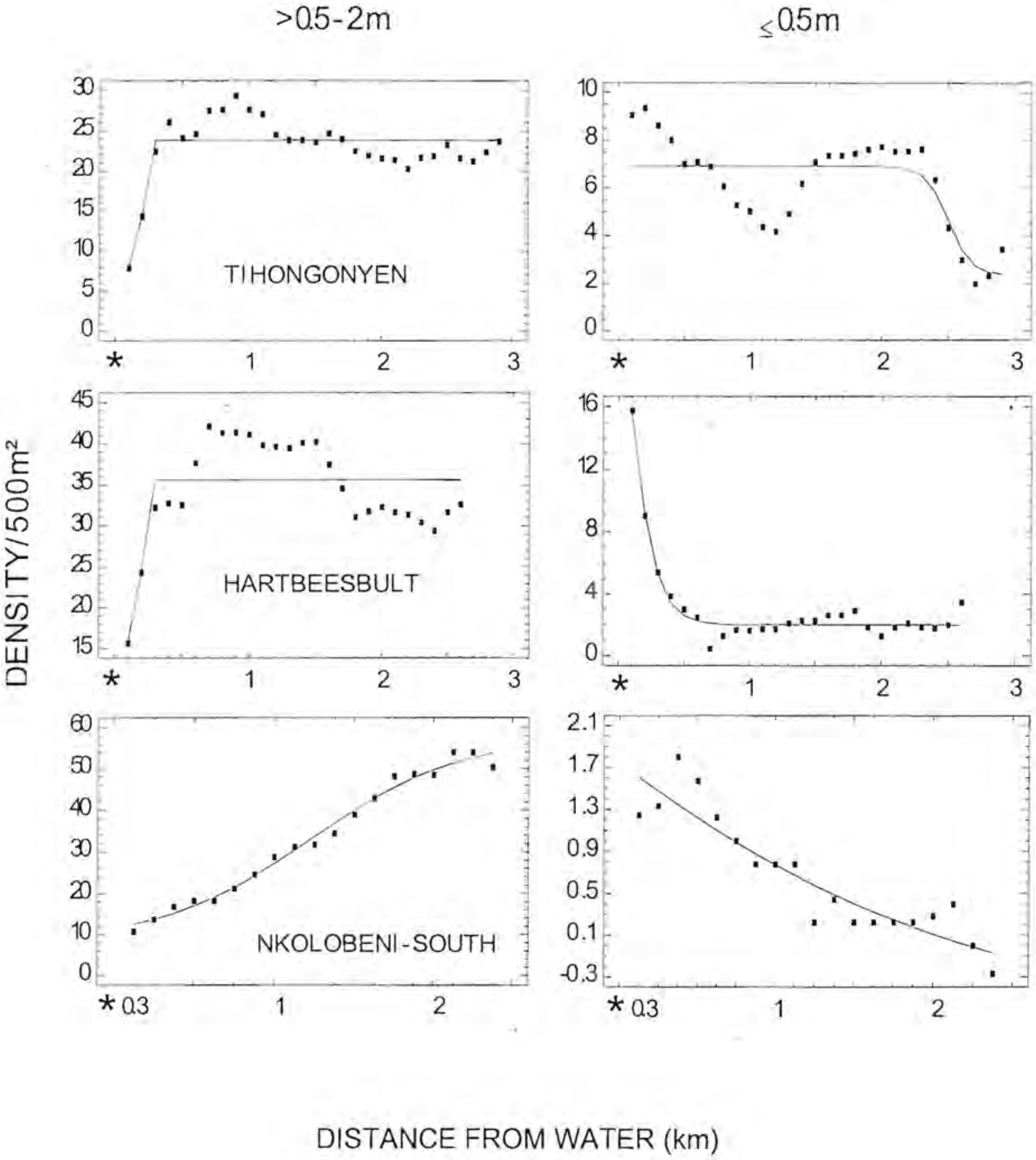

Figure 5.4 Shrub density in two height classes at three watering points on the Letaba Land System.

* = Watering Point

Table 5.5

Summary of relationships between structural variables and distance from water using the logistic equation on the Letaba Land System in the Kruger National Park

WATERING POINT	VARIABLE	LOGISTIC EQUATION	r^2
Tihongonyen	Density >0.5 - 2 m	$y = 23.2 - 15.3 / (1 + e^{-21.1 + 10.2x})$	0.69
	Density $\leq$ 0.5 m	$y = 6.9 - 4.3 / (1 + e^{37 + 1.4x})$	0.59
Hartbeesbult	Density >0.5 - 2 m	$y = 35.2 - 19.5 / (1 + e^{-24.3 - 12.8x})$	0.53
	Density $\leq$ 0.5 m	$y = 34.2 - 32.5 / (1 + e^{0.6 - 0.9x})$	0.96
Nkolobeni-South	Density >0.5 - 2 m	$y = 57 - 49.2 / (1 + e^{-2 + 0.2x})$	0.99
	Density $\leq$ 0.5 m	$y = 8 - 8.8 / (1 + e^{-0.8 - 0.08x})$	0.85

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

identified (Van der Schijff 1959; Van Wyk & Fairall 1969; Thrash 1998). However, *C. mopane* is also a species preferentially browsed by elephant (Swart 1995) and high utilization pressure close to watering points could lead to lower biomass, higher mortality and a decline in density. Swart (1995) found a higher *C. mopane* shrub density (1- 2 m class) in elephant utilized veld compared to elephant free control areas on Letaba Ranch in the Northern Province. The reason given was that elephants utilized the *C. mopane* shrubs (≤ 2 m) more and this caused coppicing from the roots, leading to an increase in density. He also found that *C. mopane* in the ≤ 0.5 m height class was not utilized much by elephants and that it was this height class that caused severe encroachment on Letaba Ranch. This height class is believed to conceal the actual impact of elephants on the ≤ 2 m class (Swart 1995) in which most of the feeding on woody vegetation is done (Guy 1976).

Since most of the individual plants in the Letaba Land System occur in the below 2 m height class, it is important to determine where in this height class the utilization of large herbivores around watering points is concentrated. It was decided to divide this class into a ≤ 0.5 m and > 0.5 - 2 m height class at all three watering points, to prevent the possible concealing effect of the ≤ 0.5 m height class. The results of this distinction are illustrated in Figure 5.4 and Table 5.5.

What became evident with this distinction was the high density of the ≤ 0.5 m height class close to the watering points. At all three watering points this height class showed high densities close to the watering point declining rapidly away from the watering point in the case of Hartbeesbult with a lower asymptote at 600 m and at Nkolobeni-South where a constant decline was present with no asymptotes being reached. At Tihongonyen the lower asymptote was only reached at 2 500 m (Figure 5.4). The > 0.5 m - 2 m height class at Tihongonyen and Nkolobeni-South (Figure 5.4) showed the same trend modelled for total and shrub density at these watering points (Figures 5.1 & 5.3). At Hartbeesbult however, this distinction shed some light on the apparently opposite trend modelled for shrub density (Figure 5.2). It is clear that the ≤ 0.5 m height class encroached over the first 600 m (Figure 5.4) concealing or influencing the shrub density to such an extent that wrong conclusions could be made if the shrub density was assessed from the ≤ 2 m height class only.

If all the height classes are assessed together it becomes clear that at Tihongonyen, Hartbeesbult and Nkolobeni-South an area of high impact occurs close to the watering points which could be compared to the sacrifice area described by Graetz & Ludwig (1978). This area radiates out to 400 m - 600 m at Tihongonyen, 600 m at Hartbeesbult and 500 m at Nkolobeni-South (Figures 5.1-5.4). This area is characterized by encroachment of the ≤ 0.5 m height class (Figure 5.4), a low density in the highly utilized > 0.5 -2 m height class and a low tree density. The higher utilization pressure and trampling close to the watering point, are factors causing encroachment in the 0.5 m class due to reduced competition from the herbaceous layer and the coppicing habit of *C. mopane*. The high utilization pressure of the > 0.5 - 2 m class eventually leads to lower densities of this class. The low tree density and ETTE density in this area are possibly due to the high utilization pressure preventing individual plants to develop into trees and keeping most individuals in the ≤ 2 m height class with small canopies.

The significant negative relationship of ETTE density (biomass) with distance from water beyond the sacrifice area at Nkolobeni-South (Figure 5.3) could seem like a contradiction when compared to that of total and shrub density. This could partly be explained by the distribution of trees (plants > 2m) in the transects, the declining tree density over the last 500 m influencing the ETTE density in this area.

In conclusion it can be said that the logistic equation successfully modelled the impact of large herbivores around watering points although the reaction in this land system was complicated and difficult to explain. The existence of a sacrifice area around watering points, with the consequent encroachment of ≤ 0.5 m shrubs and a decrease in the highly utilized > 0.5 - 2 m class were indicated. The concealing effect of the ≤ 0.5 m class described by (Swart 1995) became evident at Hartbeesbult watering point and it would be advisable to assess this height class separately in future studies.

CHAPTER 6

SKUKUZA LAND SYSTEM

The Skukuza Land System has a relatively high mean annual rainfall (550 mm) and occurs on granitic rock. It is characterized by well-defined land units and a very typical catenary sequence of soils. The crest and footslope areas cover 40 % and 37 % of the total area respectively and are the most prominent hillslope units in this landscape (Venter 1990).

Timbiten and Shiteve-teve were the two watering points sampled on the southern soils of granitic origin. The variables calculated from the data sets were total density, shrub density, tree density and ETTE density. Because in most cases watering points were placed in or close to drainage lines (spruits), the sampling of crestal areas only started some way up the catena. At Timbiten the sampling started at 300 m and at Shiteve-teve at 400 m away from the trough. The species and their densities recorded within each 100 m interval are indicated in the Appendix (Table 1.6 - 1.9).

6.1 CRESTAL AREAS

6.1.1 Results

At Timbiten total density and shrub density showed the highest density close to water and the lowest density furthest from the watering point. The lower asymptote being reached at 1 600 m and 1 800 m respectively. Tree density and ETTE density showed the opposite trend with the highest density furthest from the watering point but no upper asymptote being reached (Figure 6.1). If points on the graph are assessed, these two variables indicated an initial sharp increase over the first 600 m from the watering point (Figure 6.1).

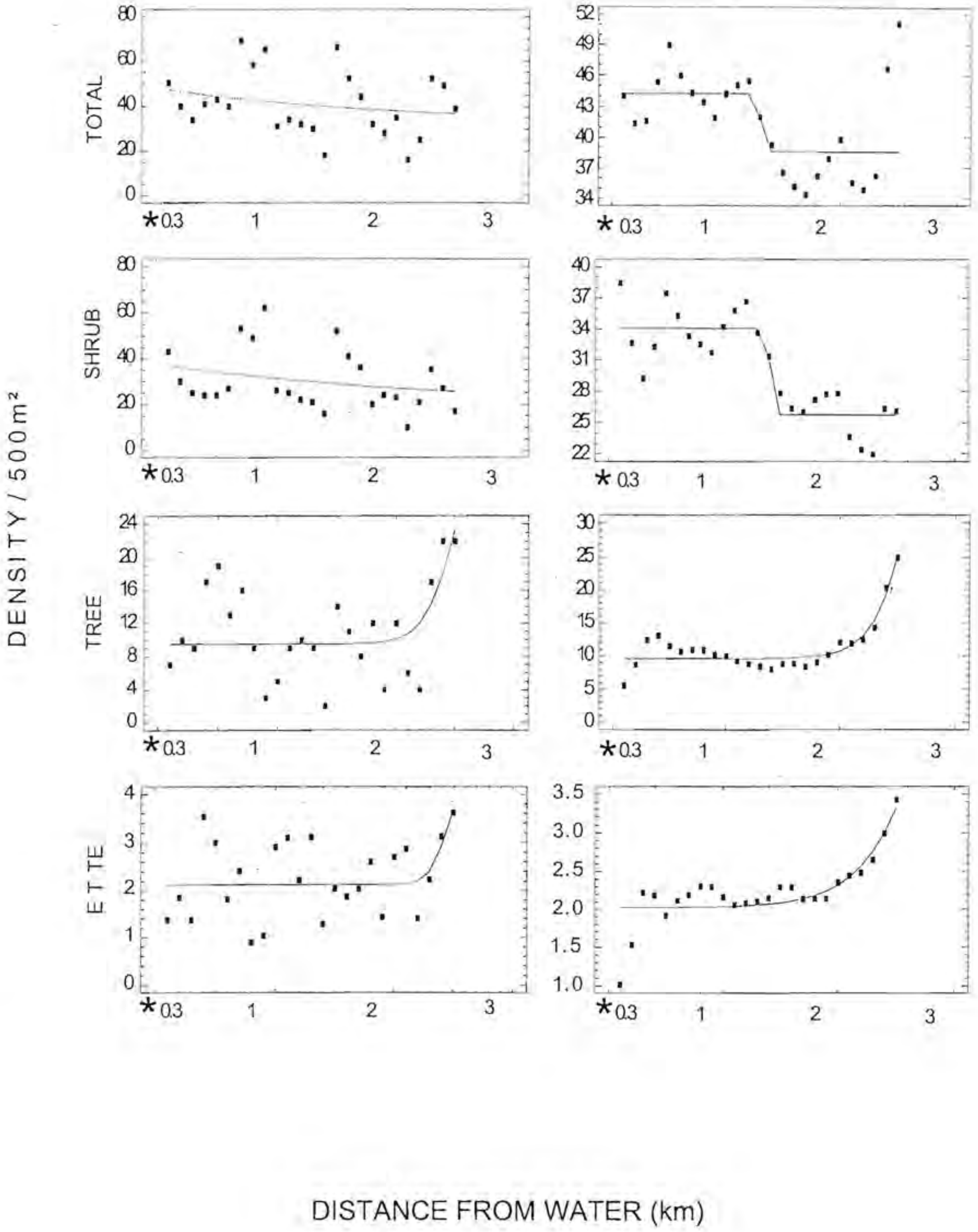

Figure 6.1 Structural variables as a logistic function of distance from water on the crestal areas at Timbiten. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 6.1

Summary of the relationships between structural variables and distance from water on the crestal areas at Timbiten on the Skukuza Land System in the Kruger National Park

TIMBITEN	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 33 + 209.9 / (1 + e^{2.5 + 0.05x})$	0.06
	Shrub Density	$y = 19 + 378.8 / (1 + e^{3 + 0.04x})$	0.09
	Tree Density	$y = 9.5 + 30.7 / (1 + e^{18.7 - 07x})$	0.34
	ETTE.Density	$y = 2.1 + 2.2 / (1 + e^{33.4 - 1.3x})$	0.18
Smoothed Data	Total Density	$y = 44.2 - 5.6 / (1 + e^{87.1 - 6.6x})$	0.36
	Shrub Density	$y = 34 - 8.3 / (1 + e^{141.9 - 10x})$	0.77
	Tree Density	$y = 9.5 + 79 / (1 + e^{15.7 - 0.5x})$	0.85
	ETTE Density	$y = 2.1 + 8.2 / (1 + e^{9.7 - 0.3x})$	0.63

y = Density of variable / 500 m²
x = Distance from water (m)
ETTE = Evapotranspiration Tree Equivalents

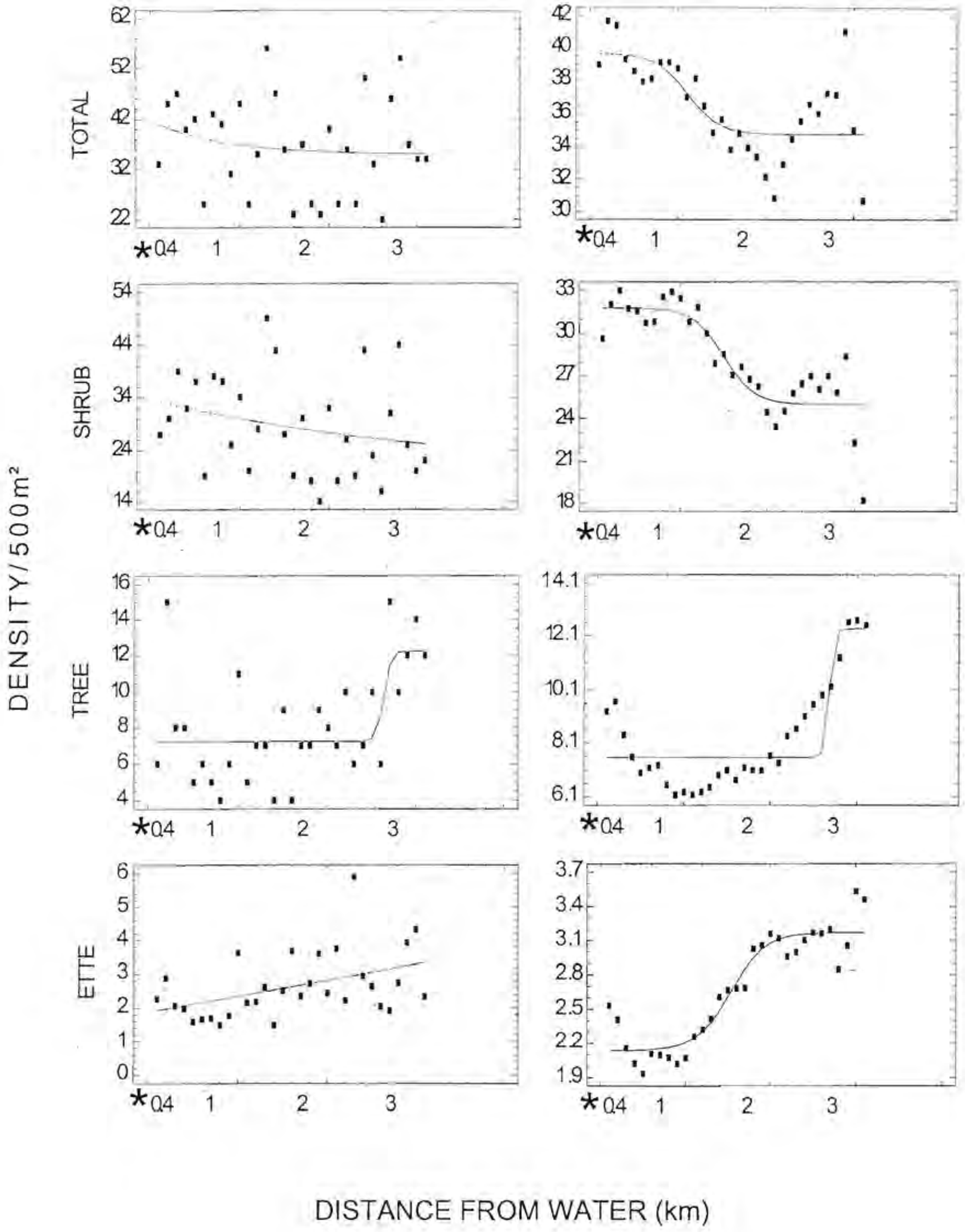

Figure 6.2 Structural variables as a logistic function of distance from water on crestal areas at Shiteve-teve. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 6.2

Summary of the relationships between structural variables and distance from water on the crestal areas at Shiteve-teve on the Skukuza Land System in the Kruger National Park

SHITEVE -TEVE	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 35 + 88.9 / (1 + e^{2.4 + 0.13x})$	0.03
	Shrub Density	$y = 23.1 + 135.1 / (1 + e^{2.4 + 0.05x})$	0.07
	Tree Density	$y = 12.2 - 5.06 / (1 + e^{-76.1 + 2.8x})$	0.39
	ETTE Density	$y = -10.1 + 30.7 / (1 + e^{0.4 - 0.006x})$	0.19
Smoothed Data	Total Density	$y = 34.7 + 4.9 / (1 + e^{-5.9 + 0.5x})$	0.52
	Shrub Density	$y = 25 + 6.7 / (1 + e^{-8.4 + 0.5x})$	0.73
	Tree Density	$y = 12.3 - 4.7 / (1 + e^{-102 + 3.8x})$	0.70
	ETTE Density	$y = 3.2 - 1.1 / (1 + e^{-7.5 + 0.5x})$	0.88

y = Density of variable / 500 m²
x = Distance from water (m)
ETTE = Evapotranspiration Tree Equivalents

Table 6.3

Linear regression analysis of structural variables on distance from water on the crestal areas of southern granitic soils of the Kruger National Park

WATERING POINT	VARIABLE	EQUATION	*P* - value	r^2
Shiteve-teve	Tree Density	$y = 5.8 + 0.14 x$	0.02	0.17
	ETTE density	$y = 1.87 + 0.04 x$	0.013	0.19

y = Structural Variable Density / 500 m²
x = Distance from water (m)
ETTE = Evapotranspiration Tree Equivalents

Shiteve-teve showed the same trends in total density and shrub density but the lower asymptote was reached at 2 000 m and 2 300 m respectively. Tree density and ETTE density show low densities close to the water and higher densities furthest from the water, the curve reaching its upper asymptote at 3 200 m and 2 400 m respectively (Figure 6.2). The points on the graphs however, indicate a relatively high tree and ETTE density over the first 800 m from the watering point.

The smoothed data at both watering points showed strong relationships with distance from water (Tables 6.1 & 6.2).

Linear regression analysis of variables on distance from water, using the original data, showed that at Shiteve-teve there was a significant but weak relationship between tree density and ETTE density and distance from water (Table 6.3).

6.1.2 Discussion

The variables showed the same trends away from the water (Figures 6.1 & 6.2) at both the watering points. The deep sandy soils of the crestal areas supply more favourable conditions for the growth of trees, when compared to soils of basaltic origin that have a higher clay content. The reason being that the water does not stay in the top soil layers very long before seeping down deeper in the sand where it is more available to woody plants than to herbaceous plants (Venter 1990; Trollope *et al.* 1998). The sandy soils thus favour the growth and survival of woody plants. The presence of the watering point with its associated higher grazing pressure around the water could possibly lead to less competition from the herbaceous layer, lower fire intensity and therefore a higher woody seedling survival (Trollope *et al.* 1998).

Therefore, changes in total density and shrub density along the transect could be interpreted as an increase in shrub density towards the watering point. This indicates woody encroachment around watering points found in other studies (Van Wyk & Fairall 1969; Smuts 1972; Thrash *et al.* 1991; Perkins & Thomas 1993b). Eckhardt *et al.* (in press) found a significant increase in woody cover over time (1940 - 1998) on the granitic soils in the KNP. The major contributor to this increase was thought to be woody individuals < 5 m high. The increase in shrub density around watering points could be one of the factors causing the increase in woody cover over time found by Eckhardt *et al.* (in press).

When assessing the graphs of tree density (Figures 6.1 & 6.2) it could possibly be interpreted as a decline in tree density towards the watering point. This could be attributed to the higher utilization pressure closer to the watering point and elephants could probably be singled out as the primary agents of tree mortality closer to water (Van Wyk & Fairall 1969; Du Toit *et al.* 1990). However, when tree density is modelled for plants > 3 m high, a decrease away from the watering point is indicated (Figure 6.3). Therefore, the increase in tree density occurring after 2 km at both watering points (Figures 6.1 & 6.2) is due to an increase in woody plants between 2 - 3 m high. This increase can be ascribed to the presence of *Strychnos madagascariensis* and *Pterocarpus rotundifolius*, both of these species forming dense stands in deep sandy soils. The dominant *Combretum spp.* are also present in high numbers but only in the ≤ 3 m height class (Appendix: Table 1. 6). Results did therefore not support the expected decrease in large trees towards the water. This somewhat complicates interpretation of the possible effect of herbivory on trees around watering points.

Possible reasons for the higher tree (> 3 m) density closer to watering points could be due to the lower competition from the overutilized herbaceous layer, giving higher survival of woody plants and therefore better recruitment and higher density of trees. The effect of herbivores on woody plant biomass (ETTE) close to water is evident in the lower ETTE density closer to water even though a higher density of plants exist (Figures 6.1 & 6.2). Plants closer to the watering points have smaller canopies, which could be attributed to higher browsing pressure closer to water, even though this higher utilization does not lead to mortality.

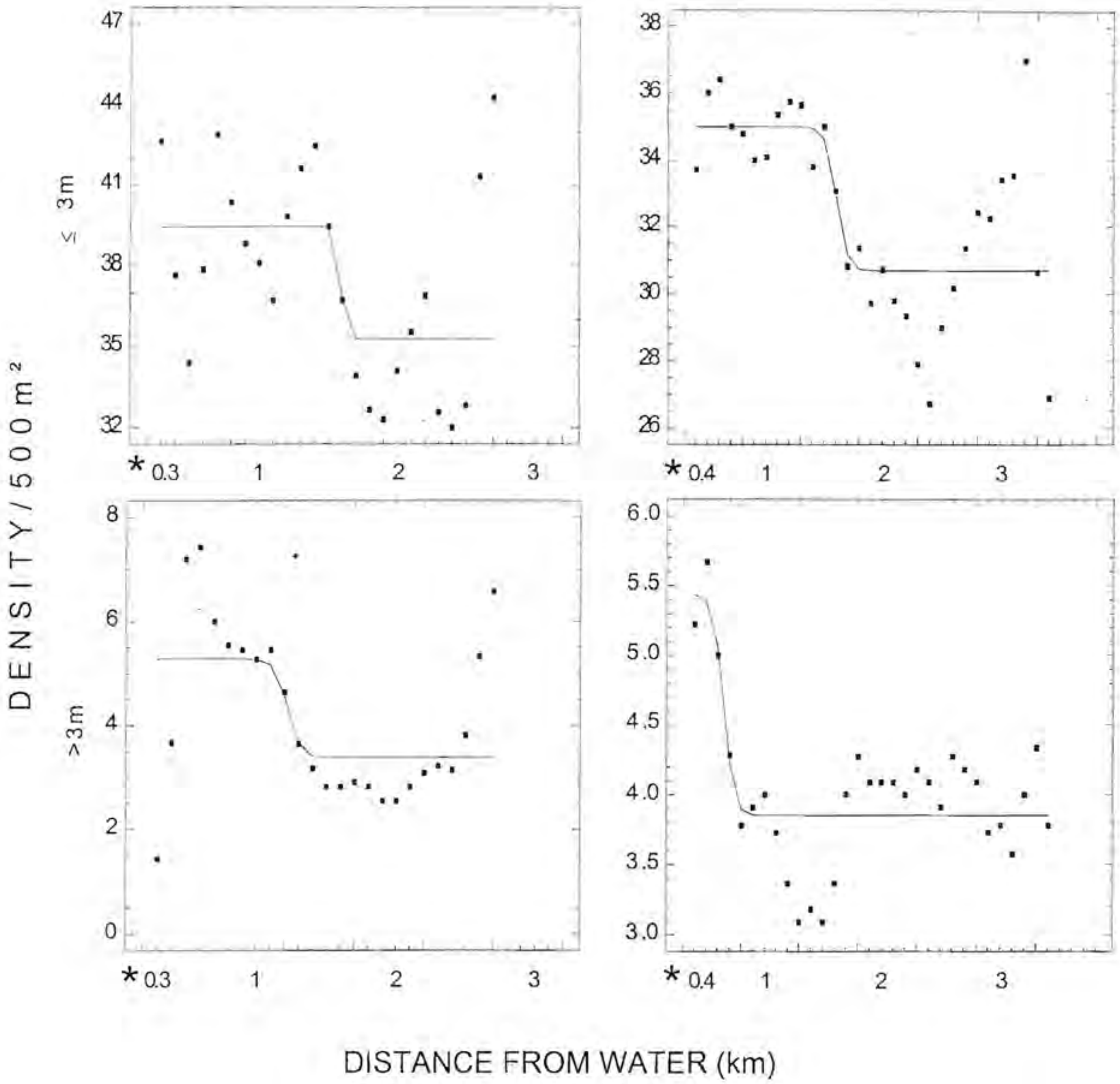

Figure 6.3 The shrub and tree density as a logistic function of distance from water at Timbiten (left) and Shiteve-teve (right). Shrubs ≤ 3 m are influenced the most by burning.

* = Watering Point

Table 6.4

Summary of relationships between structural variables and distance from water using the logistic equation on the Skukuza Land System in the Kruger National Park

WATERING POINT	VARIABLE	LOGISTIC EQUATION	r^2
Timbiten	Density $\leq$ 3 m	$y = 124.2 - 85.3 / (1 + e^{-7.1 + 0.2x})$	0.70
	Density > 3 m	$y = 8.9 - 7.3 / (1 + e^{6.9 + 0.6x})$	0.95
Shiteve-teve	Density $\leq$ 3 m	$y = 44.2 + 8.5 / (1 + e^{-13.3 - 2.8x})$	0.57
	Density > 3 m	$y = 2.4 - 2.6 / (1 + e^{135 - 5.6x})$	0.48

y = Density of variable / 500 m^2

x = Distance from water (m)

Trollope *et al.* (1998) found a negligible decline in the large tree population (canopy diameter >5 m) in the mixed *Combretum / Terminalia sericea* woodland (Gertenbach 1983) between 1940 and 1960. When the major increase in the elephant population occurred after 1960, there was a moderate to marked decline in the large tree population in this area. Eckhardt *et al.* (in press) showed a 15 % decrease in trees of > 5 m height in the same landscape. In both these studies the interaction of artificial watering points, high burning frequency and high elephant numbers were pointed out as possible contributing factors. The present study's results do not support the assumption that the decrease in large trees was caused by the presence of the watering points.

6.2 FOOTSLOPE AREAS

6.2.1 Results

The footslope areas at Timbiten and Shiteve-teve watering points were sampled and total density, shrub density, tree density and ETTE density calculated from the data. The sampling started at 500 m at Timbiten and 300 m at Shiteve-teve. The logistic curve successfully modelled the impact of distance from water on the structural variables (Tables 6.5 & 6.6).

At Timbiten total density and shrub density showed a low density close to the watering point with the highest density furthest from the water. Shrub density reached an upper asymptote at 1 200 m. The tree density and ETTE density showed the opposite trend (Figure 6.4) with both these variables reaching a lower asymptote at 1 800 m.

At Shiteve-teve all the variables showed the same relationship with distance from water i.e. a low density close to the water, with a range of increasing density and an upper asymptote being reached at 800 m for total density and shrub density and 1 800 m for tree density and ETTE density (Figure 6.5).

When the original data was tested with simple linear regression, tree density and ETTE density at Timbiten showed significant negative relationships with distance from water, although these relationships were not strong (Table 6.7).

6.2.2 Discussion

At Shiteve-teve the piosphere effect (Lange 1969; Graetz & Ludwig 1978) was indicated in the graphs of all variables examined (Figure 6.5). The first part of the logistic curve representing an area of higher impact that was described by Graetz & Ludwig (1978) as the sacrifice area. This area of higher impact extended up to 800 m from the watering point for total and shrub density and 1 800 m for tree and ETTE density. Total density at Timbiten did not show the piosphere effect (Figure 6.4), while shrub density showed the same trend found at Shiteve-teve, with the higher impact area extending up to 1 200 m from the watering point. Both tree and ETTE density showed a negative relationship with distance from water, with the lower asymptote being reached at 1 800 m (Figure 6.4).

The soils of the footslope areas have higher clay contents because of the leaching of clay minerals from the crest and midslope areas (Venter 1990). The vegetation differs from that of the crestal areas and the more palatable woody species grow in this area (Venter 1990). The trampling effect, higher utilization pressure of the more palatable species and higher competition from the herbaceous layer on clay soils are factors limiting the survival of woody plants on the footslope areas (Venter 1990; Trollope et *al.* 1998). The trampling effect and utilization pressure are inversely proportional to distance from water (Thrash *et al.* 1993) causing higher impact close to the watering point with less woody plants establishing close to water and increasing densities further from the water.

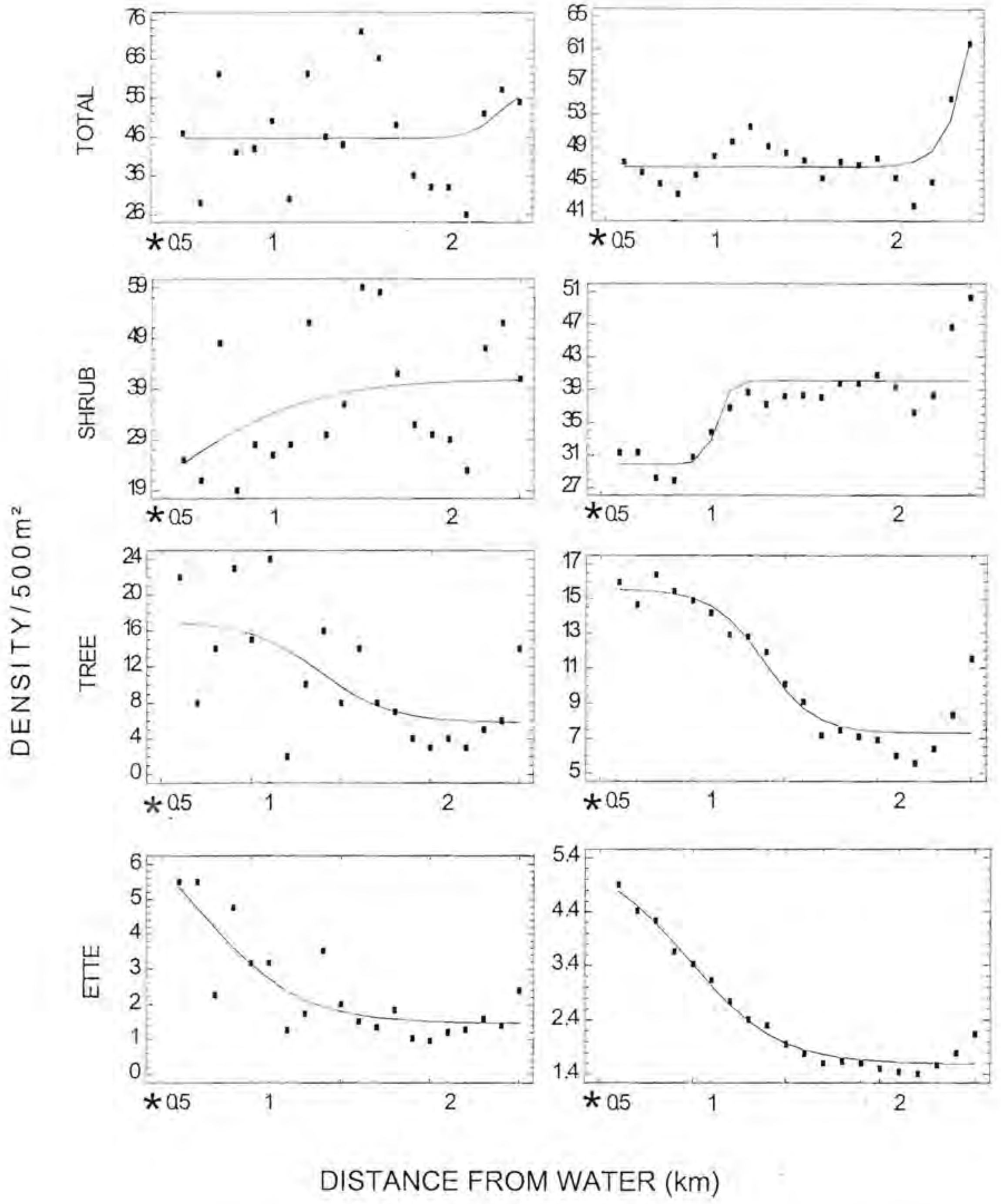

Figure 6.4 Structural variables as a logistic function of distance from water on the footslope areas at Timbiten. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 6.5

Summary of the relationships between structural variables and distance from water on the footslope areas at Timbiten on the Skukuza Land System in the Kruger National Park

TIMBITEN	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 45.6 + 12.9 / (1 + e^{24.6 + 1.3x})$	0.05
	Shrub Density	$y = 3.6 + 37.1 / (1 + e^{24.6 - 1.3x})$	0.17
	Tree Density	$y = 17.5 - 11 / (1 + e^{4.4 - 0.5x})$	0.41
	ETTE Density	$y = 7.8 - 6.3 / (1 + e^{0.8 - 0.4x})$	0.71
Smoothed data	Total Density	$y = 46.6 + 107.9 / (1 + e^{23.4 - 1.1x})$	0.67
	Shrub Density	$y = 40.3 - 10.2 / (1 + e^{-18 + 2.8x})$	0.66
	Tree Density	$y = 15.5 - 8.3 / (1 + e^{6.3 - 0.7x})$	0.89
	ETTE Density	$y = 5.4 - 3.8 / (1 + e^{2 - 0.4x})$	0.98

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

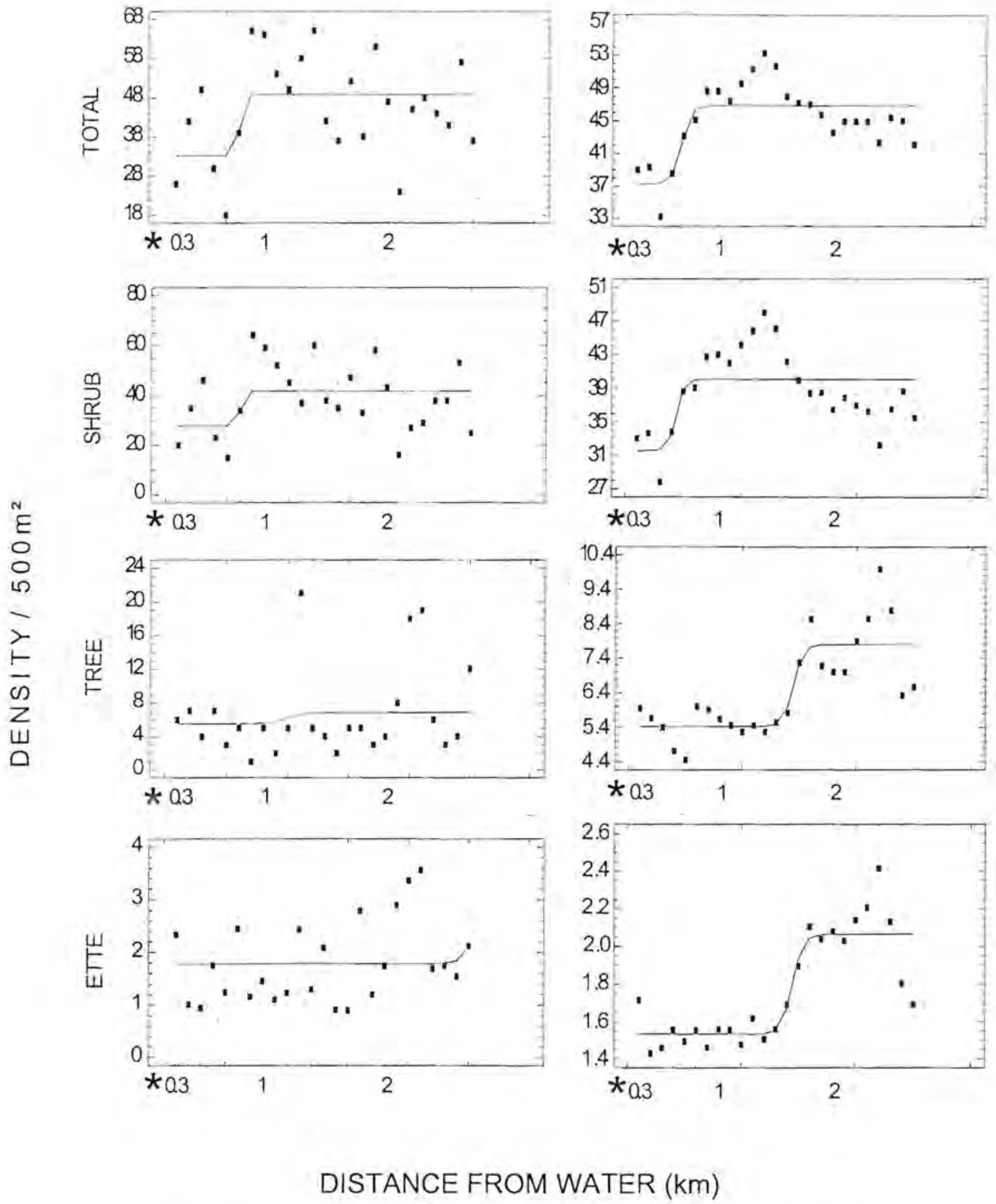

Figure 6.5 Structural variables as a logistic function of distance from water on the footslope areas at Shiteve-teve. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 6.6

Summary of the relationships between structural variables and distance from water on the footslope areas at Shiteve-teve on the Skukuza Land System in the Kruger National Park

SHITEVE-TEVE	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 33.1 + 15.6 / (1 + e^{68.1 - 11.2x})$	0.26
	Shrub Density	$y = 27.8 + 14.1 / (1 + e^{65 - 10.7x})$	0.18
	Tree Density	$y = 6.8 - 1.3 / (1 + e^{-14.2 + 1.4x})$	0.05
	ETTE Density	$y = 5.1 - 3.2 / (1 + e^{-48.9 + 1.8x})$	0.01
Smoothed Data	Total Density	$y = 46.8 - 9.6 / (1 + e^{-11.9 + 2.4x})$	0.60
	Shrub Density	$y = 40 -8.4 / (1 + e^{-14.1 + 3.2x})$	0.39
	Tree Density	$y = 7.7 - 2.3 / (1 + e^{-34 + 2.3x})$	0.68
	ETTE Density	$y = 2.1 - 0.5 / (1 + e^{-31.8 + 2.2x})$	0.79

y = Density of variable / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

Table 6.7

Linear regression analysis of structural variables on distance from water on the footslope areas of Skukuza Land System in the Kruger National Park

WATERING POINT	VARIABLE	EQUATION	*P* - value	r^2
Timbiten	Tree Density	$y = 17.68 - 0.68x$	0.006	0.17
	ETTE Density	$y = 4.2 - 0.17x$	0.00035	0.19

y = Structural Variable Density / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

The significant negative relationship between tree and ETTE density and distance from water at Timbiten (Table 6.6) could possibly be attributed to the difference in species composition at the two sites. *Combretum hereroense* is the dominant species at Timbiten (Appendix: Table 1.8) while *Albizia harveyi* dominates at Shiteve-teve (Appendix: Table 1.9). It is possible that the more tree like growth form of *C. hereroense* and the fact that it is less utilized by browsers than *Albizia harveyi*, allows the *C. hereroense* plants closer to the watering point to develop into trees.

6.3 GENERAL REMARKS

The results indicate that at watering points in the Skukuza Land System the impact of large herbivores on the woody vegetation can be adequately described by the logistic equation. The piosphere concept applies to the impact of large herbivores on woody vegetation at watering points. The initial zone of higher impact seems to radiate quite far from the watering point when compared to the 50 - 250 m sacrifice area found by Thrash (1993) for the herbaceous vegetation around watering points in the KNP. Van der Schijff (1959) described five zones in rangeland utilization around watering points in the KNP. The first zone extending up to 91 m from the trough, was trampled to dust and corresponds to the sacrifice area of Graetz & Ludwig (1978) & Thrash (1993), while the second zone extended to 1,6 km from the watering point and was grazed short and trampled. The third zone extended to 5 km from the watering point and was evenly grazed short, with the forth zone extending to 8 km grazed lightly and selectively. The range in the fifth zone, further than 8 km from the watering point, was utilized little or not at all by game during the dry season and accumulation of unpalatable material occurred. In this study the impact on shrubs extended from 800 to 1 200 m from the watering point on footslope areas and 2 000 m to 2 300 m on crestal areas, therefore the effect of large herbivores on woody vegetation (Figures 6.4 & 6.5) indicated in the graphs could possibly be compared to the second zone described by Van der Schijff (1959).

The existence of a double piosphere effect on the woody vegetation can be hypothesized (Van der Schijff 1959), where beyond the sacrifice area, another zone of high impact is descernable before the natural woody plant density is reached. Perkins & Thomas (1993a) found similar multiple zones of impact around cattlepost watering points in the Kalahari of Botswana.

However, since the watering points were placed in drainage lines, the sacrifice area as described by Van der Schijff (1959) and Thrash (1993) were not sampled for the specific catenal sequence. In other words, when referring to a specific catenal sequence, a zone of high impact was distinguished for that area specifically (Figures 6.1 & 6.2), where shrub encroachment takes place on the crestal area and similarly for the footslope area where shrub degradation and mortality occurs (Figures 6.4 & 6.5). But to avoid confusion as to when and where the definition of a sacrifice area should be applied, in this case a multiple piosphere effect is hypothesized, with a high utilization zone beyond the accepted sacrifice area.

CHAPTER 7

PHALABORWA LAND SYSTEM

The geology of the area consists mainly of granitoid rocks and it has a moderately to slightly undulating landform and scattered solitary koppies or inselbergs. *Colophospermum mopane* and *Combretum apiculatum* are the dominant trees on loam and clay soils, the latter preferring the shallow soils (Venter 1990). The crest and footslope areas cover 44 % and 34 % respectively of the total area and dominate this Land System (Venter 1990).

The two watering points sampled in this area, were Shivulani and Ledeboer. The logistic equation was fitted to the data to find a general model to describe the impact of large herbivores on woody vegetation structure around watering points. The sampling at Shivulani started at 200 m from the watering point and at Ledeboer at 500 m due to soil type changes over the first 500 m. Species and density data are indicated in the Appendix (Table 1.10 - 1.13)

7.1 CRESTAL AREAS

7.1.1 Results

At Shivulani all the variables showed a low density close to the water, with a range of increased density and an upper asymptote being reached at 1 300 m for total density, 1 400 m for shrub density and 500 m for tree density and ETTE density (Figure 7.1). If the points in the graphs of total and shrub density are assessed, it can be seen that over the first 400 m there was a higher density, not shown by the logistic curve.

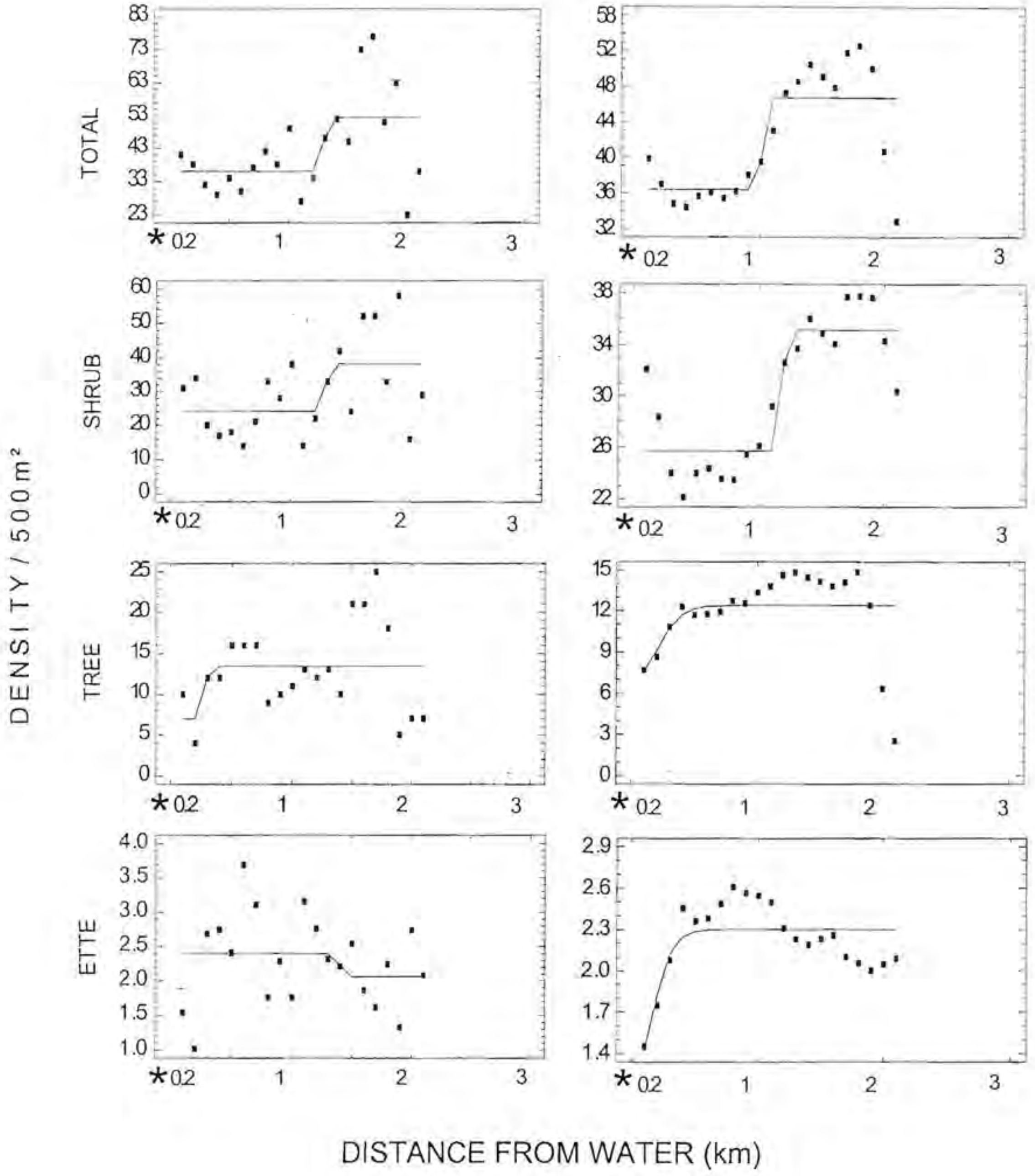

Figure 7.1 Structural variables as a logistic function of distance from water on crestal areas at Shivulani. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 7.1

Summary of the relationships between structural variables and distance from water on crestal areas at Shivulani on Phalaborwa Land System in the KNP

SHIVULANI	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 35.9 + 16.5 / (1 + e^{130 - 10.1x})$	0.33
	Shrub Density	$y = 24.1 + 14.1 / (1 + e^{121.9 - 9.4x})$	0.29
	Tree Density	$y = 7 + 6.4 / (1 + e^{43.3 - 14.8x})$	0.13
	ETTE Density	$y = 2.4 - 0.3 / (1 + e^{98.5 - 7.03x})$	0.06
Smoothed Data	Total Density	$y = 36.3 + 10.3 / (1 + e^{159.3 - 15.8x})$	0.60
	Shrub Density	$y = 25.7 + 9.5 / (1 + e^{142.6 - 11.9x})$	0.76
	Tree Density	$y = 12.4 - 6.2 / (1 + e^{-2.2 + 1.1x})$	0.16
	ETTE Density	$y = 2.3 - 1.2 / (1 + e^{-2 + 1.2x})$	0.57

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

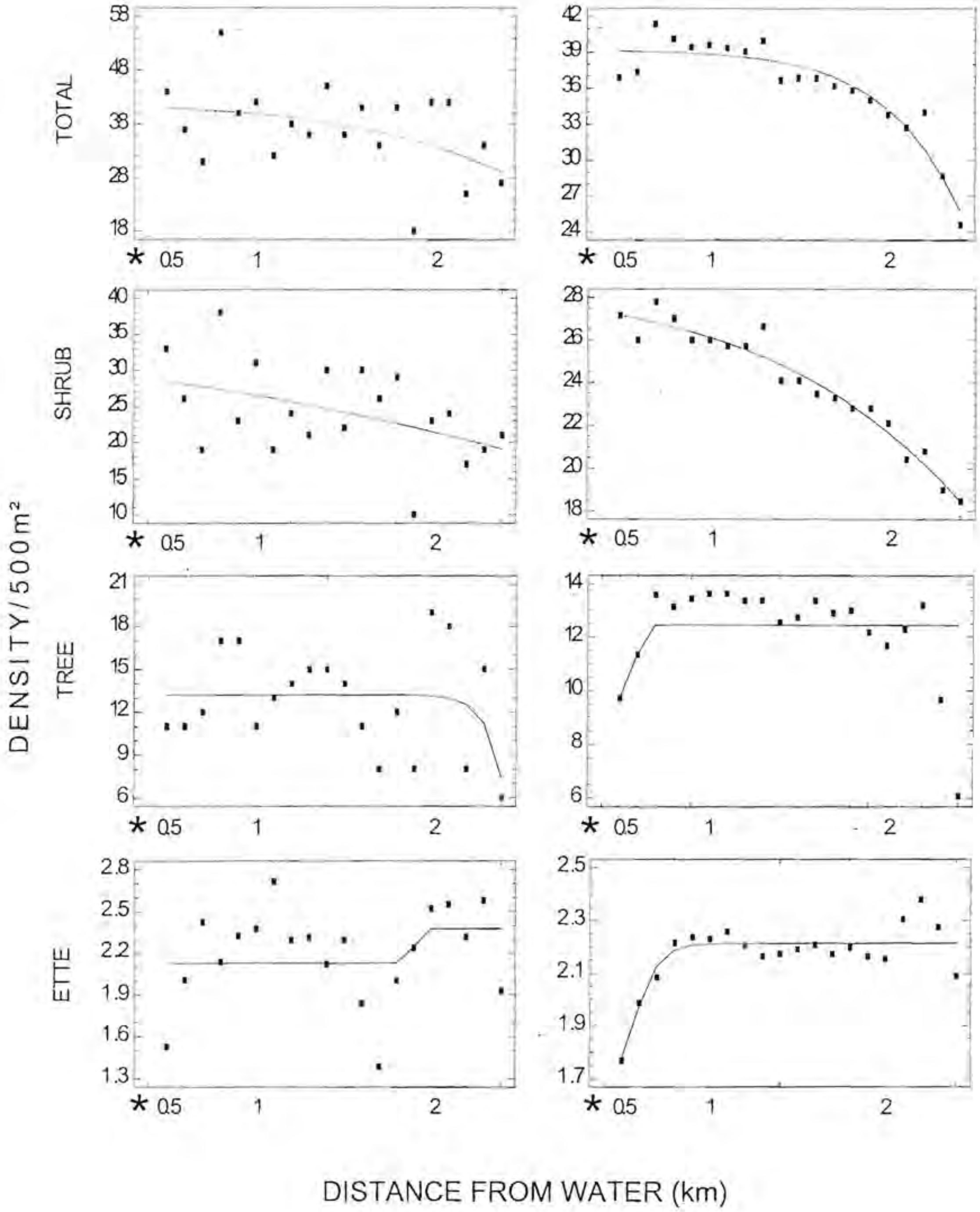

Figure 7.2 Structural variables as a logistic function of distance from water on crestal areas at Ledeboer. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 7.2

Summary of the relationships between structural variables and distance from water on crestal areas at Ledeboer on Phalaborwa Land System in the KNP

LEDEBOER	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 42 - 68.6 / (1 + e^{4.2 - 0.13x})$	0.20
	Shrub Density	$y = 38.6 - 146.7 / (1 + e^{2.6 - 0.03x})$	0.21
	Tree Density	$y = 13.2 - 30.8 / (1 + e^{15.3 - 0.68x})$	0.12
	ETTE Density	$y = 2.3 - 0.26 / (1 + e^{-109 + 7.2x})$	0.10
Smoothed Data	Total Density	$y = 39.2 -170.2 / (1 + e^{7.7 - 0.2x})$	0.89
	Shrub Density	$y = 28.5 - 55 / (1 + e^{3.7 - 0.1x})$	0.95
	Tree Density	$y = 12.4 - 2.7 / (1 + e^{-31.6 - 16x})$	0.71
	ETTE Density	$y = 2.2 - 0.6 / (1 + e^{-2.2 + 1.3x})$	0.76

y = Density of variable / 500 m^2

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

In contrast, at Ledeboer total density and shrub density showed a relationship of highest density close to the watering point and the lowest density furthest from the water and no asymptote being reached. Tree density and ETTE density showed the same trend found at Shivulani with the upper asymptote being reached at 800 m (Figure 7.2).

Linear regression analysis on original data showed that only shrub density at Ledeboer has a significant negative relationship with distance from water ($y = 29.37 - 0.48\ x$, where y = shrub density and x = distance from water; $r^2 = 20.5$; $P = 0.045$).

7.1.2 Discussion

Colophospermum mopane is a recognized encroacher, with shrubs < 1 m forming dense stands in cattle production (Smit 1994) and wildlife areas (Swart 1995). This species possesses the ability to compete with herbaceous plants due to a very superficial root system (Smit 1994). One would therefore expect an increase in mopane shrubs where overutilization of the herbaceous layer occurs because of the ability of mopane to out-compete shallow rooted plants. This encroaching ability of mopane should be evident around watering points in the KNP where sacrifice areas have been identified (Thrash 1998). However, mopane is also a species preferentially browsed by elephant (Swart 1995) and high utilization pressure close to watering points, could lead to a higher mortality and decline in density. Swart (1995) found a higher mopane shrub density in elephant utilized veld compared to elephant free control areas on Letaba Ranch in the Northern Province. The reason given was that elephants utilized the mopane shrubs (< 2 m) more and this caused coppicing from the roots, leading to an increase in density. Thrash *et al.* (1991) on the other hand, found that density and canopy cover of *Combretum apiculatum*, the other dominant woody species of the Phalaborwa Land System, was negatively influenced around the Wik-en-Weeg dam. The influence on *Combretum apiculatum* density and canopy cover showed a positive logarithmic relationship with distance from water. This meant that *Combretum apiculatum* trees were selectively damaged by elephants close to water, confirming results found by Van Wyk & Fairall (1969) and Guy (1976) on selective damage by elephants. This complicates the interpreting of spatial data where the woody vegetation is dominated by *Colophospermum mopane* and *Combretum apiculatum* and the main contributors to change in structure are elephants. This is indeed the case on the Phalaborwa Land System.

A constant feature on the crestal areas at both watering points, was the trend in tree density and ETTE density (Figures 7.1 & 7.2). This trend can be explained through the arguments raised above. The higher utilization pressure closer to the watering point, especially by elephants, causes a decrease in tree density and a decrease in biomass (ETTE). This impact occurred up to 500 m for Shivulani and 800 m for Ledeboer. The dominant tree species (> 2 m) at these watering points is *C. apiculatum,* which is selectively damaged by elephants close to water (Van Wyk & Fairall 1969; Thrash *et al.* 1991) and therefore a decline in tree density closer to watering points was observed.

The trend in shrub density found at Ledeboer (Figure 7.2) can be interpreted as an increase in shrub density (encroaching) towards the watering point. *Colophospermum mopane* being the dominant shrub species in this area, would increase closer to watering points due to the decrease in competition for moisture from the herbaceous layer (Trollope *et al.* 1989; Trollope *et al.* 1998) and the increased utilization of the < 2 m height class (Guy 1976; Swart 1995) by elephants, causing increased coppicing from the roots (Smit 1994). The effect of trampling, reduced competition and higher utilization pressure decreases away from the watering point and therefore also the shrub density. This encroachment around watering points could possibly be one of the factors leading to the increase in woody cover reported by Eckhardt *et al.* (in press) on the granitic soils.

In contrast, at Shivulani, encroaching of shrubs closer to the watering point did not occur (Figure 7.1). One possible factor that could influence the apparent different reaction to utilization, is the age of the watering point. Shivulani waterhole was opened in 1935 while Ledeboer was only opened in 1975, this constitutes a 40 year difference. The establishment of a piosphere in the herbaceous component does not take very long and according to Andrew & Lange (1986b) a piosphere pattern was evident for grass biomass after only three months in arid chenopod shrubland grazed by sheep. Jeltsch *et al.* (1997a) and Weber *et al.* (1998) indicated grazing thresholds at which woody vegetation cover increased in the Kalahari sandveld. At sustained threshold stocking rates no increase in cover occurred in the first 20 years, but after 50 years a marked increase in woody cover occurred. Woody vegetation therefore reacts much slower to utilization than the herbaceous layer.

The reaction of the woody vegetation to utilization pressure as depicted at Ledeboer (Figure 7.2) is possibly only the start of what has already taken place at Shivulani (Figure 7.1). The overall trend modelled at Shivulani by the logistic curve conformed to the piosphere effect. The sacrifice area extending up to 300 m showing an increase in shrub density due to higher *C. mopane* shrub density closer to the watering point. A zone of high utilization extending up to 1 300 m, having a low density and an increase in density occurring beyond this point. Because Shivulani was one of only a few watering points in 1935 (Pienaar *et al.* 1998), the utilization pressure and trampling was so high that even the resilient *C. mopane* could not survive close to the watering point. The higher density of watering points in later years caused a spread in utilization pressure and therefore the effect at Ledeboer will possibly develop slower and the difference between the two watering points could be attributed to the slower reaction due to lower grazing pressure. The same trends found at Ledeboer were shown at the Wik-en-Weeg dam by Thrash *et al.* 1991, with increasing density and canopy cover occurring in the first 1 000 m from the dam. These increases took place over time (1973-1990 = 17 years) and distance (from the dam) since the building of the dam. Jeltsch *et al.* (1997b) found the formation of distinct piosphere zones within less than 10 years in the higher rainfall (385 mm) areas of the Kalahari, with a woody encroachment zone occurring beyond the sacrifice zone. This means that woody density increases closer to the watering point over the first number of years and after ± 50 years this encroached area slowly deteriorates and forms a zone of high utilization beyond the recocnized sacrifice area.

7.2 FOOTSLOPE AREAS

7.2.1 Results

The footslope areas of Shivulani and Ledeboer watering points were sampled and structural variables calculated from the data. The logistic equation was then fitted to the data. The sampling at Shivulani started at 200 m and at Ledeboer at 100 m from the watering point. The footslope areas on the Letaba Land System are dominated by *Colophospermum mopane* shrubs, with *Combretum apiculatum* the only other frequent occurring species, although not in high numbers.

At Shivulani, total and shrub densities were high close to the watering point decreasing away from it with a lower asymptote being reached at 800 m from the watering point. The tree density and ETTE density showed the opposite trend (Figure 7.3) with the upper asymptote also being reached at 800 m . The model explained 36 % to 64 % of the variation when the smoothed data were used (Table 7.3).

All the variables at Ledeboer showed the same relationship with distance from water as did those at Shivulani. Total density and shrub density reaching a lower asymptote at 600 m and tree density and ETTE density reaching the upper asymptote at 600 m (Figure 7.4). When using smoothed data 35 % to 92 % of the variation was explained by the logistic model (Table 7.4).

When the original data were tested with linear regression analysis, none of the variables showed a significant relationship with distance from water.

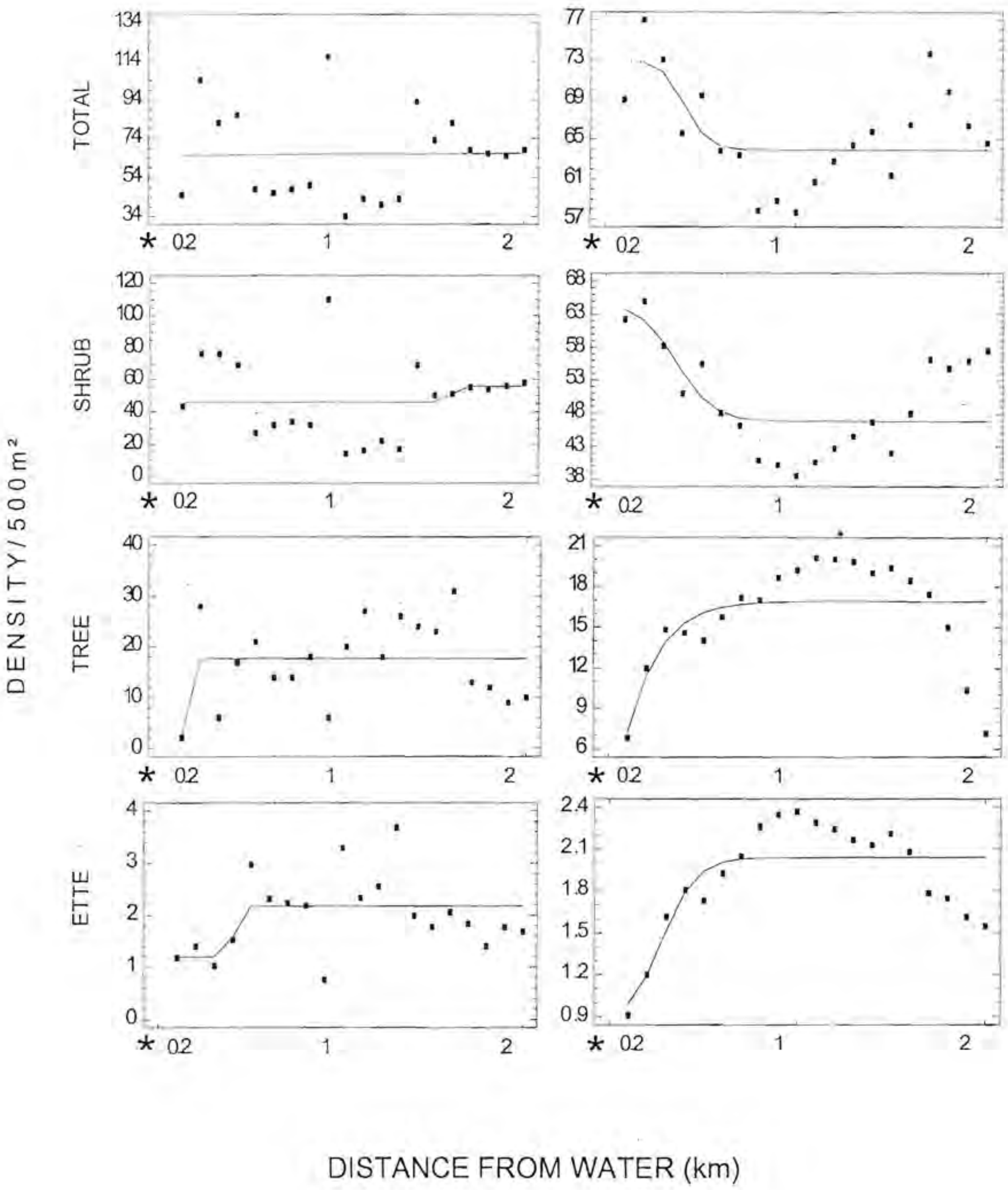

Figure 7.3 Structural variables as a logistic function of distance from water on footslope areas at Shivulani. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 7.3

Summary of the relationships between structural variables and distance from water on footslope areas at Shivulani on the Phalaborwa Land System in the Kruger National Park

SHIVULANI	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 62.9 + 22.1 / (1 + e^{-0.13 + 0{,}35x})$	0.02
	Shrub Density	$y = 55.7 - 9.9 / (1 + e^{-110.7 + 6{,}9x})$	0.03
	Tree Density	$y = 17.7 - 167.9 / (1 + e^{-1.7 + 4.03x})$	0.18
	ETTE Density	$y = 2.1 - 0.9 / (1 + e^{-21.6 + 5.3x})$	0.25
Smoothed Data	Total Density	$y = 63.9 + 9.1 / (1 + e^{-6{,}7 + 1{,}6x})$	0.38
	Shrub Density	$y = 46.8 + 17.9 / (1 + e^{-3.8 + 1{,}1x})$	0.47
	Tree Density	$y = 16.9 - 60.8 / (1 + e^{1 + 0{,}6x})$	0.36
	ETTE Density	$y = 2.1 - 1.1 / (1 + e^{-3.1 + 1{,}1x})$	0.64

y = Density of variable / 500 m²

x = Distance from water (m)

ETTE = Evapotranspiration Tree Equivalents

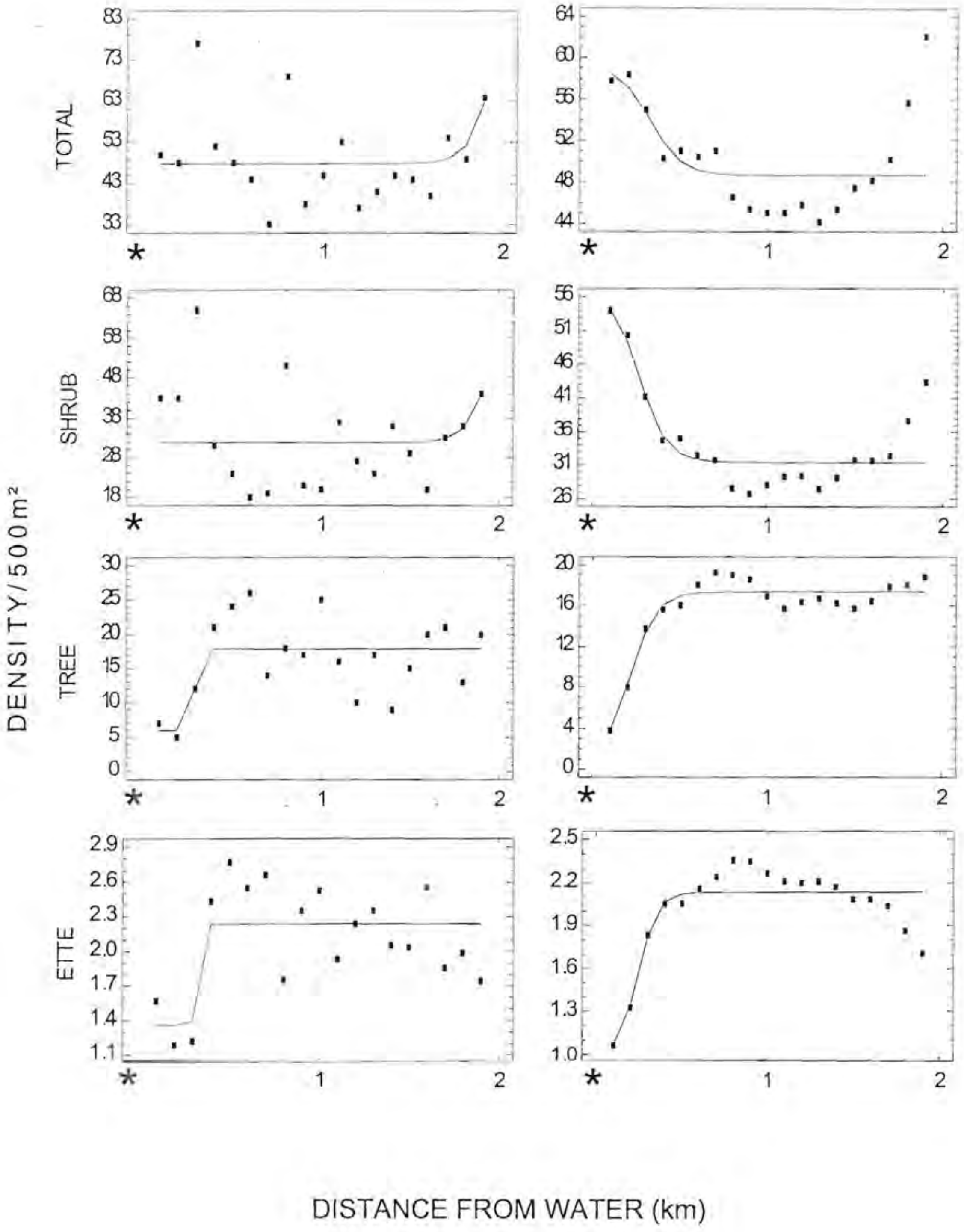

Figure 7.4 Structural variables as a logistic function of distance from water on footslope areas at Ledeboer. Original data on the left and smoothed data on the right.

ETTE = Evapotranspiration Tree Equivalents

* = Watering Point

Table 7.4

Summary of the relationships between structural variables and distance from water on footslope areas at Ledeboer on Phalaborwa Land System in the Kruger National Park

LEDEBOER	VARIABLE	LOGISTIC EQUATION	r^2
Original Data	Total Density	$y = 47.8 + 145 / (1 + e^{27.1 - 1.3x})$	0.11
	Shrub Density	$y = 31.7 + 106.8 / (1 + e^{27.2 - 1.3x})$	0.05
	Tree Density	$y = 17.8 - 11.8 / (1 + e^{-35.5 + 11.8x})$	0.42
	ETTE Density	$y = 2.2 - 0.8 / (1 + e^{-28.9 + 8.5x})$	0.54
Smoothed Data	Total Density	$y = 59.3 - 10.6 / (1 + e^{3.5 - 1.1x})$	0.35
	Shrub Density	$y = 57.1 - 25.7 / (1 + e^{3.3 -1.2x})$	0.75
	Tree Density	$y = 17.3 -16.6 / (1 + e^{-2.8 + 1.3x})$	0.92
	ETTE Density	$y = 2.1 - 1.1 / (1 + e^{-4.4 + 1.8x})$	0.80

y = Density of variable / 500 m²
x = Distance from water (m)
ETTE = Evapotranspiration Tree Equivalents

7.2.1 Discussion

The reaction of *C. mopane*, the dominant species on the footslope areas, to higher utilization pressure would be the same as found for the crestal areas. The increase in shrub density closer to the watering point could be due to the species ability to compete with the herbaceous layer, even in clayey soils and the coppicing effect in reaction to browsing. The decrease in tree density could be due to the higher utilization of trees closer to watering points by elephants and the impact of browsing on biomass (ETTE), keeping the woody plants in shrub form. It was evident that there was a lower biomass closer to the watering point even though there was an increase in shrub density.

Unlike the crestal areas, the difference in age of the watering points did not play a role in the reaction of the woody vegetation on the footslope areas. There is no evidence of a different reaction except that at Shivulani the radius of the sacrifice area extended further (Figures 7.3 & 7.4).

The similarity between the two watering points on the footslope areas could be attributed to the fact that the footslope areas consisted of clay soil and the crestal areas of sandy soils. The clay soils react faster to utilization because of the lower infiltration rate and uptake of water, causing changes in woody vegetation to occur faster. The sandy soils on the other hand react slower to utilization because of the capacity to store water in the deeper soil layers, giving the woody vegetation the ability to withstand utilization pressure (Trollope *et al.* 1998). The footslope area at Ledeboer therefore has already reached the stage of piosphere development found at Shivulani.

7.3 GENERAL REMARKS

The logistic equation successfully modelled the impact of large herbivores on the structure of woody vegetation around watering points in the Phalaborwa Land System although different stages in the development of the piosphere effect was evident. A high utilization zone beyond the sacrifice area can be hypothesized with the impact extending up to 800 m for watering points on clay soils and younger watering points (20 years; i.e. Ledeboer) on sandy soils. This zone extended up to 1 300 m for older watering points (60 years; i.e. Shivulani) on sandy soils (Figures 7.1 - 7.4). This high utilization zone beyond the sacrifice area forms part of a multiple piosphere effect evident around most watering points.

CHAPTER 8

GENERAL DISCUSSION AND CONCLUSIONS

A piosphere is a zone of attenuating stocking pressure radiating outwards from a watering point (Lange 1969). A gradient of utilization pressure develops which is greatest near the watering point and decreases as a function of distance from it (Graetz & Ludwig 1978). The piosphere effect is true for most grazing herbivores because water- dependent herbivores are forced to congregate within a maximum distance of about 10 - 15 km from watering points in the dry season (Van der Schijff 1957; Western 1975). The development of a grazing gradient which is inversely proportional to distance from water is therefore hypothesised for the Kruger National Park.

Thrash (1993, 1998) states that the provision of water for large herbivores in the KNP has a negative impact on herbaceous forage and fine fuel production potential, basal cover and standing crop. The logistic equation was found to be an acceptable general model of impact on the aforementioned parameters of the herbaceous vegetation. The equation successfully modelled the sacrifice area around the troughs, where only annual, pioneer plants occur; the transitional zones, where a rapid increase in annual and perennial species occur; and the zones beyond the direct influence of the trough, where perennial, climax species dominate. The radii of impact extended between 50 and 250 m from the watering points. Van der Schijff (1959) studied the rangeland surrounding watering points in the KNP before the water provision programme had gained momentum. He divided it into five zones according to utilization by game. The first zone, extending to about 91 m from the watering point was trampled to dust and corresponds to the sacrifice area found by Thrash (1998). The second zone extending to 1.6 km from the watering point was evenly grazed short and trampled. The third zone extending up to 5 km from the watering point was evenly grazed short. The forth zone extending up to 8 km from the watering point was lightly and selectively grazed. The range in the fifth zone, further than 8 km from the watering point, was utilized little or not at all by game during the dry season. The piosphere effect and grazing gradients were thus accepted for herbaceous vegetation surrounding watering points in the KNP. According to Thrash (1998), the first two zones recocnized by Van der Schijff (1959) constituted the sacrifice area around watering points in those years. Thrash (1998) then argue that the water provision programme seems to have achieved a wider even spread of rangeland use because he found that the impact only extended up to 250 m compared to the second zone of Van der Schijff (1959) that extended up to 1.6 km. This implies that areas not at all utilized by water-dependant herbivores during the dry season are almost non-existent in the KNP, therefore grazing capacity is now solely determined by the forage production of the vegetation.

Impalas are mixed feeders with a high rate of water turnover (Fairall & Klein 1984) and, in the KNP, are seldom found more than a few kilometres from surface water (Young 1972; Du Toit 1988). For this species a browsing gradient can be accepted but the other major browsing species, i.e. kudu, giraffe and elephant are deemed as less water-dependent (Du Toit *et al.* 1990). Unlike grass, woody foliage retains a high water content throughout the seasonal cycle, which enables African savanna browsers to be largely independent of surface water (Western 1975; Du Toit *et al.* 1990). Browsing pressure around artificial watering points, would therefore not necessarily follow the pressure gradient hypothesised in the piosphere concept. Du Toit *et al.* (1990) however, found that browsers in the central district of the Kruger National Park do concentrate around watering points and proposed a browsing-regrowth feedback loop that results in patches of highly palatable browse that attract further browsing. Seemingly water-independent species such as kudu and giraffe are therefore possibly attracted to watering points by the quality of their staple diet, *Acacia* foliage and not by the watering point itself. Belsky (1984) found that the impact of smaller browsers (impala, Grant's gazelle and Thomson's gazelle), though not dominant in the Serengeti, may be substantial in preventing woodland regeneration. Impala might also play an important role in influencing woody structure in the KNP. The only other species that significantly utilize woody vegetation are elephants. Elephants have been singled out as the primary agents of woody stratum change near surface water and the greatest damage to habitat is in the vicinity of rivers and permanent watering points (Anderson & Walker 1974).

Van Wyk & Fairall (1969) found that the utilization of woody plants by elephants in the KNP is inversely proportional to distance from water and the state of the grass cover. These factors all suggest the development of a browsing intensity gradient which is highest close to the watering point, decreasing away from it.

Most browsers will take off, at the most, a few branches when feeding, with elephants being the only browser that can uproot a whole shrub. Browsing animals therefore primarily influence the biomass of woody vegetation, rather than the density. The browsing intensity gradient that is hypothesized around artificial watering points, implies that more browsing is done closer to watering points. If a browsing intensity gradient is demonstrated around artificial watering points, this should result in an area of lower biomass closer to the watering point, with biomass increasing with distance from the watering point due to the decreasing browsing pressure.

The results from this study showed that at most of the watering points on all Land Systems the biomass (ETTE) in the areas close to watering points was negatively influenced. The area of influence extended between 500 m (Figure 5.1) and 2 300 m (Figure 6.2). The only clear exceptions being the watering points on the Satara Land System and Nkolobeni-South on the Letaba Land System. The higher biomass close to the watering points on the Satara Land System could however be explained by the reaction of the dominant species (*A. nigrescens*), to higher browsing intensities and the lack of fire effect compared to the areas further from the watering point (see Chapter 4). The trend found at Nkolobeni-South could be explained by the influence of large trees on ETTE estimates in shrub dominated areas (Chapter 5). The trends found in biomass (ETTE) at artificial watering points, indicate that a browsing intensity gradient does exist around artificial watering points in the KNP, which is greatest closer to the watering point and decreases with distance from the point. If the results on biomass impact are extrapolated for all watering points, using 800 m as mean impact distance, the vegetation within 3 % of the KNP is being affected. When the maximum distance of 2 300 m is taken this increases to 22.9 % of the KNP.

The change in biomass is associated with the change in other structural parameters i.e. shrub density and tree density. The trends found in biomass and the other structural variables used in this study can however not always be directly linked to the effect of a browsing intensity gradient around watering points. Other effects, such as high grazing pressure and trampling also influence the structure of woody vegetation.

On the eastern basaltic soils of the Satara and Letaba Land Systems the trend modelled for shrub density at watering points were consistent at all the points except one (Hartbeesbult). The impact caused by large indigenous herbivores was one of low shrub density close to the watering point with increasing density away from the watering point (Figures 4.1, 4.2, 5.1 & 5.3). The exception i.e. Hartbeesbult (Figure 5.2) could be explained by the densification effect of *C. mopane* plants in the 0.5 m height class (see Chapter 5). The impact of large herbivores on trees gave variable results in these Land Systems. However, in all cases the points in the graphs indicated a lower density close to the watering points. This should point to a high browsing pressure close to the watering point, decreasing with distance from it.

However, the high browsing pressure close to watering points, most probably is not the only cause of shrub mortality in the high utilization zone. The effect of trampling also plays an important role in woody seedling mortality. The encroachment of the 0.5 m height class on the Letaba Land System (Figure 5.4) is probably the result of lower competition from herbaceous plants close to the watering point. Thus, the impact of herbivores on woody vegetation in the vicinity of watering points should not only be ascribed to browsers alone but also includes the effects of trampling and severe grazing pressure from all large herbivores.

Three studies done in the KNP showed that on the southern basalt areas there was a marked decline in big trees. Viljoen (1988) reported a 93.4% decrease in large trees (> 5 m) in the *Sclerocarya birrea/ Acacia nigrescens* landscape (Gertenbach 1983) between 1944 and 1981 (37 years), with the major decline occurring after 1965. Trollope *et al.* (1998) showed a marked decline in large trees (> 5 m) on this landscape between 1960 an 1989. This correlates with the marked increase in elephant numbers occurring between 1963 (3 000) and 1970 (8 500) (Whyte *et al.* 1999), the three yearly burning policy being implemented between 1957 and 1992 (Van Wilgen *et al.* 1998), and the major thrust in the water provision programme between 1960 and 1969 (Pienaar *et al.* 1998). Elephants and fire were pointed out as the two strong driving forces affecting woody structure in savanna areas. Eckhardt *et al.* (in press) showed a decrease of 64% in woody cover (trees and shrubs) on the basalt areas between 1940 and 1998. Fire and herbivory (elephants) were once again pointed out as driving forces in this change.

The severe changes in the large tree population of the basaltic plains area are a cause for concern. Over most of the KNP, surface water is less than 7 km apart in the dry season (Pienaar *et al.* 1998), making the whole area available to water-dependent herbivores (Van der Schijff 1957; Western 1975). The distance of impact i.e. 2 800 m for shrub density, found at watering points on the Satara Land System (Figures 4.1 & 4.2), shows that the impact of high grazing and browsing pressures around watering points, could have influenced a large area and formed part of the decline in large trees. However tree density trends found at watering points in the present study were not strong (Tables 4.1 & 4.2). At this stage it can therefore not be concluded that the provision of artificial water and the grazing and browsing gradients accompanying artificial watering points plays a major role in the declines shown by Trollope *et al.* (1998) and Eckhardt *et al.* (in press).

The impact of large herbivores on the woody vegetation of the granitic soils on the western side of the KNP showed differing trends. On the crestal areas of the Skukuza and Phalaborwa Land Systems shrub encroachment took place close to the watering point (Figures 6.1, 6.2 & 7.2). There was one exception, Shivulani, that showed the opposite trend. The fact that this watering point is 30 years older than any of the others and was possibly subjected to higher utilization pressure, could be given as reason (Figure 7.1). The tree densities showed the opposite trend to shrub density with a decline in tree density occurring close to the watering point. The encroachment found on the crestal areas could be due to the lower competing ability of the overutilized grass layer giving shrubs a better chance to establish, while the impact on trees should be because of higher browsing pressure.

Trends in shrub density in the footslope areas differed between Land Systems. In the Skukuza Land System a decrease in shrub density was recorded close to the watering point (Figures 6.3 & 6.4), while in the Phalaborwa Land System encroachment of shrubs occurred (Figures 7.3 & 7.4). These opposing trends could be ascribed to the different species growing on footslope areas and their reaction to the conditions found in the high utilization area close to the watering point. More palatable and less browse resistant species grow on the footslope areas of the Skukuza Land System and therefore, because of the higher browsing pressure, a decline takes place closer to the watering point. On the footslopes of the Phalaborwa Land System the dominant species is *Colophospermum mopane* and this species is known to encroach where the grass layer is depleted under high utilization pressure (see Chapters 5 & 7). The trend modelled for tree density was one of lower density close to the watering point due to high browsing pressure, except at Timbiten on the Skukuza Land System where the different reaction of *Combretum hereroense* could be singled out.

On granitic soil types it can be concluded that different plant species react differently to high utilization pressure. As a result, the effect large herbivores have on the woody vegetation at artificial watering points, depends on the species composition of the vegetation and generalizations are not always possible.

When the granitic area as a whole is assessed, it is clear that a zone of higher utilization occurs around all watering points. The effect depends mainly on species and soil differences between crestal and footslope areas.

Eckhardt *et al.* (in press) found a significant increase in woody cover over time (1940 - 1998) on the granitic soils in the KNP. The major contributor to this increase was thought to be woody individuals < 5 m high. Trollope *et al.* (1998) found a moderate to marked decline in the large tree population on the Mixed *Combretum / Terminalia sericea* woodland (Gertenbach 1983) after 1960, when the major increase in the elephant population occurred. Eckhardt *et al.* (in press) showed a 15 % decrease in trees > 5 m on the same landscape. In both these studies the interaction of artificial watering points, high burning frequency and high elephant numbers were pointed out as possible primary causes for these changes. The slower reaction of the large trees to utilization on the granitic soils, compared to basaltic soils, was ascribed to the higher competing ability of trees on sandy soils due to the higher water availability in deeper soil layers (Trollope *et al.* 1998).

The increase in the < 5 m class found by Eckhardt *et al.* (in press) indicates that the tall woodland is being converted to a shrubland. The results from this study showed an increase in woody plants < 3 m high (Figure 6.3), due to lower competition from the herbaceous layer close to the watering point. This could possibly contribute to the increase found in the < 5 m class, especially since the encroached zone extends up to 1 600 m (Figure 6.3) from the watering point. However, once again the existence of the watering points can not be pointed out as the primary cause for the increase in < 5 m plants found by Eckhardt *et al.* (in press).

Thrash (1998) found that the radii of impact around watering points in the KNP extended up to 250 m and stated that this area incorporated both the sacrifice area and the transitional area described in the piosphere concept by Lange (1969). Van der Schijff (1959) found that the area around watering points were grazed short and trampled up to 1.6 km from the watering point. Five of the watering points sampled were opened between 1962 and 1964 (Mananga, Tihongonyen, Nkolobeni-South, Timbiten and Shiteve-teve), with three between 1971 and 1975 (Shibotwane, Hartbeesbult and Ledeboer) and one in 1935 (Shivulani). Thrash (1998) states that the expansion of the water provision programme achieved a better spread in rangeland use and that when his study was conducted in early 1990's the impact on the herbaceous layer only extended up to 250 m compared to the 1.6 km found by Van der Schijff (1959). This more even spread in utilization should then also apply to the browsers, which in fact are less water-dependent. This would mean that the effect of lower competition from the herbaceous layer and the accompanying shrub encroachment would only occur up to 250 m from the watering point. However, in the present study, even at points sampled by Thrash (1993), a browsing intensity gradient was proven of which the impact on biomass (ETTE) extended between 500 m and 2 300 m from the watering point. This can be interpreted in two ways, firstly that the browsing impact extends further than the grazing impact around watering points, or that the impact on the herbaceous vegetation around older (1960's) watering points extended up to 1.6 km as found by Van der Schijff (1959), with the accompanying effect on woody vegetation still evident today. Jeltsch *et al.* (1997a) found that in the Kalahari the piosphere effect would still be evident 100 years after closing down the watering point and that no change in the shrub encroachment zone would be evident. It is unlikely that the impact on woody vegetation found around watering points would be due to browsing alone. In the Skukuza Land System shrub encroachment occurred up to 2 200 m from the watering point (Figure 6.2). Shrub encroachment on sandy soils, is most likely to occur where the grass layer has been depleted and the lowered competition enables the woody plants to establish. Trends in woody vegetation found around watering points in the present study therefore correlate better with the results on herbaceous vegetation found by Van der Schijff (1959). Therefore, the age of watering points could possibly explain some of the variation found at watering points.

Jeltsch *et al.* (1997a) and Weber *et al.* (1998) indicated sustained threshold stocking rates in the Kalahari at which no increase in cover occurred in the first 20 years, but after 50 years a marked increase in woody cover occurred. The piosphere effect in woody vegetation in KNP would possibly also take longer to establish than in herbaceous vegetation. When the watering points in the different age groups (1935; 1960's; 1970's) are assessed, it can be seen that at most watering points piospheres have been established for biomass with some indication of the piosphere effects evident for most other parameters. Trends modelled for most of the parameters show different stages of piosphere development. The fact that the piosphere effect was evident for biomass, possibly shows that in savanna areas with higher rainfall the woody vegetation reacts faster to utilization around watering points than in more arid Kalahari.

One interesting observation is the difference in trends modelled for shrub density. On most of the clay soils in the KNP, piospheres have developed around watering points, possibly due to the faster reaction time on clay soils, due to lower availability of water to the woody vegetation and higher competition from the grass layer. On the sandy soils there seems to be a clear difference between the younger (Figures 6.1, 6.2 & 7.2) and older watering points (Figure 7.1). Shrub encroachment occurred close to the younger watering points, declining with distance, while at the older watering point a shrub density directly proportional to distance from water was modelled. The encroachment at younger watering points is due to the impact on the herbaceous vegetation, not due to direct utilization from browsers. While at the older watering point the constant utilization of the woody vegetation by browsers over time has caused a decrease in shrubs closer to the watering point. This trend was also found at the older watering point (Figure 4.1) on the clay soils of the Satara Land System. It can be hypothesized that over the first 30 years shrub encroachment occurs close to watering points followed by a decline in density under a constant browsing/ grazing pressure over the next 30 years.

The logistic equation satisfactory models the impact of large indigenous herbivores on parameters of woody vegetation structure as a function of distance from water in the KNP. The shape of the curve varies with utilization pressure and soil types and depends on the dominant woody species of the area.

These results indicate that the practice of providing artificial water in the form of troughs at windmills in the KNP causes the formation of a multiple piosphere effect with the existence of a zone of high utilization in woody vegetation beyond the sacrifice area described by Thrash (1993, 1998). This high utilization zone did not extend further than

600-800 m at two watering points on the Letaba Land System and the footslope areas of the Phalaborwa Land System, while in most other cases, it extended much further, even up to 2 800 m on the Satara Land System.

If the results of these all these models are extrapolated for all watering points, using 1 200 m as mean impact distance, the vegetation within 6.5 % of the KNP is being affected by the sacrifice area and higher utilization zone.

Recommendations

This study should primarily be seen as an inventory study and should be repeated in 10 years time. This would enable one to keep the effect of fire and herbivory (elephants) constant and the effect of the watering point itself, if any, should come to the fore.

The Kruger National Park has recently revised their water provision programme. It is perceived that the revised policy will assist in the restoration of intrinsic biodiversity at the landscape level through the simulation of natural availability of water (Pienaar *et al.* 1998). According to certain ecological principles, criteria for the evaluation of artificial watering points were drawn up and 132 watering points are scheduled for closure.

This will influence the impact of the sacrifice and high utilization zones over the entire KNP. This should reduce the total area impacted through higher utilization pressure around watering points from 6.5 % to 3.5 % of the KNP (1 200 m as mean distance), although one could get a greater impact and growth in the piosphere effect at the remaining watering points.

Monitoring the woody vegetation around the closed points is of essence, since possible timescales in reclaiming of the piosphere could be researched. In their simulations, Jeltsch *et al.* (1997a) found that after 100 years only the sacrifice area recovered and that no effect was evident in the encroached woody vegetation around watering points in the Kalahari. The comparison over time of closed and open watering points will give valuable insight into the recovery rate of the vegetation around artificial watering points, if any.

The age of watering points and the differences in reaction to impact by herbivores is also a point of interest and watering points of differing age should be sampled to see how long it takes before negative impact such as bush encroachment sets in.

ECOLOGICAL IMPACT OF LARGE HERBIVORES ON WOODY VEGETATION AT SELECTED WATERING POINTS IN THE KRUGER NATIONAL PARK

by

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SUMMARY

The Kruger National Park is situated in the Lowveld of Mpumalanga and the Northern Province, along the north-eastern boundary of South-Africa. It measures approximately 350 km from north to south and 65 km from east to west and covers an area of 1 948 528 ha.

The lack of quantitative data, on the impact of large herbivores on woody vegetation structure around watering points in the KNP, necessitated an in depth study of this aspect. The purpose of the study was firstly, to serve as an inventory study and secondly, to model the impact of large herbivores on the woody vegetation around artificial permanent watering points.

A diverse assemblage of igneous, sedimentary and metamorphic rocks, which covers a timescale of more than 3 000 million years, occurs within the borders of the KNP.

Sampling sites were selected to represent four combinations of high and low rainfall and two rock types. These areas constitute the largest land systems of the KNP.

By means of the BECVOL computer programme, certain structural variables related to woody structure were calculated. The structural variables chosen were total density (all woody individuals), tree density (woody individuals > 2 m), shrub density (woody individuals ≤ 2 m) and ETTE (Evapotranspiration Tree Equivalents).

The logistic curve and a third order polynomial curve were fitted to the data using non-linear regression analysis. The aim of fitting these curves was to find a model to describe impact of large herbivores on the structure of the woody vegetation around artificial watering points. In general, the logistic equation described the relationships between structural variables and distance from water better than the polynomial equation.

The logistic equation satisfactory models the impact of large indigenous herbivores on parameters of woody vegetation structure as a function of distance from water in the KNP. The shape of the curve varies with utilization pressure and soil types and depends on the dominant woody species of the area.

A browsing intensity gradient was hypothesised for woody vegetation around artificial watering points in the KNP. At most watering points on all land systems the biomass (ETTE) in areas close to watering points was negatively influenced. The zone of influence extended between 500 m and 2 300 m. This means that at a mean impact distance of 800 m, 3 % of the KNP is impacted by large herbivores around watering points.

On the eastern basaltic soils of the Satara and Letaba Land Systems the impact caused by large indigenous herbivores was one of low shrub density close to the watering point with increasing density away from the watering point. This trend modelled for shrub density at watering points was consistent at all the points, except one.

The impact of large herbivores on the woody vegetation of the granitic soils on the western side of the KNP showed differing trends. On the crestal areas of the Skukuza and Phalaborwa Land Systems shrub encroachment occurred close to the watering point. When the granitic area as a whole is assessed, it was clear that a zone of higher utilization occurred around all watering points. The effect depended mainly on species and soil differences between crestal and footslope areas.

From the results, it can not be concluded that the provision of artificial water and the accompanying grazing and browsing gradients, play a major role in the decline of large trees in the KNP.

Monitoring the woody vegetation around the closed points is of essence, the study should be repeated in 10 years time. This would enable one to keep the effect of fire and herbivory (elephants) constant and the effect of the watering point itself, if any, should come to the fore.

EKOLOGIESE IMPAK VAN GROOT HERBIVORE OP DIE HOUTAGTIGE PLANTEGROEI BY GESELEKTEERDE WATERPUNTE IN DIE NASIONALE KRUGERWILDTUIN

deur

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OPSOMMING

Die Nasionale Krugerwildtuin (NKW) is in die Laeveld van Mpumalanga en die Noordelike Provinsie geleë en vorm die noord-oostelike grens van Suid-Afrika. Die wildtuin is bykans 350 km van noord na suid en 65 km van oos na wes en beslaan 'n oppervlakte van 1 948 528 ha.

Die gebrek aan kwantitatiewe inligting aangaande die impak van groot herbivore op die houtagtige plantegroei van die NKW, het 'n studie oor hierdie aspek nodig gemaak. Die doel van die studie was eerstens, om as 'n inventaris te dien en tweedens, om die impak van groot herbivore op die houtagtige plantegroei rondom kunsmatige waterpunte te modelleer.

Binne die grense van die NKW kom 'n diverse samestelling van stollings, sedimentêre en metamorfiese gesteentes voor. Monsterpersele is geselekteer dat die grootste

landsisteme van die NKW verteenwoordig is. Persele is uitgeplaas in vier kombinasies van hoë en lae reënval en twee geologiese gesteentes.

Die BECVOL rekenaarprogram is gebruik om sekere strukturele veranderlikes van die houtagtige plantegroei te bereken. Die strukturele veranderlikes wat in ag geneem is, was totale digtheid (alle houtagtige individue), boomdigtheid (houtagtige individue > 2 m), struikdigtheid (houtagtige individue ≤ 2 m) en ETTE (Evapotranspirasie Boomekwivalente).

Die logistiese kromme en 'n derdegraadse polinomiese kromme is gepas deur middel van nie-lineêre regressie-analise. Die doel met die passing van hierdie krommes was om 'n model te vind wat die impak van groot herbivore op die struktuur van die houtagtige plantegroei om waterpunte kon beskryf. Oor die algemeen het die logistiese vergelyking die verhoudings tussen strukturele veranderlikes en afstand vanaf water beter as die polinomiese vergelyking beskryf.

Die impak van groot herbivore op veranderlikes van die houtagtige plantegroei in die NKW, as 'n funksie van afstand vanaf water, word bevredigend deur die logistiese vergelyking beskryf. Die vorm van die kromme varieer met die benuttingsdruk, grondtipes en die dominante houtagtige spesie van die gebied.

'n Gradiënt in die blaarbenuttingsintensitiet is gehipotiseer vir die houtagtige plantegroei rondom waterpunte in die NKW. Die biomassa (ETTE) op alle landsisteme is negatief beïnvloed in die gebied naby die waterpunt. Die gebied wat beïnvloed is, strek tussen 500 m en 2 300 m vanaf die waterpunt. Dit beteken dat 3 % van die NKW deur groot herbivore, wat saamdrom rondom kunsmatige waterpunte, beïnvloed word.

Die impak van groot herbivore op struikdigtheid rondom waterpunte op die basaltgronde van die Satara- en Letaba-landsisteme was een van lae struikdigtheid naby die waterpunt met 'n toename verder weg van die waterpunt. Met die uitsondering van een punt was hierdie tendens konstant by alle waterpunte.

Die impak van groot herbivore op die houtagtige plantegroei van die granietgronde van die westelike deel van die NKW het verskillende tendense getoon. Struikverdigting het naby die waterpunte op die kruingedeeltes van die Skukuza- en Phalaborwa-landsisteme plaasgevind. Wanneer die westelike granietgedeelte as geheel ondersoek word, is dit duidelik dat 'n gebied van hoër benutting rondom alle waterpunte voorkom. Die effek van die hoër benutting hang van die plantspesiesamestelling af en grondverskille tussen die kruin- en voethanggedeeltes.

Uit die resultate van die huidige studie, kan nie bewys word dat die afname in groot bome in die NKW veroorsaak is deur die teenwoordigheid van kunsmatige waterpunte en die bewiedings- en blaarbenuttingsgradiënte wat dit veroorsaak nie.

Monitering van die houtagtige plantegroei rondom waterpunte is van absolute belang, die studie behoort oor 10 jaar herhaal te word. Die effek van vuur en herbivoor benutting sal dan konstant bly en die impak van die teenwoordigheid van die waterpunt self sal dan na vore kom.

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APPENDIX

Appendix: Table 1.1

Mananga Species list

Number of individuals per 100 m interval

Acacia nigrescens	1	1	23	6	1	2	2	8	4	1	4	8	9	2	8	17	4	7	7	1	10	8	5	2	6	16	8	11	4	4	31	6	6	22	13	18	9	7	9	12	3	6
Cordia monoica	2	2	2	1	5	8	8	3	9	15	3	3	8	3	0	2	12	16	7	12	13	10	3	7	9	9	2	2	6	6	11	22	28	31	10	6	5	0	11	3	0	1
Dichrostachys cinerea	1	10	1	2	5	1	2	3	5	2	0	1	3	0	0	4	1	1	0	0	4	0	1	1	2	0	0	5	3	7	10	23	18	9	3	0	5	46	3	23	0	1
Flueggea virosa	2	0	1	1	0	0	3	5	0	0	0	0	0	4	1	0	4	2	2	4	2	0	5	1	1	1	0	0	0	1	0	0	3	0	2	2	2	0	2	0	1	0
Sclerocarya birrea	2	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	1	0	0	0	0	1	0
Boscia foetida	1	0	0	2	0	3	3	0	0	0	0	1	0	2	0	0	0	0	2	0	0	0	0	4	0	3	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Acacia tortilis	1	1	0	1	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Combretum imberbe	0	2	0	3	0	1	0	2	0	0	0	1	3	2	5	4	2	0	1	1	2	4	1	5	6	2	1	0	3	3	1	2	0	0	1	1	3	3	2	15	2	8
Commiphora africana	0	12	2	1	2	0	0	0	0	0	4	11	4	0	0	0	7	4	1	3	0	3	1	0	0	0	1	0	6	0	0	0	2	0	0	0	0	0	0	1	0	0
Grewia bicolor	0	2	1	4	1	4	1	1	1	2	2	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	0	3	0	0	0	0	0	0	0
Ximenia caffra	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albizia harveyi	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ormocarpum trichocarpum	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	6	1	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	31	3
Lonchocarpus capassa	0	0	2	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Combretum mossambicense	0	0	0	0	2	3	0	0	0	1	2	0	0	3	0	0	0	2	0	0	4	0	0	0	0	0	0	0	0	0	0	11	1	1	0	0	1	0	1	0	1	0
Olax dissitifolia	0	0	0	0	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0
Gymnosporia buxifolia	0	0	0	0	0	5	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Acacia exuvialis	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	2	0	0	1	3	3	7	0	0	0	4	2	0	0	0	2	1	2	0	0	1	1	1	2
Dalbergia melanoxylon	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Combretum collinum	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhus queinzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0

Appendix: Table 1.2
Sibotwane Species list

Number of individuals per 100 m interval

Acacia tortilis	1	0	2	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grewia bicolor	1	0	0	0	0	0	0	0	0	0	0	0	0	4	4	2	1	0	0	0	0	1	0	0	0	0	0	0
Acacia welwitschii	1	3	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	0	0	1	1	3	3	3	9	6	8	4	6	1	3	7	6	4	3	8	10	8	1	4	6	5	8	20	66
Dichrostachys cinerea	0	0	0	3	2	2	2	4	1	9	3	16	4	9	1	13	17	12	3	0	2	1	1	16	0	26	1	6
Combretum imberbe	0	0	0	3	0	0	2	3	0	2	5	8	0	1	1	3	2	2	2	0	3	0	4	2	4	5	3	2
Cordia monoica	0	0	0	3	0	1	0	0	0	2	2	1	0	1	2	1	0	0	2	1	5	3	18	6	2	3	5	3
Lonchocarpus capassa	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	4	3	0	0	0	1	0	0	0	0	0	0
Commiphora africana	0	0	0	0	5	0	0	0	3	1	0	0	6	11	17	0	0	0	0	9	2	0	1	0	0	0	0	0
Combretum mossambicense	0	0	0	0	7	0	0	7	0	0	0	0	0	0	0	0	1	1	0	0	2	0	2	0	1	0	0	0
Acacia exuvialis	0	0	0	0	0	3	0	0	0	0	1	1	0	2	3	2	5	9	13	1	0	0	0	0	1	0	0	0
Villoniguea virosa	0	0	0	0	0	5	0	0	1	0	1	0	2	0	2	0	1	1	0	0	0	0	0	0	1	1	0	3
Cissus cornifolia	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Combretum hereroense	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Combretum apiculatum	0	0	0	0	0	0	0	0	1	0	0	0	6	1	1	3	8	3	2	7	1	8	0	0	4	0	0	0
Combretum apiculatum	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Diospyros mespiliformes	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Ximenia caffra	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Ormocarpum trichocarpum	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0
Lannea schweinfurthii	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Terminalia prunoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	2	0	0	0	0	0	0
Cassia abbreviata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Ziziphus mucronata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0
Acacia grandicornuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Appendix: Table 1.3
Tihongonyen Species list

Number of individuals per 100 m interval

Colophospermum mopane	18	35	17	31	25	41	39	14	13	37	11	45	25	27	18	26	12	41	30	19	50	23	32	22	22	17	14	27	25
Combretum imberbe	0	0	1	1	0	1	0	2	1	0	1	3	0	0	1	1	0	0	0	1	2	0	0	0	0	0	0	0	1
Commiphora pyracanthoides	0	0	0	11	16	0	1	1	9	0	20	0	2	0	2	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Dichrostachys cinerea	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1
Cordia monoica	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1	0	0	0	1	0	0	0	2	2
Lonchocarpus capassa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Grewia bicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ozoroa paniculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Appendix: Table 1.4
Hartbeesbult Species list

Number of individuals per 100 m interval

Colophospermum mopane	33	26	30	37	38	34	24	30	34	59	57	59	17	37	34	31	24	37	29	22	22	26	27	33	35
Combretum mossambicense	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	0	1	0	1	4	0	10	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	1	1
Combretum imberbe	0	4	0	2	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0
Dalbergia melanoxylon	0	1	0	0	6	0	0	0	0	0	3	4	17	0	0	0	0	0	0	0	0	0	0	0	0
Dichrostachys cinerea	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Albizia harveyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Grewia bicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0
Commiphora pyracanthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	8	5	0	0	0	0
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
Ozoroa paniculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Cordia monoica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
Sclerocarya birrea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0

Appendix: Table 1.5
Nkolobeni-south Species list

	Number of individuals per 100 m interval																		
Colophospermum mopane	11	18	5	13	30	16	17	18	14	38	49	49	33	31	28	58	53	49	41
Combretum mossambicense	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dichrostachys cinerea	0	2	0	0	4	0	11	0	0	0	0	0	0	0	0	3	0	1	0
Lonchocarpus capassa	0	2	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0
Acacia nigrescens	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Combretum hereroense	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boscia foetida	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sclerocarya birrea	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0
Combretum imberbe	0	0	0	0	0	1	0	0	0	0	1	0	2	1	1	0	1	0	1
Commiphora pyracanthoides	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	10	1
Grewia bicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4	1	2	0
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Acacia karroo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cissus cornifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Appendix: Table 1.6
Timbiten Crest Species list

	Number of individuals per 100 m interval																								
Combretum zeyheri	31	4	26	26	7	21	20	13	9	13	9	11	4	4	9	5	13	4	5	6	3	2	10	19	4
Combretum apiculatum	1	22	2	2	7	3	4	5	1	0	7	4	10	2	21	21	8	11	7	3	0	1	21	9	9
Terminalia sericea	2	1	4	5	0	1	3	1	1	12	0	6	0	1	1	2	11	2	6	5	2	0	1	3	0
Pterocarpus rotundifolia	1	0	0	1	0	0	0	0	30	0	13	7	4	0	16	12	1	0	0	0	0	4	11	0	5
Dichrostachys cinerea	1	1	0	1	2	0	3	3	0	1	0	0	1	0	0	1	0	0	0	2	3	1	0	4	4
Dalbergia melanoxylon	1	1	0	0	1	5	0	5	2	1	0	0	0	0	3	3	0	1	2	0	0	0	1	1	0
Strychnos madagascariensis	8	0	0	0	0	0	27	29	13	0	0	0	2	0	6	0	7	3	3	1	0	7	0	0	0
Cordia monoica	3	0	1	1	0	6	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lonchocarpus capassa	2	0	1	1	2	1	3	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1
Boscia foetida	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Combretum hereroense	0	2	0	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnosporia buxifolia	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diospyros mespiliformis	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Sclerocarya birrea	0	0	0	2	0	1	2	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ozoroa paniculosa	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cassia abbreviata	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albizia harveyi	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5
Cissus cornifolia	0	0	0	0	0	0	0	0	0	0	1	2	2	4	2	5	0	3	2	1	0	3	2	0	0
Grewia bicolor	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	1
Lannea schweinfurthii	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	2	1	6	0	12	5	3	0	3	2
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	1	0	0	0	0	0
Acacia exuvialis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1
Ziziphus mucronata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Acacia grandicornuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Euclea crispa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Appendix: Table 1.7
Shiteve-teve crest Species list

Number of individuals per 100 m interval

Combretum apiculatum	22	7	19	3	11	12	23	19	11	14	12	18	35	24	19	12	17	14	13	20	11	13	14	12	24	11	26	18	17	20	17
Combretum zeyheri	3	12	7	21	14	7	7	2	3	4	2	12	8	5	3	3	1	1	1	2	2	11	0	13	1	1	3	5	3	4	0
Pterocarpus rotundifolia	0	8	5	4	10	0	12	16	9	19	6	1	0	14	9	4	16	4	0	2	6	1	3	20	3	2	5	8	3	7	7
Dalbergia melanoxylon	1	3	8	3	0	1	0	1	2	0	0	1	3	0	0	0	0	0	0	0	1	1	0	0	0	0	1	6	0	0	0
Cissus cornifolia	1	2	0	0	0	1	0	0	0	2	0	0	0	1	0	1	2	0	1	6	2	1	1	1	2	0	1	2	1	1	2
Albizia harveyi	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0
Acacia exuvialis	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Peltophorum africanum	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sclerocarya birrea	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	1	1	0	3	1	0	2	1	0	1	0	0
Lannea schweinfurthii	0	10	5	1	0	0	0	2	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lonchocarpus capassa	0	3	0	1	0	0	0	0	0	2	0	0	1	0	0	1	1	1	1	1	1	0	1	0	0	1	2	1	1	0	1
Strychnos madagascariensis	0	0	3	1	6	1	0	0	0	0	0	0	0	0	0	0	0	4	6	3	0	0	0	0	0	1	0	4	1	0	2
Terminalia sericea	0	0	0	2	0	0	0	0	0	1	2	2	2	1	3	0	0	1	0	0	1	3	1	0	3	3	3	5	5	1	2
Gymnosporia buxifolia	0	0	0	1	0	2	0	0	2	0	0	0	4	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0
Balanites maughamii	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Grewia bicolor	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Cordia monoica	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	1
Ziziphus mucronata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commiphora africana	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1
Acacia grandicornuta	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Ormocarpum trichocarpum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Acacia nigrescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Flueggea virosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Ozoroa paniculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Dichrostachys cinerea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0
Cassia abbreviata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Combretum collinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Appendix: Table 1.8

Timbiten Footslope Species List

Number of individuals per 100 m interval

Combretum hereroense	12	1	12	12	10	16	0	17	17	4	8	18	5	1	0	5	1	0	29	22
Acacia grandicornuta	1	3	4	6	3	5	6	8	5	1	8	2	0	6	3	10	4	7	3	0
Combretum apiculatum	2	2	2	0	1	2	0	4	3	2	15	7	7	4	0	0	3	2	0	0
Dalbergia melanoxylon	5	1	12	2	3	5	3	1	2	13	17	12	5	0	0	0	0	0	0	0
Combretum imberbe	2	4	3	0	0	0	3	3	0	1	14	10	0	1	0	0	1	0	2	4
Terminalia sericea	5	0	0	0	3	0	3	5	0	1	1	1	12	1	1	1	2	14	0	12
Dichrostachys cinerea	2	0	0	1	0	0	1	4	0	2	1	2	0	11	2	0	0	4	2	3
Flueggea virosa	7	3	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cordia monoica	3	1	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Combretum zeyheri	1	1	1	0	5	4	0	0	2	0	0	0	0	0	0	0	0	0	0	1
Euclea divinorum	2	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	4	4	0	0	8	3	1	0	1	0	0	0	0	5	0	0	0	0	2	0
Lonchocarpus capassa	1	0	0	0	0	0	0	0	0	0	0	2	0	1	1	0	1	0	0	0
Acacia exuvialis	0	3	15	3	2	2	0	11	9	8	0	1	1	1	0	8	0	5	5	0
Albizia harveyi	0	3	0	0	0	0	12	4	1	5	7	8	2	4	26	8	11	20	4	12
Cissus cornifolia	0	2	5	0	1	0	0	0	2	1	1	0	0	0	0	1	0	0	0	0
Boscia foetida	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Manilkara mochisia	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ozoroa paniculosa	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia welwitschii	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Spirostachys africana	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
Ziziphus mucronata	0	0	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Pterocarpus rotundifolia	0	0	0	0	2	4	0	0	0	0	0	0	13	0	0	0	0	0	0	0
Cassia abbreviata	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gymnosporia buxifolia	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolusanthus speciosus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia tortilis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ormocarpum trichocarpum	0	0	0	0	0	0	0	4	1	5	0	3	0	1	0	0	1	0	1	0
Grewia bicolor	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0
Sclerocarya birrea	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Combretum collinum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Euclea crispa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0

Appendix: Table 1.9
Shiteve-teve Footslope Species list

	Number of individuals per 100 m interval																								
Albizia harveyi	7	7	3	15	11	10	60	29	40	1	3	3	5	0	1	0	13	15	2	3	18	6	16	38	0
Combretum hereroense	8	2	4	0	0	0	0	5	3	6	21	0	3	1	3	1	2	0	5	3	6	3	3	0	0
Dalbergia melanoxylon	5	2	0	2	0	0	0	6	0	6	0	9	20	13	32	12	12	8	5	3	0	15	6	0	3
Combretum imberbe	2	2	0	2	4	0	0	1	8	4	0	7	3	7	1	4	0	3	0	0	0	3	0	0	1
Acacia nigrescens	2	5	2	3	0	0	0	0	0	16	20	18	0	0	0	0	0	0	1	1	0	1	1	11	1
Lonchocarpus capassa	1	0	0	0	0	0	0	0	0	6	1	1	0	1	1	1	2	1	3	2	3	4	0	0	4
Euclea crispa	1	1	3	2	1	5	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	3	2	5
Gymnosporia buxifolia	0	13	32	3	0	1	0	3	0	2	3	0	1	10	8	5	11	10	7	13	2	5	0	0	9
Acacia exuvialis	0	5	0	0	0	0	0	0	1	1	0	0	0	1	2	1	0	0	0	7	1	0	2	0	0
Flueggea virosa	0	2	1	0	0	0	0	0	0	3	2	0	3	0	0	0	0	0	0	1	1	1	0	0	0
Sclerocarya birrea	0	1	0	1	0	0	0	0	0	0	0	1	0	3	1	1	0	0	0	0	0	0	0	0	0
Euclea divinorum	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolusanthus speciosus	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peltophorum africanum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	3	0	0	0	0	1
Lannea schweinfurthii	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	5
Ormocarpum trichocarpum	0	0	0	2	2	0	4	17	0	1	5	20	0	0	0	0	0	0	0	0	0	0	9	0	1
Acacia grandicornuta	0	0	0	0	0	0	1	1	0	1	2	2	1	0	0	1	0	0	0	1	1	2	0	5	5
Ziziphus mucronata	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	1	2	0	1	0
Terminalia sericea	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cissus cornifolia	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Cassia abbreviata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pterocarpus rotundifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Rhus queinzii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Combretum apiculatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Combretum collinum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
Spirostachys africana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0

Appendix: Table 1.10
Shivulani Crest Species list

	Number of individuals per 100 m interval																				
Colophospermum mopane	18	25	10	8	16	18	12	11	28	22	13	23	37	38	28	59	51	29	44	3	2
Combretum apiculatum	7	4	10	14	13	7	10	8	4	11	7	7	9	8	9	7	5	7	2	9	9
Commiphora africana	5	3	3	3	0	0	0	4	1	0	1	1	0	0	0	1	0	0	0	0	1
Dichrostachys cinerea	4	0	1	4	1	1	0	3	0	3	0	0	0	1	1	0	0	0	0	0	8
Acacia exuvialis	6	0	0	0	0	0	3	0	1	0	0	0	0	2	5	0	14	9	12	0	0
Boscia foetida	1	0	3	0	0	0	0	0	0	4	3	0	0	0	0	2	1	0	4	0	0
Sclerocarya birrea	0	1	1	0	1	3	7	3	1	3	3	2	0	2	0	1	1	1	0	3	5
Albizia harveyi	0	1	2	0	0	1	0	3	1	1	0	0	0	0	0	0	0	2	0	1	1
Cissus cornifolia	0	1	0	0	0	0	4	3	0	1	0	1	0	1	2	0	0	1	0	1	2
Commiphora pyracanthoides	0	3	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Lannea schweinfurthii	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Grewia bicolor	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Ormocarpum trichocarpum	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Lonchocarpus capassa	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Euclea divinorum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0
Ziziphus mucronata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ozoroa paniculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dalbergia melanoxylon	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	4	0
Terminalia sericea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5
Cassia abbreviata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Appendix: Table 1.11

Ledeboer Crest Species list

Number of individuals per 100 m interval

Colophospermum mopane	23	20	22	42	35	36	18	19	19	33	19	26	23	30	7	20	22	9	4	9
Combretum apiculatum	9	13	7	9	2	3	5	7	13	7	7	12	5	6	10	12	14	6	16	12
Cissus cornifolia	2	0	2	2	1	3	4	3	0	1	1	1	2	1	0	1	1	2	3	1
Combretum mossambicense	4	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Boscia foetida	6	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Albizia harveyi	0	2	0	2	1	0	0	1	1	1	0	0	0	0	0	0	3	0	0	3
Lonchocarpus capassa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sclerocarya birrea	0	0	0	0	1	0	0	2	0	0	2	0	0	0	0	1	0	0	0	0
Commiphora africana	0	0	0	0	0	0	1	2	2	0	0	0	1	0	0	0	0	0	0	0
Acacia nigrescens	0	0	0	0	0	0	3	0	0	0	0	0	1	2	1	4	0	0	0	0
Ormocarpum trichocarpum	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Lannea schweinfurthii	0	0	0	0	0	0	0	1	1	0	6	0	0	0	0	4	2	7	10	0
Dichrostachys cinerea	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	1	1	2
Grewia bicolor	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0
Cassia abbreviata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Appendix: Table 1.12

Shivulani Footslope Species list

Number of individuals per 100 m interval

Colophospermum mopane	25	88	78	77	32	29	36	31	112	11	30	20	28	26	53	63	56	53	51	43
Combretum apiculatum	4	3	1	6	10	7	4	5	0	15	6	8	10	0	10	6	1	4	1	7
Cissus cornifolia	2	1	2	0	0	0	0	1	1	0	2	0	1	0	1	0	0	0	0	0
Commiphora africana	4	0	0	0	2	0	1	0	0	0	1	0	0	0	0	2	0	1	0	1
Sclerocarya birrea	2	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	2	0	0	1
Ozoroa paniculosa	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commiphora pyracanthoides	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Combretum mossambicense	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia exuvialis	0	8	0	1	0	3	1	7	0	2	1	0	0	1	0	5	1	7	2	10
Boscia foetida	0	2	0	0	0	0	0	0	2	3	1	1	0	0	0	0	1	0	4	0
Flueggea virosa	0	1	0	0	1	0	0	2	0	0	0	4	0	1	1	1	0	0	0	0
Albizia harveyi	0	1	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	2
Acacia nigrescens	0	0	1	0	0	5	4	1	0	2	0	0	4	51	7	2	4	1	3	4
Grewia bicolor	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	3	0
Lannea schweinfurthii	0	0	0	0	2	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0
Dichrostachys cinerea	0	0	0	0	0	1	0	0	0	0	1	0	0	7	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euclea divinorum	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Combretum imberbe	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	1	0	0	0
Combretum hereroense	0	0	0	0	0	0	0	0	0	0	1	1	0	5	0	2	1	0	0	0
Lonchocarpus capassa	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0

Appendix: Table 1.13

Ledeboer Footslope Species list

Number of individuals per 100 m interval

Colophospermum mopane	49	35	66	33	23	19	17	53	28	26	45	26	26	33	37	23	42	28	44
Boscia foetida	1	5	0	0	0	1	0	0	0	2	2	0	0	0	0	0	0	0	0
Combretum apiculatum	0	3	3	13	22	14	13	11	6	15	5	9	14	9	3	15	9	12	15
Cissus cornifolia	0	3	0	2	1	3	1	0	0	1	1	1	1	2	1	1	1	1	1
Lannea schweinfurthii	0	2	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0
Combretum hereroense	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albizia harveyi	0	0	3	1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Acacia exuvialis	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Lonchocarpus capassa	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0
Grewia bicolor	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	2	0
Acacia tortilis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Acacia nigrescens	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0
Sclerocarya birrea	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Dichrostachys cinerea	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Commiphora africana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	4
Ozoroa paniculosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ziziphus mucronata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0