IMPACTS OF LARGE HERBIVORES ON VEGETATION AND SOILS AROUND WATER POINTS IN WATERBERG PLATEAU PARK, CENTRAL NAMIBIA

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ABSTRACT

Provision of artificial water points to large herbivores leads to range deterioration and degradation, especially in semi-arid and arid ecosystems. This is a cause for concern in both protected and private lands in Namibia and elsewhere. Therefore, the objective of this study was to determine the impact of large herbivores on soils and vegetation around water points in the Waterberg Plateau Park (WPP). Five artificial water points were selected for the study. Four line-transects starting as close as possible to, and radiating away from the water points were surveyed at each water point, and five 20 m x 20 m plots at distances 0 m, 100 m, 200 m, 300 m and 500 m from the water, on each transect were used for sampling trees and soils. The nested plot design was used for sampling: 1 m x 1 m plots in which grasses and forbs were sampled, were nested within 5 m x 5 m plots used for sampling shrubs and saplings, which were nested within the 20 m x 20 m plots. All trees were identified, counted and their heights as well as basal circumferences were measured. All shrubs and saplings were identified, counted and their heights measured. Woody vegetation cover was estimated using the line-intercept method. Forbs and grasses were identified and their total cover was visually estimated. Forbs were also counted. Density was presented as individual trees, shrubs and saplings, and forbs per 400 m^2, 25 m^2 and 1 m^2, respectively. Basal area was calculated with the assumption that all stems were circular, using the formula: $BA= c^2/ (4*\pi)$. Plant species diversity was calculated for each plot using the Shannon-Wienner diversity index. The results indicated significantly lower plant densities, cover, basal areas, diversity and richness close to water points, than further away from the water points. These were a result of high degradation by large herbivores through trampling and over-utilization of vegetation around water points. To determine basal area and height distributions, the basal area and height values at the different distances from the water points were arranged into classes. Height class and basal area class distributions generally portrayed a similar trend, with a high proportion of shrubs and saplings corresponding to a high proportion of plants with smaller basal areas. Stunting of woody vegetation through browsing and a reduction in fire frequencies and intensities through controlled burning may have contributed to the establishment and therefore the high frequency of small, short woody plants at the four distances further away from the water points. The HCA classified the vegetation plots into 10 main clusters based on species presence/absence data. The DCA indicated a complex interaction of gradients which influenced the patterns in species composition. The CCA indicated that soil phosphorus, CEC and clay accounted for significant variation in species composition. Phosphorus has been introduced into the soils by large herbivores through dung and urine, while clay content was lower due to the removal of vegetation around the water points by large herbivores. It was concluded that trampling and over-utilization of vegetation by large herbivores negatively influence vegetation structure, composition and diversity around water points in the WPP.

Key words: Degradation, herbivory, large herbivores, Waterberg Plateau Park, water point, species composition, trampling.

DEDICATION

This thesis is dedicated to a generous, hardworking and loving young man; my uncle Justus Uamanovandu Mukaru. He left this world without warning on the 25th of February 2008, at a point where he was just starting to reap the benefits of his hard work. "I went through this year with a lot of questions, some of which are still unanswered, but I held on to the belief that you left us because it was your time to go and God carried me through, just as He will our entire family. Rest in eternal peace my dearest, beloved uncle."

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DECLARATION

I, Wellencia Clara Mukaru, declare hereby that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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ACRONYMS

CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
DCA	Detrended Correspondence Analysis
GPS	Global positioning system
HCA	Hierarchical Cluster Analysis
KNP	Kruger National Park
LNP	Limpopo National Park
OM	Organic matter
SWRA	Sengwa Wildlife Research Area
WPP	Waterberg Plateau Park

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

African savannas have an evolutionary history of high levels of grazing and browsing (de Klerk, 2004). This high level of herbivory significantly modifies vegetation structure and composition, reducing the growth and reproduction of individual plants, and influencing competitive outcomes and community composition (de Klerk, 2004). In the savanna biome, reduced competition from grass communities in overgrazed areas inevitably leads to an increase in the density of the woody species (Tainton, 1999). In most cases these changes are irreversible because of the effect on the grasses of the woody species, which compete strongly for moisture (Tainton, 1999). However, according Walter (1971), there is a co-existence of trees and grasses in savannas, as a result of a partitioning of soil moisture. He hypothesized that grasses are superior competitors for water in the upper soil, while trees have exclusive access at deeper layers (Walter 1971).

According to Meyer and Casey (2002), water is essential for the survival of plants and animals, both of which have developed mechanisms for dealing with their specific water requirements according to the demands of their environments. Water-related stress occurs when an organism is exposed to either a deficient or an overabundance of water relative to its ecological requirements (Meyer and Casey, 2002).

Large herbivores are plant-eating animals weighing more than 5 kg (Karanth and Sunquist, 1992; Du Toit and Cumming, 1999). Like most living organisms, most large herbivores are dependent on water. According to Danell (2006), large herbivores adapt to seasonality in a variety of ways: breeding is timed so that calving is concentrated in the optimal period for offspring survival, growth is restricted to periods of summer food abundance, and herds may be highly migratory.

In arid and semi- arid National parks and Game reserves, where there is a scarcity of water, animals are provided with perennial water as a management practice **(**Parker and Witkowski, 1999**;** Thrash, 1998). These artificial watering points may lead to large herbivores, some of which would normally migrate in search of water during dry periods, becoming sedentary. The result of that is a year-round grazing and browsing of rangeland with an increase in utilization pressure around water points (Brits *et al*., 2002).

The number and spacing of artificial sources of water across the arid and semi-arid zones fundamentally alters the character of the landscape (James *et al.*, 1999). Native wild animal species that rely on drinking water, or water as a habitat for part of their life cycle are able to persist in areas that were previously not habitable most of the time, resulting in larger and more widespread populations of these species than would otherwise be possible (James *et al.*, 1999). In a number of cases, the increase in abundance of a species may have significant negative effects on other species (James *et al.*, 1999).

Apart from these specific direct effects, the establishment of artificial water points also maintains high levels of herbivory and trampling pressure around water points. Plants and animals that are not directly affected by the presence of water are often affected by the presence of large numbers of grazing and browsing animals and the results of their activities around water points (James *et al.*, 1999). Herbivores are generally thought to enhance plant diversity by their direct consumption of competitively dominant plant species and indirect effects on plant competition (Olff and Ritchie, 1998). Consequently, management of herbivores has become a crucial component in efforts to restore or maintain biodiversity (Olff and Ritchie, 1998). However, herbivores may sometimes have weak or even negative effects on plant diversity (Olff and Ritchie, 1998), depending on the relative abundance of browsers and grazers as well as selectivity of foraging by different herbivores (Augustine and McNaughton, 1993).

According to Peterson *et al*. (2004), a strong correlation exists between vegetation composition and soil properties. For example, in systems where water and nutrients are limiting plant growth, as is the case in most semi-arid regions, plant growth is expected to decline with water run-off and loss of soil nutrients (van de Koppel *et al.*, 1997). Therefore it would be useful if herbivore-mediated changes were detected in soils before they are expressed in the vegetation.

According to the Waterberg Plateau Park Research Strategy and Monitoring Guidelines, the "Utilization of plant material by the large herbivore fauna is relatively poorly understood, and requires applied research" (MET, 1986). At the

Waterberg Plateau Park, large herbivores are confined to the plateau, where all the artificial watering points are situated, and their numbers are only manipulated through translocation and introduction (Erckie, 2007). This study will hopefully be one of the first to bring better understanding on the relationship between large herbivores, vegetation and soils in the Waterberg Plateau Park.

1.2 Statement of problem

Uneven use of rangelands by herbivores has been, and continues to be a major problem confronting range resource managers (Mphinyane, 2001). Due to the aggregation of large herbivores around water points, especially during dry seasons, large herbivores may particularly pose a great threat to the vegetation around water points through the year-round herbivory and trampling, and changes in soil physical and chemical properties.

The abovementioned impacts will in turn lead to a disappearance of some plant species and maybe a colonization of new plant species that are tolerant of the disturbance caused by large herbivores, changing the plant species composition, structure and diversity. Such changes can make the ecosystem vulnerable to perturbation and therefore may lead to a change of the entire ecosystem, resulting in a permanent loss or change of the biological diversity of the area. Consequently, this leads to changes in vegetation community patterns and ecosystem functioning (Mysterud, 2006).

Most of the animals in the Waterberg Plateau Park are large herbivores, mostly grazers. It is therefore important to monitor changes in the ecosystem as a result of large herbivore activities in order to determine degradation in the range condition at an early stage.

1.3 Objectives, questions and hypotheses

The overall objective of this study was to determine the impacts of large herbivores on vegetation and soils around water points in the Waterberg Plateau Park, central Namibia.

The specific objectives were to determine:

(a) The impact of large herbivores on plant species composition around water points in Waterberg Plateau Park.

(b) The impact of large herbivores on plant species diversity around water points in Waterberg Plateau Park.

(c) The impact of large herbivores on vegetation structure around water points in Waterberg Plateau Park

(d) The effect of large herbivores on soil physical and chemical properties around water points in Waterberg Plateau Park.

(e) Changes in range condition resulting from impacts of large herbivores around water points in Waterberg Plateau Park.

The study sought to answer the following questions:

(a) What is the effect of large herbivores on plant species composition around water points in Waterberg Plateau Park?

(b) What is the effect of large herbivores on plant species diversity around water points in Waterberg Plateau Park?

(c) What is the effect of large herbivores on vegetation structure around water points in Waterberg Plateau Park?

(d) How do large herbivores impact on soil physical and chemical properties around water points in Waterberg Plateau Park?

(e) How do large herbivores impact on range condition around water points in Waterberg Plateau Park?

The working hypotheses for the study were:

(a) There will be a difference in plant species composition among the five different distances from the water points, with the greatest difference being expected between the plots closest to the water points and those furthest away, as some plant species may disappear from around the water points due to the high levels of herbivory, trampling and changes in soil properties by large herbivores. These species may be replaced by different species, changing the plant species composition.

(b) There will be a decrease in plant species diversity around water points, because species sensitive to the increased disturbance by large herbivores will disappear from the areas and/or be reduced in abundance. This will result in a decrease in species richness and an increase in the abundance of the tolerant species, the latter resulting in lower evenness of plant species around the water points.

(c) The vegetation structural attributes (cover, density, height and basal area) will differ significantly with distance from the water points, with higher values expected at the furthest distance from the water points.

(d) There will be differences in soil physical and chemical properties with distance from the water points, because large herbivores introduce nutrients such as Phosphorus and Nitrogen to the soil, in the form of dung and urine. High levels of these nutrients are expected around water points.

(e) The condition of the range is expected to be poor around water points, with increaser and/ or invader grasses dominating, due to the heavy grazing and trampling.

CHAPTER 2

LITERATURE REVIEW

2.1 Effects of disturbance by large herbivores on vegetation

Herbivores can have a wide variety of profound impacts on ecosystems, including effects on the physical environment as well as on the plant community (Ford and Grace, 1998). Physical effects on the ecosystem include more sunlight reaching the soil surface due to a reduction in vegetation cover, with resultant increases in soil temperature, as well as increased decomposition, increased evaporation and soil salinity and altered soil structure (Ford and Grace, 1998). Herbivores can also impact their habitats by altering plant communities, enhancing nutrient cycling and altering net primary production (Ford and Grace, 1998). Reductions have been reported in canopy height and architecture, as well as in litter production and root growth, root respiration and nutrient uptake have all been observed to decrease (Ford and Grace, 1998).

Large herbivores affect vegetation community patterns and ecosystem functioning through processes such as grazing, browsing, trampling, defecation and urination (Mysterud, 2006). According to Augustine (1993), the impact of herbivory on plant communities depends on the relative abundance of browsers and grazers as well as the selectivity of foraging by any given herbivore.

Although large herbivores mostly prefer plants with a high content of nutrients and a low level of structural and chemical defenses (Mysterud, 2006), they can tolerate plants with low nutrients in the absence of vegetation with high nutrient content.
The effects of herbivores on plant species richness appear to depend on the type and abundance of herbivore species in a particular environment (Olff and Ritchie, 1998). Herbivory may increase or decrease plant species richness, depending on grazing or browsing intensity and nutrient availability (Mysterud, 2006). For example, natural populations of large grazing mammals were reported to increase plant diversity in grassland plant communities (Olff and Ritchie, 1998). The same was found when domesticated large grazers are managed at low stocking rates on productive grasslands, but high stocking rates can decrease diversity (Olff and Ritchie, 1998).

Edkins, *et al*. (2008), surveyed baobab size class distributions in the Limpopo National Park (LNP), Mozambique, and the Kruger National Park (KNP), South Africa. They found that the baobab population in the LNP, which had few elephants, had a reversed J-shaped size class distribution with many small baobabs. The many elephants in the KNP impacted the baobab population in such a way that it displayed a monomodal size-class distribution, with lack of recruitment.

Large herbivores also cause physical damage to plants (Heilmann *et al.*, 2006), by cutting, bruising and breaking them and sometimes dislodging or uprooting whole plants, particularly among plants whose leaves have high tensile strength (Owen-Smith, 1999). In a study on the impacts of black rhinoceros on *Euphorbia* trees in the Great Fish River Reserve, South Africa, Heilmann *et al.* (2006), found that black rhinos pushed over about 5- 7 % of the trees in a two-month period. Elephants in the Tarangire National Park, northern Tanzania, caused a significant decrease in many large trees, causing concern in protected areas, as large trees provide food and shelter for a variety of other animals such as birds and insects and are of high aesthetic value (Van de Vijver *et al.*, 1999).

As mentioned above, the effects of large herbivores on vegetation are not always negative. Miller (1994) investigated the interactions of large African herbivores and bruchid seed beetles with *Acacia* seeds, in which he compared the germination of bruchid-infested and un-infested seeds. He also assessed the effects of pod consumption by large herbivores on bruchid infestation and seed germination. According to Miller (1994) pod ingestion by large herbivores lowered the bruchid infestation of consumed and defecated seeds compared to un-ingested seeds. Un-infested, ingested and voided *Acacia tortilis* seeds germinated significantly better than un-infested, un-ingested seeds (Miller, 1994). Furthermore, infested *A. tortilis* seeds egested by giraffe, kudu and ostrich germinated better than infested, un-ingested seeds (Miller, 1994). It was therefore concluded that pod ingestion by large herbivores may reduce bruchid infestation, increase *Acacia* seed germination and therefore increase potential *Acacia* seedling recruitment (Miller, 1994).

In a survey made to ascertain the effect of herbivores (particularly elephants) on plant succession and the availability of browse in Lake Manyara National Park, Tanzania, found that on average about 50 % of the available browse was unused (Vesey-Fitzgerald, 1973). In all cases, young growth was favoured and, although browsing modified the structure of shrubs, the off-take was replaceable by growth (Vesey-Fitzgerald, 1973). It was also concluded that the herbivore impact on the plants and on the course of succession is not irrevocably detrimental and that occupancy by herbivores keeps the fire hazard low (Vesey-Fitzgerald, 1973).

2.2 Soil disturbance by animals

A large body of literature exists relating vegetation shifts in semi-arid grasslands to soil degradation (van de Koppel *et al*., 1997). Vegetation improves the structure and water-holding capacity of the soil preventing crust formation through the interception of raindrops (van de Koppel *et al*., 1997; Thrash, 1997). When the intensity of a rain shower exceeds the maximum infiltration rate of the soil, run-off occurs (Thrash, 1997). This run-off eventually causes accelerated soil erosion and flooding. The moisture content of the soil is also adversely affected and thus also the production of herbage (Thrash, 1997).

Vegetation protects the soil against erosion by physical binding of soil, and the retention of surface water (van de Koppel *et al*., 1997). Soil degradation occurs if plant standing crop is insufficient to prevent surface run-off of rainwater (van de Koppel *et al*., 1997). As a consequence, the proportion of the rainfall that infiltrates into the soil decreases (van de Koppel *et al*., 1997). Furthermore, run-off of water often leads to loss of nutrients via soil erosion (van de Koppel *et al*., 1997). Both run-off and soil erosion increase when vegetation cover decreases (van de Koppel *et al*., 1997). In systems in which water or nutrients are limiting plant growth, as in most semi-arid regions, plant growth is expected to decline when run-off and loss of nutrients occur (van de Koppel *et al*., 1997; Thrash, 1997).

According to Owen-Smith (1999) animals may alter the structure of the soils by loosening the soil surface or they may deform or compact the soil, depending on the type of soil and its moisture content. Clayey soils are more easily capped by large herbivore trampling than sandy soils (Thrash, 2000). Without disturbance, the soil surface may seal off and, in at least some soils, animal hooves may break up this seal, particularly when soils are dry, promoting infiltration (Owen-Smith, 1999). The loosening of soil may, however, also lead to increased soil loss associated with either wind or water erosion (Owen-Smith, 1999). When soils are relatively wet there is a tendency for trampling to compact rather than loosen its surface, particularly where their clay content is high (Owen-Smith, 1999). This compaction causes a loss of soil structure, increased bulk density and reduced pore space, which in turn will result in reduced infiltration, aeration and water holding capacity, making the general conditions less favourable for plant growth (Owen-Smith, 1999). Grazing, trampling, and dung deposition by large herbivores often result in a zone of decreasing impact on many vegetation and soil parameters, including herbaceous vegetation basal cover and soil bulk density and penetrability, away from watering points (Thrash, 1997). It is therefore reasonable to assume that excessive trampling resulting from high grazing and browsing pressures will have a detrimental long-term effects on the vegetation, as is readily apparent around water points (Owen-Smith, 1999).

2.3 Effect of providing perennial water to animals

According to Todd (2006), relatively few studies have assessed the impacts of positioning of watering points to large herbivores on plant species richness and community structure. No consistent relationship between herbaceous species diversity and distance from water points was found in the Kruger National Park (Todd, 2006). In the Mojave Desert, species richness of native plants was lower near watering points while richness of alien species was higher (Todd, 2006). In south Australia, watering points had a predominantly negative effect on species abundance at a regional scale whereas localized trends tended to be more positive (Todd, 2006).

Some animals depend on free water, while others are less dependent on it (Du Toit, 2002). As a general guideline, grazers are considered to be water-dependent animals and browsers water-independent animals (Du Toit, 2002). Grazing impact, therefore is greatest close to a watering point and decreases with distance from the water for two reasons; because the area available to graze increases with distance from the water point resulting in a reduction in density of grazers and that large grazing herbivores have to drink regularly, so they are limited in how far they can travel from water (James *et al*., 1999). As well as grazing effects, there are also effects from trampling and dust associated with the movement of animals close to the watering point (James *et al*., 1999).

Most African herbivores, especially in semi-arid and arid countries, have adapted to the seasonal availability of water by highly irregular and unpredictable migration between forage resources (Brits *et al*., 2002). During the dry seasons when there is no rainfall, water may dry up and during that time animals become thirsty and must migrate to where there is water and food, as the grass also becomes dry and hard (Kurtz and Kurtz, 2002). When rain returns the grass returns to its green colour and the water points fill up, becoming bigger and deeper and the migratory species then return to the water point (Kurtz and Kurtz, 2002).

Artificial watering points cause indigenous large herbivores to become sedentary and results in year-round grazing and browsing of rangelands with an increase in utilization pressure (Brits *et al.*, 2002). Therefore, the type of herbivory found in National parks especially around water points in present-day may be compared to grazing practices in communal land (Peterson *et al.*, 2004). According to Peterson *et al.* (2004), grazing practices in communal land are heavy and continuous throughout the year, as opposed to moderate and rotational grazing practices on privately managed rangelands.

The main reason for the establishment of large numbers of artificial sources of water in arid zones around the world has been for watering domestic stock and native wildlife (James, *et al*., 1999). Hence, the most obvious effects of artificial sources of water are those associated with grazing and trampling by large herbivorous mammals (James, *et al*., 1999). According to Parker and Witkowski (1999) and Brits *et al.* (2002), the year round grazing and browsing around water points results in a zonation of the vegetation: the area immediately around a watering point is often degraded because trampling and herbivory by animals returning regularly to water inevitably leads to pulverization of the soil surface and accumulation of dung and urine (James, *et al.*, 1999). This forms a distinct zone from the edge of the water points where mostly annual, pioneer plants survive, is observable (Parker and Witkowski, 1999), a zone which is often referred to in literature as the "sacrifice" area. This area can be bare during dry periods but supports short-lived, often unpalatable, trample-resistant 'increaser' species after rain (James, *et al.*, 1999).

A transitional zone in which the proportion of perennial plants increases fairly rapidly with increasing distance from water lies beyond the sacrifice area (Parker and Witkowski, 1999). Palatable perennial plants decline in abundance and species richness within the above-mentioned zone, because these plant species that are palatable to herbivores produce fewer seeds and surviving siblings in rangelands with high levels of herbivory (Milton *et al.*, 1994). In the Kruger National Park, grazing and browsing impacts on certain vegetation parameters only taper-off and become negligible at some point beyond 8 km from water (Brits *et al.*, 2002).

Water points play an important role in regulating animal behaviour and they influence the functioning of ecosystems (Du Toit and Ebedes, 2002). The number and location of water points may control animal populations to some degree, but the opposite is also true (Du Toit and Ebedes, 2002). Most conflicts between different species and between members of the same species occur when water points, water supplies or drinking space are limited (Du Toit and Ebedes, 2002).

2.4 Placement of water points

The distance from water that herbivores will travel to feed is a balance between water demands driven by temperature, physiology and body condition, and the availability of forage (James, *et al*., 1999). The incorrect location or placement of water points can result in either over- or under-utilization of grazing areas (Du Toit and Ebedes, 2002). This may lead to management problems such as soil erosion and bush encroachment. Another problem is a species-specific effect that could lead to undesirable ecological results (Du Toit and Ebedes, 2002). For example, when new water points were opened up in parts of the prime roan antelope habitat in the Kruger National Park, it also opened up those areas to large herds of plains ungulates like the zebra and blue wildebeest (Du Toit and Ebedes, 2002). Roan antelope are shy animals and will not drink in the presence of other animals. In this case, the new water point probably contributed to a decline in the roan antelope population (Du Toit and Ebedes, 2002). Closing such water points therefore yields better ecological results than establishing them (Du Toit and Ebedes, 2002).

Water-dependent indigenous large herbivores are compelled to forage within one-and half day's walk from permanent water supplies in the dry season (Thrash, 2000). Areas, which are further from permanent water than water-dependent indigenous large herbivores are able to move, are utilized hardly at all during the dry season (Thrash, 2000). Mobile water-dependent indigenous large herbivores are readily able to forage up to 10 km from water. However, when watering points are provided in unnaturally high densities the rotation of utilization pressure between wet season and dry season grazing areas ceases to occur and habitat diversity is reduced (Thrash, 2000).

According to Thrash (2000), once the density of watering points exceeds that at which all areas are within reach of mobile water-dependent indigenous large herbivores, additional watering points are unlikely to have an important effect on the rangeland condition. The impact of such additional watering points is rather that of greater trampling in the immediate vicinity of watering points when game paths converge and when herd animals mill around waiting to drink. Stocking rate, rainfall in the previous rainfall season and distance to the nearest other permanent watering point become important determinants of the extent of impact on rangeland condition (Thrash, 2000). In his study, nowhere did Thrash (2000) find the extent of impact on rangeland condition to exceed 200 m. He concluded that the effect of watering points on rangeland condition is of little importance relative to that of rainfall and the stocking rate of the property.

Of great importance for the wildlife manager is the effect of distance from the nearest other watering point on the extent of indigenous large herbivore impact around watering points (Thrash, 2000). The number and distribution (distance between adjacent water points) of artificial watering points determine this parameter and should therefore be considered as to limit over- and under-utilization of rangelands (Du toit and Van Rooyen, 2002; Thrash, 2000). While Thrash (2000), suggested that the positive effect of distance from the nearest other watering point on the extent of impact on rangeland condition at watering points indicates that isolated watering points have a greater effect than do clustered watering points, Du toit and Van Rooyen (2002), argues that water points that are too far apart may result in gaps of unutilized rangeland, whereas water points that are too close to each other may cause severe over utilization and trampling of the rangeland.

The movement patterns of animals lead to excessive range utilization in a given area defined by the maximum critical distance that a given animal species will move away from the nearest water (Du toit and Van Rooyen, 2002). According to Thrash, (2000), indigenous large herbivores are able to travel relatively long distances between foraging areas and watering points, and therefore a water provision system where groups of clustered watering points are separated by large waterless areas is advised. In this way habitat diversity will be maintained and the trampling in the immediate vicinity of watering points is minimized (Thrash, 2000). The nature of the rangeland and the animals involved will further serve as guidelines for the correct placement of water points (Du toit and Van Rooyen, 2002).

2.5 Responses of plants to herbivory

The level of grazing or browsing selectivity, and plant tolerance are important in determining vegetation community changes (Mysterud, 2006). The extent of impact on plant composition and diversity is therefore important for determining the optimum density of large herbivores for minimum rangeland deterioration (Thrash, 1998).

The condition of the arid savanna type is reflected particularly in changes in herbaceous layer brought about by poor management (Tainton, 1999). There is bush encroachment in many of the savanna types (Tainton, 1999). Retrogression of the grass component inevitably reduces the productive capacity of these savanna types for herbivores (Tainton, 1999). Productive capacity is reduced when preferred grasses like *Panicum maximum* and *Anthephora pubescens* are replaced with less preferred grasses like *Eragrostis pallens* and other *Eragrostis* species, and with species of *Aristida* (Tainton, 1999).

A decline in the condition of the grass layer is typically accompanied by the increase in the density of trees and shrubs (Tainton, 1999). Sensitivity of savanna to this process increases as aridity increases. According Walter (1971), in a savanna ecosystem, grasses are superior competitors for water in the upper soil, while trees have exclusive access at deeper layers. However, woody species compete more successfully than grasses for the resources needed for growth, and tolerate utilization better (Tainton, 1999). This is because trees have exclusive use of soil water at depth in the profile. While grasses cannot survive in a dense woody community because they are denied water, trees can survive in a dense grass community (Tainton, 1999). Woody species are also protected, at least partially against exclusive utilization, because part of their canopy is usually beyond the reach of browsing animals (Tainton, 1999).

In most cases changes such as bush encroachment are irreversible because of the effect on the grasses of the woody species, which compete strongly for moisture

(Tainton, 1999). The low fuel loads in areas where the grass layer has degraded also mean that fire cannot be used to help control the bush (Tainton, 1999). Expensive mechanical or chemical methods must be resorted to if these areas are to be cleared (Tainton, 1999).

Many species that have increased in abundance on rangelands possess traits that contribute to their persistence in communities with specific types of disturbance (Fuhlendorf, 1999). Likewise, high levels of herbivory have resulted in a wide range of plant mechanisms to reduce or recover from herbivory (de Klerk, 2004). These resistance traits can be divided into either avoidance or tolerance mechanisms (Fuhlendorf, 1999; (Heilmann *et al.,* 2006). Defences (avoidance mechanisms) in woody plants in eutrophic areas generally take the form of structural deterrents such as thorns, which reduce leaf accesibility rather than palatability (de Klerk, 2004; Fuhlendorf, 1999). Young established woody plants, such as *Acacia karroo*, have exhibited higher levels of defences than mature plants (de Klerk, 2004).

Tolerance mechanisms, such as the ability of some plants to re-sprout, facilitate growth after disturbance (Fuhlendorf, 1999). This allows plants to re-establish without following the progression of dispersal, establishment and development (Fuhlendorf, 1999).

2.6 Range condition

Range condition indicates the status or health of the present plant community of a rangeland in relation to its potential or climax (http://www.for.gov.bc.ca/hfd/pubs/

Docs/Fpb/RMF01/RMf-4014.htm). Range condition reflects changes in vegetation composition, productivity and soil stability (http://www.for.gov.bc.ca/hfd/pubs/Docs/Fpb/RMF01/RMf-4014.htm). The condition of the arid savanna type is reflected particularly in changes in herbaceous layer brought about by poor management (Tainton, 1999).

The Range Succession Model supposes a given rangeland has a single persistent state, known as the "climax state", in the absence of grazing (Westoby *et al*., 1989). Succession towards this climax is a steady process (Westoby *et al*., 1989). According to Westoby *et al*. (1989), grazing pressure produces changes which are also progressive and are in the opposite direction to the successional tendency, and therefore grazing pressure can be made equal and opposite to the successional tendency, producing an equilibrium in the vegetation at a set stocking rate. Under the range succession model the object of management is to choose a stocking rate, which establishes a long-term balance between the pressure of grazing and the successional tendency (Westoby *et al*., 1989).

The rate at which a range is stocked is probably the single most important management factor affecting animal performance and their effect on the range condition (Tainton *et al*., 1999). Stocking rate can simply define the number of animals of a particular class, which are allocated to a unit of area of land for a specified period of time (Tainton *et al*., 1999). It can be expressed either in terms of animal numbers per unit land area or as land area availability for each animal (Tainton *et al*., 1999).

Decreasers are dominant species of climax plant communities that are preferred by livestock and decrease in number with increases in stocking rate, grazing pressure, and deterioration in range condition (http://www.fhsu.edu/biology/ranpers/ert/success.htm). Increasers are subdominant species of climax plant communities that are less preferred by livestock and so increase, at least initially, with increases in stocking rate, grazing pressure, and deterioration in range condition (http://www.fhsu.edu/biology/ranpers/ ert/success.htm). As range condition further deteriorates, these species are also overused by herbivores and ultimately decrease (http://www.fhsu.edu/biology/ranpers/ert/ success.htm). Invaders are weedy species that are not part of the initial climax community but which invade deteriorating range sites as climax species become fewer and reduced in vigor (http://www.fhsu.edu/biology/ranpers/ert/success.htm). Once invaders are present on most range sites, their complete eradication is nearly impossible or prohibitively expensive (http://www.fhsu.edu/biology/ranpers/ert/success.htm).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location and extent

Waterberg Plateau Park (WPP) is situated between 20° 37′ S, 17° 08′ E and 20°11′ S, 17°26′ E, in central Namibia, 280 km northeast of Windhoek and 64 km east of Otjiwarongo (Fig. 1). Until recently the Waterberg Plateau Park was 40 500 ha in extent. Of that, 40 000 ha is situated on the plateau, to which the larger antelope species are confined. Earlier in 2008, a nearby farm was purchased, which added an extra 6 449 hectares to the plateau area.

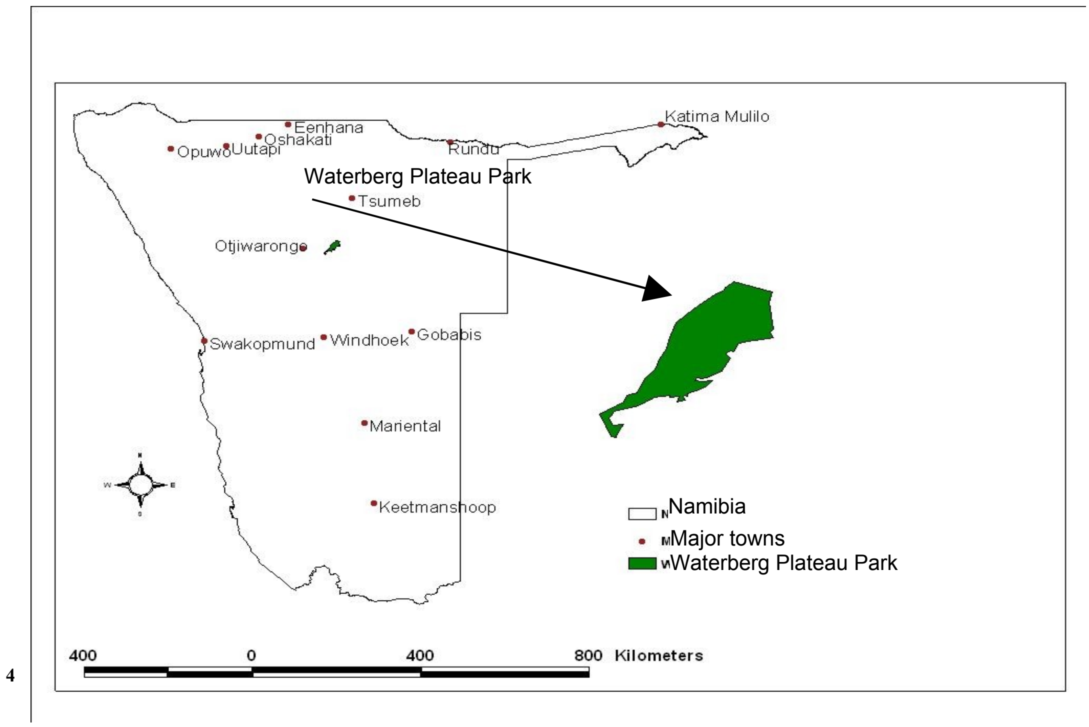


Figure 1. Location of Waterberg Plateau Park in Namibia

3.1.2 Physical features, geology and soils

The sandstone plateau lies between 1550 m and 1850 m above sea level and between 100 m to 300 m above the surrounding plains (Erckie, 2007). The top of the plateau is made up of lithofied dunes, known as aeolianite, belonging to the Etjo formation, which forms part of the Karoo sequence. It is some 200 million years old and at least 100 m thick on the Waterberg (Erb, 1993). The sandstone is brownish to light grey and medium grained (Erb, 1993). Wind-blown Kalahari sand from the Kalahari basin in the east covers the sandstone and is up to several meters deep (Erb, 1993). The soil is very nutrient-poor since it was derived from red quartzite sand, which is mainly leached out (Erckie, 2007).

The clay content of the soil on the plateau is relatively low (≤ 20 %) (Erb, 1993; Erckie, 2007). Soil pH ranges between 3.6 and 6, with an average value of 4.4, while Phosphorus (P) for both the A and B horizons is ≤ 15 parts per million (ppm), and Calcium (Ca) values fall below 200 ppm (Erckie, 2007). According to [1]Erckie, J. B. (personal communication, July 2007), the WPP soil is deficient in calcium phosphate and therefore animals are provided with salt at the water points, as a supplement for the mineral deficiency in the soil.

3.1.3 Climate

The Waterberg Plateau Park falls within the climatic region known as "Hot steppe" climatic zone according to the Köppen system of classification (Erckie, 2007). "Hot steppe" is a dry region with a deficiency in rainfall, an annual mean temperature above 18°C and receives summer rainfall (Erckie, 2007). During the winter months

[1] Chief Warden for WWP, Daan Viljoen Game Reserve and Von Bach Game Park

(May to August), high-pressure cells move south and contribute to the formation of the Kalahari high-pressure system over Botswana (Erckie, 2007). As a consequence, not much humid air flows into northern Namibia and rain during these months is an exception on WPP (Erckie, 2007). According to Erckie (2007), the topography of the WPP has an influencing factor on the local climate of the plateau, as the plateau is between 100 m to 300 m higher than the surrounding areas.

According to Du Preez (2000), the WPP tends to follow the typical summer high and winter low pattern of the Southern Hemisphere. The average daily minimum temperature for the coldest months is between 4 °C and 5 °C and during June, the temperatures can go as low as –5 °C (Erckie, 2007). The average daily maximum temperature in the hottest months ranges between 31 °C to 32 °C and from October to January temperatures rise up to 39.4 °C (Erckie, 2007).

The east winds are predominant throughout the year and are strongest between June and December (Erckie, 2007). In April and October, the north winds turn to west winds in the late afternoons, and south and southeast winds blow usually during September and October. The wind patterns influence the rain and usually the rain occurs with the north, northeast and east winds, which brings humid air from those directions (Erckie, 2007).

The annual average number of days with rainfall is 40-50 and the deviation of the annual rainfall ranges between 25-30% (Erb, 1993). More than 90% of the rainfall occurs from October-March (Erb, 1993). Four to five months get more than 50 mm of the rain per year. Potential annual evaporation averages 2800-3000 mm (Erb, 1993). This region is thus rainfall deficient. Of the total annual rainfall, 77 % falls between December and March, with February being the wettest month (Erb, 1993). According to Erckie, J. B. (personal communication, September 2008), no permanent open water is found on the plateau, but water is mostly pumped up to seven drinking troughs, from six reservoirs at the bottom of the plateau, or sometimes from 5 smaller reservoirs located on the plateau. Average annual rainfall measured below the plateau at Onjoka over the last ten years is 450.2 to ±75.4 mm.

Dew and mist occur during summer and autumn respectively (Erckie, 2007). Frost occurs in winter months and is associated with the topography of the plateau, with a higher incidence of low temperatures in the more low-lying area (Erckie, 2007).

3.1.4 Fauna

The Waterberg (mountain) is zoologically of special importance to Namibia, because of its fairly inaccessible plateau where a number of endangered species, such as the black rhino *(Diceros bicornis*), white rhino (*Ceratotherium simum*), roan antelope (*Hippotragus equinus*) and sable antelope (*Hippotragus niger*), have found refuge (Schneider, 1993; Du Preez, 2000). Most of the animals in the WPP were translocated into the park from other parts of the country, by the then Department of Nature Conservation to ensure the survival of rare and endangered species for the benefit of the entire country (Schneider, 1993). This makes the Waterberg Plateau Park a sanctuary for the game species with the objective of breeding and to provide stock for the reintroduction of species to other areas in Namibia where they naturally occur (Erckie, 2007). The animals were first translocated into the park at different intervals between 1975 and 1985 (Appendix 6).

There are very few carnivores in the park, which include leopards (*Panthera pardus*) and the brown hyena (*Hyaena brunnea*) (Erb, 1993). Most of the animals are large herbivores such as the white rhino (*Ceratotherium simum*), black rhino *(Diceros bicornis*), buffalo (*Syncerus caffer*), roan antelope (*Hippotragus equinus*), sable antelope (*Hippotragus niger*), tsessebe (*Damaliscus lunatus lunatus*), giraffe (*Giraffa camelopardalis*), eland (*Taurotragus oryx*), gemsbok (*Oryx gazella*), kudu (*Tragelaphus strepsiceros*), red hartebeest (*Alcelaphus buselaphus*), klipspringer (*Oreotragus oreotragus*), duiker (*Sylvicapra grimmia*), steenbok (*Rhaphicerus campestris*) and warthog (*Phacochoerus aethiopicus*) (Erb, 1993). Other animals also found in the park include small mammals, reptiles, amphibians and birds (Erb, 1993).

Game counts are undertaken in the dry season at all seven artificial watering points, where game species come to drink (Erb, 1993). According to Erckie, J. B. (personal communication, April 2008) counts are undertaken biannually in June and August for 48 hours. Rangers and other general workers, equipped with binoculars, operate as two person teams, each responsible for counting at a particular water point (Erb, 1993). The abovementioned teams operate from permanent hides (observation points) to which the animals are accustomed, placed approximately 50 meters from the water (Erb, 1993). Standard data sheets are used for recoding the number of animals visiting the water point during the counting period (Erb, 1993). Repeated drinking by the same animal is noted when recognized (Erb, 1993). The total abundance of game in the Waterberg Plateau Park, obtained from the August 2003, September 2006, July 2007 and August 2007 game counts were 1433, 1130, 1714 and 1959, respectively (Appendices 1 and 2).

3.1.5 Flora

The vegetation of the Waterberg Plateau Park comprises 479 species of plants in 79 genera, of which 37 are divided into more than two subspecies (Schneider, 1993). The other 42 genera consist of only one species. The family Poaceae consists of 80 species, which is the highest number of species per family in the park, with Acanthaceae consisting of 23 species (Schneider, 1993).

Waterberg Plateau Park falls within the “Tree Savanna and Kalahari Woodland” vegetation types of Namibia and consists mainly of a variety of deciduous trees and shrubs, and “hard” grasses (Erckie, 2007). The most common vegetation type on the plateau in the Bush Savanna and can be divided into three categories: One distinct subdivision consists of communities which occur in depressions or inter-dune valleys and where, due to severe frost, trees seldom reach a height more than four meters (Schneider, 1993). Generally, *Terminalia sericea* is the dominant tree of this bush savanna. Its silver-white leaves give the entire landscape a characteristic silvery-greenish-grey touch (Schneider, 1993). Amongst them also grow *Burkea africana*, *Combretum collinum* and *Ochna pulchra* (Schneider, 1993).

Another subdivision includes those plant communities occurring primarily on the dune crests and being less affected by frost (Schneider, 1993). These consist mainly of *Terminalia sericea*, but also *Burkea africana*, *Combretum collinum* and *Lonchocarpus nelsii* occur (Schneider, 1993). Particularly in the southern part of the park, trees grow to a height of over six meters (Schneider, 1993). The last sub-division forms a mosaic of the above-mentioned communities with a low density of large trees and a thick shrub stratum, also dominated by *Terminalia sericea* (Schneider, 1993).

Common trees in the Waterberg Plateau Park are *Acacia ataxacantha*, *Burkea africana*, *Combretum collinum*, *Combretum psidioides*, *Dichrostachys cinerea*, *Grewia flavescens*, *Grewia retinervis*, *Lonchocarpus nelsii*, *Ochna pulchra*, *Peltophorum africanum*, *Terminalia sericea* and *Ziziphus mucronata* (Erb, 1993). Grass species commonly occurring in the park are *Brachiaria nigropedata*, *Andropogon schirensis*, *Digitaria seriata*, *Eragrostis pallens*, *Eragrostis rigidior*, *Eragrostis jeffreysii* and *Panicum kalaharense* (Erb, 1993). According to Erckie, J. B. (personal communication, October, 2008), the WPP has six burning blocks in which the fields are burned every six years, depending on rainfall and fuel load.

3.2 Selection of sites and demarcation of plots

A total of five artificial water points, namely Geelhout, Duitsepos, Securidaca, Elandsdrink and Kiewietdrink, in the Waterberg Plateau Park were selected for the study (Fig. 2). The water points selected for the study, were those with similar gradients (landscape) around the water point (visually determined) in order to control for variations in the data, as these were used as replicates.

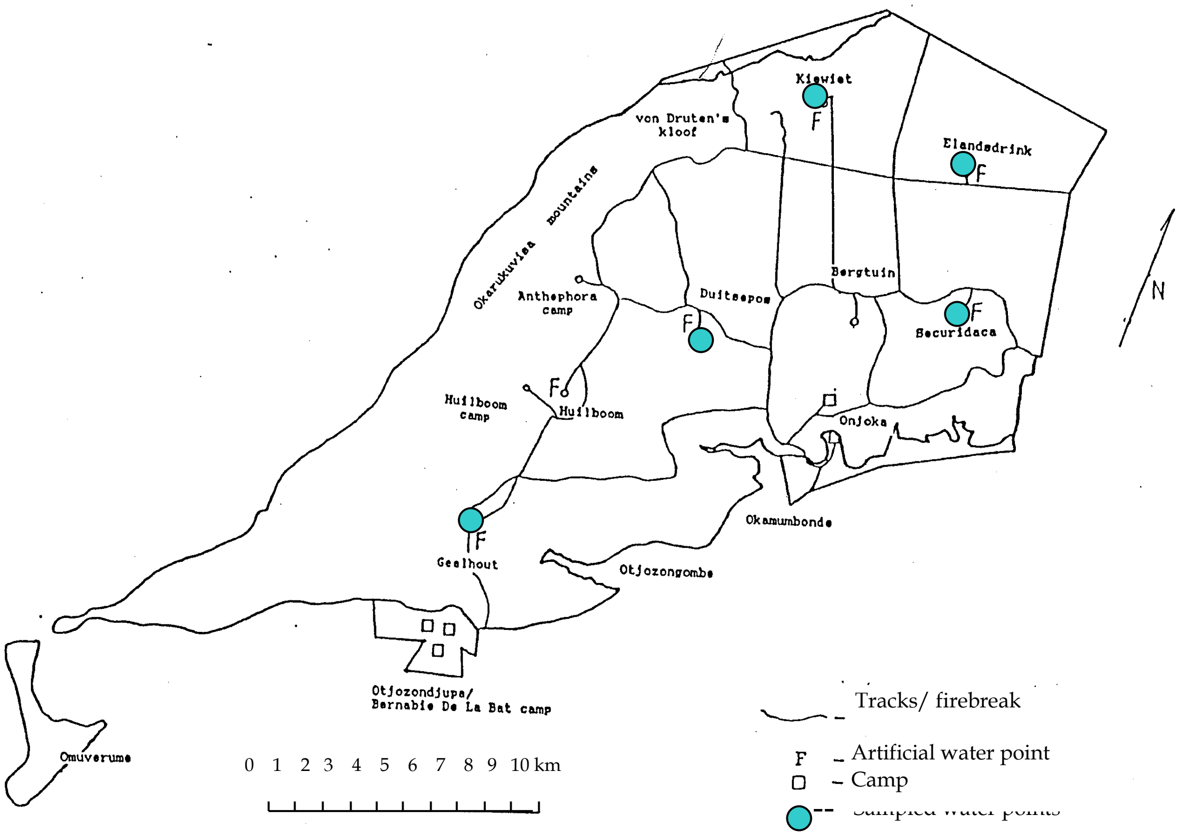


Figure 2. Location of the study sites in the Waterberg Plateau Park (WPP), adapted from Erb (1993). The sizes of the sampled water points have been altered for clarification purposes. Refer to the other two artificial water points for the original size of these water points on the map.

According to Erckie, J. B. (personal communication, August, 2008), the shortest distances (using a GPS) between the artificial water points, given in a clockwise order are: 6 km between Geelhout and Huilboom, 3 km between Huilboom and Duitsepos, 4 km between Duitsepos and Bergtuin, 2.5 km between Burgtuin and Securidaca, 6 km between Securidaca and Elandsdrink, 2.5 km between Elandsdrink and Kiwietdrink, and 4 km between Kiewietdrink and Huilboom.

3.3 Experimental design

Four line-transects (Fig. 3) starting as close as possible to, and radiating away from the water point in the northeast, northwest, southeast and southwest directions, respectively; were surveyed at each water point. Three nested square plots of 1 m x 1 m, 5 m x 5 m and 20 m x 20 m (Barbour *et al.*, 1987), at distances of 0 m, 100 m, 200 m, 300 m and 500 m from the water, were demarcated along each transect. The 1 m x 1 m plots were nested within the 5 m x 5 m and the 5 m x 5 m nested in the 20 m x 20 m (Fig. 4). Coordinates of each plot were recorded at the reference corner, to allow similar studies to be done at more or less the same place in the future (Appendix 3).

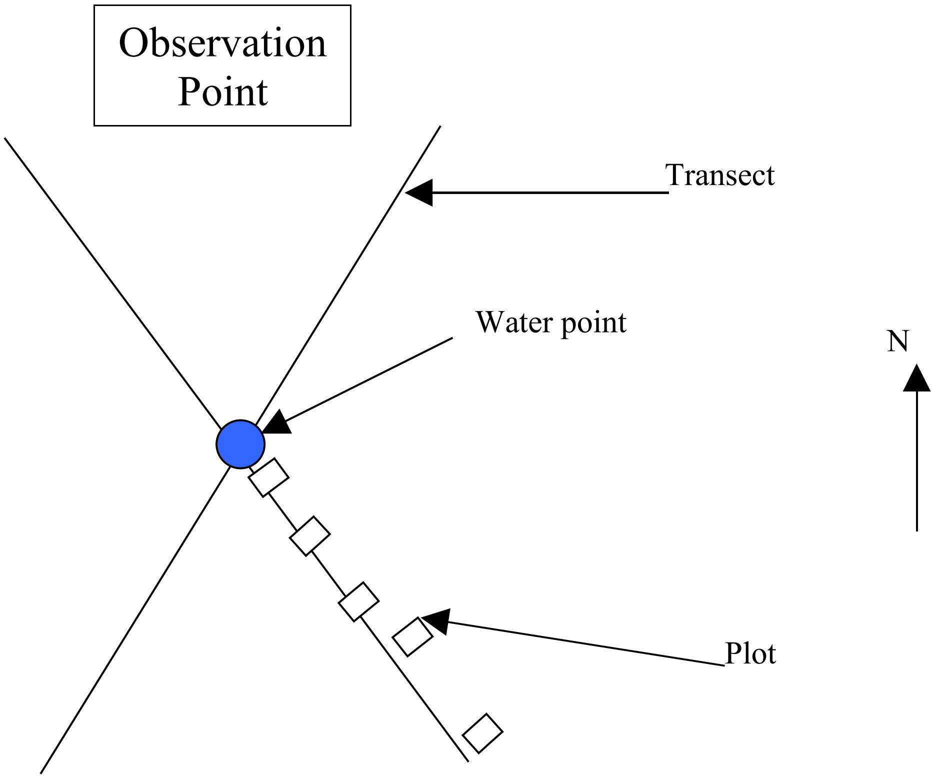
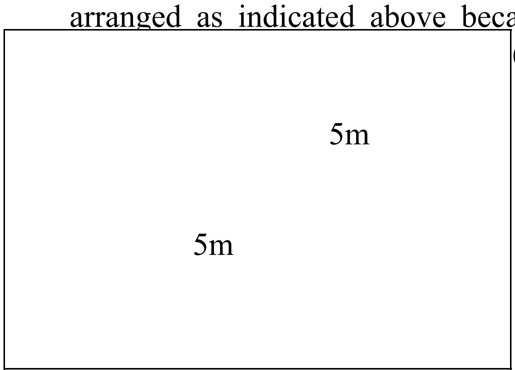


Figure 3. Demarcation of transects around the water points. Transects were arranged as indicated above because of an observation point located on the [illegible] (not drawn to scale).



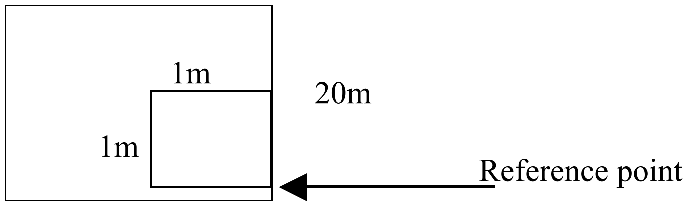


Figure 4. The nested plot design was used for the recording herbs, shrubs and saplings, and trees in 1 m^2, 25 m^2 and 400 m^2, respectively, showing the reference corner where coordinates of each plot were recorded (not drawn to scale).

3.4 Measurement of plant attributes

For this study, all woody plants with a basal circumference of ≥ 16 cm, above the basal burl, were considered as trees (Walker, 1976). Trees could be single or multi-stemmed individuals fitting the above-mentioned characteristics. An individual tree was considered to be in a plot if the center of its base was included within the plot.

Individual trees in each plot of 400 m^2 were counted and identified to species level (Appendix 4). The number of stems per tree was recorded. The height of each tree was measured by placing a 1 m and/or 2 m ranging pole as close to the tree as possible. Trees taller than the poles (usually higher than 3 to 4 m) were estimated to the nearest 0.5 m. Basal circumference was measured using a measuring tape and in the case of multi-stemmed trees, the basal circumference for each stem was measured separately.

All woody plants ≤ 3.0 m in height and/ or less than 16 cm basal circumference above the basal burl, were considered as shrubs and saplings (Walker, 1976). Shrubs and saplings could be single or multi-stemmed individuals fitting the above-mentioned characteristics. For thicket forming species, all individuals were treated as shrubs and saplings, even if they were taller than 3 m or had stem circumferences greater than 16 cm (Walker, 1976). An individual was considered to be in a plot if the center of its base was included within the plot. Saplings were included with the shrubs based on their height and basal diameter, as these did not qualify to be considered as trees.

Each shrub and sapling in the 25 m^2 plots was identified and counted and the number of stems was recorded (Appendix 4). The height of each shrub and sapling was measured in the same way as that of the trees. Basal circumference was not recorded for shrubs and saplings.

Each herbaceous plant in the plots of 1 m^2 was identified and each individual forb was counted (Appendix 4). All plants not identified in the field were collected for identification at the National Botanical Research Institute.

3.5 Measurement and estimation of cover

The line intercept method (Barbour *et al.*, 1987) was used for measuring woody vegetation cover. A measuring tape was stretched for 30 m from reference point (Mueller-Dombois and Ellenberg, 1974) and the beginning and end of each plant intercepting the tape was recorded. In the case of very high plants, the part intercepting the measuring tape was projected onto the tape and the distance recorded. Percentage cover for grasses and forbs was visually estimated in every 1 m^2 plot, respectively (Barbour *et al.*, 1987; Darrouzet-Nardi *et al*., 2008).

3.6 Soil sampling

Soil samples were collected from plots at 0 m, 200 m and 500 m from the water. At these distances, a composite soil sample was collected by taking 5 randomly distributed soil sub-samples, the top soil to a depth of 3 cm and from 3 cm to 10 cm, after removing litter on the ground surface (Kříbek *et al.*, 2005). Samples were collected in paper bags and sun-dried to halt biological activities. The sub-samples from the same plots were combined (Lejju; *et al*., 2001), 0-3 cm together and 3- 10 cm together, resulting in two composite soil samples for each 20 m x 20 m sampling plot. Each soil sample was analyzed for physical (% clay, % silt and % sand) and chemical (Cation exchange capacity (CEC), Organic matter (OM), Calcium, Potassium, Phosphorus, Magnesium, Sodium and pH) properties.

3.7 Data manipulation and analysis

3.7.1 Vegetation structure

Density was presented as individual trees, shrubs and saplings, and forbs per 400 m^2, 25 m^2 and 1 m^2, respectively. Stem density was obtained in the same manner as trees, and shrubs and saplings. The mean density and standard error for individuals and stems in each plot was calculated.

The mean woody cover and standard error was calculated as (Scholes, 2004):

Percentage woody cover per plot = $\sum ((\textit{intercepted distances})/30m)*100$

Basal area was calculated with the assumption that all stems were circular (Sutherland, 1998), using the formula:

$$BA = c^2 / (4*\pi)$$

where BA is the basal area and c is the basal circumference. The basal area values of all individual trees per plot were added together to give a total basal area per plot.

The mean densities and total basal area per 400 m^2 data were tested for normality using the Kolmogorov-Smirnov test. The Kolmogorov-Smirnov (K-S) test may be used as an alternative to the χ^2 test for a single variable, and it compares observed and expected cumulative frequencies (Quinn and Keough, 2002). The test statistic (D) is just the largest difference between the observed and expected cumulative frequencies across all possible values of the categorical variables (Quinn and Keough, 2002). The K-S test is suited for comparing two frequency distributions, where one distribution acts as the observed and the other the expected (Quinn and Keough, 2002).

Both mean densities and mean basal area data were not normally distributed and the Kruskal-Wallis test was used to test for significant differences among the different distances from the water points, while the Mann-Whitney *U*-test was used to indicate where the differences were. The Kruskal-Wallis test was also used to test for differences in percentage vegetation cover. The Wilcoxon signed rank test was used to test for differences between individual trees, and shrubs and saplings, and their stem densities, respectively.

The Kruskal-Wallis test, also known as the H-test is the non-parametric alternative to the one-way ANOVA (Struwig and Stead, 2001). The Kruskal-Wallis test uses an ordinal scale of measurement and determines whether three or more independent groups or treatments originate from the same population or not (Struwig and Stead, 2001). The groups comprise two or more categories or levels (Struwig and Stead, 2001).

The Mann-Whitney *U*-test is a powerful nonparametric statistical test commonly used as an alternative to the *t*-test (Runyon *et al*., 1996). Its power is derived from the fact that it uses most of the quantitative information inherent in the data (Runyon *et al*., 1996). It is used when the measurements fail to achieve interval or ratio scaling or when the researcher wishes to avoid the assumptions of the parametric counterpart (Runyon *et al*., 1996).

The Wilcoxon signed-rank test makes use of the sign and magnitude of the rank of differences between pairs of measurements (Ott and Mendenhall, 1990). The test provides a way to compare two populations when the variable of interest is measured on an ordinal scale (Ott and Mendenhall, 1990). It provides a nonparametric alternative to the paired *t*-test (Ott and Mendenhall, 1990).

To determine basal area distribution, the basal area values at the different distances from the water points were arranged into the following classes (cm^2): ≤ 49.99, 50-149.99, 150-249.99, 250-349.99, > 349.99. All height values of woody vegetation at the different distances from the water points were arranged into height classes (m) as follows: <1, 1-1.9, 2.0-2.9, 3.0-3.9, 4.0-4.9, 5.0-5.0, <5.9.

A Chi-square test was used to test for differences in distribution patterns of basal area and height classes among distances: 0 m, 100 m, 200 m, 300 m and 500 m from the water points. The observed and expected frequencies were compared to indicate where the differences were.

According to Runyon *et al.* (1996), the χ^2 test is a non-parametric statistic and therefore makes no requirements concerning normally distributed data or equality of variances (Runyon *et al*., 1996). There are however several basic requirements that must be met for it to be considered a valid statistical procedure (Runyon *et al*., 1996): there must be independence among the measures, the test must be conducted on frequencies, and the sample size must be sufficiently large (Runyon *et al*., 1996).

3.7.2 Soil properties

Soil chemical properties data were tested for normality using the Kolmogorov-Smirnov test. All the data were not normally distributed and the Kruskal-Wallis test was used to test for significant differences in the soil properties among the different distances from the water points, while the Mann-Whitney *U*-test was used to indicate where the differences were. The Wilcoxon signed rank test was used to test for differences in soil properties between the two depths at which soil samples were collected.

3.7.3 Plant species diversity and composition

Plant species diversity was calculated for each plot using the Shannon-Wienner diversity index (H').

$$H' = -\sum_{i=1}^{s} (p_i)(\ln p_i)$$

Where p_i is the proportion of individuals found in the i^{th} species, *ln* is the natural logarithm and s is the total number of species (Krebs, 1989). The Kruskal-Wallis test was used to test for significant differences in diversity indices (H') and species richness among the different distances from the water points, and the Mann-Whitney *U*-test was used to indicate where the differences were.

3.7.4 Range condition

The grass species identified at the different distances from the water points were categorized into decreaser or increaser species based on literature sources (Appendix 5) (http://www.fhsu.edu/biology/ranpers/ert/success.htm; Vorster, 1999). Species that could not be categorized as either decreasers or increasers were termed "unclassified" species. The mean relative proportion (%) of the grass cover for each group (decreaser, increaser or unclassified) was calculated per distance from the water. A Chi-square test was used to test for differences in the mean relative proportions of the different grass categories among the different distances from the water points.

3.7.5 Determinants of vegetation structure and composition

The Hierarchical Cluster Analysis (HCA), using the Average Linkage Between Groups method was performed on a plots-by-species matrix consisting of 100 plots and 54 species, using presence and absence data. The term cluster analysis embraces a loosely structured body of *ad hoc* algorithms, which are used in the exploration of data that arise from the measurement of a number of characteristics for each of an assorted collection of individuals or objects (Maxwell, 1977). The aim of the exploration is to see if the individuals or objects can be subdivided into groups or clusters, which on the basis of the measurements can be shown to be relatively distinct or to belong together (Maxwell, 1977).

The term ordination simply means ‘to set in order’ i.e. the arrangement of vegetation samples in relation to each other in terms of their similarity of species composition or their associated environmental controls (Kent and Coker, 2003). The data are termed floristic when the species occurring in the area under study are identified and their presence/absence or abundance is recorded during data collection (Kent and Coker, 2003).

Detrended Correspondence Analysis (DCA), an indirect gradient analysis (ordination) technique, was performed on a presence and absence matrix of plant species, to reveal relations amongst the various plant associations. The DCA method was developed as a heuristic modification to another method (CA), and was designed to correct two faults of that method (Jongman *et al*., 1995). The major of these faults is the arch effect, which is ‘a mathematical artifact, corresponding to no real structure in the data’ (Jongman *et al*., 1995). This is eliminated by ‘detrending’ (Jongman *et al*., 1995). Detrending is intended to ensure that, at any point along the first axis, the mean value of the site scores on the subsequent axes is about zero (Jongman *et al*., 1995). To this end, the first axis is divided into a number of segments and within each segment the site scores on Axis 2 are adjusted by subtracting their mean (Jongman *et al*., 1995).

Canonical Correspondence Analysis (CCA) is a direct ordination approach because it incorporates the correlation and regression between floristic data and environmental factors within the ordination analysis itself (Kent and Coker, 2003). The input matrix for this technique thus consists of both a species and environmental controls data (Kent and Coker, 2003). Direct ordination enables the simultaneous deduction of variability in the environmental data and variation in the species data (Kent and Coker, 2003).

The CCA was performed on the same species data set used for DCA. The plots used for the ordination diagrams are only those from where soil samples were collected. The explanatory data set for the CCA consisted of the following variables: % sand, % clay, Mg, pH, P, K, CEC and % OM in topsoil.

CHAPTER 4

RESULTS

4.1 Vegetation structure

4.1.1 Forb densities

Forb density ranged from 0- 9 individuals/m^2 closest to the water point (0 m), 0- 15 individuals/m^2 at 100 m, 0- 21 individuals/m^2 at 200 m, 0- 23 individuals/m^2 at 300 m and 0- 22 individuals/m^2 at 500 m from the water. The species with the highest densities per distance from the water were: *Chamaecrista biensis* with 8 individuals/m^2 at Geelhout*, Phyllanthus pentandrus* with 12 individuals/m^2 at Geelhout, *Ipomoea chloroneura* with 11 individuals/m^2 at Kiewietdrink, *Polygala pygmaea* with 13 individuals/m^2 at Kiewietdrink, and *Phyllanthus pentandrus* with 9 individuals/m^2 at Duitsepos, Securidaca and Elandsdrink, at 0 m, 100 m, 200 m, 300 m and 500 m from the water, respectively.

There was a significant difference in forb density among distances from the water ($H= 15.519$, $df= 4$, $p< 0.01$). The difference was revealed to lie between: 0 and 100 m ($p< 0.05$), 0 and 200 m ($p< 0.01$), 0 and 300 m ($p< 0.01$), and 0 and 500 m ($p< 0.01$), with forb density being significantly lower at 0 m compared to the other distances. All the other comparisons were not significantly different.

Figure 5, shows a clear increase in forb density between 0 m and 100 m from the water. The bars indicating the standard errors of the mean overlap greatly among the distances further away from the water (100 m, 200 m, 300 m and 500 m), suggesting very little variation in mean forb density among those distances (Fig. 5).

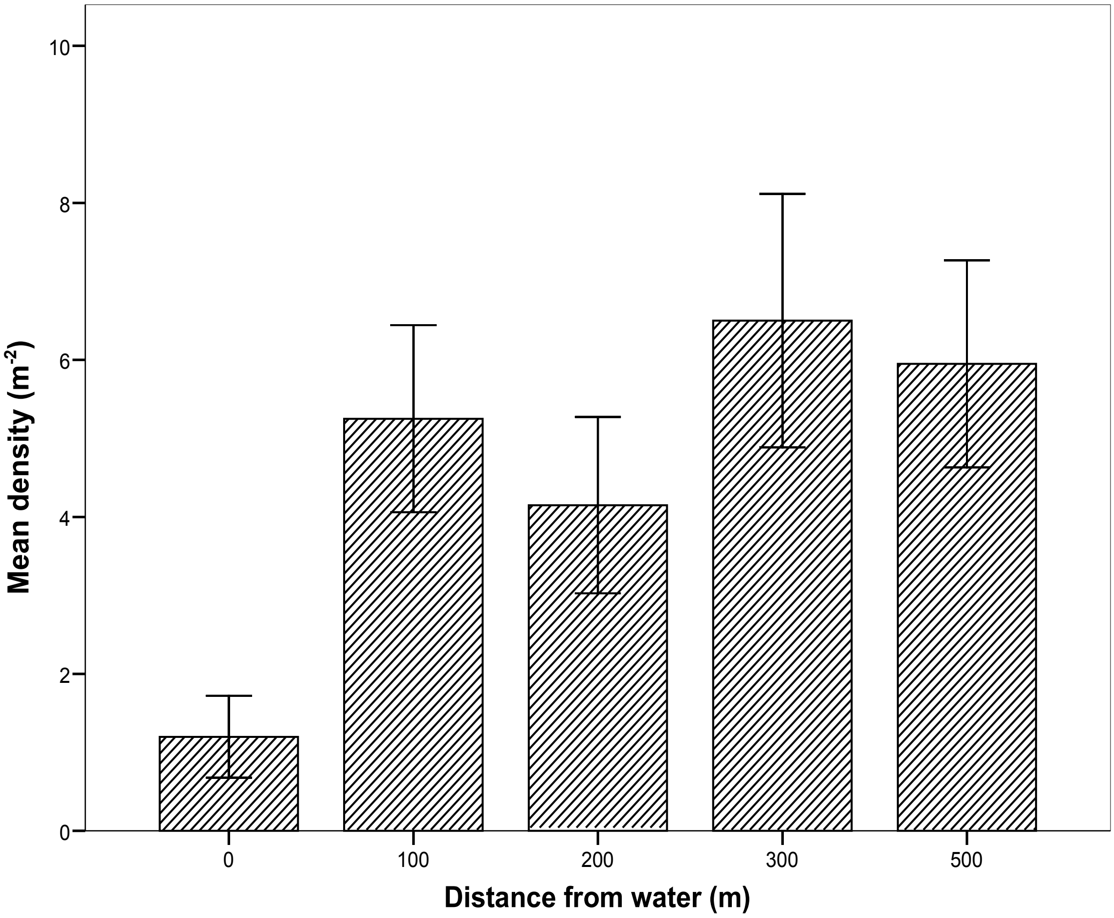


Figure 5. Comparisons of forb densities at five distances from the water points in Waterberg Plateau Park, Central Namibia. Bars indicate SEs.

4.1.2 Shrub and sapling densities

The highest shrub and sapling density values per 25 m^2 were: 1 *Ochna pulchra* at 0 m from the water at Securidaca, 37 individuals/25 m^2 at 100 m from the water at Securidaca, 30 individuals/25 m^2 at 200 m at Securidaca, 24 individuals/ 25 m^2 at 300m at Securidaca, and 44 individuals/25 m^2 at 500 m from the water at Duitsepos. The species with the highest density of shrub and saplings were: *Ochna pulchra* with

29 individuals/25 m^2, *Combretum collinum* with 25 individuals/25 m^2, *Ochna pulchra* with 16 individuals/25 m^2, and *Combretum psidioides* with 21 individuals/25 m^2, at 0 m, 100 m, 200 m, 300 m and 500 m from the water, respectively. The lowest values were 0 individuals/25 m^2, at all distances. There was a significant difference in shrub and sapling density among distances from the water ($H= 43.612$, $df= 4$, $p< 0.001$). The Mann-Whitney test revealed that shrub and sapling density was significantly lower at 0 m, compared to other four distances from the water, with $p< 0.001$ in all four comparisons. This is evident in Figure 6, where an increase in both individual shrub and sapling density and shrub and sapling stem density is observed from 0 m to the other distances from the water.

The species with the highest shrub and sapling stem densities were: *Ochna pulchra* (5 stems/25m^2) at the area in the immediate vicinity of the water point (0 m) at Securidaca, *Grewia sp.* (40 stems/25m^2) at 100 m from the water at Geelhout, *Grewia sp.* (85 stems/25m^2) at 200 m from the water at Securidaca, *Grewia sp.* (70 stems/25m^2) at 300 m from the water at Geelhout, and *Otoptora burchellii* (40 stems/25m^2) at 500 m from the water at Securidaca. Stem densities of shrubs and saplings ranged from 0- 5 stems/ 25m^2 at 0 m from the water, 0- 235 stems/25m^2 at 100 m, 0- 169 stems/25m^2 at 200 m, 0- 270 stems/25m^2 at 300 m, and 0- 233 stems/25m^2 at 500 m from the water. There was a significant difference in shrub and sapling stem density among the different distances from the water ($H= 43.674$, $df= 4$, $p< 0.001$). It was further revealed that shrub and sapling stem density was significantly lower at 0 m, than the other four distances from the water ($p< 0.001$, all comparisons).

There was no significant difference between individual and stem densities of shrubs and saplings at 0 m from the water (Z= -1.000, p= 0.317). Shrub and sapling stem densities were significantly higher than individual densities at 100 m (Z= -3.622, p< 0.001), 200 m (Z= -3.920, p< 0.001), 300 m (Z= -3.823, p< 0.001) and at 500 m from the water (Z= -3.660, p< 0.001).

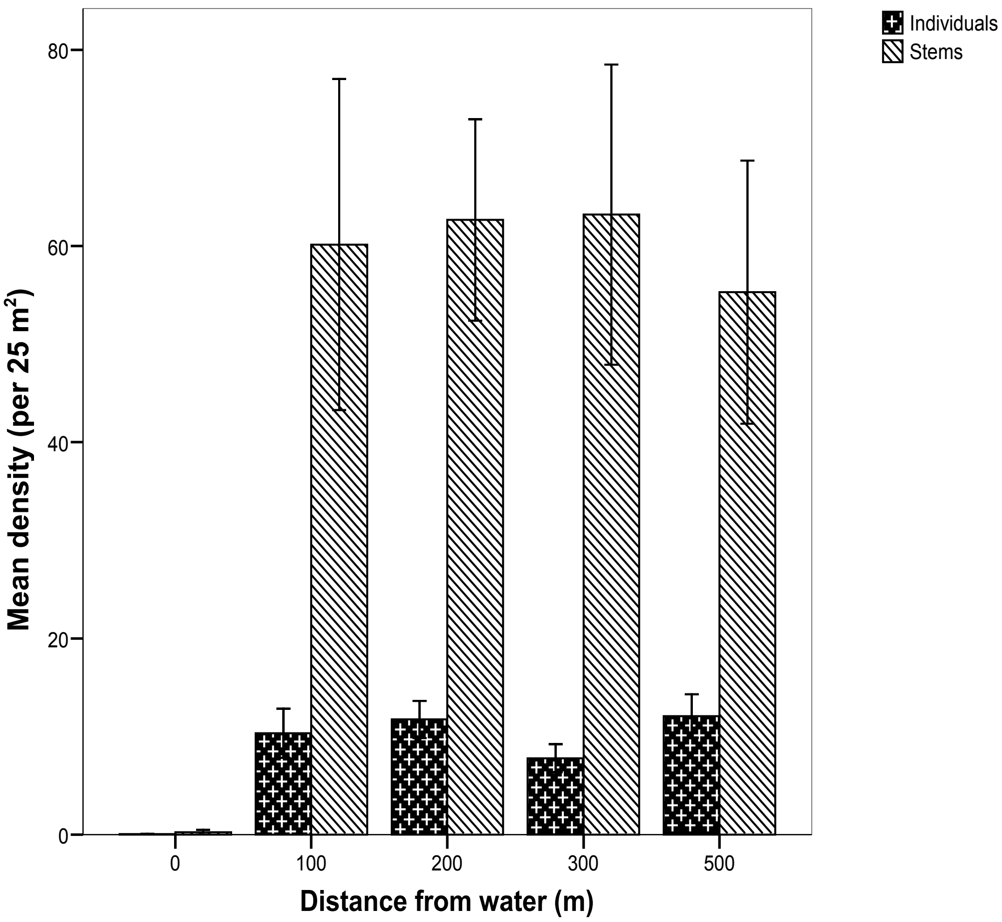


Figure 6. Comparisons of individual and stem densities of shrubs and saplings at five distances from the water point in Waterberg Plateau Park, Central Namibia. Bars indicate SEs.

4.1.3 Tree densities

Tree density ranged between 0- 3 individuals/400 m^2 at 0 m from the water, 0- 18 individuals/400 m^2 at 100 m, 0- 28 individuals/400 m^2 at 200 m, 0- 36 individuals/400 m^2 at 300 m, and 0- 52 individuals/400 m^2 at 500 m from the water. The species with the highest tree density at the different distances from the water were: *Acacia ataxacantha* and *Terminalia sericea* (2 individuals/400 m^2) at Elandsdrink, *Acacia ataxacantha* (12 individuals/400 m^2) at Elandsdrink, *Terminalia sericea* (10 individuals/400 m^2) at Elandsdrink, *Terminalia sericea* (15 individuals/400 m^2) at Securidaca, and *Terminalia sericea* (24 individuals/400 m^2) at Elandsdrink, at 0 m, 100 m, 200 m, 300 m and 500 m from the water, respectively. There was a significant difference in tree density among distances from the water ($H= 35.841$, $df= 4$, $p< 0.001$). Tree density was significantly higher at 100 m, 200 m, 300 m and 500 m, than at 0 m from the water points ($p< 0.001$, all comparisons).

Tree stem density ranged from 0- 17 stems/400 m^2 at 0 m from the water, 0- 36 stems/400 m^2 at 100 m from the water, 0- 72 stems/400 m^2 at 200 m, 0- 69 stems/400 m^2 at 300 m and 0- 67 stems/400 m^2 at 500 m from the water. The above-mentioned maximum values of tree stem densities were all recoded at Elandsdrink. The species with the highest stem densities per distance from the water were: *Acacia ataxacantha* (17 stems/400 m^2), *Combretum collinum* (25 stems/400 m^2), *Terminalia sericea* (31 stems/400 m^2), *Acacia ataxacantha* (37 stems/400 m^2) and *Terminalia sericea* (39 stems/400 m^2), at 0 m, 100 m, 200 m, 300 m and 500 m, respectively. Stem density was also significantly different among distances from the water ($H= 29.899$, $df= 4$, $p< 0.001$). There were significantly lower tree stem densities at 0 m compared to 100 m, 200 m, 300 m and 500 m from the water ($p< 0.001$, all comparisons).

There was no difference between individual tree density and stem densities at 0 m from the water ($Z = -1.604$, $p = 0.109$), while individual tree densities were significantly lower than tree stem densities at 100 m ($Z = -3.301$, $p < 0.001$), 200 m ($Z = -3.296$, $p < 0.001$), 300 m ($Z = -3.662$, $p < 0.001$), and 500 m from the water ($Z = -2.772$, $p < 0.01$).

There was a trend suggesting an increase in the mean density of individual trees, with increasing distance from the water (Fig. 7). This increase in tree density also seems to be increasingly rapid with increasing distance from the water, the steepest increase being between 0 m and 100 m from the water (Fig. 7). Tree stem density also suggests a general increase with increasing distance from the water (Fig. 7).

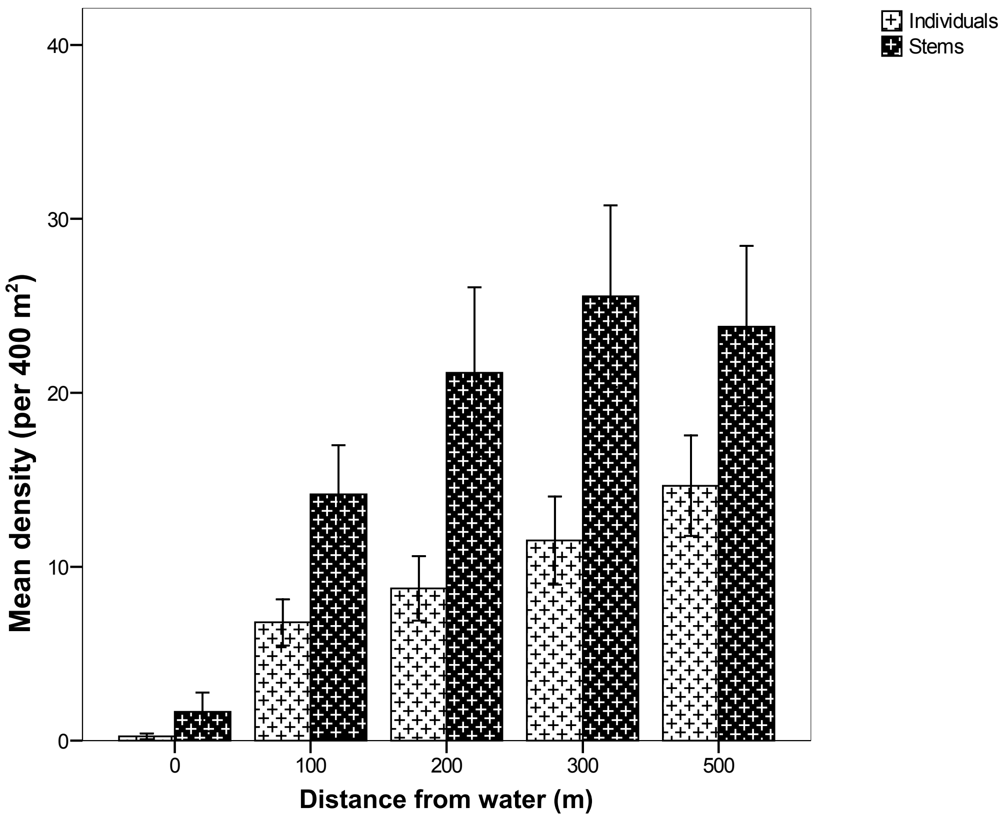


Figure 7. Comparisons of individual tree density and stem densities at five distances from the water point in Waterberg Plateau Park, Central Namibia. Bars indicate SEs.

4.1.4 Vegetation cover

Grass cover ranged between 0– 2 % at 0 m from the water, 0- 73 % at 100 m, 0.5- 39 % at 200 m, 0.02- 41 % at 300 m and 0- 35 % at 500 m from the water. The species with the highest grass cover were *Eragrostis pallens* with 70 % at Duitsepos; *Eragrostis pallens* with 35 % at Securidaca; *Aristida stipitata* subsp. *graciliflora* and *Melinis repens* subsp. *grandiflora* both with 30 % at Duitsepos and Securidaca, respectively; and *Andropogon gayanus* var. *polycladus* with 35 % at Duitsepos, at 100 m, 200 m, 300 m and 500 m, respectively. There was a significant difference in grass cover among distances from the water ($H= 42.309$, $df= 4$, $p< 0.001$). Grass cover was significantly lower at 0 m compared to the other distances from the water ($p< 0.001$). There was no difference among the other distances with regard to grass cover.

Forb cover ranged from 0– 25 % at 0 m, and the species with the highest cover at this distance was *Tribulus terrestris*, with 25 % at Duitsepos. Forb cover at 100 m from the water ranged between 0- 25 %. The other ranges of forb cover were: 0- 30 % at 200 m, 0-39 % at 300 m and 0- 32.02 % at 500 m. The highest forb cover at the other distances were from the following species: *Chamaecrista biensis* and *Phyllanthus pentandrus*, both with 15 % cover at 100 m, at Geelhout and Elandsdrink, respectively; *Acylanthos rubinosus*, with a cover of 25 % at 200 m, at Geelhout; *Polygala pygmaea*, with 25 % at 300 m, at Kiewietdrink and *Merremia tridentata* subsp. *angustifolia*, with 20 % at 500 m, at Securidaca. There was no significant difference in forb cover among distances ($H= 9.020$, $df= 4$,$p= 0.061$).

A minimum of 0 % woody cover was recorded at 0 m from the water at all the water points. Woody cover at the other distances from the water ranged from 0- 59 % at 100 m, 14- 89 % at 200 m, 12- 79 % at 300 m, and 6- 87 % at 500 m distance from the water. The species with the highest percentage woody cover per distance from the water were, *Lonchocarpus nelsii* with 18 % and 50 % at Elandsdrink and Duitsepos, respectively, *Combretum collinum* (30 % at Kiewietdrink) and *Ochna pulchra* (25 % at Geelhout), at 100 m, 200 m, 300 m and 500 m from the water, respectively.

Woody species cover was significantly different among distances from the water ($H= 45.555$, $df= 4$, $p< 0.001$). Woody cover was lower at 0 m in comparison to 100 m, 200 m, 300 m and 500 m from the water ($p< 0.001$, all comparisons). No significant differences were detected in the other comparisons.

Both grass and woody cover demonstrate a clear increase from 0 m to the further distances from the water, and the large overlaps in the bars of the standard error of the mean suggest that the mean values did not differ much at the further distances from the water (Fig. 8). Forb cover is consistently below 10 %, without large fluctuations among the distances.

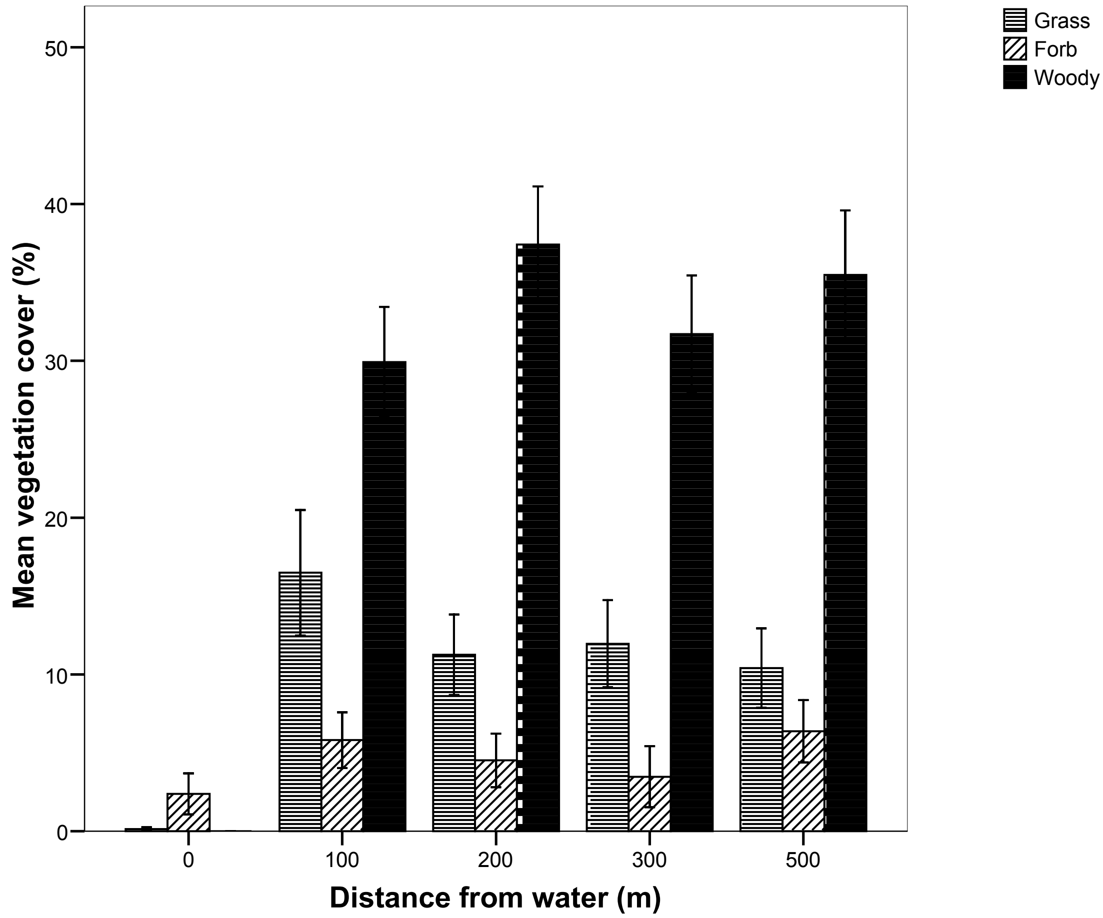


Figure 8. Comparisons of percentage vegetation cover at five distances from the water points in Waterberg Plateau Park, Central Namibia. Bars indicate SEs.

4.1.5 Heights of woody plant species

Only one sapling of *Ochna pulchra*, with a height of 0.1 m was recorded at 0 m from the water at Securidaca. The other measured shrub and sapling heights ranged from 0.1- 3 m at 100 m, 0.1- 2.5 m at 200 m, 0.1- 4 m at 300 m, and 0.1- 2.8 m at 500 m from the water. The shortest shrubs and saplings at 100 m from the water were of the species: *Bauhinia petersiana* and *Ochna pulchra* both with a height of 0.1 m at Securidaca and Elandsdrink, and *Combretum collinum* with a height of 3 m at Geelhout, was the tallest species at that distance; at 200 m from the water, *Ochna* *pulchra* had the lowest height (0.1 m) at Geelhout, Duitsepos and Securidaca, and both *Acacia ataxacantha* and *Combretum collinum* were the tallest (2.5 m) at Elandsdrink and Kiewietdrink, respectively. *Bauhinia petersiana* at Elandsdrink and *Ochna pulchra* at Duitsepos and Securidaca, had the lowest recorded height of 0.1 m at 300 m from the water and the tallest shrubs and saplings at that distance from the water was *Grewia sp.* (4 m). At 500 m from the water, the shortest shrubs and saplings were *Bauhinia petersiana* at Securidaca and Elandsdrink and *Ochna pulchra* at Elandsdrink, both with a height of 0.1 m, and the tallest shrub and sapling at that distance was *Terminalia sericea* with a height 2.8 m at Geelhout.

Tree heights ranged from 2.3- 10 m at 0 m from the water, 0.7- 8 m at 100 m distance from the water, 1- 6.5 m at 200 m from the water, 1- 7.5 m at 300 m from the water and 0.78- 7 m at 500 m distance from the water. The tallest trees at the different distances were: *Peltophorum africanum* at Kiewietdrink, *Combretum collinum* at Duitsepos, *Burkea africana* at Duitsepos and *Combretum collinum* at Securidaca, *Combretum psidioides* at Securidaca and *Peltophorum africanum* at Kiewietdrink, and *Burkea africana* at Securidaca, at 0 m, 100 m, 200 m, 300 m and 500 m, respectively. Shortest trees at the five distances from the water, in ascending order of the distances, were: *Acacia ataxacantha, Ochna pulchra*, *Terminalia sericea* and *Combretum collinum*, *Terminalia sericea* and *Combretum collinum*, and *Acacia ataxacantha*, respectively.

There was a significant difference in the proportions of the different height classes of woody vegetation among the different distances from the water (χ^2= 97.574, df= 24, p< 0.001). There were much higher observed values than expected of height class < 1 m at 100 m, class <1 and 2- 2.9 m at 200 m, 300 m, and at 500 m from the water (Fig. 9). Further contributing to the differences was the much lower observed values than expected, of the height class 5- 5.9 and > 5.9 at 100 m and 300 m from the water, class 3- 3.9 m, 4- 4.9 m, 5- 5.9 m and > 5.9 m at 200 m and 500 m.

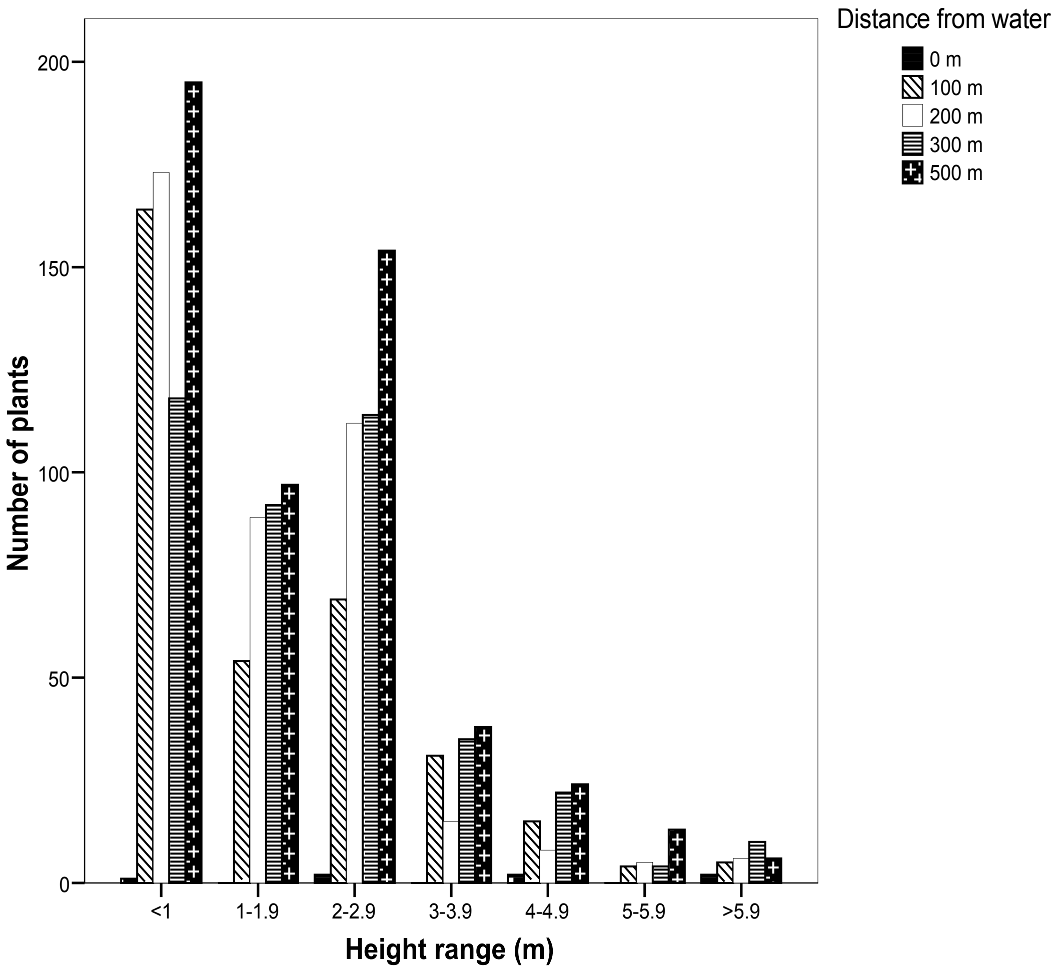


Figure 9. Comparisons of woody vegetation height frequency distribution patterns at five distances from water points in Waterberg Plateau Park, Central Namibia.

4.1.6 Tree basal area

Basal area ranged from 1.17- 968.05 cm^2 per 400 m^2 plot at 0 m, 54.83- 2048.24 cm^2 per plot at 100 m from the water, 46.15- 2441.60 cm^2 per plot at 200 m from the water, 49.10- 3867.23 cm^2 per plot at 300 m from the water, and 25.78– 2638.08 cm^2 per plot at 500 m distance from the water. The following species had the largest basal areas at the different distances from the water: *Terminalia sericea* with a basal area of 773.89 cm^2/ 400 m^2 at Elandsdrink, *Peltophorum africanum* (1081.54 cm^2 per plot) at Kiewietdrink, *Burkea africana* (688.27 cm^2 per plot) at Duitsepos, *Peltophorum africanum* (1981.38 cm^2 per plot) at Kiewietdrink and *Terminalia sericea* (435.77 cm^2 per plot) at Duitsepos, at 0 m, 100 m, 200 m, 300 m and 500 m from the water, respectively.

There was a steep increase in basal area from 0 m (48.46 cm^2) to 100 m (583.19 cm^2) followed by a fluctuation at higher basal areas from 100 m to 500 m (909.76 cm^2) distance from the water (Fig. 10). There was a significant difference in mean basal area among distances from water ($H= 30.453$, $df= 4$, $p< 0.001$). Tree basal areas were significantly lower at 0 m in comparison with the other distances ($p< 0.001$, all comparisons). No significant differences were detected in the other comparisons.

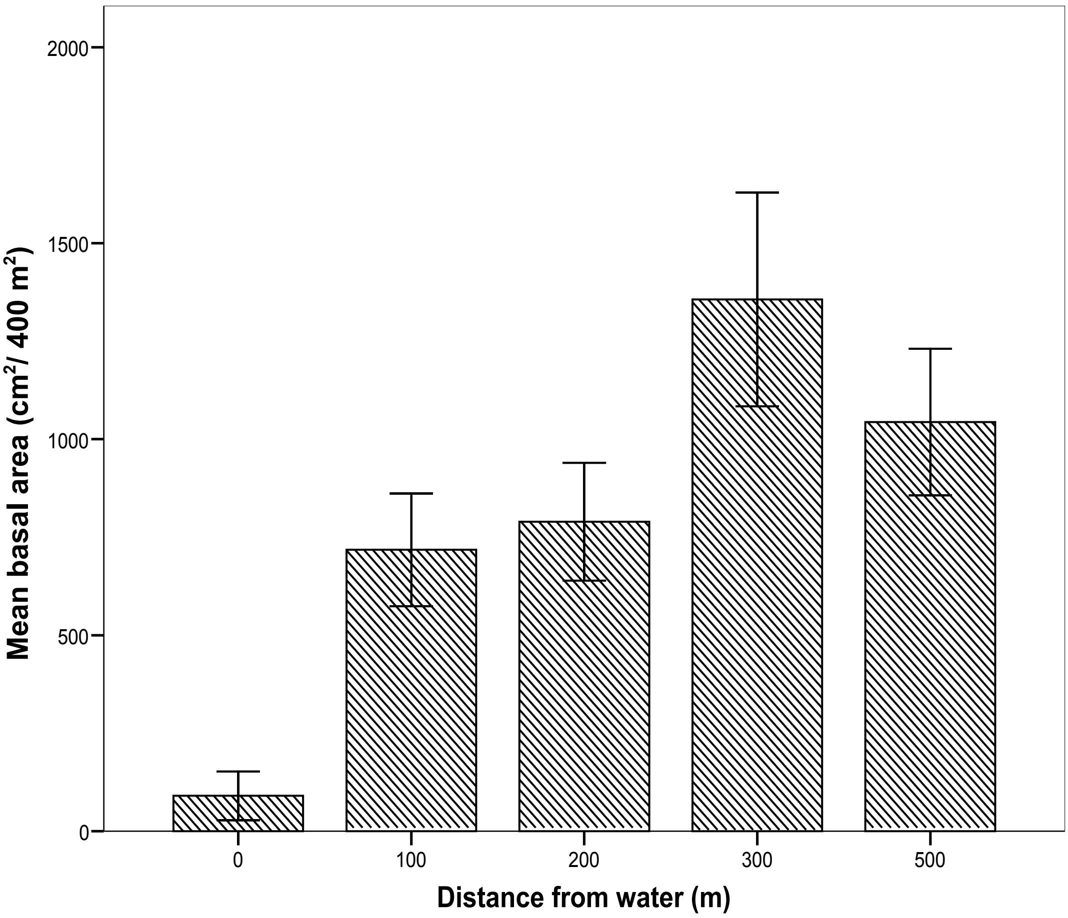


Figure 10. Comparisons of mean tree basal area at five distances from the water point in Waterberg Plateau Park, Central Namibia. Bars indicate SEs.

There was a significant difference in tree basal area distribution patterns among distances from the water point (χ^2= 44.565, df= 16, p< 0.001). There were much lower observed frequency than expected for class 150- 249.99 cm^2, 250- 349.99 cm^2 and > 349.99 cm^2, and much higher observed frequencies than expected for class ≤ 49.99 and 50- 149.99 cm^2, at 100 m, 200 m, 300 m and 500 m from the water (Fig. 11).

There were very low frequencies of basal area classes ≤ 49.99, 150- 249.99, > 349.99 observed at 0 m, while the other basal area classes were completely absent from that distance. The other four distances from the water points generally had a reversed J-shaped basal area class distribution, with many small woody plants.

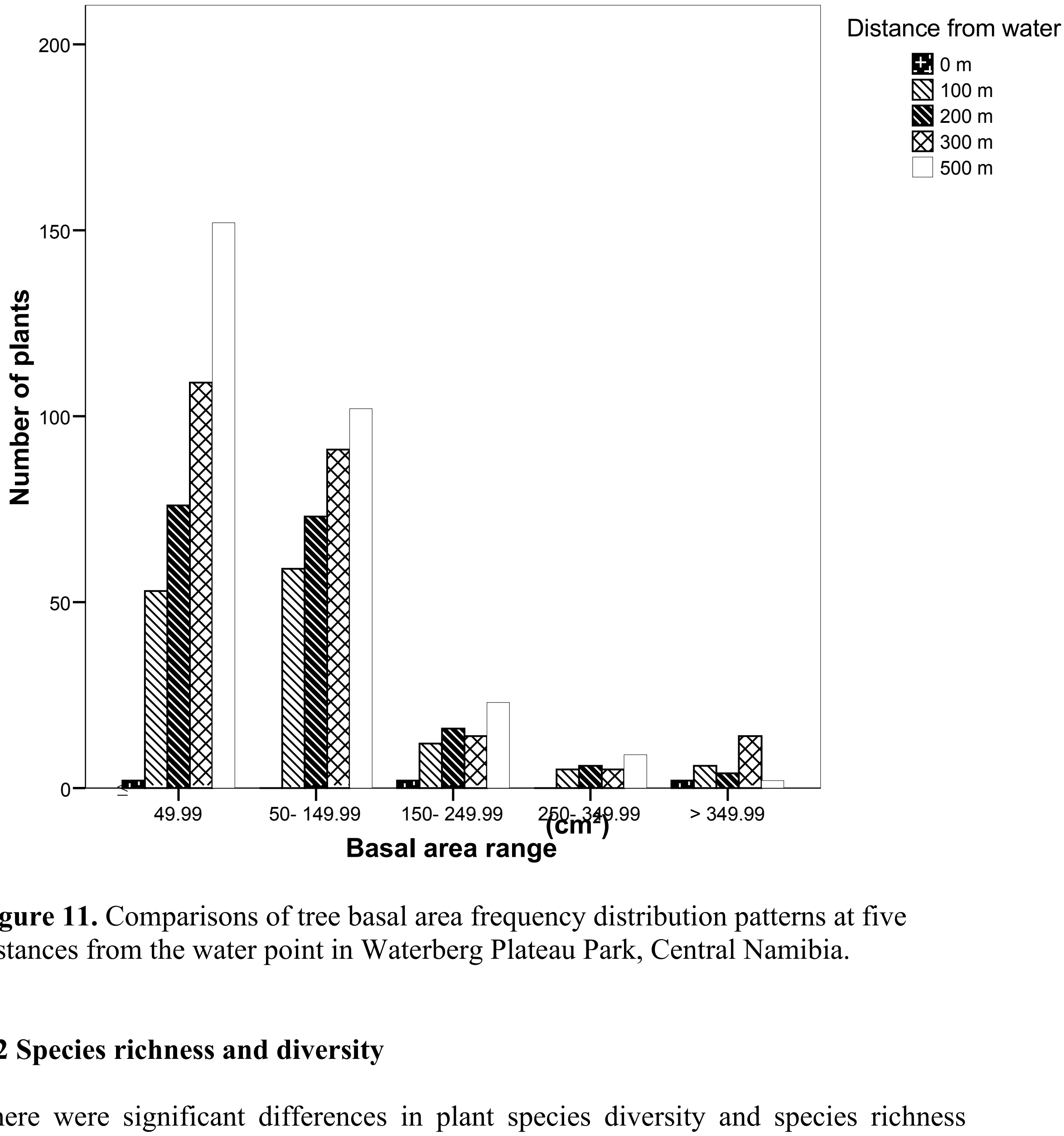


Figure 11. Comparisons of tree basal area frequency distribution patterns at five distances from the water point in Waterberg Plateau Park, Central Namibia.

4.2 Species richness and diversity

There were significant differences in plant species diversity and species richness between 0 m and the other four distances from the water ($H= 44.697$, $df= 4$, $p< 0.001$ and $H= 48.495$, $df= 4$, $p< 0.001$, respectively). Both species diversity and species richness were significantly lower at 0 m than at 100 m, 200 m, 300 m and 500 m, respectively (Table 1). No significant differences were detected in the other comparisons (Table 1).

Table 1. Mean Shannon-Wienner diversity indices and mean species richness at five distances from the water. (The superscript letters show a comparison in diversity indices and species richness among the distances from the water point. When the letters are the same in a comparison, it means there was no significant difference and *vise versa*.)

Distance from Water point (m)	Mean H’ (± Standard Error)	Mean Species Richness (± Standard Error)
0	0.20 ± 0.079^{a}	0.90 ± 0.315^{c}
100	1.41 ± 0.099^{b}	6.70 ± 0.413^{d}
200	1.53 ± 0.062^{b}	7.80 ± 0.388^{d}
300	1.44 ± 0.072^{b}	6.85 ± 0.530^{d}
500	1.42 ± 0.091^{b}	7.70 ± 0.553^{d}

Species diversity index ranged between 0.097-1.238 at 0 m, 0.240-1.952 at 100 m, 0.955-1.982 at 200 m, 0.945-1.943 at 300 m, and 0.236-2.042 at 500 m from the water. The lowest diversity indices where recorded at Duitsepos, Kiewietdrink, Geelhout, Kiewietdrink and Securidaca, for the distances 0 m, 100 m, 200 m, 300 m and 500 m from the water, respectively. Maximum diversity indices at the different distances from the water in descending order of the distances were recorded at: Kiewietdrink, Geelhout, Securidaca, Duitsepos and Securidaca, respectively.

Species richness ranged between 0-5 species at 0 m, 2- 10 species at 100 m, 5- 11 species at 200 m, 3-12 species at 300 m and 3- 13 species at 500 m from the water. Out of a total of 20 plots sampled at 0 m, 13 had no species at all. The lowest number of species at 100 m, 200 m, 300 m and 500 m, were recorded at Kiewietdrink, Securidaca and Elandsdrink, Duitsepos, and Duitsepos, respectively. The highest number of species per plot was recorded at Kiewietdrink, Geelhout and Duitsepos, Securidaca, Elandsdrink and Securidaca, at 0 m, 100 m, 200 m, 300 m and 500 m, respectively.

4.3 Soil properties

The following soil properties were generally higher at 0 m compared to distances further away from the water: Phosphorus, Potassium, Calcium, Magnesium, Sodium, Sand and Cation Exchange Capacity (Table 2). Soil pH, organic matter and clay content were lower at 0 m compared to further away from the water. While there were significant differences in the other soil properties between 0 m and further distances from the water, the soil silt content did not differ significantly throughout the transect (Table 2). As indicated in Table 2, Ca, Na and pH levels were higher in the topsoil at 0 m; Ca, Mg and pH levels were also higher in the topsoil at 200 m; while K was higher at the bottom layer, and CEC was higher in the topsoil, at 500 m from the water. No other significant differences were detected between the two depths.

Table 2. Comparisons of soil chemical and physical properties, at depths 0-3 m and 3- 10 m, at five distances from the water point in Waterberg Plateau Park, Central Namibia. (Lower case superscript letter shows a comparison between the two depths at each distance from the water, and upper case superscript letter shows a comparison among the three distances from the water. When the letters are the same in a comparison, it means there was no significant difference and *vise versa*.)

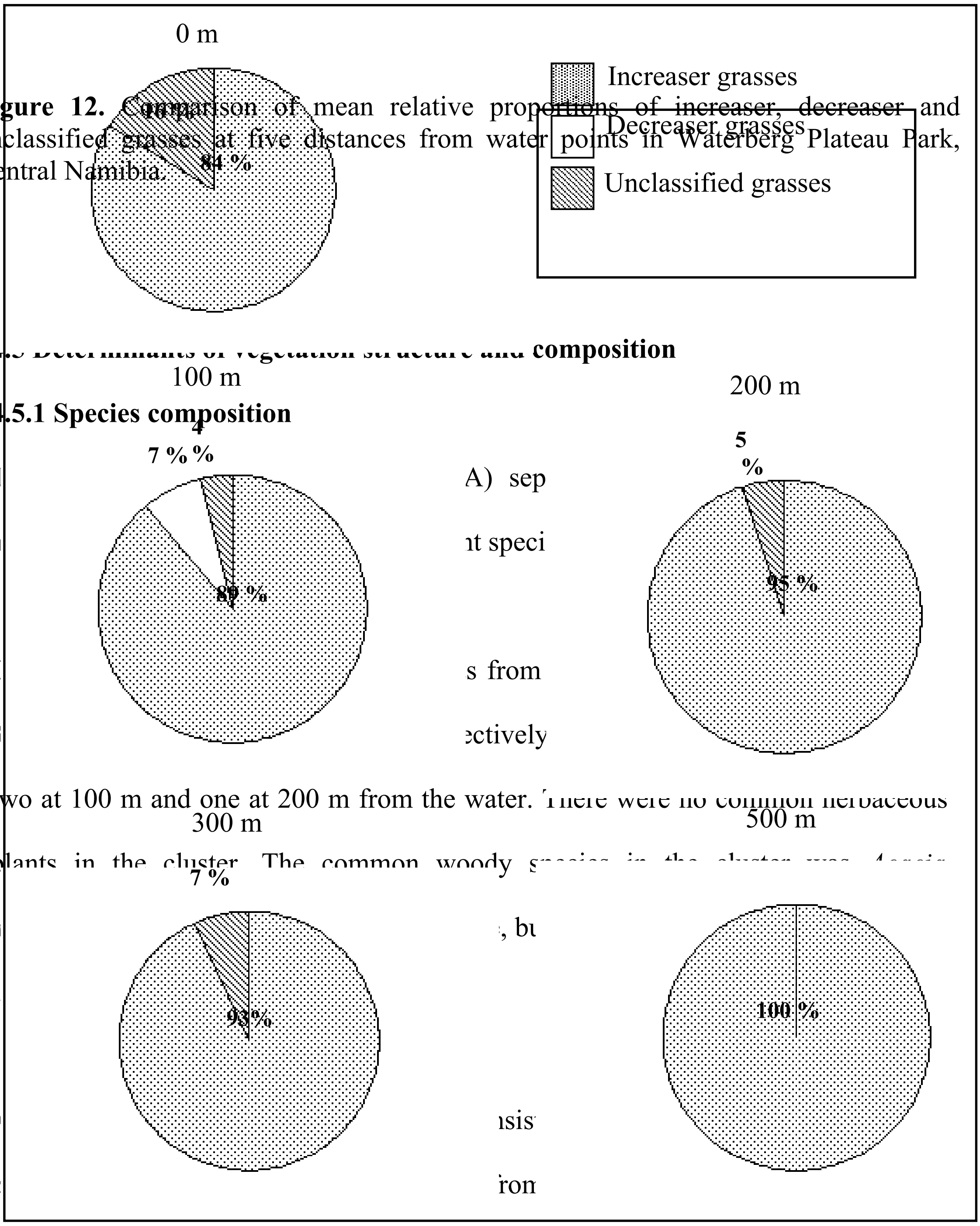
Distance from water (m)	Depth (cm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	pH (w)	OM (%)	CEC (me/100g)	Sand (%)	Clay (%)	Silt (%)
0	0- 3	8.28± 1.380^{aA}	43.70± 7.252^{aA}	54.60± 8.759^{aA}	21.60± 2.258^{aA}	3.45± 0.983^{aA}	6.09± 0.076^{aA}	0.49± 0.043^{aA}	1.09± 0.238^{aA}	93.65± 1.042^{aA}	2.41± 0.468^{aA}	3.95± 0.803^{aA}
0	3- 10	6.70± 1.315^{aA}	35.10± 6.648^{aA}	33.15± 4.879^{bA}	18.60± 2.451^{aA}	2.65± 0.789^{bA}	5.80± 0.119^{bA}	0.46± 0.028^{aA}	0.95± 0.185^{aA}	92.10± 1.168^{aA}	2.60± 0.265^{aA}	5.31± 1.116^{aA}
200	0- 3	2.97± 0.699^{cB}	12.85± 1.320^{cB}	19.75± 3.084^{cB}	7.65± 0.924^{cB}	0.55± 0.198^{cB}	5.29± 0.052^{cB}	0.55± 0.048^{cB}	0.56± 0.096^{cB}	90.97± 0.863^{cB}	3.70± 0.301^{cB}	5.34± 1.021^{aA}
200	3- 10	3.13± 0.883^{cB}	11.55± 0.985^{cB}	14.90± 2.193^{dB}	5.70± 0.677^{dB}	0.30± 0.147^{cB}	5.09± 0.057^{dB}	0.61± 0.037^{cB}	0.53± 0.096^{cB}	90.19± 0.86^{cB}	3.58± 0.333^{cB}	6.25± 0.982^{aA}
500	0- 3	3.37± 0.667^{cB}	12.85± 2.097^{cB}	26.25± 6.507^{cB}	7.95± 1.345^{cB}	0.35± 0.264^{cB}	5.12± 0.048^{cB}	0.57± 0.044^{cB}	0.43± 0.055^{cB}	90.53± 1.129^{cB}	4.30± 0.461^{cB}	5.180± 0.830^{aA}
500	3- 10	4.35± 0.995^{cB}	20.10± 4.136^{dB}	37.75± 10.134^{cB}	9.40± 1.898^{cB}	0.30± 0.179^{cB}	5.23± 0.118^{cB}	0.53± 0.051^{cB}	0.36± 0.049^{dB}	91.20± 0.832^{cB}	3.47± 0.312^{cB}	5.87± 0.895^{aA}

4.4 Range condition

There were significant differences in the mean relative proportions of increaser, decreaser and unclassified grasses among distances from the water (χ^2= 51.655, df= 8, $p< 0.001$). There were much higher observed frequencies than expected of increaser grasses at all the distances from the water. Further contributing to the differences were much lower observed frequencies than expected of unclassified grasses and the almost complete absence of decreaser grasses throughout the study area.

At 0 m (Fig. 8), increaser grasses had the largest mean relative proportion (84 %), followed by unclassified grasses (16 %). The relative mean proportion of decreaser grasses was very low at less than 1 % (Fig. 12). At 100 m from the water increaser grasses had the highest (89 %) mean proportion cover (Fig. 12). The mean proportional cover of decreaser grasses at 100 m was 7 % and unclassified grasses had 4 % mean proportion of the total grass cover (Fig. 12). Decreaser grasses had the lowest mean proportional cover of less than 1 % at 200 m, while increaser grasses had the highest mean proportion cover of 95 %, and unclassified grasses 5 % (Fig. 12). The highest mean proportion of grass cover at 300 m was of increaser species with 93 %, followed be unclassified grasses 7 % and finally decreaser species with a very low mean proportion cover of less than 1 % (Fig. 12). All the grass species at 500 m from the water were increaser grasses (100 %) (Fig. 12).

Figure 12. Comparison of mean relative proportions of increaser, decreaser and unclassified grasses at five distances from water points in Waterberg Plateau Park, Central Namibia.



4.5 Determinants of vegetation structure and composition

4.5.1 Species composition

two at 100 m and one at 200 m from the water. There were no common herbaceous plants in the cluster. The common woody species in the cluster was

Securidaca, respectively, both at 500 m from the water. The common grass species within the cluster was *Stipagrostis hirtigluma* var. *pearsonii*, and common woody species, which occurred in both tree and shrub/ sapling form were *Ochna pulchra* and *Terminalia sericea*. There were no common forb species in the cluster.

Cluster 3 was mainly confined to plots from Kiewietdrink: with two plots at 200 m, one at 300 m and three at 500 m; and two plots at Elandsdrink, both at 100 m from the water. There were no common herbaceous plants in the cluster. The common woody species included *Acacia ataxacantha*, which mostly occurred as a trees with a few shrub/sapling forms at 200 m at Kiweitdrink and at 100 m at Elandsdrink; and *Terminalia sericea*, occurring in both tree and shrub/ sapling form within the cluster.

Cluster 4 was mostly an association of vegetation from Geelhout; two plots at 100 m, one at 200 m, one at 300 m and two at 500 m, with only one plot from Duitsepos at 200 m from the water point. There were no common forb and woody species present in the cluster. The common grasses in the cluster were *Digitaria seriata*, *Eragrostis pallens* and *Stipagrostis hirtigluma* var. *pearsonii*.

Cluster 5 was generally associated with plots with very low to no vegetation cover and included most of the plots at 0 m from the water, irrespective of water point. The cluster was sub-divided into five sub-clusters based on the common species found in them.

Sub-cluster 5A consisted of two plots from Geelhout at 200 m; two from Duitsepos, one at 300 m and the other at 500 m, along the same transect; and one from Elandsdrink at 500 m from the water point. The cluster had no common herbaceous species. The common woody species were *Combretum psidioides* and *Terminalia sericea*, which both appeared as trees and shrubs/saplings within the cluster.

Sub-cluster 5B included three plots from Duitsepos, two at 100 m and one at 200 m; one plot from Securidaca, at 200 m; one from Elandsdrink at 300 m; and one plot from Kiewietdrink at 200 m. There were no common forb species in the cluster. The common grass species in the cluster was *Eragrostis pallens* and *Terminalia sericea* appeared as both a tree and shrub/ sapling within the cluster.

Sub-cluster 5C consisted of a plot from Geelhout at 200 m, three from Duitsepos; one at 200 m, 300 m and 500 m, respectively; two plots at Securidaca, one each at 200 m and at 500 m; and a plot at 200 m, at Kiewietdrink. There were no common herbaceous species in the sub-cluster and the only common woody species was *Terminalia sericea*, which occurred in tree and shrub/ sapling form, within the sub-cluster.

Sub-cluster 5D: This sub-cluster was characteristic of very few plants species (less than 5 species per plot) and included all the plots at 0 m from the water at Geelhout, Securidaca and Duitsepos; three out of the four plots at the above-mentioned distance at Elandsdrink and two out of the four at Kiewietdrink. There were no common herbaceous or woody species in the sub-cluster.

Sub-cluster 5E: This sub-cluster was also characteristic of low species richness, but unlike 5D, the plots had more than 5 species in them, and like 5D, there were no common herbaceous or woody species in the sub-cluster. It consisted of three plots from Geelhout; a plot at 100 m and two at 300 m, four plots at Duitsepos; a plot each at 100 m and 200m, and two at 500 m; two plots at Securidaca, one plot at 100 m and

300 m, respectively; and two plot at Elandsdrink, one each at 0 m and 500 m, respectively.

Cluster 6 consisted of two plots from Kiewietdrink, one plot at 0 m and 100 m, respectively; and a plot from Duitsepos at 300 m. The common species in the cluster included the forb species *Phyllanthus pentandrus* and grass species *Stipagrostis hirtigluma* var. *pearsonii*. There were no common woody species in the cluster.

Cluster 7 was mostly associated with Kiewietdrink: with one plot at 100 m, two at 300 m and one at 500 m; two plots from Geelhout, one at 100 m and 300 m, respectively; and one plot from Securidaca at 300 m. The only common species in the cluster was *Terminalia sericea*, which occurred in both tree and shrub/ sapling form, with most of the tree forms recorded at Kiewietdrink. There were no common herbaceous species in the cluster.

Cluster 8: This small cluster was a floristic association among one plot at 500 m, at Geelhout; one at 300 m, at Duitsepos; and one at 300 m, at Kiewietdrink. There were no common herbaceous species in the cluster, while the common woody species *Ochna pulchra* and *Terminalia sericea* occurred both as trees and shrub/ sapling in the cluster.

Cluster 9 was confined to Elandsdrink water point: with two plots at 200 m, 1 at 300 m and 2 at 500 m. The common grass species in the cluster was *Aristida stipitata* subsp. *stipitata*, *Indigofera daleoides* was the common forb species, and *Acacia ataxacantha* and *Combretum collinum* occurred mostly as trees and rarely as shrubs/saplings, in the cluster.

Cluster 10 was confined to Securidaca water point: with two plots at 200 m, two at 300 m and one at 500 m. The common grass common species in the cluster was *Eragrostis pallens*, the common forb species was *Phyllanthus pentandrus*, the common shrub/sapling species was *Bauhinia petersiana*, and the common tree species was *Terminalia sericea*, while *Acacia ataxacantha* and *Burkea africana* appeared in both tree and shrub/sapling form in the cluster.

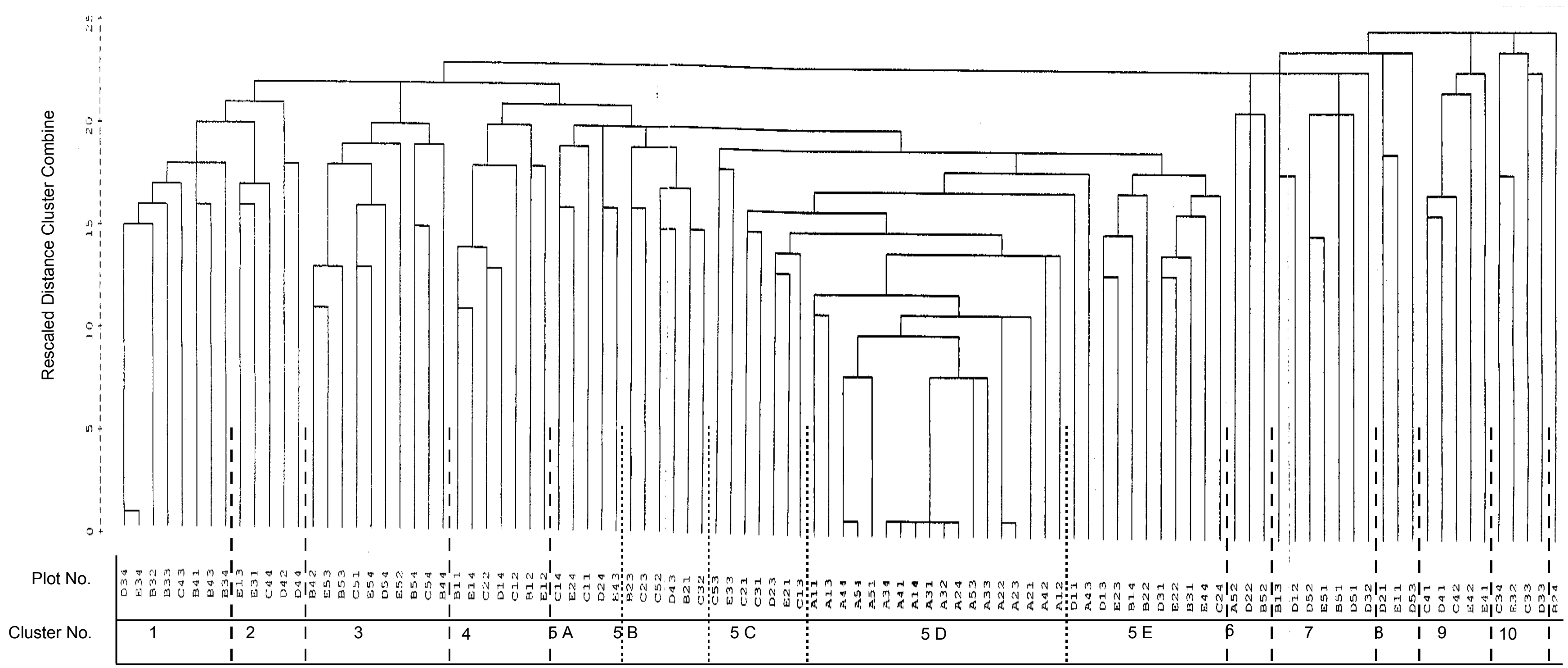


Figure 13. Hierarchical Cluster Analysis (HCA) dendrogram showing a classification of vegetation plots into 10 main clusters based on species presence/absence data. The letters in the labels refer to the distance from the water (A= 0 m, B= 100 m, C= 200 m, D= 300 m and E= 500 m) and the numbers after the letter represent the water point and transect, respectively (e.g. C51= 200 m from the water, water point 5 (Kiewietdrink) and transect 1).

4.5.2 Vegetation-environmental relationships

Detrended Correspondence Analysis (DCA) separated the plots into two main groups. Group 1 was associated with plots from the area in the immediate vicinity of the water points, at Geelhout, Duitsepos and Kiewietdrink, which in most cases had no vegetation (Fig. 14). The group corresponds to sub-cluster 5D of the HCA, which was characteristic of plots with less than five species present in them (Fig. 13).

Group 2 was a combination of all the other plots not present in Group 1; consisting of plots at all the distances and water points (Fig. 13). The group also includes all the clusters of the HCA (Fig. 13). Although there is a separation in the plots along DCA axis 1, there is an overlap in the two groups and a clustering of plots from different distances together in Group 2. As it is evident in Figure 14, most of the variation in the species composition (49 %) was explained along DCA axis 1, while 32 %, 23 % and 15 % of the variation were explained along DCA axes 2, 3 and 4, respectively. The hypothesized gradient along axis 1 was disturbance by large herbivores, and along the other axes, gradients could be other unidentified determinants of plant species composition.

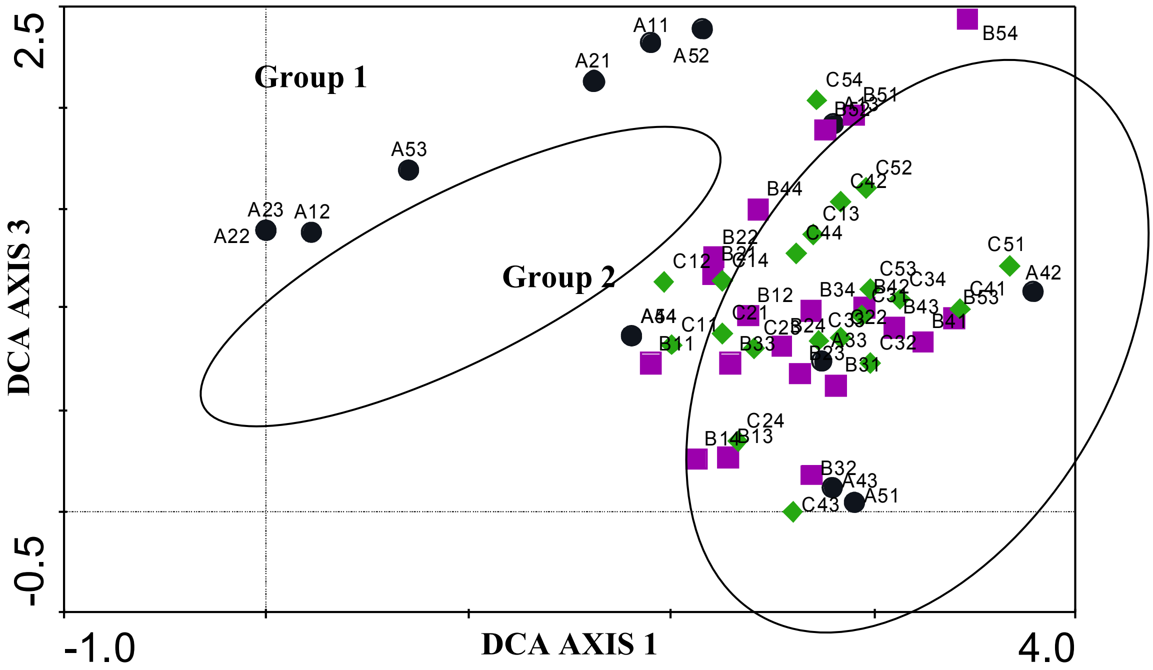


Figure 14. DCA ordination diagram showing the separation of vegetation plots into two groups along DCA axis 1. ● = 0 m, ■ = 200 m and ♦ = 500 m

The explanatory variables that significantly influenced species composition were phosphorus (P) ($F= 2.15$, $p<0.01$), cation exchange capacity (CEC) ($F= 1.82$, $p< 0.05$) and clay ($F= 1.62$, $p< 0.05$). The influence of potassium (K), magnesium (Mg), sand and organic matter (OM), were insignificant. The overall test for all canonical axes was also significant ($F= 1.472$, $p< 0.01$).

The explainable variation in species composition along CCA axis 1 was positively correlated with clay, OM, pH, P, K and CEC, and negatively correlated with sand and Mg. The second axis was positively correlated with sand, Mg and pH, K and P, and negatively correlated OM, CEC and clay.

The direction and influence of environmental variables indicate that P and K positively influenced species composition in the direction of plots at 0 m (Group 1, Fig. 15), at water points 4 (Elandsdrink) and 5 (Kiewietdrink). CEC, P, K, pH, Mg and clay, positively influenced species composition in the directions of a mixture of plots at different distances, mostly at water point 4 and 5 (Group 2, Fig. 15). Although phosphorus positively influenced species composition at Elandsdrink and Kiewietdrink, at different distances, the influence was stronger towards the plots at the water points (Group 1) (Fig. 15). Sand and organic matter mostly influenced species composition in the direction of water point 1 (Geelhout), 2 (Duitsepos) and 3 (Securidaca) (Group 3, Fig. 15). There were no measured environmental variables that strongly influence the species composition in Group 4, consisting of plots at 0 m, at Geelhout, Duitsepos and Securidaca (Fig. 15). Group 4 was characterized by plots corresponding to HCA sub-cluster 5D and DCA Group 1, which had very low vegetation cover.

The variations in the species composition along the different axes were explained as follows: 20 % of the variation was explained along CCA axis 1, 18 % along CCA axis 2, 13 % along CCA axis 3 and 12 % along CCA axis 4. In total, 20.7 % of the observed variation in species composition was explained by the explanatory variables used in the CCA analysis.

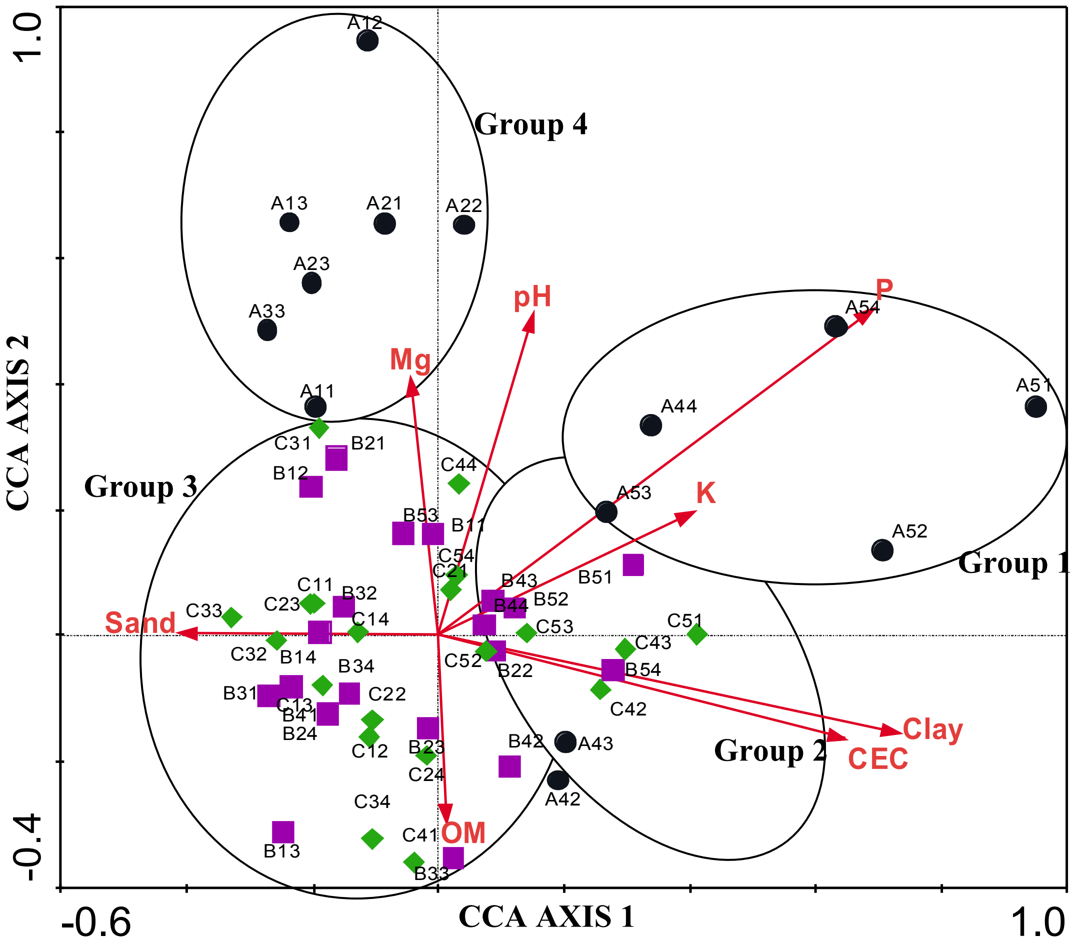


Figure 15. Canonical correspondence analysis (CCA) ordination diagram indicating the influence of soil properties on vegetation composition around water points in the Waterberg Plateau Park, Central Namibia. ● = 0 m, ■ = 200 m and ♦ = 500 m

CHAPTER 5

DISCUSSION

5.1 Impacts of large herbivores on vegetation structure

The significant differences detected in vegetation structure were only between 0 m and the other distances from the water (Figs. 5, 6, 7, 8 and 10). The rapid increase in vegetation cover, density and basal area from the former distance to the latter distances is an indication that the area around the water points is highly degraded by large herbivores. This area in the immediate vicinity of the water point contained no or very little vegetation, mainly due to trampling and over-utilization for many years. It therefore generally corresponds to the sacrifice zone, which is described by Parker and Witkowski (1999), as a distinct zone extending out from the edge of the water points in which only annual, pioneer plants survive.

According to James *et al*., (1999), the sacrifice zone can be bare during dry periods, but supports short-lived, often unpalatable, trample resistant “increaser” species after rain. Most of the plots at 0 m in this study were bare, possibly because those areas have been exposed to such intense degradation by large herbivores, that even increaser species have become overused (http://www.fhsu.edu/biology/ranpers/ert/success.htm). Another reason for that result might be that those areas have been exposed to sustained disturbance by large herbivores, leading to the local extinction of some species due to the depletion of the soil seed bank (James *et al*., 1999).

No significant differences were detected in density, cover and basal area, among 100 m, 200 m, 300 m and 500 m from the water points (Figs. 5, 6, 7, 8 and 10). A possible reason may be because while the first plots (0 m) always fell within an area of high degradation, the other distances may have fallen within areas of different levels of degradation at different water points. These different levels of degradation may depend on the number of large herbivores visiting the specific water point and their residence periods in areas around the water points. This consequently masked the differences in vegetation structure among the above-mentioned distances although there were trends suggesting an increase with increasing distance from the water, especially in tree densities (both individual and stem densities).

The significantly high densities of shrubs and saplings at the four distances further away from the water points in the Waterberg Plateau Park may be further explained by a reduction of fires occurring in the park through controlled burning (Erckie, J. B.: personal communication, October, 2008). According to Thomas and Douglas (1999), shrubs are more susceptible to fires than grasses, and so a reduction in fire frequency and/or intensity can promote shrub establishment. Mapaure (2001) confirmed that argument in his finding that shrub densities increased in the Sengwa Wildlife Research Area (SWRA), with reduced fire intensities. Therefore the fires in the WPP might be frequent enough to keep the woody plants from growing into trees, but not too frequent to prevent shrub and sapling establishment at the above-mentioned distances.

The height class distribution throughout the study area generally portrayed a similar trend to that of basal area class distribution, with a high proportion of shrubs and saplings corresponding to a high proportion of plants with smaller basal areas. The presence of trees around the water points, although very few, may indicate that these trees were already very large by the time the water points were established therefore they could not be trampled by large herbivores. The woody species at the water points may also be able to grow tall and large because they are able to fully utilize water (both surface and deeper water) and nutrients, due to the low densities and therefore reduced competition for such resources. Another explanation for the above-mentioned result may be a reduction in fire frequencies and intensity around the water points due to the removal of grasses (fuel) (Vesey-Fitzgerald, 1973).

Large herbivore disturbance through browsing may have contributed to stunting of woody vegetation at the four distances further away from the water points, resulting in a high proportion of shorter woody plants (height classes <1 m, 1- 1.9 m and 2-2.9 m). Other factors such as competition for water and nutrients, and may be the occasional fires, may have further contributed to the high proportion of smaller, shorter woody plants (shrubs and saplings) at those distances.

5.2 Impacts of large herbivores on plant species richness, composition and diversity

Both species richness and diversity were lowest at 0 m and highest at 500 m from the water, but there were no significant differences from 100 m to higher distances (Table 1). This decrease in species richness and diversity is the result of the high intensities of browsing, grazing and trampling by large herbivores around the water points. Trampling may induce physiological changes that lead to a change in competition parameters between species, altering plant species, which can inhibit primary production (de Mazancourt, *et al*., 1999). The result of that in the WPP was very few tolerant species to no species at all found within 20 m from the water. The above argument is supported by Mysterud (2006), that herbivory may decrease plant species richness, depending on factors such as grazing or browsing intensity and nutrient availability.

The dominant plant species at various distances from the water may further demonstrate the impact of large herbivores around water points in the Waterberg Plateau Park. *Stipagrostis hirtigluma* subsp. *pearsonii*, the common grass species at 0 m, but with a very low cover compared to grass species at further distances is an annual, pioneer grass and not highly palatable grazing (Muller, 1984). Grass species generally dominating at further distances include *Eragrostis pallens*, *Aristida stipitata* subsp. *stipitata* and *Aristida stipitata* subsp. *graciliflora*. These *Aristida* subspecies are woody, pioneer grasses, which have little forage value (Muller, 1984). *Eragrostis pallens* is a coarse, densely tufted perennial, a climax grass of the central and northern Kalahari, which is abundant in the *Terminalia sericea*-veld (Muller, 1984). The above-mentioned dominant Aristidae (*Aristida* and *Stipagrostis*) species are typically found in the arid regions of southern Kalahari (Scholes *et al*., 2002). Therefore, although these species are not highly palatable to herbivores, their presence in the study area may not necessarily indicate that large herbivore disturbance has resulted in a degradation of the rangeland, as they naturally occur in undisturbed Kalahari veld.

The most common forb species throughout the study area, especially at distances further away from the water, was *Phyllanthus pentandrus*, which is an annual or sub-perennial herb, often a weed of cultivated and disturbed ground in sandy localities (Radcliffe-Smith, 1996). The presence of this species in large numbers may be an indicator that there is high disturbance by large herbivores within the study area, which may further suggest that the entire study area falls within highly disturbed areas by large herbivores.

Common woody species in the study area were *Ochna pulchna, Terminalia sericea*, *Combretum collinum*, *Combretum psidioides* and *Acacia ataxacantha*. The above-mentioned woody species also confirm those commonly found in the park by Erb (1993). According to Mapaure (2001), species, which survive better in disturbed areas, will increase in numbers through proliferation of originally present cohorts and/or by invasion. This process leads to changes in the species composition, richness and diversity of the rangeland (Mapaure, 2001). Rangelands that have undergone such changes may then be maintained at the new state by large herbivores and fire (Mapaure, 2001). In his study, Mapaure (2001) observed that species like *Terminalia sericea* and *Combretum collinum* had a high potential to increase with large herbivore (elephant) disturbance, particularly on loose sands. Therefore, although species such as *Terminalia sericea* and *Combretum collinum* naturally occur on loose sands, they may increase in numbers when these areas are disturbed, therefore changing the species diversity of the area.

Another reason that may further explain the species composition within the study area may be the distribution of water points in the park. Water points that are too far apart may result in gaps of un-utilized areas of the rangeland, whereas water points that are too close to each other may cause severe over-utilization and trampling of the rangeland (Du Toit and Van Rooyen, 2002). The distances between the artificial water points in the Waterberg Plateau Park (shortest distances, using GPS, given in a clockwise order) do not exceed 6 km. Considering that mobile water-dependent indigenous large herbivores are readily able to forage up to 10 km from water (Thrash, 2000), the areas between water points in the WPP, are easily accessible to large herbivores. These areas are therefore in danger of over-utilization by large herbivores with increasing impact that may lead to bush encroachment (Du Toit and Ebedes, 2002), changing the species composition of the area.

Such a change may also affect other large herbivore species such as the Roan and Sable antelope which are endangered species. These animals require tall grass in which to forage and in which their young may remain hidden, and are thus usually associated with areas of low herbivore use intensity (Thrash, *et al*., 1995).

It should however be noted that the higher levels of degradation at the water points in comparisons to distances further away from the water may not be avoided (Mphinyane, 2001). This is because even those areas that are properly stocked may be degraded near the water points, due to the fact that around water points large herbivores aggregate in a small area; feeding, trampling, defecation and urinating (Mphinyane, 2001). As this study indicated, such degradation leads to changes in species composition, and a decrease in species richness and diversity around the water points. With increasing distance from the water there is an exponential increase in the size of the feeding area. Therefore the impact of large herbivores decreases and become negligent at greater distances from the water, depending on how far from the water points the animals are able to travel (James *et al*., 1999).

5.3 Variation in physical and chemical properties in the soil due to large herbivore activities

Soil pH, Phosphorus, Potassium, Calcium, Magnesium, Sodium and Sand content were higher at the water point than at distances further away (Table 2). The above-mentioned soil nutrients (cations) are being deposited into the soil in high amounts by large herbivores through urine. The soils around the water points have a high percentage of sand and sandy soils have a low electrical charge to bind cations (Ketterings *et al*., 2007). Therefore there were high levels of these unbound elements closer to the water.

Soil organic matter and clay content were lower at 0 m compared to further away from the water point (Table 2). This is due to the presence of vegetation at the further distances from the water point protecting the soil from erosion, and introducing organic matter into the soil through dead plant materials, like leaves and roots. As a result there are higher biological activities in the soil further away from the water points, than close to them. The presence of vegetation and the introduction of organic matter in the soil in turn reduces the porosity of the soil, thus protecting the small clay particles from being washed deep into the soil. This resulted in significantly higher clay content at the four distances further away from the water than around the water points.

Sandy soils have a low CEC and therefore they are not able to bind a high amount of cations (Ketterings, *et al*., 2007). Low CEC soils are more likely to develop potassium and magnesium (and other cation) deficiencies, while high CEC soils are less susceptible to leaching losses of these cations (Ketterings, *et al*., 2007). While the other cations were higher in the topsoil, potassium was higher in the sub-soil. Potassium is usually highly soluble, and as a result is leached from the soil faster than the other cations (Vitosh, 2005).

The soil clay content, pH, P and Ca levels (Table 2), in this study fell within the ranges established in previous studies for the WPP (Erb, 1993; Erckie, 2007). These values were generally described as being relatively low and this confirms the soils of WPP as being nutrient-poor. This study also confirms the findings that ecosystems where water or nutrients are limiting plant growth, as in most semi-arid regions, experience declines in plant growth when loss of nutrients occurs (van de Koppel, *et al*., 1997).

5.4 Overall determinants of vegetation structure, composition and range condition

Vegetation associations in this study did not represent a clear separation of the plots according to the four distances away from the water points, but there was an indication of an association of the plots at the water point, most of which showed a clear grouping in the HCA sub-cluster 5D (Fig. 13). A few HCA clusters separated the plots into floristic associations according to water points; such as cluster 1, which clustered plots from Securidaca and Elandsdrink together; cluster 3, which clustered plots from Kiewietdrink and Elandsdrink together; cluster 4 which clustered plots from Geelhout and Duitsepos together; cluster 9, which was confined to Elandsdrink; and cluster 10, which was confined to Securidaca (Fig. 13). This clustering suggests that large herbivores have different degrees of impacts at the different water points and/or that there are other factors influencing species composition around different water points in addition to herbivory. Such factors may include the influence of fire, plant available moisture and plant available nutrients.

Although there was a separation of plots into two main groups along DCA axis 1 (Fig. 14), it should be noted that an overlap exists between the two groups, suggesting a more complex relationship than just the influence of large herbivores on plant species composition. This complex relationship may be due to different degrees of degradation at the different water points, as a result of the number and type of large herbivores visiting the water points and/or the above-mentioned factors. In a case where the highly degraded area at some water points extended beyond 20 m, all the plots within the highly degraded area, irrespective of distance from the water point, grouped together. Therefore, since the size of the sacrifice area is different at the different water points, a complex grouping of the plots emerged. Only 49 % of the variation in species composition was explained along DCA axis 1.

The CCA generally grouped the plots from Elandsdrink and Kiewietdrink together and those from Geelhout, Duitsepos and Securidaca together (Fig. 15). This separation was also observed in the HCA clusters 3, 4, 9 and 10 (Fig. 13), suggesting that the impact of large herbivores at water points in the WPP varies among water points, as was evident in the complex DCA grouping (Fig. 14). It should further be noted that although CCA groups 1 and 4 both consisted of plots at the water points, they were grouped separately (Fig. 15). This clearly indicates that there is a disturbance gradient between the two groups, with Group 4, which is characterized by very low vegetation cover being more degraded than Group 1. It is therefore hypothesized that Group 1 will eventually move towards group 4 with more degradation.

The CCA indicated a clear influence of phosphorus, cation exchange capacity and clay content on plant composition (Fig. 15). Together, all the explanatory variables used in the CCA analysis accounted for 20.7 % of the observed variation in species composition. Phosphorus was the most important environmental variable influencing species composition along CCA axis 1, clearly indicating that species composition at Kiewietdrink was a result of significantly higher levels of phosphorus at 0 m than at the other distances from the water point. Both cation exchange capacity and clay significantly influenced species composition at Kiewietdrink and Elandsdrink. The above-mentioned results were expected as large herbivores aggregate around water points, constantly introducing phosphorus into the soil through urine (Ruess, 1987), and also influence clay and CEC through the removal of vegetation around water points. The other measured variables did not have a significant influence on the species composition in the study area, again suggesting that there are other environmental variables not measured in this study, which may explain the groupings of plots in the CCA ordination diagram (Fig. 15).

The mean relative proportions of increaser grasses were significantly higher than these of decreaser and unclassified grasses throughout the study areas (Fig. 12). Decreaser grasses, although low in cover throughout the study, displayed a pattern of decline with increasing distance from the water point, and at 500 m, the grass species composition was restricted to increaser species (Fig. 12). As the area at 500 m is the furthest from the water point and may therefore serve as a control, the WPP may naturally be dominated by increaser species. Decreaser grasses may only appear following high degradation as was found to be the case around the water points. Further supporting this argument, most of the grass species dominant in the study area were increasers belonging to the genus *Aristida* and *Stipagrostis*, which according to Scholes *et al*. (2002), are typical inhabitants of ecosystems such as that of WPP. The increaser-decreaser concept might therefore not be a suitable way of determining range condition in the Waterberg Plateau Park, or in Kalahari sand-dominated landscapes in general.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

It was evident in the HCA, DCA, and CCA that large herbivores led to significant changes in species composition around the water points in the WPP, leading to the acceptance of hypothesis (a). The Hierarchical Cluster Analysis and Canonical Correspondence Analysis indicated that species composition also differed among water points. This led to the conclusion that the species composition around water points in the WPP may depend on a combination of factors such as type and number of large herbivores, fire, soil available moisture and soil available nutrients. Therefore, there is a difference in the impact of large herbivores at different water points, depending on the nature of interactions among these determinants.

The grouping of plots in the DCA ordination diagram was therefore a result of plots at different distances, at different water points, having similar levels of degradation. It can also be due to that plots at the same distance at different water points had different levels of degradation. This grouping of plots due to the different levels of degradation at different water points masked the impact of large herbivores on species composition at the further four distances from the water. Thus, the degradation gradient is more complex than initially thought.

Plant species richness and species diversity were significantly lower around water points in the Waterberg Plateau Park. This was a result of high intensities of herbivory and trampling, which led to only a few tolerant species to no species at all surviving at the water points. This study therefore accepts hypothesis (b), concluding that large herbivores led to a decline in plant species richness and diversity around water points in the Waterberg Plateau Park.

Vegetation cover and densities were significantly lower around water points, in the Waterberg Plateau Park due to high levels of herbivory and trampling. The few woody plants at the water points were mostly large and tall. This led to the conclusion that the trees at that distance were already large by the time the water points were established and therefore were not trampled by large herbivores. The reduction in fire frequencies around the water points due to the removal of grasses by large herbivores may be another reason for the tall, large trees at the water points. It was also concluded that these trees may be less preferred by large herbivores and/or are tolerant to the disturbance, and they are also able to maximize water and nutrient uptake due to reduced competition. The other distances had a higher proportion of short and small woody species compared to tall large trees, probably due to the stunting of woody species through browsing, high competition for soil nutrients and water and the occasional fires. This study therefore accepts hypothesis (c), concluding that large herbivores led to significant changes in vegetation structure around water points in the Waterberg Plateau Park.

As it was hypothesized (hypothesis d), soil phosphorus levels were higher closest to the water point than at further distances from the water. This is a result of the nutrient input through dung and urine, by large herbivores aggregating at the water points.

There were significantly higher cations (Potassium, Calcium, Magnesium, Sodium) at the water points because sandy soils have a low CEC. The soils at the water points had significantly higher sand content, resulting in a significantly higher amount of unbound cations in the soil. Soil clay and organic matter contents were significantly higher at the four distances further away from the water, due to the significantly higher plant densities, introducing organic matter into the soil. The organic matter introduced into the soil through plant material further reduces deep drainage and thus protects clay particles from being washed deeper down the profile. Potassium was higher in the subsoil than in the topsoil, because its high solubility leads to it being leached faster than the other elements in the soil. It was concluded that large herbivores led to differences in the soil chemical and physical properties around water points in the WPP, through removal of vegetation and the effects of high amounts of dung and urine added to the soil. This led to the acceptance of hypothesis (d).

This study could not determine the condition of the range with the increaser-decreaser concept, and therefore no concrete conclusion was drawn regarding the condition of the range using that method. Hypothesis (e) could therefore not be accepted or rejected based on that concept. It should however be noted that the results of vegetation structural attributes, species richness and diversity, HCA, DCA and CCA, generally suggested high degradation around water points due to large herbivore activities.

6.2 Recommendations

a) This study has shown that introduction of artificial water points lead to a reduction in species diversity due to repeated year round utilization by large herbivores. Management goals should therefore focus on the maintenance of biodiversity and natural ecological processes of the ecosystem. It is recommended that access to the water points in the WPP be rotated in order to minimize the level of degradation around the water points. Such a system will allow some watering points to be filled and others to rest and recover for a year while the others are being utilized, and then the ones that were in use rest while the rested ones are utilized.

b) The location of water points is crucial with respect to the impact of large herbivores around water points, as it determines the area that is easily accessible to large herbivores and therefore highly impacted. It is recommended that in addition to the above recommendation, a water provision system of clusters of watering points separated by large waterless areas, as proposed by Thrash (2000), be adopted. Therefore one cluster of water points will be used for a year, and another cluster for the following year. The rotation will in turn also minimize the impact of water points located too close to each other. This kind of system is suitable for the WPP because it will allow the park to have areas further than the distance from the water in which large herbivores are readily able to forage. These areas will therefore be less impacted by large herbivores and "shy" species like roan antelope and sable antelope can forage and have young hidden in such areas.

In order to avoid few or many clusters and/or water points in the park, the size of the park should be used as guide to determining the number of clusters and water points per cluster.

c) In order to further reduce the overall residence time of large herbivores around water points, it is recommended that the mineral supplements (salt licks) be provided throughout the park, and not just at the water points. As a result, water-independent large herbivores will have reduced residence time at the water points.

d) As it was evident in the grouping of plots in the classification and ordination diagrams; vegetation composition, structure and diversity within the study area are affected by a combination of factors. For long-term monitoring, the data of this study should therefore be used in conjunction with other management plans that are in place; such as fire management plans (Ruess and Halter, 2008). This will be essential to the understanding of long-term changes in soils and vegetation in the Waterberg Plateau Park.

e) Future studies should consider the size of the sacrifice area at each water point as a guide to sampling design, rather than systematically using the distance from the water as a gradient at which the impacts of large herbivores are determined.

f) Further research should concentrate on developing a reliable way of determining range condition in ecosystems naturally dominated by increaser grass species with less reliance on the increaser-decreaser concept.

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APPENDICES

Appendix 1. Water point game counts in the WPP for August 2003, September 2006, July 2007 and August 2007 (obtained from the Onjoka office, WPP)

Game Species	Aug.-03	Sept.-06	Jul.-07	Aug.-07
Black Rhino (*Diceros bicornis*)	56	29	39	56
White Rhino (*Ceratotherium simum*)	50	36	36	17
Buffalo (*Syncerus caffer*)	323	373	589	642
Roan antelope (*Hippotragus equinus*)	131	164	149	166
Sable antelope (*Hippotragus niger*)	71	37	72	187
Red hartebeest (*Alcelaphus buselaphus*)	16	14	8	49
Giraffe (*Giraffa camelopardalis*)	5	11	87	89
Eland (*Taurotragus oryx*)	422	299	496	475
Oryx (*Oryx gazella*)	32	11	31	21
Kudu (*Tragelaphus strepsiceros*)	65	89	77	86
Duiker (*Sylvicapra grimmia*)	1	9	4	5
Steenbok (*Rhaphicerus campestris*)	1	0	1	0
Springbok (*Antidorcas marsupialis*)	0	0	0	1
Tsessebee (*Damaliscus lunatus*)	1	11	4	0
Warthog (*Phacochoerus aethiopicus*)	99	37	116	155
Baboon (*Papio sp.)*	130	0	3 trps	1 trp
Porcupine (*Hystrix cristata*)	1	1	1	6
Honey badger (*Mellivora capensis*)	2	0	0	2
Brown hyaena (*Hyaena brunnea*)	1	0	0	1
Leopard (*Panthera pardus*)	0	0	0	0
Cheetah (Acinonyx jubatus)	0	0	0	0
Jackal (*Canis mesomelas*)	26	9	1	0
Total	1433	1130	1714	1959

Appendix 2. Game counts at the water points selected for the study, for August 2003, September 2006, July 2007 and August 2007 (obtained from the Onjoka office, WPP)

A: Geelhout

Game Species	**Aug.-03**	**Sept.-06**	**Jul.-07**	**Aug.-07**
Black Rhino (*Diceros bicornis*)	11	6	3	4
White Rhino (*Ceratotherium simum*)	18	14	3	2
Buffalo (*Syncerus caffer*)	56	93	40	81
Roan antelope (*Hippotragus equinus*)	63	47	51	50
Sable antelope (*Hippotragus niger*)	8	0	1	1
Red hartebeest (*Alcelaphus buselaphus*)	1	0	0	7
Giraffe (*Giraffa camelopardalis*)	0	1	0	4
Eland (*Taurotragus oryx*)	79	38	81	168
Oryx (*Oryx gazella*)	0	0	0	0
Kudu (*Tragelaphus strepsiceros*)	0	0	0	0
Duiker (*Sylvicapra grimmia*)	0	0	0	1
Springbok (*Antidorcas marsupialis*)	0	0	0	0
Tsessebee (*Damaliscus lunatus*)	0	0	0	1
Warthog (*Phacochoerus aethiopicus*)	21	0	24	32
Baboon (*Papio sp.*)	39	0	1	0
Jackal (*Canis mesomelas*)	1	0	0	1
Porcupine (*Hystrix cristata*)	0	0	1	1
Brown hyena (*Hyaena brunnea*)	0	0	0	0
Honey badger (*Mellivora capensis*)	0	0	0	0
Total	**297**	**199**	**205**	**353**

B: Duitsepos

Game Species	Aug.-03	Sept.-06	Jul.-07	Aug.-07
Black Rhino (*Diceros bicornis*)	0	7	7	8
White Rhino (*Ceratotherium simum*)	8	5	2	0
Buffalo (*Syncerus caffer*)	0	141	273	238
Roan antelope (*Hippotragus equinus*)	0	28	23	4
Sable antelope (*Hippotragus niger*)	0	29	4	129
Red hartebeest (*Alcelaphus buselaphus*)	3	8	7	13
Giraffe (*Giraffa camelopardalis*)	4	6	14	22
Eland (*Taurotragus oryx*)	0	26	68	61
Oryx (*Oryx gazella*)	0	0	11	5
Kudu (*Tragelaphus strepsiceros*)	0	16	15	27
Duiker (*Sylvicapra grimmia*)	0	0	4	1
Springbok (*Antidorcas marsupialis*)	0	0	0	0
Tsessebee (*Damaliscus lunatus*)	0	0	0	0
Warthog (*Phacochoerus aethiopicus*)	0	7	27	31
Baboon (*Papio sp.*)	0	0	0	0
Jackal (*Canis mesomelas*)	0	2	1	0
Porcupine (*Hystrix cristata*)	1	0	0	0
Brown hyena (*Hyaena brunnea*)	0	0	0	0
Honey badger (*Mellivora capensis*)	2	0	0	0
Total	**18**	**275**	**456**	**539**

C: Securidaca

Game Species	**Aug.-03**	**Sept.-06**	**Jul.-07**	**Aug.-07**
Black Rhino (*Diceros bicornis*)	7	3	0	4
White Rhino (*Ceratotherium simum*)	4	0	7	0
Buffalo (*Syncerus caffer*)	40	14	67	86
Roan antelope (*Hippotragus equinus*)	8	33	34	47
Sable antelope (*Hippotragus niger*)	1	0	10	9
Red hartebeest (*Alcelaphus buselaphus*)	5	6	0	19
Giraffe (*Giraffa camelopardalis*)	0	0	40	0
Eland (*Taurotragus oryx*)	61	45	117	47
Oryx (*Oryx gazella*)	1	6	0	0
Kudu (*Tragelaphus strepsiceros*)	11	18	21	9
Duiker (*Sylvicapra grimmia*)	0	0	0	0
Springbok (*Antidorcas marsupialis*)	0	0	0	0
Tsessebee (*Damaliscus lunatus*)	0	0	0	0
Warthog (*Phacochoerus aethiopicus*)	9	4	0	11
Baboon (*Papio sp.*)	0	0	0	0
Jackal (*Canis mesomelas*)	0	1	0	0
Porcupine (*Hystrix cristata*)	0	0	0	0
Brown hyena (*Hyaena brunnea*)	0	0	0	0
Honey badger (*Mellivora capensis*)	0	0	0	2
Total	**147**	**130**	**296**	**234**

D: Elandsdrink

Game Species	**Aug.-03**	**Sept.-06**	**Jul.-07**	**Aug.-07**
Black Rhino (*Diceros bicornis*)	2	1	4	9
White Rhino (*Ceratotherium simum*)	2	2	4	0
Buffalo (*Syncerus caffer*)	64	41	87	35
Roan antelope (*Hippotragus equinus*)	1	10	17	30
Sable antelope (*Hippotragus niger*)	0	1	2	4
Red hartebeest (*Alcelaphus buselaphus*)	0	0	0	0
Giraffe (*Giraffa camelopardalis*)	0	0	4	5
Eland (*Taurotragus oryx*)	0	56	22	10
Oryx (*Oryx gazella*)	0	4	5	7
Kudu (*Tragelaphus strepsiceros*)	7	23	7	6
Duiker (*Sylvicapra grimmia*)	0	0	0	0
Springbok (*Antidorcas marsupialis*)	0	0	0	0
Tsessebee (*Damaliscus lunatus*)	0	11	0	0
Warthog (*Phacochoerus aethiopicus*)	1	0	13	18
Baboon (*Papio sp.*)	0	0	1	0
Jackal (*Canis mesomelas*)	0	0	0	0
Porcupine (*Hystrix cristata*)	0	0	0	0
Brown hyena (*Hyaena brunnea*)	0	0	0	0
Honey badger (*Mellivora capensis*)	0	0	0	0
Total	**77**	**149**	**166**	**124**

E: Kiewietdrink

Game Species	Aug.-03	Sept.-06	Jul.-07	Aug.-07
Black Rhino (*Diceros bicornis*)	14	11	15	12
White Rhino (*Ceratotherium simum*)	9	0	16	8
Buffalo (*Syncerus caffer*)	1	2	1	18
Roan antelope (*Hippotragus equinus*)	26	0	5	12
Sable antelope (*Hippotragus niger*)	28	1	36	11
Red hartebeest (*Alcelaphus buselaphus*)	0	0	0	0
Giraffe (*Giraffa camelopardalis*)	0	4	0	1
Eland (*Taurotragus oryx*)	69	62	19	26
Oryx (*Oryx gazella*)	23	1	9	0
Kudu (*Tragelaphus strepsiceros*)	16	14	3	0
Duiker (*Sylvicapra grimmia*)	0	0	0	0
Springbok (*Antidorcas marsupialis*)	0	0	0	0
Tsessebee (*Damaliscus lunatus*)	0	0	0	0
Warthog (*Phacochoerus aethiopicus*)	21	4	10	0
Baboon (*Papio sp.)*	0	0	0	0
Jackal (*Canis mesomelas*)	4	0	0	0
Porcupine (*Hystrix cristata*)	0	0	0	0
Brown hyena (*Hyaena brunnea*)	0	0	0	0
Honey badger (*Mellivora capensis*)	0	0	0	0
Total	**211**	**99**	**114**	**88**

Appendix 3. The GPS readings of all the plots

Water point	Transect direction	Distance from water	Degrees S	Degrees E
Geelhout	Southwest	0	20°28.564'	017°14.619'
Geelhout	Southwest	100	20°28.571'	017°14.565'
Geelhout	Southwest	200	20°28.574'	017°14.509'
Geelhout	Southwest	300	20°28.586'	017°14.453'
Geelhout	Southwest	500	20°28.583'	017°14.335'
Geelhout	Northeast	0	20°28.554'	017°14.637'
Geelhout	Northeast	100	20°28.551'	017°14.697'
Geelhout	Northeast	200	20°28.545'	017°14.762'
Geelhout	Northeast	300	20°28.546'	017°14.821'
Geelhout	Northeast	500	20°28.534'	017°14,932
Geelhout	Southeast	0	20°28.558'	017°14.645'
Geelhout	Southeast	100	20°28.596'	017°14.683'
Geelhout	Southeast	200	20°28.635'	017°14.722
Geelhout	Southeast	300	20°28.661'	017°14.775'
Geelhout	Southeast	500	20°28.691'	017°14.891'

Geelhout	Northwest	0	20°28.544'	017°14.623'
Water point	**Transect direction**	**Distance from water**	**Degrees S**	**Degrees E**
Geelhout	Northwest	100	20°28.497'	017°14.603'
Geelhout	Northwest	200	20°28.445'	017°14.588'
Geelhout	Northwest	300	20°28.395'	017°14.569'
Geelhout	Northwest	500	20°28.291'	017°14.532'
Duitsepos	Southwest	0	20°23.570'	017°18.150'
Duitsepos	Southwest	100	20°23.595'	017°18.106'
Duitsepos	Southwest	200	20°23.618'	017°18.050'
Duitsepos	Southwest	300	20°23.651'	017°18.007'
Duitsepos	Southwest	500	20°23.715'	017°17.915'
Duitsepos	Northeast	0	20°23.547'	017°18.166
Duitsepos	Northeast	100	20°23.530'	017°18.219'
Duitsepos	Northeast	200	20°23.513'	017°18.274'
Duitsepos	Northeast	300	20°23.492'	017°18.327'
Duitsepos	North east	500	20°23.451'	017°18.434'
Duitsepos	Southeast	0	20°23.562'	017°18.173'
Duitsepos	Southeast	100	20°23.589'	017°18.215'
Duitsepos	Southeast	200	20°23.620'	017°18.266'
Duitsepos	Southeast	300	20°23.645'	017°18.134'
Duitsepos	Southeast	500	20°23.696'	017°18.413'
Duitsepos	Northwest	0	20°23.557'	017°18.145'
Duitsepos	Northwest	100	20°23.526'	017°18.101'
Duitsepos	Northwest	200	20°23.492'	017°18.059'
Duitsepos	Northwest	300	20°23.459'	017°18.016'
Duitsepos	Northwest	500	20°23.403'	017°17.910'
Securidaca	Southwest	0	20°21.669'	017°22.863'
Securidaca	Southwest	100	20°21.701'	017°22.824'
Securidaca	Southwest	200	20°21.742'	017°22.782'
Securidaca	Southwest	300	20°21.777'	017°22.741'
Securidaca	Southwest	500	20°21.855'	017°22.666'
Securidaca	Northeast	0	20°21.645'	017°22.880'
Securidaca	Northeast	100	20°21.607'	017°22.912'
Securidaca	Northeast	200	20°21.564'	017°22.947'
Securidaca	Northeast	300	20°21.515'	017°22.973'
Securidaca	North east	500	20°21.475'	017°23.096'
Securidaca	Southeast	0	20°21.659'	017°22.883'
Securidaca	Southeast	100	20°21.666'	017°22.936'
Securidaca	Southeast	200	20°21.685'	017°22.990'
Securidaca	Southeast	300	20°21.713'	017°23.042'
Securidaca	Southeast	500	20°21.767'	017°23.146'
Securidaca	North west	0	20°21.656'	017°22.858'
Securidaca	Northwest	100	20°21.642'	017°22.807'

Securidaca	Northwest	200	20°21.616'	017°22.754'
Securidaca	Northwest	300	20°21.595'	017°22.701'
Securidaca	Northwest	500	20°21.542'	017°22.602'
Water point	**Transect direction**	**Distance from water**	**Degrees S**	**Degrees E**
Elandsdrink	Southwest	100	20°19.269'	017°22.487'
Elandsdrink	Southwest	200	20°19.303'	017°22.441'
Elandsdrink	Southwest	300	20°19.342'	017°22.401'
Elandsdrink	Southwest	500	20°19.413'	017°22.319'
Elandsdrink	Northeast	0	20°19.199'	017°22.534'
Elandsdrink	Northeast	100	20°19.165'	017°22.560'
Elandsdrink	Northeast	200	20°19.122'	017°22.599'
Elandsdrink	Northeast	300	20°19.081'	017°22.635'
Elandsdrink	Northeast	500	20°19.001'	017°22.717'
Elandsdrink	Southeast	0	20°19.220'	017°22.544'
Elandsdrink	Southeast	100	20°19.245'	017°22.593'
Elandsdrink	Southeast	200	20°19.257'	017°22.650'
Elandsdrink	Southeast	300	20°19.279'	017°22.700'
Elandsdrink	Southeast	500	20°19.300'	017°22.802'
Elandsdrink	Northwest	0	20°19.222'	017°22.516'
Elandsdrink	Northwest	100	20°19.191'	017°22.470'
Elandsdrink	Northwest	200	20°19.175'	017°22.421'
Elandsdrink	Northwest	300	20°19.151'	017°22.368'
Elandsdrink	Northwest	500	20°19.127'	017'22.258'
Kiewietdrink	Southwest	0	20°18.507'	017°19.365'
Kiewietdrink	Southwest	100	20°18.563'	017°19.348'
Kiewietdrink	Southwest	200	20°18.611'	017°19.331'
Kiewietdrink	Southwest	300	20°18.657'	017°19.302'
Kiewietdrink	Southwest	500	20°18.761'	017°19.257'
Kiewietdrink	Northeast	0	20°18.481'	017°19.374'
Kiewietdrink	Northeast	100	20°18.452'	017°19.408'
Kiewietdrink	Northeast	200	20°18.421'	017°19.455'
Kiewietdrink	Northeast	300	20°18.386'	017°19.500'
Kiewietdrink	Northeast	500	20°18.317'	017°19.587'
Kiewietdrink	Southeast	0	20°18.496'	017°19.376'
Kiewietdrink	Southeast	100	20°18.526'	017°19.425'
Kiewietdrink	Southeast	200	20°18.561'	017°19.470'
Kiewietdrink	Southeast	300	20°18.600'	017°19.511'
Kiewietdrink	Southeast	500	20°18.666'	017°19.600'
Kiewietdrink	Northwest	0	20°18.490'	017°19.352'
Kiewietdrink	Northwest	100	20°18.460'	017°19.313'
Kiewietdrink	Northwest	200	20°18.420'	017°19.276'
Kiewietdrink	Northwest	300	20°18.389'	017°19.227'
Kiewietdrink	Northwest	500	20°18.339'	017°19.126'

Appendix 4. The list of plant species recorded in the study area during the study

Number	Species
1	*Acacia ataxacantha* DC.
2	*Acacia fleckii* Schinz
3	*Achyranthes aspera* var.*sicula* L.
4	*Ancylanthos rubiginous* Desf.
5	*Andropogon gayanus var. polycladus* (Hack.) W.D.Clayton
6	*Aristida meridionalis* Henrard
7	*Aristida stipitata* subsp. *graciliflora* (Pilg.) Melderis
8	*Aristida stipitata* subsp. *Stipitata* Hack.
9	*Bauhinia petersiana* Bolle
10	*Burkea africana* Hook.
11	*Chamaecrista biensis* (Steyaert) Lock
12	*Combretum collinum* Fresen.
13	*Combretum psidioides* Welw.
14	*Commelina africana africana* L.
15	*Croton gratissimus* Burch.
16	*Cyperus margaritaceus* Vahl
17	*Dicoma anomala* Sond. subsp. *gerrardii* (Harv. ex F.C.Wilson) S.Ortíz & Rodr.Oubiña
18	*Digitaria seriata* Stapf
19	*Eragrostis omahekensis* De Winter
20	*Eragrostis pallens* Hack.
21	*Euphorbia forksalii* J.Gay
22	*Fimbristylis exilis* (Kunth) Roem. & Schult.
23	*Grewia sp.* (Herb Linn)
24	*Hermbstaedtia odorata* Burchell T. Cooke
25	*Indigofera daleoides* Benth. ex Harv.
26	*Ipomoea welwitschii* Vatke ex Hallier f.
27	*Ipomoea chloroneura* Hallier f.
28	*Limeum fenestratum* (Fenzl) Heimerl
29	*Limeum sulcatum* var. *sulcatum* (Klotzsch) Hutch.
30	*Lonchocarpus nelsii* (Schinz) Heering & Grimme
31	*Melhania acuminata* Mast.
32	*Melinis repens* subsp. *grandiflora* Hochst. Zizka
33	*Melinis repens* (Willd.) Zizka subsp. *repens* (Willd.) Zizka
34	*Merremia tridentata* subsp. *angustifolia* Jacq. van Ooststr.

35	*Mollugo cerviana* (L.) Ser. ex DC.
36	*Ochna pulchra* Hook.
37	*Otoptera burchellii* DC.
38	*Peltophorum africanum* Sond.
39	*Phyllanthus omahekensis* Dinter & Pax
40	*Phyllanthus pentandrus* Schumach. & Thonn.
41	*Pogonarthria squarrosa* (Roem. & Schult.) Pilg.
42	*Polygala pygmaea* Gürke
43	*Sida cordifolia* L.
44	*Spermacoce subvulgata* var. *subvulgata* (K. Schum.) Garcia
45	*Stipagrostis hirtigluma* (Steud. ex Trin. & Rupr.) De Winter var. *pearsonii* Henrard
46	*Talinum arnotii* Hook.f.
47	*Tephrosia purpurea* (Linn.) Pers.
48	*Terminalia sericea* DC.
49	*Tricholaena monachne* (Trin.) Stapf & C.E.Hubb.
50	*Tribulus terrestris* L.
51	*Vernonia poskeana* Vatke & Hildebr. subsp. *bostwanica* G.V. Pope
52	*Ximenia americana* L.
53	*Ximenia caffra* Sond.
54	*Ziziphus mucronata* Willd.

Appendix 5. Classification of grass species recorded in the study (Gambiza J.: personal communication, August, 2008; Vorster, 1999)

Grass	Classification
Andropogon gayanus var. *polycladus*	Decreaser
Aristida meridionalis	Increaser
Aristida stipitata subsp. *graciliflora*	Increaser
Aristida stipitata subsp. *stipitata*	Increaser
Digitaria seriata	Unclassified
Eragrostis omahekensis	Unclassified
Eragrostis pallens	Increaser
Melinis repens subsp. *grandiflora*	Unclassified
Melinis repens subsp. *repens*	Increaser
Tricholaena monachne	Increaser
Pogonarthria squarrosa	Increaser
Stipagrostis hirtigluma var. pearsonii	Increaser

Appendix 6. Years in which animals were translocated into the Waterberg Plateau Park (MET, 1986).

Game species	**Year**	**Number**
White Rhino	1975/76	National security
Black Rhino	1980's	National security
Buffalo	1980- 1989	45
Roan antelope	1975-181	No number given
Sable antelope	1978- 1981	60
Tsessebe	1985	14
Giraffe	1972- 1981	19
Eland	1972	85 (to supplement resident 200)