

**EFFECT OF PERENNIAL WATER ON SOIL, VEGETATION AND
WILD HERBIVORE DISTRIBUTION IN SOUTHEASTERN
ZIMBABWE**

by
Sarah Clegg

**Submitted in partial fulfilment of the requirements of the degree of
Master of Science**

**In
The Department of Range and Forage Resources
University of Natal, Pietermaritzburg
Private Bag X01
Scottsville
3209**

February 1999

DECLARATION

This thesis is the result of the author's original work except where acknowledged or specifically stated in the text. It has not been submitted for any other degree or examination at any other university or academic institution.


.....
Sarah Clegg, February 1999

ABSTRACT

The effects of artificially supplied perennial water on soil properties, vegetation dynamics and the distribution of large herbivores was investigated in southeastern Zimbabwe. Data collection took place between March 1997 and July 1998. Water points were situated primarily on three different soil types (clay-loam, sandy-clay-loam and sand), and in four different vegetation types (Hill communities, *Colophospermum mopane* veld, *Acacia nigrescens* woodland and *Albizia petersiana* woodland). One water point in *C. mopane* veld (Bandama) had been closed two years prior to data collection, while another, in the Hill community (Manyoka), had been introduced, two years prior to data collection.

Changes in physical (infiltration) and chemical (organic carbon and nutrients) properties of soils around water points were largely restricted to within 100 m of water. Chemical enrichment of the soil occurred only at water points that had been in place for more than two years. Soil surface conditions were altered to distances beyond 100 m from water. Manyoka (the new water point) was an exception, with extreme changes limited to within 100 m of water.

Herbaceous and woody species composition changed in response to distance from water with changes best described by asymptotic equations. Changes in species composition of the woody component appeared to be longer lasting than changes to the herbaceous component. Most perennial grass species declined close to water, but *Urochloa mosambicensis* increased close to water in areas outside of the Hills. Herbaceous species diversity was adversely affected by distance from water on sandy soils (Hill communities and *A. petersiana* woodland), but was largely unaffected on clay-loam (*A. nigrescens* woodland) and sandy-clay-loam soils (*C. mopane* veld). Woody species composition and density was altered out to 500 m from perennial water in *Acacia nigrescens* woodland on clay-loam soils. Results suggest that this vegetation type may be susceptible to bush encroachment close to water. Trends in woody canopy utilisation were generally similar to trends in woody species composition, and it is proposed that the former may be used to indicate future changes in the latter. Conversion of trees to shrubs was highest at Manyoka (the new water point) indicating that woody destruction by elephants is extreme during the initial years following water introduction.

Large herbivore biomass was greatest close to water (< 1 km) during the dry season but not during the wet season. Herbivore species distributions appeared to be influenced by the position of perennial water, but since all range was within easy access of water, it is unlikely that animal distributions were constrained directly by the position of surface water. It is more likely that herbivores were spatially separated on the basis of habitat type.

ACKNOWLEDGEMENTS

My sincere thanks to the donors and trustees of Malilangwe Conservation Trust for financial support, accommodation and materials with which to conduct my research. Thank you also to my parents for their support throughout the past two years and for accommodating us during the write up-phase.

I am grateful to Dr. Jeremy Anderson for initiating this project and giving useful advice during the early stages.

Thanks to my supervisor, Professor Tim O'Connor and co-supervisor, Dr Pete Goodman for sharing their time and knowledge with me. It has been a privilege to learn from you both.

Thank you to the following organisations and individuals:

- The Zimbabwe Sugar Association for analysing the soil samples and allowing me to use their facilities to dry herbaceous matter.
- Craig Morris for always being available to give statistical advice.
- Bill and Jane Clegg for the use of their computer over the last two years, and for help in the field.
- Mr R Sparrow for historical background.
- The staff of Malilangwe for their friendship and willingness to help in all aspects of this project. Special thanks to Mr Julius Matsuve for months of valuable input and enthusiastic assistance in the field.

Lastly, thanks Bruce for your encouragement and interest, and for your tireless patience while teaching me some of the statistical procedures used in this thesis.

CONTENTS

DECLARATION	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
CONTENTS.....	v
CHAPTER 1 : INTRODUCTION	1
CHAPTER 2 : A REVIEW OF THE LITERATURE.....	3
1. INTRODUCTION.....	3
2. SEASONAL MOVEMENTS.....	4
3. THE NEED FOR ADDITIONAL WATER	5
4. THE IMPLICATIONS OF WATER INTRODUCTION.....	6
5. THE BIOSPHERE.....	7
6. DETERMINANTS OF BIOSPHERE SEVERITY	9
6.1. Age of water point	9
6.2. Density and species utilising watering points.....	10
6.3. Drinking site selection.....	10
6.4. Site sensitivity.....	13
6.5. Water dependency	14
7. IMPACTS ON SOIL PROPERTIES.....	20
7.1. Physical changes.....	20
7.2. Chemical changes	22
8. IMPACTS ON THE VEGETATION.....	24
8.1. Herbaceous changes.....	25
8.2. Woody changes.....	28
9. IMPACTS ON BIRD AND MAMMAL POPULATIONS	33
9.1. Water, food and cover	33
9.2. Predation	38
9.3. Disease.....	39
10. THE INFLUENCE OF CLIMATE	40
11. MANAGEMENT AND MANIPULATION.....	41
CHAPTER 3 : STUDY SITE	45
LOCATION	45
CLIMATE.....	46
RELIEF, GEOLOGY AND SOILS	48
VEGETATION	50
<i>Colophospermum mopane communities</i>	51
<i>Hill communities on sandstone outcrops</i>	51
<i>Paragneiss communities</i>	52
<i>Acacia nigrescens / open C. mopane</i>	52
<i>Open Acacia savanna</i>	52
<i>Albizia woodland</i>	53

<i>Riverine / Alluvium</i>	53
HISTORY OF PERENNIAL WATER AND LAND USE	54
LARGE HERBIVORE POPULATIONS	55
CHAPTER 4 : STUDY DESIGN	56
STUDY SITE SELECTION	56
1. <i>Soils and vegetation</i>	56
2. <i>Large herbivore distributions</i>	59
DATA COLLECTION	59
1. <i>Soils and vegetation</i>	59
2. <i>Large herbivore distributions</i>	60
3. <i>Raw data</i>	60
DISCUSSION	61
CHAPTER 5 : SOIL RESPONSES.....	63
INTRODUCTION.....	63
METHODS	64
1. <i>Nutrient status</i>	64
2. <i>Texture and depth</i>	64
3. <i>Soil surface conditions</i>	64
4. <i>Infiltration</i>	65
ANALYSIS.....	66
RESULTS	67
Relationships amongst variables	67
1. <i>Nutrient status</i>	68
2. <i>Texture and depth</i>	73
3. <i>Soil surface conditions</i>	73
4. <i>Infiltration</i>	80
DISCUSSION	82
1. <i>Nutrient status</i>	82
2. <i>Texture and depth</i>	84
3. <i>Soil surface condition</i>	84
4. <i>Infiltration</i>	86
CHAPTER 6 : VEGETATION RESPONSES.....	88
INTRODUCTION.....	88
METHODS	89
1. <i>Herbaceous data</i>	89
1.1. <i>Species composition</i>	89
1.2. <i>Biomass</i>	90
2. <i>Woody data</i>	90
ANALYSIS.....	91
1. <i>Herbaceous data</i>	91
1.1. <i>Species composition</i>	91
1.2. <i>Biomass</i>	92
2. <i>Woody data</i>	92
2.1. <i>Species composition</i>	93

2.2. Density.....	93
2.3. Stem area.....	93
2.4. Utilisation.....	93
RESULTS	94
1. <i>Herbaceous data</i>	94
1.1. Species composition.....	94
1.2. Biomass.....	96
2. <i>Woody data</i>	101
2.1. Species composition.....	101
2.2. Spatial distribution of selected species.....	105
2.3. Density (all woody species).....	107
2.4. Stem area (all woody species).....	107
2.5. Utilisation.....	111
DISCUSSION	118
1. <i>Herbaceous data</i>	118
1.1. Species composition.....	118
1.2. Biomass.....	120
2. <i>Woody data</i>	122
2.1. Species composition.....	122
2.2. Spatial distribution of selected species.....	123
2.3. Density (all woody species).....	124
2.4. Stem area (all woody species).....	125
2.5. Utilisation.....	126
CHAPTER 7 : LARGE HERBIVORE DISTRIBUTIONS.....	129
INTRODUCTION.....	129
METHODS	130
1. <i>Wet season count data</i>	131
2. <i>Dry season count data</i>	131
ANALYSIS.....	132
RESULTS	133
DISCUSSION	139
CHAPTER 8 : CONCLUSION	142
REFERENCES.....	146
APPENDIX 1. STUDY SITES	158
APPENDIX 2. SOILS.....	163
APPENDIX 3. VEGETATION.....	171
APPENDIX 4. LARGE HERBIVORE DISTRIBUTIONS	173

CHAPTER 1 : INTRODUCTION

The subject of perennial water introduction, particularly to wildlife systems, is a controversial one. Much of the controversy is based on the fact that water management is a powerful tool that when appropriately used achieves remarkable results (Davison 1977), but when inappropriately used, can be detrimental (Owen-Smith 1996). Amongst range managers there is generally confusion regarding what is appropriate and what is inappropriate water management.

Perennial water management (placement, amount and rotation) effects all ecosystem components. Soils are altered close to water through increased trampling and defecation. Botanical species composition and structure is altered indirectly through the modified soil environment, and directly through utilisation and trampling. Changes in the vegetation affect the quality and availability of forage and cover for mammals and birds. It has been suggested that closely spaced water (< 5 km apart, where stocking rates are high) leads to an homogenisation of vegetation (Collinson 1983). The grading of heavy to lightly utilised rangeland away from water is lost as all rangeland is intensively utilised to the same level. Certain mammal and bird species flourish in the modified environment, while others decline in number or are eliminated as habitat essential for their survival diminishes (Goodman 1982; Collinson 1983; Reid & Flemming 1992, unseen, as cited by Landsberg *et al.* 1997).

Water points provide foci for animal activity, particularly in arid and semi-arid regions during the dry season. Because most large herbivores require water on a regular basis, the position of perennial water influences the distribution of animals. If water points are placed far enough apart, and if stocking rates are moderate, utilisation intensity declines with distance from water, resulting in a zone of attenuating impact (a piosphere) around water points (Lange 1969). Distance from water therefore represents an easily measured gradient of utilisation that is high close to water and decreases with distance.

The extent of the zone modified by the provision of perennial water varies between and within water points. Variations in piosphere size are attributed to the rainfall of a particular area, age of the water point (Andrew & Lange 1986a; 1986b; Perkins & Thomas 1993a; 1993b), soil type, vegetation type, herbivore species mix, and the

component (variable) measured. For example, at a particular water point the extent of the piosphere will be different for herbaceous species composition, woody species composition, species richness, utilisation, surface conditions and nutrients. The sensitivity of each component to the presence of perennial water will be reflected in the size of specific piospheres. Depending on the importance of each component to the objectives of the property, piosphere size will be weighted accordingly.

Because landscapes are seldom uniform, responses to disturbance (e.g. the introduction of perennial water) may vary between sites. The effects of perennial water in each area already with, or targeted for future introductions of perennial water should be investigated. Water placement based solely on distance apart does not cater for landscape heterogeneity, and therefore consideration of site sensitivity is essential to sound rangeland management, particularly where biodiversity is one of the management objectives.

The effects of perennial water on soils and vegetation have been well documented (Andrew & Lange 1986a; 1986b; Perkins & Thomas 1993a; 1993b; Thrash *et al* 1991a; 1991b; Thrash 1993; Dougill & Cox 1995). There is however a paucity of information regarding the response of different soil and vegetation types to perennial water under similar management and in similar climatic conditions. Further, it is often stated that niche separation of large herbivores occurs along the distance from water gradient (Goodman 1982; Collinson 1983). However, little quantitative investigation regarding the distribution of large herbivore species has been conducted, especially in areas where perennial water is closely spaced. This thesis addresses these issues by examining the effects of perennial water on soil, vegetation and the distribution of large herbivores at Malilangwe Conservation Trust in southeastern Zimbabwe. The objectives were:

1. to determine the response of different soils and vegetation types to the presence of perennial water,
2. to compare the wet and dry season distributions of large herbivores and to comment on the spatial distribution of individual species during the dry season with respect to perennial water, and
3. to give broad recommendations on where perennial water should be placed so as to minimise adverse effects on the environment.

CHAPTER 2 : A REVIEW OF THE LITERATURE

1. INTRODUCTION

In many post-colonial African nations, providing water to previously dry regions has resulted in the expansion of agriculture into areas historically only utilised by hunter-gatherer and pastoral nomadic groups (Perkins & Thomas 1993a). In many arid and semi-arid regions of Africa, dry season water was restricted to perennial rivers, pools along ephemeral rivers, and occasionally, pans or springs held water through the dry season. Wet season water was largely ubiquitous. Today, most developed or partially developed areas of Africa are artificially supplied with water during the dry season. This means that while in the past, human and animal numbers, and land utilisation were constrained during the dry season, today, for the most part they are not. The provision of additional water away from natural perennial sources has allowed greater dispersion and utilisation of dry season forage.

These days eco-tourism and hunting are competing with cattle production as land use options. For example, in southern Africa many ranches have foregone livestock production in favour of wildlife. Management strategies are defined by land-use objectives, and management success can only be judged against the objectives for a particular area (Collinson 1983). Where land use objectives have changed from cattle to game ranching, management strategies must be revised.

Fire policy, population culling and water provision are three of the most important tools available to wildlife managers (Owen-Smith 1996). The management strategy adopted for water will influence every other management strategy (Goodman 1982). Inappropriate placement of water can lead to soil degradation, over or under-utilisation of grazing, bush encroachment, a decline in faunal and floral diversity, and inefficient use of water. In short, poor water placement may result in a decline in ecosystem stability, resilience and biodiversity (Owen-Smith 1996). In contrast, wise placement of water can control the number and distribution of animals, and switching off artificially provided water will encourage grazing rotation. Information is gathered from research conducted in arid and semi-arid regions which are utilised by game and domestic stock.

2. SEASONAL MOVEMENTS

In the past wild animals were able to move between distant perennial water supplies. Today there are few places where extensive migrations can still occur. Seasonal changes in animal distribution may be large-scale migrations, such as the Serengeti wildebeest migration which covers an ecosystem of 25 000 km² (Norton-Griffiths 1973). However, localised movements of animals in response to seasonal changes still occur in confined areas (Jarman 1972; Western 1975; Davison 1977). Based on the pattern of movement, three systems are identified: migratory, resident and dispersal (Western 1975). Dispersal systems describe a wet season dispersal and a dry season concentration of populations relative to water. This system of seasonal movement is specific to water-dependent species (obligate drinkers) and is not observed for water-independent species.

During the dry season in arid and semi-arid regions, water-dependent species concentrate in the vicinity of permanent water. Feeding is restricted to the distance animals are capable of ranging between perennial water and food. This range size varies between species depending on mobility, forage selection (Western 1975; Louw 1984), behavioural adaptation (Parris 1984; Mills 1984) and physiological ability to go without water (Lamprey 1963; Taylor 1969; Young 1970b). Within a species, foraging distance from water varies with moisture content of forage (Jarman 1972), available shade (Foran 1980), ambient temperature, saltiness of water and forage (Andrew 1988; du Toit 1996), age, sex, reproductive status and health of individuals (Davison 1977; Pickup 1994; du Toit 1996). The maximum dry season range for an individual probably represents the point beyond which energy lost through travelling to better quality forage exceeds energy gains from that forage (Pickup 1994). Despite the variations illustrated above, general dry season range limits have been estimated for common large ungulates and elephants (*Loxodonta africana*) (Young 1970a; Western 1975; Goodman 1982; Collinson 1983; Smithers & Skinner 1990; Owen-Smith 1996).

During the wet season, natural pans fill and water is largely ubiquitous (Lange 1969; Western 1975; Davison 1977). Animals disperse and move away from the heavily utilised dry season range to tap better quality, undepleted forage. Because of the abundance of water, animals rarely need to travel more than a few kilometres to drink. At

the same time, drinking requirements are reduced as a result of the increased moisture content of forage (Lamprey 1963; Jarman 1972; Western 1975). Although species such as impala (*Aepyceros melampus*) and wildebeest (*Connochaetes taurinus*) may remain in the vicinity of perennial water (Young 1970b; Parris 1984), a major portion of the large herbivore biomass is shifted off the dry season range, allowing a recovery period during the wet season (Owen-Smith 1996). Excessive provision or insufficiently spaced perennial water will increase dry season range at the expense of wet season range. This means that the wet season grazing area may not be large enough to relieve the dry season grazing area, and the recovery period for the latter may be retarded (Owen-Smith 1996).

3. THE NEED FOR ADDITIONAL WATER

Land utilisation in the past was dynamic, with fluctuating pastoralist, elephant and wild grazing herbivore distributions corresponding to climatic cycles (Vesey-Fitzgerald 1965; Laws 1970; Weir 1971). The human population explosion of recent decades has been the single factor responsible for the disruption of these patterns (Laws 1970). Mans progressive occupation of land has resulted in the compression of wild animal ranges (Laws 1970; Weir 1971; Mwalyosi 1990; Dublin *et al.* 1990) to the extent that even where wildlife areas are not bounded by fences, natural movements in response to available water and food are restricted. With this in mind, the ecological necessity to artificially provide water in areas where perennial sources are unreliable or insufficient is obvious. The economic incentive to water provision relies on tourist satisfaction. Providing perennial water adds to the attractiveness of a park, attracts game to the protected area and provides a focus where game-viewing opportunities can be predicted. All these factors increase the economic viability of protected areas (Weir 1971; Owen-Smith 1996).

4. THE IMPLICATIONS OF WATER INTRODUCTION

Surface water management in semi-arid systems is one of the most controversial and abused range management tools in the wildlife and conservation industry (Goodman 1996). The introduction and placement of artificial water in semi-arid systems requires careful consideration (Van der Schijff 1959; Young 1970b; Ayeni 1977; Goodman 1982; Owen-Smith 1996). Water should only be introduced when and where clear objectives have been stated and natural sources have been quantified (Burkett & Thompson 1994).

Much work has been done on the impact of large herbivores around perennial watering points in arid and semi-arid Australia (Lange 1969; Foran 1980; Andrew & Lange 1986a; Andrew & Lange 1986b; Andrew 1988; Pickup & Chewings 1988; Pickup 1991; Pickup 1994). Similar work has been done in the Kalahari (Child & Parris 1971; Parris 1984; Kalikawa 1990; Perkins & Thomas 1993a; 1993b; Tolsma *et al.* 1987; Van Rooyen *et al.* 1990; Van Rooyen *et al.* 1994). Research in both areas has quantified the effects of domestic stock on soil and vegetation. In addition, the Australian studies investigated the impacts of small herbivores such as kangaroo and rabbits, while the Kalahari studies looked at the impacts of wild ungulates. Studies in neither area consider the impact of megaherbivores. Only a few studies, for example, Bromwich (1972) in Gonarezhou National Park, Zimbabwe, Thrash (1993) and Thrash *et al.* (1991b) in the Kruger National Park, South Africa, and Conybeare (1991, unseen, as cited in Thrash *et al.* 1995) in Hwange National Park, Zimbabwe, have quantified the impact of elephant on environmental factors close to water. According to Laws (1970), after man, the African elephant has had the greatest effect on African habitats. He attributes this to its large size and longevity. Since *elephants play a major role in habitat modification, it is essential that their impact not be over looked.

5. THE PIOSPHERE

Herbivore rangeland utilisation is seldom uniform (Foran 1980; Andrew 1988; Pickup & Chewings 1988). It varies with forage quality and cover, topography, soil surface conditions, and distance from water. The 'piosphere' (Figure 1a), a term coined by Lange (1969), describes the ecological system of interactions between a watering point, its surrounding vegetation and the grazing animal. This zone of ecological impact is focused around a watering point in dry areas (Andrew 1988), where impacts are most pronounced close to water and decrease with distance from water. Piosphere patterns generally reflect concentricity of stocking pressure around water (Andrew & Lange 1986a), and where factors such as topography, soil depth and texture are uniform, impacts attenuating from the water point focus are approximately radial. In Australia, these patterns are clearly seen from satellite photography (Andrew & Lange 1986a). Ecological variables which reflect herbivore impact with distance from water include: changes in the chemical and physical properties of soils (Perkins & Thomas 1993a; 1993b; Lange 1969; Andrew & Lange 1986a; Tolsma *et al.* 1987), changes in the condition of the soil surface (Lange 1969; Graetz & Ludwig 1978; Pickup & Chewings 1988), changes in the composition of herbaceous and woody species (Lange 1969; Thrash *et al.* 1991a; Tolsma *et al.* 1987), physiognomy (Thrash *et al.* 1991b), diversity (Owen-Smith 1996), density (Perkins & Thomas 1993a; 1993b; Tolsma *et al.* 1987; Graetz & Ludwig 1978), biomass (Graetz & Ludwig 1978; Andrew & Lange 1986b), and herbage defoliation (Andrew & Lange 1986b). A number of researchers (Graetz & Ludwig 1978; Thrash *et al.* 1993) have proposed the sigmoid curve (described by a logistic equation with parameters for upper and lower asymptotes) as the best descriptor of the response of soils, vegetation and grazing to distance from water. The curve (Figure 1b) describes an area of extreme herbivore impact, where the herbaceous community consists mainly of annuals (Thrash *et al.* 1993) or poisonous plants (Tolsma *et al.* 1987). This area is known as the sacrifice zone and is represented by the lower asymptote of the sigmoid curve (this zone is not always evident). Towards the end of the dry season, the section of sacrifice zone immediately adjacent to water is often grazed and trampled bare.

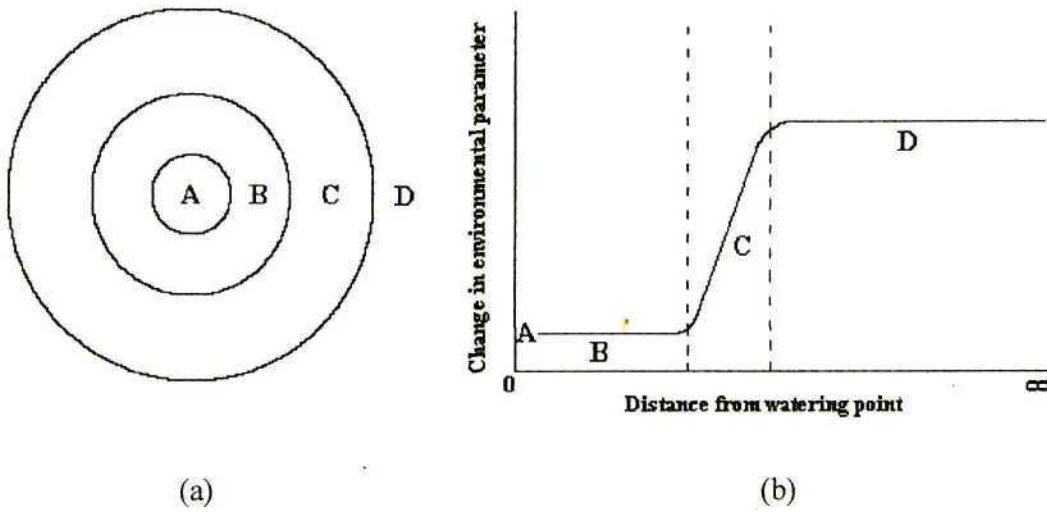


Figure 1. (a) Hypothetical diagram of a 'piosphere'. (b) The sigmoid relationship between utilisation sensitive parameters (vegetation or soils) and distance from a watering point. A = water point, B = sacrifice zone, C = zone of maximum change and D = zone where the influence of the watering point becomes negligible.

The upper asymptote of the sigmoid curve represents the point beyond which the influence of the watering point becomes negligible (Graetz & Ludwig 1978). This point can only be recognised where piosphere impact zones from one water point do not overlap or touch those of another. Similarly, this point will not be found unless the full extent of the piosphere has been measured. In a number of piosphere studies, linear equations best fit the distribution of values of interest against distance from water (Lange 1969; Andrew & Lange 1986a; 1986b; Thrash *et al.* 1991a). These results are obtained where only the initial sections of the logistic curve (which are essentially linear) have been measured (Andrew & Lange 1986b). The distance over which the linear slope persists, i.e. before reaching an upper asymptote, reflects the sensitivity of a particular parameter to the effects of the water point (Graetz & Ludwig 1978).

6. DETERMINANTS OF PIOSPHERE SEVERITY

Piosphere severity and speed of development are affected by the age of the water point, the density and species of animal using the watering point, and the sensitivity of the site in which the water point is placed. Provided ecological changes occur in response to the presence of water, animal impacts will decrease with distance from water.

6.1. Age of water point

The longer a water point has been in place, the greater the cumulative effect of animals on the environment. Andrew and Lange (1986a; 1986b) monitored the impact of introducing water to a near-pristine chenopod shrubland in South Australia. Soil changes were monitored for the first 2.5 years, and vegetation changes were monitored for the first eight years under light sheep stocking rates. Results showed that changes to soil condition occur faster than changes to the vegetation. Piosphere patterns for dung deposition, sheep track development, lichen cover and grass biomass were detected within the first three months. After six months, *Marrubium vulgare*, an introduced weed, had invaded the vicinity of the water trough. Soil compaction, measured for the first time at six months after water installation, showed a piosphere pattern. Compaction was confined to sheep tracks, and an increase in surface soil bulk density of 20% was observed. The piosphere pattern for the development of sheep tracks and the destruction of lichen crusts became more pronounced with time. After 2 years, the effect of the water point on infiltration extended to 10 m, while the effect on the density of sheep tracks extended to 800 m. *Atriplex vesicariae*, a palatable shrub, showed no decrease in density after two years, but after eight years a marked piosphere pattern in mortality was observed. The piosphere pattern for defoliation of the palatable shrubs *A. vesicariae* and *Mairana sedifolia*, as well as for forage biomass, became more prominent with time.

Perkins and Thomas (1993a; 1993b) studied the impacts associated with borehole dependent cattle ranching in the Kalahari. Their results showed that older boreholes generally had a higher canopy cover than more recently sunk boreholes, indicating an increase in bush encroachment with time. A number of woody species were associated with the age of a borehole. These included *Croton gratissimus*, *Boscia albitrunca*,

Rhizogum brevispinosum and *Acacia ataxacantha*. It must be noted that the increase in canopy cover with increasing age of borehole occurred in the absence of wild browsing ungulates and more importantly, in the absence of elephant.

6.2. Density and species utilising watering points

Just as animal impacts on soil and vegetation increase with proximity to water due to increased animal pressure, an overall increase in animal numbers is expected to increase impact severity to all parts of the biosphere. Depending on the species of animal utilising a water point, the impact on vegetation and soils will differ. Larger animals, and animals whose foraging nature is particularly destructive, will modify environmental variables more severely than smaller, less destructive foragers. The dependency of species on surface water will determine how much time is spent around permanent water.

6.3. Drinking site selection

The vegetation surrounding a water point, topography of the area, water quality and the physical characteristics of a water point influence species selection of drinking sites.

Habitat preference plays an important role in species selection of drinking site. Preferred habitats are those where forage and cover requirements for a particular species are met. Several authors have noted that animals were distributed in relation to certain structural types of vegetation (Weir 1971; Jarman 1971; Young 1970a). While the more secretive species such as kudu (*Tragelaphus strepsiceros*) and bushbuck (*Tragelaphus scriptus*) prefer to drink from wooded water sources, plains loving species such as zebra (*Equus burchelli*) and wildebeest prefer to drink at open waters. Jarman (1971) found that in the Serengeti National Park, Kenya, most access paths to water were sited where visibility at the water's edge was better, and where water was faster flowing. Specific choice of drinking place is attributed to antipredator behaviour. Selection for faster flowing water may be an attempt to avoid crocodiles (*Crocodylus niloticus*) while open drinking sites offer better visibility i.e. greater warning time and better opportunity to run fast. Zebra rely on having good warning of diurnal mammalian predators, and being able to run fast to avoid them. The selection of less open drinking sites by impala may be attributed to their ability to jump and scatter under surprise attack. This 'escape

behaviour' would function best where animals could remain under cover, making themselves less visible to predators (Jarman 1971). The vegetation through which the path passes influences path selection to water. As with drinking sites, Jarman (1971) found that zebra and kongoni (*Alcelaphus buselaphus*) chose the most open conditions available, while impala selected paths that offered cover. In each case, the paths chosen reflected the species habitat preference, and habitat preference corresponded to the availability of each species preferred food: grass for zebra and kongoni, and grass, herbs and shrubs for the impala. Similarly, in Zimbabwe, along Lake Kariba's shoreline, Jarman (1972) found that species drank at shores whose landward side resembled their feeding habitat. Buffalo (*Cyncercus caffer*) showed significant selection for shores backed by *Combretum* woodland over shores backed by *Colophospermum mopane*. Elephant and impala showed preferences for water adjacent to *C. mopane*, and black rhinoceros, (*Diceros bicornis*) for water adjacent to *Combretum* species. In each case the vegetation type adjacent to the drinking site corresponded to the species' feeding habitats at that time of year.

Topography, while linked to species habitat preference, will constrain species drinking site selection. Where pans are situated in hilly or mountainous country, water is less accessible (Pickup & Chewings 1988; Stafford Smith & Pickup 1990) and utilisation of the surrounding area is much reduced. Plains species and large herds of buffalo and elephant seldom visit topographically restricted water points (pers. obs.). Although relatively fewer animals utilise water in hilly terrain, localised impacts are extreme because trampling and grazing efforts are concentrated along a few access paths (pers. obs.). In general, it seems that the total impacts of herbivores on soil and vegetation in these areas is small relative to areas of flatter terrain, but erosion potential may be increased as a result of steeper gradients and run off from surrounding rock outcrops (Whitlow 1980). In addition, where terrain is rocky, modification of the soil environment may be limited. In the Serengeti, Jarman (1971) found that animals selected drinking sites along rivers where banks were less steep. His (1972) results were similar for drinking sites along the banks of Lake Kariba. Only klipspringer (*Oreotragus oereotragus*) selected drinking sites on steep shores, while elephant, buffalo, black rhino, impala and kudu avoided these areas to varying degrees. Buffalo almost completely avoided steep shores, while elephant and kudu showed only a small preference for flat shores.

Game shows a clear preference for certain water point types over others. The physical characteristics of a water point i.e. whether the water point is natural or man made, whether it is a dam, pan, river or zoogenous pool (a pool created by animals wallowing or digging), influences its selectivity. In general, Jarman (1972) found that in the Zambezi Valley, where animals had a direct choice between drinking from the lake shore and drinking from zoogenous pools, they displayed a significant ($P < 0.001$) preference for the latter. He attributes this preference to possible concentrations of sodium ions as a result of the development of pools from salt licks and wallows. Davison (1977) in Hwange, and Ayeni (1977) in Tsavo, Kenya, trace the evolution of many natural waterholes to the erosion of termitaria through wildlife activity. Since the soils of termitaria are rich in salts (Hesse 1955), water accumulating on these soils will be mineral rich and more attractive to animals. While animals are attracted to water of mild salinity, they are generally repulsed by water high in salts. Where salinity exceeds a critical point, water becomes toxic. Excessive salinity levels of surface water at the end of the wet season, caused primarily by dung eutrophication, have been proposed as a possible initiate of the zebra and wildebeest migration away from the southern plains of the Serengeti National Park (Gereta & Wolanski 1998). Wild ungulates are however able to tolerate higher water salinity levels than those considered safe for domestic stock (Child & Parris 1971). Apart from total salinity, individual ions and salts play an important role in the selection of drinking sites by particular species. Gemsbok in the Kalahari appear to prefer water with high carbonate and bicarbonate concentrations (Child & Parris 1971), while elephants in Hwange were observed selecting water rich in sodium (Weir 1971). Elephants avoided pans supplied by borehole water low in sodium content, where no soil sodium was available locally.

Cement reservoirs are preferred by elephant, buffalo, black rhino and warthog (Weir & Davison 1965; Young 1970a; Jarman 1972; Davison 1977; du Toit 1996). Despite their wallowing requirements these species select clean, mud-free drinking water. In Hwange, elephants were found to drink from stone or concrete reservoirs and use the adjacent pan for splashing and mud bathing (Weir & Davison 1965). In Kruger, Young (1970a) calculated that elephant preferred to drink water from high concrete reservoirs over earth dams by 66.7 %. In contrast, earth dams were favoured as drinking sites over

concrete drinking troughs by blue wildebeest (94.7 %), zebra (76.5%), buffalo (66.7%) and impala (64 %). Large breeding herds of buffalo were recorded generally to prefer water from open streams or large earth dams, while small bull herds select concrete drinking troughs.

6.4. Site sensitivity

Individual components of the physical environment (rate of soil erosion, quality of soil, density of vegetation, vegetation community structures, etc.) may respond to, and recover from, disturbance and degradation at different rates by displaying different sensitivities (Abel & Blaikie 1989; O'Reagain & Turner 1991; Perkins & Thomas 1993a). Sites that resist permanent change, or recover well following disturbance are likely to tolerate the introduction of permanent water better than those that do not. Site factors which influence soil stability include slope, soil texture, structure, organic material, profile permeability and soil chemistry (Dept. Agric. 1994). Soils high in silt and fine sand are most susceptible to compaction by trampling (Dept. Agric. 1994), and soil compaction leads to a reduction in profile permeability. Course sands are resistant to soil compaction and usually exhibit good permeability. Where permeability or infiltration is reduced, less water is available for plant growth and more water washes over the soil surface increasing the potential for sheet and gully erosion. Since uplands on non-sandy soils are naturally prone to erosion (Owen-Smith 1996), the placement of water here, or on a slope will increase erosion potential (Dept. Agric. 1994). In contrast, siting water where surface gradients are gentle, or in bottomlands, will encourage vegetation recovery during the wet season because soil, water and nutrients accumulate here (Owen-Smith 1996).

The following soils are particularly vulnerable to erosion (Dept. Agric. 1994) and under no circumstances should water be established on them. *Duplex soils* have an abrupt transition from permeable topsoil to an impervious subsoil. Once the topsoil has been disturbed, the subsoil weathers quickly and becomes extremely erodible. *Tunneling soils* occur as a result of chemical or mechanical processes in high clay content soils. Water seeps through vertical or horizontal tunnels formed by small fissures, cracks or termite runs. These tunnels increase in size and ultimately collapse forming erosion gullies. The A horizon of soils at *sodic sites* is particularly vulnerable to erosion, having inherently low

organic matter content, and generally coarse texture. Heavy grazing and trampling leads to the removal of protective grass cover, and aggregate structure of the topsoil is compromised to the extent that it erodes quickly, leaving an exposed clay B horizon. Management practices that promote high grazer concentrations on these sites potentially accelerate the removal of grass cover and promote the formation of sodic sites (Chappel & Brown 1993). Heavy utilisation and poor soil conditions lead to the replacement of productive perennial swards by annual swards, which produce small quantities of forage and provide little protection to the soil surface (Thrash *et al.* 1993).

While soil degradation and forage reduction represent unanimous unwanted change, a reduction in biodiversity, or the loss of endemic or rare communities, only represent habitat deterioration where objectives aim to maintain diversity. Evidence suggests that habitat diversity or patchiness promotes the stable co-existence of animal species and maintains stability of ecosystems in general (Goodman 1982). Conservation areas aim to maintain species diversity of all ecosystem components, and consequently, management decisions that threaten diversity, are not recommended. Since introducing water to previously waterless areas challenges the existing ecology and reduces spatial diversity where water points are placed too close to one another (Walker & Goodman 1982; Collinson 1983), introducing water to areas of unique habitat or species composition, would not be in line with the objectives of a protected area. Unique habitats are those that offer refuge, or a source of food to species which depend heavily on the presence of that habitat for survival. Unique habitats also include botanically valuable species, or simply areas of aesthetic appeal, which may not retain their appeal if affected by the presence of a water point. Careful placement of water can reduce animal impact on sensitive or unique habitats by drawing animals away from these areas.

6.5. Water dependency

Water dependency and herbivore species distribution are discussed with respect to the dry season. Water dependency is related to a species physiological and behavioural adaptation to coping without water (Taylor 1969; Western 1975; Parris 1984). It is also related to the moisture content of an animal's forage (Lamprey 1963; Western 1975). For the purpose of this review, herbivore species have been divided into three categories based on their

reliance on water. *Obligate water-bound* species are those that require surface water regularly for survival. *Facultative water-bound* species are those that will drink when water is available, but can survive satisfactorily without surface water. *Non water-bound* species are those that do not require regular surface water and will not drink regularly, even when surface water is available. Much confusion has been associated with the second group, the facultative water-bound species typified by impala. These species, while generally associated with water during the dry season, are known to survive long periods at great distances from water (Lamprey 1963; Young 1970a; Davison 1977). In Kruger, Young (1970a) noted that when impala were found at great distances from water, their daily range was very small (0.32 x 0.16 km), and the areas where they were found often harboured green forage. This is consistent with a reduced water requirement when the moisture content of forage is high. In most cases, obligate water-bound species are grazers, while facultative water-bound and non water-bound species are browsers or mixed feeders (Table 1).

Table 1. Distribution of feeding strategies between species with different dry season surface water requirements (Adapted from Western 1975)

Obligate water-bound		Facultative water-bound		Non water-bound	
Zebra ^{*1,2,3}	+G	Giraffe ^{1,6}	B	Eland ^{1,2}	B
Wildebeest ^{1,2,3}	G	Ostrich ²	M	Klipspringer ¹	B
Buffalo ^{1,2,3}	G	Impala ^{1,3,5}	M	Gemsbok ²	G
Elephant ^{1,2,3}	M	Nyala ¹	M	Steenbok ⁴	M
Reedbuck ^{2,5}	G	Warthog ¹	G		
Waterbuck ^{2,5}	G				
Sable ¹	G				
Roan ¹	G				
L. Hartebeest ¹	G				
White Rhino ¹	G				
Black Rhino ¹	B				

*1. Smithers & Skinner (1990); 2. Western (1975); 3. Young (1970a); 4. Young (1972);

5. Goodman (1982); 6. du Toit *et al.* (1990)

+G = Grazer; M = Mixed feeder; B = Browser

Western (1975) attributes the dependency of grazers on surface water to a physiological barrier set in place by a low water content of grass. In contrast, most non water-bound species select high water content browse in order to maintain a positive water balance. It has been noted that as the dry season progresses, the moisture content of grass drops while that of browse is maintained (Lamprey 1963; Western 1975; Bell & Jachmann 1984; Pellew 1983). It is due to this decline in the moisture content of grass that elephant increase the proportion of woody forage in their grass dominated diet (Laws 1970; Anderson & Walker 1974) and consequently destruction of the woody component becomes more obvious as the dry season progresses (pers. obs.). In Tsavo, Napier Bax and Sheldrick (1963) noted that damage to woody species reached a peak during droughts. Other examples of grazers switching to browse during dry periods include springbok in the Kalahari (Mills 1984), roan (*Hippotragus equinus*) in the Northern Transvaal (Wilson 1975), waterbuck in Rwenzori National Park, Uganda (Spinach 1982), and buffalo in southeastern Zimbabwe (Mloszewski 1983). Grazers or mixed feeders who cannot satisfy their moisture requirements through forage intake depend heavily on the availability of surface water.

Although water-bound and facultative water-bound species are distinct in their water requirements, they are similar in their spatial distribution around water. Based on distribution from water, the two groups are jointly categorised as water-dependent species (Goodman 1982). Goodman has identified two subdivisions based on species mobility within this category (Figure 2).

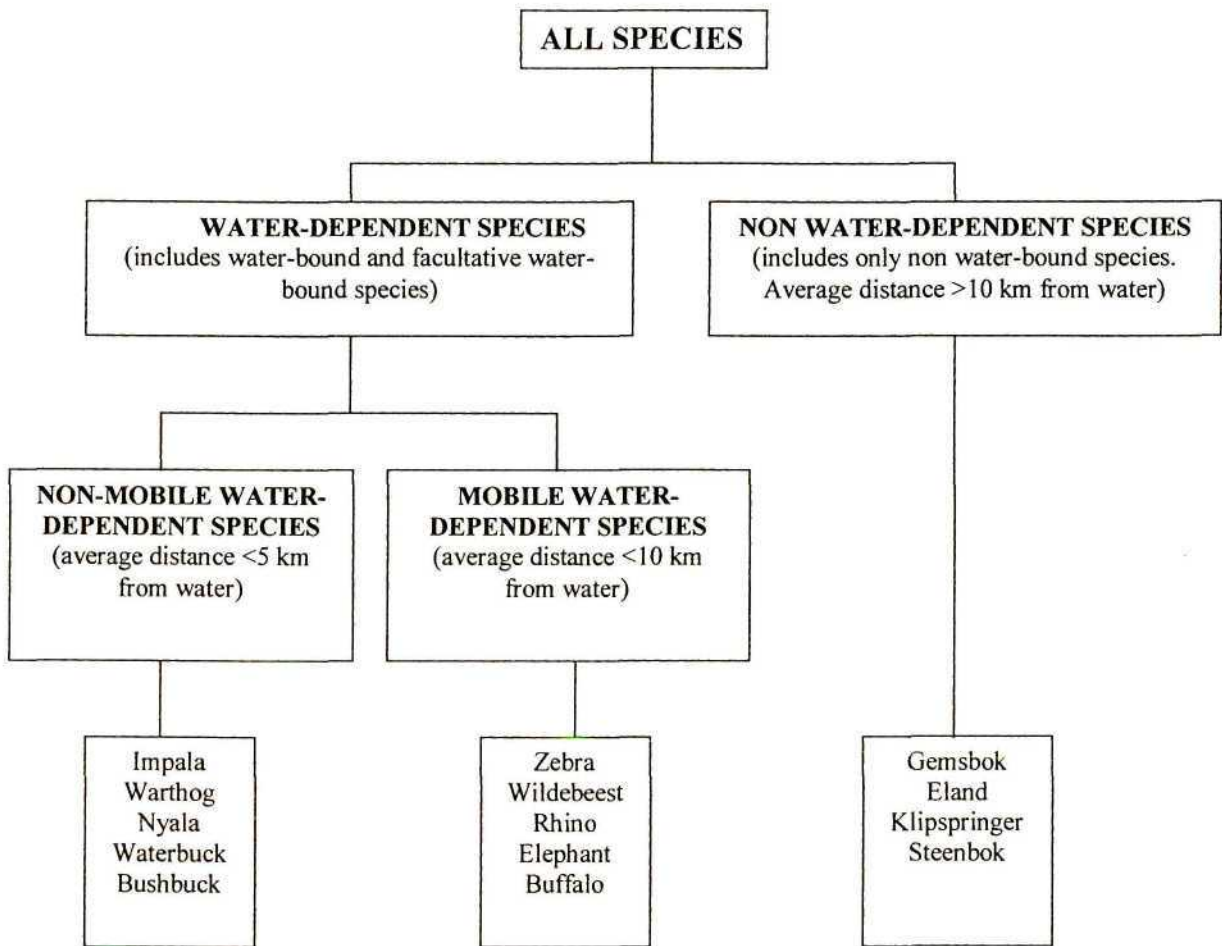


Figure 2. Classification of species based on dry season home range size.

The first group, termed water-dependent non-mobile species, consists of species that do not travel far from water, their densities dropping off dramatically beyond 5-6 km from water (Young 1970a; Goodman 1982; Collinson 1983). This group includes species such as warthog (*Phacochoerus aethiopicus*), nyala (*Tragelaphus angasii*), impala, sable, roan, Lichtenstein's hartebeest (*Alcephalus lichtensteinii*), waterbuck (*Kobus ellipsiprymnus*) and bushbuck (Goodman 1982; Collinson 1983, Smithers & Skinner 1990). Sable, roan and Lichtenstein's hartebeest require a specific habitat which is difficult to attain in protected areas which aim to maximise ecotourism opportunities. These three species require water on a regular basis, but at the same time their feeding and cover requirements demand medium to tall grass (Grobler 1981; Wilson 1975; Booth 1980). Medium to tall

grass is relatively under-utilised grass, and under-utilised grass is not common close to water in a well populated protected area. This combination of requirements makes providing habitat for these three species difficult. The second group, water-dependent mobile species consists of species that are able to travel greater foraging distances from water, their numbers decreasing considerably beyond 10 km. Such animals include zebra, wildebeest, buffalo, elephant and white rhino (*Ceratotherium simum*) (Goodman 1982; Collinson 1983; Smithers & Skinner 1990). Non water-dependent species, which include gemsbok (*Oryx beisa*), eland (*Taurotragus oryx*), steenbok (*Raphicerus campestris*) and klipspringer do not require, or take water regularly (Taylor 1969; Young 1970a; Western 1975; Smithers & Skinner 1990). In the Amboseli basin of Southern Kenya, eland and gemsbok densities remained relatively high, even at distances of as much as 35 km from water (Western 1975). Similarly, klipspringer are reported to be found in areas where water is only seasonally available (Smithers & Skinner 1990).

The average maximum distance travelled daily, as well as the average radius travelled from water is given in Table 2 for the water dependent species studied by Young (1970a) during the wet and dry seasons in Kruger. Young's results show that for all

Table 2. The average maximum daily distance (km) travelled and the average foraging radius range from water during wet and dry seasons in the Kruger National Park (Adapted from Young 1970a)

Species	Wet season average max.	Dry season average max.	Wet season average radius	Dry season average radius
Elephant	10.8	5.5	1.0	6.0
Buffalo	6.3	6.0	0.8	7.9
Zebra	1.3	5.6	1.0	7.3
Wildebeest	1.1	3.9	1.0	7.4
Impala	1.4	1.6	0.6	2.3

species, the average daily distance from water during the dry season (dry season average radius) exceeds the average daily distance travelled in the same season (dry season average maximum). Young (1970a) explains these figures by his observation that during the dry season animals often wander away from water for several days, i.e. their daily range area does not always include a visit to water. When comparing the average dry season and wet season foraging radii, it is found that the dry season forage radius from water is greater than that for the wet season. This implies that relative to dry season foraging range, wet season foraging range is small since animals do not need to travel far from water to find quality forage. When wet and dry season maximum foraging distances are compared, note that the wet season maximum distance travelled by elephant and buffalo herds exceeds the distances travelled during the dry season. These results would not be anticipated considering the ubiquity of water, and the availability of quality forage nearby. Young (1970a) attributes the greater wet season daily travel distance to the tendency of these two species to 'muddy' water in wet season pans through trampling or wallowing. Both elephant and buffalo require clean drinking water (Young 1970a; Davison 1977), so they are forced to move from one pan to the next, thus increasing their daily travel range. In contrast impala, zebra and wildebeest do not 'muddy' their water and consequently are normally found to drink from the same water point and cover a small range. It is interesting to note that in the Amboseli, Western (1975) found on average more than 90 % of zebra, wildebeest, impala, buffalo, elephant, giraffe (*Giraffa camelopardalis*) and ostrich (*Struthio camelus*) were distributed within 6 km of water. Species such as giraffe and ostrich are considered non water-dependent, and it is possible that their distribution may be influenced indirectly by the presence of water i.e. perennial water may modify some other environmental factor to which these species are responding. For example, the heavy utilisation of range around a water point may make it more attractive to certain species so that they are attracted to the forage in the vicinity of water, rather than to the water itself. Du Toit *et al.* (1990) suggests that in Kruger, giraffe are attracted to waterholes to browse heavily utilised *Acacia nigrescens* rather than to drink. When browsing pressure becomes focused on a localised patch of *A. nigrescens* through heavy utilisation by impala in the vicinity of water, a physiological response is induced whereby palatability is increased leading to a feedback loop of further browsing.

Browsing or pruning of mature woody shoots (as practised by horticulturists) reverses ageing by reducing between-shoot competition for nutrients. Growth is stimulated through a release of apical dominance and increased concentrations of nutrients in remaining shoots (Moorby & Wareing 1963). Results obtained by du Toit *et al.* (1990) suggest that severe pruning of *A. nigrescens* in the vicinity of water stimulates shoot regrowth and increases leaf nitrogen and phosphorus levels. Carbohydrate demands are increased as a result of accelerated regrowth, giving rise to a carbohydrate deficit and consequent reduction of secondary metabolite synthesis. Increased shoot and leaf nutrients, together with reduced defence chemicals, usually constitutes palatable browse (du Toit *et al.* 1990). While these results focus on the advantages associated with heavy defoliation around water, preliminary evidence from this study suggests that severe defoliation of *A. nigrescens* ultimately leads to replacement of this species by less palatable species.

7. IMPACTS ON SOIL PROPERTIES

Land degradation, as defined by the UNEP (1992), is the result of ‘irreversible changes, reflecting loss of ecosystem resilience’. Abel and Blaikie (1989) specify that these irreversible changes should reduce productivity. Soil factors in dry lands are regarded as particularly critical, since unlike vegetation, they have a low resilience to degradation (Thomas 1993). While this may be true for most soils in arid regions, where soils have a low silt-clay fraction, e.g. in the Kalahari, this theory does not hold (Perkins & Thomas 1993a). According to Abel & Blaikie (1989), unless grazing is accompanied by soil degradation, resilience is seldom at stake and observed changes in Kalahari vegetation communities are perceived to be reversible. On robust soils, grazing alone may result in a change in plant species composition without changes to soil properties. Most changes in species composition however, reflect changes in soil water and nutrient availability (Dougill & Cox 1995).

7.1. Physical changes

Trampling is the principal factor responsible for soil physical changes in a grazing or browsing system. The degree of trampling is proportional to the number and weight of

animals utilising a site, and since water focuses animal activity in dry areas, it can be anticipated that trampling effects will increase with proximity to water. A number of changes in soil physical properties have been linked to trampling, and show a response pattern with distance from water. In South Australia increases in track or path development have been recorded close to water (Lange 1969; Andrew & Lange 1986a). Tracks showed a clearly defined radial pattern, and over time, intensity and area covered by tracks increased. Animal tracks or paths are areas of extreme trampling, where the changes in soil physical nature, as described below, are at a maximum.

Increased soil compaction and bulk density, and decreased water infiltration in the vicinity of water points has been recorded by Perkins and Thomas (1993a) in the Kalahari, and by Andrew and Lange (1986a) in South Australia. In both cases changes in compaction and infiltration were limited to the immediate area around the water point. In the Kalahari study, changes in infiltration capacity, soil surface resistance and subsoil compaction, while significantly different at the water trough itself, did not vary consistently with distance from water. In the Kalahari, localised impacts on soil physical characters are attributed to the low silt-clay fraction of the soils, and imply that soils with a higher sand fraction are more resistant to physical degradation. In the Australian case, changes in soil compaction, bulk density and wetting front did not extend beyond 30 m from the water trough. Increased compaction and runoff not only reduces water infiltration and subsequent plant water availability, but it also decreases the potential for seedling establishment (Stafford Smith & Pickup 1990).

Excessive trampling results in the destruction and loss of the herbaceous layer close to water, and bare areas, where detached soil particles are available for transport are prone to erosion (Pickup & Chewings 1988; Stafford Smith & Pickup 1990). Where infiltration rates are low, and slope gradient is high, erosion potential is expected to increase, especially where animal paths concentrate flow, which may result in gully formation (Whitlow 1980). Despite the increased potential for erosion near water points, Kalahari research has shown no water erosion (Perkins and Thomas 1993b) and limited wind erosion around water points. Wind erosion surface ripples were restricted to the sacrifice zone, in this case 400 m from the water point (Perkins and Thomas 1993a). Gentle gradients and high infiltration rates reduce erosion potential in Kalahari sands.

High infiltration rates are attributed to the low silt-clay fraction of these soils.

Many range managers, and particularly cattle ranchers, perceive soil cryptogams or lichen crusts as a negative indication of range condition (pers. obs.). Holistic resource managers believe that the lichen crust forms an impermeable layer, which reduces water infiltration and prevents seedling establishment (Savory 1996. Pers. comms.). In reality, the soil cryptogam may offer many benefits including soil nitrogen fixation (Rogers *et al.* 1966) and reduced soil erosion (Johansen 1986, unseen, as cited by Pieper & Heitschmidt 1988). No lichen taxa of the soil crust are 'increaser' species (Rogers & Lange 1971), and as is characteristic of 'decreaser' species, the cryptogam crust in Andrew and Lange's (1986a) sites show a decline with increased utilisation and proximity to the water point.

7.2. Chemical changes

Dung deposition is a good correlate of time spent by animals in an area (Andrew & Lange 1986a; Tolsma *et al.* 1987; Dougill & Cox 1995) and number of animals using an area (Weir 1971; Tolsma *et al.* 1987). Dung and urine contains large quantities of essential plant nutrients such as nitrogen, phosphorus and potassium (Weir 1971; Tolsma *et al.* 1987). The amount of dung deposited per hectare can be translated to nutrient inputs per hectare (Weir 1971). In Eastern Botswana, the creation of artificial water points resulted in an increase in nutrients near boreholes as a result of increased dung deposition (Tolsma *et al.* 1987). In many cases the transport of nutrients by cattle (Tolsma *et al.* 1987) and game (Weir 1971) is centripetal towards the water point. This means that nutrients are being removed from one area (further from water) and deposited in another (close to water). Phosphorus in particular, is prone to deficiency in heavily grazed areas (Weir 1971; Tolsma *et al.* 1987; Dougill & Cox 1995; Hatton & Smart 1984). Weir (1971) described phosphorus levels (in the form P_2O_5) of soil and grass with distance from a pan along a transect which graded from a grassland into a woodland. Except for the region close to the pan, which had exceptionally high phosphorus levels, and the scrub and elephant impacted woodland fringe (3 - 5.5 km), which had very low phosphorus levels, all other regions showed similar values of soil and grass phosphorus. Weir (1971) suggests that the phosphorus being depleted from the woodland fringe was being deposited close to water. It is likely that the spatial change in nutrient status in response to

the presence of a pan will lead to further changes in plant species composition. According to Weir (1971), it is probable that the fringe of annual grasses, only found around artificially maintained pans, are able to outcompete perennial species as a result of their ability to thrive under conditions of high phosphorus (and other nutrients). He further speculates the possible change (already observed at the time of the study) in grass species composition of the scrub and woodland fringe, to dominance by species tolerant of low soil phosphorus levels. In general, in the Kalahari and Botswana, the zone of increased organic input is confined to within 100 m of a water point (Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995). Depending on the age of a water point, the density of animals using it, and the number of obstructions to movement (e.g. number and distribution of trees or shrubs), figures varied slightly (Tolsma *et al.* 1987). In contrast, in Hwange, Weir (1971) found that dung deposition within a grassland peaked at 1 km from the pan, while that in a woodland peaked at 0.5 kms. The differences in location of nutrient peak levels between Tolsma *et al.* (1987), Perkins & Thomas (1993a & 1993b) and Dougill & Cox's (1995) Kalahari studies (<100 m), and Weir's (1971) Hwange study (0.5 - 1 km), may be attributed to the fact that the first four piosphere studies investigated the effects of domestic stock around a water point, while the fifth study, that by Weir (1971), investigated the impacts of wild ungulates and elephant on the environment surrounding a pan. Wild animals are more skittish than cattle, and tend to spend relatively less time in the immediate vicinity of water, where they are easy targets for predators (Smuts 1978; Senzota & Mtsho 1990). This may offer an explanation for the dung deposition peak in the Hwange study being at a greater distance from water than in the other four studies. The difference in dung deposition peaks in the woodland and grassland in the Hwange study may be the result of animals spending more time close to water (0.5 km) in the woodland where they are hidden from predators, than in the grassland (1 km) where they are exposed. While dung deposition is a good correlate of time spent in an area, it is not necessarily a good indication of defoliation pressure (Taylor *et al.* 1986, *unseen*, as cited in Andrew & Lange 1986a). For example many piosphere studies show that more dung is either deposited close to water, where there is little palatable forage, and consequently little foraging (Tolsma *et al.* 1987), or it has been deposited away from areas of heavy defoliation as suggested by low phosphorus levels (Weir 1971).

8. IMPACTS ON THE VEGETATION

Species composition and structure of vegetation surrounding water points is altered by herbivore activity. Changes in vegetation occur directly as a consequence of grazing, browsing and trampling. Indirect changes in floral species composition occur as a result of the modification of environmental factors. These include changes in the physical and chemical properties of soils, and changes in competitive potential and light availability through the loss or introduction of new plants. Since the factors to which plants respond (defoliation, trampling, and fertilisation) show patterns of variation with distance from water, it would be expected that plant species composition and structure would follow similar patterns. Most Kalahari piosphere studies describe a consistent pattern in vegetation change with distance from water (Child & Parris 1971; Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995). These patterns usually grade from a sacrifice zone (described in section 5) close to water, followed by a bush encroached zone, then a zone of palatable grasses and finally, a zone of under-utilised, unpalatable grasses. The extent of each zone varies between studies, and it is important to note that communities are not discrete, but represent a continuum of change along a gradient of animal utilisation intensity (Perkins & Thomas 1993a). Field (1977) defined 'vegetation damage' in a predominant grazing system as the increase in bare ground (as evident in the piosphere sacrifice zone), encroachment of woody shrubs and trees and the replacement of high herbage production species by less productive species. Kalikawa (1990) argues that encroachment of woody shrubs and trees may not necessarily represent ecological degradation in a wildlife system where, in addition to grazers, there is a large component of browsing species. An increase in woody plants close to water may be attributed, not only to the competitive advantage that woody plants have over grasses following heavy defoliation and suppression of the latter (Whitlow 1983; Skarpe 1990), but also to an increase in the size of the woody seed-bank (Perkins & Thomas 1993b). Browsing animals, as well as cattle, ingest many *Acacia* seeds (Tolsma *et al.* 1987), which are transported in dung and deposited close to water. Seed germination is stimulated after passing through the digestive tract of animals, and the fertile soil environment close to watering points (described in section 7.2) encourages seedling survival. Many of the

common bush encroachment species, e.g. *Acacia* species and *Dichrostachys cinerea*, thrive on fertile soils, and although they are palatable they are often spinescent (Owen-Smith & Cooper 1987; Tolsma *et al.* 1987), even at the seedling stage. These physical defence mechanisms reduce herbivory to some extent (Owen-Smith & Cooper 1987). Zoochorous seeds, those that are transported by adhering to animals bodies, also accumulate in the vicinity of water, or along animal paths leading to water (Tolsma *et al.* 1987; Andrew & Lange 1986b). Many forb and pioneer grass seeds e.g. *Tribulus terrestris* and *Tragus berteronianus* are transported in this manner, and these particular species are often reported to increase in the vicinity of watering points (Tolsma *et al.* 1987; Thrash *et al.* 1993; Perkins & Thomas 1993b). While the seedbank of generally ‘undesirable’ species increases with proximity to water, that of ‘desirable’ or palatable species often declines. Preferred species are constantly being defoliated and are unable to set seed before they die. Consequently the seed bank of these species is depleted (Andrew & Lange 1986b) and this ultimately leads to the replacement of palatable species by less palatable species.

8.1. Herbaceous changes

Grazing pressure close to water is generally several times greater than that further away (Pickup & Chewings 1988). This is due to the fact that available grazing area increases exponentially with distance from water (Figure 3), and animals constantly utilise the relatively small area close to a water point on their way to and from drinking.

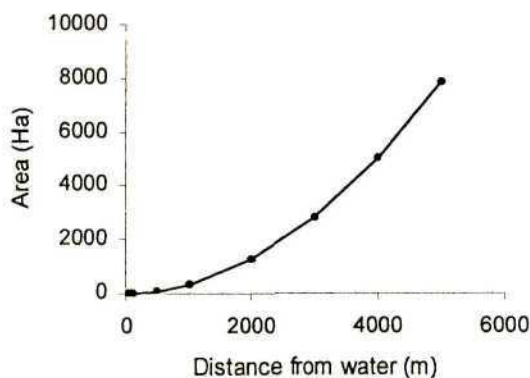


Figure 3. The relationship between range area and distance from a water point (Adapted from Perkins & Thomas 1993b).

As stated above (section 6), the degree of impact to rangeland around a water point depends on a number of factors, including the age of a water point and the number of animals utilising it. In general, heavily utilised or overgrazed rangelands exhibit a reduction in highly preferred grasses, forbs and shrubs and an increase in the non-palatable species, particularly woody species (Pieper & Heitschmidt 1988). Thrash *et al.* (1993) documented a shift in the herbaceous community composition from perennial species to annual species as watering points were approached. This change in species composition resulted in a decline in forage production and soil surface protection. It must be noted that while annual grass production is low relative to perennial grass production, annual species foliage is usually of higher nutritive value than that of perennial species (Kelly & Walker 1976). Perennial grasses are generally poor competitors under intensive utilisation (Stafford Smith & Pickup 1990). Annual species are better adapted to intensive utilisation, but these species inherently have a low basal cover, and their foliage provides little protection to the soil surface. In contrast, perennial grasses generally have a larger basal cover and are able to capture rainwater in their foliage and funnel it into their rhizospheres via their tuft bases (Kelly & Walker 1976). Although the replacement of perennial species by annuals is common in semi-arid grazing systems, a few piosphere studies have shown surprising results with respect to the distribution of three palatable perennial grasses, namely *Urochloa mosambicensis*, *Digitaria eriantha* and *Brachiaria nigropedata*. In separate studies, and in localised areas, these three species have shown an increase in cover with proximity to a water point. Case studies are discussed below.

In the Kalahari Desert, Botswana, regions of low herbivore utilisation (> 1500 m from boreholes) were associated with palatable grasses such as *Antheophora pubescens*, *Schmidtia pappophoroides* and *Eragrostis nindensis*. Heavily utilised sites closer to boreholes were dominated not only by unpalatable or low bulk species such as *Perotis patens* and *T. berteronianus*, but also by the perennial species *B. nigropedata* and nutritious *D. eriantha*. The latter species was most strongly correlated with this zone (Perkins and Thomas 1993a; 1993b). In Kruger, a similar decline in basal cover of *S. pappophoroides* was found near a dam, but *D. eriantha* declined in the vicinity of the water point (Thrash *et al.* 1991a), illustrating that under different environmental conditions the same species may respond differently to a similar disturbance. The

unpalatable *Pogonarthria squarrosa*, and palatable perennial *U. mosambicensis* increased in the vicinity of the dam. In a separate study in the same area, the latter species also increased close to troughs (Thrash *et al.* 1993). In the former study significant positive relationships between percent total basal cover of the herbaceous stratum, percent basal cover of grasses and forbs and percent basal cover of both the increaser and decreaser ecological groups were found with distance from water. While the regression line for the decreaser group was a logarithmic curve reaching an upper asymptote after 2 km, that for the increaser group was linear implying that the upper asymptote would only be reached beyond the distance sampled in their study. This suggests that the increaser ecological group, which is generally considered less vulnerable to high utilisation, was more affected by the presence of the dam than the decreaser group. Similar trends were found for grass and forbs, with forbs demonstrating greater sensitivity to the presence of the dam. Variables which show positive relationships with distance from water are those which have been negatively impacted by the presence of the dam. Only a few species, namely *P. squarrosa* and *U. mosambicensis* appeared to benefit from the establishment of the dam. Thrash *et al.* (1991b) also studied the impact of game on the woody vegetation around the same dam. Their results suggest that in response to the effects of the dam, the herbaceous stratum is more sensitive than the woody stratum. This is attributed to the greater susceptibility of the herbaceous component to trampling. While herbaceous composition may be more severely affected by heavy utilisation around waterholes at a given point in time, the woody component is probably more seriously affected over the long term (Laws 1970). Changes to the woody component are longer lasting because of the longer growth cycles (several hundred years in the extreme case of the baobab) of trees relative to grasses and forbs, and therefore a longer replacement time (Laws 1970). Modification of the woody strata (section 8.2) will, however, have a marked effect on the micro-climate for herbaceous plants (Bromwich 1972; Hatton & Smart 1984). Changes in the availability of essential plant resources such as light, nutrients and water may result in a change in herbaceous community composition.

8.2. *Woody changes*

Kalahari piosphere studies consistently show an increase in woody vegetation as a consequence of the water point (Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995; Child & Parris 1971). Similar results are however not common in other areas where herbivore mix differs. The Kalahari sites, and the study sites discussed below differ considerably in climate and geology. While these environmental factors may play an important role in the observed differences in response of woody plants to permanent water, it is possible that the type of animals in each area may influence the results. In the Kalahari studies, few browsers and no elephants were present, while in the studies discussed below, elephants and browsers constitute a large proportion of the herbivore biomass. The reaction of woody plants to increased utilisation in the vicinity of water varied in wildlife areas with elephants. Some results showed no change in total woody canopy cover, woody community composition, species richness, or relative woody density with distance from water, while others showed changes based on selective defoliation or damage (Thrash *et al.* 1991b). Since defoliation or damage to selected height classes, species or individuals increases with increased herbivore density, it follows that preferred plants will be more severely defoliated or damaged close to water.

Utilisation and damage to woody plants accelerates during the dry season (section 6.5) as the availability of surface water and grass moisture content decreases (Napier Bax & Sheldrick 1969; Western 1975; Bell & Jachmann 1984; Pellew 1983). Species selectivity (Buechner & Dawkins 1961; Anderson & Walker 1974; Guy 1976; Thrash *et al.* 1991b), height class selectivity (Laws 1970; Anderson & Walker 1974; Guy 1976; Thrash *et al.* 1991b), and individual plant selection (Buechner and Dawkins 1961; Pellew 1983; Laws 1970; Anderson & Walker 1974; du Toit *et al.* 1990) have been recorded in studies both in the vicinity of water, and away from it. Although no relationship between relative total canopy cover and distance from the dam was detected in the Kruger study (Thrash *et al.* 1991b), significant logarithmic relationships were found for particular height classes and woody species selectively taken by browsers, particularly by elephants.

Canopy cover of woody plants > 0.5 and ≤ 2 m decreased with proximity to water in the Kruger Park (Thrash *et al.* 1991b), suggesting selective browsing of individuals in this height class. Guy (1976) also found that elephants in Sengwa, Zimbabwe, mostly

browsed woody vegetation between 0.57 m and 2 m in height. These results are not consistent in all parts of Africa. Dublin *et al.* (1990) and Pellew (1983) in the Serengeti and Mwalyosi (1990) in Tanzania, found that elephants selectively ignore seedling and regeneration less than 1 m in height. Utilisation of browse under 1 m is attributed to browsing antelope (Pellew 1983). Where browsing of the smaller height classes is severe, replacement of mature canopy trees is prevented and the maintenance or perpetuation of future canopy woodland is precluded. An example of a situation where seedling development into mature trees is largely prevented by severe defoliation is the Mana Pools floodplain in Zimbabwe. This is evidenced by the prolific growth of woody saplings inside an herbivore enclosure. There is no such woody sapling growth or survival outside of the enclosure (pers. obs.). Large numbers of browsing antelope concentrate on the floodplain close to the river and their continued severe browsing of small woody plants and seedlings prevents their development to mature canopy trees. When the current canopy trees die, the woodland will be replaced by an open area or grassland with small woody plants held at this height by browsing. Changes in woodland structure or physiognomy also occur following heavy elephant damage to mature trees (Anderson & Walker 1974; Pellew 1983; Cumming *et al.* 1997). Because vegetation utilisation increases with proximity to water, the effects will be more pronounced close to water (Graetz & Ludwig 1978). In Kruger Thrash *et al.* (1991b) recorded an increase in the density of small stems (< 20 mm in diameter) and short (≤ 1 m in height) *Combretum apiculatum* plants as the water point was approached. The authors attributed the increase in individuals of smaller height classes, not to recruitment of new individuals, but rather to recoppice of taller plants damaged by elephants. The similar increase in *C. apiculatum* stems < 20 mm in diameter close to water was probably also due to regrowth from a persistent root stock. Thrash *et al.* (1991b) speculate that the density of *C. apiculatum* regrowth in the short height class will be directly proportional to the amount of damage to *C. apiculatum* plants in taller height classes. Pellew (1983) found that in the Serengeti, heavy elephant utilisation of mature canopy trees lead to a conversion of high canopy woodland to regeneration thicket. A similar change in physiognomic structure of vegetation was observed by Anderson and Walker (1974) in Sengwa research area. In this study it was found that elephants were responsible for approximately 63 % death or

conversion of trees to shrubs over a seven year period. According to the authors, most damage occurred along drainage lines and routes taken to and from water. In many wildlife areas a mature canopy woodland is desired for its aesthetic appeal (Pellew 1983). In contrast low regeneration thicket obscures game viewing by reducing visibility.

Disturbance, like vegetation change, is a natural phenomenon that can have diversifying effects (Anderson & Walker 1974; Mwalyosi 1990). Elephants can aid woodland regeneration by uprooting or killing canopy trees, thereby allowing suppressed saplings to grow out (Childes & Walker 1987; Mwalyosi 1990). Mwalyosi (1990) found that in *Acacia tortilis* woodland in Manyara National Park, Tanzania, elephants were responsible for thinning out the mature closed canopy. Their removal of tall trees created light gaps which encouraged regeneration and recruitment of *A. tortilis* seedlings.

Woody mortality is greater for all height classes close to water, but is most pronounced for tall trees i.e. > 2 m (Thrash *et al.* 1991b). According to Field (1971), elephant damage to tall trees has a far greater effect on survival than damage to smaller trees. In line with this, Anderson and Walker (1974) state that shrubs are likely to regenerate faster than trees following damage.

It appears that elephants alone are rarely responsible for the death of the trees (pers. obs.) that they damage. In many cases elephant damage initiates the death process by injuring trees and making them vulnerable to attack by insects, fungi (Anderson & Walker 1974; Thomson 1975), fire (Buss 1961; Buechner & Dawkins 1961), or excessive browsing (Pellew 1983). In Chizarera Game Reserve, Zimbabwe, Thomson (1975) found that most, if not all trees damaged by elephants ultimately died as a result of breakdown by other organisms such as borers and fungi. Trees such as *A. tortilis* which have soft wood, are particularly susceptible to damage by wood boring insects (Thomson 1975). Fire causes severe damage, and ultimately mortality, when it follows fresh debarking or breaking, before fire resistant cork layers are formed (Buechner & Dawkins 1961). In many cases fire is responsible for preventing regeneration of plants damaged by elephants (Buechner & Dawkins 1961; Pellew 1983). In a similar way, browsers prevent regeneration of canopy trees whose height and available browse has been reduced by elephant damage to heights accessible to shorter browsers. Preliminary investigations indicate that continued severe selection of previously damaged or browsed plants can

ultimately lead to the death of targeted individuals (du Toit & Bryant, *unpublished manuscript*, unseen, as cited in du Toit *et al.* 1990).

A number of studies have shown that animals preferentially select previously browsed or damaged individual plants. Buechner and Dawkins (1961) observed a preference for severely damaged trees by elephants in Murchison Falls National Park, Uganda. Animals repeatedly attacked damaged trees rather than browse on less damaged adjacent trees. Similarly, Anderson and Walker (1974) in Sengwa, and Laws (1970) in East Africa found that elephants preferred to browse on new regrowth from previously damaged trees. Selection for regrowth has also been recorded for giraffe in the Serengeti (Pellew 1983) and in Kruger (du Toit *et al.* 1990). The reason for this selection has been attributed to the increased nutrient content of regrowth and has been described in more detail above (section 6.5).

Numerous studies report selection of particular woody species by browsers and elephants (Buechner & Dawkins 1961; Napier Bax & Sheldrick 1963; Laws 1970; Anderson & Walker 1974; Guy 1976). Within a single community, herbivore damage among species is considered primarily a reflection of palatability differences between species (Coley *et al.* 1985). Forage quality plays a part in selection, and some scientists have found correlation's between selected species and the nutrient content of browse (Napier Bax & Sheldrick 1963; du Toit *et al.* 1990), others have found no correlation at all (Anderson & Walker 1974). Still other scientists attribute disproportionate damage of species to the height of forage (Guy 1976), or the ease with which trees can be pushed over (Van Wyk & Fairall 1969; Guy 1976). In the Kruger study (Thrash *et al.* 1991b), *C. apiculatum* was more severely impacted than *C. mopane* as the dam was approached. While survival rates for both species decreased with proximity to water, mortality was greater for the former species. In addition to this, *C. mopane* canopy cover and density showed no relationship with distance from water, but that of *C. apiculatum* did. These results suggest either greater sensitivity to utilisation, or preferential selection for the former species. Guy (1976) also detected disproportionate selection for *Combretum* species over *C. mopane* in Sengwa. In contrast, three Zimbabwean studies, one in Sengwa research area (Anderson & Walker 1974) and the other two in Gonarezhou National Park (Bromwich 1972; Tafangenyasha 1997) have reported elephant preference for *C. mopane*.

It would appear that species preference varies from area to area depending on the suite and abundance of species available. Although this species is heavily utilised, both Anderson & Walker (1974) and Bromwich (1972) comment on its resistance to damage. In Gonarezhou, Bromwich (1972) recorded that elephant damage to *C. mopane* woodland in the immediate vicinity of an artificially maintained waterhole amounted to 47 % two years after the introduction of water. Damage declined with distance from water, and at approximately 800 m away from the waterhole amounted to 23 %. Within a two year period most of the trees surrounding the pan had been broken or uprooted by elephants and damage to all trees amounted to over 77 %. Bromwich (1972) found that although *C. mopane* trees sustained more damage than other species, mortality of these plants was less than for other species. Anderson and Walker (1974) also report of the resistance of *C. mopane* to heavy utilisation as evidenced by the amount of regrowth following damage. These views would support the results found by Thrash *et al.* (1991b), which indicate a greater resistance of *C. mopane* than *C. apiculatum* to increased utilisation around a water point. The ability of a species to withstand heavy utilisation should be considered when siting new perennial water. Thrash *et al.* (1991b) found that *C. apiculatum* is more often pushed over or broken than *C. mopane*. Selective destruction of *C. apiculatum* over *C. mopane* is attributed to the fact that the former species is more easily pushed over than the latter (Van Wyk & Fairall 1969; Field 1971; Guy 1976). Selective browsing of preferred woody species has resulted in the replacement of more valuable forage (and timber) species by less valuable species (Buechner & Dawkins 1961; Laws 1970; Anderson & Walker 1974). In Sengwa, Anderson and Walker (1974) reported that the preferred riverine species, *Acacia robusta* and *Grewia flavescens* have declined markedly as a result of elephant damage, the latter species being replaced by *Combretum mossambicense*.

9. IMPACTS ON BIRD AND MAMMAL POPULATIONS

Environmental conditions determine the success of particular species, because species which compete better under one set of environmental conditions may not perform well under another (Keddy 1992). Changes in environmental conditions generally lead to an increase in certain species at the expense of others. Availability and type of food, cover (perching or nesting sites for birds) and water (Collinson 1983) are environmental factors which influence the success of birds and animals. The introduction of permanent water will change all three of these factors to some degree, either directly or indirectly. Predation and disease spread are also influenced by the provision of water.

9.1. *Water, food and cover*

The water requirements of different species has been dealt with in some depth (section 6.5.) and for the purpose of this section the three groups based on dry season home range size (Figure 2, section 6.5) will be considered: *mobile water-dependent* species, *non-mobile water-dependent* species and *water-independent* species.

Food requirements vary considerably between species. Herbivores are grouped into three major categories based on food selection. *Grazers* represent species whose diet consists predominantly of grass, *mixed feeders* feed on grass, forbs and woody plants, while *browsers* rely almost exclusively on twigs, leaves, pods and flowers for their nutritional requirements. Of the species that graze, some require high quality, short, sparse stands of annual grasses. Impala and warthog fall into this group. Buffalo and zebra require bulk, while wildebeest, white rhino and waterbuck require forage between the two extremes (Collinson 1983). These three groups include the more common species. Sable, roan and hartebeest, the rarer species, fall into a separate group, since they selectively feed on medium to tall stands of perennial grass. Although there is some separation between grazing species based on forage height and ecological group, there is a great deal of overlap, which means that competition for forage between species exists (Collinson 1983).

Cover facilitates escape from predators or extreme weather conditions. Based on a species 'escape strategy', habitat selection will be determined by the type of cover that

affords either the opportunity to hide from, or escape from predators. Species which require open habitats, and which rely on seeing predators in advance and running from them, include zebra, wildebeest and hartebeest. Woodland or thicket species such as nyala, kudu and bushbuck require a closed habitat in order to hide themselves and their calves from predators. Similarly sable, roan and reedbuck (*Redunca arundinum*), which require tall perennial grass for feeding, hide their young in the long grass.

Due to the increased pressure around a water point, vegetation and soils are impacted with increasing severity as the water point is approached (section 5). The environment around the water point is modified, and, depending on a number of factors, some of which include the age of the water point and the number and species of animal utilising it, the effect can, in extreme cases, extend as far out as 8 km from the water point (Van der Schijff 1959; Pickup 1991). Concentric zones of impact develop around a theoretical water point, and the new environments in each zone either promote or suppress particular species, based on their requirements for water, food and cover (Figure 4).

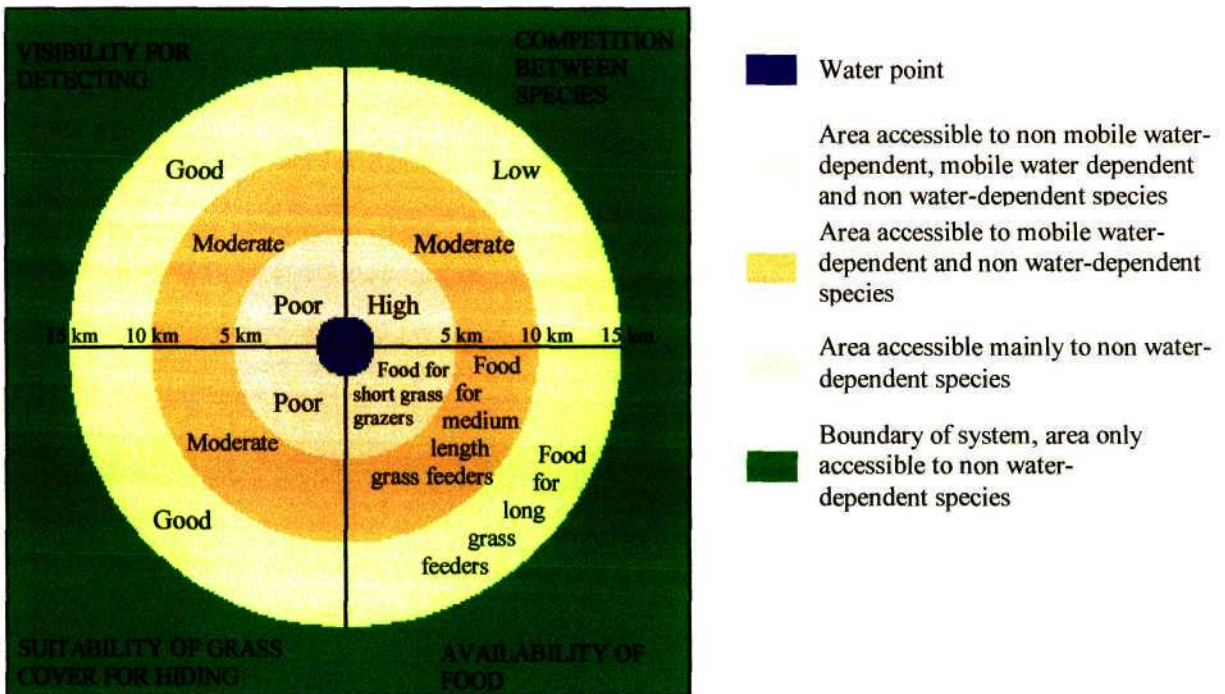


Figure 4. Simplistic diagram illustrating utilisation of environment by various species, competition between species and availability of living requirements (Adapted from Collinson 1983).

The development of a piosphere is a natural phenomenon which increases biodiversity, however, where water points are located uniform distances apart, and too close to one another, it is hypothesised that veld is grazed or browsed down to the same level, and the habitat becomes homogenous (Figure 5). Over-grazing close to water leads to a decline in grass cover and fuel load, which results in low frequency and intensity fires. Low fire frequency and intensity encourages bush encroachment (Collinson 1983). Uniform heavy grazing obviates a grading from short, heavily utilised grass close to water, to tall lightly utilised grass further away. In this situation, species which rely on lightly impacted vegetation for food and cover (generally the rarer species defined above) will be eliminated, while species which flourish under more heavily utilised environments (usually common species defined above) will increase as more range and food becomes available to them.

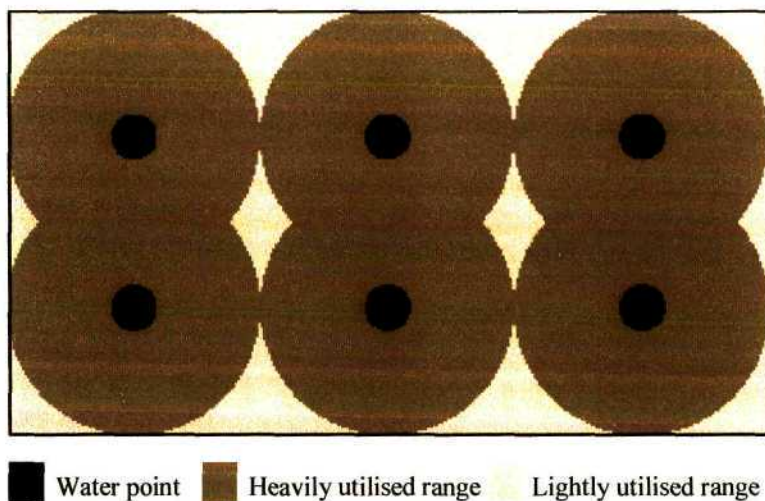


Figure 5. Diagram illustrating the hypothetical situation when water points are situated uniformly and too close together (Adapted from Collinson 1983).

In systems where the introduction of dry season water allows water-dependent species access to all parts of the veld, animal numbers escalate (carrying capacity of the land increases), as more suitable habitat becomes available to them. In many cases carrying capacity is exceeded, and while surface water may be sufficient to sustain the increased animal densities through drought periods, the available forage is not. When drought

strikes, massive starvation induced die-offs occur because forage resources are depleted (Owen-Smith 1996). In most cases, and particularly in areas where additional dry season water has been supplied, it is forage, rather than water, that controls herbivore survival through drought periods (Van Rooyen *et al.* 1990; Perkins & Thomas 1993b; Owen-Smith 1996). Animal populations in two adjacent pieces of land with dissimilar placement of water are compared by Walker *et al.* (1987) following the 1982-1983 drought. The two areas compared are the central area of the Kruger National Park and the Klaserie Private Nature Reserve. Mean water point spacing in the two sites was >10 km and 2 km respectively. Prior to the drought Klaserie carried a total biomass of ungulates 40 % greater than the adjacent section of Kruger. Following the drought, the biomass of ungulates in the Klaserie was 40 % lower than that in the Kruger section. To give an idea of how different species under different stocking rates were affected by the drought, losses suffered by species in the two areas are given below (Table 3).

Table 3. Percentage mortality of species in the Klaserie Private Nature Reserve and the adjacent central area of the Kruger National Park following the 1982-1983 drought (Figures adapted from Walker *et al.* 1987)

Species	Klaserie PNR	Kruger NP
Wildebeest & Zebra	80 - 90%	<10%
Buffalo & Waterbuck	80 - 90%	30%
Impala	75%	35%
Sable	92%	15%
White Rhino	69%	Unaffected

Owen-Smith (1996) attributes the difference in herbivore mortality between sites to the differences in mean water point spacing. Water point placement in the Klaserie allowed all species access to all range, so no grazing reserves remained and animals starved to death during the drought. The abundance of water in the Klaserie supported inflated stocking levels in the short term, but at the expense of the populations ability to survive severe droughts.

Land managers in the past have tried to spread the utilisation of animals across the landscape by introducing water to relatively under-utilised areas in the hope of relieving pressure and degradation on areas originally close to water (Goodman 1982; Collinson 1983). Results did not yield the desired effect. In the long term, the additional water did not reduce the high animal numbers and heavy utilisation in areas originally with water, but it did increase animal numbers and degradation in areas where water was newly introduced. Populations of water dependent species that do not require tall grass, exploded as more habitat became accessible to them through the introduction of artificially supplied water (Goodman 1982). These animals included the more common species such as impala, warthog, zebra and wildebeest. Habitat that was once suitable for less competitive species, and tall grass feeders, was replaced by habitat suitable for the more common species that are good competitors for food, and do not require tall perennial swards. The increase in water dependent species is often paralleled by a decline in the number of water independent and rare species, as their habitat became modified by heavy utilisation (Goodman 1982; Owen-Smith 1996). Laws (1970) foresaw this when he wrote ‘...In situations where overpopulation already exist, the provision of artificial waterholes to spread (elephant) use, will almost invariably aggravate the problem by providing new foci for damage’.

Just as water dependent mammal populations exploded with the provision of permanent water, many water dependent bird species have become more abundant as their geographic ranges have expanded (Landsberg *et al.* 1997). Some bird species have declined as food sources and appropriate habitats have been reduced through increased herbivore utilisation. In Australia, where there are no megaherbivores, Reid and Flemming (1992, unseen, as cited in Landsberg *et al.* 1997) found that canopy dwelling birds increased in number while ground dwelling species declined as a consequence of perennial water introduction. They attribute this to the impacts of grazing on habitat of the latter group. Grass seed eating birds will probably be more severely impacted than fruit or insect eating species in heavily grazed areas. In Zimbabwe, in an area heavily impacted by elephants, Cumming *et al.* (1997) reported a decline in bird species diversity unparalleled in the adjacent woodland, similar in species composition, but not impacted by elephant. Cumming *et al.* (1997) attribute the decline in avian diversity to a change in woodland

physiognomy through elephant destruction of canopy trees. MacArthur (1964) who reported that bird species diversity is correlated with foliage height diversity in woodlands supports their assumption. The reduction of canopy trees will also mean a reduction in nesting sites for hole nesting birds and mammals such as squirrels. As already mentioned heavily utilised areas can be used as examples for what could happen around water points where herbivores concentrate.

9.2. Predation

Predators follow prey populations, and since prey concentrates around water, hunting opportunities for predators are greater in these regions (Young 1970a; Davison 1977; Smuts 1978; Berry 1982; Hitchcock 1996; Owen-Smith 1996). Young (1970a) found that in Kruger, more kills were made in the vicinity of perennial water during the dry season than during the wet season. The greater concentrations of game around perennial water during the dry season probably accounts for these differences. Based on ethological characteristics of game, certain species are more vulnerable to predators than others (Young 1970b). The intrepidity of sable and inquisitiveness of tsessebe (*Damaliscus lunatus*) make them easy targets for predators. A drastic decline in the roan antelope population 3 years after the 1982-1983 drought was reported in the Kruger Park (Harrington 1995, unseen, as cited by Owen-Smith 1996). Roan numbers crashed from 450 in 1986 to 45 in 1993. A similar but less severe decline in sable and tsessebe numbers was also observed. The decline was attributed to a combination of increased predator and grazing pressure following the 1982-1983 drought. As little forage remained in the zebra and wildebeest dominated areas after the drought, these species, followed by lions (*Panthera leo*), moved north to the areas occupied by roan antelope, where forage resources still remained close to water. The increase in zebra and wildebeest populations in the roan range suppressed grassland recovery and drew increased numbers of lion to the area (Owen-Smith 1996). The suppression of grassland recovery by wildebeest following disturbances other than drought, e.g. heavy domestic grazing, has been reported elsewhere (Parris 1984). In an attempt to halt the decline in roan numbers, 12 water points in the roan range were closed in 1994 in the hope of encouraging an exodus of zebra, wildebeest and lion.

9.3. Disease

Water points provide ideal situations for the spread of disease, both directly and indirectly. Disease spread is facilitated directly through increased physical contact of individuals and species congregating at water. For many parasites or viruses the water point provides an ideal environment for breeding (mosquitoes), survival (anthrax; foot-and-mouth, worms, fleas) or intermediate hosts (bilharzia). Both mud and water provide mediums for the survival and spread of disease. An investigation into the death of a large number of buffalo in the Kruger Park found that these animals were infested with bilharzia, and it appeared that bilharzia infestation was correlated with the regularity with which buffalo bathed (Young 1970a). Young (1970a) also found that bilharzia snails were not restricted to natural water points, but had spread to artificial water supplies and cement dams. The spread of anthrax has been associated with water points in Kruger (Young 1970a) and in Etosha National Park, Namibia (Berry 1982; Cloudsley-Thompson 1990). In Kruger, vultures have been implicated in contaminating drinking water with anthrax by bathing in it. In Etosha, gravel pits, formed during the construction of roads, filled with water during the rains, providing new sites for the spread of the deadly disease. According to Cloudsley-Thompson (1990) this led to the wildebeest population crash, where numbers dropped from 25000 to 2500 (90 % decline) in 30 years. Zebra numbers also declined from 16000 to 5000 over a shorter period.

While water points in one respect encourage the spread of disease, they also provide a means by which disease can be controlled. This is achieved either by introducing medication to drinking water, or concentrating game so that infected individuals can be darted and treated or exterminated (Young 1970a).

The placement of water plays an important role in the spread of disease. The closer water is placed, the greater the chances of disease spread. During the dry season large numbers of parasite eggs are deposited in dung in the vicinity of perennial water. These eggs only hatch with the onset of the spring rains, a time when animals have left their dry season range and moved to their wet season range (Young 1970a). As a result, most parasite eggs hatch and the larvae die before finding a host. Movements between wet season and dry season ranges can only occur where water is placed far enough apart to create grazing free zones. These zones are not utilised during the dry season, and forage is

reserved for the wet season when these areas again become accessible. Water placed too close together (Figure 5) makes all range accessible during the dry season, leaving no distinct wet season range. This means that there is no spatial separation between wet and dry season ranges and the incidence of infection increases. The placement of water near boundaries of protected areas is not advisable (Young 1970a), as it facilitates the migration of animals in and out of the protected area. The opportunity for disease to spread from the protected area to outside the reserve and vice-versa is logically correlated with animal movements across the boundary.

10. THE INFLUENCE OF CLIMATE

Semi-arid ecosystems are characteristically unstable, being subjected to wide variations in rainfall, fire and herbivore numbers (Walker & Noy Meir 1982; Thomas 1993). Because these systems have evolved under fluctuating environmental conditions, they are extremely resilient to permanent change, and they have the ability to recover from perturbations (Holling 1973). In these areas, short term extreme variation in vegetation cover are common and occur in response to erratic rainfall, which produces growth pulses (Van Rooyen *et al.* 1990; Pickup 1991; Perkins & Thomas 1993a). Foran (1987) found changes in cover of over 50 % in periods of less than 2 years. Following a growth pulse, moisture becomes limiting once more and plant activity is reduced (Pickup 1994). Vegetation dries off and is eaten, converted to surface litter or burnt. In a grazing system, the effect of defoliation and trampling results in a reduction of cover, which reaches a peak close to water (section 5). These effects become progressively smaller with distance from water, but progressively larger with time, until the next rainfall period. In situations where degradation has not occurred and where the grazing effect is temporary, vegetation recovers following good rains and the grazing gradient disappears. Pickup (1991) defines degraded areas as those where the grazing gradient does not fully disappear in the growth pulse following heavy rainfall. This definition provides a useful classification measure with which to assess the severity of biosphere effects. A number of studies in arid and semi-arid systems have shown that where stocking concentrations are not excessive,

piosphere patterns for shrubs, forbs and grasses disappear during periods of rapid growth (Austin *et al.* 1981; Andrew & Lange 1986b; Perkins & Thomas 1993b). These findings confirm that the effects of climate on plant growth can override stocking effects where stocking rates are moderate to low (Andrew & Lange 1986b).

11. MANAGEMENT AND MANIPULATION

The importance of a spatial separation of wet and dry season ranges has been mentioned in connection with the spread of diseases and parasites, but it is also important with respect to maintaining quality forage. If water sources are not sufficiently widely spaced, the wet and dry season ranges overlap (Figure 5). The same range is continually utilised, and plants are deprived of a recovery period. Under natural conditions a recovery period would be achieved through the shift in utilisation between wet and dry season ranges. Owen-Smith (1996) proposes a geometric model for the placement of water in extensive protected areas. The model requires that the wet season range be twice the size of the dry season range in order to achieve similar utilisation. Owen-Smith (1996) cites a number of reasons for this: (1) Animals spend more time in the wet season range as water is only restricted to perennial sources for about four months of the year, (2) plants are less resistant to defoliation during the rainy season when they are growing, and therefore grazing pressure should be lighter, and (3) vegetation growing away from rivers or artificially maintained natural pans is probably not as resilient to disturbance because it does not benefit from increased soil moisture, clay and nutrients which accumulate in bottom lands.

For the 2:1 ratio of wet season to dry season range to be achieved, point water sources such as dams or pans, which have a radial effect on veld utilisation, should be separated by a distances of at least 3 times the potential daily travel distance of animals.

Most African ungulates easily travel distances of 5 km from water per day. According to Owen-Smith's (1996) model, this suggests that perennial water points should be placed at least 15 km apart (Figure 6a).

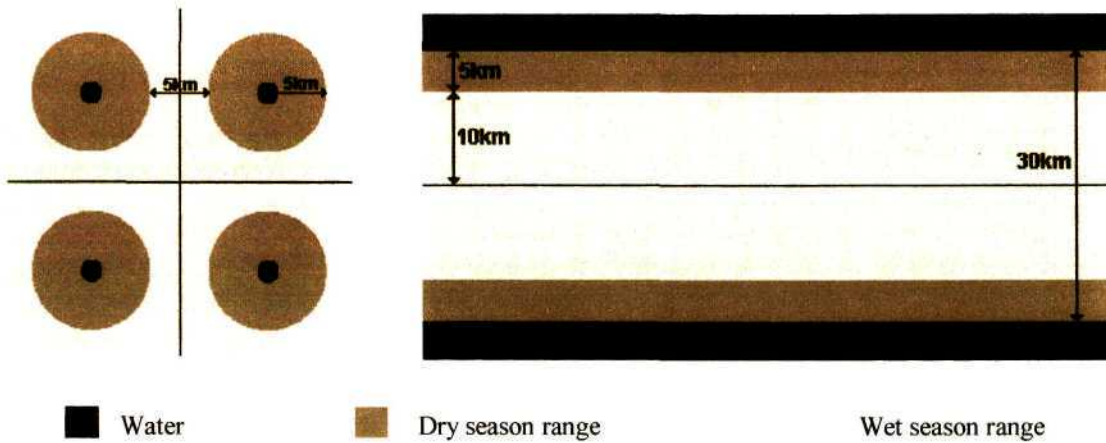


Figure 6. The geometric model for minimal spacing between perennial water points. (a) point sources, (b) rivers (After Owen-Smith 1996).

In order to achieve a 2:1 ratio between wet season to dry season range where rivers are concerned, spacing between rivers, or point water sources situated in an approximate line (less than 5 km apart), needs to be at least 6 times the average animal daily travel distance. Again using 5 km as the average daily distance travelled, this implies that for the 2:1 ratio to be met, rivers or point water sources described above, need to be at least 30 km apart (Figure 6b). The introduction of additional water points between rivers creates another ‘theoretical river’ that produces another dry season concentration zone, and proportionate loss of wet season range. In order to achieve a distance of 30 km (6 times the average animal walking distance) between theoretical rivers, the provision of additional water should not be considered unless the distance between rivers exceeds 60 km (Owen-Smith 1996).

Owen-Smith’s model primarily addresses the aspect of distance between water points. It is however important to be aware that there are a number of other issues, mostly site specific, that require consideration. Site sensitivity, the effect that increased utilisation has on different soils and vegetation types, is for example one aspect that should not be overlooked.

Different species react dissimilarly to the introduction of perennial water, and because water points are preferentially selected based on water quality, type of water point as well as surrounding topography and vegetation. Because of this, the provision of

additional water supplies a tool with which park managers can regulate species movements and numbers, and manipulate vegetation utilisation to meet park objectives. In section 6.5, the necessity for buffalo, elephant, black rhino and warthog to have clean drinking water as well as water with which to wallow is discussed. It is also reported (Young 1970a) that buffalo and elephant will move from one water point to the next, ‘muddying’ water and then moving on to find clean drinking water. If park managers aim to increase predictability of sightings of these two species, both clean water (which by the nature of the source should be difficult to dirty) as well as muddy wallowing water should be provided as part of the same watering point (Figure 7).



Figure 7. Buffalo show a distinct preference for clean water in troughs as opposed to muddy water in a pan. Elephants show the same preference (Photograph from Davison 1977).

The location of water points can be used to draw animals away from rare or sensitive vegetation or soil types, or it can be used to attract animals to areas which managers consider under utilised or require thinning. Pumping water with above average sodium content can make some pans more attractive to game, and particularly to elephants (Weir 1971). Because many additional water supplies are human controlled, being either pumped to or having gate valves, managers are able to empty or switch water supplies off to rest veld around water points when utilisation becomes excessive (Thrash *et al.* 1993).

In this way managers are able to rotate veld utilisation in much the same way as herding animals from one paddock to the next.

Augmenting water supplies should not be considered a 'necessary evil', but should rather be viewed as one of the most useful tools available to management in meeting the objectives of a park.

CHAPTER 3 : STUDY SITE

LOCATION

Malilangwe Conservation Trust (MCT) is situated in the southeast lowveld of Zimbabwe, between latitudes 20° 58' and 21° 15' S, and longitude 31°47' and 32° 01' E. MCT is made up of two properties: Lone Star Ranch, in the south, occupies just over two thirds of MCT; and Maranatha Ranch, in the north, occupies the remaining one third of the property. Together, the ranches cover an area of approximately 40 000 ha (Figure 8).

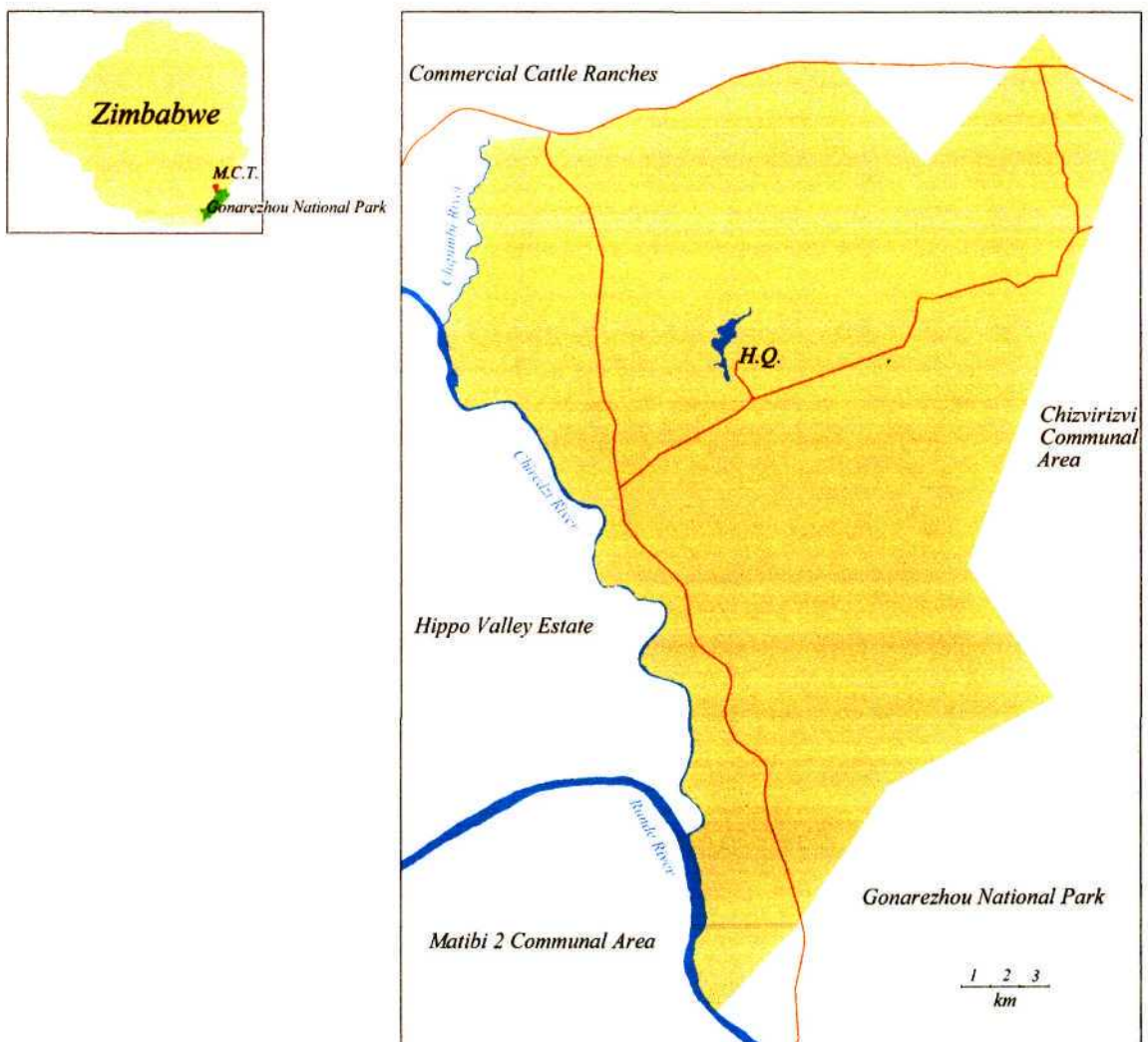


Figure 8. The location of Malilangwe Conservation Trust.

CLIMATE

An estimate of the mean annual rainfall for Malilangwe is 541.6 mm (rainfall records: 1951 - 1997), with most rain falling between November and March (Figure 9).

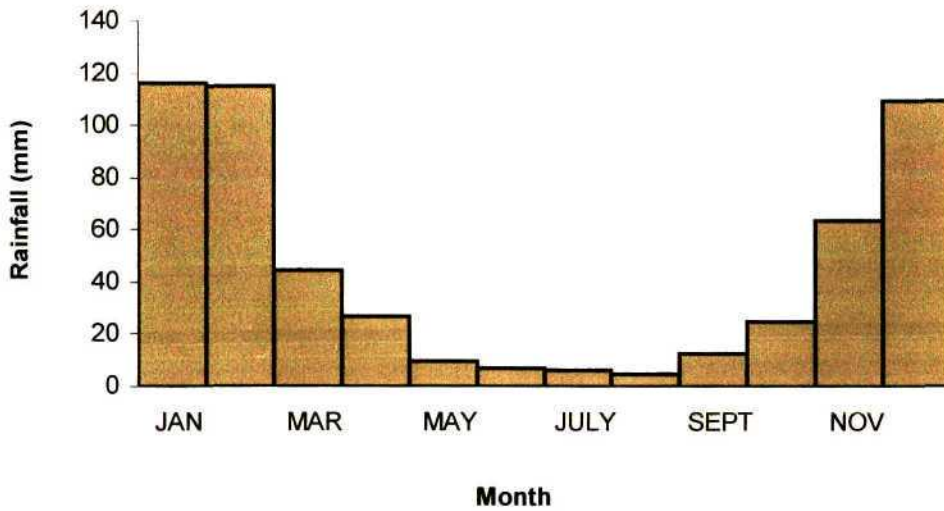


Figure 9. Mean monthly rainfall for Malilangwe.

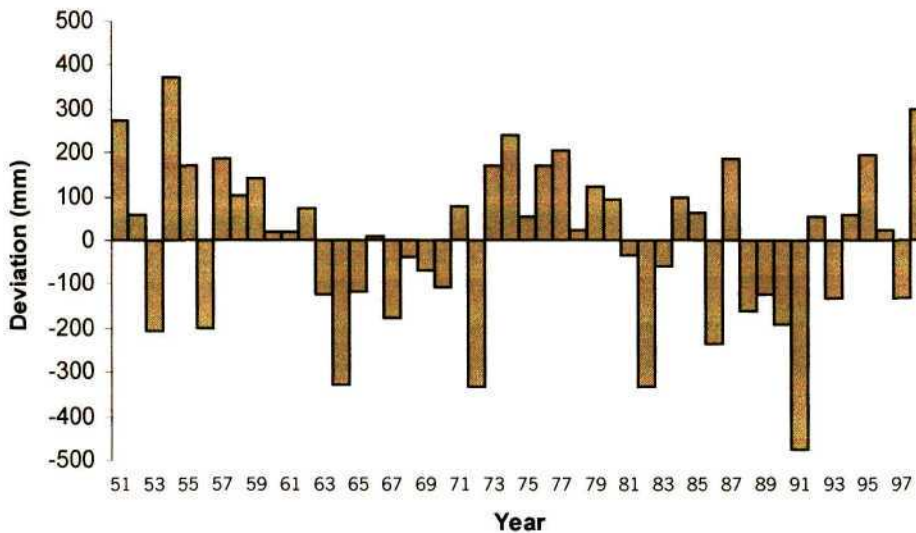


Figure 10. Malilangwe rainfall: Deviation from the seasonal (July – June) mean.

Rainfall is erratic (Figure 10) and the area is prone to droughts. It appears that the southeast lowveld experiences similar rainfall patterns to those experienced in the summer rainfall regions of South Africa. Tyson (1986) has proposed that in these regions rainfall largely follows a cyclical pattern. At Malilangwe cycles generally follow a sequence of approximately nine years of below average rainfall followed by nine years of above average rainfall (Figure 10). The 1991/1992 drought was exceptional, and probably unprecedented (O'Connor 1997) because the amount of rain that fell (72 mm) lies outside the 99 % confidence range as calculated by O'Connor (1997).

Mean summer temperatures range from around 22 °C - 36 °C (Ferguson 1995), but it is not unusual for temperatures to reach > 45 °C (Kelly & Walker 1976). Winter temperatures generally range between 5.5 °C and 25.5 °C (Ferguson 1995).

RELIEF, GEOLOGY AND SOILS

The main geological features of Malilangwe run in a north east to south west direction. Of these, the Malilangwe sandstone ridge is the most prominent. Topography gently declines in a south westerly direction towards the two major rivers in the area, the Chiredzi and Runde. The area is described as one of low relief (Booth 1980; Ferguson 1995) with altitudes ranging from 510 m at Hunyugwe to approximately 300 m above sea level (A.S.L.) in the south west of the property. A basic outline of the geology is given on the Relief map of Malilangwe (Figure 11).

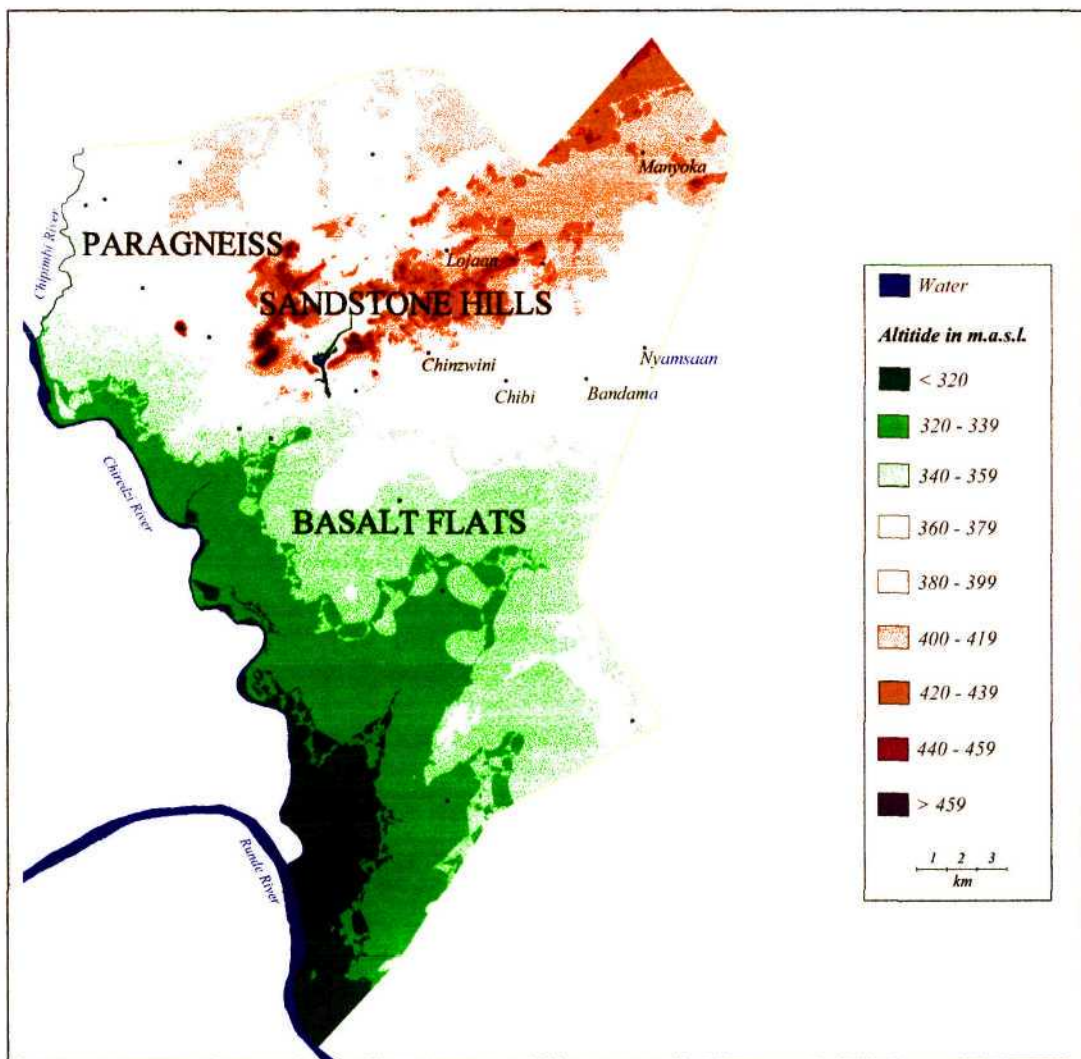


Figure 11. Relief map of Malilangwe.

The Malilangwe range, or the Hills, as they are referred to, are formed from rocks of the lower Karroo system and are cut by numerous faults (Swift *et al.* 1953). The upper sandstones, which are cream or white in colour, are of aeolian origin. The lower sandstones are red, and are poorly exposed at Malilangwe. Both sandstones weather to produce fine sand with less than 8 % clay (Elwell 1996).

Soils formed from paragneisses, which are the oldest rocks at Malilangwe (Swift *et al.* 1953), are found to the north of the Hills. These soils consist mainly of coarse grained sands formed from weathering acid gneiss and granulites of the basement complex. Numerous dolerite dykes, which run north east to south west, intrude these gneisses (Elwell 1996). The topography is gently undulating. Bare sodic patches, which are susceptible to gully, rill and sheet erosion, occur in bottom lands in the north west.

To the south of the Malilangwe range lies a moderately flat plain underlain by Jurassic basalt of the Umkondo system. As a consequence of the topography and parent rock, this area is referred to as the basalt flats. Upper members of the soil catena are generally shallow (5 - 20 cm), well drained (Elwell 1996), light brown sandy-clays. Soils situated lower in the catena are dark grey to black vertisols which are generally deeper than 1 m. Clay content can be as much as 56 % (Clegg 1999), and soils are prone to shrinking and swelling with changes in soil moisture content. When cracks seal, the soils may become waterlogged.

VEGETATION

Prior to this study a vegetation map separating areas based on biomass had been generated using satellite imagery (Stalmans 1994). While this map provides useful information regarding the spatial variation in biomass loads, it is too broad to provide information regarding the species composition of various communities and their boundaries. Consequently a more refined vegetation map was developed using LANDSAT imagery (1994) and the supervised classification module of IDRISI for windows (version 1.0, 1995). A field knowledge of MCT was essential for the production of this map, since areas of known species composition were used as training sites to detect areas of similar reflectance. The vegetation of MCT was divided into 7 major groups (Figure 12).

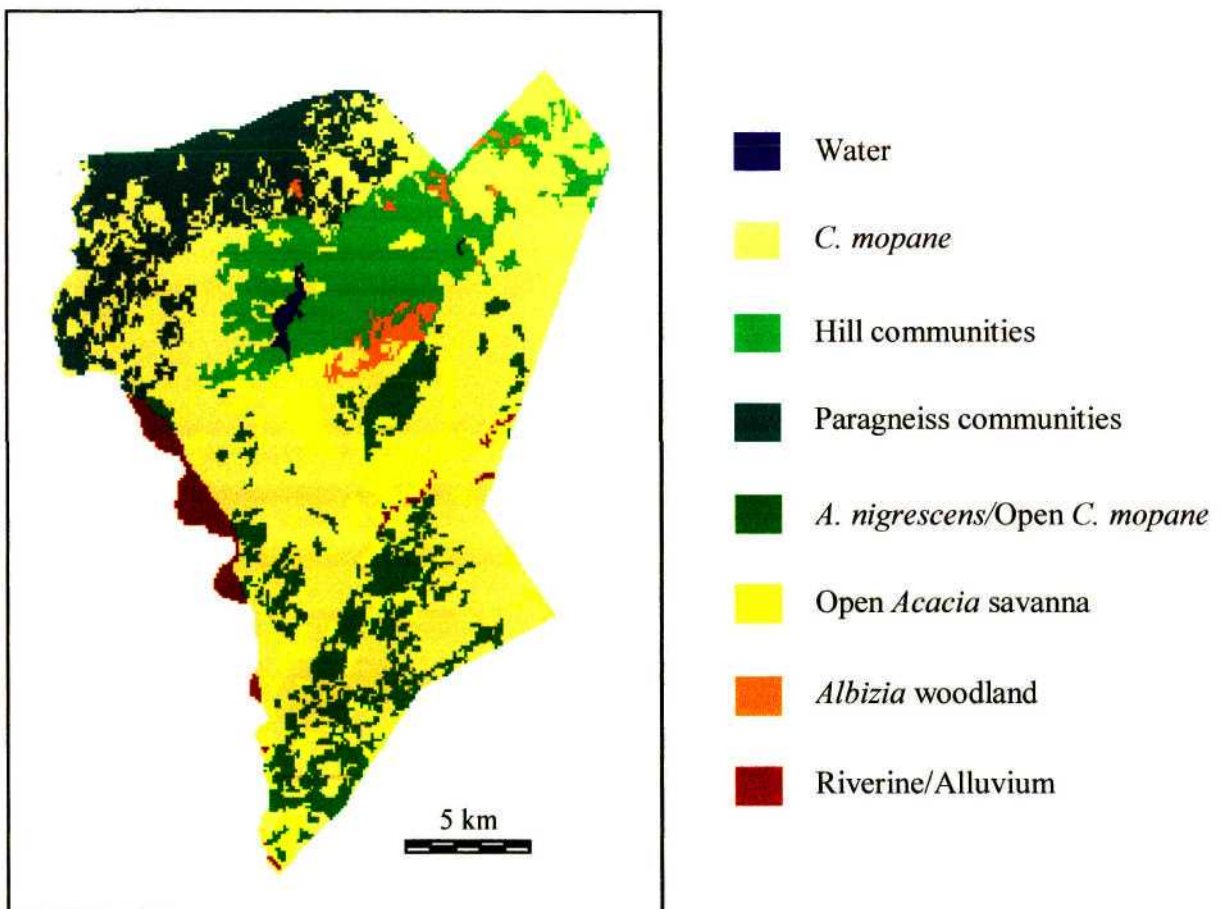


Figure 12. A species based vegetation map of Malilangwe.

***Colophospermum mopane* communities**

Veld dominated by *C. mopane* constitutes the greatest part of MCT, occupying approximately 51 % (20200 ha) of the property

Short, dense stands of *C. mopane* dominate the shallow basalt derived soils. Shrubs commonly associated with this woodland include *Grewia bicolor* and *Grewia flavescens*. Grasses usually include *U. mosambicensis*, *Heteropogon contortus*, *Tricholaena monachne*, *Cenchrus ciliaris*, *Aristida adscensionis* and *Enneapogon cenchroides*.

In the north east of the property, slightly more open communities of *C. mopane* occur with *A. nigrescens*, *Combretum imberbe* and *Sclerocarya birrea*. In the mid western region of MCT, the dominant woody plants are *C. mopane* and *C. apiculatum*. Other prominent woody plants include *Grewia villosa*, *Terminalia prunioides* and *Pterocarpus brenanii*. Dominant shrub and grass species are similar to those found in the 'short dense' *C. mopane* community described above.

Taller, more open stands of *C. mopane* are found on sandy alluvium along the southern reaches of the Chiredzi River, as well as on sandy soils on the transition of the sands and basalts. *Grewia bicolor* and *Maerua parvifolia* dominate the understory of this woodland, both species are relatively sparse, giving an open appearance. Grass cover, particularly along the sandy alluvium, is sparse.

Hill communities on sandstone outcrops

This vegetation type is second largest in areal extent, occupying approximately 14 % (5374 ha) of the property.

Mosaics of *Brachystegia glaucescens* and *Androstachys johnsonii* dominate where sandstone is exposed and, possibly, where soils are shallow. On the sandstone itself, *Ficus abutilifolia* proliferates, while in sandy pockets between outcrops, where soils are deep (>1 m), woody species such as *Spirostachys africana*, *Xeroderris stuhlmannii*, *Julbernardia globiflora* and *Terminalia sericea* occur. *Coffea racemosa*, *Monodora junodii* and *Pteleopsis myrtifolia* often constitute a part of the shrub layer in this community. Dominant grasses include *Panicum maximum*, *D. eriantha*, *Pogonarthria squarrosa* and *P. patens*.

Paragneiss communities

The paragneiss communities are best described as variable woodland recognised by a mix of *C. apiculatum*, *A. nigrescens*, *C. mopane* and *Grewia bicolor*. Less common, but conspicuous species include *Adansonia digitata* and *Kirkia acuminata*. Common grasses include *U. mosambicensis*, *Heteropogon contortus*, *P. squarrosa*, *Eragrostis* and *Aristida* species.

Acacia nigrescens / open C. mopane

Acacia nigrescens and open *C. mopane* woodland are grouped into one vegetation type. It is important to note that these two species generally occur in separate patches, i.e. *A. nigrescens* and *C. mopane* are not normally spatially mixed. Both woodlands have similar spectral signatures, similar herbaceous species composition, and occur on deeper, heavier textured soils within short *C. mopane* on basalt. For these reasons they have been combined on the vegetation map. The *A. nigrescens* woodland type dominates northern patches, while many southern patches, particularly in the vicinity of the hartebeest boma, constitute the open *C. mopane* type. Perennial grasses include *U. mosambicensis*, *Sorghum versicolor*, *P. maximum*, *Sehima galpinii* and *C. ciliaris*. Common annual grass species include *Brachiaria eruciformis* and *E. cenchroides*. *Indigofera schimperi* and *Duospermum quadrangulare* are relatively common large forbs associated with this vegetation type.

Open Acacia savanna

This vegetation type occurs predominantly along drainage lines, and where bush was cleared for cultivation. Woody plants include sparsely spaced *Acacia tortilis* and *Dichrostachys cinerea*. Along drainage lines *Lonchocarpus capassa*, *Combretum imberbe* and *Hyphaene coriacea* occur. *Acacia borleae* thickets occur in localised patches. The herbaceous layer is dominated by *U. mosambicensis*, but in the shallow valleys of drainage lines tall grass communities of *Ischaemum afrum* and *Setaria incrassata* are found.

Albizia woodland

In flat areas with sandy soils *Albizia petersiana* is dominant, with *Commiphora pyracanthoides*, *M. junodii*, *D. cinerea*, *G. bicolor*, *G. flavescens*, *Hippocratea indica* and *Hippocratea crenata* also being prevalent. Common grasses include *U. mosambicensis*, *D. eriantha* and *P. patens*. *Waltheria indica*, *Hermannia borganiflora*, *Celosia trigyna* and *Pupalia lappacea* also constitute an important part of the herbaceous layer. *Albizia* woodland and Hill community soils are derived from the same parent material, but support different floral species composition. This is possibly because the former communities do not benefit from run off from the Sandstone hills.

Riverine / Alluvium

Riverine vegetation occurred along the Chiredzi River, and in small patches along the upper reaches of the Mahande and Benji Systems. Prior to 1958, when Tsetse Control ordered the elimination of riverine vegetation, alluvium along the Chiredzi River supported mature riverine forest. A few *Xanthocercis zambesiaca* and *Cordyla africana* trees remain as relics of the former forest. Today the alluvial deposits support regenerating woodland, dominated by *A. tortilis*, *C. imberbe* and *L. capassa*; and shrub thickets of *Capparis sepiaria* and *Maytenus senegalensis*.

HISTORY OF PERENNIAL WATER AND LAND USE

Prior to 1949, the area known today as Malilangwe was government owned Crown Land. Tsonga people (Shangaans) lived and ran cattle predominantly along the Chiredzi and Runde rivers, and few settlements existed away from these largely perennial water sources. A few springs and seeps in the Hills, and in the Chiloveka area in the south held water through most dry seasons (Figure 13a). Europeans settled in the region in 1949, and began commercial cattle ranching. Additional perennial water was necessary so that stock could utilise grazing further from the rivers. By 1951 dam building had begun, and later water was pumped to seasonal pans and cement troughs (Figure 13).

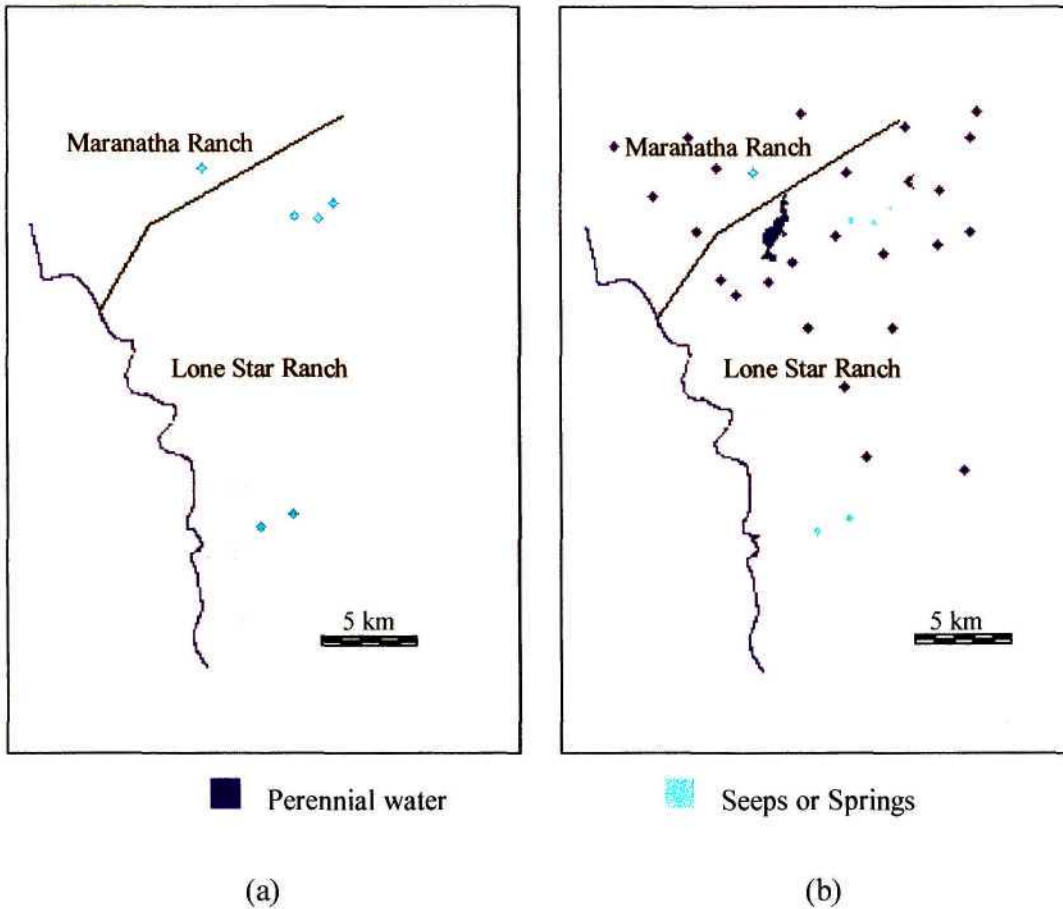


Figure 13. (a) The spatial position of water prior to 1959, and (b) between 1963 and 1994 (Water along the Chiredzi and Runde Rivers is limited to pools during dry years).

In the past, the Chiredzi and Runde rivers were largely perennial, and even during drought periods there were always pools in the river beds (Sparrow, pers. comms.). A combination of the reduced rainfall of recent years, the building of dams and weirs (e.g. the Mangerenji Dam up stream on the Chiredzi River), irrigation schemes, and poor farming practices, are possibly responsible for the observed decline in water carried by these rivers.

Following the 1983 drought, huge cattle losses were sustained on Lone Star, and the few surviving cattle were removed by 1985. Between this time and 1994 (when the land was purchased by Malilangwe Conservation Trust) photographic safaris and trophy hunting provided the main income for Lone Star.

LARGE HERBIVORE POPULATIONS

At present large herbivores include impala, zebra, wildebeest, buffalo, kudu, nyala, bushbuck, sable, eland, waterbuck, duiker (*Sylvicapra grimmia*), grysbok (*Raphicerus sharpei*), steenbok, giraffe, warthog, bushpig (*Potamochoerus porcus*), white rhino and elephant. Black rhino, reedbuck, Lichtenstein's hartebeest and roan antelope have been reintroduced, the latter three species await release. Hippopotamus (*Hippopotamus amphibius*) occur in the Malilangwe Dam and in pools along the Chiredzi River. Elephant numbers were drastically reduced during the mid-1950s as part of the Tsetse control programme. In recent years, elephant numbers have increased and their impacts on the vegetation are becoming increasingly evident. Not all wild ungulate populations have reached ecological carrying capacity, and further introductions are anticipated.

CHAPTER 4 : STUDY DESIGN

STUDY SITE SELECTION

1. Soils and vegetation

Where possible, two water points similar in size and structure were selected in the dominant vegetation types. Water points eligible for this study had to meet with the following criteria:

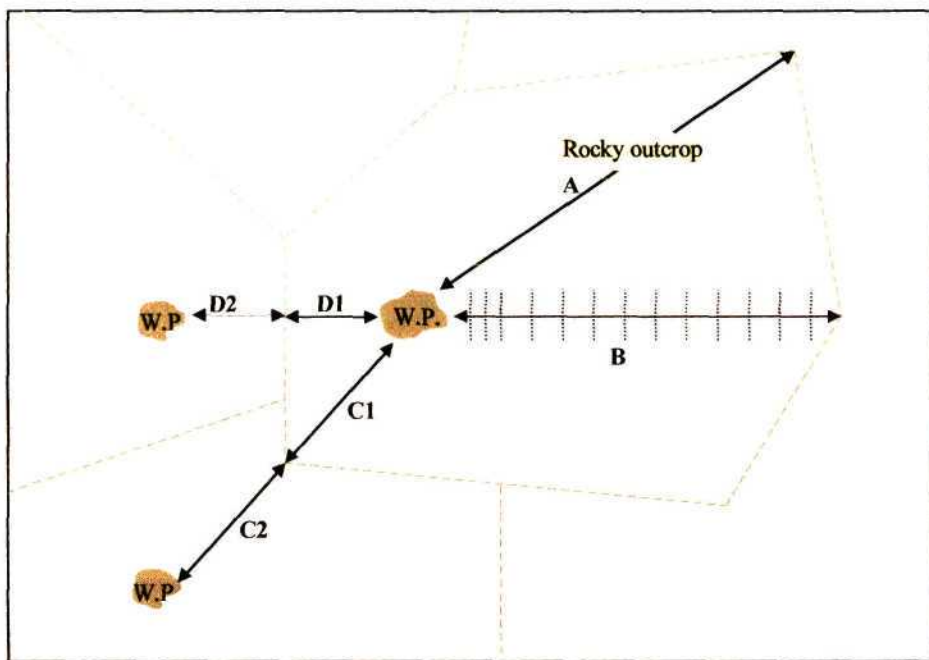
1. The histories of water points had to be known (therefore selection was restricted to Lone Star Ranch).
2. Water points must have functioned as perennial sources for at least eight years.
3. Any perennial source, no longer functioning as such, may not have been dry for more than two dry seasons prior to data collection.
4. Topography, soils and vegetation had to remain relatively homogenous (i.e. no abrupt changes that were obviously the result of a factor or factors other than distance from water e.g. major changes in soil or topography) in at least one direction (compass bearing) for at least 600 m from the water point.

The following procedure was followed in order to establish where vegetation and soil transects should be situated.

1. Using orthophotos, distance polygons were traced around each water point on Lone Star Ranch. Polygon perimeters defined the mid-points between each water point and its neighbours (Figure 14). These polygons defined the maximum bounds suitable for sampling, before the effects of neighbouring water points confounded results.
2. Areas within polygons that showed the greatest potential for long sampling areas (i.e. where the polygon perimeter was furthest from the water point) were investigated in greater detail. Aerial photographs of these regions were studied under the stereoscope. Potential study areas (compass bearing lines / bearing lines)

were discarded if they were obstructed by (i.) rocky outcrops, mountains or hills, (ii.) rivers, streams or dams, (iii.) an abrupt change in vegetation, unrelated to the presence of the water point, or (iv.) human habitation, old fields or air strips. If a bearing line was disqualified, the next longest direction (bearing line) was considered and examined in the same way.

- Once a bearing line was accepted its bearing from the water point was read off the orthophoto and the line was ground truthed to confirm that all criteria were met.



W.P. Water point ←→ Potential bearing lines | Transect lines - - - Polygon perimeter

A = the longest compass bearing line (direction of bearing line = 42° from the water point), but this is obstructed by a rocky outcrop, so is not selected for the study.

B = the next longest compass bearing line (direction of bearing line = 90° from the water point), there are no obstructions in this direction, and it is therefore selected for the study. Note that transect lines along which data were collected are orientated at 90° to the compass bearing line.

C1 and C2, D1 and D2 = represent bearing lines of equal length. The point where bearing lines meet represents the midpoint between two water points and determines where a polygon perimeter should be drawn.

Figure 14. Diagram illustrating the procedure for bearing line selection. The transects along which data were collected ran perpendicular to the selected bearing line.

Selected water points included: two in *C. mopane* veld (Nyamsaan and Bandama pans), two in the Hill community (Chinzwini and Lojaan dams) and one on the interface of the Flat Sandveld and the basalt-derived clays (Chibi pan). All these water points were originally natural seasonal pans or seeps that had been pumped to or dammed to enable them to hold water through the dry season. An extra water point was included in the study, to investigate initial responses to water introduction in a Hill community. This water point satisfied few of the criteria on which other water points were chosen. It had been in place for only two dry seasons prior to data collection and the bearing line did not extend beyond 175 m from the water point before encountering a change in environmental conditions. Unlike the other water points, it was a cement based artificial pan. The spatial positions of sampled water points are shown in Figures 11 and 15, and historical and environmental details for each water point are given in Appendix 1, Table 1).

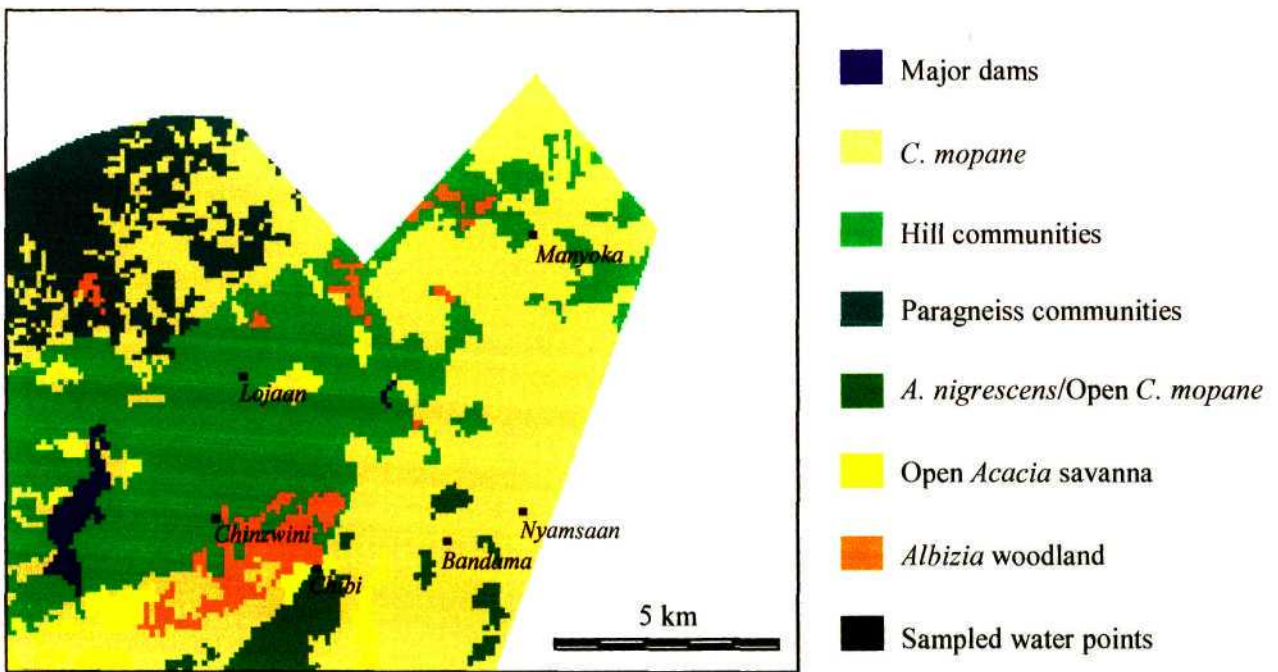


Figure 15. The north-eastern section of MCT showing the spatial position of sampled water points.

At the time of data collection, all water points, except Bandama (which had not been pumped to for the preceding two dry seasons), continued to function as perennial sources of water.

2. Large herbivore distributions

Animals were identified and counted, and their locations were recorded for the whole of MCT as well as the adjacent Hippo Valley Estates Game Section and the area of Maranatha Ranch not owned by MCT (to the west of the Chipimbi River, Figure 8).

DATA COLLECTION

1. Soils and vegetation

Soil nutrient status, soil depth, soil surface conditions (excluding infiltration rates), and all components of the herbaceous layer were sampled between the 27/03/97 and the 12/05/97. The woody layer was sampled between the 22/05/97 and the 30/06/97.

The herbaceous layer and soil surface conditions (excluding infiltration rate, signs of gully erosion and number of paths) were sampled using 1 m² quadrats placed 1m apart along 50 m long transects orientated at 90° to the compass bearing line. Transect were located at distances of 10 m, 30 m, 60 m, 100 m (and at intervals of 100 m thereafter) from the water point (Figure14). At Manyoka the 175 m distance point was sampled instead of the 200 m point because the criteria specified above were not met at distances beyond 175 m from this water point. For no water points were the selection criteria met beyond 1000 m from a water point, and consequently no water point had more than 13 transects. The first transect was situated 10 m from the high water mark. This clarification was necessary for dams whose areal extent fluctuates from month to month or from year to year depending on rainfall. Soil depth, texture and nutrient status was sampled at 10 m intervals along transect lines, and the number of rills and/or gullies as well as the number of animal paths crossing the length of the transect line were recorded.

The woody layer was sampled along the same transect lines, but in stead of using 25 quadrats, a single belt transect, 50 m long by variable width was used. The width of each belt transect was determined by the density of trees in the area (details are given in Chapter 6, Methods).

For small water points, transects close to water (those at 10 m and in some cases those at 30 m from the water point) were sampled along a 25 m tape. This was done in

order to avoid samples on either end of the sample line being far beyond the required distance from water for a particular transect. Sample points along the 25 m long transects were half the distance apart in order to yield the same number of sample points (e.g. herbaceous and soil surface sample quadrats were placed adjacent to one another while soil depth and nutrient status samples were taken at 5 m intervals instead of at 10 m intervals). In the case of gullies, rills and animal paths, the number observed crossing the 25 m long transects was multiplied by two in order to give an estimate of the number that would be expected to cross a 50 m long transect.

Infiltration rates were measured in the dry season (20/07/98 and 21/07/98) when antecedent soil moisture was unlikely to influence rates of infiltration. Soils were dry at the time of measurement, and even at 5 m from the water point there was no indication that soils here were moister than those further away. Measurements were made with a constant head of water in the equalising tube thus ensuring that a constant pressure was exerted on the water infiltrating the soil.

Infiltration tests were excluded from (1) sandy soils, because the large soil particle size prevents compaction, and obviates a change in infiltration rate, (2) clay-loam soils, because of the self-mulching nature of these soils and the large number of cracks which prevent accurate measurements, and (3) soils where the adjacent water point had been rested for more than one dry seasons prior to sampling. Only Nyamsaan pan fitted the criteria and was sampled for infiltration rate with distance from the water point.

2. Large herbivore distributions

Aerial count data was collected during the wet and dry seasons of 1997. Details are given in Chapter 7, Method.

3. Raw data

Raw data are available from the Wildlife Information Manager, Malilangwe Conservation Trust, Private Bag 7085, Chiredzi, Zimbabwe.

DISCUSSION

Bearing lines were not chosen at random because the longest possible gradient of distance from water was required in order to establish patterns related to distance from water. This could only be done by selectively choosing areas where long bearing lines were accepted within the criteria specified. A systematic approach was also used to locate transects and quadrates. Again this was necessary in order to trace changes in vegetation and soils over the whole distance gradient. Transects were placed close to one another close to water where changes over short distances were likely to occur (at 10 m, 30 m 60 m and 100 m). They were placed further apart, further from water where more gradual changes were expected (at 200 m, 300 m, 400 m etc.). Because the procedure for bearing line selection, and the spatial positions of transects were specified before data collection began, sites were in no way biased by the author's interpretation or opinion of how they should be.

It is important to be aware that the bearing line and transects sampled were not necessarily representative of the landscape in which they were embedded (in most cases however, they were). They were selected to represent areas where variability in factors (other than distance from water) that determine plant species composition and soil variables was minimal within a selected vegetation and soil type. From these transects the relative effects that wild herbivores have on different soils and vegetation types was investigated.

Due to time constraints inherent in an MSc study, a compromise had to be made between having many replicate samples in few vegetation and soil types, or having fewer replicates, but covering a wider range of vegetation and soil types. Since the main objective of this study was to give recommendations on where water would be best placed in order to minimise adverse effects on the environment, the latter option was selected as it gave information (not as detailed) across a wide variety of environmental conditions. In addition, replicates and controls weren't always available or as appropriate as one might hope (Bandama pan had not held water for two dry seasons prior to data collection, and Manyoka pan was not situated in a natural depression as were all the other water points studied. Chibi Clay and Chibi Sand, although sampled from the same water point, had no replicates in similar vegetation types).

Most of the water points sampled in this study were situated in natural depressions in the landscape, which suggests that natural gradients away from these sites were likely to have existed prior to the site being made into a perennial water source. However, selected bearing lines did not extend across obvious changes in topography, so transects were located in similar topographical positions. Changes in soil depth and texture (Appendix 2, Table 1) were, for the most part unrelated to distance from water, further confirming that topographical changes did not have a major influence on patterns of variation in soil and vegetation along the transects sampled. Values for soil depth and texture were included as covariables during Correspondence Analysis (ter Braak 1988), but they did not account for a significant portion of the variation indicating that they were not responsible for changes in response variables (see Chapter 6).

CHAPTER 5 : SOIL RESPONSES

INTRODUCTION

In semi-arid savannas, chemical and physical properties of soils influence plant species composition, morphology and above ground biomass (Scholes 1990a; Scholes & Walker 1993). Soil chemistry plays an important role in plant nutrition while soil physical properties are important in determining plant water supply (Scholes & Walker 1993). Both chemical and physical properties of soil can be altered by herbivores in the vicinity of water. Soil chemistry is altered by increased nutrient inputs in the form of dung and urine (Weir 1971; Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995), while physical aspects such as soil compaction, bulk density and infiltration rate are altered through increased trampling (Lange 1969; McCalla *et al.* 1984; Andrew & Lange 1986a; Perkins & Thomas 1993a).

Parent material is the initial determinant of soil chemical status. Base rich lavas, such as basalt erode to form soils high in mineral content, generally with a high silt-clay content. In contrast, sandstones characteristically give rise to sandy, relatively infertile soils (Scholes & Walker 1993).

Based on soil nature, soils react dissimilarly to an increase in animal pressure. Increased nutrient inputs are expected to be more obvious on nutrient poor soils than on nutrient rich soils, while the effects of trampling are expected to be more severe on soils with a high silt-clay fraction and a low sand fraction (Warren *et al.* 1986). Where montmorillonite is the dominant clay fraction, for example on vertisols, soils are self mulching, and the compacting effect of trampling is largely lost.

Other studies have shown that soil surface conditions such as the amount of surface litter (McCalla *et al.* 1984; Warren *et al.* 1986), proportion of bare ground (Brotherson *et al.* 1983; Kalikawa 1990), proportion of capped soil surface (Andrew & Lange 1986), number of paths (Andrew & Lange 1986) or erosion rills (Perkins & Thomas 1993a), as well as infiltration rates (Wood & Blackburn 1981; Warren *et al.* 1986; Perkins & Thomas 1993a) respond to increased animal utilisation either under

heavy stocking rates or close to water points, where stocking rates are high. Changes in soil surface conditions have implications for range condition.

The objectives of this chapter were: (1) to establish nutrient and carbon enrichment patterns with distance from water on different soils; (2) to determine the effect of increased utilisation around water points on soil surface conditions, and (3) to establish soil infiltration rates with distance from water on soil susceptible to compaction.

METHODS

1. Nutrient status

The susceptibility of soils to chemical change through increased nutrient inputs (dung and urine) close to water points was investigated.

Five soil cores were collected from the top 15 cm of the soil at each transect. Soil samples from all 5 cores were pooled for each transect in order to reduce the cost of analyses. Samples were air dried prior to analysis. Nutrient and carbon concentrations, as well as pH and soil water conductivity were investigated with distance from water.

2. Texture and depth

Soil texture and depth are unlikely to change significantly as a consequence of the water point, unless excessive soil erosion occurs. Data on soil texture and depth was collected to explain changes that may not have been due to the presence of the water point.

Soil depth was measured by sinking a bucket auger to depth (i.e. to contact with saprolite, hard rock or a dense stone layer), or to a maximum of 90 cm where soils were deep. As for soil nutrient data, 5 samples were taken at 10 m intervals along transects. The same pooled soil samples used to establish soil nutrient status were used to establish soil texture at each transect.

3. Soil surface conditions

Percent areal cover of litter, bare ground, capping and area trampled were estimated and averaged for 25 quadrates per transect. Estimates were ranked according to Table 4.

Table 4. Rank score table

RANK SCORE	RANGE	MIDPOINT OF RANGE (%)
0	0	0
1	1	1
2	2 – 10	6
3	11 – 25	18
4	26 – 50	38
5	51 – 75	63
6	76 – 95	86
7	96 – 100	97

Litter was defined as dead woody or non-woody material in contact with the ground. Non-woody material included obstructions to water flow such as rocks, dung, bones or leaf litter. Bare ground included soil surfaces devoid of living macrofloral material or litter as defined above. Soil caps/crusts were either clay caps, sand crusts or microfloral crusts (also known as lichen crusts or soil cryptogram crusts). Trampled areas were either bare soil surfaces with numerous spoor and scrape marks, or herbaceous material that had been flattened by animals.

The number of paths, rills and gullies crossing transects were counted.

4. Infiltration

At distances of 5, 10, 20, 30, 60, 100 and 300 m from water, infiltration measures were taken using a CSIRO disk permeameter (A. L. Franklin Precision Engineers, Sydney, Australia). Six infiltration readings were taken at each distance: three replications were made on, and three were made off animal paths. Average infiltration rates for each repetition were calculated from a minimum of 10 consecutive relatively constant infiltration rate readings (the typical pattern of infiltration of water into a dry soil is for an initial rapid rate of infiltration followed by a slower, more constant rate).

ANALYSIS

For each transect the 5 pooled soil cores were analysed for % organic carbon (C) and total nitrogen (N). Organic C content was tested using the Walkley-Black Method (Walkley 1934) and total N was determined using the Sulphuric acid – hydrogen peroxide Method. Available phosphorus (P) was calculated by using a modification of the resin extraction method where 15 ml of extract was made up to 25 ml as opposed to the practice of 10 ml extract being made up to 100 ml in the resin extraction method. The modified method provides a more sensitive test. Exchangeable cations (potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and total cations) were determined by Atomic Absorption (A/A). In this method, 10 g of sample was added to 100 ml of extract solution (molar neutral ammonium acetate), shaken for one hour, filtered and diluted to volume. The calcium chloride method, where a dilute solution of calcium chloride (0.01 M CaCl₂) was used instead of conventional distilled water was used to determine pH. The calcium chloride method is known to give a truer meaning of what soil acidity will be under field conditions during the growing season. Note that on average the calcium chloride pH is about 0.7 units lower than the water pH. Conductivity was established using a 1 : 5, soil : water suspension to conduct an electric current. Note that the 1 : 5 conductivity will give a lower ($\pm 1/5$) value than the saturation extract conductivity. Soil texture was established for each transect by using the pedologists' moist bolus test (McDonald *et al.* 1990, unseen, as cited by Tongway & Hindley 1995). Soil depth was estimated by finding the average depth of five auger holes at each transect. All analyses were done by the Zimbabwe Sugar Association (Private Bag 7006, Chiredzi, Zimbabwe).

As a prelude to the analysis of individual variables, the relationships amongst variables (nutrients, organic C, soil surface conditions and biomass) were investigated for individual water points using Principal Components Analysis (PCA) (ter Braak 1988). If particular variables were consistently associated with one another across all water points, further analysis of only one of the associated variables was considered necessary. Variables such as texture or depth were removed from the analysis if they were uniform for all sites at a water point. Species scores were centred and standardised, and correlation co-efficients were generated for pairs of variables at each water point.

Organic C, total N, available P and cations were plotted against distance from water. Organic C and total N trends with distance from water were summarised for three soil types: clay-loam, sandy-clay-loam and sand. Data for clay-loam soil was obtained from Chibi Clay, for sandy-clay-loam soils from Nyamsaan and Bandama, for sandy Hill soils from Chinzwini, Lojaan, and Manyoka, and for Flat Sandveld from Chibi Sand.

Direct gradient analysis was used to illustrate the relationship between soil surface conditions and distance from water. Sigmoid logistic curves ($y = a + c / \{1 + e^{-b(D - m)}\}$, where $D =$ distance from water) were fitted to the data using non-linear regression (GENSTAT 5 1988).

The experiment for soil infiltration involved two factors: distance and path. Analysis of variance (ANOVA) was conducted to determine the effect of distance, path and their interaction, on the rate of infiltration. Differences between means were examined using the Least Significant Difference (LSD) method (Steel & Torrie 1980).

RESULTS

Relationships amongst variables

No variables were consistently associated with one another across all the water points. On sandy-clay-loam soils (Nyamsaan and Bandama) positive correlations ($P < 0.01$) were found between pH, conductivity and Ca. At Nyamsaan all three variables were correlated with one another and correlation co-efficients all exceeded 0.872. At Bandama both pH and conductivity ($r = 0.955$), and Ca and conductivity ($r = 0.829$) were correlated. On sandy Hill soils highly correlated pairs were not consistent between water points. At Chinzwini organic C and total N were significantly ($P < 0.01$) correlated ($r = 0.868$) as were pH and Ca ($r = 0.899$), and litter and K ($r = 0.818$). Only conductivity and Mg ($r = 0.803$) were highly correlated ($P < 0.01$) at Lojaan. On Flat Sandveld (Chibi Sand) most nutrients, trampling, paths, pH and conductivity were highly correlated ($P < 0.01$) with one another. Highest correlations were found between Ca and total N ($r = 0.958$), pH and K ($r = 0.953$), trampling and Na ($r = 0.938$), trampling and total N ($r = 0.932$), Ca and Mg ($r = 0.909$) and Ca and Na ($r = 0.903$). At Chibi Clay pH and Ca were positively

correlated ($r = 0.871$), as were trampling and P ($r = 0.859$), capping and P ($r = 0.805$) and trampling and Na ($r = 0.798$). Note that at Chibi Sand trampling and Na were also positively correlated ($P < 0.01$). At Manyoka no variables were correlated at the $P < 0.01$ level, possibly due to low sample size ($n = 5$). At the $P < 0.05$ level trampling was positively correlated with bare ground ($r = 0.958$), paths were positively correlated with trampling ($r = 0.928$) and negatively correlated with biomass ($r = -0.905$).

PCA diagrams illustrating the relationship between variables at each water point are given in Appendix 2, Figures 2 - 8. On the PCA diagrams, variables that lie close to one another are positively correlated, while those that lie opposite one another are negatively correlated.

1. Nutrient status

Increased organic C levels close to water (up to 30 m) were observed on sandy-clay-loam (Mopane) and sandy soils (Hills and Chibi Sand) where water points had been in place for more than two dry seasons (Figure 16). Organic C levels did not show a response to distance from water on clay-loam soil (Chibi Clay) or at the new water point on sandy soil (Manyoka).

Total N (Figure 17) increased close to water on all soil types where water points had been in place for more than two dry seasons. Total N levels at Manyoka showed no response to distance from water. Enrichment extended further on clay-loam and sandy-clay-loam soils (300 m) than on sandy soils (10 m). On sandy-clay-loam soils, total N content was generally much higher than on other soils. No N enrichment was observed at Manyoka.

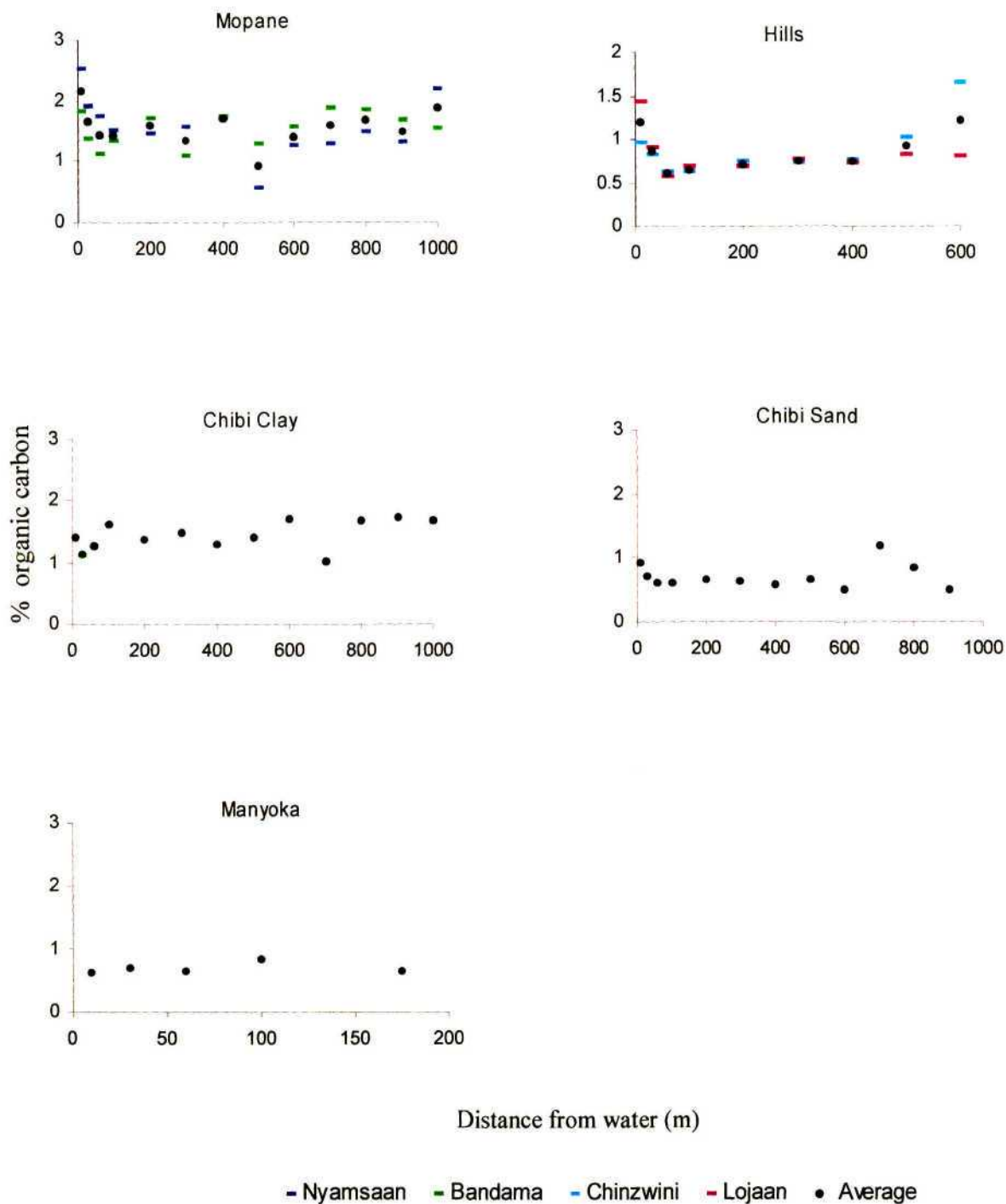


Figure 16. Percent organic carbon on clay-loam, sandy-clay-loam and sandy soils with distance from water points.

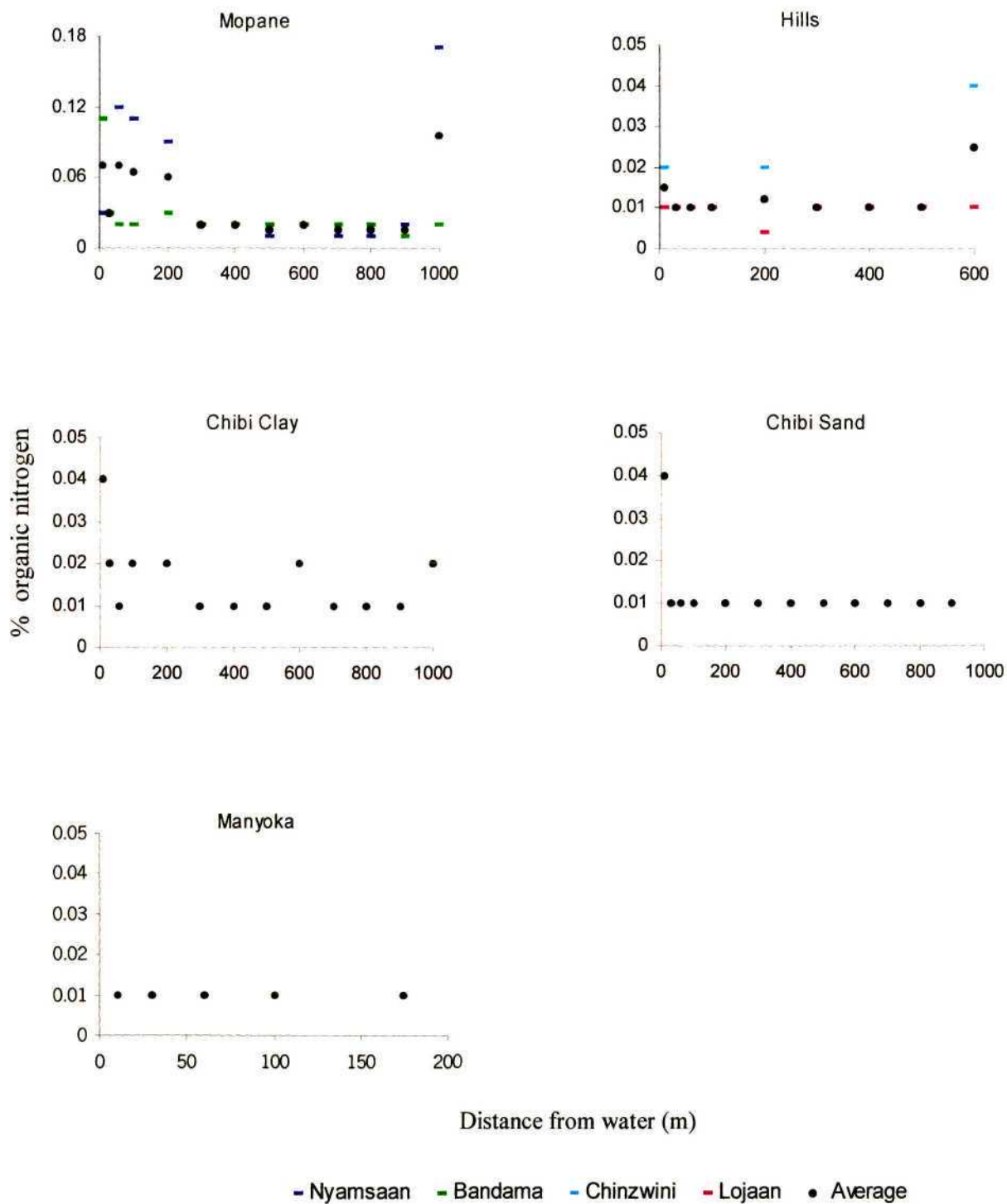


Figure 17. Percent total nitrogen on clay-loam, sandy-clay-loam and sandy soils with distance from water

On clay-loam soil, available phosphorus (Figure 18) increased in the vicinity of the water point, but total exchangeable cations (Ca, Mg, K and Na) only displayed a relative increase in the immediate vicinity of water (10 m). An increase in cations was observed beyond the 30 m sample point (trends for individual cations are given in Appendix 2, Figures 8- 12).

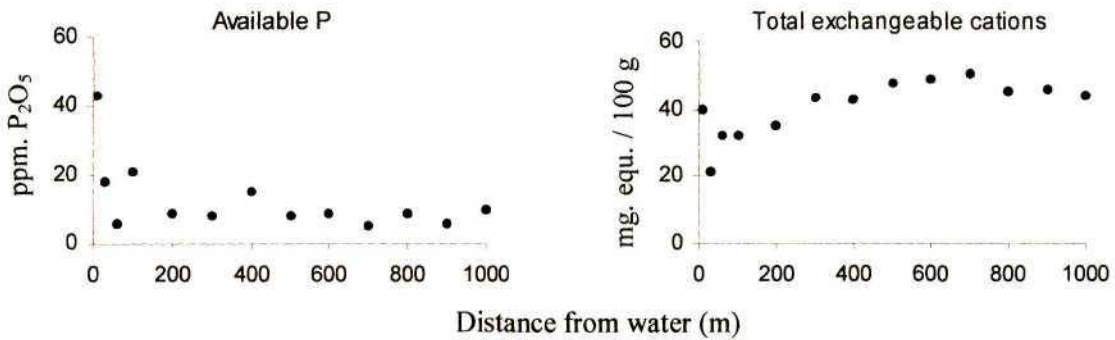


Figure 18. Available phosphorus and cations in clay-loam soil with distance from water.

On sandy-clay-loam soils available P increased locally from 100 m up to the water point (Figure 19). Beyond 200 m available P increased with distance from water. Total exchangeable cations showed a similar local increase, but the increase extended only to the 30 m point.

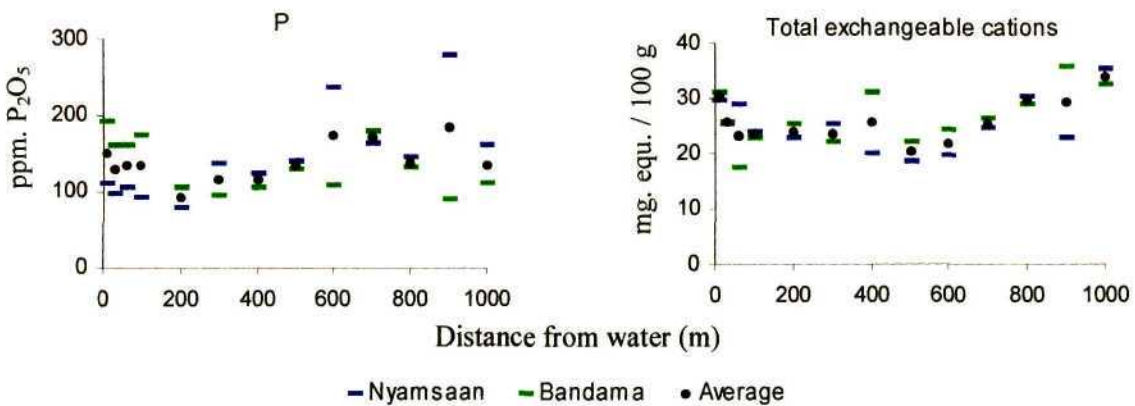


Figure 19. Available phosphorus and cations in sandy-clay-loam soils with distance from water.

No clear pattern for available P with distance from water emerged on sandy Hill soils (Figure 20). Results suggest that there may be a local increase in total cations close to water at both Chinzwini and Lojaan.

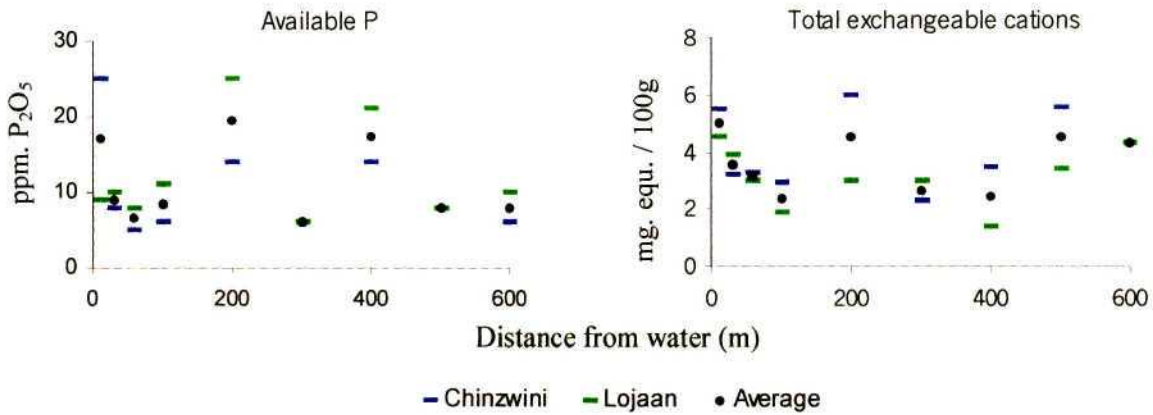


Figure 20. Available phosphorus and cations in sandy Hill soils with distance from water.

Flat Sandveld displayed the clearest response of nutrients to distance from water, but enrichment was restricted to areas close to water (Figure 21). Available P enrichment extended to 100 m from water and in this zone values were approximately 3.5 times greater than they were in areas beyond 100 m from the water point. Total exchangeable cation enrichment extended to a distance of 60 m from water, but was markedly higher at the 10 m point.

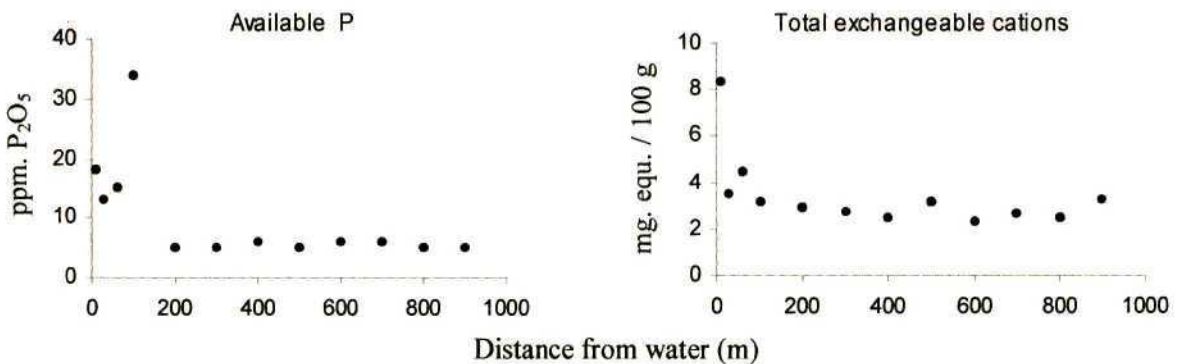


Figure 21. Available phosphorus and cations in a flat sandy soil with distance from water.

No change in available P or total exchangeable cations was detected with distance from water at Manyoka (Figure 22).

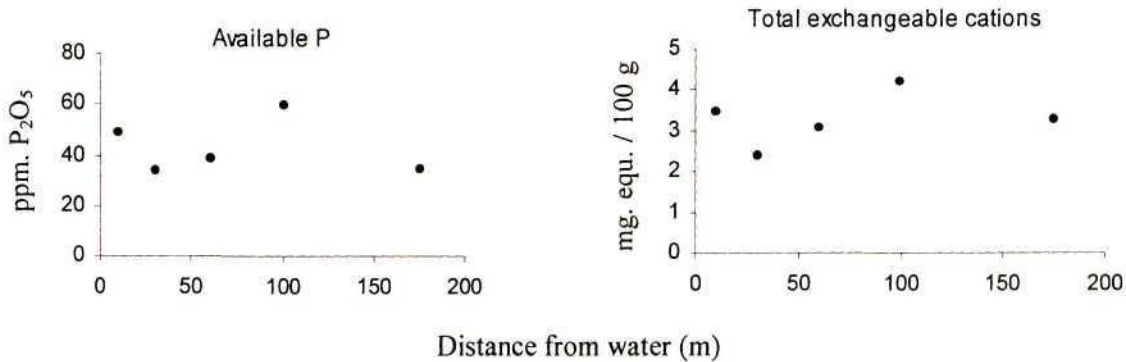


Figure 22. Available phosphorus and cations in soil around Manyoka with distance from water.

2. Texture and depth

Slight variations in soil texture and depth were observed in *C. mopane* veld and at Chibi Clay (Appendix 2, Table 1). No relationships were found between variables and texture or depth, except at Bandama where depth was correlated with biomass ($r = 0.724$).

3. Soil surface conditions

Increased bare soil surface close to water was more pronounced on sandy soil (Chinzwini, Lojaan, Manyoka and Chibi Sand) than on sandy-clay-loam or clay-loam soils (Figure 23). Bare ground close to Manyoka was very high (89 %). In Hill environments an increase in exposed soil surface only extended to 60 m while at Chibi Sand it appeared to extend to 400 m from water. The logistic distribution for exposed soil surfaces at this water point was obscured by high aerial cover of *P. maximum* and litter at the 30, 60 and 100 m distance points (Chapter 6, Figure 32). Equations for fitted curves are given in Appendix 3, Table 1. Exposed soil surfaces in *C. mopane* veld on sandy-clay-loam soils was generally higher than on other soil types. Declines in exposed soil surfaces were gradual and equilibrium did not appear to be reached within the distance sampled. At Chibi Clay, percent exposed soil surface declined with proximity to water over the entire distance measured (1000 m). However, within 200 m of water there was a relative increase in exposed soil surface.

True capping was only observed on sandy-clay-loam soils in *C. mopane* veld. On sandy and clay-loam soils lichen and soil surface crusting was apparent. The sand and lichen crusts described in this study were permeable and could be broken or penetrated with a pen. In contrast the true caps observed on sandy-clay-loam soils were largely impermeable and could only be broken with a metal instrument such as an auger.

On sandy-clay-loam soils capping was higher than on other soils, and a peak was observed at 60 m from water (Figure 24). On sandy-clay-loam soils, as for clay-loam soils, capping and crusting declined with distance from water (note that the decline in capping between the 10 and 60 m distance points on sandy-clay-loam soils denotes the sacrifice zone for this variable at Nyamsaan and Bandama). Crusting on sandy soils generally increased with distance from water (Chibi Sand, Lojaan and Manyoka). At Chinzwini however, no pattern for crusting was evident.

Trampling increased with proximity to water for all water points (Figure 25), but increases were most severe (40 – 60 %) on sandy soils (Chinzwini, Lojaan, Manyoka and Chibi Sand). In contrast, trampling on sandy-clay-loam (Nyamsaan and Bandama) was only 20 % greater close to water. On Clay-loam increased trampling was only evident at 10 m where it was extreme (> 6 times greater than at other sites sampled).

Percent litter (Figure 26) increased close to water at the older water points on sandy soils (Chinzwini, Lojaan and Chibi Sand), but the opposite trend was observed at the recently established water point (Manyoka). In *C. mopane* veld, except for a small peak close to water, percent surface litter generally increased with distance from water. At Chibi Clay litter cover was slightly higher close to water.

The increase in path number extended further from water in *C. mopane* veld (900 m) and at Chibi Clay (600 m) than at other water points (Figure 27). In the Hills path number remained fairly high, declining only slightly with distance from water. On Flat Sandveld (Chibi Sand) path number was exceptionally high close to water (up to 30 m) but dropped off quickly with distance. Number of paths per 50 m was generally a satisfactory measure of track density, but a more appropriate measure would have been path area. Path area would have better described situations (e.g. at Nyamsaan, Figure 27) where many narrow paths converged to form fewer wider paths close to water.

Only one gully was encountered at 300 m from water at Chinzwini.

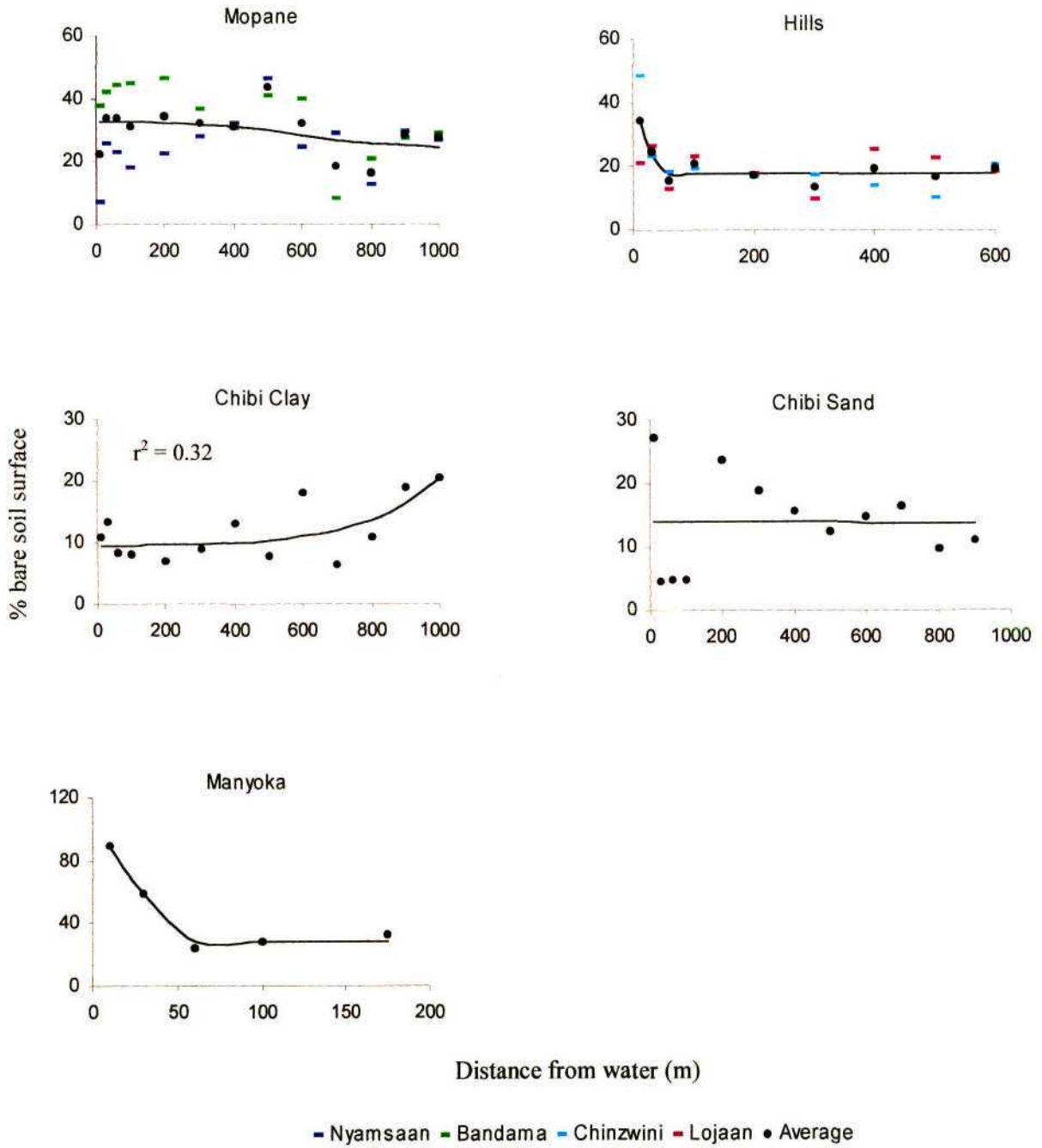


Figure 23. Percent bare soil surface with distance from water.

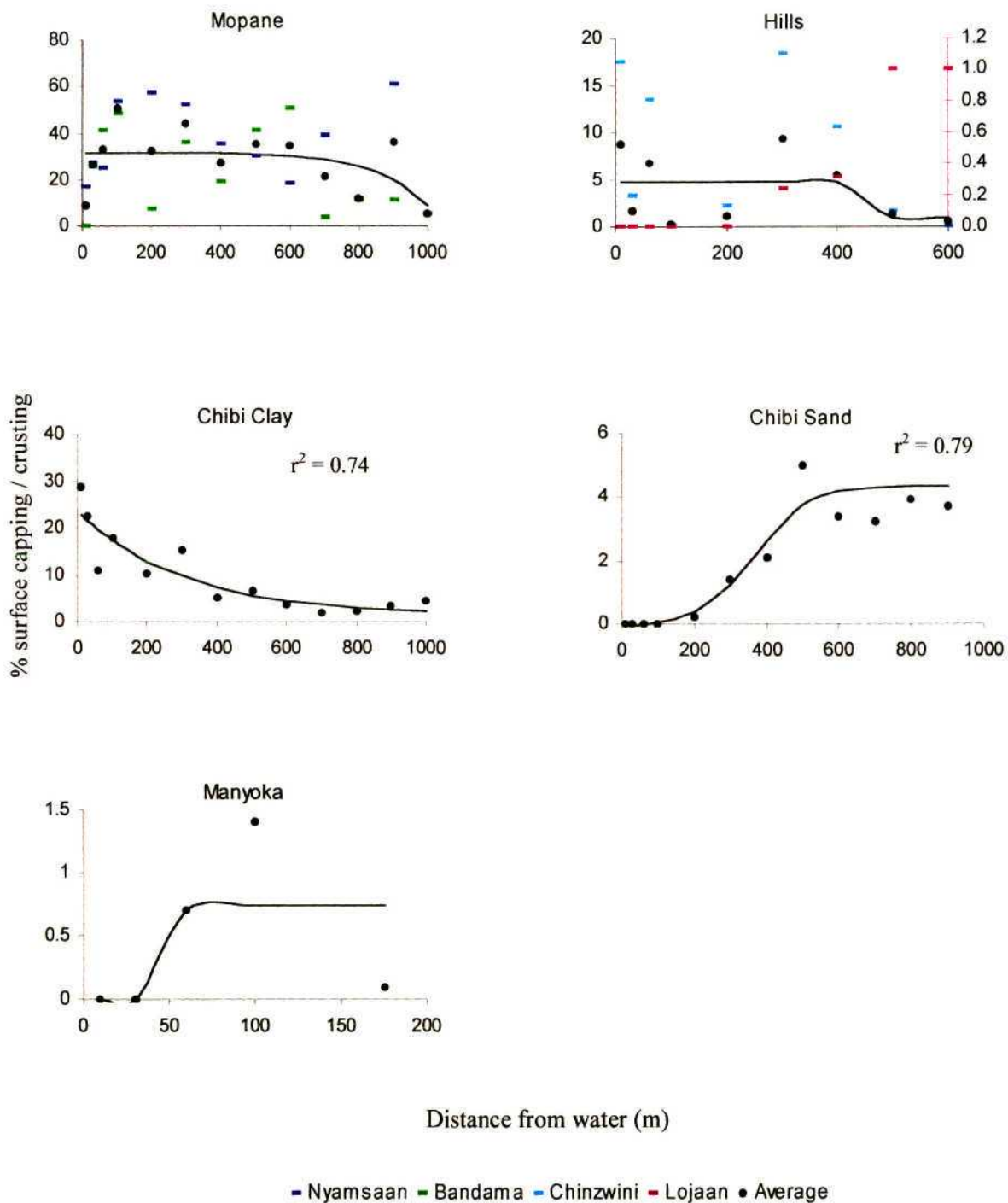


Figure 24. Percent capping / crusting with distance from water (note that the secondary y-values for Hills corresponds to values for Lojaan).

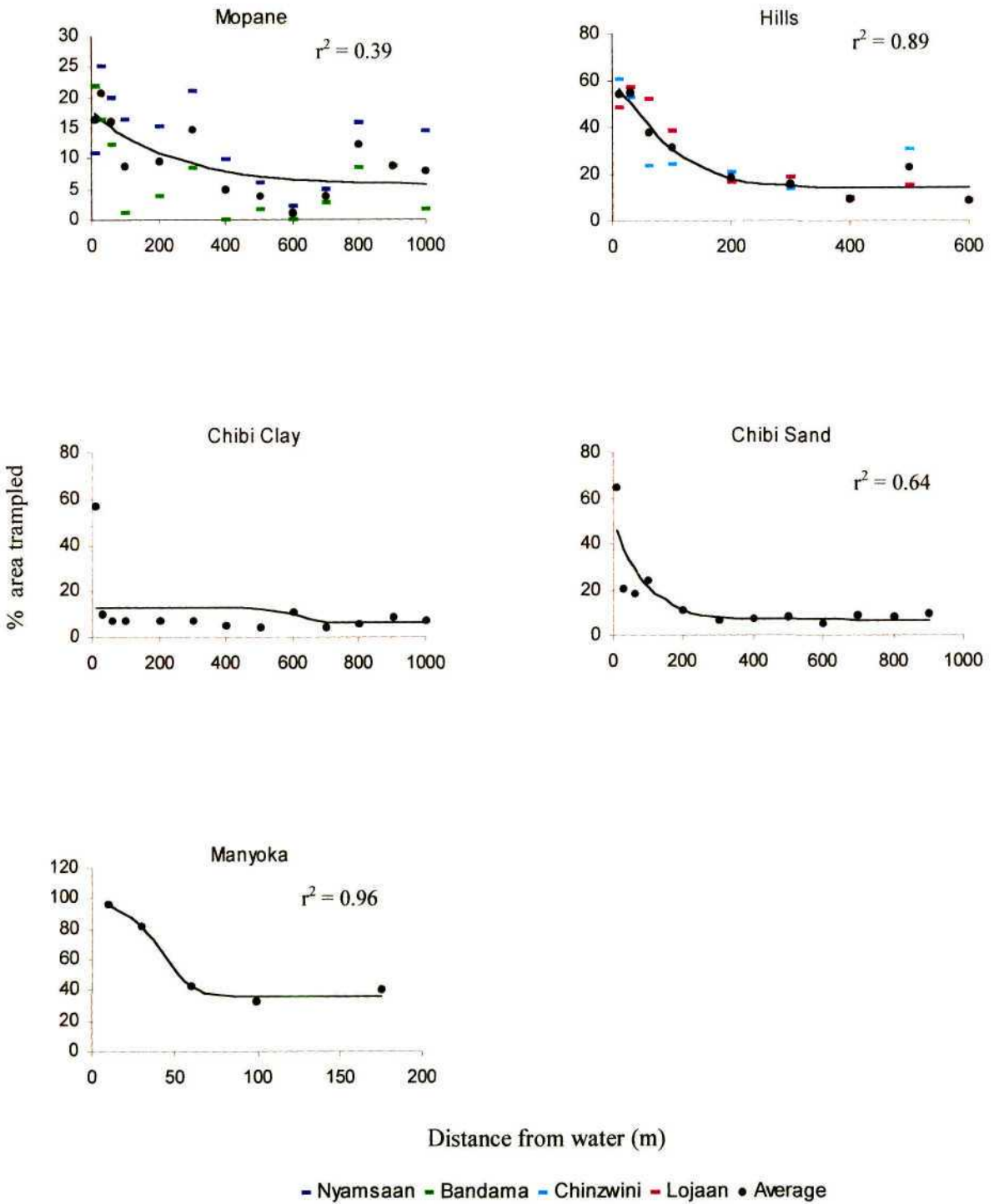


Figure 25. Percent area trampled with distance from water.

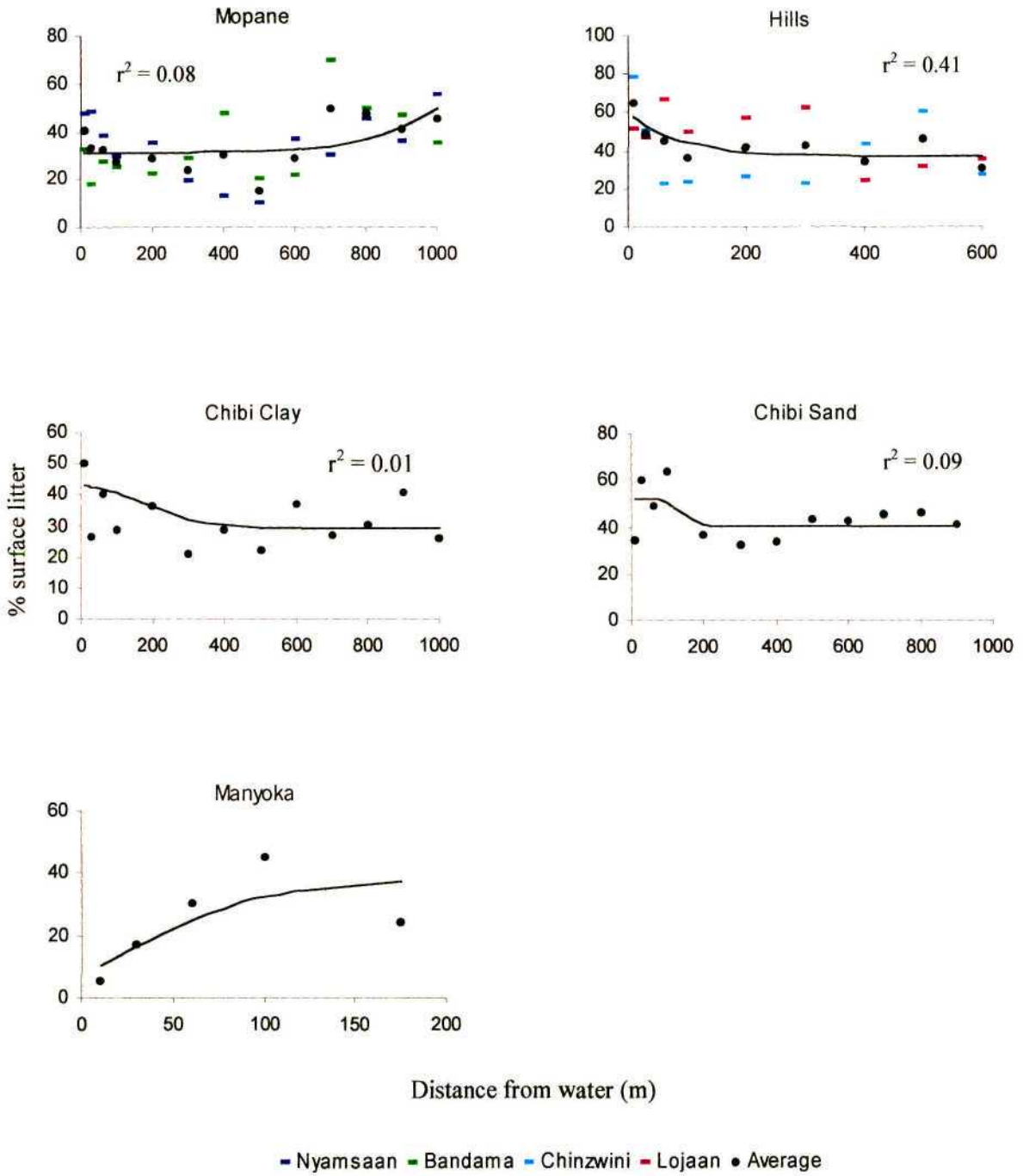


Figure 26. Percent litter with distance from water.

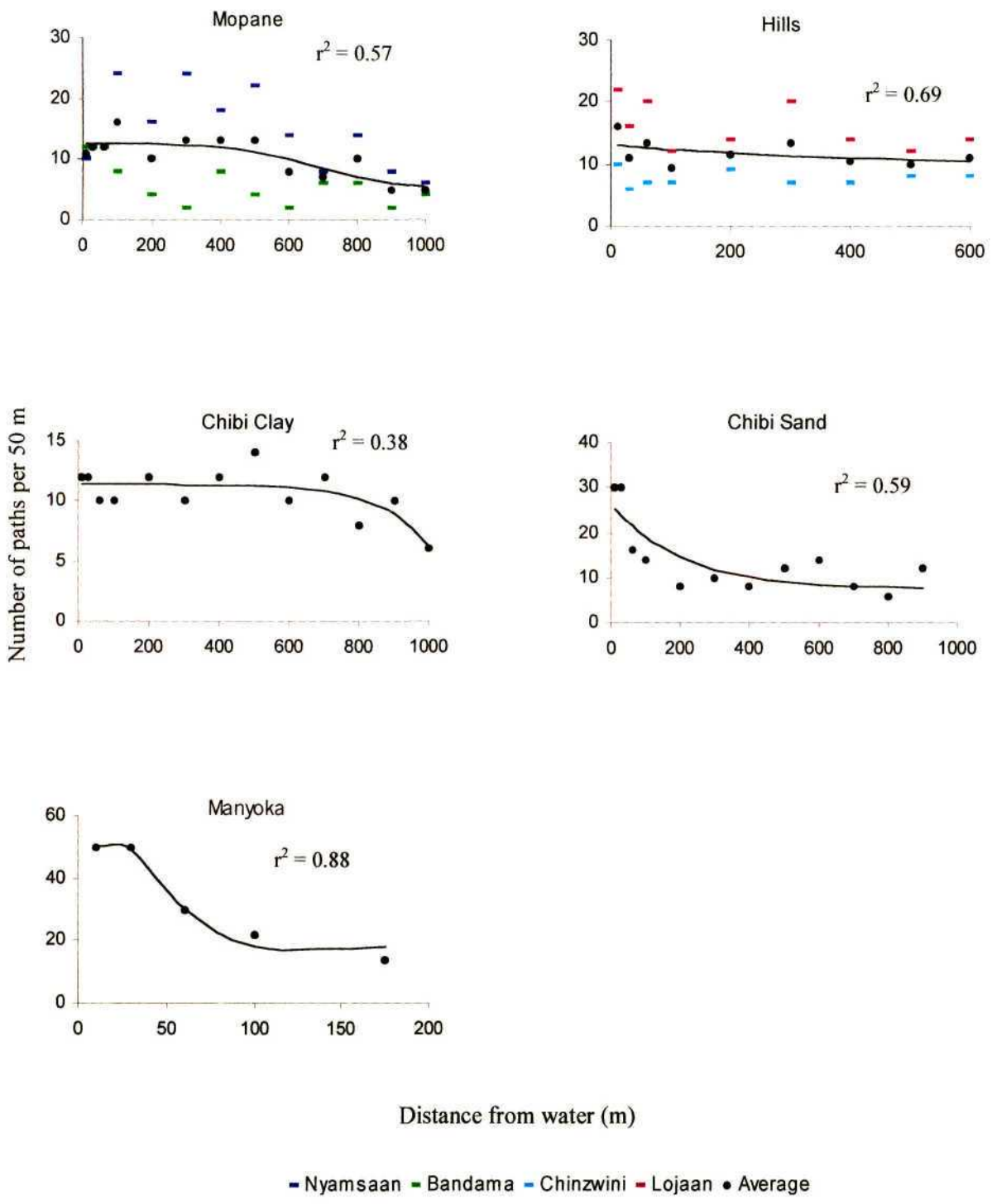


Figure 27. Number of paths with distance from water.

4. Infiltration

Analysis of variance was conducted for on path data only, off path data only, and a pooled data set created by combining data from both on and off paths. The results are summarised in Tables 5 - 8.

Table 5. Mean infiltration rates on and off paths with distance from water (within a column, infiltration rates for distances with letters in common are not significantly different at the 0.05 % level)

<i>Distance from water</i> (m)	<i>Mean infiltration rate (ml/min.)</i>		
	<i>On paths</i> (n=3)	<i>Off paths</i> (n=3)	<i>Overall</i> (n=6)
5	14.8 ^A	13.9 ^A	14.4 ^A
10	23.8 ^A	33.0 ^B	28.4 ^B
20	12.8 ^A	33.3 ^B	23.1 ^{AB}
30	15.0 ^A	31.6 ^{AB}	23.3 ^B
60	15.6 ^A	38.4 ^B	27.0 ^B
100	15.0 ^A	36.6 ^B	25.8 ^B
300	24.0 ^A	37.4 ^B	30.7 ^B

Table 6. Summary of results of Analysis of Variance for Infiltration rates overall (i.e. data from pooled on and off paths)

<i>Source</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P <</i>
Path	1	2273.4	27.89	0.005
Distance	6	168.3	2.06	0.1
Path X Distance	6	107.6	1.32	NS
Error	28	81.51		

Table 7. Summary of results of Analysis of Variance for Infiltration rates on paths

<i>Variation</i>	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>P <</i>
Distance	6	381.326	63.55	1.097	NS
Error	14	811.44	57.96		
Total	20	1192.76			

Table 8. Summary of results of Analysis of Variance for Infiltration rates off paths

<i>Variation</i>	<i>Df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>P <</i>
Distance	6	1265.2029	210.8672	2.007	NS
Error	14	1470.96	105.0686		
Total	20	2736.1629			

Paths had a significant ($P < 0.005$) effect on infiltration rates, with infiltration rates on paths generally slower than off paths (Tables 5 and 6). The main effect of distance was not significant when data for on paths and off paths was analysed separately, but was significant at the 90 % level when the two data sets were pooled (Tables 6, 7 and 8).

Infiltration rate was not reduced at distances greater than 5 m from the water point (Figure 28).

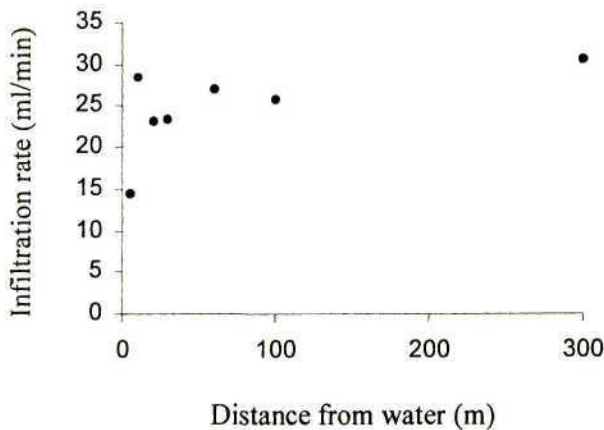


Figure 28. Infiltration rate with distance from water.

No relationship between distance from water and infiltration rate on paths was found (Table 7). Off paths there was a difference ($P < 0.01$) between infiltration rate at the first distance (5 m) and the remaining six distance points. After the first distance point (5 m), infiltration rates off paths were consistently, but not always significantly, higher than on paths (Figure 29).

The interaction between distance and path on infiltration rate was not significant.

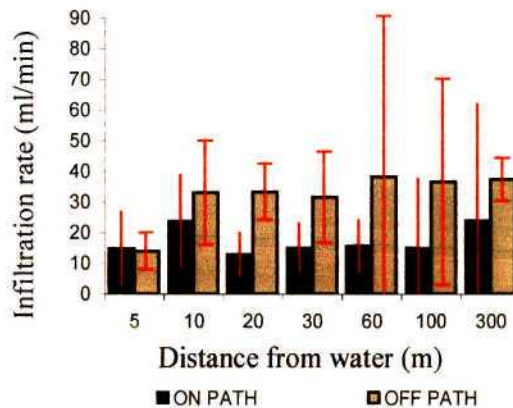


Figure 29. Infiltration rates on and off paths with distance from water. Error bars represent 95 % confidence intervals.

DISCUSSION

1. Nutrient status

Depending on soil texture, patterns for soil nutrients varied to some degree with distance from water. However, in nearly all cases except at Manyoka, local increases in nutrients and organic C were observed close to water (up to 100 m). Other authors have also measured increased dung levels close to water (Weir 1971; Tolsma *et al.* 1987; Perkins & Thomas 1993b; Dougill & Cox 1995; Andrew & Lange 1986a). Similar localised nutrient increases were observed in the Kalahari up to 50 m from boreholes (Perkins & Thomas 1993b) and in South Australia, where enrichment, measured by weight of dung, was largely restricted to the area within 200 m of water points (Andrew & Lange 1986a). In

eastern Botswana, at a water point that had been in operation for more than 30 years, most nutrients showed enrichment up to 400 m, but K, P and N enrichment was restricted to within 50 m of the water point. In general, organic C and nutrient enrichment are considered positive by-products of the water point, but beneficial effects on forage production can only be realised where stocking rates are moderate to low. Where stocking rates are high, trampling, heavy grazing and compaction close to water reduce plant growth.

The absence of a pattern for nutrient enrichment with distance from water at Manyoka implies that increased dung inputs close to water require more than two years of moderate game stocking on sandy Hill soils for soils to become enriched. At Chibi Clay (Flat Sandveld), nutrient enrichment was more clearly associated with distance from water than at other water points. Rocky outcrops around water points in the Hills may be responsible for variations in nutrient levels, particularly at distances greater than 100 m from water. On clay-loam soils, which are already base rich, enrichment close to water was only observed for nutrients (N and P) which are generally deficient in all soil types, including clay (Stevenson 1986). On sandy-clay-loam soils, beyond 300 m from water, factors other than distance from water appeared to be influencing nutrient patterns. These factors do not, however influence total N content. Nitrogen content generally increases when C levels increase (Stevenson 1986), but a factor that results in the independent increase of C is the addition of fresh litter (Scholes & Walker 1993). The pattern for percent litter on sandy-clay-loam soils (Mopane, Figure 26) follows very closely that for percent organic C, but not N (Figure 17). This suggests that on sandy-clay-loam soils, surface litter may have a greater impact on C levels than dung, and may influence the C:N ratio by increasing C relative to N where litter is high. It is important to note that N, which is a limiting nutrient (Scholes & Walker 1993), did increase close to water. On clay-loam and around established water points on sandy soils, the limiting nutrient, N, again increased close to water. Similar increases in N were observed close to water in eastern Botswana (Tolsma *et al.* 1987).

Nutrient and C enrichment was possibly greater on the Flat Sandveld than on clay-loam and sandy-clay-loam because sandy soils are generally nutrient poor, and therefore relative nutrient enrichment (dung or urine inputs) should have a more pronounced effect

on sand than on soils which were already relatively eutropic. In comparison to the sandy soils in the Hills, Flat Sandveld possibly displayed a clearer enrichment pattern around water because there were fewer obstructions to movement. Rocky outcrops in the Hills concentrate animals and water run-on. In the absence of these obstructions, more homogenous utilisation and foraging gradients would be expected, and these are more likely to be influenced by the position of water points. In addition, more animals may frequent the Flat Sandveld relative to the Hills. Reasons for this assumption are: (1) the Flat Sandveld is close to the nutrient rich basalt flats, which are favoured foraging grounds. More animals (particularly grazers which appear to produce more dung) possibly utilised the adjacent sandveld than the sandveld in the Hills, which is further away; and (2) the Flat Sandveld is more accessible than the Hills, suggesting that more animals may be attracted to this area. Piosphere patterns are generally more pronounced where a greater number of animals are using a water point (Weir 1971; Tolsma *et al.* 1987).

2. Texture and depth

The absence of clear trends for soil texture and depth along the gradient of distance from water confirmed that transects were reasonably appropriately placed so as to minimise the effects of soil texture and depth on response variables.

3. Soil surface condition

Exposed soil surfaces were most pronounced close to water on sandy soils. This is possibly because grass tufts on sand appear to be more easily kicked out by hoof action (pers. obs.). Piospheres for bare ground on sand were smaller (60 m) in the Hills than in the Flat Sandveld (500 m at Chibi Sand). Likely reasons for the development of a larger clearer piosphere on the Flat Sandveld relative to the Hills have been examined (nutrient enrichment discussion). The increase in *P. maximum* which lead to a decline in bare ground at 30, 60 and 100 m may be attributed either to shading from a few large *Acacias* (Kennard & Walker 1973), or fertilisation through dung and urine inputs close to water (*P. maximum* is known to respond positively to fertilisation (Cunningham Laboratory 1964)). While nutrient enrichment was high at the 10 m point, *P. maximum* cover and total biomass were low, and the proportion of bare ground was high. Heavy trampling

close to water is likely to account for poor production, even where nutrient levels are high. Excessively high values (> 90 %) for bare ground close to water at Manyoka may be because plants more resistant to grazing, trampling and being kicked out, had not yet established. Fortunately, bare ground on sand does not have as serious implications on infiltration and erosion, as it does on other soils. On sandy-clay-loam and clay-loam soils at MCT increased bare ground did not appear to be associated with distance from water. This may be because plant roots are held more firmly in sandy-clay-loam and clay-loam than in sand.

Capping and crusting, though functionally different on the soils described in this study, have been discussed collectively. Where trampling is excessive, both soil crusts and cap destruction is expected by hoof action. At Chibi Clay and Chinzwini this does not occur. It would appear that on sandy-clay-loam soils, after the initial decline in capping or crusting (possibly due to destruction close to water) a general decline in capping away from water is observed. This suggests that reduced capping close to water may be a function of cap destruction, while reduced capping further away may be a function of reduced cap formation where cover is good. This hypothesis however requires testing. Elsewhere cryptogam crusts have been shown to be severely reduced in heavily utilised areas through both grazing and trampling (Rogers & Lange 1971; Brotherson *et al.* 1983). At Malilangwe on sandy-clay-loam soils (Mopane) caps generally form on exposed surfaces, where they play an important role in stabilising the soil surface (Rogers & Lange 1971; Anderson *et al.* 1982). Areas with high capping on sandy-clay-loam soils (Figure 24) generally corresponded with areas high in bare ground (Figure 23). In contrast, on exposed clay-loam soils at MCT, self-mulching surfaces are unfavourable to the development of cryptogam crusts or caps. Cryptogam crusts are known to develop in close association with grass plant crowns (Tongway & Hindley 1995). In this study, bare ground (Figure 23) was negatively correlated with capping (Figure 24) and positively correlated with surface litter (Figure 26) on clay-loam soil. Surface cover (in the form of grass plant crowns or litter) possibly promotes the existence of a cryptogam crust by providing a moist environment where cracking and self-mulching is reduced.

Increased trampling close to water is a function of increased utilisation, and so was anticipated. However, the nature of variations in the effect of trampling on different soils

was not known. On sandy soils the spatially limited extent of the effects of increased trampling may be due to lighter utilisation (relative to that on other soil types), while localised, severe increases in trampling effects close to water may be attributed to greater site sensitivity, relative to that on other soils. As for bare ground, the effect of trampling close Manyoka (10 and 30 m) was excessive (> 80%), and may be attributed to the vulnerability of areas unaccustomed to year round heavy pressure.

Litter plays an important role in soil water absorption and retention (Stevenson 1986). It also provides a layer, which protects the soil surface from raindrop impact (Micelle *et al.* 1984; Warren *et al.* 1986). Increased litter cover close to water at all water points, except Manyoka, is possibly the result of animals trampling grass and breaking off branches en route to water. Other studies that have investigated the effect of stocking rates on litter cover have found the opposite trends. In intensively utilised systems, also in southeastern Zimbabwe, litter cover estimates were higher under light utilisation than under intensive utilisation (Kelly & Walker 1975). In the same study litter cover was found to be lower where perennial grasses, excluding *U. mosambicensis* dominated. The same was found for established water points at MCT (Chapter 6). Increased litter will have an advantageous effect in the vicinity of water by reducing erosion potential. Undecomposed material provides obstructions to flow, thereby reducing the rate of surface run-off (Tongway & Hindley 1995).

Path number was expected to be higher close to water. The fact that path number declined only slightly with distance from water in the Hills may be attributed to the presence of rocky outcrops. Animal paths would be concentrated along the only access routes and path number would therefore possibly remain high further from water.

4. Infiltration

Heavy stocking rates, as would occur close to a water point, are almost universally detrimental to water infiltration (Wood & Blackburn 1981; Dadkhah & Gifford 1981; McCalla *et al.* 1984; Warren *et al.* 1986). It is uncertain whether reduced infiltration is the result of animal hooves on the soil, or the removal of vegetation which would otherwise protect the soil surface, increase soil porosity through root activity, and provide an environment suitable for soil arthropod and microbe activity (Warren *et al.* 1986).

Compaction on sandy-clay-loam soil, as measured by infiltration rate (on and off paths) was only obvious at 5 m from water, suggesting that compaction was confined to the area close to water. Similar results were found in South Australia around water points used by cattle (Andrew & Lange 1986). In addition the entire area within 5 m of water was severely effected by trampling as evidenced by low infiltration rates, both on and off animal paths. At distances of greater than 5 m, infiltration rate was consistently lower on, than off animal paths. Results suggest that beyond 5 m from water reduced infiltration through increased compaction was limited to animal paths. Since paths represent compacted areas, path area could be used as a surrogate measure to determine the extent of compaction or reduced infiltration around a water point.

CHAPTER 6 : VEGETATION RESPONSES

INTRODUCTION

Changes in stocking pressure are commonly known to have an effect on herbaceous species composition (Pickup 1991; O'Reagain & Turner 1992; O'Connor 1994), biomass (Kelly & Walker 1976) and cover (McCalla *et al.* 1984; O'Reagain & Turner 1992). Changes in vegetation are brought about not only by changes in grazing pressure (Kelly & Walker 1976), but also by changes in trampling pressure, soil nutrient status (Medina 1985; Scholes 1990a) and infiltration rate where plant available water is reduced (Dadkhah & Gifford 1980). Similar changes in woody species composition and utilisation may be expected in a browsing system, particularly in the presence of elephants. Changes to the woody component are not expected to be as severe as changes to the herbaceous layer, because the latter is more susceptible to trampling and is exposed to utilisation by a greater biomass of herbivores (Chapter 7, Figure 61). In contrast, changes to the woody component are expected to be more persistent than changes to the herbaceous layer because woody plants are longer lived and have a slower growth rate (Laws 1970).

Water points provide sites of maximum herbivore activity, with herbivore impacts decreasing with distance from water. In the last two decades a fair amount of work has been done on vegetation gradients away from watering points. Most work has been done in Australia (Lange 1969; Foran 1980; Andrew & Lange 1986a; Andrew & Lange 1986b; Andrew 1988; Pickup & Chewings 1988; Pickup 1991; Pickup 1994) and Botswana (Child & Parris 1971; Parris 1984; Kalikawa 1990; Perkins & Thomas 1993a; 1993b; Tolsma *et al.* 1987; Van Rooyen *et al.* 1990; Van Rooyen *et al.* 1994; Dougill & Cox 1995), but some has been conducted in the Kruger National Park (Thrash 1993; Thrash 1998a; 1998b; Thrash *et al.* 1991a; 1991b; 1993). In general, for established water points, changes in species composition have been found to follow logistic or sigmoid logistic distributions with distance from water (Graetz & Ludwig 1978). Similar trends may be expected for biomass estimates or utilisation of vegetation with distance from water. The piosphere, which describes changes associated with utilisation around water points is

discussed in detail in Chapter 2, section 4. Gaining insight into the spatial extent of piospheres and sacrifice zones allows managers to monitor the effects of herbivore utilisation for different water points on different soils and in different vegetation types over time. This provides information concerning the robustness of sites which is valuable information when siting water points. It may also give some indication of how far apart water points need to be placed in a particular environment, and when water points should be switched off to rest veld.

The aim of this chapter was to assess the extent and nature of the effect of perennial water on species composition and utilisation of the herbaceous and woody components in different vegetation types at MCT.

METHODS

Vegetation was sampled at the end of the growing season (March - May 1997) when species composition was best represented, and biomass estimates should reflect long term change following the rainy season growth pulse (Pickup 1991). Transects were located as described in Chapter 4 but the 30 m sample point was omitted for most woody transects, because the belt transect width for sample sites (transects) on either side (10 m and 60 m) encompassed the 30 m site.

1. Herbaceous data

One m² quadrats (placement described in Chapter 4) were used to establish species composition, percent areal cover and utilisation per species. The herbaceous layer included grasses, forbs and woody seedlings < 0.3 m in height. One m² quadrats were selected as this size quadrat was found to be small enough to allow relatively accurate estimates of cover, and large enough to incorporate the suite of species representative of Zimbabwe's lowveld (Kelly & Walker 1976).

1.1. Species composition

Within each of the 25 quadrats along a transect, individual species were identified and

ranked (Table 4) for percent aerial cover.

1.2. Biomass

The comparative yield method (Haydock & Shaw 1975) was adapted to accommodate the wide variety in species composition, density and height of herbaceous stands within each vegetation type. Photographs representing herbaceous stands common to each of the sampled vegetation types were taken and allocated a numerical identity. These photographs were used as references to estimate standing biomass in each of the 1 m² quadrats described above. Biomass in each of the photographed stands, as well as every 15th quadrat assessed, was calculated by clipping and oven drying the above ground biomass within a quadrat. From this data average biomass weights for each reference stand were calculated.

2. Woody data

Belt transects of variable size were used to describe the woody strata. Transect size was determined by the density of woody plants at a sample site (Walker 1976). Each transect had to include 15 individual shrubs (woody plants < 2 m) for analysis of shrubs, and 15 individual trees (woody plants > 2 m) for analysis of trees. The 2 m height cut off, separating shrubs and trees, was selected to represent the maximum height of browse accessible to most browsing ungulates. In general the belt transect length followed the 50 m transect for herbaceous data collection, with transect width varying.

All woody plants within belt transects were identified, measured for height, stem circumference and utilisation. Multistemmed plants, and plants where stems joined below ground level, were recorded as single individuals, but stem circumferences were measured and recorded separately.

Canopy utilisation was determined by estimating the proportion of canopy removed by elephants or browsers (Walker 1976). Utilisation per individual was ranked following Table 4. It was also noted if plants were snapped, bent or pushed over by elephant activity. The proportion of a plant that was dead was noted, and the cause of death was attributed to one of three categories, (1) elephants, (2) drought or (3) other and unknown. If there were signs of elephant utilisation, then elephants were noted as

responsible for damage, however where die-back was limited to the upper portions of intact branches, death was attributed to drought. Where the cause of death was uncertain it was marked as such.

ANALYSIS

1. Herbaceous data

1.1. Species composition

For each quadrat, the midpoint of assigned ranked classes (% values) were used as a measure of aerial cover for each species. Mean aerial cover was calculated for each species at each distance. Species poorly represented and sited only once, or twice not close to one another, were omitted from the analysis. Correspondence Analysis (CA), without any prior transformation, was used to summarise species compositional differences between transects for each water point. The effects of soil texture and depth were removed by including these variables as covariables in the analysis. The first axis co-ordinates were tested for a functional relationship with distance from water using regression analysis (Microsoft Excel '97). In each case distance values were log-transformed. In all cases, except at Bandama, Lojaan and Manyoka there was a strong relationship ($P < 0.001$) with distance from water. The first axis co-ordinates of site scores were then used to determine whether a logistic relationship existed between distance from water and species composition (Thrash *et al.* 1983). Logistic sigmoid curves ($y = a + c / \{1 + e^{-b(D - m)}\}$, where $D = \text{distance}$) were fitted to co-ordinate scores using non-linear regression (GENSTAT 5 1988). Obvious outlier points were excluded from the analysis, regression lines were replotted and r^2 values were given for each fit (equations of fitted curves are given in Appendix 3, Table 1). Curves were plotted only where $P < 0.05$ for the relationship between distance and site cores. Exceptions were made for water points in Hill communities (Chinzwini, Lojaan and Manyoka) where curves were fitted to $P < 0.08$ because of the accepted noise factor in these communities due to topography.

Four major herbaceous groups: perennial grasses, annual grasses, forbs and woody seedlings, were investigated for abundance (as measured by % aerial cover) with distance

from water. Abundance trends for perennial grass species were investigated in greater detail. Changes in aerial cover with distance from water were investigated individually for three key species. *Urochloa mosambicensis* was selected as a key species because it is a dominant grass at MCT, and because it is a perennial species that has the ability to withstand drought (Judd 1979). *Digitaria eriantha* was selected for further investigation because this species is a favoured and nutritious forage grass (Van Oudtshoorn 1992) which is fairly well represented on sandy soils at MCT. *Panicum maximum* was studied in more detail because it is a valuable forage species which is known to respond well to fertilisation (Cunningham Laboratory, CSIRO 1964; van Oudtshoorn 1992), and is often associated with shading from tree canopies (Kennard & Walker 1973). The cumulative response of all perennial grasses, excluding *U. mosambicensis* and *P. maximum*, was investigated with distance from water. Perennial grasses used in this analysis included *D. eriantha*, *C. ciliaris*, *Chloris roxburghiana*, *Enteropogon macrostachyus*, *Eragrostis lehmanniana*, *Eragrostis superba*, *Eragrostis rigidior*, *H. contortus*, *P. squarrosa*, *S. pappophoroides*, *T. monachne*, *Panicum coloratum* and *S. galpinii*. *Urochloa mosambicensis* and *P. maximum* were excluded from the analysis because they do not respond like most other perennial grass species to disturbance (either they behave like pioneer species or respond more strongly to shading or fertilisation than disturbance).

Species richness was calculated per transect.

1.2. Biomass

A value for biomass at each distance was calculated by a two stage analysis. First, the estimated masses for reference stands were calculated by using data from clipped quadrats. Second, reference stand estimated weights were substituted for reference stand identity numbers, and the estimated average biomass at each sample site was calculated from the 25 assessed quadrats. Logistic curves were fitted to data where possible.

2. Woody data

Total stem area was calculated from measured stem circumferences using the equation (circumference²) / 4π. Individual stem areas for multistemmed plants were calculated separately and the products were summed to give one value for stem area per individual.

Stem density (m^2 / ha) was calculated for each transect, and values were regressed against distance from water. Trees and shrubs were analysed separately.

2.1. Species composition

Total stem area was calculated for all tree and shrub species separately, and together. Total stem area scores for each species at each sample site were used in Correspondence Analysis. The same procedures employed to establish herbaceous species composition trends were used to find trends in shrub, tree and woody (i.e. tree and shrub together) species composition with distance from water.

2.2. Density

The density of shrubs, trees and all woody plants was calculated as individuals per hectare, per sample site. Density values were plotted against distance from water.

2.3. Stem area

Total stem areas of shrubs and trees were calculated separately and plotted against distance from water.

2.4. Utilisation

Unlike herbaceous material, utilisation of woody plants is evident for months and even years after it occurs. Utilisation of trees, shrubs and all woody plants was established by using weighted utilisation scores ($\{\text{stem area} \times \text{utilisation score}\} / 100$). Utilisation by elephants, other browsers and all browsers with distance from water was calculated for shrubs, trees and all woody plants. Shrubs (woody plants < 2 m high) that obviously would have exceeded 2 m in height had they not been damaged by elephants, were marked as being converted from trees to shrubs. Assessments were based on stem circumference for a particular woody species, and signs of snapping or bending by elephants. Woody plants were marked as being utilised by elephants if damaged branches or trunks showed signs of twisting, bark stripping or snapping. Kudu, buffalo and eland can inflict damage with their horns to smaller woody stems (up to ± 9 cm in diameter) that looks remarkably like elephant damage (pers. obs.). Since most woody damage

showing signs of snapping and ripping is the result of elephant feeding, when the agent of damage in these circumstances was uncertain, elephants were marked as responsible. Some damage caused by kudu, buffalo or eland may have been attributed to elephants.

RESULTS

1. Herbaceous data

1.1. Species composition

The cumulative fit per species, and species scores indicated that in general species did not respond in the same way to distance from water across all water points. A few species (*P. maximum*, *Cucumis* sp. and *C. trigyna*) were well explained by the first axis at both Chinzwini and Lojaan. At both water points all three species increased with proximity to the water point. The same trends were not observed outside of the Hills or at the new water point (Manyoka). Similarly, in *C. mopane* veld (Nyamsaan and Bandama) only *A. adscensionis*, *S. pappophoroides* and *I. schimperi* were closely correlated with the first axis, and increased with distance from water. Similar responses were not evident in other vegetation types. *Urochloa mosambicensis* was the only herbaceous species that was well explained by the first axis of CA for all water points (except Nyamsaan) outside of the Hills. In all cases *U. mosambicensis* increased close to water (eigenvalues for the first axis of CA are given in Appendix 3, Table 1).

Herbaceous species composition with distance from current perennial water points was generally well described by logistic curves (Figure 30). Equations of fitted curves and species score : distance correlations (r^2 and P values) are given in Appendix 3, Table 1. Only Bandama, the water point which had not held water for the preceding two dry seasons, showed no logistic pattern for species composition with distance from water. The lower portion of the logistic curve, that which describes the sacrifice zone, was only evident for Chibi Sand. For most water points equilibrium (the upper asymptote of the logistic graph) was reached between 100 and 200 m from water. For Chibi Sand it was only reached at about 600 m from water, while for Manyoka it was reached at approximately 30 m from water.

Aerial cover of perennial grass, as a whole (Figure 31), did not appear to decline close to water except in Hill vegetation (Chinzwini, Lojaan and Manyoka) where *U. mosambicensis* was poorly represented. In general, annual grass and forb cover responded similarly to distance from water. Aerial cover of both groups was reduced close to water at all sites except Chinzwini. Increased woody seedling cover was generally confined to 10 or 30 m from water points.

When key perennial species were investigated separately for trends with distance from water (Figure 32), it was found that different species responded dissimilarly to distance from water on different soils or in different vegetation types.

Urochloa mosambicensis increased with proximity to water at all water points except those in the Hills (where *U. mosambicensis* is not normally abundant). Increases were not confined to the immediate vicinity of water, but were observed over entire distances sampled.

Digitaria eriantha was only represented at established water points (> two dry seasons old) on sand and in *C. mopane* veld on sandy-clay-loam (i.e. not present at Manyoka or Chibi Clay). Aerial cover of *D. eriantha* was severely reduced close to water on Flat Sandveld (Chibi Sand) with no *D. eriantha* recorded within 400 m of the water point. In *C. mopane* veld where *D. eriantha* cover is naturally very low, a slight reduction in cover was observed close to water. No reduction in *D. eriantha* cover close to water was observed over the distance gradients sampled in the Hills.

P. maximum increased close to water, but unlike trends observed for *U. mosambicensis*, increases were localised, and limited to within 400 m of water points.

Aerial cover of all perennial grasses except *U. mosambicensis* and *P. maximum* increased with distance from water in all vegetation types. A decline in perennial grass cover under heavy stocking pressures is consistent with reports in the literature (O'Reagain & Turner 1992). Most severe declines in perennial grass cover close to water were observed on sandy soils (Chinzwini, Lojaan and Manyoka and Chibi Sand) with the Manyoka point demonstrating the greatest change (80 %) in cover over the shortest distance (175 m). *C. mopane* veld showed the smallest decline in perennial grass cover (excluding *U. mosambicensis* and *P. maximum*) followed by Chibi Clay. Although the reduction in perennial grass cover close to water was not severe at Chibi Clay (< 40 %)

the apparent suppression of perennial grass cover extended far from water (to about 500 - 600 m from the water point).

Reductions in species richness close to water were most prominent on sandy soils (Chinzwini, Lojaan, Manyoka, and Chibi Sand) (Figure 33). Species richness in the Hills declined linearly with proximity to water points. This suggests that the entire extent of the piosphere for species richness had not been measured (Andrew & Lange 1986a). Herbaceous species diversity at Chibi Sand was approximately six times lower close to water (10 m) than it was beyond 200 m from water, where it would appear that equilibrium had been reached. No clear declines in species richness were observed with distance from water in *C. mopane* veld or at Chibi Clay.

1.2. Biomass

Logistic curves were generally poor descriptors of wet season trends in herbaceous biomass with distance from water (Figure 34). Biomass in Hill vegetation was clearly reduced close to water, but the spatial extent of reduction was smaller at Manyoka (100 m) than at the two older water points (> 600 m). Biomass reduction at Manyoka was however more severe (only $\pm 15 \text{ g / m}^2$ at 10 m). On Flat Sandveld (Chibi Sand) and clay-loam (Chibi Clay) substantial reductions in biomass were limited to the immediate vicinity of water (10 m).

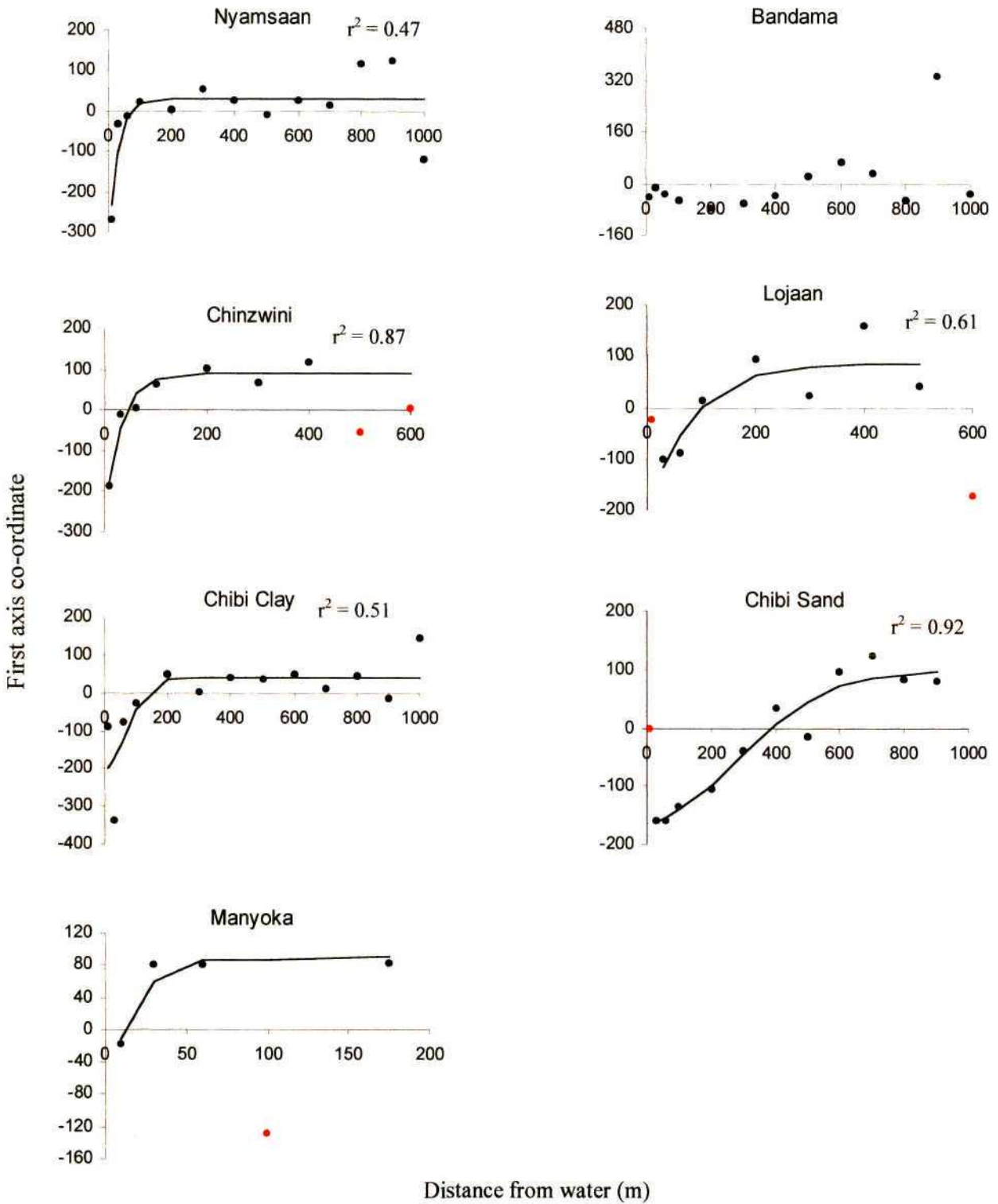


Figure 30. First axis Correspondence Analysis co-ordinate scores for herbaceous species composition in relation to distance from water (red dots indicate values that were not included in the regression analysis).

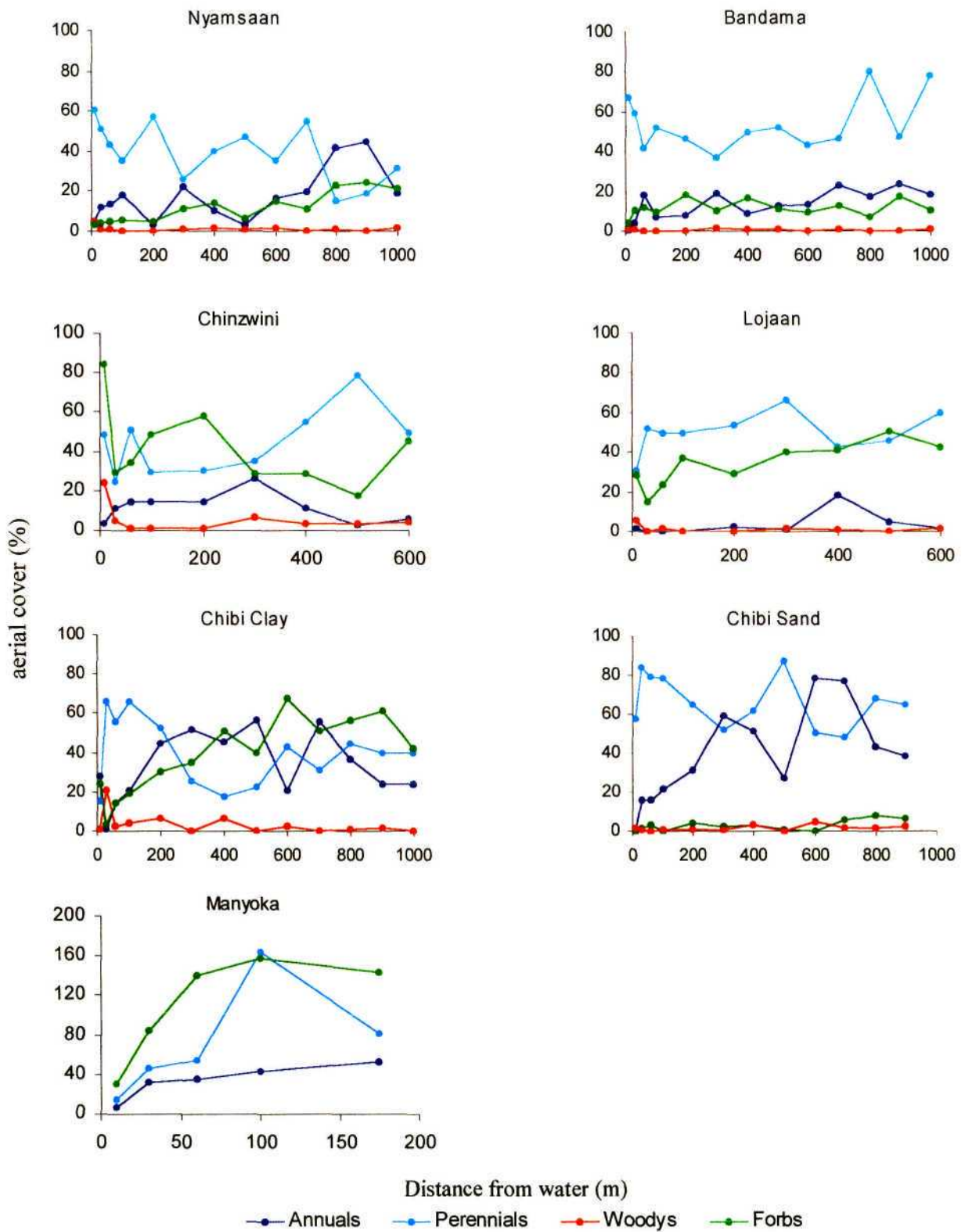


Figure 31. Percent average aerial cover of perennial grasses, annual grasses, forbs and woody seedlings.

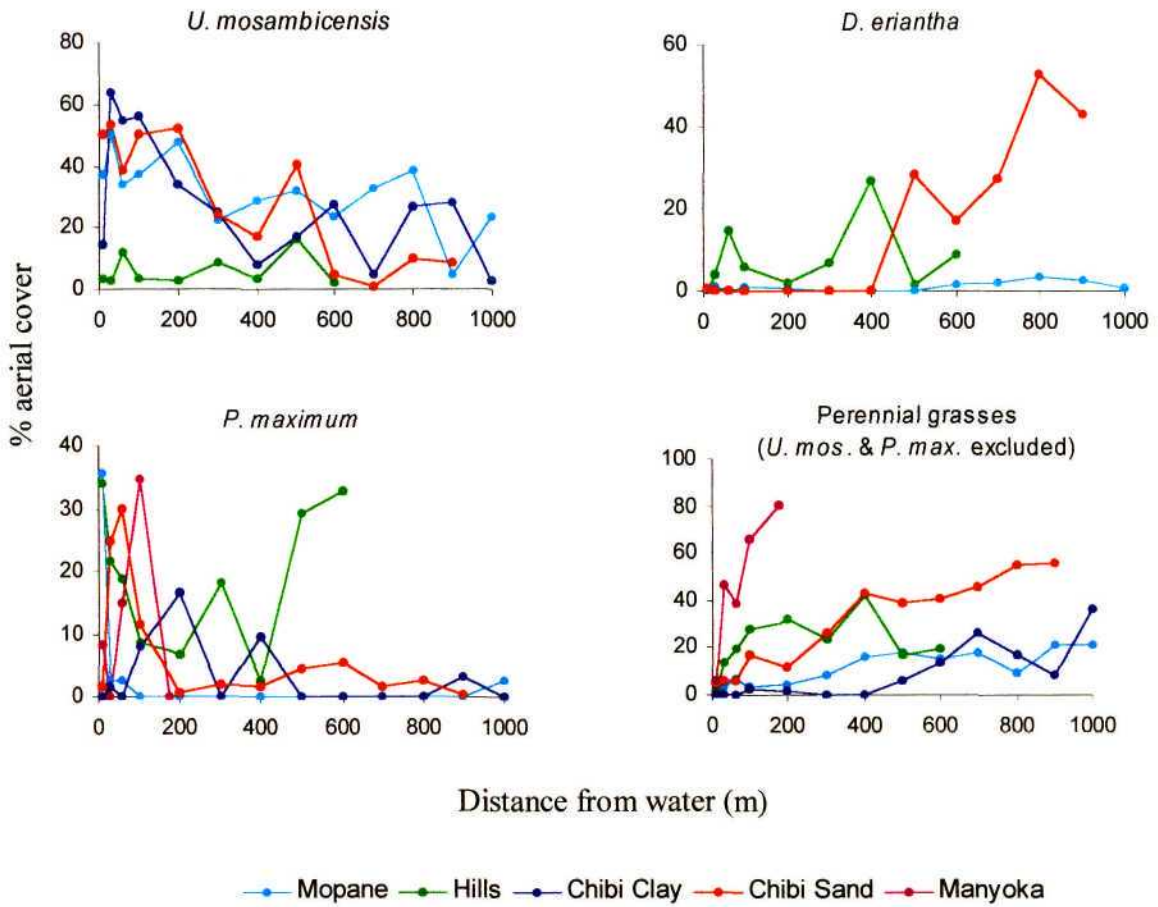


Figure 32. Percent aerial cover of perennial grasses: *Urochloa mosambicensis*, *Digitaria eriantha*, *Panicum maximum* and all perennial grasses excluding *U. mosambicensis* and *Panicum maximum*.

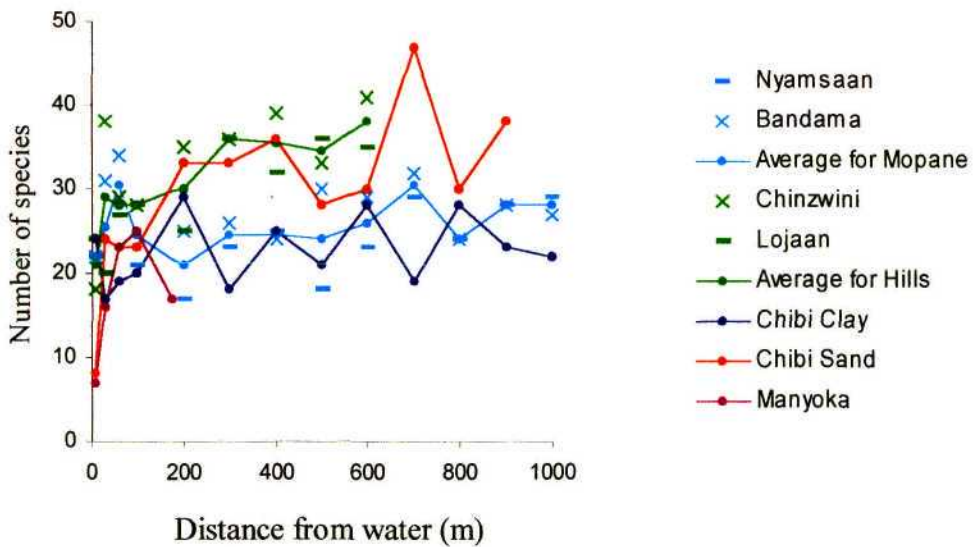


Figure 33. Species richness at different sites and in different vegetation types with distance from water.

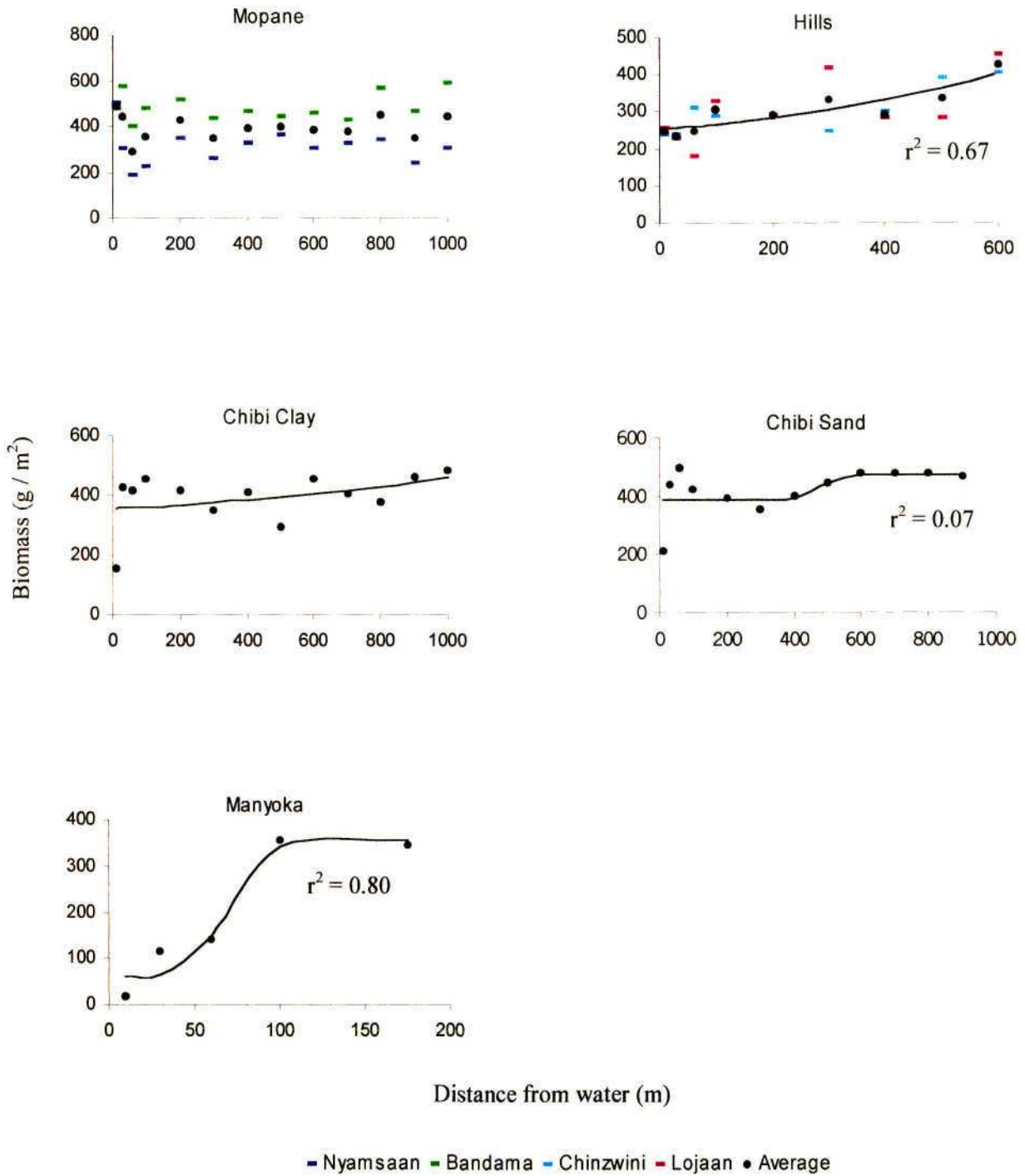


Figure 34. Average above ground biomass with distance from water.

2. Woody data

2.1. Species composition

Cumulative fit per species and species scores revealed that, across vegetation types, the same woody species were seldom strongly correlated with the first axis and responded in the same way to distance from water.

Shrub, tree and woody (trees and shrubs) species compositions with distance from water were satisfactorily described by logistic curves (Figures 35 – 41). Possibly due to the extent of sampling distances, Manyoka tree and woody species compositions were best described by exponential curves (Figure 41). Only where sufficient sample points were included, or where residual variance did not exceed variance of response variates, were r^2 values displayed (distance : species score correlations, first axis CA eigenvalues and equations of fitted curves are given in Appendix 3, Tables 2 – 4).

Piospheres for species composition of all woody plants were generally larger (Figure 30; Figures 35 - 41) and more strongly associated with distance from water (Appendix 3, Tables 1 - 4) than those for herbaceous and shrub species composition at the same water points. In general, shrubs did not show clear relationships for species composition with distance from water. Woody species composition at Lojaan appeared to be most severely effected by the placement of water, with upper asymptotes possibly being reached at distances of greater than 500 m from water for trees and all woody plants (Figure 38) In addition sacrifice zones, represented by the lower asymptote of the sigmoid logistic curve, were only evident for Lojaan tree and woody species composition (Figure 38). In contrast to herbaceous species composition (Figure 30), tree and woody species composition at Bandama still followed logistic distributions with distance from water. Note that this water point had not held perennial water for two dry seasons prior to data collection.

Exponential fits for trees and all woody species composition at Manyoka suggest that the upper limit of the piosphere may be reached beyond the distance sampled (Figure 41). Small sample size prevents conclusive interpretation.

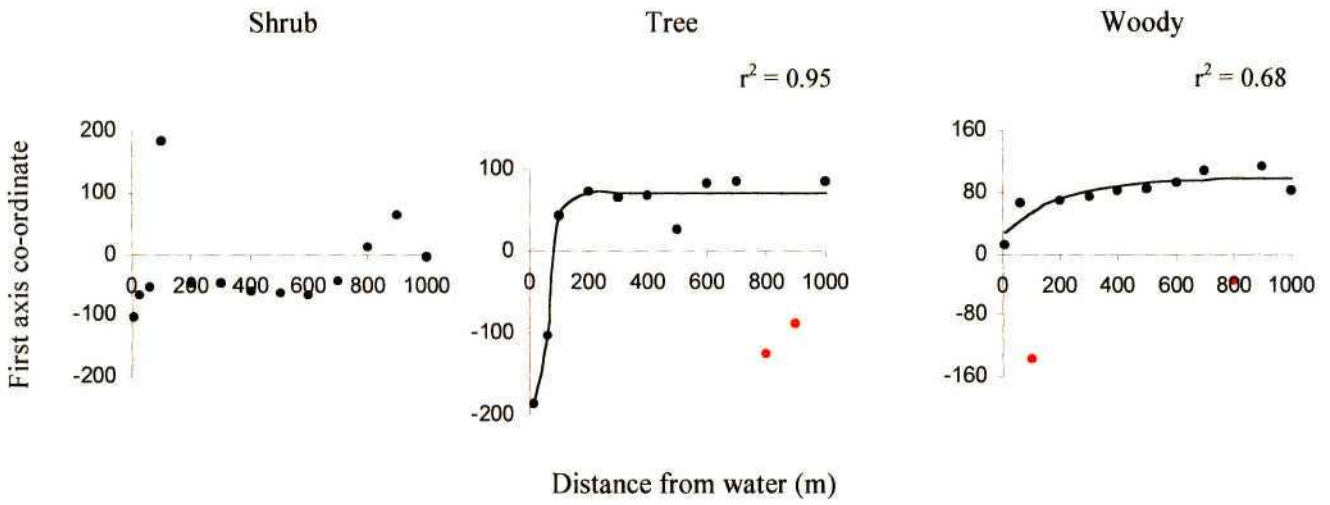


Figure 35. Nyamsaan: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water (red dots indicate values that were not included in the regression analysis).

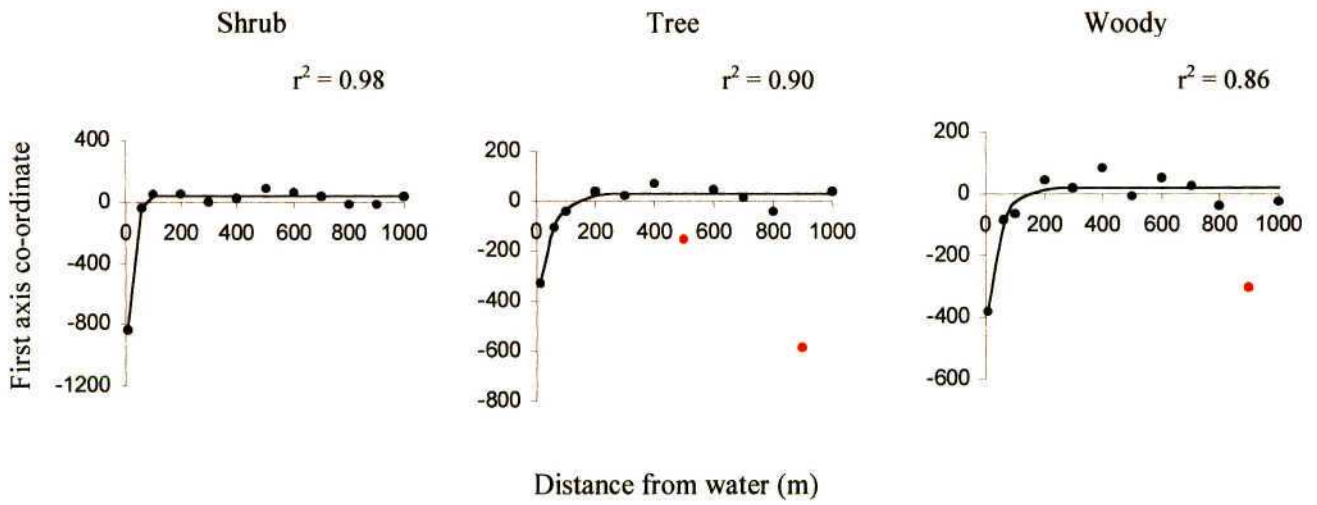


Figure 36. Bandama: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water (red dots indicate values that were not included in the regression analysis).

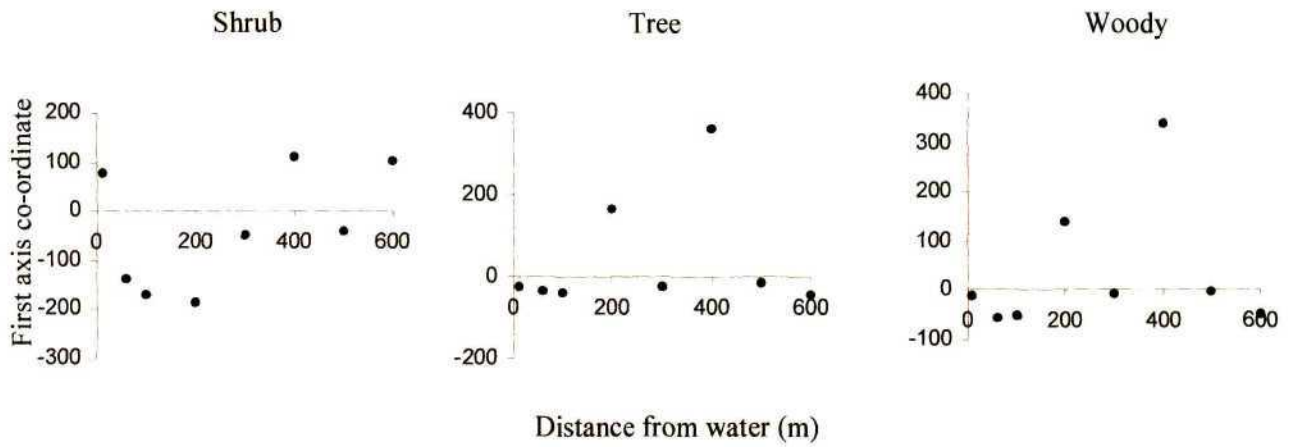


Figure 37. Chinzwini: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water.

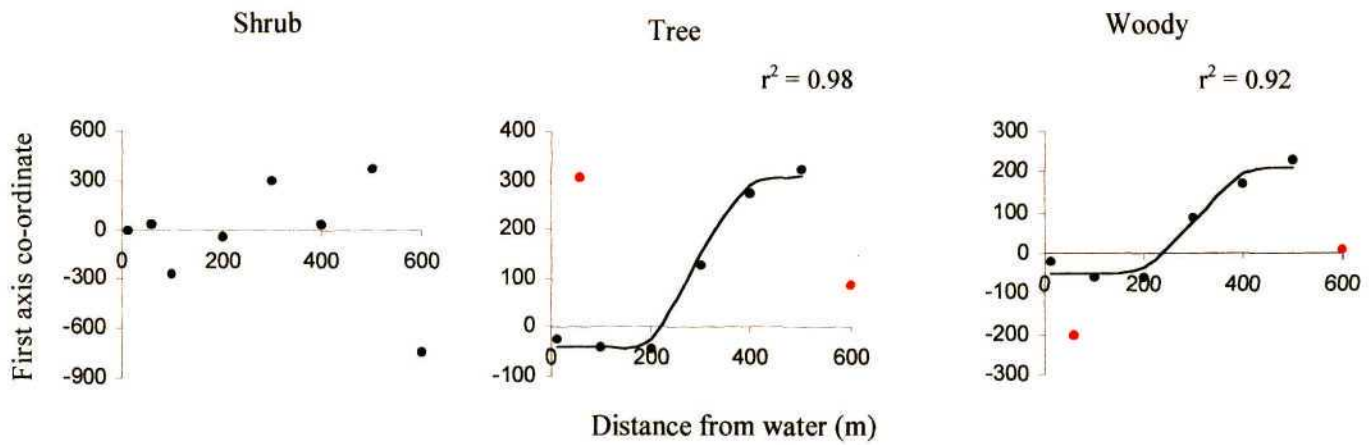


Figure 38. Lojaan: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water (red dots indicate values that were not included in the regression analysis).

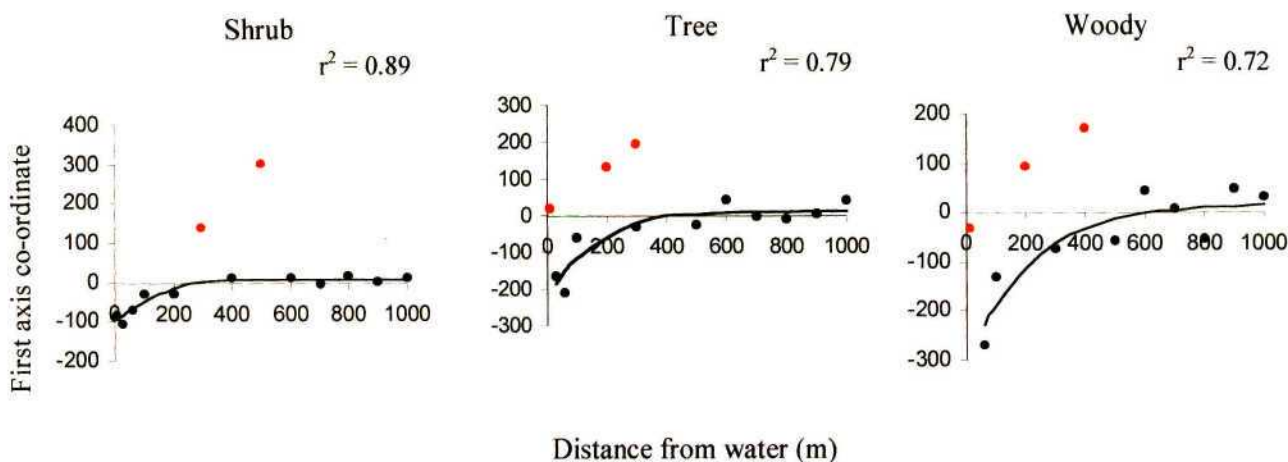


Figure 39. Chibi Clay: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water (red dots indicate values that were not included in the regression analysis).

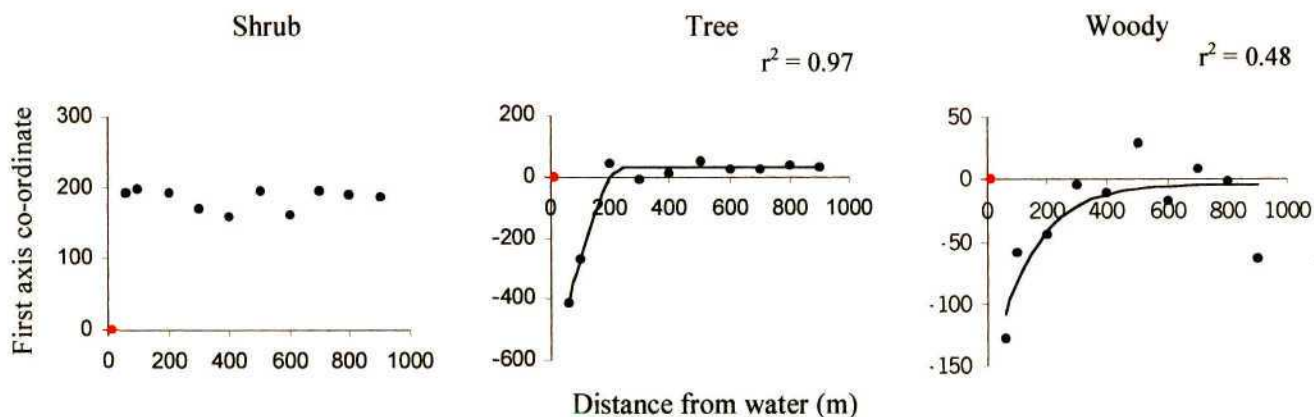


Figure 40. Chibi Sand: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water (red dots indicate values that were not included in the regression analysis).

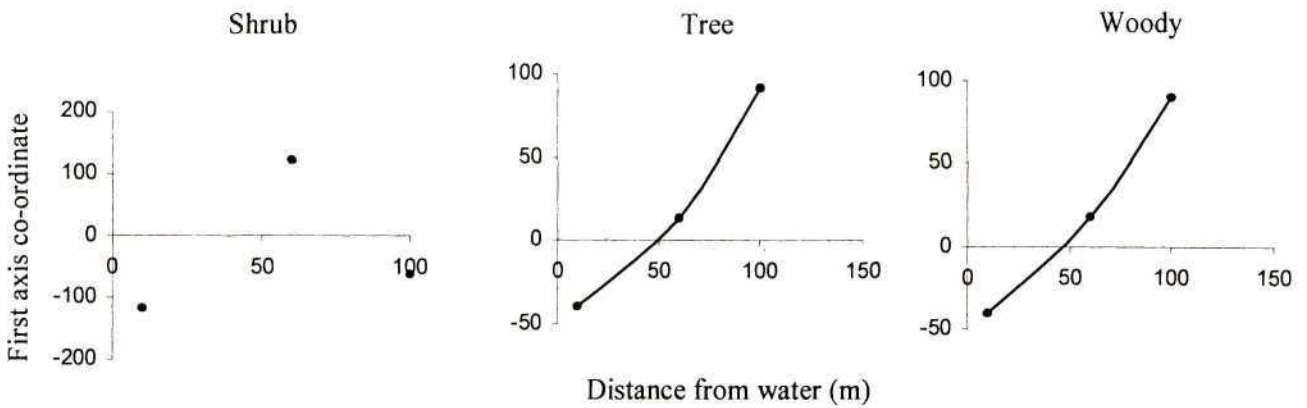


Figure 41. Manyoka: First axis Correspondence Analysis scores for species composition of shrubs, trees and shrubs and trees together (woody) with distance from water.

2.2. Spatial distribution of selected species

Most woody species in semi-arid savannas appear to grow in patches. It is hypothesised that because of this, and because sample size was restricted by time constraints (only one belt transect per distance), only a few species were well represented across the distance from water gradient. Only these species were considered for the investigation of the response of a particular woody species to distance from water. Change in density along the distance from water gradient was measured as (1) number of individuals (per ha) and (2) stem area (m^2/ha). Regressions for both measures of density are presented for those species that were well represented across the entire distance from water gradient at particular water points.

An increase in both stem area and number of individual *Terminalia sericea* trees was observed close to water at Lojaan. A decline in *Julbernardia globiflora* trees is suggested close to water at Manyoka, but insufficient sample points limit interpretation of trends. *C. mopane* was well represented at both Nyamsaan and Chibi Clay. Densities respond dissimilarly at these water points. Stem area and number of *C. mopane* trees increased almost linearly with distance from water at Nyamsaan, but declined sharply beyond 100 m from water at Chibi Clay. At Nyamsaan number of individual trees showed a clearer increase with distance from water than stem area. *Albizia petersiana* was well presented at Chibi Sand and at Chinzwini. As with *C. mopane*, this species responded dissimilarly at the two water points. At Chinzwini an abrupt increase in tree density and stem area was observed within 100 m of the water point. In contrast, at Chibi Sand density and stem area of *A. petersiana* trees increased beyond 100 m from the water point.

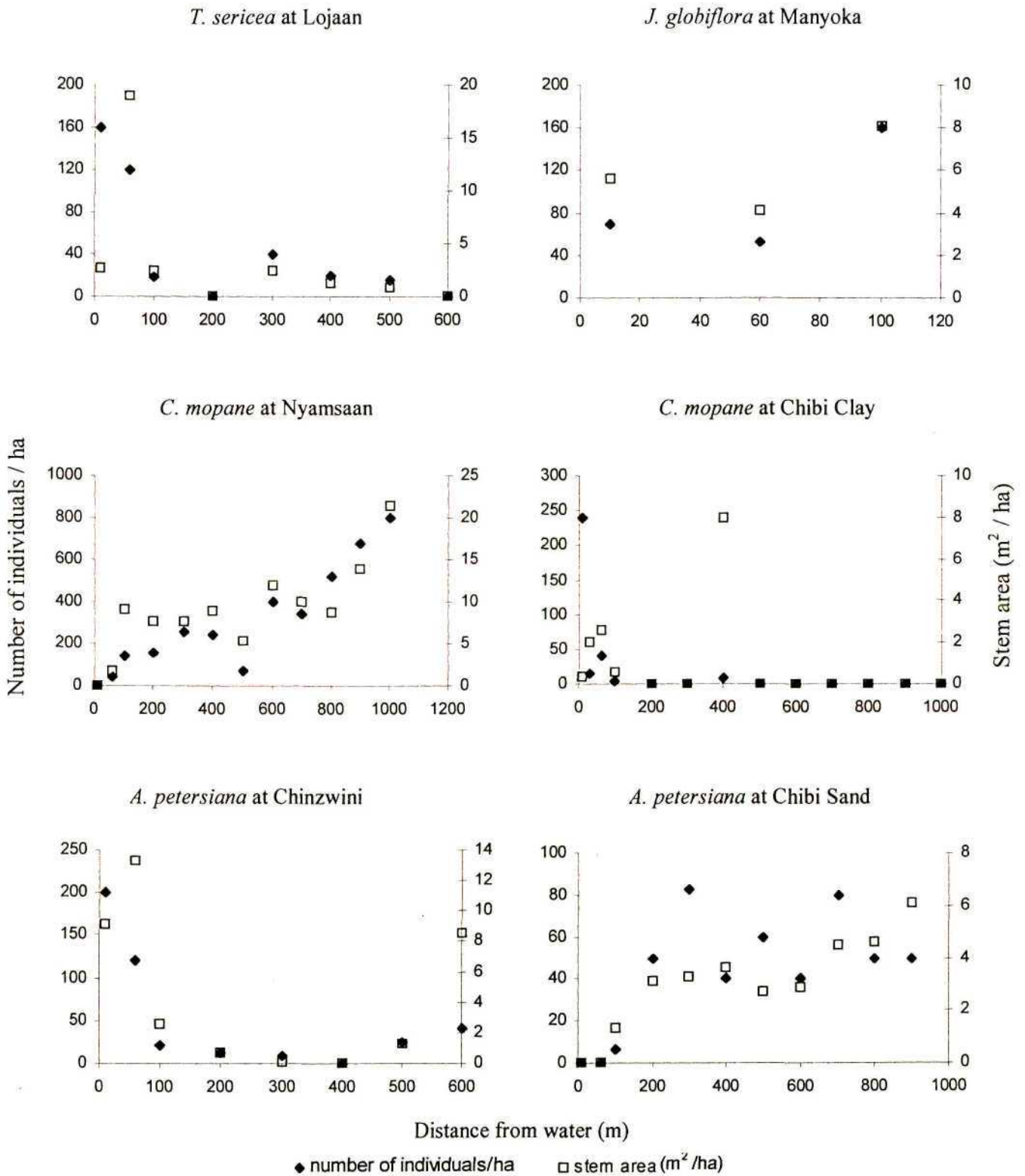


Figure 42. Densities of selected species with distance from water at Lojaan, Manyoka, Nyamsaan, Chibi Clay, Chinzwini and Chibi Sand.

2.3. Density (all woody species)

Woody density on the whole responded dissimilarly to distance from water in different vegetation types (Figure 43). In Hill vegetation shrub and tree densities were high close to and far from established water points (Chinzwini and Lojaan). At Chibi Clay (*A. nigrescens* woodland) an increase in woody density close to water was observed. Exceptionally high shrub densities, particularly at the 30 m distance point (± 7957 individuals / ha) were recorded. Most of these individuals were *C. mopane* seedlings. In contrast, woody densities in *C. mopane* veld on sandy-clay-loam (Nyamsaan and Bandama) were low close to water. On Flat Sandveld (Chibi Sand) woody densities also declined close to water. No apparent trend for density of trees or shrubs with distance from water was noted at Manyoka.

2.4. Stem area (all woody species)

Trends for total stem area of trees and shrubs with distance from water varied between water points in different vegetation types. In *C mopane* veld (Nyamsaan and Bandama) (Figures 44 and 45) total stem area was higher close to water (100 – 400 m) for shrubs, but not for trees. In contrast, total tree stem area was high close to established water points in the Hills (Chinzwini and Lojaan), with shrub stem area showing no clear response to distance from water. Total tree and shrub stem area declined close to water at Chibi Sand, but the reverse was observed at Chibi Clay. Too few data points make interpretation of stem area trends at Manyoka unreliable.

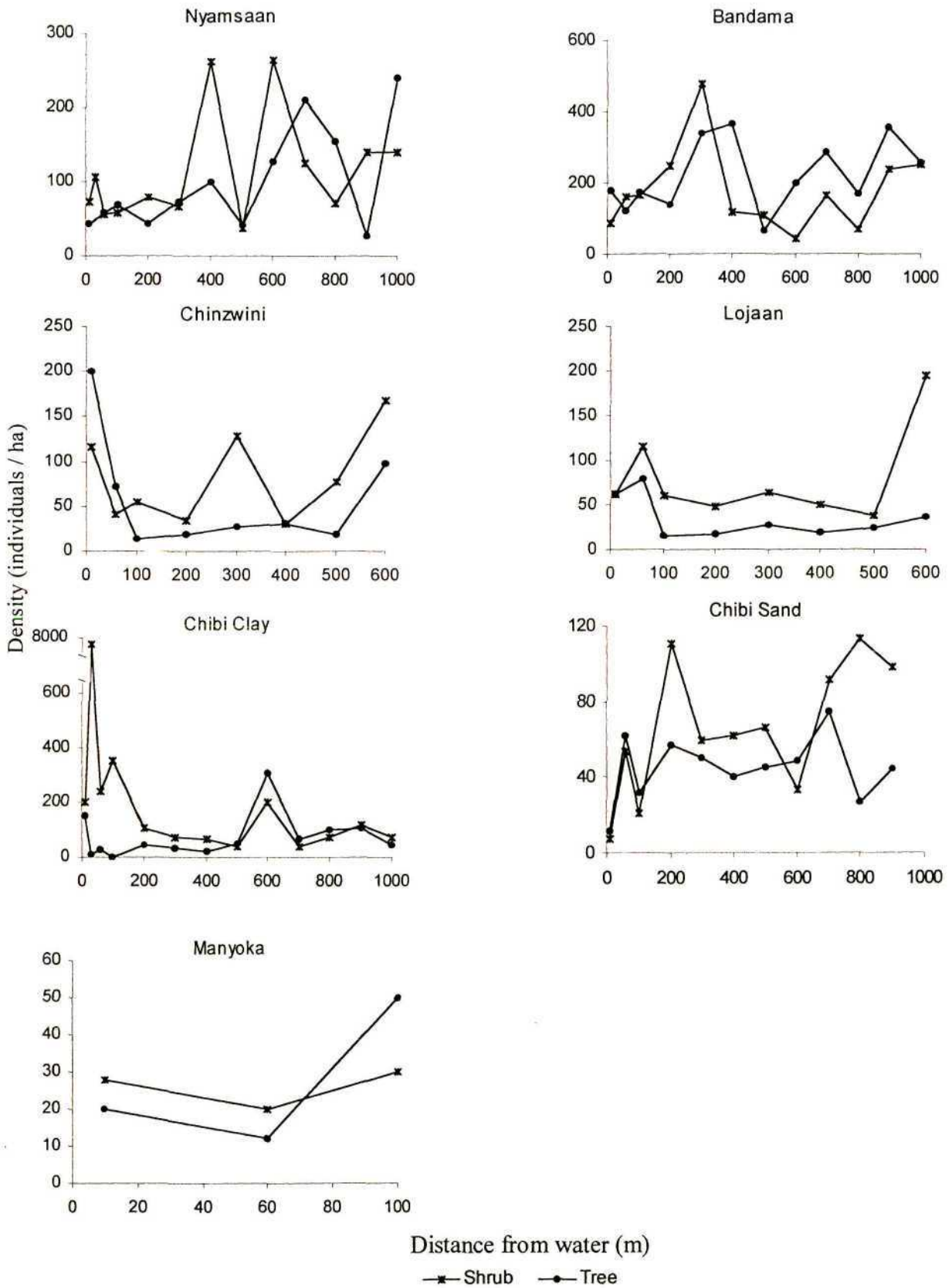


Figure 43. Densities of trees and shrubs with distance from water.

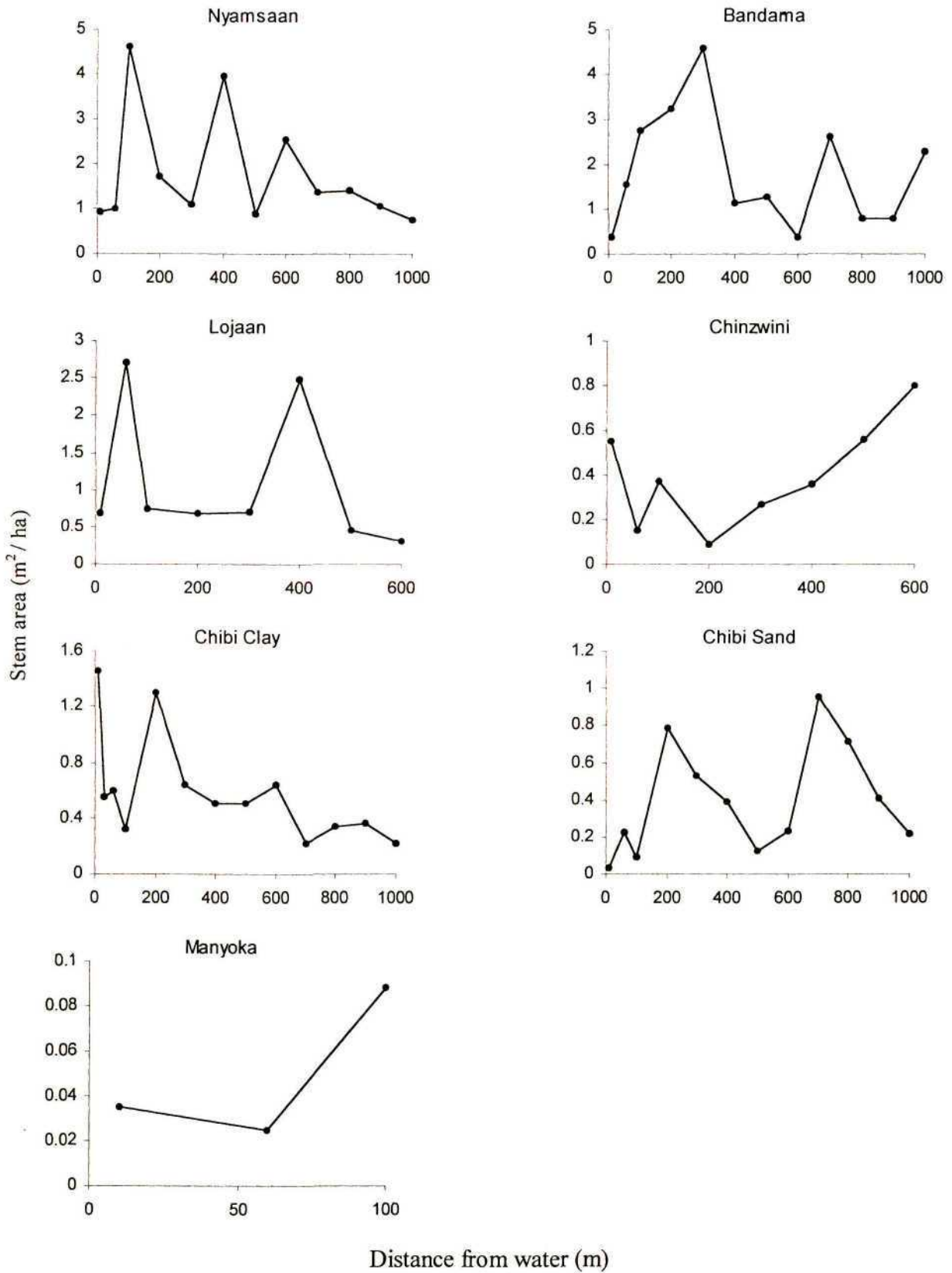


Figure 44. Total shrub stem area with distance from water.

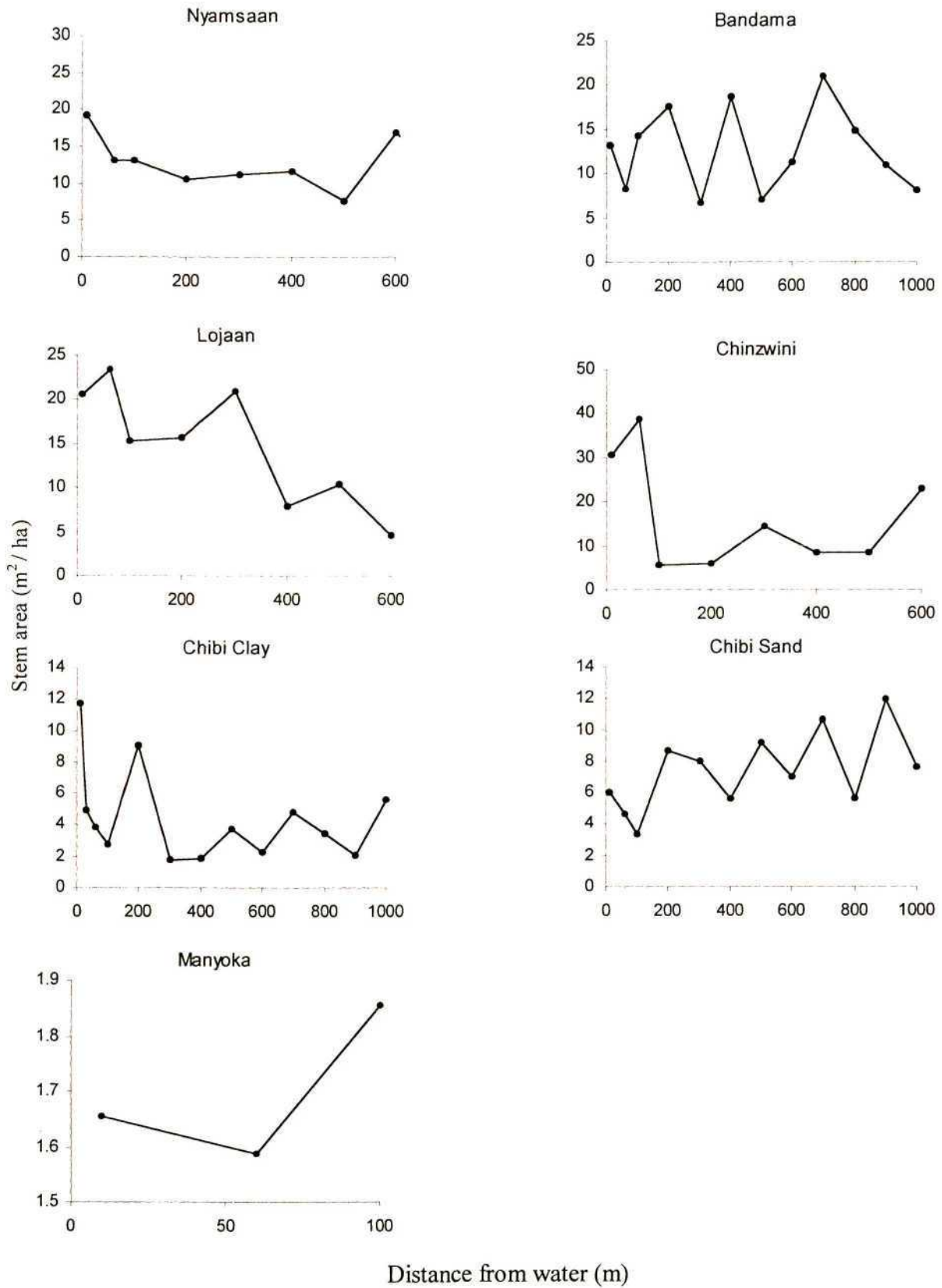


Figure 45. Total tree stem area with distance from water.

2.5. Utilisation

Canopy utilisation

Increased utilisation close to water was generally clearer for elephants and all browsers than for utilisation by browsers other than elephants (Figures 46 – 51). Patterns for woody utilisation were most obscure on sandy soil (Chinzwini and Lojaan and Chibi Sand) suggesting either that there was no increase in utilisation close to water, or that the utilisation gradient had not begun to decline within the distance sampled. High utilisation scores suggest that the latter is more likely.

When comparing piosphere sizes for species composition of all woody plants (trees and shrubs together) with utilisation gradients, it was found that the two were generally closely associated. The limit of the piosphere for woody species composition (upper asymptote) was either the same as, or very close to the distance at which woody utilisation declined. At the time of data collection, increased woody utilisation in *C. mopane* veld appeared to be limited to approximately 700 m of the water point still in operation (Nyamsaan, Figure 46), and 100 m of the closed water point (Bandama, Figure 47). When comparing woody utilisation piosphere sizes in *C. mopane* veld with those for woody species composition (shrubs and trees together, Figures 35 and 36), it was found that the piosphere for utilisation was 100 m larger than that for species composition at the water point still in operation (Nyamsaan), and 100 m smaller for the closed water point (Bandama).

At Chibi Clay high utilisation scores were limited to within 600 m of water (Figure 48) which is approximately the distance at which woody species composition reached equilibrium (Figure 39).

In Hill vegetation, scores for average percent canopy utilised were very variable, particularly for elephant utilisation at Chinzwini (Figures 49 and 50). No clear patterns related to distance from water emerged within the area sampled. Results are similar to those obtained for Chinzwini woody species composition (Figure 37), but not for Lojaan (Figure 38), where woody species equilibrium was reached within the distance sampled (400 m).

Utilisation by elephants and all browsers at Chibi Sand was variable for both trees and shrubs, and no pattern with distance from water was detected within the area sampled.

Utilisation of shrubs by browsers clearly increased between 400 m and the water point, but similar increases were observed beyond 400 m. The piosphere for woody species composition also extended to 400 m (Figure 40).

Too much weight should not be placed on utilisation trends obtained for Manyoka (Figure 52), however results indicate that utilisation of shrubs by browsers other than elephants appeared to be greater close to water. Utilisation by all browsers followed a similar but less obvious trend with distance from water.

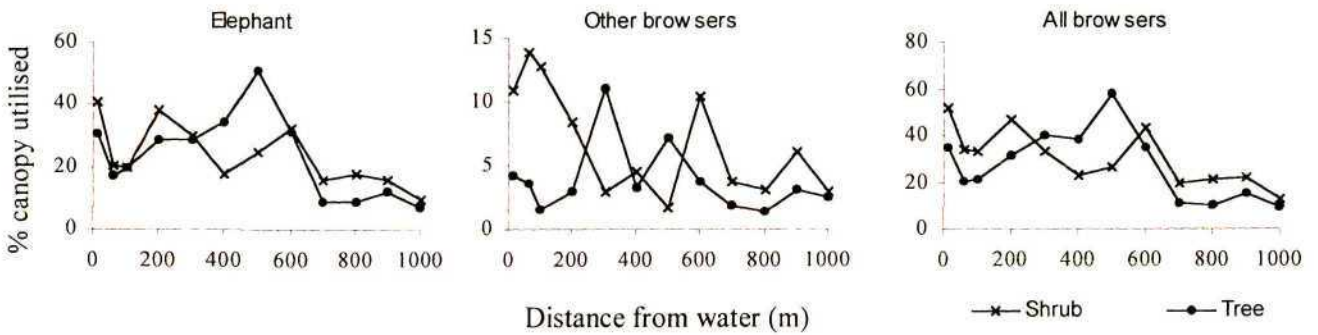


Figure 46. Nyamsaan canopy utilisation with distance from water.

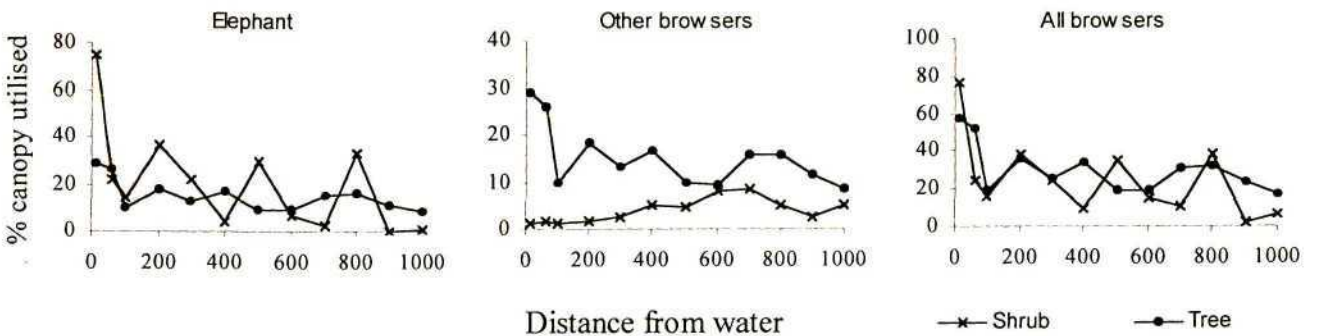


Figure 47. Bandama canopy utilisation with distance from water.

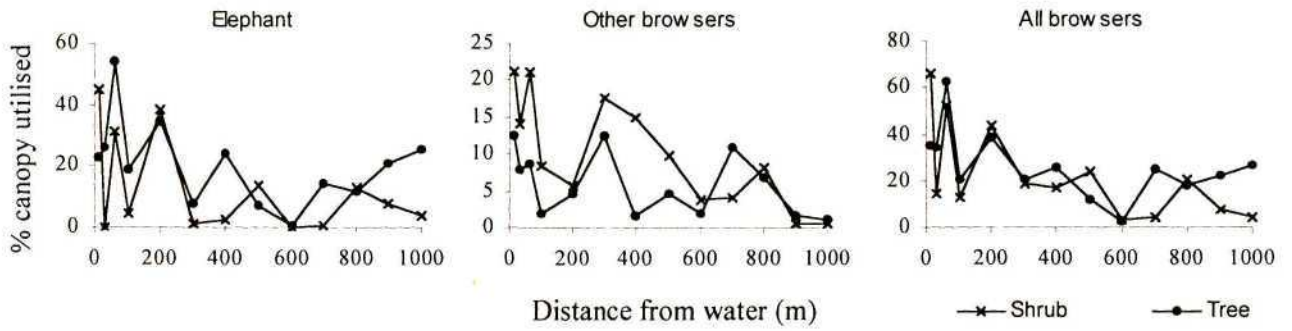


Figure 48. Chibi Clay canopy utilisation with distance from water.

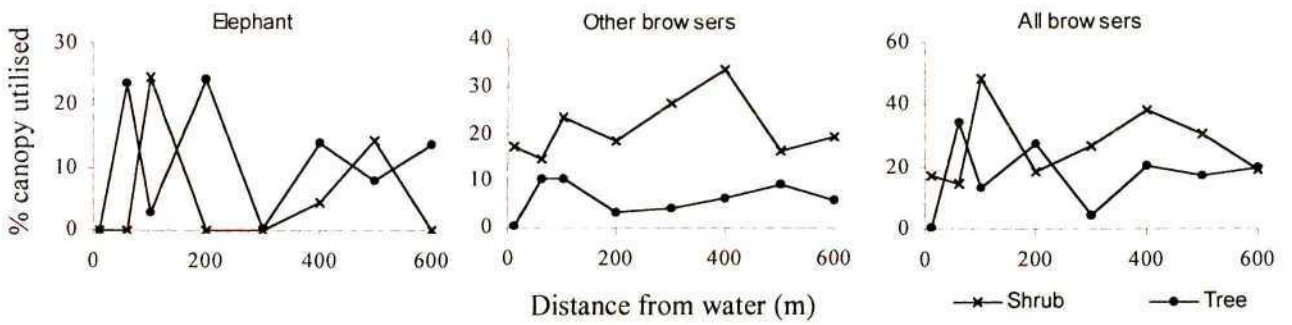


Figure 49. Chinzwini canopy utilisation with distance from water.

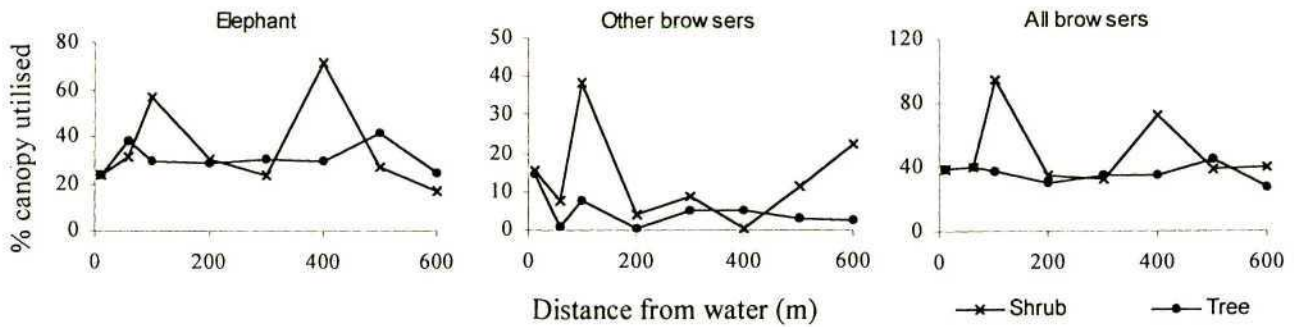


Figure 50. Lojaan canopy utilisation with distance from water.

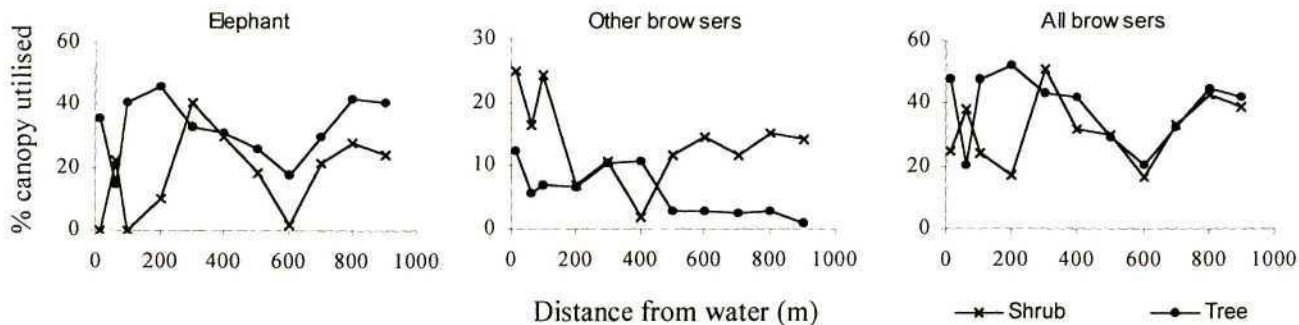


Figure 51. Chibi Sand canopy utilisation with distance from water.

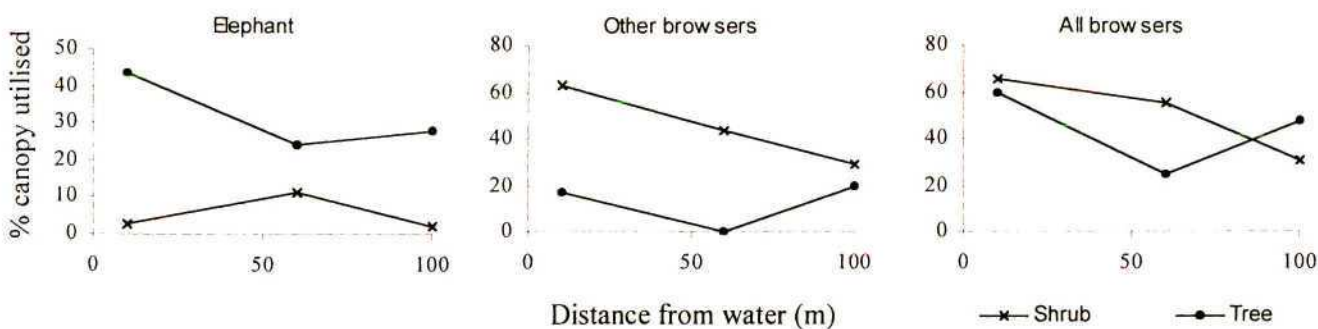


Figure 52. Manyoka canopy utilisation with distance from water.

Conversion of trees to shrubs

The percent of trees (previously > 2 m) converted to shrubs (< 2 m) by elephants breaking or pushing them over is shown graphically (Figure 53). Photographs illustrating the response of different woody species to snapping or bending are shown in Figures 54 and 55.

In *C. mopane* veld conversions were generally higher in the regions close to water, with peaks recorded between 200 and 500 m from water. In Hill communities high conversion values were recorded further from water. Had it been possible to measure tree conversions in the Hills to distances of 1000 m from water, similar results to those found in *C. mopane* veld (specifically at Bandama) may have been observed.

Except for a peak at 1000 m from water, reduction in tree height to less than 2 m

was fairly consistent at Chibi Clay. In contrast, conversion of trees to shrubs was restricted to within 300 m of water at Chibi Sand.

Substantial proportions of trees were converted to shrubs at Manyoka. Approximately 106 times more trees were converted to shrubs at this water point than at any other water point studied. Too few sample points at this water point prevent any interpretation of conversion trends with distance from water.

After Manyoka, percent conversion of trees to shrubs was highest in *C. mopane* veld, followed by the Hills and finally by vegetation on clay-loam and sandy soil around Chibi water point.

Observation of the response of different woody species to utilisation (particularly by elephants) indicates that all species do not recover to the same extent. For example *C. mopane* trees seldom die following snapping or being pushed over by elephants. In fact they usually recoppice prolifically following damage (Figure 54). In contrast species such as *J. globiflora* (Figure 55) and *Sclerocarya birrea* generally show poor recoppice ability and are invaded by borer and fungi soon after damage.

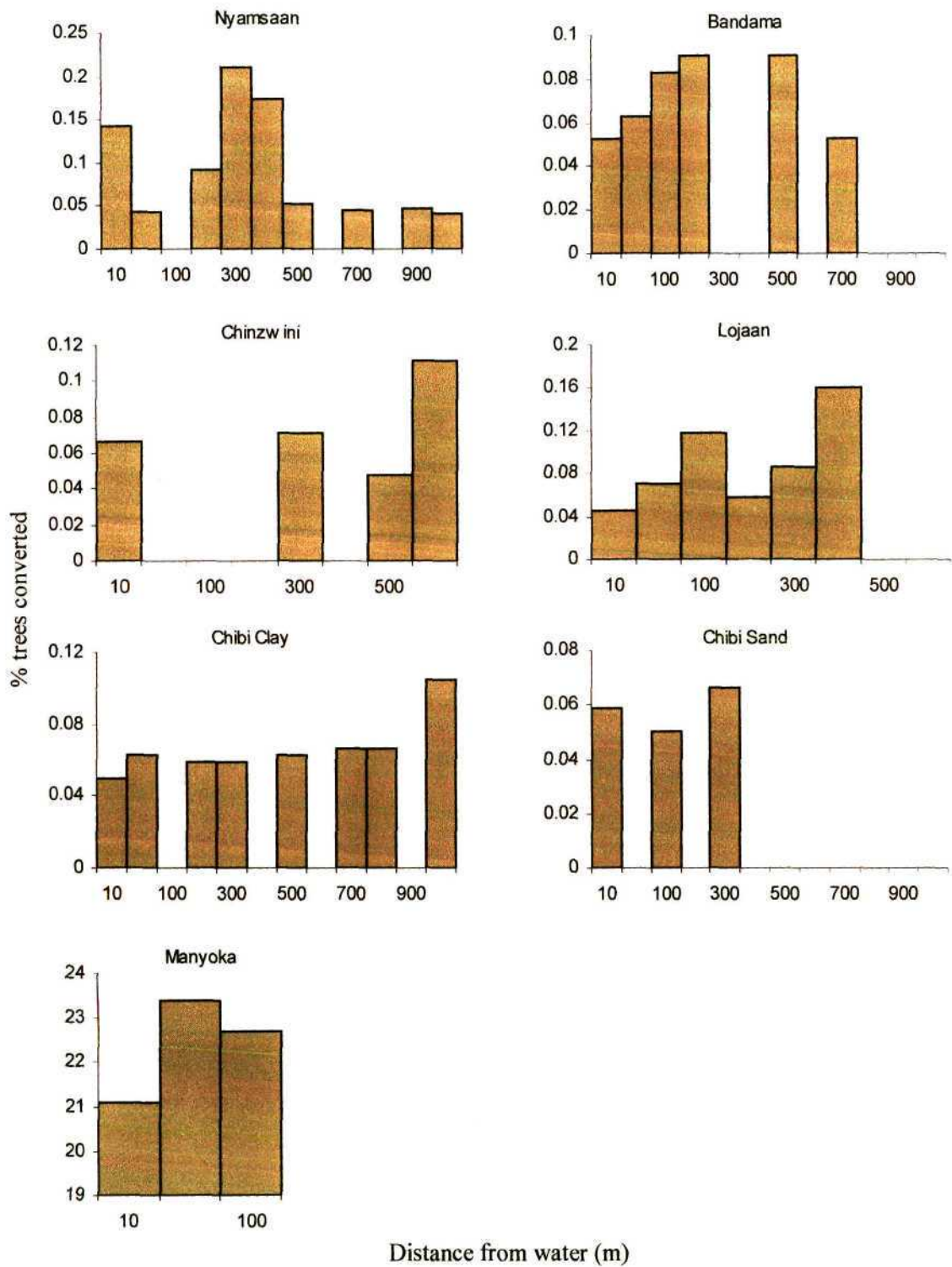


Figure 53. Percent trees converted to shrubs with distance from water.



Figure 54. Typical regrowth of a *C. mopane* tree after being pushed over by elephants.

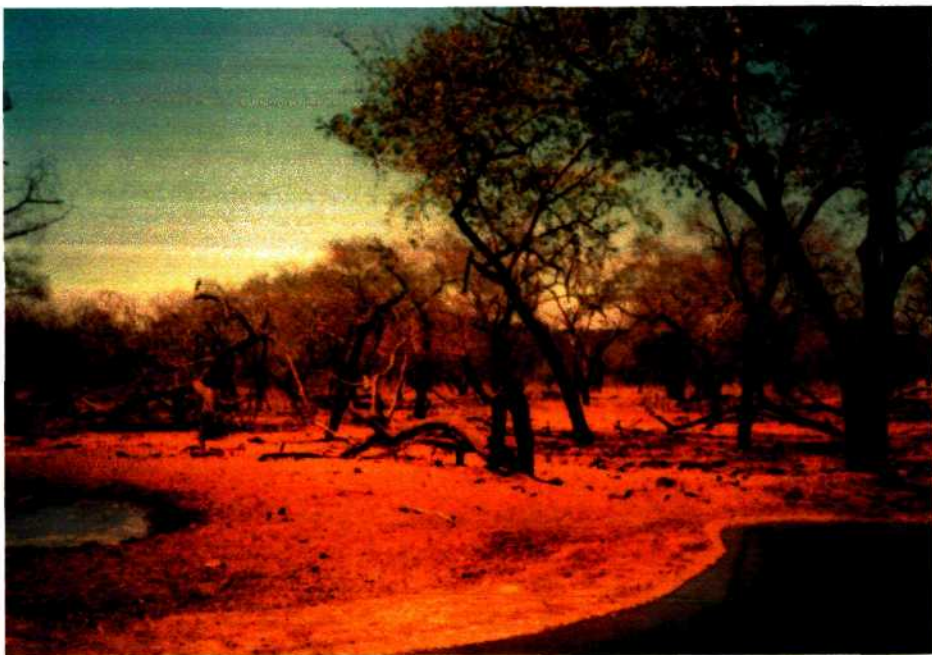


Figure 55. Typically poor regrowth of Hill trees (*J. globiflora* in this photograph) after being pushed over by elephants.

DISCUSSION

1. Herbaceous data

1.1. Species composition

Graetz and Ludwig (1978) proposed that some measures of vegetation and soils follow logistic distributions with distance from water. Results for herbaceous species composition with distance from functioning perennial water points at MCT support this proposal. Similar trends were found for herbaceous species composition in the Kruger Park (Thrash *et al.* 1993), but not in the Kalahari Gemsbok National Park, where species composition was not associated with distance from water (Van Rooyen *et al.* 1994). The absence of a piosphere effect at the recently closed perennial water point (Bandama), suggests that ephemeral pans at MCT may not display classical herbaceous piosphere effects because they are not utilised during the dry season. Although it cannot be proved that a herbaceous species piosphere existed at Bandama prior to closure of this water point, there is no reason to believe that there should not have been one. Results also suggest that in *C. mopane* veld changes to herbaceous species composition resulting from heavier stocking rates around water points may be 'short term'. Once grazing pressure is released piosphere patterns for species composition begin to disappear (provided rainfall is not limiting). This is a hypothesis that requires further testing.

At Manyoka a localised but prominent logistic distribution for species composition indicates that changes to the composition of the herbaceous layer on sandy soils occurs soon (< 2 years) after the introduction of a water point.

The sigmoid distribution for herbaceous species composition at Chibi Sand implies that utilisation was having a severe effect on species composition close to water (as indicated by the lower portion of the sigmoid curve). Large changes in species composition over the distance gradient may be caused by high herbivore utilisation, poor tolerance to utilisation of species growing in this area, and a lack of physical obstructions in the form of rocky outcrops (discussed in detail in the discussion of Chapter 5). It is also possible that the change in species composition could be attributed to proximity to a change in soil / vegetation type, as this water point is situated on the junction of two soil types.

In the past, palatable perennial grasses (which make up a large portion of grasses known as 'decreaser species') were believed to decline when utilisation was high, while annual grasses, forbs and woody plants generally increased (O'Reagain & Turner 1992; Stafford Smith & Pickup 1990). In this study, results did not entirely support these generalisations. Consistent patterns for distance from water were not observed for perennial grasses as a whole, because two important species, namely *U. mosambicensis* and *P. maximum*, did not respond in the same manner as most perennials to the utilisation gradient. Once these species were removed from analyses, it was evident that aerial cover of most perennial grasses was reduced close to water. This suggests that most perennial grasses are more heavily impacted close to water. General reductions in annual grass and forb aerial cover close to water, though not as severe as for perennial grass, suggest that both groups of plants are being impacted. A similar decline in basal cover of forbs was recorded close to water points in the Kruger Park (Thrash *et al.* 1991a). Invasions of woody seedlings are generally associated with declines in herbaceous cover (Brown & Archer 1989). In this study, woody seedlings peaked in the immediate vicinity of established water points, where biomass was generally low. When herbaceous cover declines competition for resources is reduced and woody plants are able to establish. In addition, when fuel loads are low woody seedlings are less likely to be destroyed by fire.

Aerial cover trends for perennial grasses in *C. mopane* veld, and at Chibi (Clay and Sand) were largely influenced by the presence of one grass, *U. mosambicensis*. Although *U. mosambicensis* is a palatable perennial grass, it is seen as an indicator of veld disturbed by heavy grazing or prolonged droughts (Judd 1979; van Oudtshoorn 1992). Its ability to colonise and persist under adverse conditions allows it to proliferate close to water outside of the Hills. In the Kruger Park similar increases in basal cover of *U. mosambicensis* were recorded close to water (Thrash *et al.* 1993). *Panicum maximum*, is another perennial species that appears to be more strongly associated with factors other than utilisation. *Panicum maximum* is known to respond well to fertilisation (Cunningham Laboratory, CSIRO 1964; van Oudtshoorn 1992), and localised increases in aerial cover close to water suggest that this grass may be responding to nutrient enrichment gradients which are normally localised close to water (Chapter 5; Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995). *Digitaria eriantha* can be an indicator of

good veld condition (Van Oudtshoorn 1992). It is a valuable grass, highly digestible and palatable, with a high leaf production (Van Oudtshoorn 1992). Declines close to water at Chibi Sand are possibly a consequence of heavy utilisation of this species. Similar declines in *D. eriantha* were observed under heavy stocking rates in southeastern Zimbabwe (Kelly & Walker 1976) and close to water in the Kruger Park (Thrash *et al.* 1991a), but the opposite trend was observed in the Kalahari (Perkins & Thomas 1993b). At MCT, reductions close to water were lower in *C. mopane* veld because *D. eriantha* was almost absent in this vegetation type, even far from water.

Greater reductions in species diversity close to water on sandy soils implies that the suite of species growing on sandy soils may be more susceptible to destruction through heavy utilisation than that growing on clay-loam (Chibi Clay) or sandy-clay-loam soil (Nyamsaan and Bandama). Declines in species diversity were also observed as boreholes were approached in eastern Botswana (Tolsma *et al.* 1987), but in southern Australia patterns for diversity varied with distance from water between sites (Landsberg *et al.* 1997). An alternative explanation for the reduction in species diversity on sandy soils may be attributed to some other gradient, unrelated to the water point, such as topography or interactions with the woody overstory. Since bearing lines and transects were orientated through relatively homogenous areas (Chapter 4) so as to minimise the effects of external variables, this is unlikely.

1.2. Biomass

Biomass possibly showed only slight relationships with distance from water because sampling followed the rains, and the growth pulse (Pickup 1991) had largely evened out the effect of grazing and trampling. Biomass in *C. mopane* veld appeared to recover substantially following the rainy season (during the dry season herbaceous cover is near zero up to about 30 m from perennial water points (pers. obs.)). The slight increase in biomass observed in the immediate vicinity of water (10 m) may be explained by exceptionally high *P. maximum* values, and an overall increase in biomass could be related to nutrient enrichment in this zone (Chapter 5, Figures 17 and 19; Pickup 1991). Near linear increases in biomass with distance from water in the Hills suggests (1) that the extent of the piosphere for biomass reduction extended beyond 600 m from water and (2)

that the effect of the grazing gradient had not been evened out even after the rainy season (growth pulse). Where the effects of grazing gradients are temporary, vegetation recovers following the rainy season, and grazing gradients disappear (Pickup 1991). Persistent reductions in biomass close to water following the growth pulse (rainy season) imply that the effect of utilisation around water in the Hills has reduced the ability of the herbaceous component to recover following the rainy season. An alternative hypothesis may be to attribute the decline in biomass to some factor unrelated to the water point e.g. topography or woody cover. However, if topography were responsible for the observed pattern in biomass one would expect to see the opposite trend (biomass high close to water, declining with distance). Also, changes in topography were kept to a minimum through selection of appropriate bearing lines. If woody cover were regulating biomass over the distance from water gradient, one would expect to see patterns for woody density and stem area following associated patterns. This would present a possible hypothesis since tree stem area increased both close to and far from water in the Hills (Figure 45). The increase close to water may be attributed to water collecting in the bottomlands (close to where the water point is today). The increase far from water may be attributed to greater run-on from the surrounding hills. It is interesting to note that with many vegetation variables sampled in the Hills, the values close to water (10 – 100 m) were similar to those far from water (500 and 600 m points). Examples are *D. eriantha* aerial cover, *P. maximum* cover, all perennial grasses excluding *U. mosambicensis* and *P. maximum* (Figure 32), density of trees and shrubs (Figure 43) and density of tree stem areas at Chinzwini (Figure 45).

The severe but localised reduction in biomass close to water at Manyoka suggests that the age of a water point may influence the spatial extent of piospheres. Other researchers have found that the age of water points plays an important role in determining the degree of impact on the surrounding vegetation (Andrew & Lange 1986b; Perkins & Thomas 1993a; 1993b). On a graph (e.g. Chapter 2, Figure 1b), the spatial extent of the piosphere is represented by the change along the x-axis, while the severity of the effect is shown by the change along the y-axis. Biomass at Chibi Clay and Chibi Sand was only reduced in the immediate vicinity of water (10 m), suggesting that permanent changes to biomass had not occurred except close to water.

2. *Woody data*

2.1. *Species composition*

Because woody plants take longer to grow, and because they generally survive for longer periods than herbaceous species, changes in species composition of the woody component are expected to have occurred over a long period (where stocking rates are moderate to low), and changes are expected to be longer lasting than changes to the herbaceous layer (Laws 1970). Where pressure from large destructive animals, such as elephants, is high, changes to species composition of the woody layer may occur over a short period.

Although woody species compositions did not show as clear logistic piosphere patterns as herbaceous species composition, correlations with distance from water were better, and piosphere effects generally extended further from water (recognised by the upper asymptote of the logistic curve). Results suggest that woody species composition may be a more reliable index of utilisation over extended periods, because woody plants are longer lived and species composition is not as susceptible to changes in response to small climatic variations. Woody species composition describes the cumulative effect of years of utilisation over the distance gradient, but herbaceous species composition can recover following good rainy seasons where stocking rates are moderate. However, this hypothesis requires testing over an extended period. In contrast Thrash *et al.* (1991a; 1991b) reported that changes in species composition over the distance gradient were more severe and extended further from water for herbaceous than for woody species. This they attribute to the herbaceous component being subject to more trampling than the woody component.

Clear logistic piospheres for woody species composition evident at Bandama (the closed water point) support the notion that changes to woody plants are longer lasting than changes to herbaceous plants (a herbaceous species piosphere was not evident at the same water point). Linear relationships for tree and all woody species compositions were evident at Manyoka, suggesting that changes in woody species composition can occur over a short period (two years) where utilisation by elephants is high.

Woody species composition piospheres were largest in the Hills and at Chibi Clay (*A. nigrescens* woodland), suggesting that water points had greater effects on woody species composition in these vegetation types.

2.2. Spatial distribution of selected species

Results suggest that a species may respond dissimilarly to distance from water (utilisation) depending on the environment in which it is growing. Both *C. mopane* and *A. petersiana* were recorded growing in different environments where their apparent responses to the position of perennial water were opposite. Differences in nutrient levels in different environments may make species more attractive to browsers in one area than in another (du Toit *et al.* 1990), and heavy utilisation could result in a decline in density of the selected species. Results only support this hypothesis for *A. petersiana* at Chibi Sand (Figure 21 and 42). An alternative hypothesis for the observed patterns could be that the density of species is responding to some factor other than distance from water. For example Chibi water point is situated on the junction of two soils and vegetation types (Figure 15). *A. petersiana* is a dominant species in Flat Sandveld (Chibi Sand) and is absent from *A. nigrescens* (Chibi Clay). The observed decline in *A. petersiana* close to Chibi pan could be attributed to proximity to the *A. nigrescens* woodland. The increase in *C. mopane* close to water at Chibi Clay (*A. nigrescens* woodland) cannot be explained in the same way because the adjacent vegetation type (*A. petersiana*) has a relatively low density of *C. mopane* trees relative to that found in *A. nigrescens* woodland.

To the east of Nyamsaan pan (opposite direction to bearing line) species composition changes slightly to include more *A. nigrescens* and *D. cinerea*. Environmental factors responsible for the change in species composition to the east of Nyamsaan may be responsible for the decline in *C. mopane* close to the water point. While this is a possible hypothesis, results from this study indicate that *C. mopane* has been heavily impacted within 500 m of Nyamsaan pan (Figure 53). *C. mopane* density increases at distances greater than 500 m from the same pan (Figure 42).

A. petersiana increased in density close to water at Chinzwini. Chinzwini is situated close to the Flat Sandveld which supports *A. petersiana* woodland (Figure 15). This, together with the fact that *A. petersiana* is poorly represented at Lojaan (the other dam in the Hill community) suggests that the increase in this species close to water is unlikely to be a function of the water point, but rather a function of proximity to the nearby *A. petersiana* Woodland.

2.3. Density (all woody species)

Measures of shrub and tree densities give insight into where future changes in vegetation structure will occur. A radical increase in shrubs (predominantly immature trees) relative to trees suggests that bush encroachment has already, or may occur in the future. A large number of trees relative to shrubs suggests that a woodland may not prevail in the future because of low recruitment into the tree category.

Reductions in total woody density (trees and shrubs) in the vicinity of water in *C. mopane* veld and at Chibi Sand suggest that water introduction in these vegetation types may have the effect of 'opening up' the woody component and increasing visibility for game viewing. Declines in woody density close to water in *C. mopane* veld are likely to be the result of heavy utilisation as observed in the vicinity of water, but may also be caused by competition with the herbaceous layer (discussed below).

Reductions in woody density close to water at Chibi Sand are unlikely to be a consequence of browsing and trampling alone, because woody utilisation at this water point was not limited to the area close to water. Reductions in the woody component close to water are more likely to be due to competition with herbaceous components, and particularly *U. mosambicensis*. *Urochloa mosambicensis* forms dense stands close to water in *C. mopane* veld (Nyamsaan and Bandama), *A. petersiana* woodlands (Chibi Sand) and to a less extent in *A. nigrescens* woodland (Chibi Clay) at MCT. In almost all cases woody density was inversely correlated with aerial cover of *U. mosambicensis*. Only where *U. mosambicensis* aerial cover was low (i.e. in the Hills), did woody density increase close to water.

Although not investigated in this study, rocky depressions on sandy soils, where infiltration is good (Dadkhah & Gifford 1980), are likely to promote woody plant survival because water is more accessible to deeper rooted (woody) plants (Stuart-Hill & Tainton 1989). This may explain the generally higher woody densities close (up to 30 m) to established water points in the Hills. Similarly at the base of rock outcrops, run-off is high and more subsurface water is available for growth. This may be the reason for the increased woody densities at the 500 and 600 m sample points. In both cases increased woody densities are unlikely to be the result of the water point.

Only Chibi Clay showed signs of increasing bush encroachment, as evidenced by

the high density of shrubs relative to trees close to water. Bare ground was low and *U. mosambicensis* cover was high where woody shrub density was highest, but woody seedlings may have established at a time when bare ground was higher (e.g. following the 1991 – 1992 drought). Similar bush encroached zones were documented close to water in the Kalahari (Child and Parris 1971; Tolsma *et al.* 1987; Perkins & Thomas 1991a; 1991b; Dougill & Cox 1995).

Too few sample points and too much variability prevent discussion of woody density at Manyoka.

2.4. Stem area (all woody species)

High shrub stem area and low density close to water in *C. mopane* veld implies that fewer, larger shrubs occur close to water. Results suggest that plants old enough to be trees are being maintained as shrubs close to water. High utilisation scores and values for conversions of trees to shrubs recorded close to water verifying that this is likely to be the case. The lack of a clear pattern for tree stem area with distance from water in *C. mopane* veld suggests that the water point has not adversely affected this component. At Chibi Clay, high shrub and tree stem areas and densities close to water show that bush encroachment began some time ago (increase in trees), but has accelerated recently (relatively greater increase in shrubs), particularly at the 30 m sample point. An increase in woody plants in this region is supported by an inspection of the 1974 –1991 aerial photographs. In contrast to the increase in woody plants close to water at Chibi Clay, low stem areas and low densities for both trees and shrubs were observed close to water at Chibi Sand. One of the reasons for this decline may be attributed to browsing and trampling close to water on sandy soil, where unlike the adjacent nutrient rich clay-loam soil, relatively poor colonisation rates may occur. This assumption is supported by very low values for woody seedlings in the herbaceous layer close to water at Chibi Sand.

In the Hills, values for tree stem areas largely correspond with density scores. High tree stem area and density close to water suggests that trees are favoured more than shrubs close to water (perhaps because roots can access water that is deeper and further away).

2.5. Utilisation

Canopy utilisation

Because heavy utilisation or damage precedes changes in species composition, it is proposed that the spatial extent of woody utilisation may indicate future piosphere sizes for species composition. Where perennial water points have been closed, woody species composition piospheres are expected to be evident even when utilisation piospheres are reduced.

Close associations between sizes of woody species (trees and shrubs together) composition piospheres and utilisation gradients at the same water point suggest that the two variables are linked. At Chibi Sand, where the utilisation gradient for all browsers far exceeded the length of the woody species composition piosphere, results indicate that the species composition piosphere for woody plants may expand substantially in the future. Although at the time of data collection elephant utilisation exceeded that for other browsers, it would appear that woody species composition at this water point was influenced largely by utilisation from browsers other than elephants (piospheres for browser utilisation extended to 400 m from water as did woody species composition piospheres). This is supported by the fact that elephant densities were maintained at very low levels prior to the change in land ownership in 1994. Increased elephant numbers in recent times may mean enlarged woody species piospheres in the future (as indicated by the length of the utilisation effect of elephants and all browsers).

Highly variable values (particularly for elephants and all browsers) for utilisation at Chinzwini suggest that utilisation is either in its initial stages (which is unlikely), or the piosphere for utilisation extended beyond the distance sampled. The species composition piosphere also appeared to extend to beyond the distance sampled. A smaller piosphere pattern for species composition relative to utilisation at Lojaan suggests that the piosphere for species composition may increase in the future. Generally high utilisation values and the lack of a clear utilisation pattern in the Hills may occur because rock outcrops restrict access to water. Animals are forced to move through the same valleys between rocky outcrops, thereby concentrating utilisation for greater distances from water.

Conversion of trees to shrubs

The proportion of large trees that are converted to shrubs gives an indication of changes in woody structure due to elephant utilisation. Excessively high conversions imply that major changes in woodland structure have, or in the future will occur. High conversions of trees to shrubs can form barriers to vision, thus reducing tourist opportunities. Conversion statistics also give insight to changes in woody forage distribution due to elephant activity. If tall trees are converted to heights of less than 2 m, and continue to coppice following snapping or bending, more forage will be accessible to a greater biomass of browsers.

Extremely high values for conversion of trees to shrubs at Manyoka suggest that in time woody structure in the vicinity of this water point may be completely altered through elephant activity. Similarly herbaceous biomass (Figure 34), surface cover, trampling and path number (Chapter 5, Figures 23, 25 and 27) were severely affected at Manyoka. The effects of a recent introduction of perennial water appear to be more extreme, but more localised than the effect where the disturbance has been in place for a number of years.

When considering long established water points, conversions of trees to shrubs were higher around water points in *C. mopane* veld than in any other vegetation type sampled. High conversions close to water imply that elephants have had a greater impact on altering woody structure in the vicinity of water points in *C. mopane* veld. In addition more trees are functioning as coppicing shrubs close to water. Higher conversions in this vegetation type may be attributed to the resilience of the dominant species, *C. mopane*, to heavy utilisation by elephants. Other authors have commented on the prolific coppicing ability of this species following severe elephant utilisation (Bromwich 1972; Anderson & Walker 1974). In communities where dominant species are resilient to this type of damage (e.g. *C. mopane*), converted individuals persist as living 'shrubs', and over time more converted trees become evident. In communities where species are generally less resilient to elephant impact (and woodborers or fire following elephant damage), trees subjected to heavy utilisation, die and decompose. Evidence of elephant conversion of trees to shrubs are lost over time in these communities. For example, more trees may have been converted to shrubs in Hill communities but because many species in this vegetation type have soft wood, unlike *C. mopane*, they are prone to destruction by borer (Thompson

1975), fungi (Anderson & Walker 1974) and fire (Buechner & Dawkins 1961) once heartwood is exposed through elephant damage. Death and quick decomposition of softwooded species will leave no evidence of the tree conversion a few years after. Relative to conversion statistics in communities with less resilient woody species, communities dominated by resilient species will appear to have had more individuals converted to shrubs. Research into the response of different woody species following heavy elephant utilisation is required to verify these ideas.

Although more trees may be converted to shrubs at some point(s) away from the immediate vicinity of water in *C. mopane* veld, in the Hills and at Chibi Clay, canopy utilisation scores do not show similar patterns. This implies that elephants do not necessarily spend more time foraging at distance points where conversions were high. Certain woody species are selectively pushed over or snapped off by elephants (Van Wyk & Fairall 1969; Guy 1976). The distances at which conversions were high may indicate sites where selected species were growing in relatively high concentrations. Similarly, in Australia cattle were found to ignore rangeland close to water but grazed some distance away, where forage quality was better (Pickup & Chewings 1988).

The 300 m limit for conversion of trees to shrubs at Chibi Sand suggests that elephants were having the greatest impact on woody structure in the immediate vicinity of water. These results are possibly due to a combination of woody species composition and proximity to the nutrient rich basalt flats that support a large portion of MCTs herbivore biomass. Close to water at Chibi Sand woody species composition includes a large portion of *A. nigrescens* and *A. tortilis* trees. Further away *A. petersiana* dominates the woody layer. When *Acacia* trees (which are generally single stemmed when they are older) are snapped or bent by elephants, the entire tree is converted to shrub height. In contrast when multistemmed *A. petersiana* trees are impacted by elephants, normally at least one stem will remain above 2 m in height, and the plant will not be recorded as having been converted to shrub status.

CHAPTER 7 : LARGE HERBIVORE DISTRIBUTIONS

INTRODUCTION

The position of perennial water has been known to influence the seasonal distribution of animals (Western 1975). In extensive wildlife areas, and where perennial water sources are relatively far apart, i.e. >10 km apart, water dependent species concentrate in the vicinity of perennial water during the dry season. Seasonal pans fill during the wet season, and species disperse away from the heavily utilised range close to water (Young 1970a; Western 1975; Owen-Smith 1996). These seasonal shifts are more pronounced the further perennial water sources are apart, because range utilisation is restricted by the distance animals can forage away from water during the dry season.

Apart from water requirements, animals have feeding and shelter requirements, which differ from species to species. In many cases forage quality and vegetative cover are influenced by the position of perennial water. Forage quality may be altered close to water through heavy grazing, trampling and increased nutrient inputs through dung deposition. Depending on the soils, plant species composition, intensity of utilisation and herbivore species requirements, this may improve or reduce the quality of forage. Similarly, spatial variations in vegetative structure may be influenced by the presence of perennial water. Riverine vegetation is often associated with perennial water sources, specifically with rivers or drainage lines. Over grazing in the vicinity of perennial water can lead to bush encroachment (Child & Parris 1971; Tolsma *et al.* 1987; Perkins & Thomas 1993a; 1993b; Dougill & Cox 1995), or a reduction in grass height to the extent that it no longer affords cover. Similarly heavy utilisation of the woody component by elephants close to perennial water points can lead to loss of woody cover.

Different species may be attracted to different distance zones from water, not necessarily because of their need to be close to surface water, but because of their food and shelter requirements.

The aims of this chapter were to establish whether or not large herbivores at MCT display: (1) a seasonal variation in range utilisation with respect to distance from perennial water, and (2) a spatial separation in species during the dry season with respect to perennial water.

METHODS

Aerial surveys were flown in the wet season (February 1997) and in the dry season (October 1997). For both seasons, surveys were conducted in the morning and data was collected along pre-determined, parallel east-west orientated transects. Wet season transects were 2.5 km apart (Figure 56a), while those for the dry season were 1 km apart (Figure 56b and c). Technical problems experienced during the first day (Figure 56b) of the dry season count necessitated a recount on the 4th day (Figure 56c). Observations for both the 1st and 4th day were included in the analysis, as the additional information improved the data set for this particular investigation.

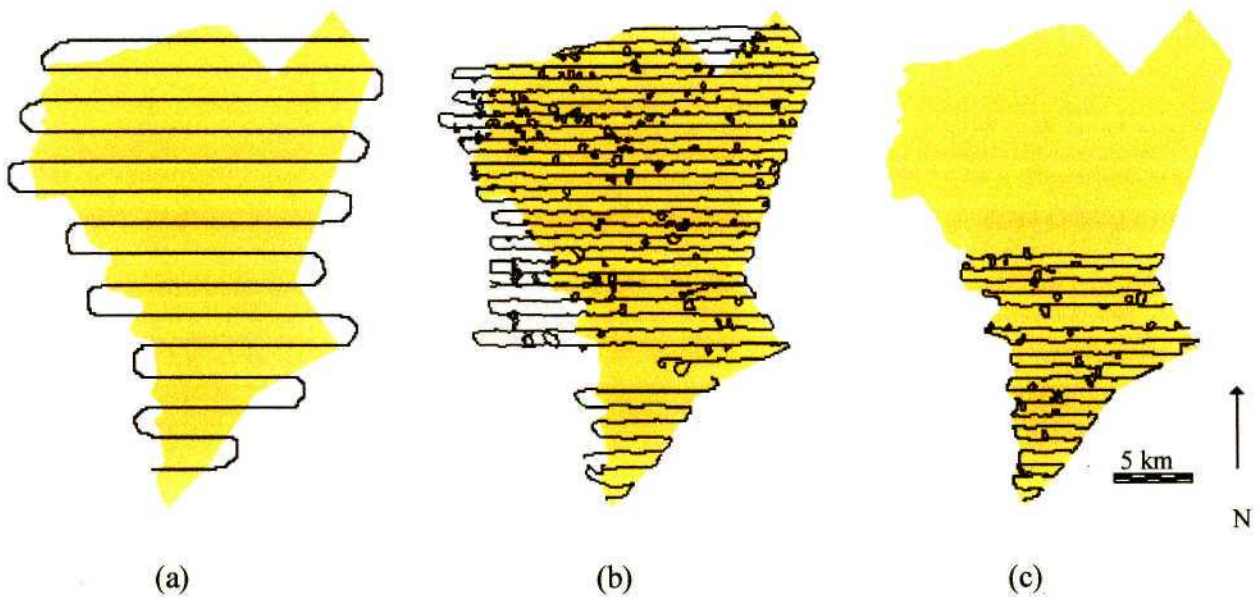


Figure 56. (a) Wet season (February 1997) and (b) and (c) dry season (October 1997) count flight paths.

1. Wet season count data

The wet season count was conducted during a single morning. Data was collected from a Piper Cub aircraft with two observers, (one observer plus pilot). Struts were calibrated for each observer to indicate ground distance zones of 0 - 100 m; 101 - 200 m; 201 - 300 m and 301 - 400 m from the plane when flown at 400 feet. The GPS error was calculated by flying over a known landmark, and taking several readings when flying in an easterly and westerly direction. The error for each flight direction was calculated by finding the difference between the average position recorded when flying in each direction, and the true position of the landmark as read off the orthophotos. Sightings were adjusted accordingly. Transects were flown at a speed of approximately 65 - 80 knots in an easterly direction. A westerly wind prevailed, so speed was slightly greater in that direction. When animals were sighted, their identity, GPS position, distance zone, and group size were recorded.

2. Dry season count data

Dry season counts were conducted over a 4 day period (mornings only) from a 5 seater Jet Ranger helicopter. The crew included 2 observers, a data recorder and the pilot. False strut markers were calibrated for each observer to demarcate 5 ground distance zones: 0 - 30 m; 31 - 90 m; 91-150 m; 153 - 400 m and 401 - 500 m when the helicopter was flown at 300 feet. Speed was approximately 50 knots. Animal sightings as well as surface water was recorded. When animals were sighted, their identity, group size and distance zones were recorded directly to an onboard notebook PC that was linked to the helicopters GPS. The GPS error was negligible for this count because the helicopter was flown at low altitude and speed. Observations were automatically tagged with the location, time and date. Surface water was similarly tagged. When large groups of elephant, buffalo, hippo or sable were sighted, the helicopter deviated from the transect line, a total group count was taken, and the helicopter returned to the transect to continue the count from the point of departure.

ANALYSIS

For both seasons, base maps were created by drawing concentric rings, 500 m apart, around recorded perennial water sources, using the DISTANCE module of IDRISI for windows (version 1.0, 1995). For each season, separate maps depicting the spatial positions of all sightings in relation to distance from water were constructed by overlaying sightings onto the base maps. By using the ANALYSIS, EXTRACT function of IDRISI, the above maps were interrogated to give exact distances from water for all sightings. Sightings were placed in distance zones of 0 – 1 km, 1-2 km, 2-3 km and > 3 km from water. Note that all distance zones described from here on refer to distance from water. Twenty one percent of MCT lay within the 0 – 1 km zone, 42 % lay within the 1 – 2 km zone and 26 % lay within the 2 – 3 km zone. Only 11 % of MCT lay beyond 3 km from water. To avoid unrepresentative results as a consequence of small sample areas, the remaining distance zones were grouped to form the > 3 km distance zone.

Individual sightings were allocated one of the four distance zones defined above. For individual species calculations, the number of individuals recorded in each distance zone was divided by the area of that zone. This gave the number of individuals per hectare of each species within the four distance zones.

For calculations involving more than one species (e.g. the spatial distribution of grazers, browsers and mixed feeders with respect to distance from water) different sized herbivores were standardised on the basis of estimated energy requirements using metabolic mass, i.e. body mass^{0.75} (Coe *et al.* 1976). The animal unit (A.U.), used by agriculturists, equates to a domestic steer weighing 456 kg. The number of a given species making up one A.U. has been calculated and figures are given in Collinson & Goodman (1982). Duiker were not included in this type of analysis because A.U. equivalents were not available for this species. Omission of this species from the grouped analysis is considered to be of little consequence because only a few sightings of this small herbivore were made in the dry season (Appendix 4, Table 2).

The number of individuals of a species within a distance zone was divided by the A.U. value assigned to that species. Animal unit values for various species could then be added together to give one value for a number of species within a distance zone.

RESULTS

The distributions of all species during the wet and dry seasons are shown in Figure 57.

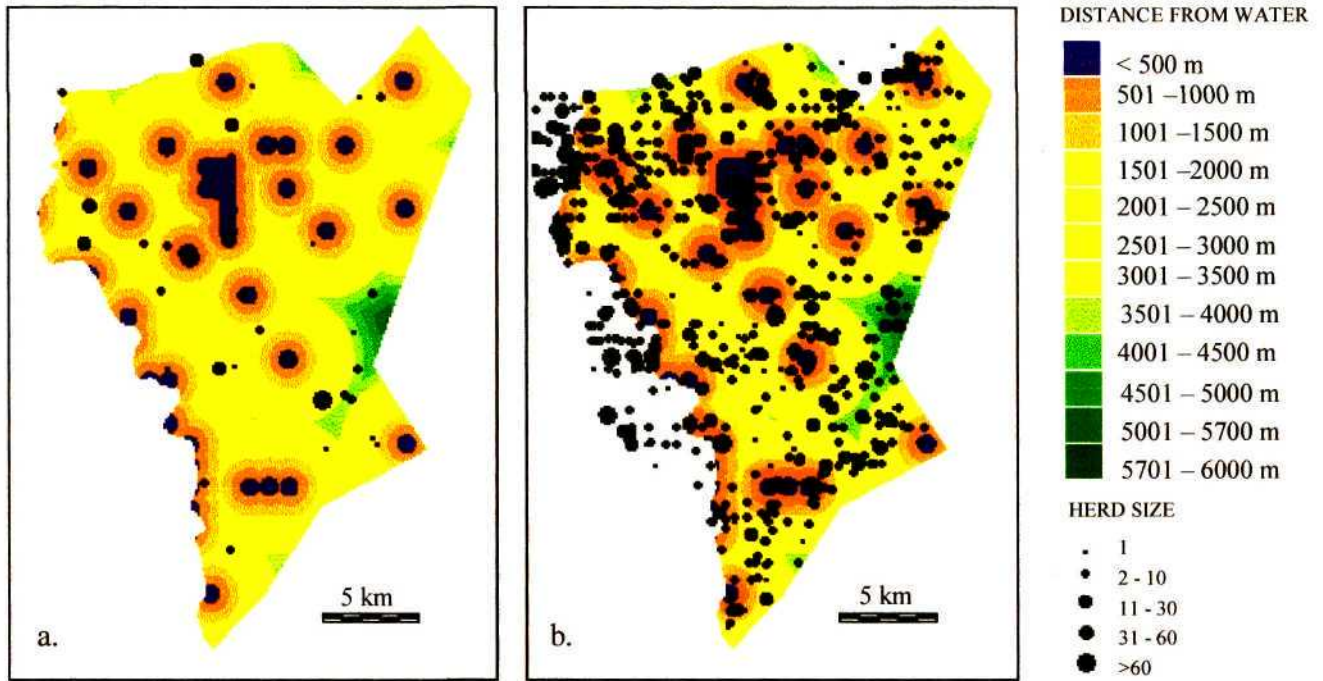


Figure 57. Spatial positions of all sightings during (a) the wet season and (b) the dry season of 1997.

Wet season sample size was small, and restricted mainly to large herds of large animals with few sightings made in the Hills. In contrast, the dry season sample size was large and included both individual and small animals, as well as numerous sightings in the Hills. The reduction in sightings during the wet season can be attributed to two factors: (1) During the wet season plant foliage is dense and obscures vision, and (2) the sampling strategy adopted for the wet season did not maximise the potential for observations as much as the dry season sampling strategy did. Specifically, there were fewer crew members during the wet season count, the plane was flown at a greater speed and higher altitude, and time spent counting was less than one quarter of that spent counting during the dry season.

The wet and dry season distribution of large herbivore biomass with respect to distance from perennial water, is shown below (Figure 58).

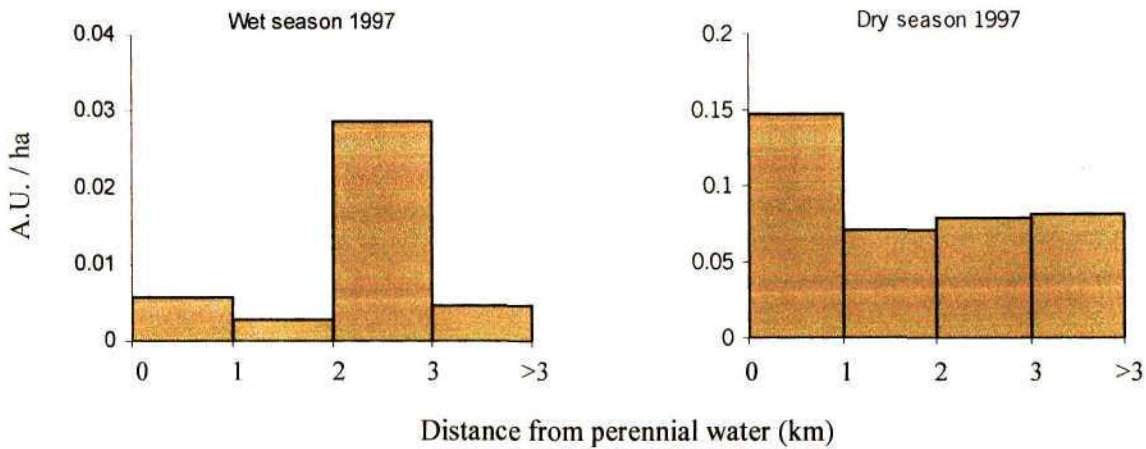


Figure 58. The spatial distribution of large herbivores (A.U. / ha) in relation to distance from water for the 1997 wet and dry seasons.

During the wet season, animal biomass (A.U. / ha) in the 2 – 3 km zone was six times that in any other distance category. During the dry season herbivore biomass within 1 km of water was greater than that in any other distance zone.

The distribution of herbivore species during the dry season is of particular importance, because it is during this season that resources such as food and water are likely to be limiting. The spatial distribution of a species during the dry season gives insight to that species basic requirements. The majority of species require surface water on a regular basis, and because of this, pressure on soils and vegetation in the vicinity of perennial water is greatest during the dry season. For these reasons, only the dry season count data was used to examine differences between species distributions. The distributions, as well as herd sizes are given for each of the commonly sighted herbivores during the 1997 dry season count (Figure 59). Calculation details are available in Appendix 4, Table 2.

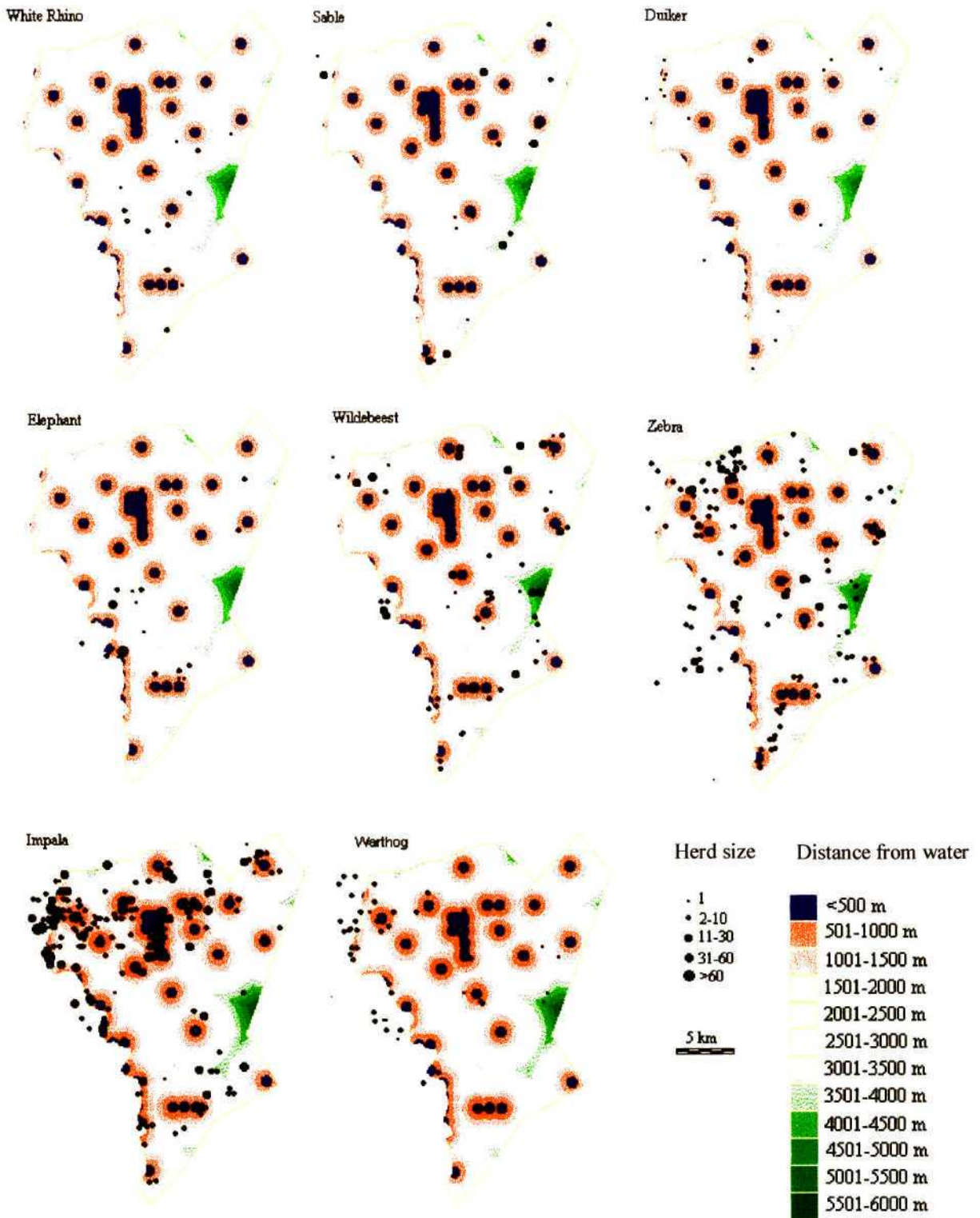


Figure 59a. The spatial distribution of white rhino, sable, duiker, elephant, wildebeest, zebra, impala and warthog during the 1997 dry season.

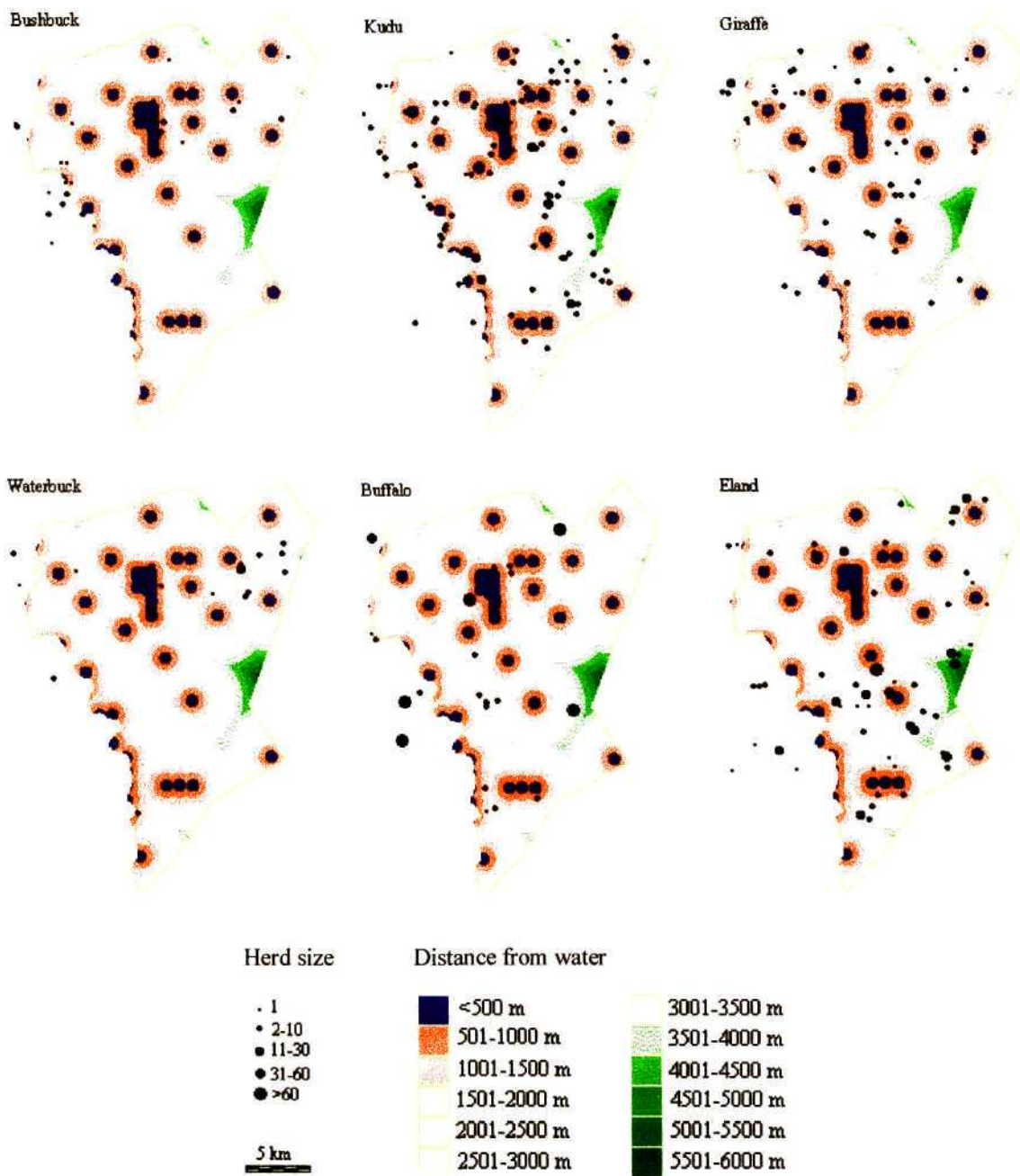


Figure 59b. The spatial distribution of bushbuck, kudu, giraffe, waterbuck, buffalo and eland during the 1997 dry season.

Histograms (Figure 60) provide objective information regarding the distribution of species per distance zone. While this information is good for simply finding out where animals are situated with respect to water, information regarding distributions related to factors other than water are lost. For this reason both distribution diagrams (Figure 59), which provide all round distribution data, and distribution histograms need to be considered when investigating species distributions with respect to perennial water.

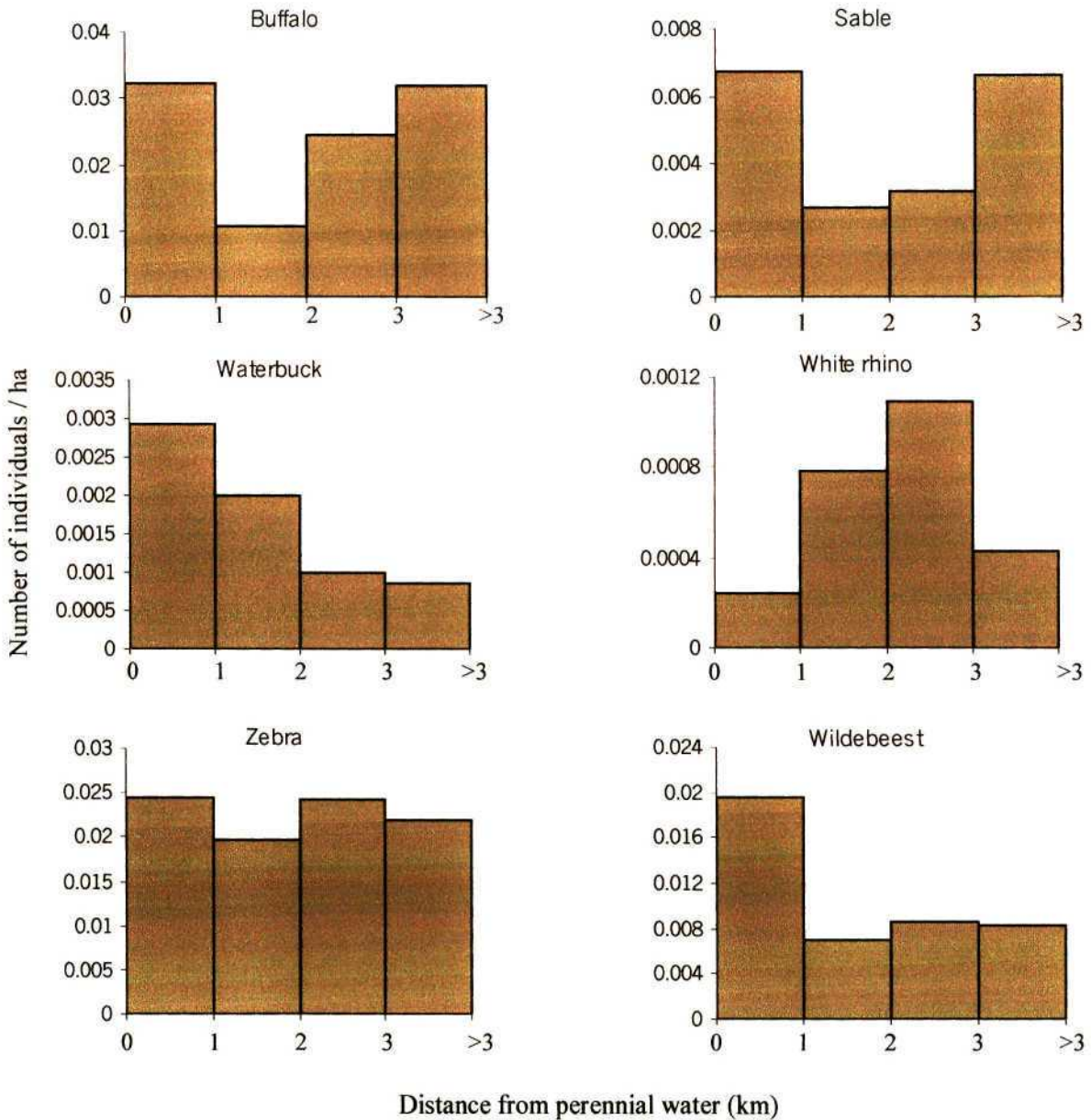


Figure 60a. The spatial distribution of large herbivore species (individuals / ha) in relation to distance from water during the 1997 dry season.

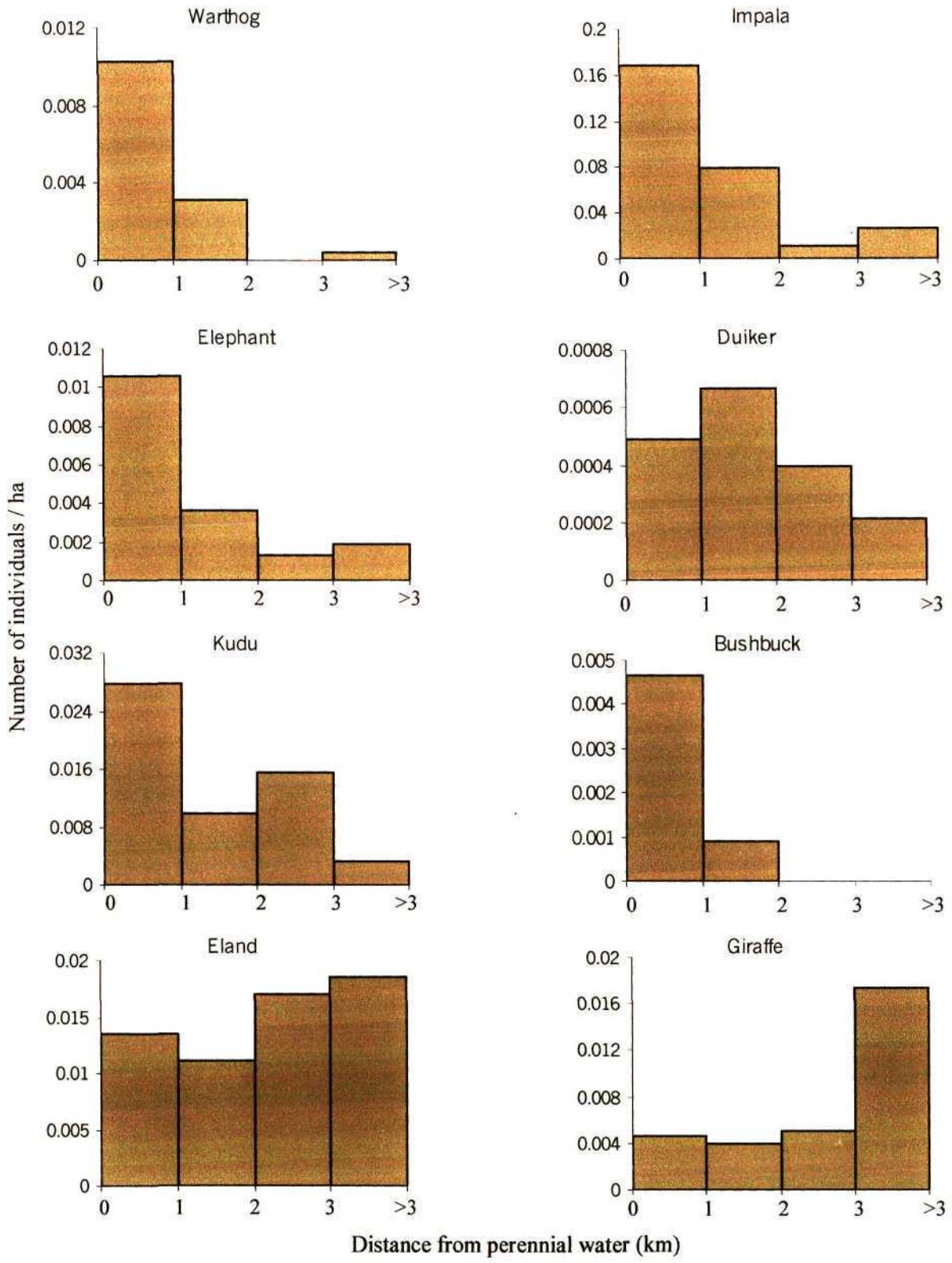


Figure 60b. The spatial distribution of large herbivore species (individuals / ha) in relation to distance from water during the 1997 dry season.

The spatial distribution of the three major herbivore feeding groups are given in relation to the position of perennial water (Figure 61). Grazers included hippo (all sighted within 1 km of water), buffalo, sable, waterbuck, white rhino, zebra, wildebeest and warthog. Mixed feeders included impala and elephant, and browsers included kudu, bushbuck, eland and giraffe. Calculation details are given in Appendix 4, Table 1.

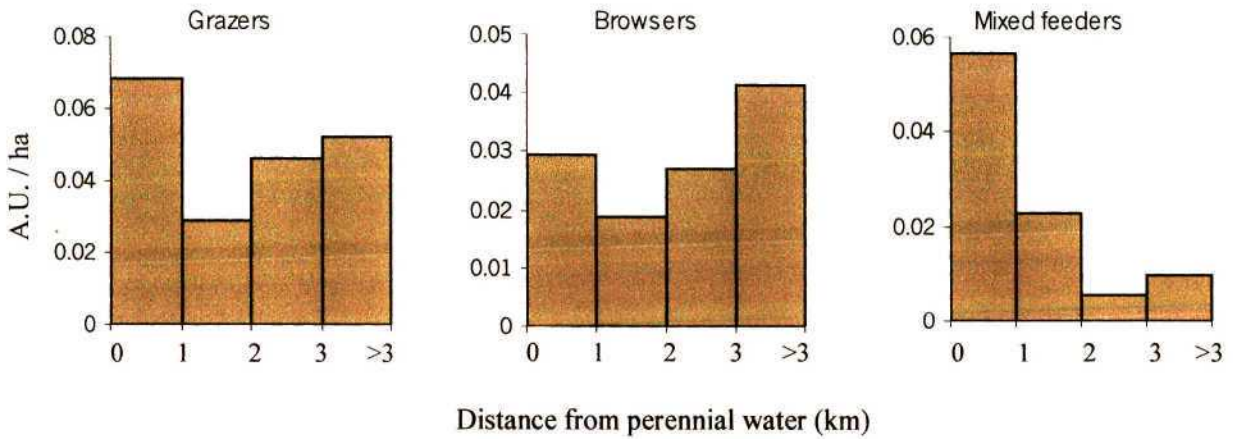


Figure 61. The spatial distribution of grazers, browsers and mixed feeders (A.U. / ha) during the 1997 dry season.

DISCUSSION

Perennial water at MCT was closely spaced (average: 3.5 km apart), with less than 1 % of rangeland being more than 5 km from water (Appendix 1, Figure 2). All large herbivores are capable of travelling distances of 5 km per day with ease (Collinson 1983; Owen-Smith 1996). This means that practically all rangeland at MCT is within walking distance of water for all species. It is interesting therefore, that species were not randomly distributed with respect to distance from water.

There was a shift in peak animal densities from the 0 – 1 km zone during the dry season, to the 2 – 3 km zone during the wet season. In the Kruger Park Thrash (1995) documented a similar concentration of animals close to water during the dry season. Steep drop offs in density were recorded at distances > 0.5 km. A shift away from perennial

water during the wet season has also been documented (Jarman 1972; Western 1975; Davison 1977) and is attributed to the fact that water is largely ubiquitous during the wet season (which is the case at MCT), and consequently herbivores are no longer attracted to rangeland close to perennial water. Where rangeland has been heavily impacted during the preceding dry season(s) herbivores will actively forage away from perennial water points. At MCT animal distribution data for the wet season indicates that herbivores are not actively avoiding the 0 – 1 km zone, suggesting that forage quality has not been compromised to the extent that animals will avoid these areas. This suggests that forage quality does not decline substantially beyond 1 km from water. This assumption however, cannot be verified because analysis of the vegetation was limited to within 1 km of water.

Grazer biomass was highest close to water (0 - 1 km), but a steady increase was observed between the 1 - 2 km and > 3 km zones. Of the three foraging groups (grazers, browsers and mixed feeders), grazers are most dependent on surface water because the moisture content of their forage (grass) drops off substantially during the dry season (Lamprey 1963; Western 1975; Bell & Jachmann 1984; Pellew 1983). Consequently grazing species are those whose distribution is most severely limited by distance from water, and whose densities are generally concentrated close to water (Western 1975; Goodman 1982; Collinson 1983). While the highest values for grazer biomass were in the zone closest to water, relatively high values in the zones furthest from water were also observed. At MCT perennial water points are close (< 5 km apart), and all range is within easy walking distance of water (Appendix 1, Figure 2), this could explain high grazer biomass even in the zone furthest from water. From the distribution diagram (Figure 59a) it is apparent that most sable sightings were made near water points that were close to areas relatively far from perennial water. Rangeland further from perennial water is comparatively lightly utilised, and is more likely to provide tall grass, which is preferred by sable for forage and shelter (Wilson 1975; Collinson 1983). The histogram shows that, as with all grazers, after 1 km from water, sable densities increased up to distances > 3 km from water. By contrast, Grobler (1981) in Matopos National Park, Zimbabwe, recorded that sable were never more than 1 km from water. Unlike the distribution of most grazers at MCT, waterbuck densities increased steadily towards water. Waterbuck are considered the most water-dependent of all antelope (Taylor *et al.* 1969), and are seldom found more

than a few kilometres from water (Estes 1991). A greater requirement for surface water is therefore likely to be the reason for the observed pattern of distribution of this species.

Mixed feeders (impala and elephant) showed very similar distributions relative to perennial water. More than half of the total biomass of each of these species was distributed in the first distance zone (0 – 1 km). Lowest densities for both species were observed in the 2 – 3 km zone. Impala are facultative water-dependent species, whose distribution close to water at MCT was supported by similar reports in the literature (Goodman 1982; Estes 1991; Smithers & Skinner 1990). Elephants are capable of travelling large distances between water and forage, so theoretically they are not confined to areas close to water. However, if their feeding requirements are met close to water there is no incentive for them to forage further away.

Browser biomass peaked furthest from water (> 3 km), but was next highest closest to water. The distributions of species within the browser category varied substantially. Duiker and bushbuck densities were highest close to water (< 2 km), while eland and giraffe densities increased with distance from water. Like most browsers (Western 1975), duiker (Wilson 1966, unseen, as cited in Estes 1991) and bushbuck do not require water on a regular basis, and their apparent attraction to areas close to water is more likely to be a response to habitat requirements.

While herbivore distributions at MCT do not indicate that forage quality has declined notably close to perennial water points, management should be aware that this situation is not likely to persist. Reasons for this statement include:

- (1) The fact that just prior to this study MCT had experienced a sequence of above average rainfall years that would have had a positive effect on plant recovery following utilisation, and
- (2) Data was collected at a time when animal biomass was reasonably low following substantial population reductions during the 1992 drought. Animal populations are still building up and carrying capacity for most species has not been reached.

While the opportunities for more detailed analyses of data exist (for example a multivariate approach to determine the effects of soils, vegetation and distance from water on herbivore distributions), this was considered beyond the scope of this study.

CHAPTER 8 : CONCLUSION

The results of this study indicate that of all vegetation types sampled, *C. mopane* veld on sandy-clay-loam soils was least adversely affected by the introduction of perennial water. In contrast, *Albizia petersiana* woodland on flat sandy soils, and Hill communities on sandy soils were most adversely affected by the introduction of perennial water. Unfavourable changes included declines in herbaceous species diversity and cover.

In the Hill Community, perennial grass cover and herbaceous biomass declined close to water. Prior to the introduction of perennial water in the Hills, bottomlands such as those in which artificial perennial water has been placed, are likely to have been subject to higher utilisation than the surrounding area because subsurface water would have collected here making green forage available further into the dry season. The introduction of perennial water to some of these bottomlands has increased their attractiveness to herbivores because year round water and greener forage are available irrespective of rainfall. In the past surface water would only have been available in the Hills during the dry season following above average rainfall years when:

1. Animals would not have relied heavily on perennial water because forage would have had a higher moisture content,
2. Many seasonal pans on the property would have held water and
3. The vegetation would have been more capable of tolerating high herbivore impacts.

In addition, during these years water would have been widespread, particularly in the Hills, and herbivores would not have concentrated in so few areas (as they do today with the artificially provided perennial water).

Acacia nigrescens woodland on clay-loam soil appeared to be susceptible to bush encroachment close to water.

Although soil physical properties (infiltration rates) were altered close to water in *C. mopane* veld on sandy-clay-loam soils, chemical changes to the soil, and unfavourable changes to the vegetation were minimal compared with changes in other vegetation types. Specifically:

1. *Colophospermum mopane* veld showed the smallest decline in herbaceous species

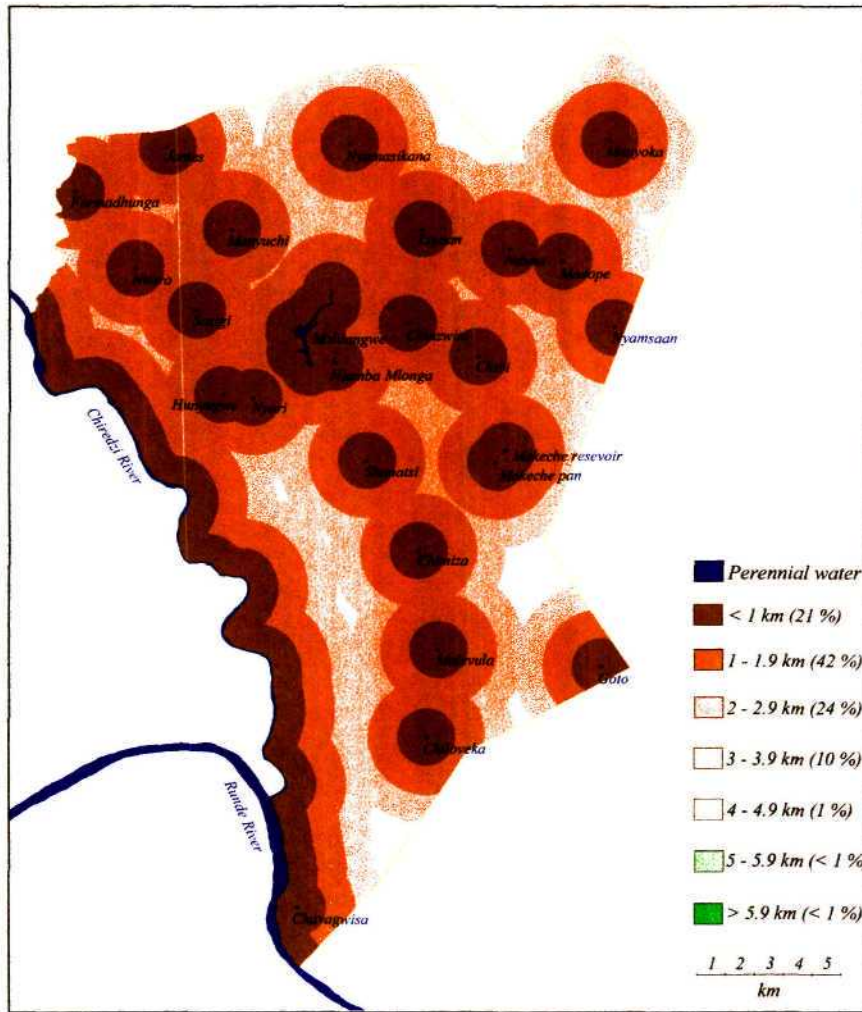
richness close to water,

2. perennial grass cover, because of the occurrence of *U. mosambicensis*, increased close to water,
3. both herbaceous and woody species composition reached equilibrium close to water (in most cases within 200 m of water),
4. relative to other vegetation types, herbaceous biomass was not adversely affected close to water, and
5. no signs of bush encroachment were observed close to water.

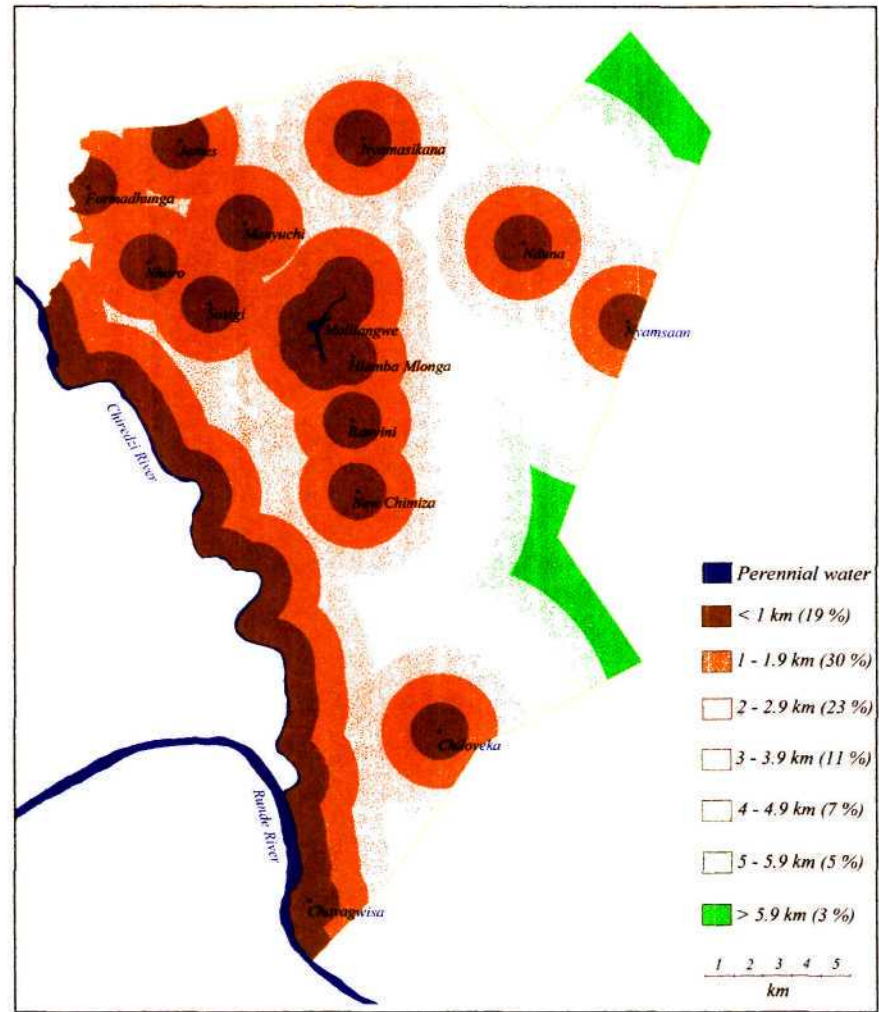
Furthermore, *C. mopane* is particularly resilient to utilisation (Bromwich 1972; Anderson & Walker 1974) as evidenced by prolific regrowth following heavy utilisation. In addition, *C. mopane* veld constitutes the largest vegetation type at MCT, occupying more than 51 % of the ranch. As such it is not a particularly rare vegetation type that requires special preservation.

For the reasons examined above, I would recommend that water be sited primarily in *C. mopane* veld. Further, I would recommend that where possible artificial perennial water be removed from the Hill communities and the Flat Sandveld where species diversity and range condition is compromised. With the relocation of perennial water primarily out of the Hills and into *C. mopane* veld, one would expect a redistribution of herbivores and consequently higher utilisation of *C. mopane* veld. Whether *C. mopane* veld would exhibit the same apparent resilience under heavier stocking rates than at the time of this study is likely but not certain. Regardless, relative to other vegetation types considered in this study, *C. mopane* veld is most likely to withstand heavier utilisation (that inevitably occurs around perennial water points in semi arid regions) than other vegetation types. Continued monitoring of areas close to perennial water is recommended.

In order to achieve a more distinct separation between wet and dry season herbivore range utilisation, and in order to accommodate future increases in animal pressure it would be recommended that the area of 'waterless zones' (areas more than 5 km from perennial water) be increased. This would be achieved by removing some water points, thus allowing greater distances between remaining water points, and the opportunity for the development of forage reserve areas that are necessary in times of drought.



(a)



(b)

Figure 62. The distribution of perennial water (a) at the time of data collection and (b) the proposed distribution of perennial water (areas of rangeland within various distance classes of distance from water are given in the key).

Figure 54 illustrates the proposed locations for perennial water at MCT. Recommendations for the redistribution of perennial water are based on the findings of this thesis, information gained from previous research (see References), suggestions made by Dr Peter Goodman, landscape features and range condition at MCT, and tourism requirements. Reasons for recommendation are given in Table 9.

Table 9. Proposed fate of perennial water and reasons for suggestions

<i>Water point</i>	<i>Proposed future</i>	<i>Reasons for proposal</i>
Malilangwe	Remain	Lodge situation (Pamushana Lodge); Water source for property
Hlamba Mlonga	Remain	Camp situation (Simbiri Camp)
Nduna	Remain	Lodge situation (Nduna Lodge)
Chinzwini	Close	Hill Community vulnerable to utilisation (species composition and biomass compromised close to water)
Lojaan	Close	Hill Community vulnerable to utilisation (species composition and biomass compromised close to water)
Hunyugwe	Close	Hill Community vulnerable to utilisation (species composition compromised); Too close to other perennial water points
Nyari	Close	Surrounding area degraded through heavy utilisation
Madhope	Close	Too close to other perennial water points
Chibi	Close	<i>Albizia</i> woodland vulnerable to heavy utilisation close to water
Makeche	Close	Too close to other perennial water points
Chimiza	Move	Close to vlei / dambo which is vulnerable to heavy utilisation. Move to site away from dambo, in <i>C. mopane</i> veld, in natural seasonal pan
Malevula	Close	Close to vlei / dambo which is vulnerable to heavy utilisation
Goto	Close	Removal creates a waterless zone resulting in relatively under utilised habitat as well as a forage reserve for times of drought
Nyamsaan	Remain	In <i>C. mopane</i> veld, therefore relatively resilient
Chiloveka	Remain	Not researched
Chavagwisa	Remain	Not researched
Manyoka	Close	Site vulnerable to heavy utilisation (Species composition and biomass compromised; woody plants severely impacted)
Nyamasikana	Remain	Not researched
James	Remain	Not researched
Manyuchi	Remain	Not researched
Formadhunga	Remain	Not researched
Nhoro	Remain	Not researched
Sosigi	Remain	Not researched
Shanatsi	Move	Visibility poor for tourism, replace with Banyini pan on old land

REFERENCES

- Abel NOJ & Blaikie PM. (1989) Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe. *Land Degradation and Rehabilitation* **1**:101-123
- Anderson GD & Walker BH. (1974) Vegetation composition and elephant damage in the Sengwa wildlife research area, Rhodesia. *Journal of the South African Management Association* **4**(1):1-14
- Anderson DC, Harper KT & Rushforth SR. (1982) Recovery of cryptogamic crusts from grazing on Utah winter ranges. *Journal of Range Management* **35**:355-359
- Andrew MH. (1988) Grazing impact in relation to livestock watering points. *TREE* **3**(12):336-339
- Andrew MH & Lange RT. (1986a) Development of a new piosphere in arid chenopod shrubland grazed by sheep. 1. Changes to the soil. *Australian Journal of Ecology* **11**:395-408
- Andrew MH & Lange RT. (1986b) Development of a new piosphere in arid chenopod shrubland grazed by sheep. 2. Changes to the vegetation. *Australian Journal of Ecology* **11**:411-424
- Arnold TH & de Wet BC (Eds.). (1993) *Plants of Southern Africa: names and distribution*. Botanical Institute, Pretoria
- Austin MP, Williams OB & Belbin L. (1981) Grassland dynamics under sheep grazing in an Australian Mediterranean type climate. *Vegetatio* **47**:201-211
- Ayeni JSO. (1977) Waterholes in Tsavo National Park, Kenya. *Journal of Applied Ecology* **14**:369-378
- Bell RHV & Jachmann H. (1984) Influence of fire on the use of *Brachystegia* woodland by elephants. *African Journal of Ecology* **22**:157-163
- Berry HH. (1982) The wildebeest problem in the Etosha National Park: a synthesis. *Madoqua* **13**(2):151-157
- Booth VR. (1980) *A study of Lichtenstein's hartebeest *Alcephalus lichtensteini* (Peters, 1852) and its habitat in southeastern Rhodesia*. M.Sc. thesis, University of Pretoria

- Bothma J du P (Ed.). (1996) *Game ranch management*. J.L. van Schaik Publishers, Pretoria, South Africa
- Bromwich MC. (1972) *The effect of introducing permanent water into a seasonal pan on game and vegetation*. Certificate in Field Ecology, Research Report, University of Rhodesia
- Brotherson JD, Rushforth SR & Johansen JR. (1983) Effects of long-term grazing on cryptogam crust cover in Navajo National Monument Ariz. *Journal of Range Management* **36**(5):579-581
- Brown JR & Archer S. (1989) Woody invasion of grasslands: establishment of honey mesquite (*Prosopis glandulosa* var. *glandulosa*) on sites differing in herbaceous biomass and grazing history. *Oecologia* **80**:19-26
- Buechner HK & Dawkins HC. (1961) Vegetation change induced by elephants and fire in Murchison Falls National Park, Uganda. *Ecology* **42**(4):752-766
- Burkett DW & Thompson BC. (1994) Wildlife association with human-altered water sources in semi-arid vegetation communities. *Conservation Biology* **8**(3):682-690
- Buss IO. (1961) Some observations of food habits and behaviour of the African elephant. *Journal of Wildlife Management* **25**:131-148
- Coe M.J, Cumming, DH, & Phillipson J. (1976) Biomass and production of large herbivores in relation to rainfall and primary production. *Oecologia* **22**:341-354
- Collinson R. (1983) The implications of providing artificial water points indiscriminately. *Tshomarelo News* **13**:17-26
- Collinson RFH & Goodman PS. (1982) An assessment of range condition and large herbivore carrying capacity of the Pilanesberg Game Reserve, with guidelines and recommendations for management. *Inkwe* **1**:1-54
- Chappell CA and Brown MA. (1993) The use of remote sensing in quantifying rates of soil erosion. *Koedoe* **36**(1):1-14
- Child G & Parris R. (1971) Use of mineralised water by Kalahari wildlife and its effects on habitats. *East African Wildlife Journal* **9**:125-142
- Childes SL & Walker BH. (1987) Ecology and dynamics of the woody vegetation on the

- Kalahari Sands in Hwange National Park, Zimbabwe. *Vegetatio* 72:111-128
- Clegg BW. (1999) *Plant ecology and degradation of basalt-derived dambos in semi-arid, southeastern Zimbabwe*. Unpublished M.Sc. thesis, University of Natal, Pietermaritzburg
- Cloudsley-Thompson JL. (1990) Etosha and the Kaokoveld: Problems of conservation in Namibia. *Environmental Conservation* 17(4):351-354
- Coley PD, Bryant JP & Chapin FS. (1985) Resource availability and plant antiherbivore defense. *Science* 230(4728):895-899
- Cumming DHM, Fenton MB, Rautenbach, Taylor RD, Cumming GS, Cumming MS, Dunlop JM, Ford AG, Hovorka MD, Johnston DS, Kalcounis M, Mahlangu Z & Portfors CVR. (1997) Elephants, woodlands and biodiversity in southern Africa. *South African Journal of Science* 93:231-236
- Cunningham Laboratory CSIRO, Brisbane, Australia. (1964) *Some concepts and methods in sub-tropical pasture research* (Bulletin 47). Alden Press, Oxford, London
- Dadkhah M & Gifford GF. (1980) Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. *Water resources bulletin* 16(6):979-986
- Davison E. (1977) *Wankie: The story of a great game reserve*. 2nd Edition. Regal Publishers, Salisbury, Rhodesia
- Department of Agriculture, Republic of South Africa. (1994) *A Primer on soil conservation*. Course for agricultural college students
- Dougill A & Cox J. (1995) Land degradation and grazing in the Kalahari: New analysis and alternative perspectives. Overseas Development Institute. *Pastoral development network paper* 38c
- Dublin HT, Sinclair ARE & McGlade J. (1990) Elephants and fire as causes of multiple stable states in the Serengeti-Mara woodlands. *Journal of Animal Ecology* 59:1147-1164
- du Toit JG. (1996) Water for game. In: Bothma J du P. (Eds.). *Game ranch management*. pp 95-108. J.L. Van Schaik Pub, Pretoria, South Africa
- du Toit JT, Bryant JP & Frisby K. (1990) Regrowth and palatability of *Acacia* shoots

- following pruning by African savanna browsers. *Ecology* **71**(1):149-154
- Elwell HA. (1996) *An assessment and management of soil and water resources on Malilangwe Conservation Trust*. Unpublished Report for Malilangwe Conservation Trust, Zimbabwe
- Estes RD. (1991) *The behaviour guide to African mammals*. Russel Friedman Books, South Africa
- Ferguson CD. (1995) *Anuran community structure and density of temporary and permanent standing waters in three land use types in the lower Save-Runde river catchment, southeastern Zimbabwe*. M.Sc. thesis, University of Zimbabwe, Zimbabwe
- Field CR. (1971) Elephant ecology in Queen Elizabeth National Park, Uganda. *African Wildlife Journal* **9**:99-124
- Foran BD. (1987) Detection of yearly cover change with Landsat MSS on pastoral landscapes in Central Australia. *Remote Sensing of Environment* **23**:333-350
- Foran BD. (1980) Change in range condition with distance from watering points and its implications for field survey. *Australian Rangeland Journal* **2**(1):59-66
- Genstat 5. (1988) *Reference Manual*. Clarendon Press, Oxford
- Gereta E & Wolanski E. (1998) Wildlife – water quality interactions in the Serengeti National Park, Tanzania. *African Journal of Ecology* **36**:1-14
- Goodman PS. (1982) *The dilemma of artificial water points in Mkuzi Game Reserve*. Unpublished Natal Parks Board Report, South Africa
- Goodman PS. (1996) *Large herbivore carrying capacity, species mix and management*. Unpublished report for Malilangwe Conservation Trust, Zimbabwe
- Graetz RD & Ludwig JA. (1978) A method for the analysis of piosphere data applicable to range assessment. *Australian Rangeland Journal* **1**(2):126-136
- Grobler JH. (1981) Feeding behaviour of sable *Hippotragus niger* (Harris 1838) in the Rhodes Matopos National Park, Zimbabwe. *South African Journal of Zoology* **16**:259-262
- Guy PR. (1976) The feeding behaviour of elephant (*Loxodonta africana*) in the Sengwa area, Rhodesia. *South African Journal of Wildlife Research* **6**(1):55-63
- Hatton JC & Smart NOE. (1984) The effect of long-term exclusion of large herbivores

- on soil nutrient status in Murchison Falls National Park, Uganda. *African Journal of Ecology* **22**:000-000
- Haydock KP & Shaw NH. (1975) The comparative yield method for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **15**:663-670
- Hesse PR. (1955) A chemical and physical study of soil of termite mounds in East Africa. *Journal of Ecology* **43**:449-461
- Hitchcock D. (1996) Wildlife observed in Kutse Game Reserve, Botswana, at pans with either artificial or natural water sources. *African Journal of Ecology* **34**:70-74
- Holling CS. (1973) Resilience and stability of ecological systems. *Annual Reviews of Ecology and Systematics* **4**:1-23
- Idrisi for Windows. (1995) Graduate School of Geography, Clark University, Worcester, USA
- Jarman PJ. (1971) Selection of drinking places by large mammals in the Serengeti woodlands. *East African Wildlife Journal* **9**:158-161
- Jarman PJ. (1972) The use of drinking sites, wallows and salt licks by herbivores in the flooded Middle Zambezi Valley. *East African Wildlife Journal* **10**:193-209
- Judd BI. (1979) *Handbook of tropical forage grasses*. Garland Press, New York
- Kalikawa MC. (1990) Baseline vegetation description at artificial watering points of Central Kalahari Game Reserve. *African Journal of Ecology* **28**:253-256
- Keddy PA. (1992). Assembly and response rules: two goals for predictive community ecology. *Journal of Vegetation Science* **3**:157-164
- Kelly RD & Walker BH. (1976) The effects of different forms of landuse on the ecology of a semi-arid region in south-eastern Rhodesia. *Journal of Ecology* **64**:553-575
- Kennard DG & Walker BH. (1973) Relationships between tree canopy cover and *Panicum maximum* in the vicinity of Fort Victoria. *Rhodesian Journal of Agricultural Research* **11**:145-153
- Lamprey HF. (1963) Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. *East African Wildlife Journal* **1**:63-72
- Landsberg J, James CD, Morton SR, Hobbs TJ, Stol J, Drew A & Tongway H. (1997) *The effect of artificial sources of water on rangeland biodiversity*. Final Report

to the Biodiversity Group, Environment Australia

- Lange RT. (1969) The piosphere: sheep track and dung patterns. *Journal of Range Management* **22**:396-400
- Laws RM. (1970) Elephants as agents of habitat and landscape change in East Africa. *Oikos* **21**:1-15
- Louw GN. (1984) Water deprivation in herbivores under arid conditions. In: Gilchrist FM & Mackie RI (Eds.) *Herbivore nutrition in the subtropics and tropics*. pp 106-126. Science Press, Craighall, South Africa
- MacArthur RH. (1964) Environmental factors affecting bird species diversity. *American Naturalist* **98**:387-397
- McCalla GR, Blackburn WH & Merrill LB. (1984) Effects of livestock grazing on infiltration rates, Edward Plateau of Texas. *Journal of Range Management* **37**(3):265-269
- Medina E 1985. Requirements, conservation and cycles of nutrients in the herbaceous layer In Walker BH (Ed.) *Determinants of tropical savannas*. IRL Press Limited, Oxford, UK
- Mills G. (1984) Rainfall, windpumps and the Kalahari ecology. *Custos* **13**(4):27-30
- Mloszewski MJ. (1983) *The behaviour and ecology of the African buffalo*. Cambridge University Press, Cambridge
- Moorby J & Wareing PF. (1963) Ageing in woody plants. *Annals of botany* **27**(106): 291-309
- Mwalyosi RBB. (1990) The dynamic ecology of *Acacia tortilis* woodland in Lake Manyara National Park, Tanzania. *African Journal of Ecology* **28**:189-199
- Napier Bax P & Sheldrick DLW. (1963) Some preliminary observations on the food of elephants in the Tsavo National Park (East) of Kenya. *East African Wildlife Journal* **1**:40-53
- Norton-Griffiths M. (1973) Counting the Serengeti wildebeest using two-stage sampling. *East African Wildlife Journal* **11**:135-150
- O'Reagain PJ & Turner JR. (1991) An evaluation of the empirical basis for grazing management recommendations for rangeland in southern Africa. *Journal of the Grassland Society of Southern Africa* **9**(1):38-48

- O'Connor TG. (1994) Composition and population responses of an African savanna grassland to rainfall and grazing. *Journal of Applied Ecology* **31**:155-171
- O'Connor TG. (1997) *Range condition and trend on Malilangwe Conservation Trust: Historical, changes, impact of and recovery from drought, management and monitoring*. Unpublished report for Malilangwe Conservation Trust, Zimbabwe
- Owen-Smith N & Cooper SN. (1987) Palatability of woody plants to browsing ruminants in a South African savanna. *Ecology* **68**(2):319-329
- Owen-Smith N. (1996) Ecological guidelines for waterpoints in extensive protected areas. *South African Journal of Wildlife Research* **26**(4):107-112
- Parris R. (1984) Pans, rivers and artificial waterholes in the protected areas of the south-western Kalahari. *Koedoe Supplement* 1984:63-82
- Pellew RAP. (1983) The impacts of elephant, giraffe and fire upon the *Acacia tortilis* woodlands of the Serengeti. *African Journal of Ecology* **21**:41-74
- Perkins JS & Thomas DSG. (1993a) Spreading deserts or spatially confined environmental impacts? Land degradation and cattle ranching in the Kalahari Desert of Botswana. *Land Degradation & Rehabilitation* **4**:179-194
- Perkins JS & Thomas DSG. (1993b) Environmental responses and sensitivity to permanent cattle ranching, semi-arid western central Botswana, pp. 273-286 In: Thomas DSG & Allison RJ (Eds.) 1993. *Landscape Sensitivity*. John Wiley & Sons Ltd., Chichester
- Pickup G. (1991) *Spatial models for identifying land degradation*. Paper presented at the 4th International Rangeland Congress, Montpellier, France, 22-26th April, 1991.
- Pickup G. (1994) Modelling patterns of defoliation by grazing animals in rangelands *Journal of Applied Ecology* **31**:231-246
- Pickup G & Chewings VH. (1988) Estimating the distribution of grazing and patterns of cattle movement in a large arid zone paddock. *International Journal of Remote Sensing* **9**(9):1469-1490
- Pieper RD & Heitschmidt RK. (1988) Is short term grazing the answer? *Journal of Soil and Water Conservation* March-April 1988:133-137

- Rogers RW, Lange RT & Nicholas DJD. (1966) Nitrogen fixation of arid soil crusts. *Nature* **209**:96-97
- Rogers RW & Lange RT. (1971) Lichen populations on arid soil crusts around sheep watering places in South Australia. *Oikos* **22**:93-100
- Savory A. (1996) Personal communications. Karoi Farmers day, Zimbabwe
- Scholes RJ. (1990a) The influence of soil fertility on the ecology of southern African dry savannas. *Journal of Biogeography* **17**:415-419
- Scholes RJ. (1990b) The origin and extent of nutrient-enriched patches within a nutrient-poor savanna in South Africa. *Journal of Biogeography* **17**:463-470
- Scholes RJ & Walker BH. (1996) *An African Savanna - synthesis of the Nylsvley study*. Cambridge University Press, Great Britain
- Senzota RBM & Mtahko G. (1990) Effect on wildlife of a water-hole in Mikumi National Park, Tanzania. *African Journal of Ecology* **28**:147-151
- Sinclair ARE. (1977) *The African buffalo*. Chicago University Press, Chicago
- Skarpe C. (1990) Shrub layer dynamics under different herbivore densities in an arid savanna, Botswana. *Journal of Applied Ecology* **27**:873:885
- Smithers RHN & Skinner JD. (1990) *The mammals of the southern African subregion*. 2nd Edition. University of Pretoria, South Africa
- Smuts GL. (1978) Interrelations between predators, prey and their environment. *Bioscience* **28**(5):316-320
- Sparrow R. (1997) Personal communications. Malilangwe Conservation Trust, Zimbabwe
- Stalmans M. (1994) *Vegetation survey of Malilangwe*. Unpublished Report for Malilangwe Conservation Trust, Zimbabwe
- Stafford Smith DM & Pickup G. (1990) Pattern and production in arid lands. *Proceedings of the Ecology Society of Australia* **16**:195-200
- Steel RGD & Torrie JH. (1980) *Principles and procedures of statistics and biometrical approach*. McGraw-Hill Book Company (2nd Edition), Singapore
- Stevenson FJ. (1986) *Cycles of soil*. John Wiley & Sons, Inc., United States of America
- Stuart-Hill GC & Tainton NM. (1989) Water utilisation patterns around isolated *Acacia karroo* trees in the False Thornveld of the eastern Cape. *Journal of the Grassland society of southern Africa* **6**(4):195-204

- Swift WH, White WC, Wiles JW & Worst BG. (1953) The geology of the lower Sabi coalfield. *Southern Rhodesia Geological Survey Bulletin* No. 40. Government Printer, Salisbury
- Tafangenyasha C. (1997) Tree loss in Gonarezhou National Park (Zimbabwe) between 1970 and 1983. *Journal of Environmental Management* 49:355-366
- Taylor CR. (1969) The eland and Oryx. *Scientific American* 220:89-95
- Taylor CR, Spinage CA & Lyman. (1969) Water relations of the waterbuck, an East African antelope. *American Journal of Physiology* 217:630-634
- Taylor RD & Walker BH. (1978) Comparisons of vegetation use and herbivore biomass on a Rhodesian game and cattle ranch. *Journal of Applied Ecology* 15:565-581
- ter Braak CJF. (1988) *CANOCO – a Fortran program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis (version 2.1)*. Ministry of Agriculture and Fisheries, Wageningen
- Thomas DSG. (1993) Sandstorm in a teacup? Understanding desertification. *The Geographical Journal* 159:318-331
- Thomson PJ. (1975) The role of elephants, fire and other agents in the decline of *Brachystegia boehmii* woodland. *Journal of South African Wildlife Management association* 5(1):11-18
- Thrash I. (1993) *Implication of providing water for indigenous large herbivores in the Transvaal lowveld*. Ph.D. (wildlife management) thesis, University of Pretoria, Pretoria
- Thrash I. (1998a) Impact of large herbivores at artificial watering points compared to that at natural watering points in Kruger National Park, South Africa. *Journal of Arid Environments* 38:315-324
- Thrash I. (1998b) Impact of water provision on herbaceous vegetation in Kruger National Park, South Africa. *Journal of Arid Environments* 38:437-450
- Thrash I, Nel PJ, Theron GK & Bothma J. du P. (1991a) The impact of provision of water for game on the basal cover of the herbaceous vegetation around a dam in the Kruger National Park. *Koedoe* 34(2):121-130
- Thrash I, Nel PJ, Theron GK & Bothma J. du P. (1991b) The impact of provision of

- water for game on the woody vegetation around a dam in the Kruger National Park. *Koedoe* **34**(2):131-148
- Thrash I, Nel PJ, Theron GK & Bothma J. du P. (1993) Impact of water provision on herbaceous community composition in the Kruger National Park. *African Journal of Range and Forage Science* **10**(1):31-35
- Thrash I, Nel PJ, Theron GK & Bothma J. du P. (1995) Dry season herbivore densities around drinking troughs in the Kruger National Park. *Journal of Arid Environments* **29**:213-219
- Tolsma DJ, Ernst WHO & Verwey RA. (1987) Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. *Journal of Applied Ecology* **24**:991-1000
- Tongway D & Hindely N. (1995) *Manual: Assessment of soil conditions of tropical grasslands*. Canberra: CSIRO
- Tyson PD. (1986) *Climatic change and variability in southern Africa*. Cape Town, Oxford University Press
- UNEP. (1992) *World Atlas of Desertification*. Edward Arnold, Sevenoaks
- van Oudtshoorn F. (1992) *Guide to grasses of South Africa*. National Book Printers, Cape Town
- Van der Schijff HP. (1959) Weidingsmoontlikede en weidings - probleme in die Nasionale Kruger Wildtuin. *Koedoe* **33**(1):63-88
- Van Rooyen N, Bezuidenhout D, Theron GK & Bothma J du P. (1990) Monitoring of the vegetation around artificial watering points (windmills) in the Kalahari Gemsbok National Park. *Koedoe* **33**(1):63-88
- Van Rooyen N, Bredenkamp GJ, Theron GK, Bothma J du P & Le Riche EAN. (1994) Vegetational gradients around artificial watering points in the Kalahari Gemsbok National Park. *Journal of Arid Environments* **26**:349-361
- Van Wyk P & Fairall N. (1969) The influence of the African elephant on the vegetation of the Kruger National Park. *Koedoe* **12**:96-127
- Vesey-Fitzgerald DF. (1965) The utilisation of natural pastures by wild animals in Rukwa Valley, Tanganyika. *East African Wildlife Journal* **3**:38-48
- Walkley A. (1947) Organic carbon by the Walkley-Black oxidation procedure. *Soil*

Science **63**:251-264

- Walker BH. (1976) An approach to the monitoring of changes in the composition and utilisation of woodland and savanna vegetation. *South African Journal of Wildlife Research* **6**(1):1-32
- Walker BH & Goodman PS. (1982) *Implications for stability theory for wildlife management*. Proceedings of the International Conference on the Management of Large Mammals in African Conservation Areas. Pretoria
- Walker BH & Noy Meir I. (1982) Aspects of the stability and resilience of savanna ecosystems. In: Huntley BJ (Ed). *Ecology of Tropical Savannas*, Springer Verlag, Berlin
- Walker BH, Emslie RH, Owen-Smith RN & Scholes RJ. (1987) To cull or not to cull: lessons from a southern African drought. *Journal of Applied Ecology* **24**:381-401
- Warren SD, Thurow TL, Blackburn WH & Garza NE. (1986) The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *Journal of Range Management* **39**(6):491-495
- Weir JS & Davison E. (1965) Daily occurrence of African game animals at water holes during dry weather. *Zoologica Africana* **1**(1):353-368
- Weir JS. (1971) The effects of creating additional water supplies in a Central African National Park. In Duffey E & Watt AS (Eds.) *The Scientific Management of Animal and Plant communities for Conservation*. Blackwell Scientific Publications, Oxford, pp. 367-376
- Western D. (1975) Water availability and its influence on the structure and dynamics of a savannah large mammal community. *East African Journal of Wildlife* **13**:265-286
- Whitlow JR. (1980) Land use, population pressure and rock outcrops in the tribal areas of Zimbabwe Rhodesia. *Zimbabwe Rhodesia Agricultural Journal* **77**(1):3-12
- Whitlow JR. (1983) Hydrological implications of land use in Africa, with particular reference to Zimbabwe. *Zimbabwe Agricultural Journal* **80**(5):193-211
- Wilson DE. (1975) *Factors affecting roan and sable antelope populations on nature reserves in the Transvaal with particular reference to ecophysiological aspects*.

D.Sc. Thesis, University of Pretoria, Pretoria

- Wood MK & Blackburn WH. (1981) Grazing systems: Their influence on infiltration rates in the Rolling Plains of Texas. *Journal of Range Management* **34**(4):331-335
- Wood MK, Eckert RE, Blackburn WH & Peterson FK. (1982) Influence of crusting soil surfaces on emergence and establishment of Crested Wheatgrass, Squirreltail, Thurber Needlegrass, and Fourwing Saltbush. *Journal of Range Management* **35**(3):282-287
- Young E. (1970a) *Water as faktor in die ekologie van wild in die Nationale Krugerwildtuin*. D.Sc. thesis. University of Pretoria, South Africa
- Young E. (1970b) *Water in game management*. Unpublished report. Proceedings of the Water Year Convention, Pretoria, South Africa
- Young E. (1972) The value of waterhole counts in estimating wild animal populations. *Journal of the Southern African Wildlife Management Association* **2**(1):22-23

APPENDIX 1. STUDY SITES

Table 1. Histories and descriptions of water points used in this study

<i>Water point name</i>	<i>Nyamsaan</i>	<i>Bandama</i>	<i>Chinzwini</i>	<i>Lojaan</i>	<i>Chibi</i>	<i>Manyoka</i>
<i>Geology</i>	Basalt	Basalt	Sandstone	Sandstone	Junction of Sandstone and Basalt	Sandstone
<i>Soils</i>	sandy-clay-loam	sandy-clay-loam	fine sand	Fine sand	fine sand and clay-loam	fine sand
<i>Topographical position</i>	Bottomland	Bottomland	Bottomland	Bottomland	Bottomland	Gentle mid-slope
<i>Structure</i>	Clay lined natural pan	Clay lined natural pan	Weir between outcrops. Sandstone bottom	Weir between outcrops. Sandstone bottom	Clay lined natural pan	Cement based pan
<i>Size at the time of this study</i>	≈ 60 x 20 m	≈ 30 x 40 m	≈ 50 x 60	≈ 50 x 70 m	≈ 7 x 8 m	≈ 5 x 5 m
<i>Historical status</i>	Seasonal	Seasonal	Seasonal	Seasonal	Seasonal	No pan
<i>Years pumped to (P) or dammed (D)</i>	1987 – 1999 (P)	1987 – 1994 (P)	1963 – 1999 (D)*	1963 – 1999 (D)*	1950 – 1998 (P)	1996 – 1999 (P)
<i>Status at the time of this study</i>	Perennial	Seasonal	Perennial	Perennial	Perennial	Perennial
<i>Surrounding topography</i>	Fairly flat. A drainage line is situated about 50 m to the east of the dam	Fairly flat	Sandstone outcrops with wide (≈ 150 m) vegetated valleys surrounding the area on all sides except the south-east. The south-east side slopes down toward the <i>Albizia</i> Woodland	Sandstone outcrops with wide (≈ 150 m) vegetated valleys surrounding the area on all sides	Sandy soils largely flat, but with a very gradual slope downwards from the north to meet clay-loam soils situated on fairly flat terrain	Terrain gently sloping downwards from the north. Sandstone outcrops to the north and west. One isolated small (10 x 5 m) rock outcrop in the immediate vicinity of the pan, other larger outcrops at least 100 m away
<i>Nearest perennial neighbour</i>	Bandama (2183m)	Nyamsaan (2183 m)	Chibi (2707 m)	Nduna (3216 m))	Bandama (2601 m)	Nduna (4968 m)
<i>UTM start point**</i>	0393695; 7672715	0391661; 7672216	0386649; 7672944	0387159; 7676285	0389060; 7671802 (Chibi Clay) 0389042; 7671927 (Chibi Sand)	0393510; 7679314
<i>Compass bearing line</i>	225°	185°	70°	68°	190° (Chibi Clay) 315° (Chibi Sand)	197°
<i>Length of selected bearing line</i>	1000 m	1000 m	600 m	600 m	1000 m (Chibi Clay) 900 m (Chibi Sand)	175 m

*dams filled by bowser during 1983 and 1992 droughts. **UTM start points taken using GPS with averaging function (error < 50 m)

Table 2. Transects at which data was collected*

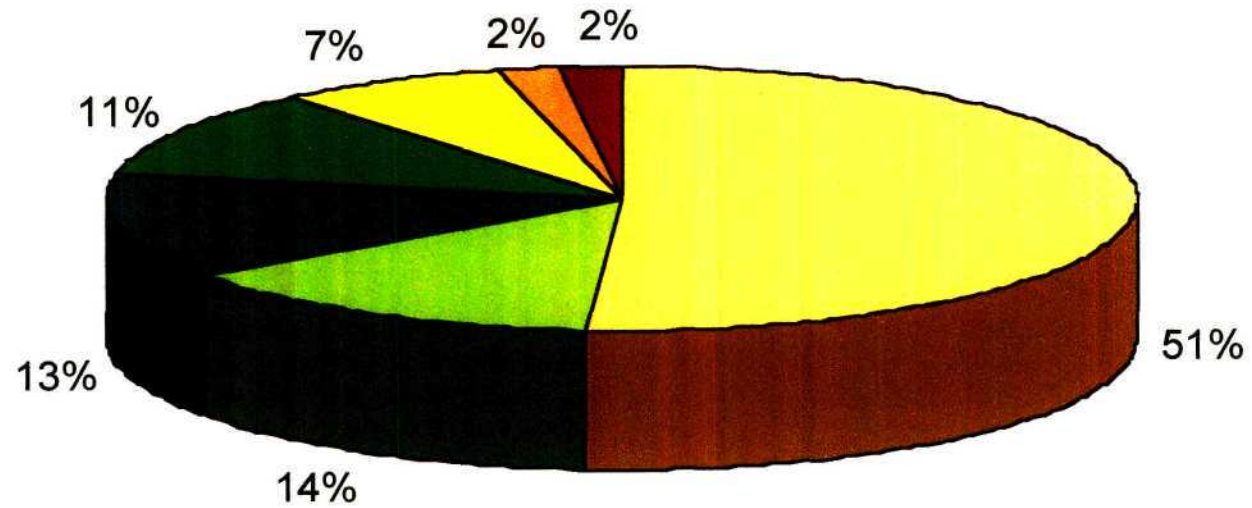
Transect distance (m)	<i>Nyamsaan</i>			<i>Bandama</i>			<i>Chinzwini</i>			<i>Lojaan</i>			<i>Chibi Clay</i>			<i>Chibi Sand</i>			<i>Manyoka</i>		
	Herb	Shru	Tree	Herb	Shru	Tree	Herb	Shru	Tree	Herb	Shru	Tree	Herb	Shru	Tree	Herb	Shru	Tree	Herb	Shru	Tree
10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
30	✓	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✓	✓	✓	✓	✗	✗	✓	✗	✗
60	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
175	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
200	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
400	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
500	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
600	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
700	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗
800	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗
900	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗
1000	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗	✗	✗

* Woody data was not collected where densities were low because in these situations adjacent belt transects overlapped. Soil data (except infiltration rate) were collected where the herbaceous layer was sampled.

Table 3. Mean monthly rainfall and monthly rainfall (mm) for the year prior to, and for the period over which this study was conducted*

	<i>January</i>	<i>February</i>	<i>March</i>	<i>April</i>	<i>May</i>	<i>June</i>	<i>July</i>	<i>August</i>	<i>September</i>	<i>October</i>	<i>November</i>	<i>December</i>
1996	300.0	205.0	33.0	33.0	13.5	5.0	33.5	6.0	4.0	2.5	64.5	66.5
1997	167.5	119.5	72.5	36.0	0.0	0.0	8.5	0.0	9.5	17.0	40.2	70.4
1998	184.3	63.0	17.9	3.8.0	0.0	0.0	2.0	6.0	0.0	28.9	68.3	159.6
*Mean	117.0	117.9	46.9	26.8	9.8	7.06	6.36	4.6	12.4	24.9	63.8	110.4

*Mean monthly rainfall was calculated from HQ rainfall records collected between 1951 and 1998 i.e. over a 47 year period.



- C. mopane : 20201 ha
- Hill communities: 5374 ha
- Paragneiss communities: 5112 ha
- A. nigrescens/Open C. mopane: 4197 ha
- Open Acacia savanna: 2776 ha
- Riverine/Alluvium: 773 ha
- Albizia woodland: 602 ha

Figure 1. The proportions of each of the major vegetation types at MCT.

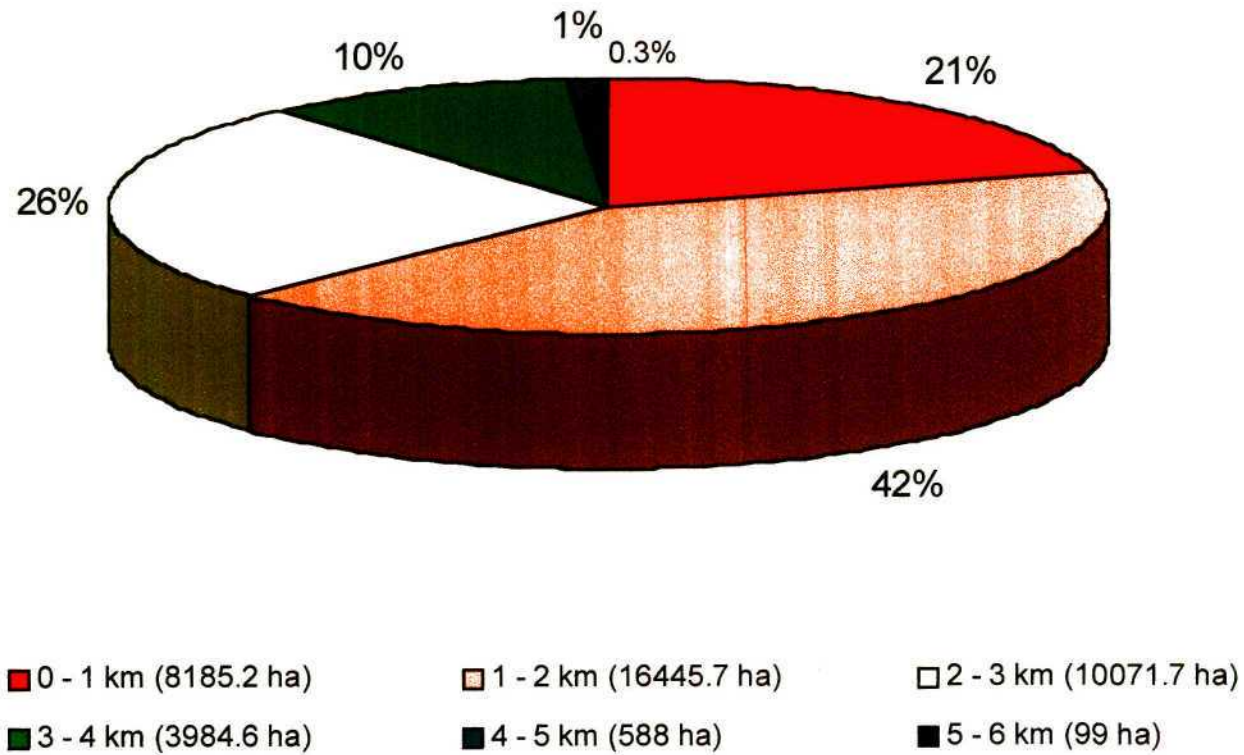


Figure 2. The proportion of MCT rangeland within x km of water.

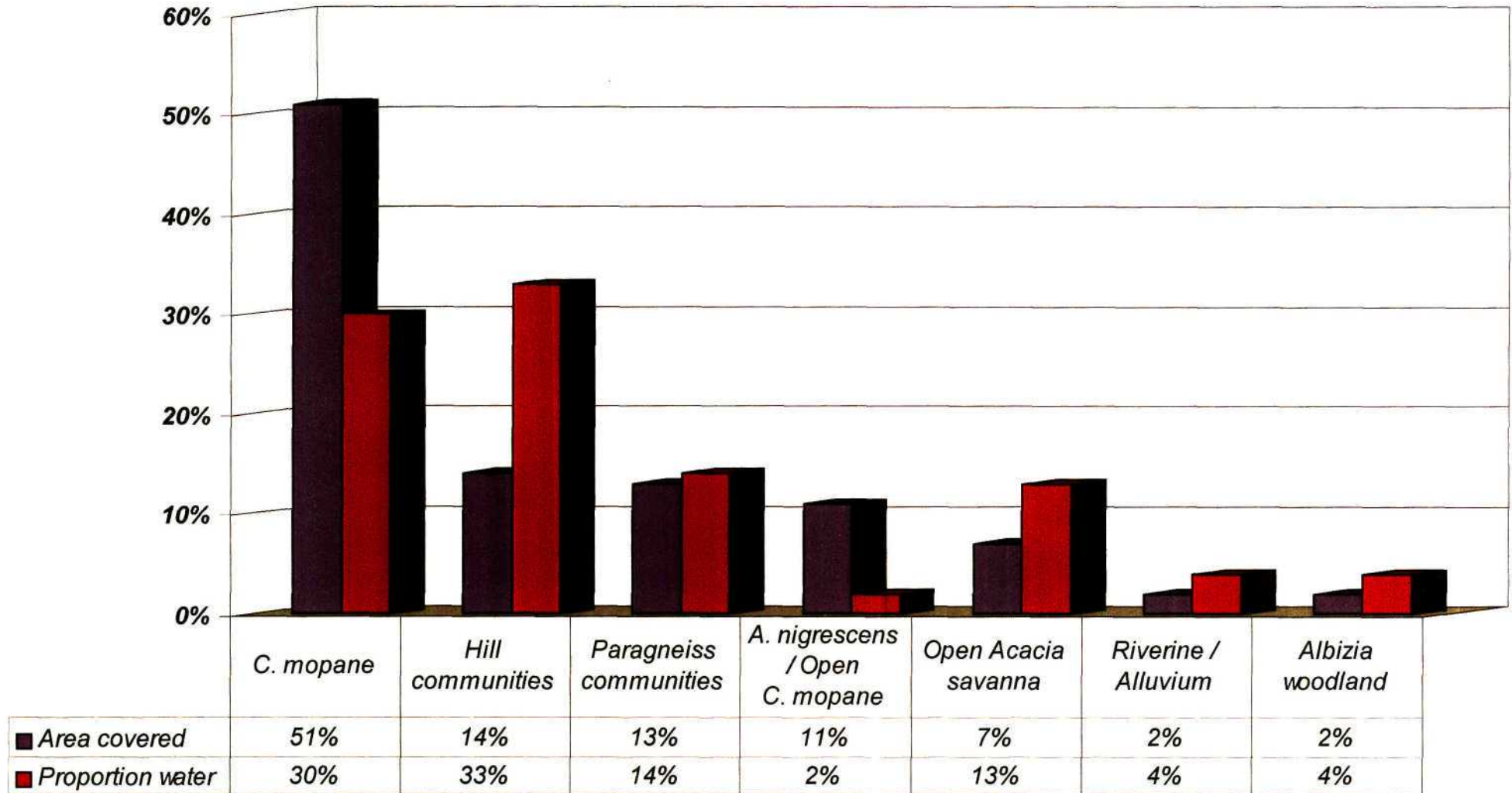


Figure 3. The approximate proportion of artificially provided perennial water relative to area within each vegetation type at MCT.

APPENDIX 2. SOILS

Table 1. Soil texture and average soil depth for each transect

<i>Transect location</i>	<i>Nyamsaan</i>		<i>Bandama</i>		<i>Chinzwini</i>		<i>Lojaan</i>		<i>Chibi Sand</i>		<i>Chibi Clay</i>		<i>Manyoka</i>	
	Texture	Depth (cm)	Texture	Depth (cm)	Texture	Depth (cm)	Texture	Depth (cm)	Texture	Depth (cm)	Texture	Depth (cm)	Texture	Depth (cm)
<i>10 m</i>	SaCL	5 cm	SaCL	19 cm	S	>90 cm	S	62 cm	S	56 cm	CL	85 cm	S	>90 cm
<i>30 m</i>	SaL	6 cm	SaL	26 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	70 cm	S	>90 cm
<i>60 m</i>	SaCL	9 cm	SaL	12 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	60 cm	S	>90 cm
<i>100 m</i>	SaCL	13 cm	SaL	19 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	60 cm	S	>90 cm
<i>175 m</i>													S	>90 cm
<i>200 m</i>	SaCL	19 cm	SaCL	21 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	51 cm		
<i>300 m</i>	SaCL	8 cm	SaCL	11 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	70 cm		
<i>400 m</i>	SaCL	9 cm	SaCL	10 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	70 cm		
<i>500 m</i>	SaCL	17 cm	SaCL	10 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	70 cm		
<i>600 m</i>	SaCL	12 cm	SaL	8 cm	S	>90 cm	S	>90 cm	S	>90 cm	CL	70 cm		
<i>700 m</i>	SaCL	24 cm	SaL	5 cm					S	>90 cm	SaCL	70 cm		
<i>800 m</i>	SaCL	28 cm	SaCL	25 cm					S	>90 cm	CL	70 cm		
<i>900 m</i>	SaCL	13 cm	SaCL	25 cm					S	>90 cm	SaCL	70 cm		
<i>1000 m</i>	SaCL	46 cm	SaCL	36 cm							CL	70 cm		

Texture key: S = sand; Sa = sandy; C = Clay; L = loam

Shaded blocks represent distances not sampled

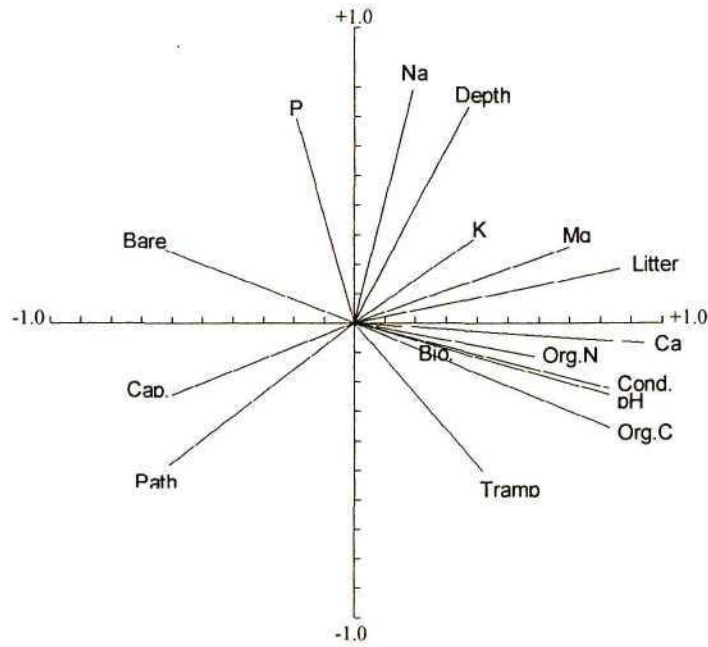


Figure 1. Diagram showing the first and second axes of principal components analysis (PCA) of Nyamsaan for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.387 and second axis: 0.167).

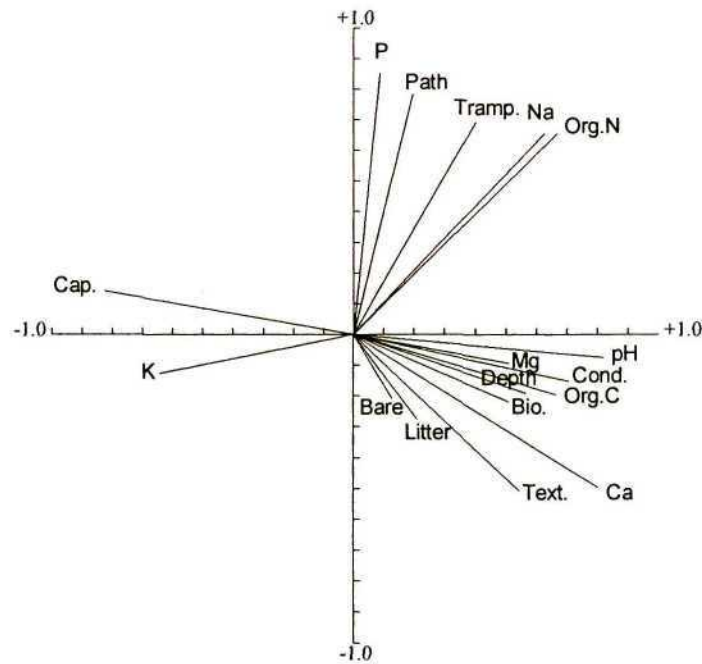


Figure 2. Diagram showing the first and second axes of principal components analysis (PCA) of Bandama for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for first axis: 0.329 and second axis: 0.205).

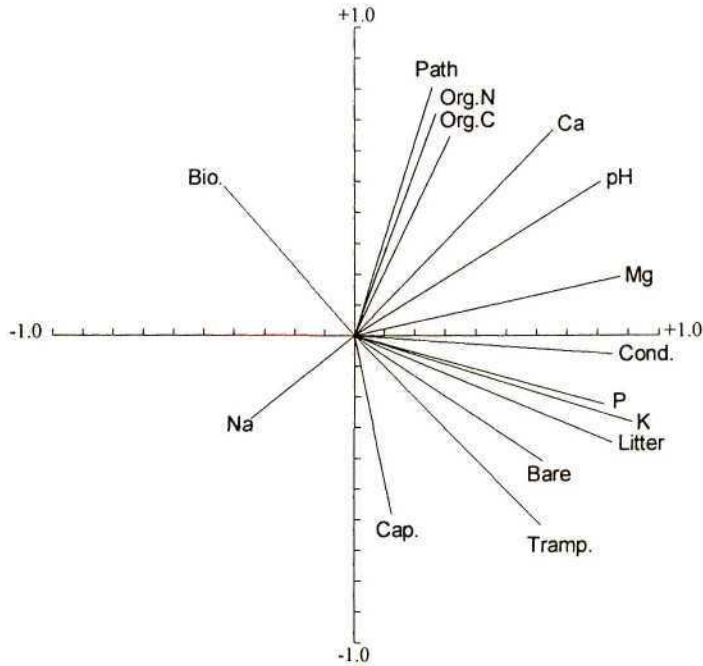


Figure 3. Diagram showing the first and second axes of principal components analysis (PCA) of Chinzwini for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.408 and second axis: 0.251).

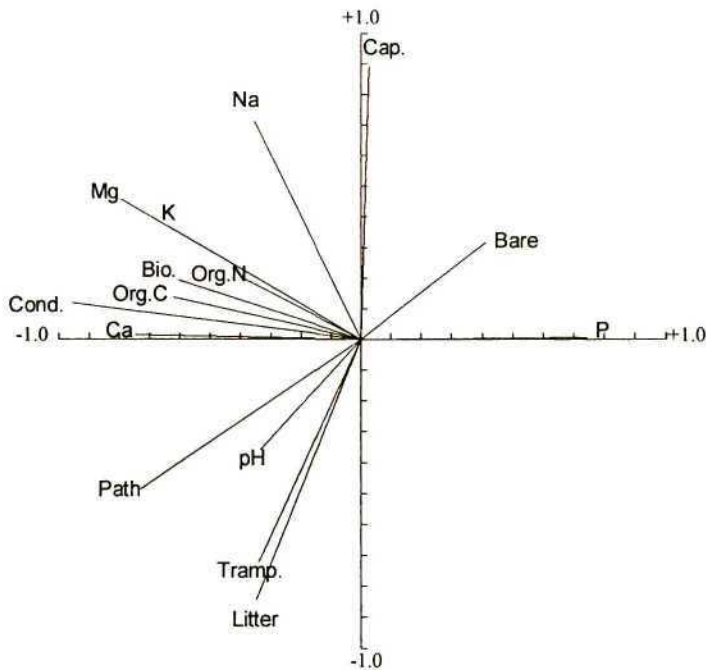


Figure 4. Diagram showing the first and second axes of principal components analysis (PCA) of Lojaan for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.352 and second axis: 0.217).

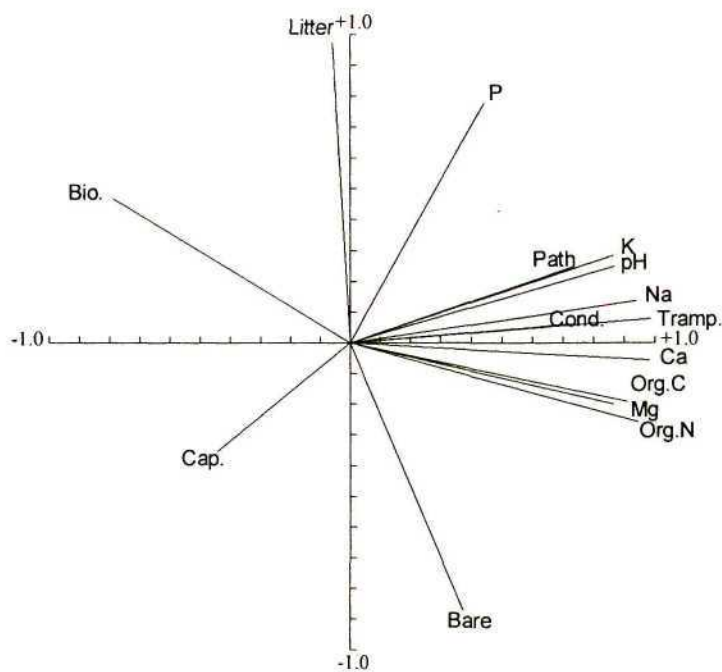


Figure 5. Diagram showing the first and second axes of principal components analysis (PCA) of Chibi Sand for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.601, and second axis: 0.202).

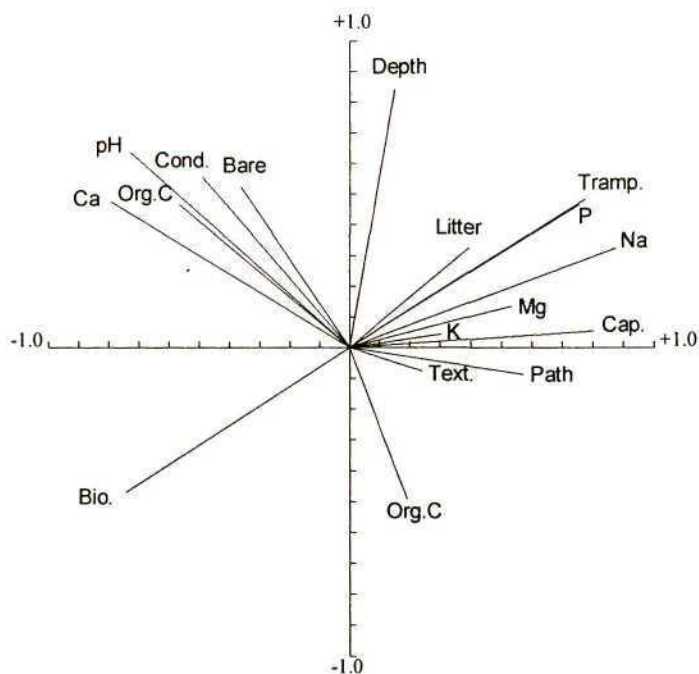


Figure 6. Diagram showing the first and second axes of principal components analysis (PCA) of Chibi Clay for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.50 and the second axis: 0.194).

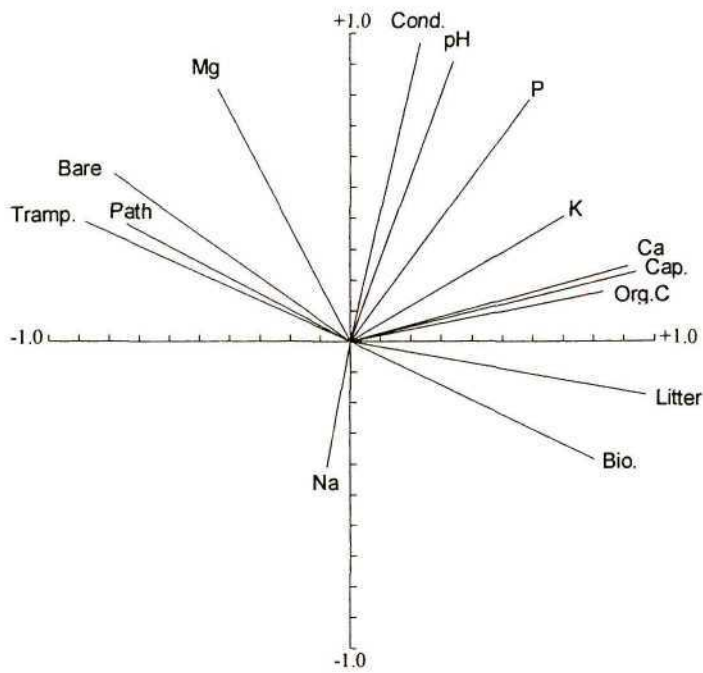


Figure 7. Diagram showing the first and second axes of principal components analysis (PCA) of Manyoka for soil nutrients, surface conditions and herbaceous biomass (Eigenvalues for the first axis: 0.51 and second axis: 0.306).

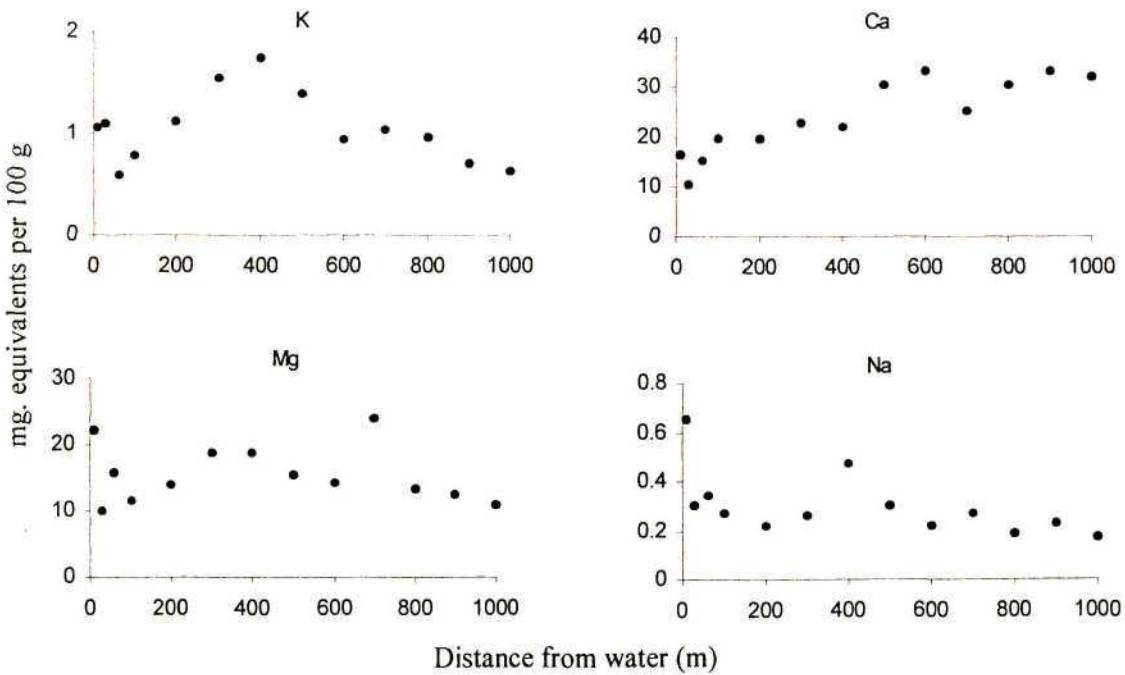


Figure 8. Exchangeable cations: Potassium, calcium, magnesium and sodium with distance from water on a clay-loam soil (Chibi Clay).

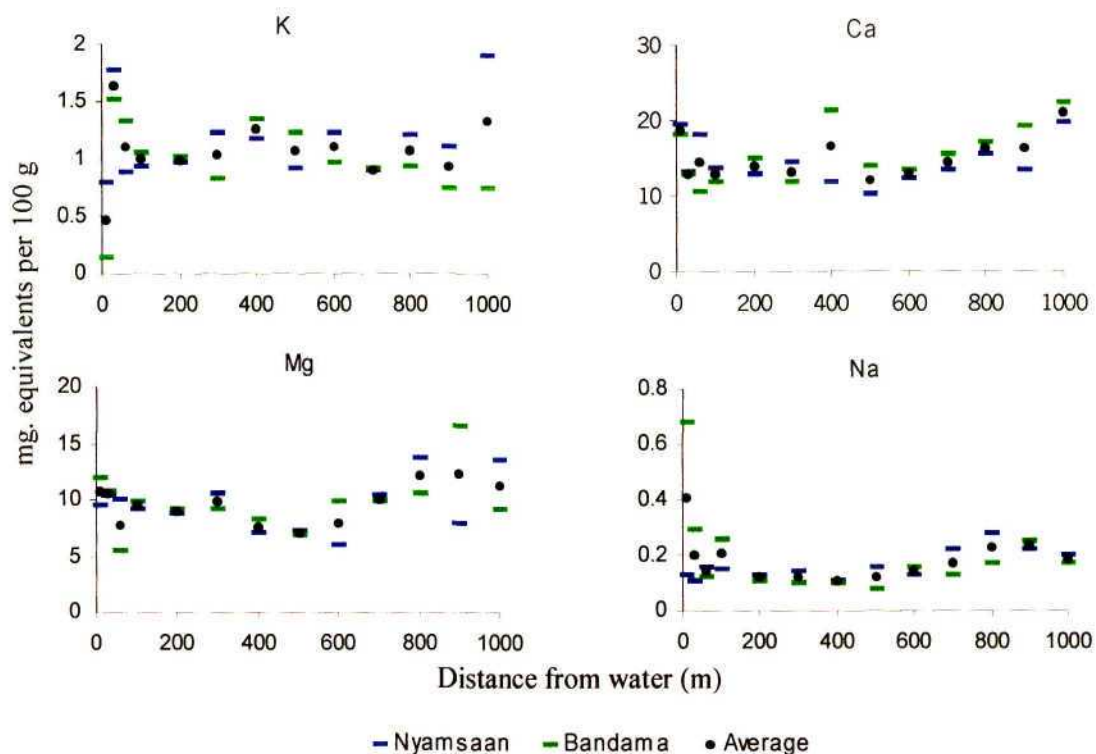


Figure 9. Exchangeable cations: Potassium, calcium, magnesium and sodium with distance from water on sandy-clay-loam soils (Nyamsaan and Bandama).

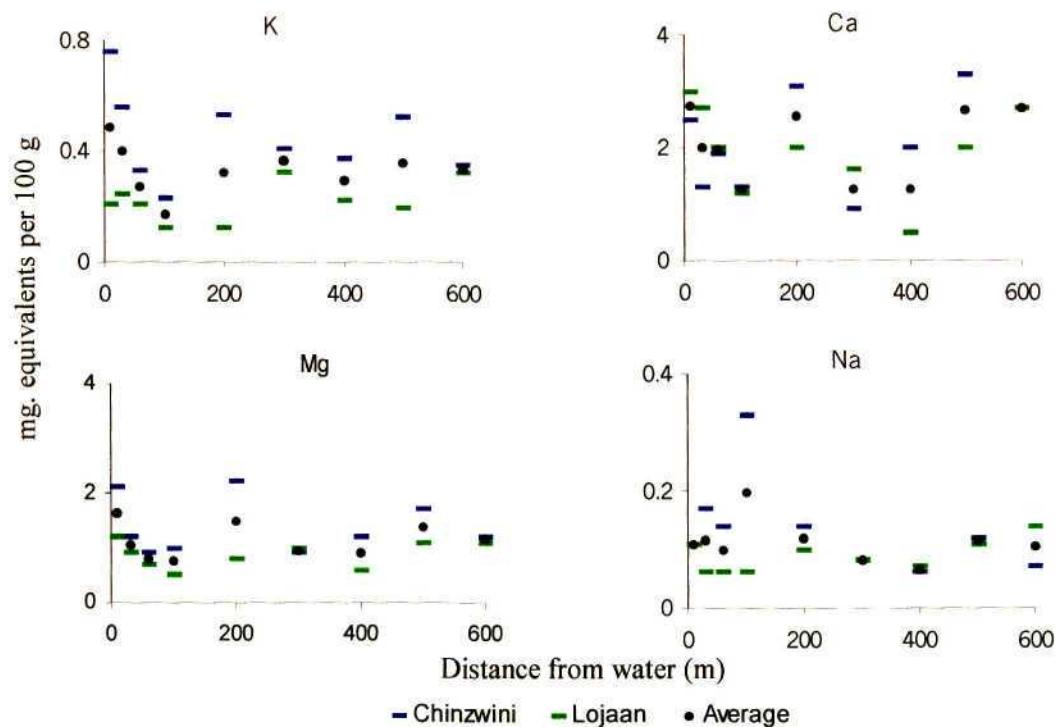


Figure 10. Exchangeable cations: Potassium, calcium, magnesium and sodium with distance from water on sandy Hill soils (Chinzwini and Lojaan).

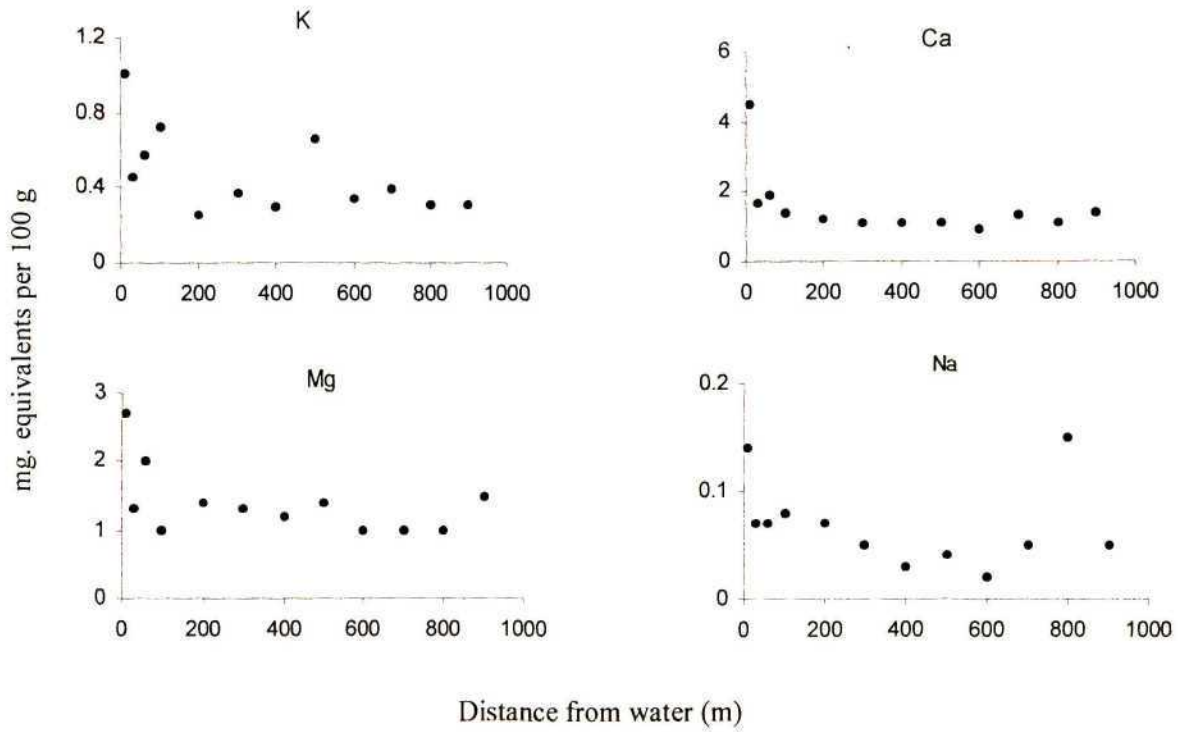


Figure 11. Exchangeable cations: Potassium, calcium, magnesium and sodium with distance from water on a flat sandy soil (Chibi Sand).

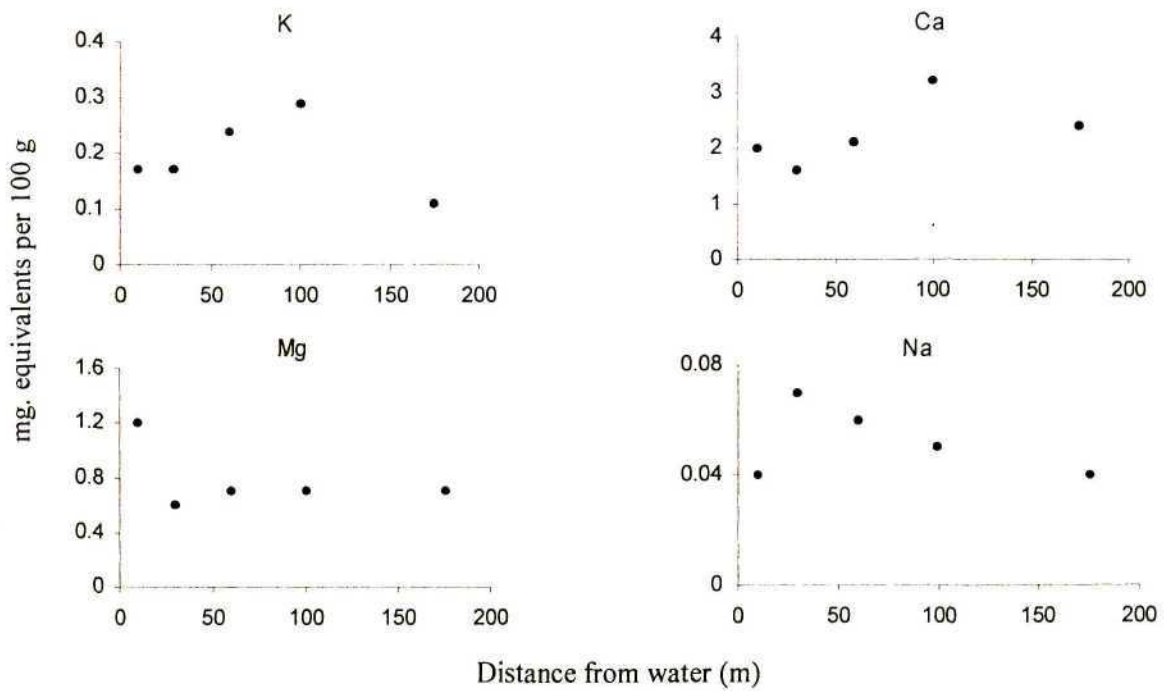


Figure 12. Exchangeable cations: Potassium, calcium, magnesium and sodium with distance from water on a new sandy Hill soil (Manyoka).

Table 2. Soil surface variables: Equations for fitted logistic curves (D = Distance value)

Surface condition variable	Water point / Transect	Equation of fitted curve
Bare soil surface (%)	Mopane	$y=23.98+8.89/(1+e^{(0.007D-4.2)})$
	Hills	$y=17.7+21.77/(1+e^{(0.115D-55.2)})$
	Chibi Clay	$y=2.16+76.04/(1+e^{(-0.005D+9.5)})$
	Chibi Sand	$y=-14.18-0.49/(1+e^{(-0.013D+17.1)})$
	Manyoka	$y=28.13+60.92/(1+e^{(0.347D-10.5)})$
Capping / Crusting (%)	Mopane	$y=31.83-1170/(1+e^{(-0.007D+11.1)})$
	Hills	$y=0.88+3.84/(1+e^{(0.089D-40.3)})$
	Chibi Clay	$y=1.29+467.2/(1+e^{(0.003D+3)})$
	Chibi Sand	$y=-0.08+4.48/(1+e^{(-0.013D+0.1)})$
	Manyoka	$y=0.75-0.75/(1+e^{(0.366D-19.3)})$
Area trampled (%)	Mopane	$y=5.67+1077/(1+e^{(0.004D+4.2)})$
	Hills	$y=14.03+72.3/(1+e^{(0.017D-0.5)})$
	Chibi Clay	$y=1.12+51.6/(1+e^{(0.02D+2.6)})$
	Chibi Sand	$y=6.88+757/(1+e^{(0.012D+2.8)})$
	Manyoka	$y=36.37+62.4/(1+e^{(0.104D-4.1)})$
Surface litter (%)	Mopane	$y=30.92+112.7/(1+e^{(-0.006D-8)})$
	Hills	$y=36.83+1348/(1+e^{(0.012D+40.2)})$
	Chibi Clay	$y=3.41+5.87/(1+e^{(0.005D+2.4)})$
	Chibi Sand	$y=40.26+11.72/(1+e^{(0.052D-7.6)})$
	Manyoka	$y=-9.23+47.52/(1+e^{(0.026D+0.6)})$
Number of paths	Mopane	$y=4.85+7.77/(1+e^{(0.008D-5.5)})$
	Hills	$y=10.11+49.79/(1+e^{(-0.003D-2.7)})$
	Chibi Clay	$y=-150.8+162.2/(1+e^{(0.008D-11)})$
	Chibi Sand	$y=7.66+1137/(1+e^{(0.005D+4.1)})$
	Manyoka	$y=17.83+33.03/(1+e^{(0.115D-6.4)})$

APPENDIX 3. VEGETATION

Table 1. Herbaceous species: First axis species score correlations with distance from water, first axis eigenvalues and logistic (or *exponential) curve equations (D = Distance value)

Water point / transect	Distance : Species score correlation		First axis eigenvalue	Equation of fitted curve
	r ²	P		
Nyamsaan	0.66	0.46	0.46	$y = -12206 + 12238 / (1 + e^{(-0.034D - 3.5)})$
Bandama	0.09	0.31	0.31	No curve fitted
Chinzwini	0.83	0.43	0.43	$y = -10797 + 108861 / (1 + e^{(-0.03D - 3.4)})$
Lojaan	0.59	0.27	0.27	* $y = 86.8 - 295(0.988^D)$
Chibi Clay	0.52	0.32	0.32	$y = -238.6 + 281.1 / (1 + e^{(-0.029D + 2.1)})$
Chibi Sand	0.88	0.46	0.46	$y = -202.4 + 301.3 / (1 + e^{(-0.07D + 2.1)})$
Manyoka	0.65	0.47	0.47	$y = -102.8 + 192.8(1 + e^{(-0.087D + 0.99)})$

Table 2. Shrub species: First axis species score correlations with distance from water, first axis eigenvalues and logistic (or *exponential) curve equations (D = Distance value)

Water point / transect	Distance : Species score correlation		First axis eigenvalue	Equation of fitted curve
	r ²	P		
Nyamsaan	0.34	0.061	0.96	No curve fitted
Bandama	0.58	0.006	0.61	$y = -840 + 876.6 / (1 + e^{(-0.144D + 6.3)})$
Chinzwini	0.91	0.045	0.61	No curve fitted
Lojaan	0.74	0.06	0.63	No curve fitted
Chibi Clay	0.84	0.0001	0.68	* $y = 10.79 - 115.2(0.993^D)$
Chibi Sand	0.09	0.045	0.55	No curve fitted
Manyoka	0.12	0.77	0.75	No curve fitted

Table 3. Tree species: First axis species score correlations with distance from water, first axis eigenvalues and logistic (or *exponential) curve equations (D = Distance value)

Water point / transect	Distance : Species score correlation		First axis eigenvalue	Equation of fitted curve
	r ²	P		
Nyamsaan	0.77	0.0008	0.41	$y = -189.6 + 259.5 / (1 + e^{(-0.071D + 4.9)})$
Bandama	0.72	0.0019	0.79	$y = -1994 + 2024 / (1 + e^{(-0.022D + 1.3)})$
Chinzwini	0.06	0.6406	0.74	No curve fitted
Lojaan	0.76	0.05	0.76	$y = 39 + 351.2 / (1 + e^{(-0.028D + 8.5)})$
Chibi Clay	0.42	0.059	0.59	* $y = 11.9 - 242.1(0.993^D)$
Chibi Sand	0.76	0.0005	0.37	$y = -417.8 + 448.1 / (1 + e^{(-0.087D + 9.4)})$
Manyoka	0.99	0.026	0.1	* $y = -92.9 + 46.97(1.014^D)$

Table 4. Woody species: First axis species score correlations with distance from water, first axis eigenvalues and logistic (or *exponential) curve equations (D = Distance value)

Water point / transect	Distance : Species score correlation		First axis eigenvalue	Equation of fitted curve
	r ²	P		
Nyamsaan	0.86	0.0001	0.43	$y = -3307 + 3404 / (1 + e^{(-0.005D - 3.8)})$
Bandama	0.64	0.002	0.68	$y = -8613 + 8630 / (1 + e^{(-0.024D - 2.8)})$
Chinzwini	0.36	0.211	0.74	No curve fitted
Lojaan	0.79	0.044	0.73	$y = -48.4 + 261.2 / (1 + e^{(-0.027D + 8.4)})$
Chibi Clay	0.55	0.022	0.58	$y = -11808 + 11827 / (1 + e^{(-0.005D + 3.6)})$
Chibi Sand	0.47	0.029	0.43	$y = -4.04 + 3026 / (1 + e^{(-0.008D + 2.9)})$
Manyoka	0.99	0.044	0.1	* $y = -131.2 + 82.66(1.01^D)$

APPENDIX 4. LARGE HERBIVORE DISTRIBUTIONS

Table 1. Seasonal spatial distribution of large herbivores at MCT

<i>Feeding group</i>	<i>Distance from water</i>	<i>Biomass carried:</i>	
		<i>*Wet season (A.U./ha)</i>	<i>*Dry season (A.U./ha)</i>
Grazers	0 – 1 km	0.001985	0.068207
	1 – 2 km	0.001737	0.029110
	2 – 3 km	0.026364	0.045921
	> 3 km	0.002257	0.052309
Browsers	0 – 1 km	0.001466	0.029428
	1 – 2 km	0.000411	0.018885
	2 – 3 km	0.001733	0.027207
	> 3 km	0	0.041325
Mixed feeders	0 – 1 km	0.002168	0.056580
	1 – 2 km	0.000828	0.022803
	2 – 3 km	0.000680	0.005283
	> 3 km	0.002551	0.009703
All feeding groups	0 – 1 km	0.005619	0.147342
	1 – 2 km	0.002976	0.070798
	2 – 3 km	0.028776	0.078411
	> 3 km	0.004808	0.080984

*Details on area size for each distance from water zone and animal unit (A.U.) equivalents, may be found in Appendix 4, Table 2.

Table 2. Dry season spatial distribution of large herbivores at MCT

<i>Species</i>	<i>Distance from water</i>	<i>Number of individuals</i>	<i>Area of zone (ha)</i>	<i>Number of individuals/ha</i>	<i>*A.U. equivalents</i>	<i>A.U./ha</i>
Buffalo	0 – 1 km	264	8185.2	0.032253	1.01	0.031934
	1 – 2 km	176	16445.7	0.010702	1.01	0.010596
	2 – 3 km	246	10071.7	0.024425	1.01	0.024183
	> 3 km	150	4671.6	0.032109	1.01	0.031791
Bushbuck	0 – 1 km	38	8185.2	0.004643	7.5	0.000619
	1 – 2 km	15	16445.7	0.000912	7.5	0.000122
	2 – 3 km	0	10071.7	0	7.5	0
	> 3 km	0	4671.6	0	7.5	0
Duiker	0 – 1 km	4	8185.2	0.000489	Unknown	
	1 – 2 km	11	16445.7	0.000669	Unknown	
	2 – 3 km	4	10071.7	0.000397	Unknown	
	> 3 km	0	4671.6	0.000214	Unknown	
Hippo	0 – 1 km	30	8185.2	0.003665	0.53	0.006915
	1 – 2 km	0	16445.7	0	0.53	0
	2 – 3 km	0	10071.7	0	0.53	0
	> 3 km	0	4671.6	0	0.53	0
Eland	0 – 1 km	111	8185.2	0.013561	1.25	0.010849
	1 – 2 km	184	16445.7	0.011188	1.25	0.008951
	2 – 3 km	171	10071.7	0.016978	1.25	0.013583
	> 3 km	87	4671.6	0.018623	1.25	0.014899
Elephant	0 – 1 km	87	8185.2	0.010629	0.36	0.029525
	1 – 2 km	59	16445.7	0.003588	0.36	0.009965
	2 – 3 km	13	10071.7	0.001291	0.36	0.003585
	> 3 km	9	4671.6	0.001927	0.36	0.005352

<i>Species</i>	<i>Distance from water</i>	<i>Number of individuals</i>	<i>Area of zone (ha)</i>	<i>Number of individuals/ha</i>	<i>A.U. equivalents</i>	<i>A.U./ha</i>
Giraffe	0 – 1 km	38	8185.2	0.004643	0.69	0.006728
	1 – 2 km	66	16445.7	0.004013	0.69	0.005816
	2 – 3 km	51	10071.7	0.005064	0.69	0.007339
	> 3 km	81	4671.6	0.017341	0.69	0.025132
Impala	0 – 1 km	1373	8185.2	0.167742	6.2	0.027055
	1 – 2 km	1309	16445.7	0.079595	6.2	0.012838
	2 – 3 km	106	10071.7	0.010525	6.2	0.001698
	> 3 km	126	4671.6	0.026975	6.2	0.004351
Kudu	0 – 1 km	228	8185.2	0.027855	2.48	0.011232
	1 – 2 km	163	16445.7	0.009911	2.48	0.003997
	2 – 3 km	157	10071.7	0.015588	2.48	0.006286
	> 3 km	15	4671.6	0.003211	2.48	0.001295
Sable	0 – 1 km	55	8185.2	0.006719	1.97	0.003411
	1 – 2 km	44	16445.7	0.002675	1.97	0.001358
	2 – 3 km	32	10071.7	0.003177	1.97	0.001613
	> 3 km	31	4671.6	0.006636	1.97	0.003368
Waterbuck	0 – 1 km	24	8185.2	0.002932	2.19	0.001339
	1 – 2 km	33	16445.7	0.002007	2.19	0.000916
	2 – 3 km	10	10071.7	0.000993	2.19	0.000453
	> 3 km	4	4671.6	0.000856	2.19	0.000391
Warthog	0 – 1 km	84	8185.2	0.010262	5.68	0.001807
	1 – 2 km	51	16445.7	0.003101	5.68	0.000546
	2 – 3 km	0	10071.7	0	5.68	0
	> 3 km	2	4671.6	0.000428	5.68	7.5E05

<i>Species</i>	<i>Distance from water</i>	<i>Number of individuals</i>	<i>Area of zone (ha)</i>	<i>Number of individuals/ha</i>	<i>A.U. equivalents</i>	<i>A.U./ha</i>
Wildebeest	0 – 1 km	160	8185.2	0.019547	2.14	0.009134
	1 – 2 km	114	16445.7	0.006932	2.14	0.003239
	2 – 3 km	87	10071.7	0.008638	2.14	0.004036
	> 3 km	39	4671.6	0.008348	2.14	0.003901
White rhino	0 – 1 km	2	8185.2	0.000244	0.41	0.000596
	1 – 2 km	13	16445.7	0.00079	0.41	0.001928
	2 – 3 km	11	10071.7	0.001092	0.41	0.002664
	> 3 km	2	4671.6	0.000428	0.41	0.001044
Zebra	0 – 1 km	199	8185.2	0.024312	1.86	0.013071
	1 – 2 km	322	16445.7	0.01958	1.86	0.010527
	2 – 3 km	243	10071.7	0.024127	1.86	0.012972
	> 3 km	102	4671.6	0.021834	1.86	0.011739

*Animal unit (A.U.) equivalents taken from Collinson and Goodman 1982.