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Seitlhamo, Wilfred

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MAPPING AND QUANTIFYING THE IMPACT OF GRAZING AROUND WATER POINTS IN A SMALL SEMI-ARID SAVANNA GAME RESERVE

Wilfred Seitlhamo

Research report submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Sciences

Faculty of Science, University of the Witwatersrand, Johannesburg

May 2011

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science at the University of the Witwatersrand. It has not been submitted before for any degree or examination in any other University.



_____

Wilfred Seitlhamo

Date: 01.06.11

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- Mr. Johnson Arkhaar, Research Manager, NWPTB. Thank you for assisting with the statistical analysis (correlations) of some of my data.
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ABSTRACT

The widespread provision of water points in protected areas in semi-arid savannas has supported associated increases in cumulative grazing pressure. This study addresses the management implications of artificial water provision which causes the development of grazing gradients of increasing herbivore impact at artificial water point sites. The aim of the study was to map and quantify the impact of grazing and trampling at water points sites in a 4 600 ha sized semi arid savanna game reserve (Mafikeng Game Reserve in the North West Province).

Aerial photographs and SPOT imagery were used to identify the extent of the sacrifice zone for the period before the reserve was established (1980), and after establishment (2003 and 2009). To quantify the herbaceous species, relative percentage frequency and composition, the frequency of occurrence of species at water point sites was measured along four 100 m transect following cardinal directions (north, east, south, west). Furthermore, Landscape Function Analysis (LFA), which uses indicators that can be assessed rapidly to determine the functional status of the rangelands, was applied. The landscape zones or cover types were related to 10 distance categories within a 100 m transect.

The results indicate the increasing extent of the sacrifice zone since the provision of the artificial water points. The water points that are situated away from the river were characterized by Increaser II species. Increaser I and Decreaser species characterized water points which are situated along the river. Species composition was influenced by environmental variables such as soil type and depth and the spatial location of water points in relation to natural water source. The results of the study suggest changes in plant composition and soil cover that are probably related to accumulated long-term loss of herbaceous vegetation cover around water points, with special emphasis on water points that are situated away from the natural water source in the central part of the reserve. This part of the reserve attracts higher concentrations of animals probably due to the water points, which causes loss of herbaceous vegetation.

In order to minimize degradation of the areas surrounding water points in the central part of the reserve, the rotational opening and closing of water points situated away from the river should be explored, based on the system change, to allow vegetation recovery. Also, the non-operating water point near the natural source should be opened in an attempt to attract animals to underutilized areas, to allow uniform desirable utilization of the entire reserve, taking the reserve's objectives into account.

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INTRODUCTION

Managers of protected areas have a range of methods at their disposal for controlling the movements of animals (Cronje *et al.* 2005), one of these being water provision, along with fire and animal harvesting (Owen-Smith 1996). The availability and distribution of water can influence ecosystem structure and function at a range of scales and organizational levels (Cronje *et al*. 2005; Redfern *et al*. 2005). This is due to the impact that water availability has on various ecosystem processes and feedbacks that affect both animals and plants (Gaylard *et al.* 2003; Cronje *et al*. 2005). Only the spatial and temporal variability of artificial water sources (such as boreholes) can be controlled by reserve management (Cronje *et al*. 2005), whereas natural water sources vary over space and time in relation to environmental factors (Gaylard *et al.* 2003).

Animals move between places used for feeding or resting and those used for drinking (Ayeni 1975; Western 1975; Thrash and Derry 1999; Derry 2004; Smet 2004). Hence the distribution of wildlife is also related to surface water distribution (Fryxell and Sinclair 1988; Epaphras *et al.* 2008). This is even more accentuated during the dry season when wild ungulates drink more frequently to maintain or retain body moisture (Western 1975; Du Toit 2002; Mutinda 2002; Epaphras *et al.* 2008), which is important for metabolism and energy, especially for non-ruminants (Fryxell and Sinclair 1988, Owen-Smith 2002). Water is further limited to fewer water points during the dry season than in the wet season (Du Toit 2002; Mutinda 2002; Epaphras *et al*. 2008), putting more pressure on the resources around the few available water points during the dry season (Owen-Smith 2002). This can result in over-utilization and degradation of the areas surrounding water points; leading to soil erosion, overgrazing, tree destruction, bush encroachment, trampling, and even local desertification (Parker and Witkowski 1999; Rawlinson 2000; Mutinda 2002; Epaphras *et al.* 2008).

The concentration of impacts associated with the congregation of animals at water points and the declining grazing pressure with the distance from water gives rise to a utilization gradient termed piosphere pattern (Andrew and Lange 1986). The term piosphere was introduced by the Australian Robert Lange in 1969 (Thrash and Derry 1999; Derry 2004) when describing sheep movement in relation to water provision in a shrub land. The grazing gradient can be defined as patterns reflecting the concentricity of stocking pressure around water points, mineral licks, bedding grounds etc (Andrew and Lange 1986; Washington-Allen *et al*. 2004). At

the center of the piosphere, experiencing the highest herbivore pressure, trampling usually generates an area reduced to mud referred to as a sacrifice zone (Thrash and Derry 1999).

Satellite imagery has increasingly been used in combination with models of animal movement to survey grazing impacts (Lind *et al*. 2003) and land degradation in general (Kerr and Ostrovsky 2003) at both broad and small scale (Washington-Allen *et al*. 2004). Most of the studies using satellite remote sensing (RS) for this purpose have been carried out in Australian rangelands (Lind *et al*. 2003). The use of grazing gradients and satellite imagery for degradation assessment has been refined by Pickup and Chewings (1994). They classify grazing gradients as 'normal', 'inverse' and 'composite'. Normal gradients show an increase of vegetation cover with increasing distance from water. Inverse gradients involve decreasing vegetation cover with increasing distance, and finally a composite gradient combines the two (Pickup and Chewings 1994).

THE NEED FOR THE STUDY

Research on water distribution and the impacts of augmenting water supplies for animals has been investigated in both large and small conservation areas (Gaylard *et al.* 2003; Cronje *et al.* 2005). Most studies indicate that water provision in protected areas is crucial; therefore policies on water provision needs to be carefully thought by wildlife managers (Owen-Smith 1996; Gaylard *et al*. 2003). Gaylard *et al.* (2003) discussed the associated implications of water provision for heterogeneity and ecosystem processes. The provision of water in conservation areas, in principle, aims to support herbivore populations during the dry season especially during drought (Cronje *et al.* 2005), by minimizing the influence of temporal variability in rainfall (Gaylard *et al.* 2003).

The development of vegetation zones resulting from a gradient of decreasing herbivore impact away from artificial drinking troughs has been recognized in Kruger National Park (KNP) (Thrash *et al*. 1995; Thrash 1998; Thrash and Derry 1999; Thrash 2000; Redfern *et al*. 2003). Epaphras *et al*. (2008) indicated that the increase in the number of water holes to enhance tourism in Ruaha National Park (RNP), Tanzania, resulted in increased habitat over-utilization and degradation around water points. Vegetation gradients around artificial water points in the Central Kalahari Game Reserve of Botswana were studied by Makhabu *et al*. (2002). Their results indicated severe degradation of habitat closer to the water point and

decreased impact away from the water points. In the semi-arid rangelands of the Oshana ecosystem in Northern Namibia, there are concerns that artificial water points for livestock contribute to the processes that can lead to desertification (Nangula and Oba 2004). Chamaillé-Jammes *et al*. (2009) indicated a decrease of woody cover within 1 km of water points in Hwange National Park, Zimbabwe. Recorded changes pointed out by James *et al.* (1999) in the Australian savanna vegetation in response to grazing around artificial sources of water are: 1) the development of a zone of extreme degradation around the water (up to 0.5 km) where soil crust is broken, erosion is high and unpalatable plants dominate (also Thrash *et al*. 1995), 2) an increase in the number of unpalatable perennial shrubs beyond the extreme degradation zone, particularly in semi-arid habitats, and 3) a decrease in abundance of palatable native perennial grass due to selective grazing.

The increase in the number of water points, particularly in areas where water does not occur naturally can lead to the increase in the populations of water-dependent species such as zebra (*Equus burchelli*) and blue wildebeest (*Connnochaetes taurinus*) (Cronje *et al*. 2005). This increase in animal numbers in relation to increased water availability, during drought period, can lead to potentially catastrophic animal mortalities as a result of overgrazing (Owen-Smith 1996, 2002; Gaylard *et al.* 2003). The size of the conservation area in relation to the availability and distribution of water points influences the area's spatial and temporal heterogeneity (Cronje *et al*. 2005). The smaller the area, the more intensively it needs to be managed (Bothma 1996). This is because smaller areas are not self-regulating (Trollope 1990).

The key objectives of Mafikeng Game Reserve (MAF) are:

1. To proactively participate in the water allocation structures in upper reaches of the Molopo River basin and to ensure that wetlands within the system are appropriately managed;
2. To facilitate environmental education opportunities within the reserve;
3. To provide wildlife based tourism activities for recreation and to add value to the economy of the area; and
4. To sustainably manage the veld and indigenous wildlife populations, and where the opportunity arises, maximize income in a sustainable manner.

The natural water source in MAF is the non-perennial Molopo River which enters the reserve from the east and flows westwards in the northern half (Seitlhamo 2002). Artificial water points were put in MAF in 1992 (B. Brockett *Pers. comm.*) when the reserve was established. There are currently five (5) main artificial water points in the reserve of which three (3) are operating (Figure 1). Three of the five (5) water points (of which one is operating) are confined along the Molopo River, which is a natural water source in the reserve. The other two (2) water points which are currently operating are situated in the central part of the reserve which is devoid of natural water. The creation of the two aforementioned water points conflict with the recommendations of the current management plan of the reserve (Davies 2002). The management plan states that any water which is supplied for animal must be confined to the wetland area along the Molopo River where water occurs naturally. The distance between the water points is approximately 2.5 km. The geometric model by Owen-Smith (1996) states that water points would need to be separated by at least 3x the potential travel distance of animals from water to grazing areas for the relative extent of the wet season range to twice that of the dry season range. Daily travelling of up to 5 km seem typical for medium-sized ungulates such as black wildebeest, zebra and red hartebeest. Therefore, the afore-mentioned water points, based on geometric model are too close to each other.

Reserve management is intending an additional artificial water point further south-east (near the new camp site) of the reserve to fulfill tourism objectives. The approximate distance (of the camp site and new water point) from one of the water point situated in the central part of the reserve is 2.3 km. The intention is also to close one of the water points situated in the central part of the reserve, but still the creation of the afore-mentioned water point conflicts the reserve management plan since it will be situated in the area which is devoid of natural water. Although the water point will enhance animal visibility for tourists, it might also result in habitat over-utilization and degradation due to herbivore aggregation especially during the dry season. The extent of degradation might add to the currently observed degradation due to the limited distance (± 2.3 km) between the old water point and the envisaged one to be created.

STUDY QUESTIONS AND HYPOTHESES

The impact zones resulting from a gradient of decreasing herbivore impact away from artificial water points in the reserve prompted me to conduct this study. The study aims to map and

quantify the impact of grazing and trampling on herbaceous vegetation around the five artificial water points, in order to address the management implications of the provision of artificial water points in the reserve.

The key questions posed in this study relate to the impact around water points as a result of grazing and trampling by herbivores:

1) Has the extent of the sacrifice zone around water points increased since they were created?
2) To what extent has the structure and function of the landscape has changed as a result of the provision of artificial water points?
    a. How does species richness at water points compares between operating and non-operating water points?
    b. How does severity of grazing and trampling impact compares between water points which are near natural water source and those that are away?
3) What is the relationship between distance from water points and landscape zones (e.g. bare soil, grass, shrubs, and open thickets)?
4) How does species composition around water points differ between the dry and wet seasons?

The hypotheses that were tested are:

1) The extent of the sacrifice zone at the water point site has increased since the provision of the artificial water points
2) The landscape structure and function has been affected by the provision of artificial water points.
    a. Species richness is lower at operating water points than at non-operating water points.
    b. The grazing and trampling impact on the herbaceous vegetation is been more severe at water points which are far from the natural water source than those which are nearer. Furthermore, more Increaser II species are at water points that are far from natural water source.
3) Bare soil decreases with increasing distance from water; whereas grass cover, both shrubs and thickets density increases with increasing distance.

4) Season influences species composition and richness around water points, where more annual herbaceous species increased during the wet season.

MATERIALS AND METHODS

Study area

The study was conducted in Mafikeng Game Reserve (MAF), situated in the central part of the North West province, South Africa (Figure 1). The reserve is 4600 ha in size and was established in 1992 (Brockett 2002) under the then Bophuthatswana National Parks Board (BopParks). The reserve lies between the latitudes 25º50'5.3" and 25º54'5.4"S and longitudes 25º47'25.9" and 25º39'3.2"E (Seitlhamo 2002).

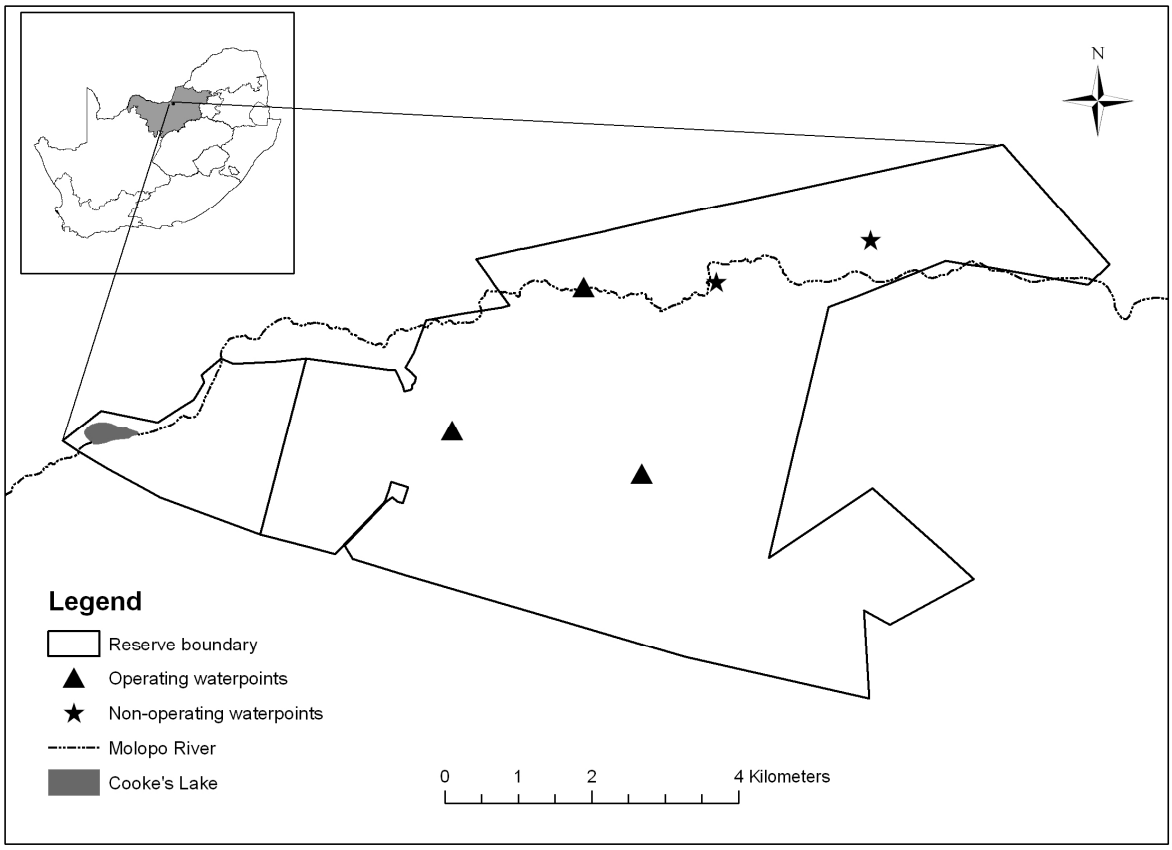


Figure 1 **Study area: Mafikeng Game Reserve (4600 ha), located in the central part of the North West Province, South Africa. The operating and non-operating water points and Molopo River are indicated on the map. The western section (where Cooke's Lake is) does not form part of the main reserve.**

The terrain of the reserve is relatively flat with plains (BopParks and Van Riet Landscape Architects 1991, Seitlhamo 2002). The elevation ranges from 1263-1420 m above sea level. Some areas of the reserve were used as land for cultivation long before the reserve was established (Seitlhamo 2002). The large part of the reserve is underlain by andesitic lavas of the Allanridge Formation, Ventersdorp Supergroup (BopParks and Van Riet Landscape Architects 1991, Mucina and Rutherford 2006).

The climate of the area is characterized by warm to hot summers (35 ºC) and cool winters (15 ºC). The highest ever temperature recorded was 40.2 ºC in January 1973 and the lowest temperature -9.7 ºC in July 1926 (BopParks and Van Riet Landscape Architects 1991). Light frost is experienced occasionally in winter. The mean annual rainfall was 547 (SD: ±390 mm) over the last 25 years with most of the rain falling from October to March. The seasonal rainfall for the past six years was above average, except for the 2006/07 season (Figure 2). The 2009/10 season covering the study period is illustrated in Figure 3; where above average rainfall fell during the months of November, January and April.

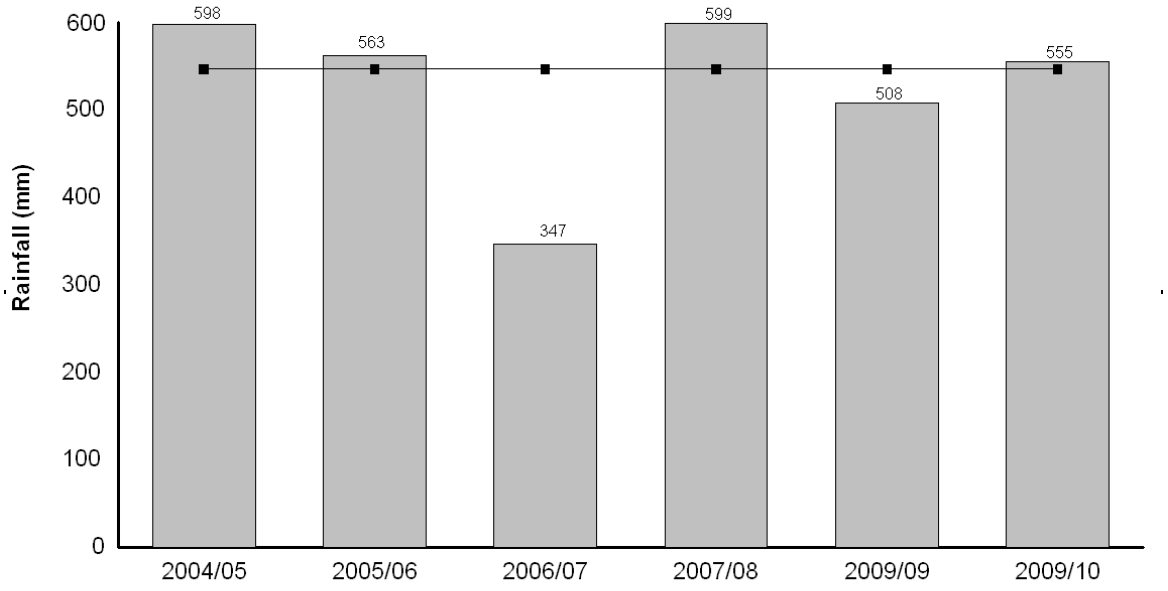


Figure 2 **Seasonal rainfall (bars) of Mafikeng Game Reserve from 2004/05 to 2009/10 and long term mean rainfall (line). Rainfall data collected from five rainfall stations situated inside the reserve.**

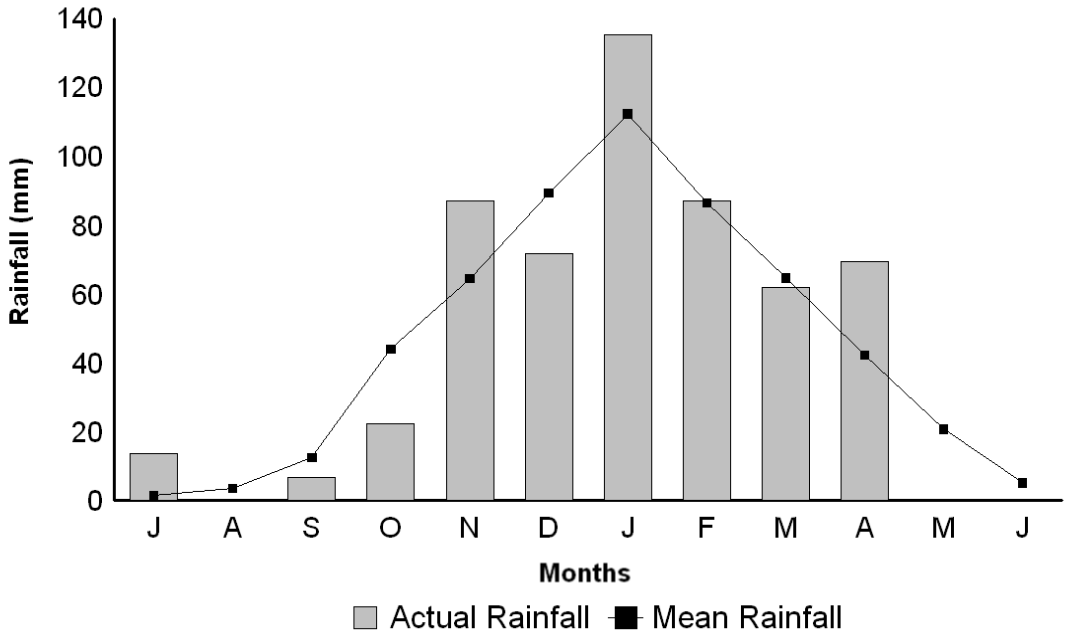


Figure 3 **Monthly rainfall during the study period (bars) and long term monthly rainfall (line).**

The non-perennial Molopo River enters the reserve from the east and flows westwards in the northern half (Seitlhamo 2002). The vlei and the floodplain along the Molopo River are dry for most of the year. The dryness of the vlei and the non-flowing of the river is probably due to low rainfall in the area (BopParks and Van Riet Landscape Architects 1991) as well as the fact that the flow of water is retarded by the pumping of water from the Molopo Eye upstream, which is the major source of water for the Molopo River. However, the vlei area has the potential to retain soil moisture for long periods without rainfall, due to the existence of a soft plinthic horizon (Seitlhamo 2002).

The savanna vegetation was classified by Acocks (1975) as mixed bushveld. Mucina and Rutherford (2006) reclassified the vegetation as dry *Cymbopogon-Themeda* veld. The vegetation cover types were mapped by Adcock (1991) for reserve planning purposes. The cover types with the greatest extent are *Rhus lancea* open woodland on calcrete soil (33.6%), followed by *Acacia tortilis*/*R. lancea* open woodland (21.9%), and *A. tortilis* open woodland (18.7%) (Figure 4). The dominant grasses are *Cymbopogon plurinodis*, *Themeda triandra*,

Elionuris muticus, *Enneapogon scoparius*, *Heteropogon contortus* and *Eragrostis lehmanniana* (Adcock 1991).

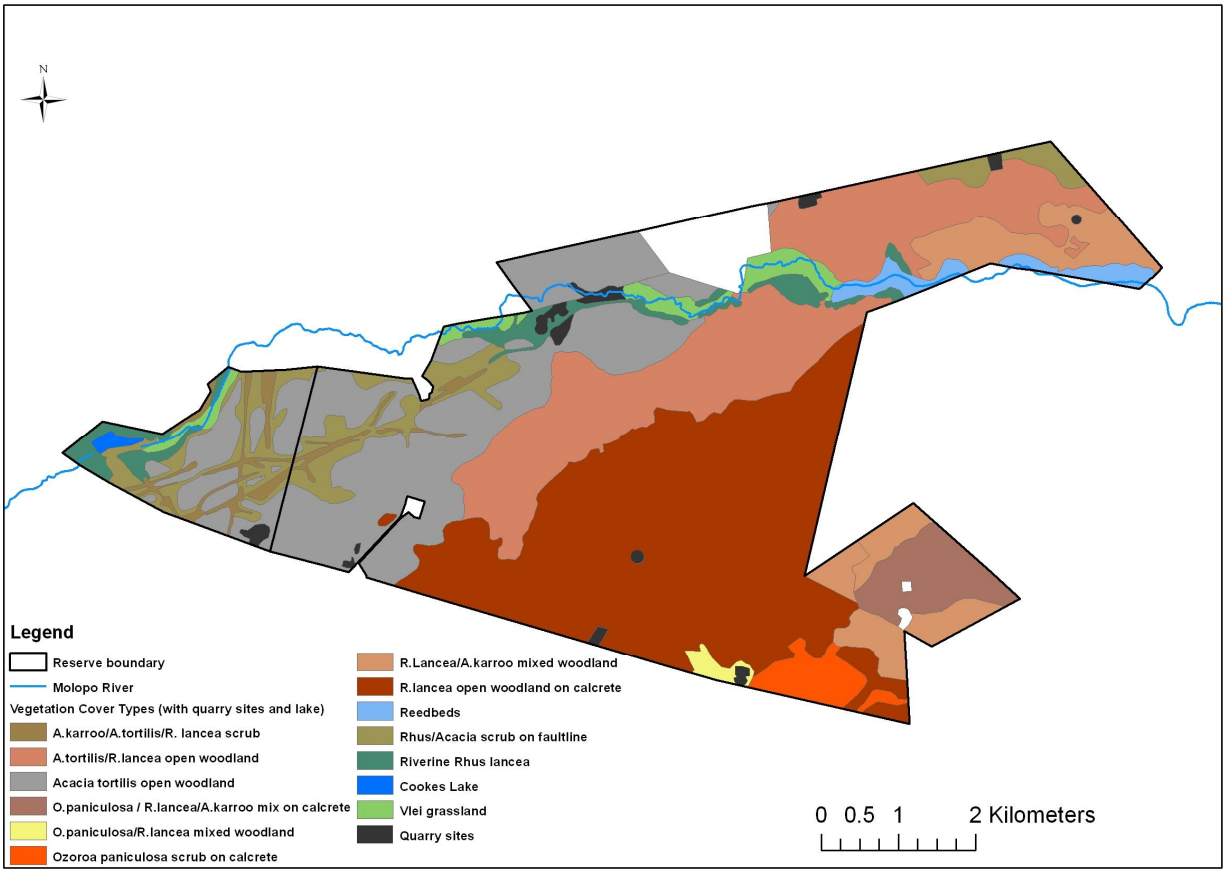


Figure 4 Vegetation cover types for Mafikeng Game Reserve (after Adcock 1991)

MAF is stocked with a range of herbivores species including: white rhino *Ceratotherium simum* (40), giraffe *Giraffa camelopardalis* (27), buffalo *Syncerus caffer* (71) zebra (117), gemsbok *Oryx gazella* (66), black wildebeest *Connnochaetes gnou* (267) blesbok *Damaliscus dorcas* (197), red hartebeest *Alcephalus buselaphus* (98), eland *Tragelapus oryx* (24), impala *Aepyceros melampus* (188), springbok *Antidorcas marsupialis* (237), waterbuck *Kobus ellipsiprymus* (44), Kudu *Tragelapus strepsiceros* (41), warthog *Phacochoerus aethiopicus* (185), and ostrich *Struthio camelus* (61). The animal numbers are based on the 2009 population estimates (aerial counts) (Knoop *et al*. 2010).

Fire has been used as a management tool in MAF since 1995 (B. Brockett *pers. comm*.). Fire is mostly applied before spring growth, except for the vlei area which is burnt earlier in

winter in order to enable a 'green flush'. The 'green flush' should assist animals as a food source during the dry season (Seitlhamo 2005). However, the exact timing of burns varies from year to year due to environmental factors such as extended dry periods, rainfall, herbivory and unplanned fires, which have an impact on vegetation structure and thus prevent consistent prescribed burning program.

Data collection

Imagery data for identifying the extent of the sacrifice zone

Ortho-photographs, aerial photography and satellite imagery (Table 1) were used to identify and quantify the extent of the sacrifice zone around the water points. Images for both the period before and after the reserve was established were classified, with the aim of comparing the extent of the sacrifice zone at the current artificial water point sites before and since their creation. The following images were classified (Table 1): ortho-photograph acquired in 1980 (12 years before the reserve was established), aerial photograph acquired in 2003 (11 years after the reserve was established), and SPOT (**S**ystème **P**our l'**O**bservation de la **T**erre) imagery acquired in 2008 (16 years after the reserve was established). The months of acquisition for both the ortho-photograph and aerial photograph are unknown, which decreases the accuracy of the comparison due to the risk of detecting seasonal differences rather than spatial and temporal differences. All the data were georeferenced to Universal Transverse Mercator projection and World Geodetic System (WGS84) datum.

Table 1 Description of data used for identifying the extent of the sacrifice zone around water points

Year (month)	Type of data	Spatial Resolution/scale	Source
1980 (unknown)	Ortho-photograph (1 band)	1: 10 000	GISCOE
2003 (unknown)	Aerial photograph (1 band)	1: 20 000	Surveys and Mapping
2009 (July)	SPOT (3 bands)	20 m	Land Affairs, Mafikeng

Vegetation and soil sampling

Vegetation is a good indicator of degradation, although it may be influenced by historical events such as past grazing regimes and human settlements (Smet 2004). Environmental variables such as distance from water point, soil type and ground cover are related to herbaceous species composition.

After examiningt various sampling methods, I decided to use Landscape Function Analysis (LFA) (Tongway and Hindley 2004, 2005) to assess the function of the landscape and the step-point method (Mentis 1981) to determine herbaceous species composition.

Landscape Function Analysis

LFA is a monitoring procedure developed by CSIRO (Tongway and Hindley 2004, 2005; Manson *et al*. 2007). It field indicators to quickly determine the functional status of rangelands. LFA determine the location and size of vegetation "patches", where resources accumulates, and bare soil areas ("inter-patches") where resources may be mobilized or lost (Tongway and Hindley 2004, 2005). Many or other monitoring procedures are limited to 1) composition (what species are present?) and 2) structure (what are the morphological forms of the biota?). LFA explicitly addresses landscape function (how does the landscape work as a system) (Ampt *et al*. 2007), and looks to place a given site on a continuum between highly functional and highly dysfunctional. As such, LFA complements existing procedures that assess rangeland condition (Tongway and Hindley 2004, 2005). There are three principal steps in the LFA process (Tongway and Hindley 2004, 2005). These are 1) description of the geographic setting, 2) characterization of the landscape (the spatial distribution of patches and inter-patches), and 3) the soil surface assessment (SSA) of each patch/inter-patch types identified in step 2).

LFA data (patches and inter-patches) were collected along four 100 m line transects radiating from the water point following four cardinal directions (Figure 5). The transect width was 10 m (5 m on either side of transect central line). Data on site location (global positioning system (GPS) point of the start and end of transect), compass bearing of transect, slope, aspect, lithology, soil type, and general vegetation description were collected in addition to actual landscape organization data. A 100 m measuring tape was used to mark transects. Transects were not permanently marked, however the GPS points and the bearing were used when transects were revisited. The LFA field data acquisition manual (Tongway Hindley 2004, 2005)

states that line transects along which data are collected must be aligned with the maximum slope. However, if the slope is very low to flat (as was the case with MAF), the transect direction was not critical. In case there is a clear indication of a change in resource flow direction (i.e. patches), a transect should follow this by putting a bend (or turning point) in the line and note its location and new compass bearing (Tongway Hindley 2004, 2005). A change in resource flow direction was not observed during the surveys in MAF. For transects that were crossing the road, a 10 m buffer on either side of the road was used to exclude such areas from sampling due to the edge effect associated with roads.

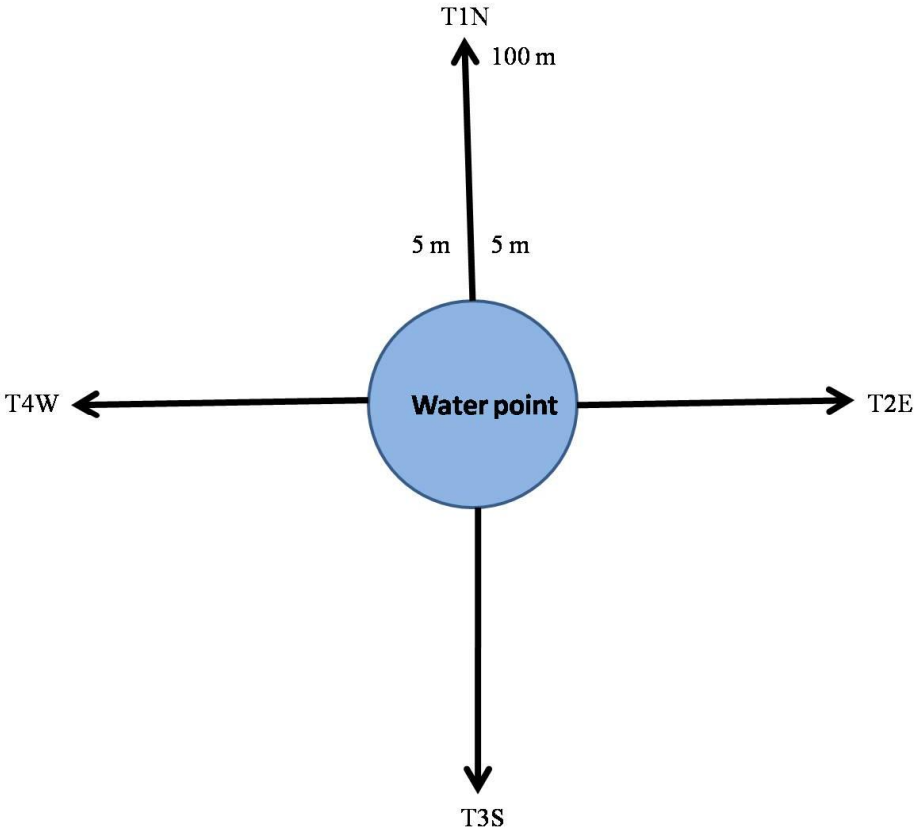


Figure 5 **Illustration of sampling transects radiating from the water point. T1N = transect 1 north direction; T2E = transect 2 east direction; etc.**

Each patch/inter-patch type identified in the landscape organization data has its own soil surface properties (Tongway Hindley 2004, 2005). The soil surface assessment (SSA) was done after the landscape continuous log record was compiled on a set of query zones located within examples of each patch and inter-patch type. Observations of soil surface features were made using the already measured lengths of the patch/inter-patches in landscape organization transect

tape to define the query zone. The assessment needs a minimum of five replicates of each patch/inter-patch (if possible) for statistical reliability (Tongway and Hindley 2004, 2005). More than one query zone was identified within a single zone if five replicates were not available for a given patch/inter-patch type, which happened mostly for rare patches and inter-patches along a transect. Query zones were distributed along the full length of a transect as recommended by Tongway and Hindley (2004, 2005). The following indicators were collected for SSA: rain splash protection (perennial vegetation up to 0.5 m, rocks >2 cm, logs >1 cm), perennial cover (biomass), litter cover (annual plants, fallen leaves, sticks, grasses etc), cryptogram cover (cover of algae, fungi, mosses etc), crust brokenness (brokenness of crust and availability of material for erosion), erosion (nature and severity of active loss of soil material), deposited material (sand, gravel and rock), soil surface roughness and surface nature (resistance to disturbance). Slake test and soil texture were not done due to time constraints and unavailability of testing equipment. The specific objectives of the SSA indicators are described in Appendix 1.

Sampling was conducted at the end of the dry season (28 August - 9 September 2009) and during the wet season (17-24 February 2010) covering the 2009/10 season.

Herbaceous species data collection

Herbaceous species assessment included the recording of parameters such as abundance, frequency and composition collected from the same transect as LFA using plot-less distance measuring technique. The step-point method (Mentis 1981, Everson and Clarke 1987, Thrash 1998, Landsberg *et al*. 2003, Evans and Love undated) was used. Step-point sampling methods have shown to be efficient in terms of time and lend themselves readily to statistical analysis (Panagos and Reilly 2006). They also provide accurate and objective method for determining the botanical composition and total cover of herbaceous vegetation (Mentis 1981; Everson and Clarke 1987; Evans and Love undated).

In applying the step point sampling, a single pin was used (Evans and Love undated). An individual step-point was established by lowering the pin (in this case, a metal dropper) to the ground, guided by a definite notch on the toe of the boot. At each step-point, the boot was placed at ~30° angle to the ground to avoid disturbing plants in the immediate vicinity and the pin was lowered perpendicularly to the sole of the boot until it either hits the herbaceous plant

or the ground. Any herbaceous plant hit by the pin was identified and recorded. Species that were not identified during sampling were assigned nick names so that they could be recorded consistently, and then collected for identification at a later stage. If no herbaceous plant was hit, the pin was pushed into the ground and the plant nearest to it in a forward direction (~180º arc) was recorded (Evans and Love undated). A total of 100 step-point samples were collected per LFA transect, making a total of 400 samples around each water point.

Data analysis

Identifying the extent of the sacrifice zone

Hybrid classification (combination of supervised and unsupervised classification) of aerial photography and satellite imagery was used to detect the extent of the sacrifice zone. First, a preliminary unsupervised classification was performed with 15 spectral response clusters, based on the inherent statistical patterns of the data (10 and 30 clusters were tested but could not yield suitable results). The Iterative Self-Organizing Data Analysis (ISODATA) algorithm (Dely *et al*. 199;, Makgale 2006; Munyathi and Makgale 2009) was used with 12 iterations for each classification. The ISODATA technique identifies naturally occurring grouping or clusters within an image dataset (Lelliesand *et al*. 2004; Makgale 2006; Munyathi and Makgale 2009). The unsupervised classification algorithm defined clusters which did not necessarily coincide with the boundaries of the homogenous pixels, and created clusters that contain a variety of ground conditions (for the same cover) which were difficult to interpret, thus resulted in spectral confusion.

The spectral signatures generated by editing the clusters after pixel training were used in a supervised maximum likelihood classification. The filtering technique (median and majority filters with 3x3 moving window) were applied to minimize “salt and pepper” effect and spectral confusions. The processing of imagery was performed in Erdas Imagine 8.6. The Erdas format files (.img) were converted into a vector to enable the calculation of the area size of the extent of the sacrifice zone polygons in a geographic information system (GIS).

Landscape Function Analysis

Landscape organization data

The landscape organization data collected along transects had two purposes. The first was to identify the patch and inter-patch zones to produce indices describing how effectively the landscapes regulate vital resources at a hill slope scale (Tongway and Hindley 2004, 2005), and the second, to facilitate SSA at the 1 meter scale.

The landscape organization indices used were: mean length of landscape zones and the mean width of patch and inter-patches along transects. These indices determine the contribution of each zone to the whole site (water point). The Microsoft Excel spreadsheet template (version 3, updated in 2005, available at http://members.iinet.net.au/%7Elfa_procedures/) developed by Tongway and Hindley (2005) was used. The spreadsheet calculates all the indices automatically as the raw data is entered. For the landscape organization data, the individual landscape zones mean length and patch-inter-patch width were compared between the operating water points (away and along) the river and non-operating water points which are situated along the river for the both dry and wet seasons.

The distribution and proportion of landscape zones in relation to distance from water points was determined for operating water points (away from the river) and non-operating water points (along the river) for the dry and the wet seasons. The distance from water was transformed into a categorical variable (Adler and Hall 2005), subdividing a 100 m transect into 10 m distance classes. The number of individual landscape zones was determined per distance class. Furthermore, a statistical analysis (Spearman Correlation) was performed to test the significance of the relationship between individual landscape zones in relation to distance from water point. (Adler and Hall 2005). The statistical analysis was performed in SAS for Windows 9.1.3 program.

Soil surface assessment

The soil surface condition classes of landscape query zones were combined to derive the following three major soil habitat quality indices each of which have distinct significance for landscape function monitoring (Tongway and Hindley 2004, 2005) (Figure 6):

- *Stability* (S) or resistance to erosion: the ability of the soil to withstand erosive forces, and to reform after disturbance.

- *Infiltration/runoff* (I): how the soil partitions rainfall into soil-water, and runoff water which is lost from the local system. Infiltration is slowed by compact soil surfaces (e.g. a scald)
- *Nutrient cycling* (NC): how efficiently organic matter is cycled back into the soil.

The data above are presented in a 0 to 100 scale for each individual query zone as well as for the site as a whole (expressed as percentage). The indices were calculated automatically in the Excel spreadsheet template developed by Tongway and Hindley (2004, 2005).

The data collected by SSA method does not have a predictive capacity if collected only once (Tongway and Hindley 2004, 2005). The predictive capacity can be achieved through regular monitoring which provides a time series record of ecosystem change or development. SSA indices does not automatically classify a site into good, moderate or poor (Tongway and Hindley 2004, 2005). The significance of a particular numerical value comes from comparing disturbed sites with analogue sites. Index values do not absolutely indicate the functional state: these depend on the biome type e.g. a nutrient cycling index of 25 may represent highly functional grassland, but dysfunctional woodland.

The contribution of each landscape query zone SSA indices to the whole site (water points transects) was compared between operating water points (along and away the river) and non-operating along the river for the dry and wet season. Landscape query zones with indices value of less than 2 were averaged and referred to as others, to enable emphasis on those making a significant contribution.

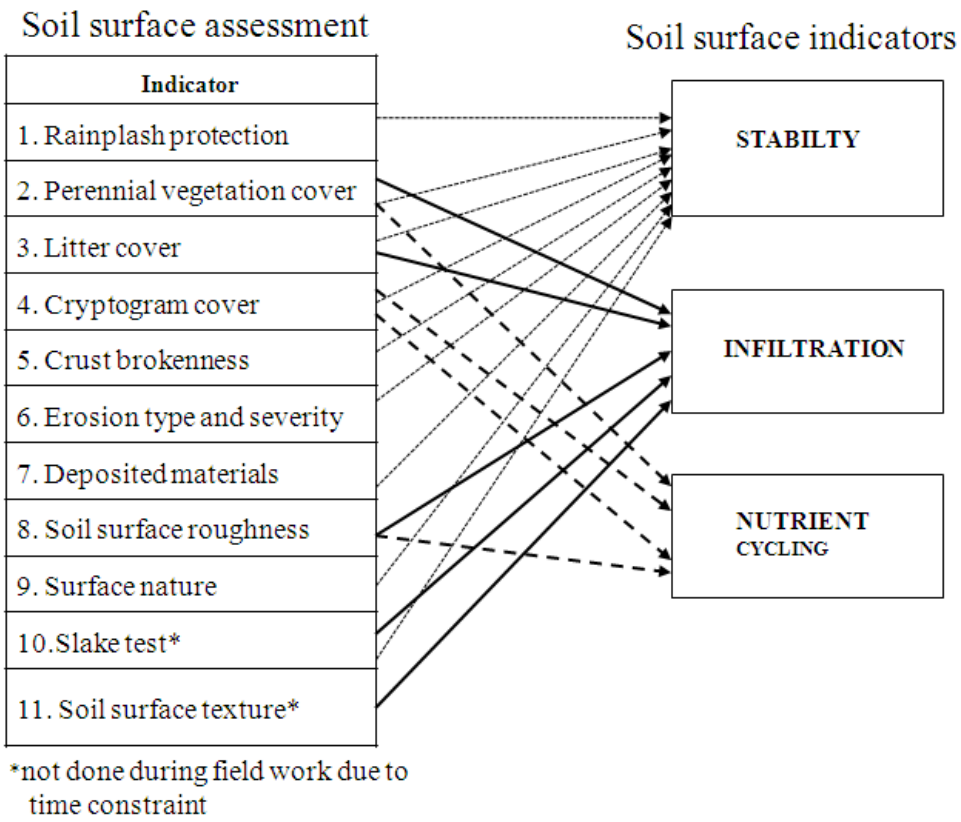


Figure 6 **The combination of soil condition classes to derive indices of stability, infiltration, and nutrient cycling (adapted from Tongway and Hindley 2005, Ampt *et al.* 2007)**

Herbaceous species

Species abundance

The mean species abundance for all transects per water point was determined. A comparison of mean abundance of species between operating water points (along and away from the river) and non-operating water points (along the river) was made for the dry and wet seasons using bar graphs. The forbs were lumped together. Species with a mean abundance of less than 2% were lumped together as "others". Furthermore, a statistical analysis (Pearson's correlation) was done to test the relationship between herbaceous species abundance and the water point location (away or along the river) and status (operating or not operating). The statistical analysis was performed on SAS for Windows 9.1.3 program.

Species composition

The species composition data of all the water points was analyzed using ordination technique. Ordination is a means of examining relations between species distributions and the distributions of associated environmental factors and gradients (McGarigal *et al.* 2000, Ter Braak and Smilauer 2002; Lachance and Lavoie 2004). Canonical correspondence analysis (CCA), ordination technique was selected for the analysis using CANOCO for Windows 4.5 program (Ter Braak and Smilauer 2002). The species data collected around the water points is unimodal or categorical, hence the use of CCA. CCA is a direct gradient analysis technique that is capable of directly relating a set of environmental variables to a set of species (Fernandez-Gimenez and Allen-Diaz 2000; McGarigal *et al.* 2000; Tarhouni *et al*. 2007). It does this by identifying the patterns of variation in community composition that can be best explained by the environmental variables (Ter Braak and Smilauer 2002). The technique is based on the rationale that species are assumed to have Gaussian-shaped responses to compound environmental variables. The main advantage of the technique is that it allows a preliminary appraisal of how species composition varies with the environment (Ter Braak and Smilauer 2002).

Accordingly, CCA analysis was undertaken on the water point data to determine if the location of water points (away or along the river), their status (operating or not operating), soil type and depth and slope where they are situated had an effect on the herbaceous species composition variation. All the species, irrespective of mean abundance values were used. The dry and wet season data were analyzed separately.

The CCA was further subjected to a Monte Carlo permutation test (199 permutations). The Monte Carlo permutation test determines the statistical significance of the relation between species and the chosen set of environmental variables (McGarigal *et al.* 2000; Fynn 2005; Tarhouni *et al*. 2007; Jabeen and Ahmad 2009). Two tests were applied, one based on the first canonical eigenvalue, which determines the significance of the first ordination axis, and the second one based on the sum of all canonical eigenvalues, which determines the significance of all canonical axes together.

The ordination biplot diagram produced through the application of CCA displays species and sites as points and environmental variables as arrows (Ter Braak and Smilauer 2002; Jabeen and Ahmad 2009). The points are plotted to the direction of maximum change of the entire set of environmental variable across the diagram. The length of an arrow is proportional to the

magnitude of change in that direction of maximum change of environmental variable. A long arrow is more closely correlated in ordination than those with short arrow, and is much more important in influencing the species variation. The angles between arrows represent correlations, and the smaller the angle, the greater the correlation (Ter Braak and Smilauer 2002; Jabeen and Ahmad 2009).

RESULTS

Extent of sacrifice zone around water points

The color scheme of the classified spectral signatures for the images was displayed on the default black and white/grayscale colors (Figure 7). With this color scheme, pixels representing bare soil or the low vegetated areas were assigned white or brighter colors, which made it easier to identify such conditions on the classified image.

A sacrifice zone could not be identified from the water points which are situated along the river from all the classified images, probably due to vegetation cover. Also a sacrifice zone could not be identified from the 1980 ortho-photograph. The water points which are away from the river (water point 1 and water point 2) had a sacrifice zone in 2003 with a further steady increase of the extent in 2009 (Table 2 and Figure 7). Water point 2, which is more central in the reserve on a calcrete soil, had a larger size of the sacrifice zone in 2003 and 2009 (Table 2) than water point 1, which is on the more sandy soil. The difference in the actual increase of the size of the sacrifice zone was 0.24 ha and 0.37 ha for 2003 and 2009 respectively (Table 2).

Table 2 **Area sizes (ha) of the sacrifice zones around the two water points which are situated away from the river for 1980, 2003, and 2009**

Year	Size of sacrifice zone (ha)	
	Water point 1	Water point 2
1980	na	na
2003	0.30	0.51
2009	0.54	0.88
Difference	0.24	0.37

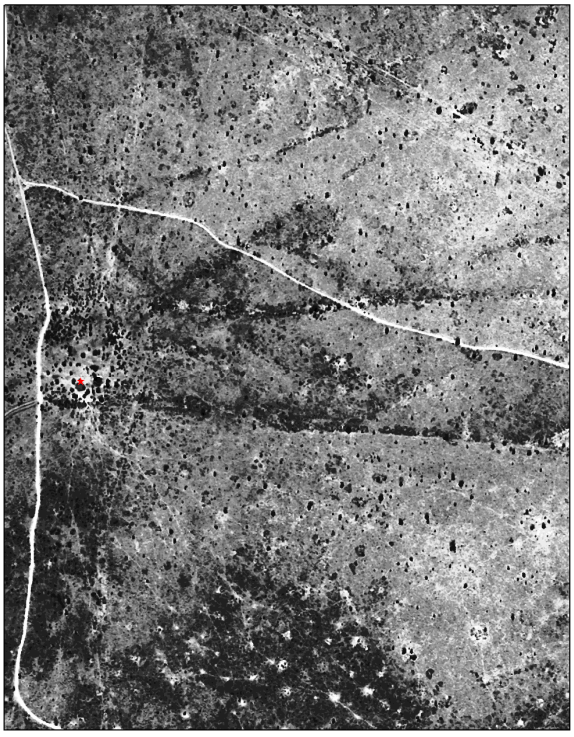
Water point 1 site 2003



Water point 2 site 2003



Water point 1 site 2009



Water point 2 site 2009

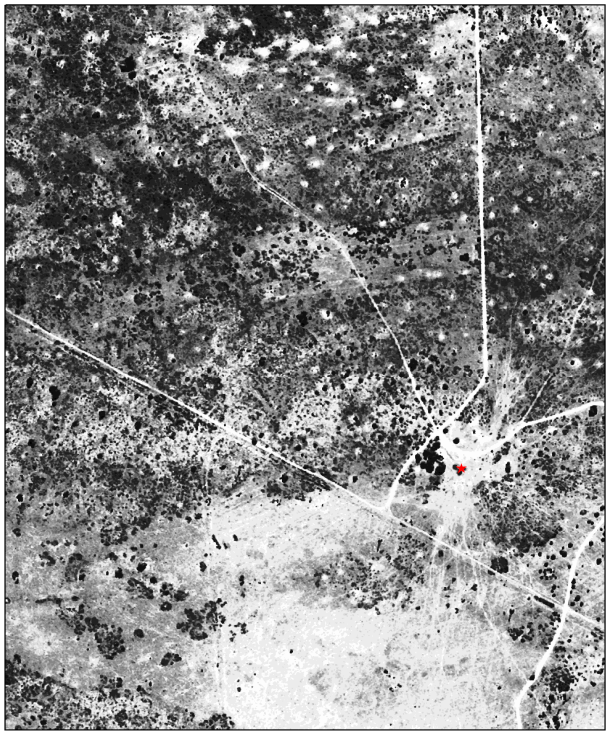


Figure 7 **Water point sites for the two water points which are situated away from the river, indicating impact from the 2003 aerial photograph and 2009 SPOT imagery. The water points are indicated with red stars.**

Landscape Function Analysis

Landscape organization

A total of 10 landscape zones (bare soil, bare rock, bare soil-rock, grass, closed thickets, open thickets, shrubs, shrub log complex, shrub rock complex and plant hummocks) were identified along transects at the water points (see Appendix 3 for landscape zones description).

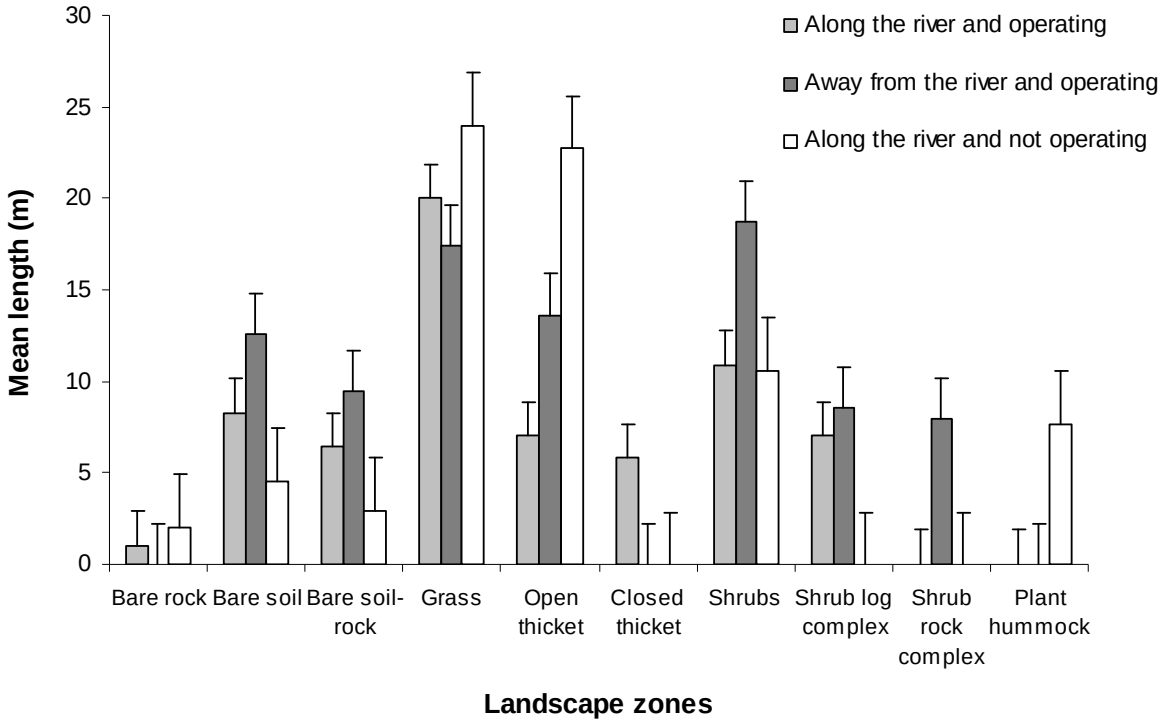
Of these landscape zones, bare soil, grass, open thicket and shrubs contributed to the whole landscape for all the water points, as they had longer lengths and wider than the other landscape zones. Closed thicket and plant hummock were rare and recorded only in one transect around the operating and non-operating water points along the river respectively.

Dry season

The general trends in landscape zones indicated grass, shrubs, open thickets and bare soil as the main contributors for all the water points (all had longer mean lengths than the other landscape zones) (Figure 8a). Grass, open thicket, and shrubs were higher at water points along the river. The contribution of grass and open thicket was lower at operating water points away from the river. Bare soil, indicated by longer mean length, was higher at operating water points away from the river as compared to non-operating water points. Closed thicket which comprised of riverine (*Rhus lancea*, *Combretum erythrophyllum*, and *Celtis africana*) vegetation was recorded at one transect at an operating water point along the river.

The amount of vegetation cover was indicated by the patch lengths and inter-patch widths. Patches were greater at non-operating water points along the river, as expected (Figure 8b), indicating more vegetation cover, followed by operating water points along the river. The inter-patch width was greater at operating water points which are away from the river, indicating a greater amount of bare soil (Figure 8b). The non-operating water points had a graeter amount of vegetation, indicated by a shorter inter-patch width.

a



b

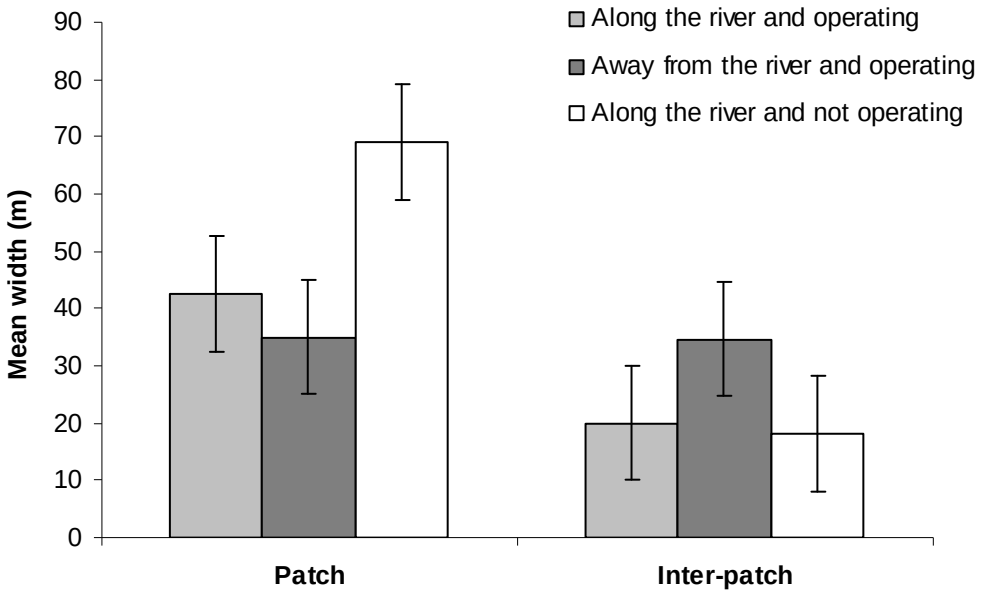


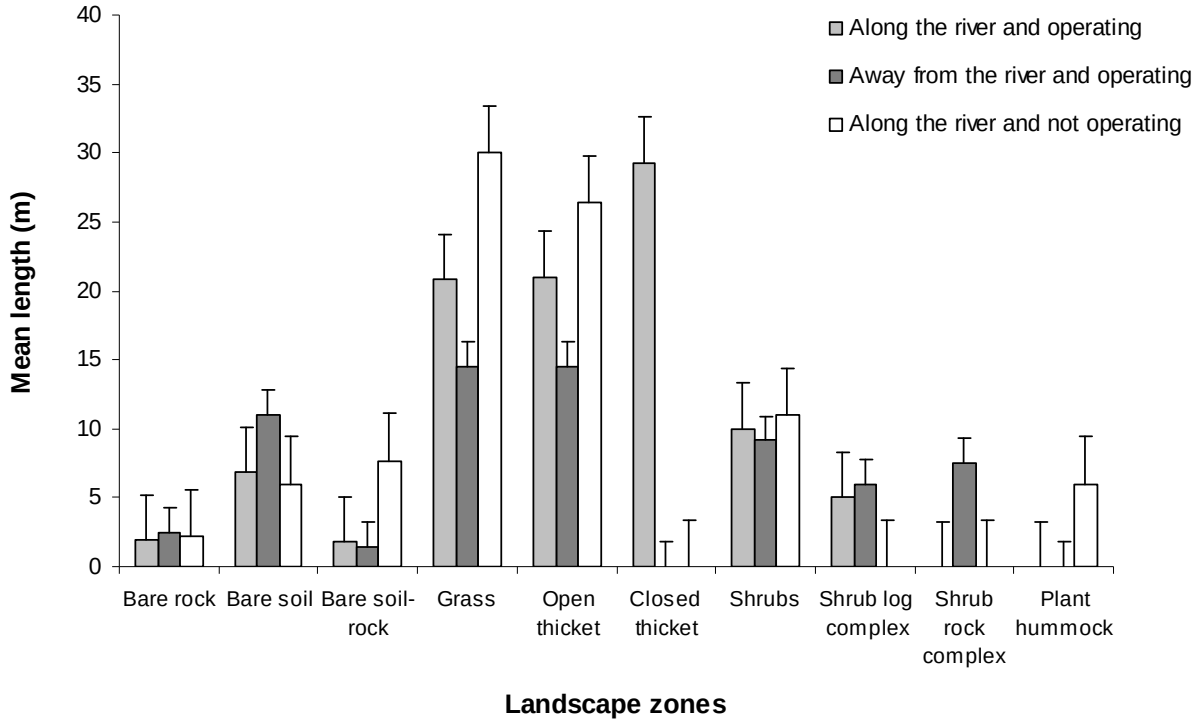
Figure 8 **Mean lengths (SE) of landscape zones (a) and mean width (±SE) of patch/inter-patch (b) of operating (along vs. away from river) and non-operating water points (along the river) for the dry season**

Wet season

The trends in landscape zones indicated an increased amount of vegetation cover, with grass, open thicket, and closed thicket as the main contributors (all had longer mean lengths than in the dry season) (Figure 9a). The amount of bare soil was greater at water points which are away from the river. The shrub density was almost equal at all the water points, but slightly greater at the non-operating water points which are along the river.

The patch amount was greater at water points which are along the river due to the increased vegetation cover. The amount of inter-patches decreased as a result of improved soil cover during the wet season (Figure 9b), however, the operating water points which are away from the river had a greater amount of inter-patches.

a



b

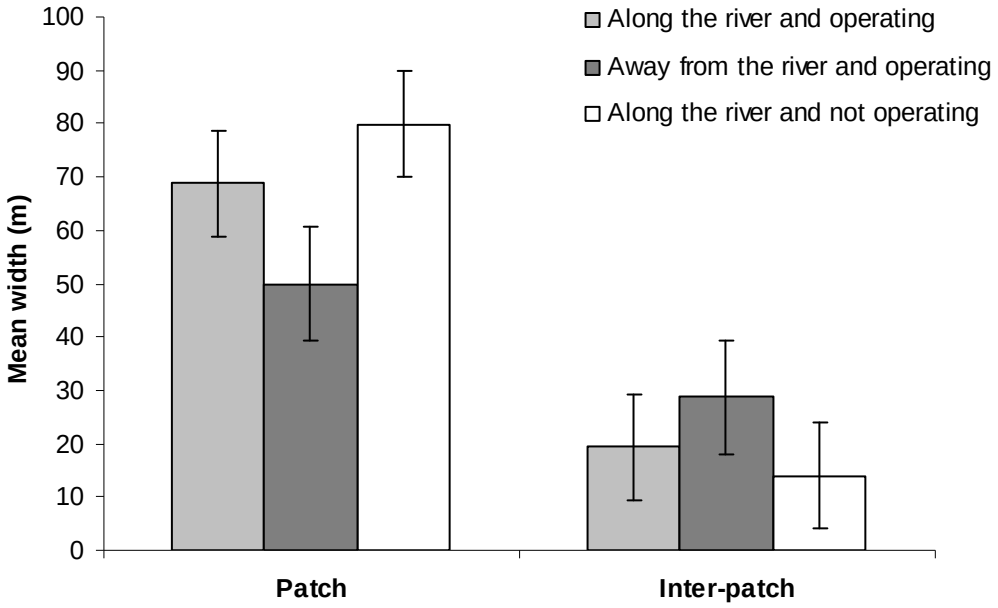


Figure 9 **Mean lengths (SE) of landscape zones (a) and mean width (±SE) of patch/inter-patch (b) of operating (along vs. away from river) and non-operating water points (along the river) for the wet season**

Landscape zones in relation to distance from water

Dry season

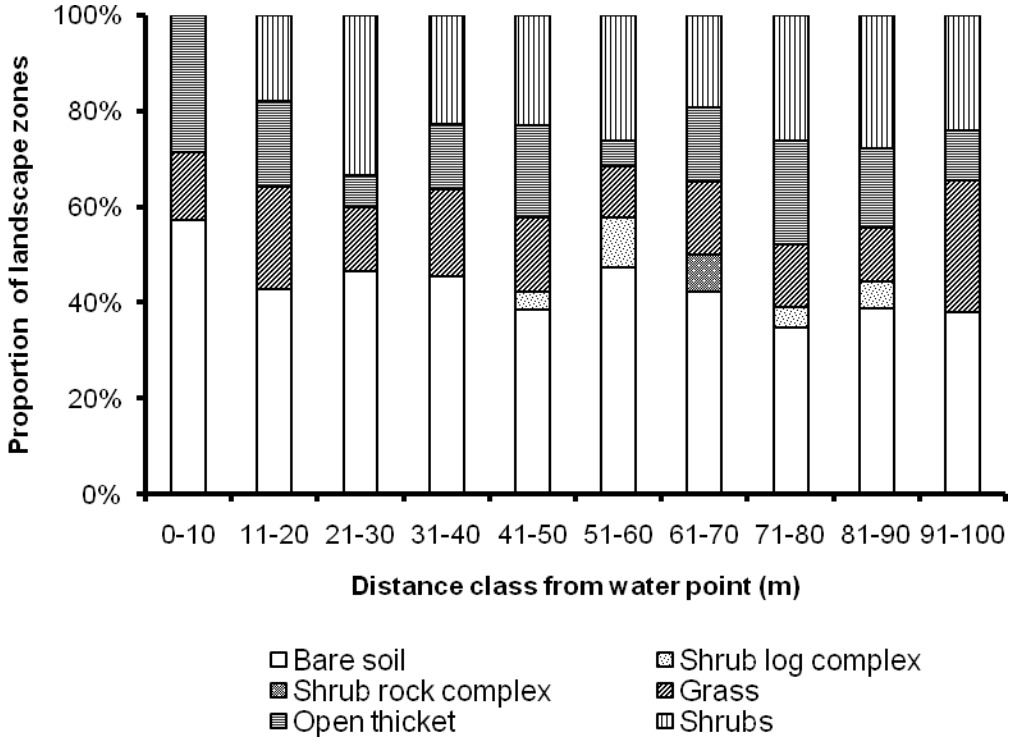
The distribution and amount of landscape zones along transects were related to distance from water points. The operating water points which are away from the river had the greater amount of bare soil (58%) closer to the water point, which possibly would defines the sacrifice zone (Figure 10a). The grass cover was greater as the distance increase from the water points. The shrub density increased with the increasing distance from water. The open thickets density had a varying amount among the distance classes, with mostly *Acacia tortilis* (27%) trees being closer to the water point at water point 1, which situated away from the river.

The operating water point along the river indicated a different distribution and proportion of landscape zones when compared to the water points which are away from the river. The amount of grass cover was greater closer to the water point (overall 44%), but was lower further away from the water point (Figure 10b). The three transects this operating water

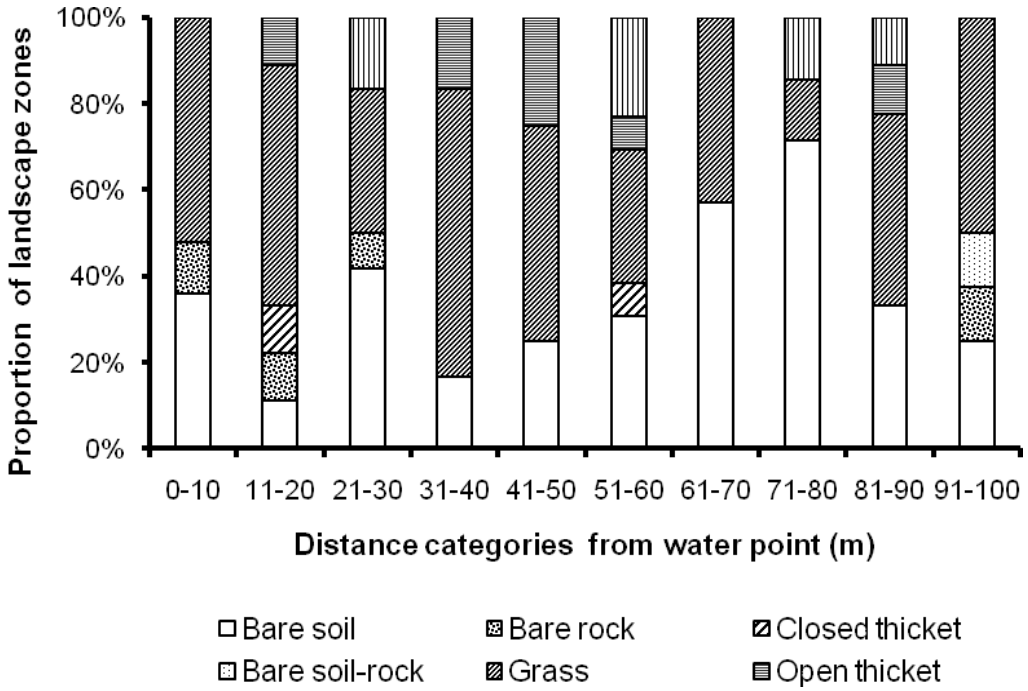
point were dominated by shrubs and thickets. The greater amount of grass cover indicated an improved soil cover at water points which are along the river. The amount of bare soil at water points along the river was lower closer to the water point when compared to water points which are away from the river. The shrub density was lower, and decreased with increasing distance; however the opposite pattern was expected for the shrubs. The density of open thickets increased with increasing distance from the water point.

The non-operating water points along the river, had the greater amount of grass cover (overall 40%), as expected (Figure 10c). The greater amount of grass cover suggests less around the non-operating water points. The similar pattern was indicated for the operating water points along the river. Bare soil (overall proportion of 28%), also indicated a slight decrease with increasing distance from the water point. The amount of bare soil, despite being lower, was greater than expected at non-operating water points. Shrubs and open thickets density increased with increasing distance from water.

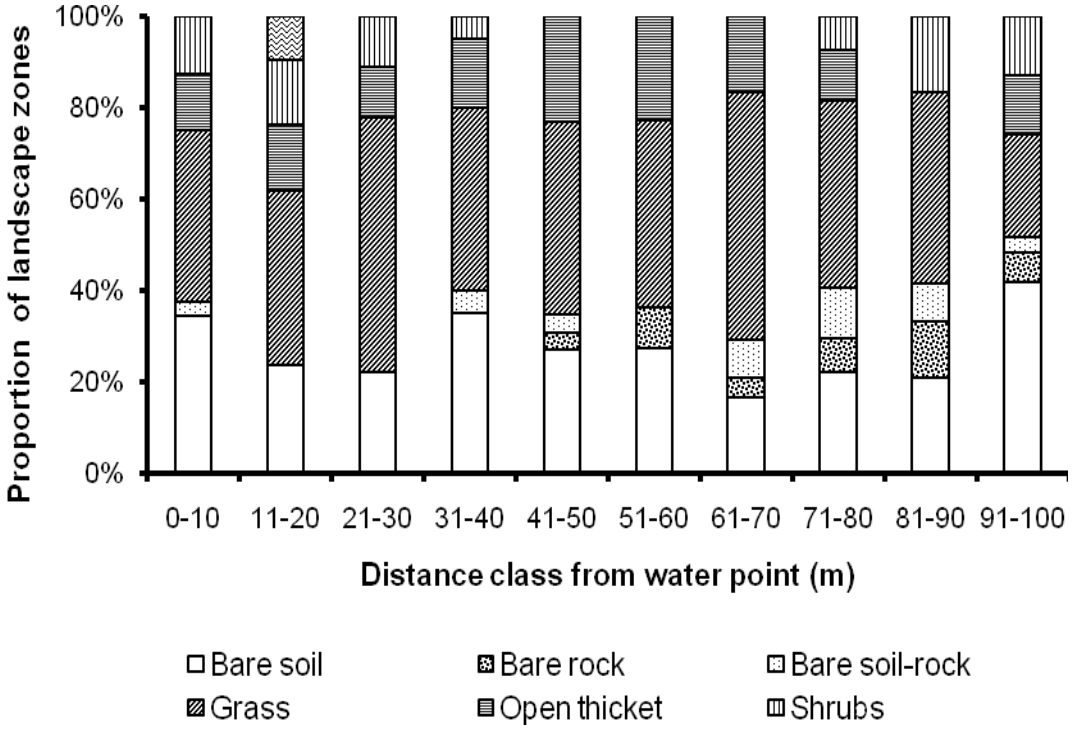
a



b


100%
80%
60%
40%
20%
0%
Proportion of landscape zones
0-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
91-100
Distance categories from water point (m)
Bare soil
Bare rock
Closed thicket
Bare soil-rock
Grass
Open thicket

c


100%
80%
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40%
20%
0%
Proportion of landscape zones
0-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
91-100
Distance class from water point (m)
Bare soil
Bare rock
Bare soil-rock
Grass
Open thicket
Shrubs

Figure 10 **Proportion of landscape zones in relation to distance from water point for the dry season, a – operating and away from the river, b – operating and along the river, and c – non-operating and along the river**

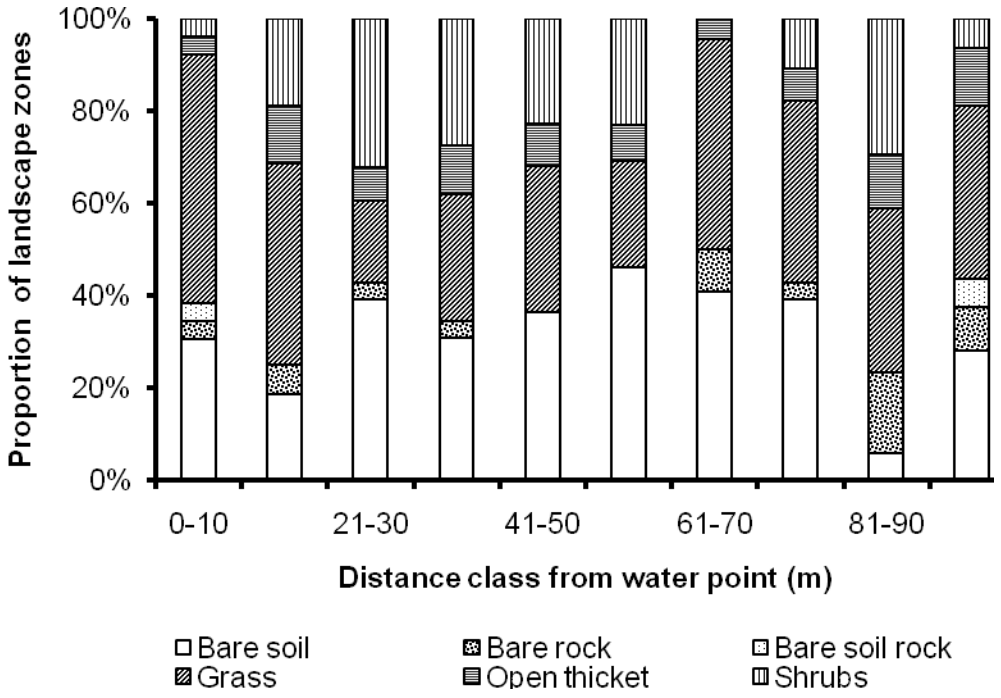
Wet season

The operating water points away from the river had a greater amount of bare soil (32%), which decreased slightly with increasing distance from water (Figure 11a). The sacrifice zone was not clearly defined. The grass cover was greater (36%). The shrub density (17%) generally increased with increasing distance from water, as expected. open thicket density (9%) remained constant.

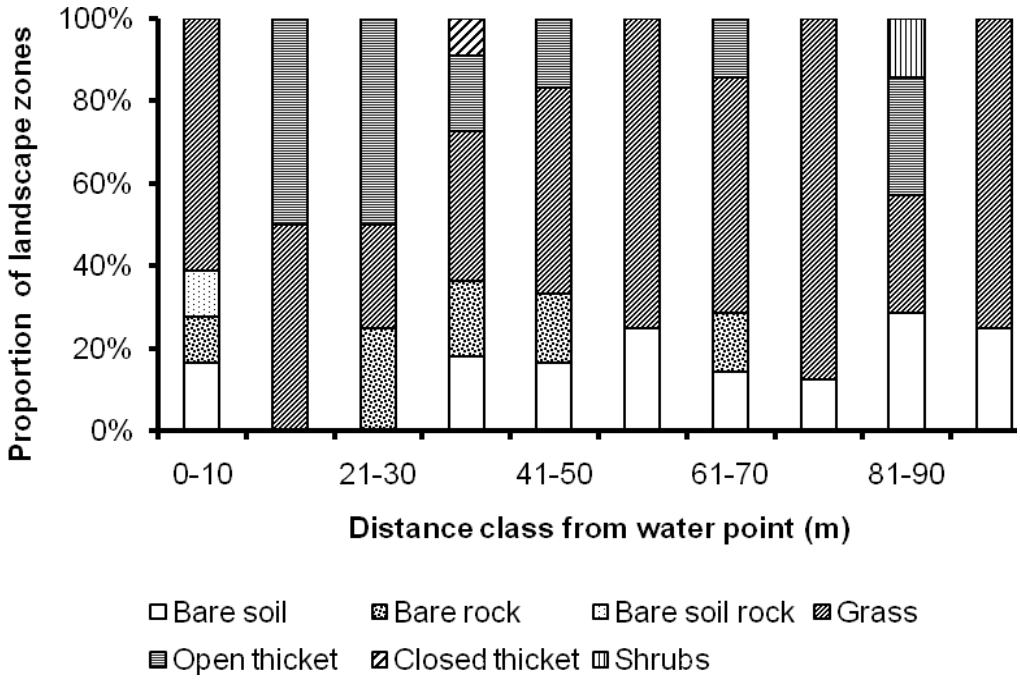
The operating water point which is along the river had a decreased amount of bare soil (17%), as expected (Figure 11b); however bare soil had an unexpected pattern, increasing with increasing distance from water. the grass cover was greater (overall proportion of 55%), and increased with increasing distance from the water point. The density of pen thicket (overall 13%) decreased with increasing distance from water; however, this pattern was not expected. The shrub density was low (overall 1%).

The non-operating water points situated along the river had the greater amount of grass cover (overall 49%), as expected. Bare soil (overall 30%) increased with increasing distance from the water point, however the opposite was expected (Figure 11c). The amount of bare soil was also expected to be lower at non-operating water points than at the operating water points along the river. Shrub and open thicket density remained constant.

a


100%
80%
60%
40%
20%
0%
Proportion of landscape zones
0-10
21-30
41-50
61-70
81-90
Distance class from water point (m)
Bare soil
Bare rock
Bare soil rock
Grass
Open thicket
Shrubs

b


100%
80%
60%
40%
20%
0%
Proportion of landscape zones
0-10
21-30
41-50
61-70
81-90
Distance class from water point (m)
Bare soil
Bare rock
Bare soil rock
Grass
Open thicket
Closed thicket
Shrubs

c

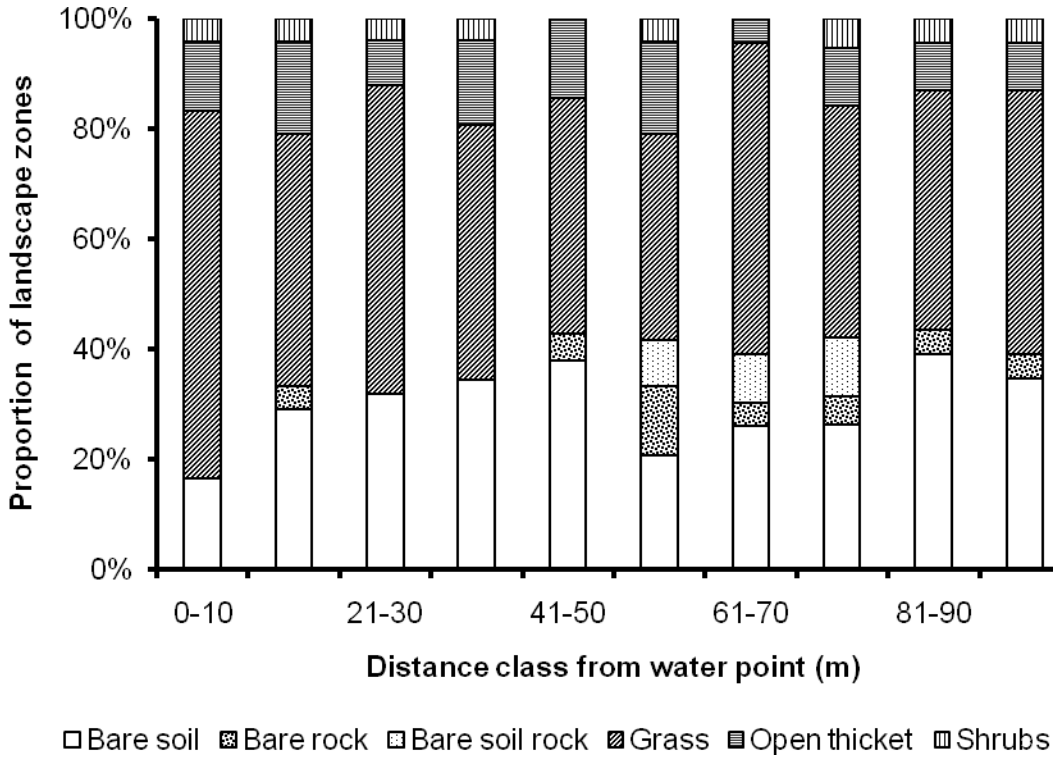


Figure 11 **Proportion of landscape zones in relation to distance from water point for the dry season, a – operating and away from the river, b – operating and along the river, and c – non-operating and along the river**

Correlation analysis of landscape zones in relation to distance from water

The relationship between operating water points away from the river indicates:

1. A negative relationship with bare soil (Correlation coefficient rho = -0.062, P = 0.05), where bare soil decreased with increasing distance from the water point.
2. A negative relationship with grass cover (rho= -0.218, P = 0.040), however the grass cover was expected to increase with increasing distance from the water point.
3. A weak relationship with open thicket density (rho = 0.045, P = 0.299), which is contrary to what was expected.
4. A positive relationship with shrub density (rho = 0.133, P = 0.002), as was expected.

The relationship between operating water points along the river indicates:

1. A weak relationship with grass cover (rho = -0.029, P = 0.204) and bare soil (rho = 0.024, P = 0.747). The results are contrary to what was expected, as grass was expected to increase with increasing distance from the water point and bare soil decreasing with increasing distance.
2. A positive relationship open thicket density (rho = 0.186, P = 0.002), increasing with increasing distance from the water point.
3. A positive relationship with shrub density (rho = 0.307, P = 0.004).

The relationship between non-operating water points along the river indicates:

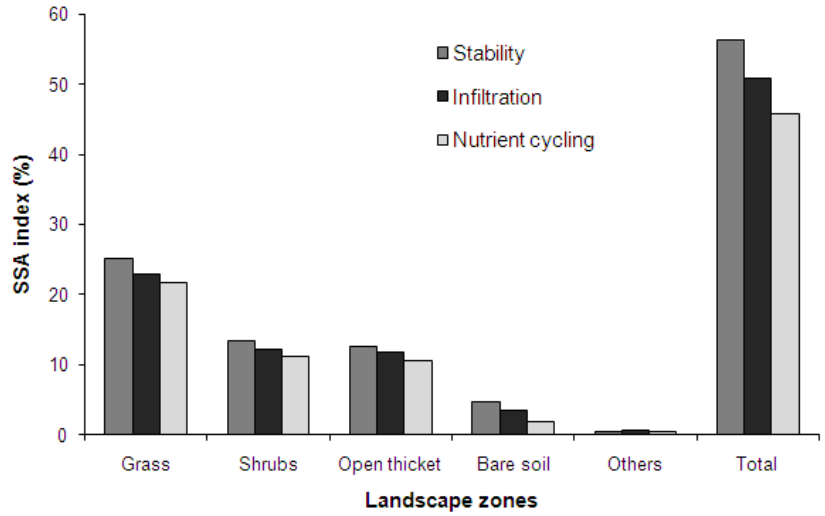
1. A weak relationship with bare soil (rho = 0.068, P = 0.366) and grass cover (rho = 0.019, P = 0.793), probably related to less utilization at non-operating water point.
2. A positive relationship with bare soil with rocks (rho = 0.091, P = 0.032), which is contrary to what was expected.
3. A negative relationship with open thicket density (rho = -0.084, P = 0.045). This trend was unexpected.
4. A positive relationship with shrub density (rho = 0.092, P = 0.033), where the shrub density increased with increasing distance from the water point, as was expected.

Soil surface analysis

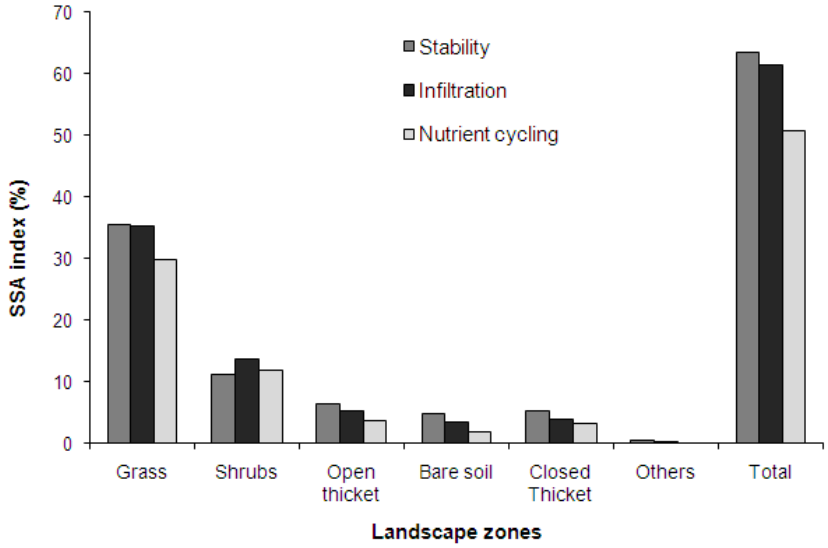
Dry season

The SSA indices indicated that grass was the major contributor in terms of potential to accumulate resources in all the water points (S=15, I =13, NC=12 for operating water points; S=35, I=31, NC=26 for non-operating water points) (Figure 12a-c). Overall, the water points which are away from the river had a lower in terms of potential to accumulate resources (total indices: S=45, I=39, NC=32), probably due to low soil cover when compared to water points along the river (S=55, I=51, NC=43). Open thicket indicated a potential to accumulate resources at non-operating water points (S=16, I=13, NC=12). The contribution of open thicket was lower at operating water points along the river (S=4, I=4, NC=4) than the operating water points away from the river (S=9, I=7, NC=6), however the opposite pattern was expected.

a


60
50
40
30
20
10
0
SSA index (%)
Stability
Infiltration
Nutrient cycling
Grass
Shrubs
Open thicket
Bare soil
Others
Total
Landscape zones

b


70
60
50
40
30
20
10
0
SSA index (%)
Stability
Infiltration
Nutrient cycling
Grass
Shrubs
Open thicket
Bare soil
Closed Thicket
Others
Total
Landscape zones

c

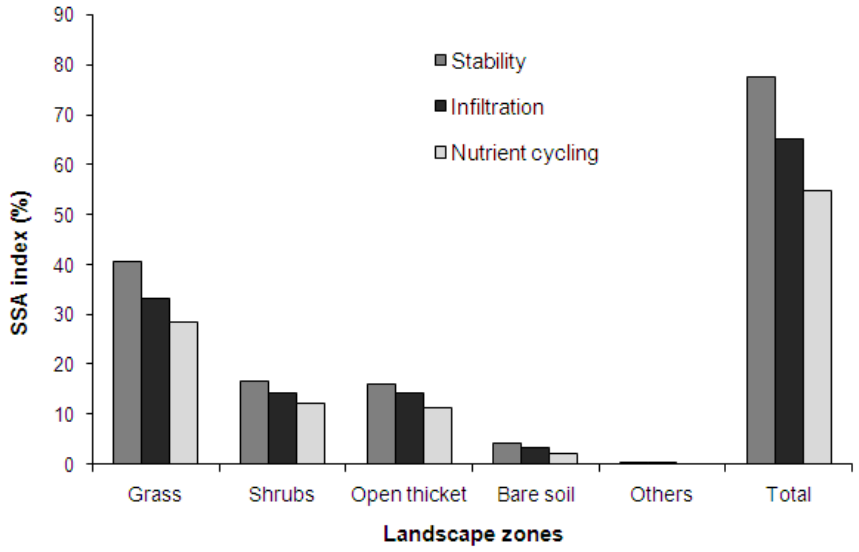
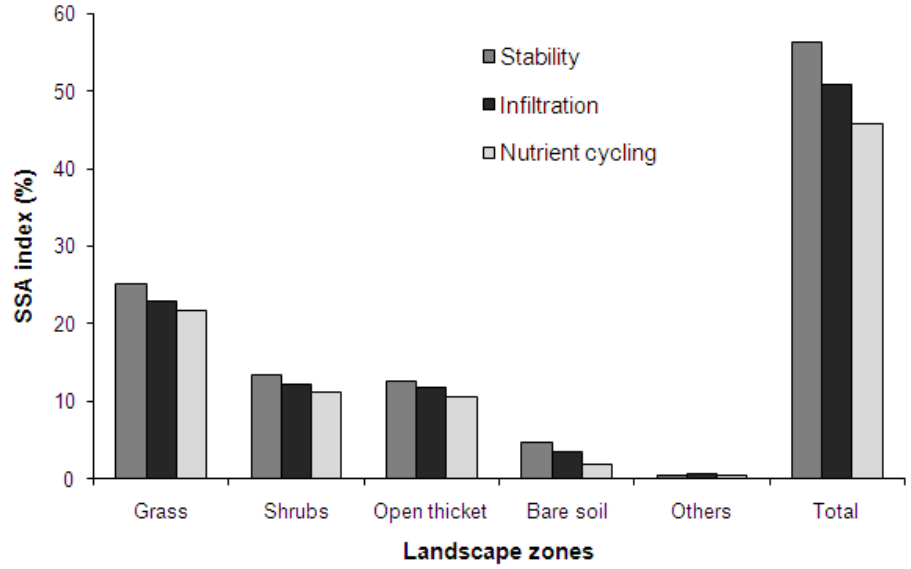


Figure 12 **Soil surface assessment indices indicating individual landscape zones contribution to the whole site for the dry season, a - operating water points away from the river , b - along the river, c - and non-operating water points along the river.**

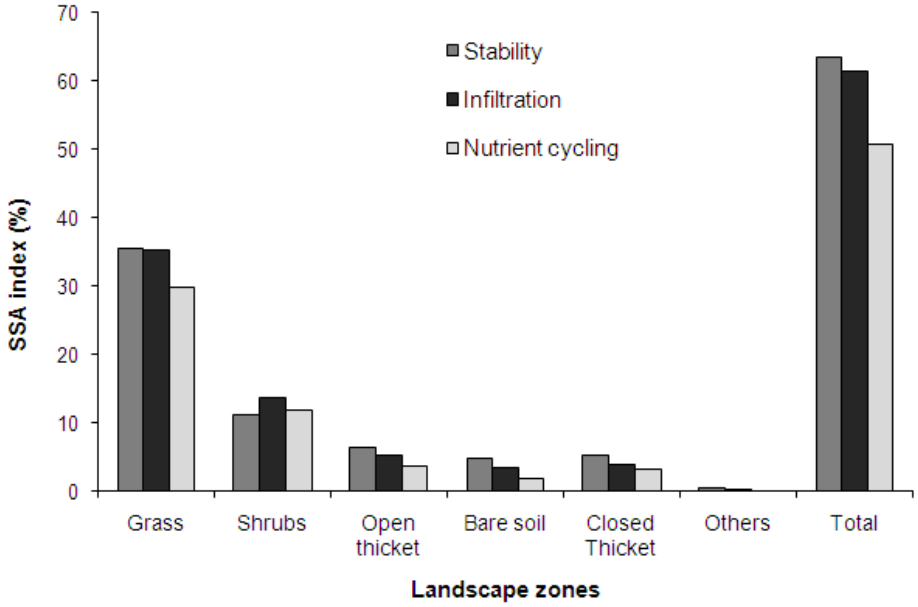
Wet season

Grass was a major contributor in terms of potential to accumulate resources for all the water points (S=25, I=23, NC=22 for operating water points away from the river; S=35, I=35, NC=30 for operating water point along the river; S=40, I= 33, NC=29 for non-operating water points) (Figure 13a-c). Shrubs and open thicket (both second most contributors) had an equal contribution, except at operating water points along the river (shrubs: S= 11, I=13, NC=12; open thicket: S=6, I=5, NC=4). The total indices for wet season indicated that the landscape at non-operating water points had a greater potential to accumulate more resources (S=78, I= 65, NC=54) when compared to the other water points during the wet season.

a


60
50
40
30
20
10
0
SSA index (%)
Stability
Infiltration
Nutrient cycling
Grass
Shrubs
Open thicket
Bare soil
Others
Total
Landscape zones

b


70
60
50
40
30
20
10
0
SSA index (%)
Stability
Infiltration
Nutrient cycling
Grass
Shrubs
Open thicket
Bare soil
Closed Thicket
Others
Total
Landscape zones

c

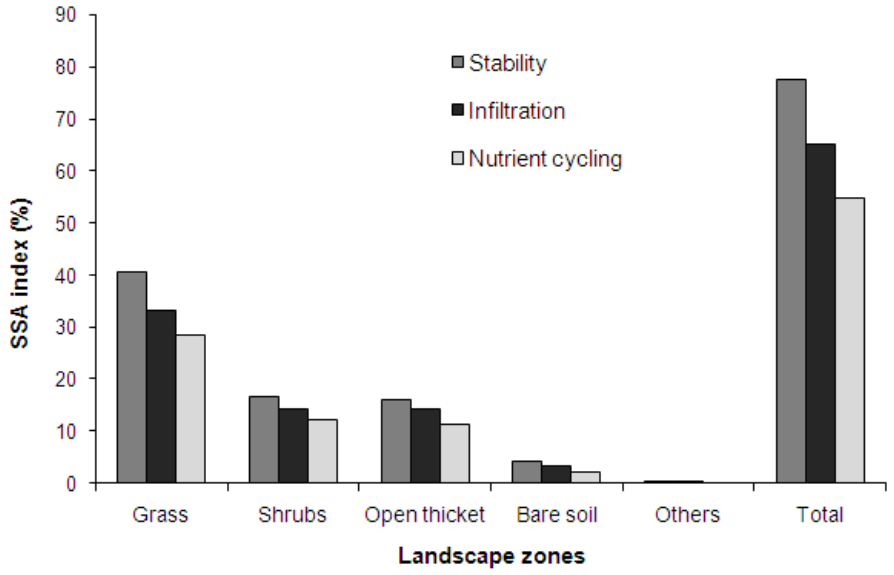


Figure 13 **Soil surface assessment indices indicating individual landscape zones contribution to the whole site for the wet season, a - operating water points away from the river , b - along the river, c - and non-operating water points along the river.**

Herbaceous species

Species abundance

A total of 36 herbaceous species (27 during the dry season and 34 during wet season) were recorded from 20 transects (Appendix 2). Forbs and creepers were lumped together.

Dry season

The species abundance was influenced by the spatial location of the water points (away or along the river) and the status of the water points (operating or non-operating). The relationship between the operating water points away from the river indicates a negative relationship with species abundance (rho = -0.453, P = 0.003); so do between operating water points along the river (rho = -0.785, P = 0.001). The non-operating water points along the river had a positive relationship with species abundance (rho = 0.553, P = 0.003).

Species such as *Cynodon dactylon* and *Sporobolus pyramidalis* were abundant around water points along the river and operating (Figure 14a), with a mean abundance of 34% and 12.8% respectively. *Eragrostis lehmanianna, Aristida congesta* and the forbs were equally dominant at operating water points away from the river. *Panicum maximum*, mostly found under *Acacia tortilis* open thickets was most abundant at water points away from the river and operating as compared to water points along the river. The abundance of species such as *Eragrostis rigidior* was not influenced by the location and status of the water points. *Cymbopogon plurinodis* was abundant (mean abundance 10%) at water points along the river and not operating, followed by *Elionuris muticus* and *Heteropogon contortus*. Species such as *Hyperthelia dissoluta* and *Imperata cylindrica* which were associated with a vlei area were only recorded at water points along the river.

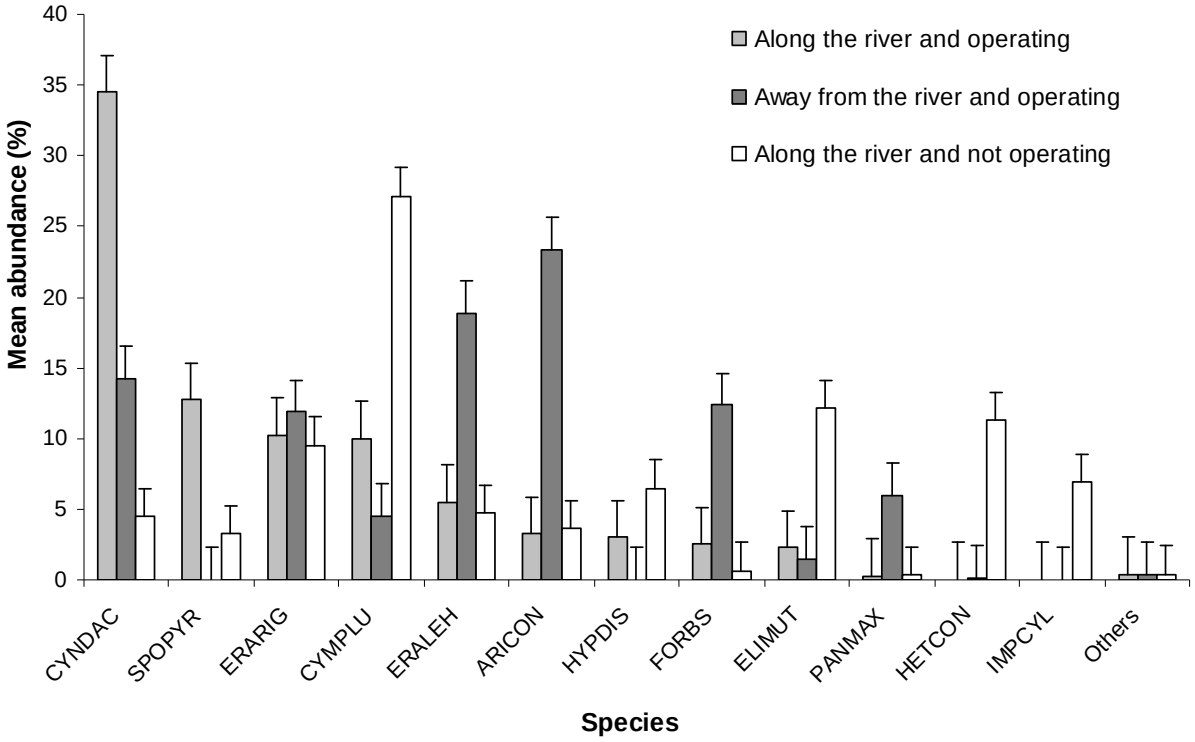
Wet season

New species were recorded during the wet season, as expected. The relationship between operating water points away from the river indicates a negative relationship with species abundance and (rho = -0.466, P = 0.050), so do with operating water points along the river (rho = -0.615, P = 0.011). There was a week relationship between non-operating water points with species abundance (rho = -0.217, P = 0.420).

Species such as C. *dactylon (*37%) was most abundant at both water points away and along the river. *Sporobolus pyramidalis* (13%) was abundant at water points along the river. The forbs were most abundant at the water points along the river and operating (Figure 14b). Species such as *E. lehmanniana*, *A. congesta*, and *Eragrostis obtusa* were most abundant at water points away from the river. New species such as *Eragrostis obtusa* and *Skchuria pinnata* were also recorded at water points away from the river. The non-operating water points along the river were dominated by species such as *C. plurinodis* (19%), *H. contortus* (20%), and *E.muticus*; with new species such as *Enneapogon scoparius* and *Themeda triandra* being recorded. The mean abundance of both species was less than 2% during the dry season. *Panicum maximum* was most abundant at water points along the river as opposed to water points away from the river during the dry season. *Eragrostis rigidior* had a mean abundance of less than 2% during the wet season. Surprisingly, *H. dissoluta* had a mean abundance of less

than 2%, with an abundance value of 1.8% at the water points which are along the river and not operating.

a



b

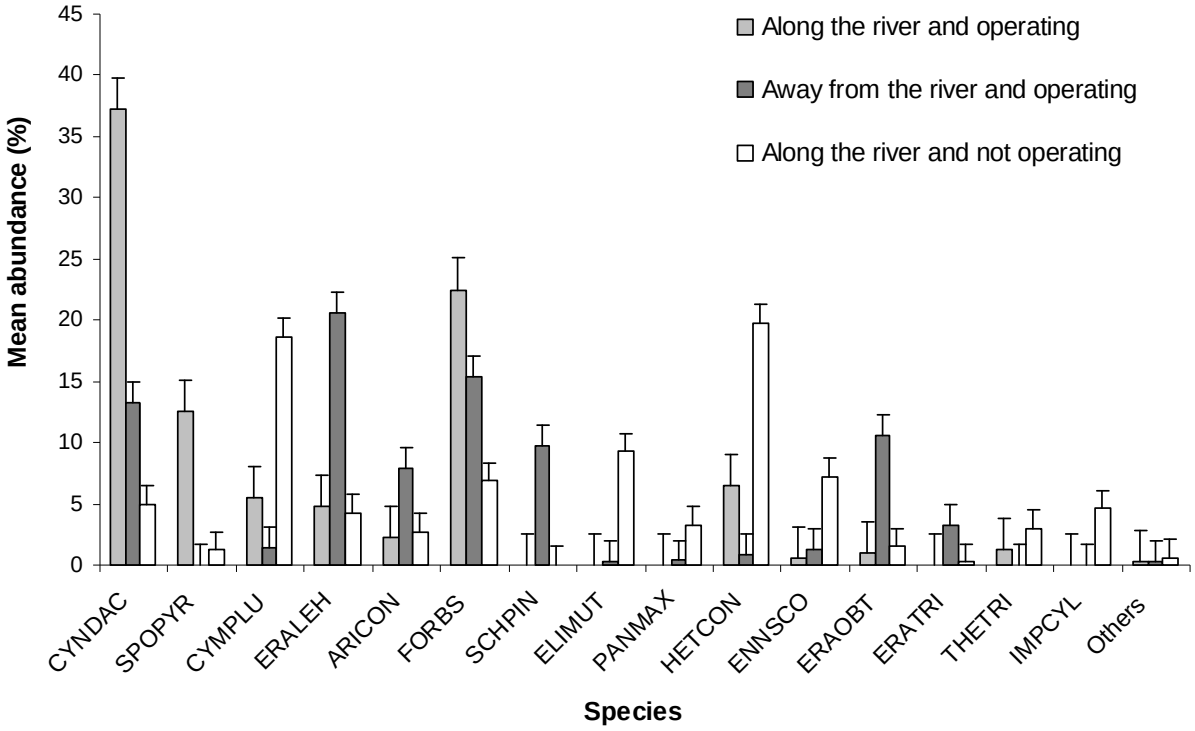


Figure 14 **Mean (SE) species abundance for operating (along vs. away from river) and non-operating water points (along the river) for (a) dry season and (b) wet season. The species codes explanations are presented in Appendix 4.**

Species composition

Dry season

CCA of the species composition data confirmed a statistically significant relationship between species and the whole set of environmental variables, as shown by the Monte Carlo test, in the test applied on the reduced model (first canonical axis: F = 4.159, P = 0.0050, all canonical axes: F = 3.655, P = 0.0050). The first two axes accounted for 81.9% of the variation (Table 3).

Table 3 Eigenvalues of the CCA for herbaceous species in relation to environmental variables for the dry season

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.462	0.284	0.165	0.407
Species-environment correlations	0.944	0.804	0.809	0.000
Cumulative percentage variance:				
of species data	20.6	33.3	40.7	58.9
of species-environment relation	50.7	81.9	100.0	0.0
Sum of all eigenvalues	2.240			
Sum of all canonical eigenvalues	0.911			

There was a clear pattern of certain species occurring at water points away and along the river depending on the set of environmental variables. Species such as *A. congesta*, *E. lehmanniana*, *T. bertonianis*, *S. pinnata*, and the forbs appeared to be strongly correlated to water points which are situated away from the river on shallow red brown sandy soils and also operating (Figure 15). These species are plotted on the left side of the biplot diagram. *H. contortus*, *C. plurinodis* and *E. muticus* occurred more abundantly around water points which are not operating and along the river. Dark brown clay soils and water points along the river were characterized by species such as *I. cylindrica*, *H. dissoluta*, and *B. nigropedata*. The operating water points along the river on deep dark grey colluvial and slightly moist soils were characterized by species such as *T. triandra*, *C. dactylon*, *T. minuta* and *S. pyramidalis* species (Figure 15). Slope did not appear to be an important factor in influencing species composition due to the flat terrain of MAF.

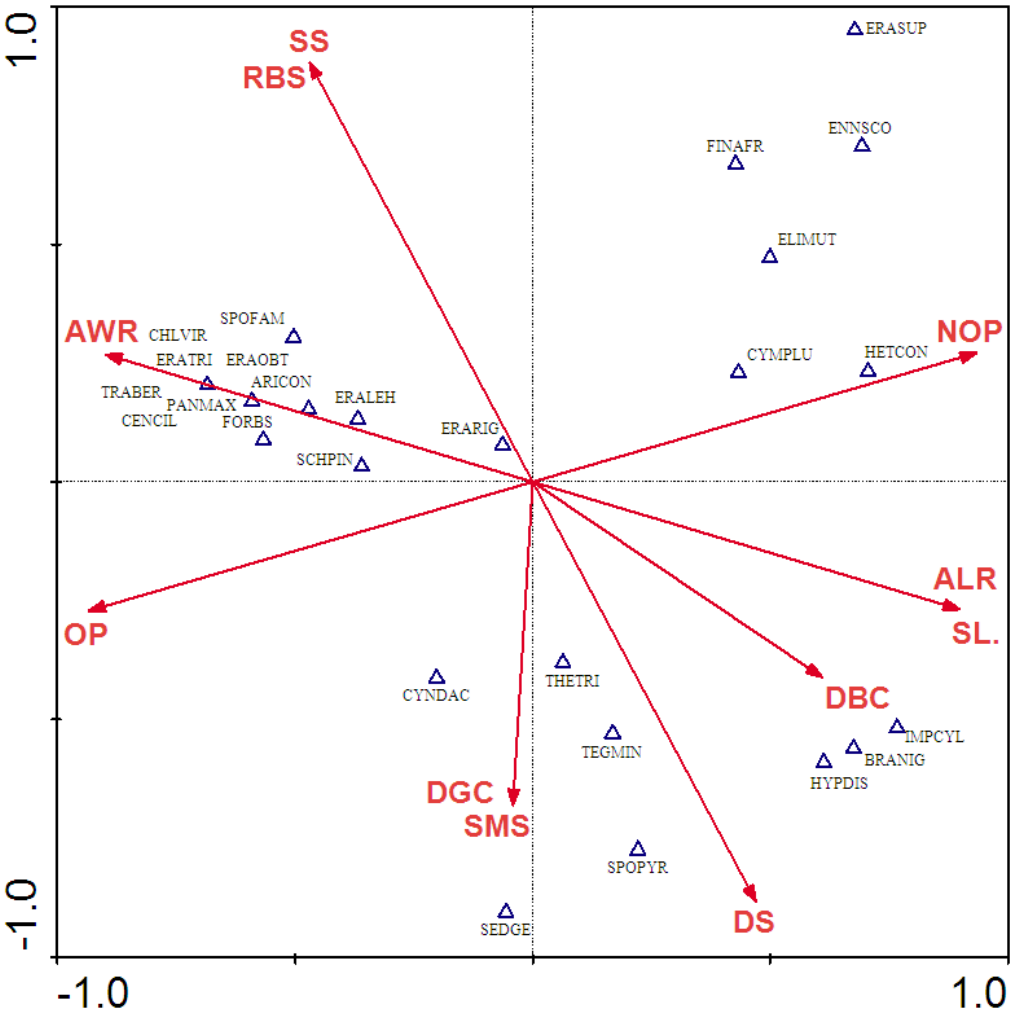


Figure 15 **CCA biplot of species in relation to environmental variables of all water points for the dry season. Environmental variables code explanations: AWR = away from river, ALR = along the river, OP = operating water points, NOP = not operating water points, DBC = dark brown clay, RBS = red brown sand, DGC = dark grey colluvial, SS = shallow soil, DS = deep soil, SMS = slightly moist soil, SL = slope (%). The species code explanations are indicated in Appendix 4.**

Wet season

CCA of the species composition data also confirmed a statistically significant relationship between species and the whole set of environmental variables. The Monte Carlo test results applied using reduced model on the data indicated significant eigenvalues (first canonical axis:

F = 3.594, P = 0.0050, all canonical axes: F = 2.960, P = 0.0050). The first two axes accounted for 81.2% of the variation (Table 4).

Table 4 **Eigenvalues of the CCA of herbaceous species in relation to environmental variables for the wet season**

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.523	0.304	0.191	0.436
Species-environment correlations	0.968	0.805	0.819	0.000
Cumulative percentage variance:				
of species data	18.3	29.0	35.7	51.0
of species-environment relation	51.4	81.2	100.0	0.0
Sum of all eigenvalues	2.853			
Sum of all canonical eigenvalues	1.018			

Species such as *M. repens*, *C. virgata*, *E. obtusa*, *E. lehmanniana*, *A. congesta*, *D. eriantha*, and *S. pinnata* were strongly correlated with operating water points away from the river (Figure 16). Water points situated along the river and not operating indicated a strong correlation to species such as *S. fimbriatus*, *P. maximum*, *H. contortus*, *T. triandra* and *C. plurinodis*, contrary to what was observed during the dry season. Species such as *S. verticelata*, *H. dissoluta*, *S. sphacelata*, *D. amplectens*, *I. cylindrica* were correlated to dark brown clay soils around water points along the river. Forbs, *C. dactylon* and *S. pyramidalis* were correlated to slightly moist dark grey collovium soils. Again slope did not appear to be an important factor influencing species composition. .

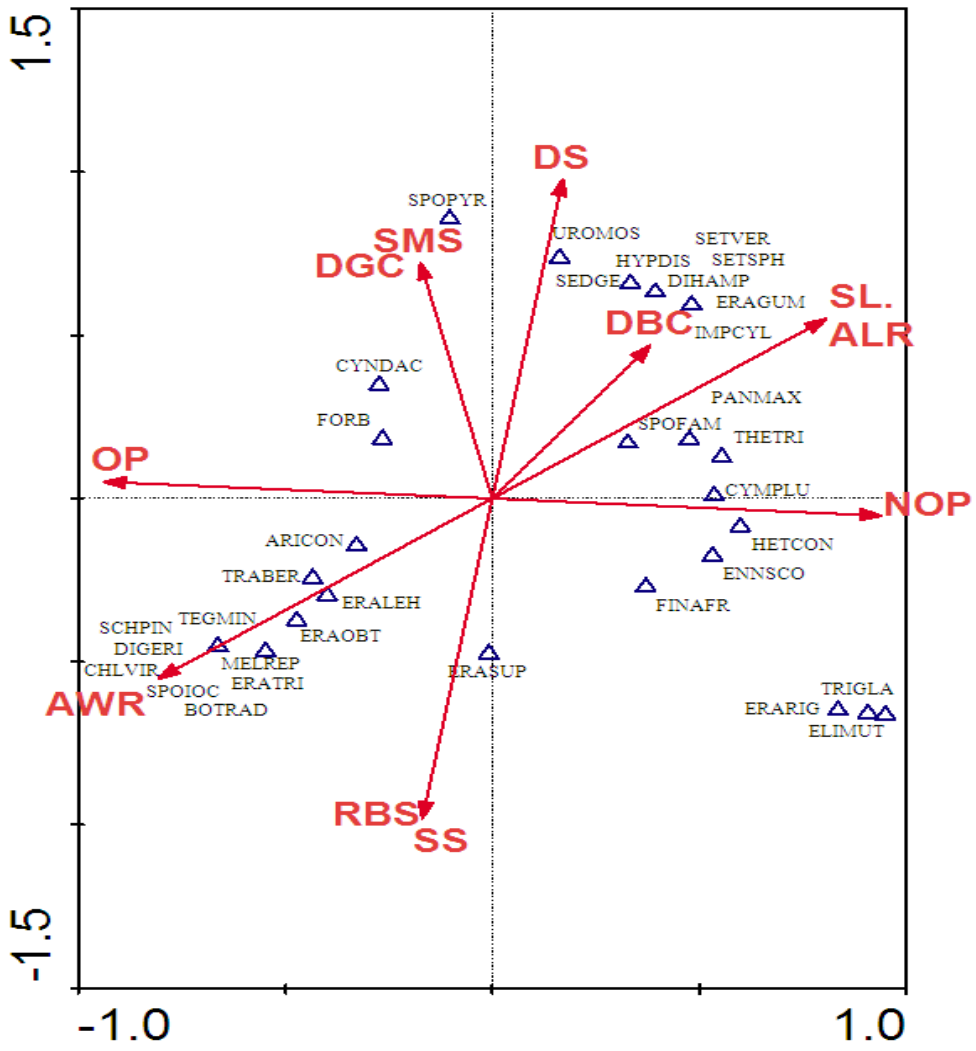


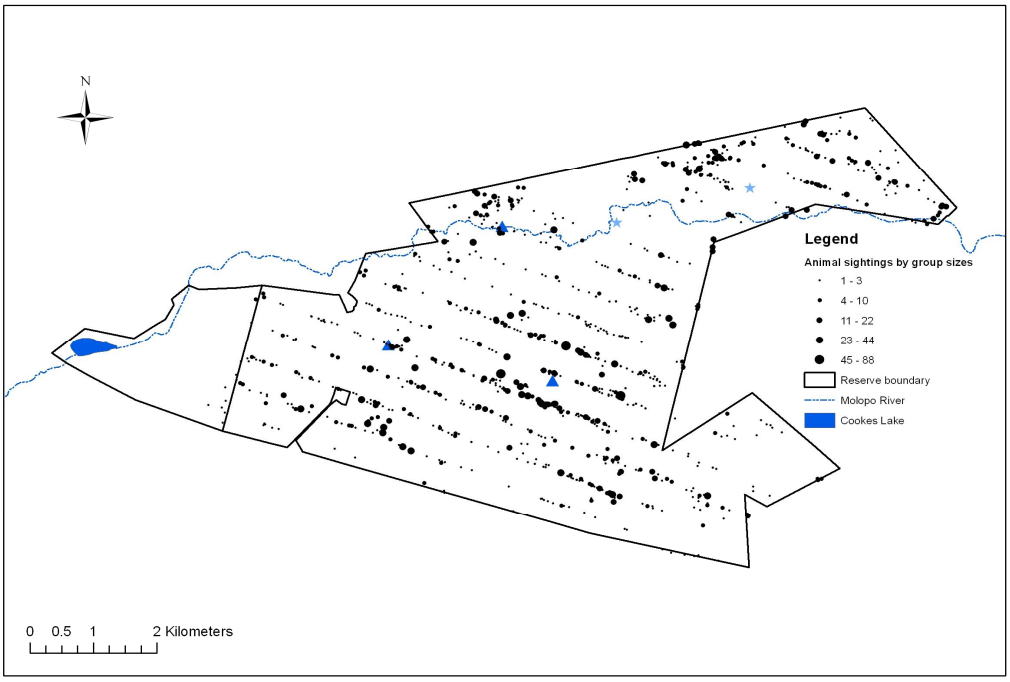
Figure 16 **CCA biplot of species in relation to environmental variables of all the water points for the wet season. Environmental variables code explanations: AWR = away from river, ALR = along the river, OP = operating water points, NOP = not operating water points, DBC = dark brown clay, RBS = red brown sand, DGC = dark grey colluvial, SS = shallow soil, DS = deep soil, SMS = slightly moist soil, SL = slope (%)**

Herbivore distribution and densities

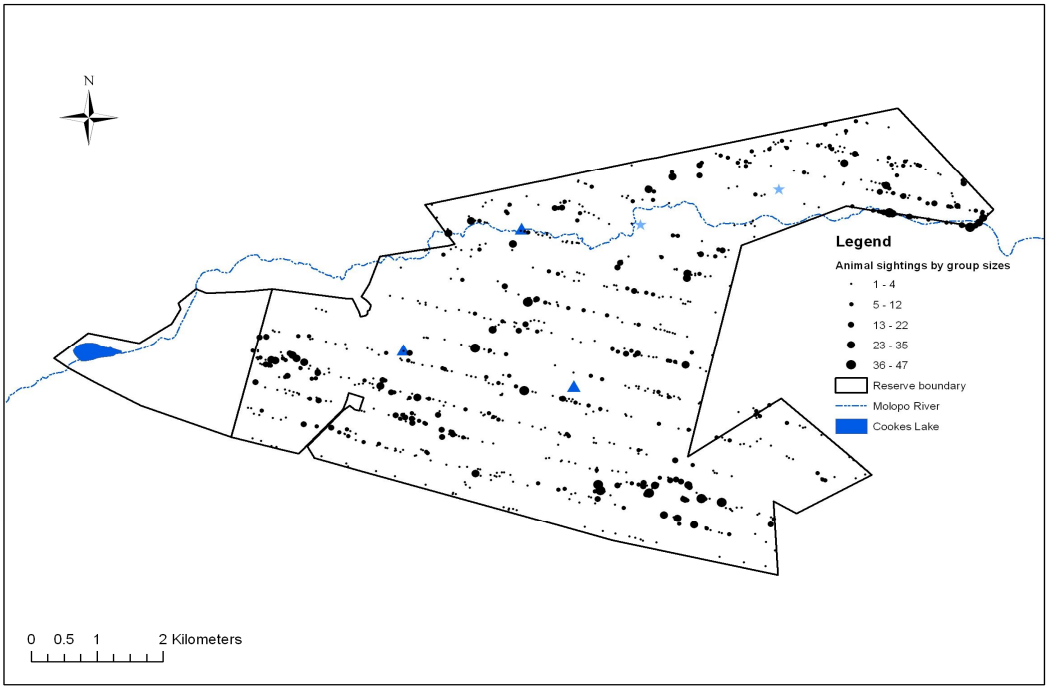
The animal density maps from the annual aerial animal surveys are conducted during the dry season (August-September) in 2005, 2008 and 2009 are presented in Figure 17. Although the data is limited to three years, it can be seen that the higher density of animals was generally on the central to the south part than the north to north eastern area. However, some concentration of of animals was occasionally observed in the north eastern area in during the 2005 aerial surveys due to the temporary water point created as a result of tank overflow from the reserve manager's house. Also the higher animal concentration in the western part was specifically attributed to temporary water point which was caused by a leaking pipe from the water works of the Department of Water Affairs.

The animal stocking level for reserve in 2009 is indicated in Appendix 5. The stocking level was generally low in 2009 (animal numbers based on the population estimates for 2009). The agricultural stocking rate (after Van Rooyen 2002) was at 9 ha per livestock unit (LSU). An upper limit of 8 ha/LSU was initially recommended for the reserve, which implies that the stocking level was acceptable. The animal numbers has been reduced to desirable level through live sales.

a



b


N
Legend
Animal sightings by group sizes
1 - 4
5 - 12
13 - 22
23 - 35
36 - 47
Reserve boundary
Molopo River
Cookes Lake
0 0.5 1 2 Kilometers

c

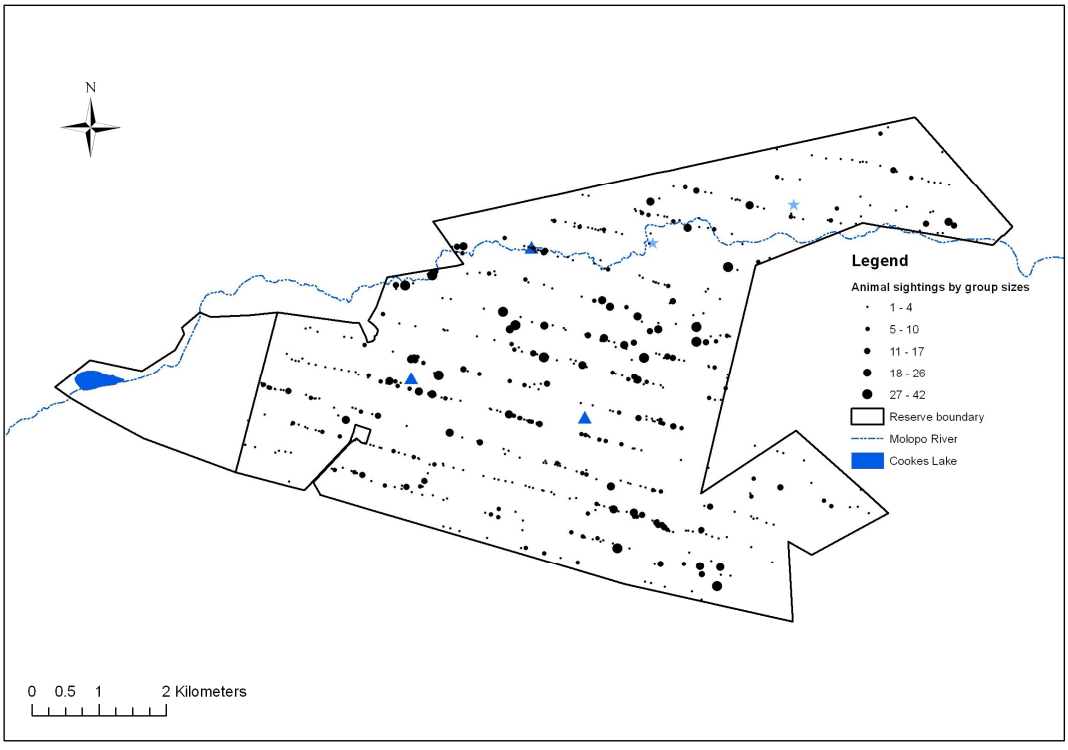

N
Legend
Animal sightings by group sizes
1 - 4
5 - 10
11 - 17
18 - 26
27 - 42
Reserve boundary
Molopo River
Cookes Lake
0 0.5 1 2 Kilometers

Figure 17 **Animal distribution and density from the aerial surveys for (a) 2005, (b) 2008 and (c) 2009. Bigger dots represent a large group size. Operating water points (triangles) and non-operating water points (stars) are indicated.**

DISCUSSION

Extent of the sacrifice zones

A trend in the extent of the sacrifice zone was identified despite the use of different sources of data and spectral confusions, as explained in the imagery analysis. Regarding hypothesis 1, the image classification results showed a steady increase of the sacrifice zone at water points which are situated away from the river since the establishment of the reserve, as shown on the 2003 and 2009 imagery and Table 2. Water point 2 indicates more impact on vegetation cover than water point 1. The reason for such impact might be due to the fact that water point 2 normally experience higher animal density than water point 1 (Figure 17.), and is situated on a shallow calcrete soil. Water point 1 is situated on a much deeper sandy soil. There was no sacrifice zone identified in 1980, probably due lack of animal activities during that year since the reserve was not established yet. Imagery for the period 1995-1998 could have given a much better picture in relation to the increase of the sacrifice zone; due to the intermediate period after the reserve was established. The water points along the river indicated a minimal impact on vegetation cover, hence the extent of sacrifice zones were not identified. These water points are situated in the part of the reserve, which is normally attracting lower concentration of animal activity (Figure 17) except during the periods after a fire (*Pers. obs.*) as compared to those which are away from the river. Also, the vlei area (where these water points are situated) has the potential to retain soil moisture for long periods without rainfall due to the existence of a soft plinthic horizon.

The resolution of photographs and imagery appeared to have been coarse, therefore limiting the ability to identify the extent of the sacrifice zone clearly. A much higher resolution i.e. 5 m could have been ideal to have better identified the extent of sacrifice zone and reduce spectral confusion that occurred. Also for consistency, the same type of data could have been used, but ideal historical data is difficult to obtain. The unknown month of acquisition for photographs decreased the accuracy of the comparison due to the risk of detecting seasonal differences rather than real spatial differences.

Landscape Function Analysis

The landscape organization results show a trend of higher soil cover for both the dry and wet season around operating water points along the river than those that are away from the river. However the wet season had a higher soil cover than the dry season due to the effect of the greater amount of rainfall received. Regarding hypothesis 3, the soil surface analysis results suggest grass cover as the main contributor in terms of potential to accumulate resources for all the water points for both the dry and wet season. However, the water points which are situated along the river show greater potential to accumulate resources due to the higher amount of soil cover in the vlei area. Therefore, the results of this study indicate the reduced function at operating water points away from the river. Parker and Witkowski (1999), Thrash 1998 and Gaylard *et al*. (2003), indicated in the Kruger National Park that water points contribute to deterioration of rangeland condition and change in vegetation composition. Disturbance regimes are a natural part of all plant communities, however scientific literature (Rawlinson 2000) provides examples where concentrated use of an area by animals can lead to trampled vegetation, soil compaction, and increased nitrogen deposition. Abiotic and biotic properties of savanna may be altered at artificial water points (Owen-smith 1996).

Definite landscape zones (cover types) show patterns of increasing and decreasing abundance (frequency) with proximity to water, concurring with hypothesis 2. However, the correlation results indicate weak relationship between some landscape zones and distance from water, which is contrary to what was expected. For example, there was no relationship between bare soil and distance from water around the non-operating water points along the river. The weak relationship can be attributed to less utilization at non-operating water points. Grass cover also indicated a weak relationship with distance at non-operating water points as was expected due to less utilization. During the wet season, open thickets indicate a decrease with increasing distance from water, contrary to what was expected. Previous studies indicated that gradients of utilization pressure develop around water points, with the greatest impact near the water point and decreasing pressure as distance away from the water point increases (Brits *et al*. 2000; Makhabu *et al*. 2002; Derry 2004; Nangula and Oba 2004; Adler and Hall 2005).

Surprisingly, the shrub density decreased during the wet season than in the dry season. This pattern might be as a result of shrubs that could have been classified as open thicket during the wet season due to their increased height, and also not being clearly visible due to the re-

growth of other vegetation in the wet season. Also, the operating water points along the river are much more similar in distribution and proportion of landscape zones to those that are away from the river during the dry season. This pattern is unexpected and also unexplainable, unless there was a non-operating water point situated along the river that could have been used as a control.

The LFA interpretational framework, which provides a process to identify critical thresholds in landscape function, was not applied. This was due to insufficient continuous monitoring data available from any of the water point sites to give a time series for rangeland to fully demonstrate the concept. Tongway and Hindley (2004, 2005) indicated that, typically, a minimum of 6 time series points of those representing initial and final values respectively would be needed, with accuracy of the predictions of outcomes as more data are included in the analysis over time. Data for this study were only collected for two seasons (dry and wet) covering one rainfall season. Therefore, repeatable data have to be collected at the water point sites over time in order to get the meaningful interpretation (Farmer *Pers. Comm*.)

Herbaceous species: abundance and composition

Differences in grazing gradient surrounding the water points and spatial location of the water point are reflected in the vegetation composition. In support of hypothesis 1b, the water points away from the river are characterized by mostly Increaser II species (e.g. *C. dactylon*, *E. rigidior* and *E. lehmanniana*); probably due to concentrated animal activity that favours Increaser II species. Increaser 1 species (e.g. *C. plurinodis* and *I. cylindrica*) and Decreaser species (e.g. *P. maximum* and *T. triandra*) characterize water points which are situated along the river. These areas have low concentration of animal activity (see Figure 17), especially the non-operating water points, and are currently less utilized. The trend in herbaceous species abundance for both the dry and wet season was almost similar, except that few annual species were recorded during the wet season, supporting hypothesis 4. The results concur with previous studies. For example, Parker and Witkowski (1999) and Rawlinson (2000) found that water points with high animal activity exhibit higher Increaser II species than Increaser I and Decreasers. Also Tarhouni *et al*. (2007) indicated that grazing gradients expand under continuing grazing pressure for many years after the establishment of the water points or wells, which appears to be the case in MAF. However, the animal stocking level was within the

recommended limit (8 ha/LSU) set out for the reserve (Appendix 5), which supports concept of accumulated impacts on vegetation for many years in the reserve.

Previous studies (e.g. Brits *et al*. 2000; Landsberg *at al*. 2003; Vetaas 2003; Adler and Hall 2005; Fynn 2005) indicated that multiple environmental factors influence plants community and coexistence. The ordination results indicate a clear grouping of species in relation to the environmental variables for both the dry and the wet season. During the dry season, most Increaser II species were related to operating water points situated away from the river on shallow red brown soils. The operating water points along the river on slightly moist dark grey colluvial soil are characterized by both Increaser I and II species. The dark brown clay soil at the non-operating water point along the river is characterized by Increaser I species. The differences in soil depth are reflected by the species present at the two extremes of the soil gradient. *Themeda triandra, S. pyramidalis, I. cylindrica* and *H. dissoluta* are typical species occurring in deep soils, whereas *S. fimbriatus, A. congesta,* and *E. lehmanniana* occur on shallow soils. The results concur to some extent with the findings by Makhabu *at al*. (2002) in the central Kalahari in Botswana and Oliver (2007) in the semi-climatic regions of the Free State, where soil depth and clay in the A-horizon were identified as having an important influence on the distribution of sites in the ordination space. Nangula and Oba (2004) found that in the Oshana ecosystems in Nambia, annual grazing and soil texture showed the greatest correlation with the distribution of the plant community types. The species composition during the wet season indicates a similar response in relation to environmental variables as with the dry season, except that additional species (mostly annuals) related to wet conditions were recorded. The above average 2008/09 seasonal rainfall (Figure 2) covering the wet season data collection period has influenced the occurrence of new annual species. However, the forbs appear to have shifted on the CCA biplot diagram in the wet as compared to the dry season, and correlate to dark grey colluvial soils. The dark grey colluvial soils form the major part of the vlei area in the reserve. Slope was not an important factor influencing species composition in MAF due to the flat terrain of the reserve.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the results of this study:

i. The location of water points in a landscape had an impact on the herbaceous layer. The relative prominence of the Increaser II species across the water points situated away from the river is of concern, because they are not balanced by a comparable number of Increaser I and Decreaser species.

ii. Grass species such as *E. lehmanniana*, *E. rigidior*, *A. congesta* and the forbs with a low grazing value mainly occurred at water points away from the river, mainly occurred on shallow red brown sandy soil. Grasses with high grazing value such as *T. triandra* and *P. maximum* mostly occurred at water points along the river on deep dark grey colluvial soils.

iii. There was also a general increase of bare soil at close proximity of water points, more especially the water points which away from the river, with soil cover increasing with increasing distance from water.

iv. The image classification results, although the classification was not done consistently, gave an indication that the provision of artificial water points in the areas which are devoid of natural water causes the increased grazing and trampling impact by herbivores on the vegetation layer. Hence the steady increase of the extent of the sacrifice zone.

v. The seasonal variation of species abundance and composition was indicated by the study results, where annual species appeared to have been more closely related to the wet season than the dry.

vi. There was more utilization on herbaceous vegetation by herbivores in the central part of the reserve due to high animal activity, which are probably attracted by the two artificial water points in the area. The high animal activity attributes to he increase in abundance of Increaser II species.

The recommendations based on the study are as follows:

i. Since the management plan of the reserve specifies that, artificial water provision should be confined within the natural water source, which is, the non-perennial Molopo River, the number of water points situated away from the river should be removed or reduced.

ii. Water points on the other hand provides points of attraction to tourists because of the higher animal concentrations they draw (Owen-Smith 1996). Therefore**,** management plan of the reserve needs to be altered in order to address the wildlife-based tourism objective. The rotational closing and opening system of the two water points can be explored on the basis of the changes in the system, thereby allowing recovery in terms of herbaceous vegetation cover and composition at two water point sites.

iii. Based on the current indication of grazing pressure in the central part of the reserve, where the water points which are away from the river are, the proposed provision of the new water point further south east of the reserve should not be pursued by reserve management. This is based on the fact that the new water point will add to the current rangeland degradation further to the south of the reserve.

iv. Of the two non-operating water points along the river, one of them should be opened; especially the one further east. The part of the reserve where these water points are situated is currently less-utilized with low concentration of animals. Also the vlei area, which has the potential to hold soil moisture for a long period despite the non-flowing of the Molopo river forms part of the less utilized area of the reserve.

v. This study should be repeated in order to allow the collection of time series data that will assist in performing meaningful and time-series analysis of rangeland changes around water points using LFA interpretational framework.

vi. Finally, the adaptive management approach (learning by doing) should be implemented, given the need to fulfill both the conservation and tourism objectives.

APPENDICES

Appendix 1 Soil surface analysis indicators and their specific objectives (adapted from Tongway and Hindley 2005)

Indicator	Objective
Rainplash protection	Assess the degree to which physical surface cover and projected improve the effect of raindrops impacting on the soil surface
Perennial vegetation cover	Estimate the "basal cover" of perennial grass and/or density of canopy cover of trees and shrubs
Litter	Assess the amount, origin and degree of decomposition of plant litter, to assess nutrient cycling
Cryptogram cover	Assess the cover of cryptograms (e.g. algae, fungi, lichens, mosses, liverworts and fruiting bodies of mycorrhizas) visible on the soil surface
Crust brokenness	Assess to what extent the surface crust is broken, therefore to what extent loosely attached soil material is available for erosion
Soil erosion type and severity	Assess the type and severity of recent/current soil erosion i.e. soil loss from the query zone
Deposited materials	Assess the nature and amount of alluvium recently transported to and deposited within a query zone
Soil surface roughness	Assess the surface roughness for its capacity to capture and retain mobile resources such as water, seeds, topsoil and organic matter
Surface nature	Assess the ease with which the soil can be physically disturbed to release material suitable for removal by wind or water
Slake test*	Assess the stability of natural soil fragments when rapidly wetted
Soil surface texture*	Assess the texture class of the surface soil as it affects infiltration

*not done during field work due to time constraints and equipment unavailabilty

Appendix 2 Mean abundance and frequency of herbaceous species recorded around water points for the dry and wet seasons

	Dry season		Wet season	
SPECIES	Frequency (%)	Mean abundance (%)	Frequency (%)	Mean abundance (%)
Cymbopogon plurinodis	70	9.1	90	14.7
Cynodon dactylon	70	14.4	85	14.8
Aristida congesta	80	11.5	65	4.7
Eragrostis rigidior	80	10.6	75	9.0
Eragrostis lehmanniana	75	10.6	70	10.9
Elionuris muticus	50	5.9	25	3.8
Forbs (any other)	75	5.7	100	13.4
Heteropogon contortus	30	4.6	55	9.6
Sporobolus pyramidalis	25	3.9	25	3.0
Hyperthelia dissoluta	35	3.2	15	0.8
Imperata cylindrica	10	2.8	10	1.9
Panicum maximum	55	2.6	40	1.5
Fingerhuthia africana	40	1.1	35	0.6
Skchuria pinnata	40	0.9	30	3.9
Tagetes minuta	30	0.8	5	0.1
Themeda triandra	35	0.8	45	1.5
Sporobolus fimbriatus	30	0.8	30	0.9
Bracharia nigropedata	15	0.5	0	0.0
Enneapogon scoparius	20	0.3	50	3.5
Sedge	15	0.3	15	1.0
Eragrostis trichophora	5	0.2	25	1.4
Eragrostis obtusa	10	0.1	65	5.1
Chloris virgata	5	0.1	10	0.4
Cenchrus cilliaris	5	0.1	0	0.0
Eragrostis superba	5	0.1	45	1.0
Tragus berteronianus	5	0.1	15	0.5
Urochloa mosambicensis	0	0.0	15	0.6
Bothriochloa radicans	0	0.0	15	0.5
Diheteropgon amplectens	0	0.0	5	0.4
Setaria sphacelata	0	0.0	5	0.2
Setaria verticilata	0	0.0	5	0.2
Eragrostis gummiflua	0	0.0	5	0.1
Melinis repens	0	0.0	5	0.1
Sporobolus ioclados	0	0.0	5	0.1
Trichoneura glandiglumis	0	0.0	5	0.1
Digitaria eriantha	0	0.0	5	0.1

Appendix 3 Landscape zones identified along the transects at the water points for the dry and wet seasons

Landscape zone	Description
	Inter-patches
Bare soil	consists of soil only
Bare rock	consists of one rock or few loose rocks
Bare rock-soil	combination of rocks and bare soil
	Patches
Grass	any herbaceous species (grass, forbs, herbs, creepers)
Closed thicket	closed canopy riverine tall vegetation (mostly *Rhus lancea* and *Celtis Africana*)
Open thicket	open vegetation of more than l meter tall
Shrubs	vegetation of less than 1 meter tall
Shrub log complex	combination of shrubs and fallen dead logs/brush
Shrub rock complex	combination of shrubs and loose rocks
Plant hummock	vegetation that grows on rocks or old tree stumps.

Appendix 4 Species acronyms and full species names for herbaceous data collected around water points in Mafikeng Game Reserve

ARICON - *Aristida congesta* subsp. *congesta*
BOTRAD - *Bothriocloa radicans*
BRANEG - *Brachiaria negropedata*
CYNDAC - *Cynodon dactylon*
CHLVIR - *Chloris virgata*
DIHAMP - *Diheteropogon amplectens*
DIGERI - *Digitaria eriantha*
ERAGUM - *Eragrostis gummiflua*
ELIMUT - *Elionurus muticus*
ERASUP - *Eragrostis superba*
HETCON - *Heteropogon contortus*
HYPDIS - *Hyperthelia dissoluta*
IMPCYL - *Imperata cylindrica*
MELREP - *Melinis repens*
SPOFAM - *Sporobolus fimbriatus*
SPOIOC – *Sporobolus ioclados*
SPOPYR - *Sporobolus pyramidalis*
SETSPH - *Setaria sphacelata*
SETVER - *Setaria verticelata*
TRABER - *Tragus berteronianus*

THETRI - *Themeda triandra*
UROMOS - *Urochloa mosambicensis*
CYMPLU – *Cymbopogon plurinodis*
ERAOBT - Eragrostis *obtusa*
TEGMIN – *Tagetes minuta*
ERALEH – *Eragrostis lehmanniana*
ERARIG – *Eragrostis rigidior*
ENNSCO – *Enneapogon scoparius*
SCHPIN – *Schuria pinnata*
FINAFR – *Fingerhuthia africana*
PANMAX – *Panicum maximum*
CHLVIR – *Chloris virgata*
TRIGLA – *Trichoneura grandiglumis*

Appendix 5 Animal stocking level for Mafikeng Game Reseve (after Van Rooyen 2002) from the 2009 animal population estimates.

Species	Animals per Large Animal Unit*	Percentage grasses and herbs in diet*	Percentage woody plants and fruit in diet*	Current numbers	LSU's for grazers	LSU's for browsers	Recommended numbers	LSU's for grazers	LSU's for browsers	Recommended removals
Bulk feeders:										
Zebra	1.51	93%	70%	117	72.06	54.24	100	61.59	46.36	-17
White rhino	0.36	100%	0%	40	111.11	0.00	35	97.22	0.00	-5
Buffalo	0.90	78%	22%	71	61.53	17.36	60	52.00	14.67	-11
Waterbuck	1.80	84%	16%	44	20.53	3.91	50	23.33	4.44	6
					265.24	75.51		234.14	65.47	
Selective grazers:										
Black wildebeest	2.17	81%	19%	218	81.37	19.09	200	74.65	17.51	-18
C. reedbuck	4.84	95%	5%	2	0.39	0.02	15	2.94	0.15	13
M. reedbuck	9.30	95%	5%	6	0.61	0.03	0	0.00	0.00	-6
Ostrich	4.08	80%	20%	48	9.41	2.35	70	13.73	3.43	22
Gemsbok	1.77	75%	25%	66	27.97	9.32	50	21.19	7.06	-16
Blesbok	4.27	90%	10%	197	41.52	4.61	200	42.15	4.68	3
Red hartebeest	2.69	75%	25%	98	27.32	9.11	100	27.88	9.29	2
					188.60	44.54		182.55	42.14	
Mixed feeders:										
Impala	6.10	45%	55%	188	13.87	16.95	200	14.75	18.03	12
Springbok	6.51	32%	68%	237	11.65	24.76	200	9.83	20.89	-37
Eland	0.98	50%	50%	24	12.24	12.24	40	20.41	20.41	16
Warthog	4.71	70%	30%	165	24.52	10.51	150	22.29	9.55	-15
					62.29	64.46		67.29	68.89	
Browsers:										
Giraffe	0.63	1%	99%	27	0.43	42.43	25	0.40	39.29	-2
Kudu	2.40	15%	85%	14	0.88	4.96	50	3.13	17.71	36
					1.30	47.39		3.52	56.99	
Size of area		4600 ha								
Total LSU's					517.43	231.89		487.50	233.49	
Stocking level (ha/LSU					8.9	19.8		9.4	19.7	
Ratio between feeding groups:										
Bulk feeders					51.3%			48.0%		
Selective feeders					36.4%			37.4%		
Mixed feeders					12.0%			13.8%		
Browsers					0.3%			0.7%		

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