

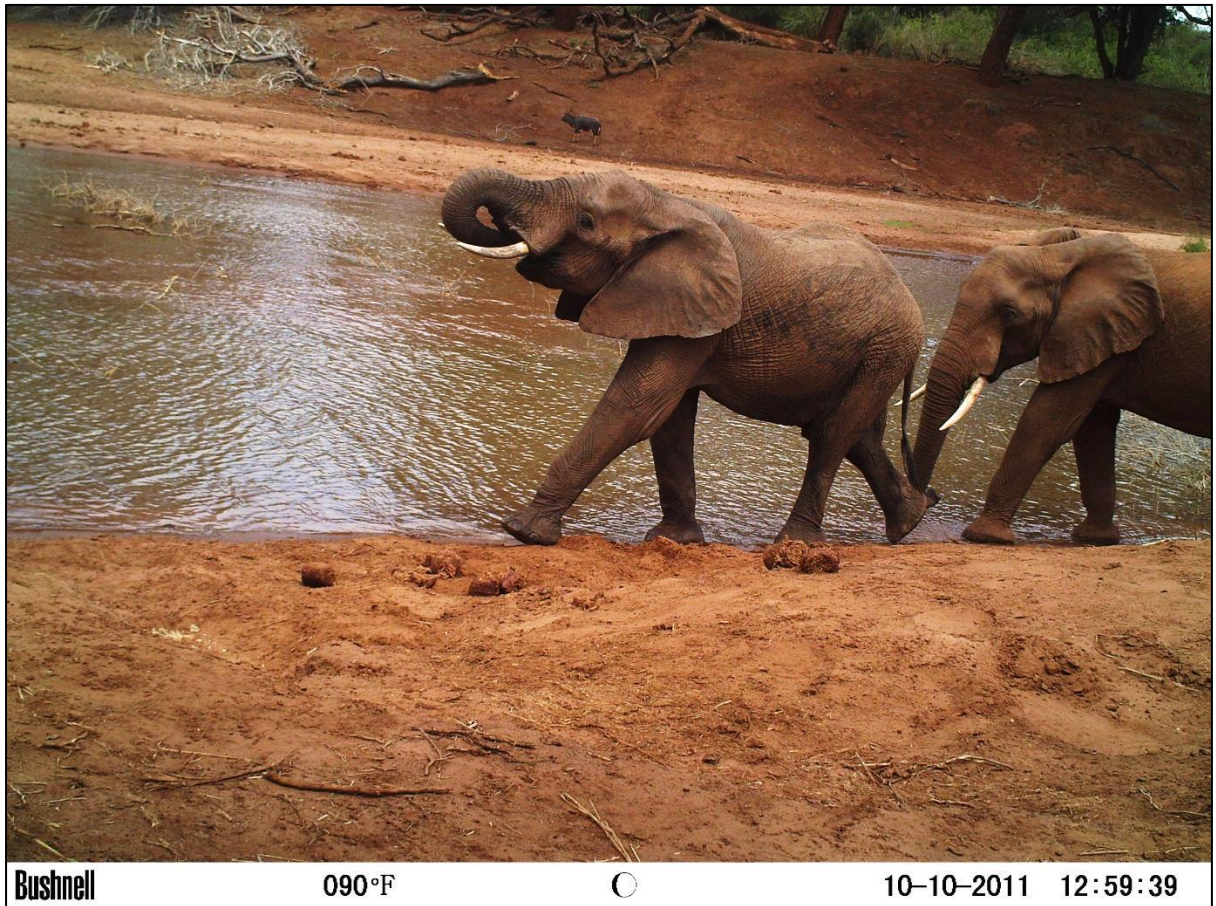
THE INFLUENCE OF PAN CHARACTERISTICS ON THEIR SEASONAL USAGE BY MAMMALS WITHIN THE MAKULEKE RAMSAR WETLAND SYSTEM

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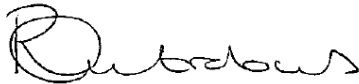


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DECLARATION

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

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A handwritten signature in black ink, appearing to read 'Rutabara', written in a cursive style.

Signed on 22nd October 2014 in Johannesburg

ABSTRACT

Central to the study of animal ecology is the usage an animal makes of its environment. In arid and semi-arid environments worldwide, the availability of surface water largely determines the behaviour, distribution and abundance of animals. As a consequence, the distribution and quality of water are factors that influence carrying capacities of protected areas in environments such as the Kruger National Park, South Africa. Just as wildlife may select water sources according to water quality, they may also select drinking locations according to perceived predation risk. Predation risk can therefore strongly influence the patch use and resource selection of animals. Similarly, human traffic and activity in natural areas can also have an effect on the behaviour and resource use of resident wildlife. This research investigates mammal usage patterns at selected water sources within the Makuleke Wetland System in Kruger National Park to contribute towards management planning for this important Ramsar Wetland Site. The research examines daily and seasonal trends in usage as well as possible links to water quality, land cover and human disturbance.

Camera traps were set up seasonally at perennial pans and rivers within the Makuleke Wetland system to determine mammal species' usage patterns. Environmental characteristics associated with each water source, such as water quality, vegetation cover and extent of human activity were also determined. A cluster analysis and Canonical Correspondence Analysis (CCA) were run in order to determine how environmental variables may influence mammal species' seasonal drinking site selection.

Overall, mammals appear to be selecting for drinking sites with increased distances to ground cover where they are more likely to see predators in advance. Mammal species appear to be avoiding the Zimbabwean border as a result of human activity in the Zimbabwean side of the Great Limpopo Transfrontier Park. The perennial pans and rivers appear to be a significant water source during the dry months to large herbivore and large carnivore species, which display the greatest seasonal fluctuations. Elephants show the greatest demand for water during the dry season and access the perennial water sources throughout the day and night. The Makuleke wetland system, and in particular the perennial water sources, provide an important dry season refuge for the northern Kruger National Park's and the Greater Limpopo Transfrontier Park's elephant population.

The Luvuvhu River and its associated pan (Nwambe), within its floodplain, are sources of water for the greatest diversity and richness of species when compared to the water sources associated with the Limpopo floodplain, within the Makuleke Wetland System. Information from this study may aid South African National Parks management with their "adaptive management" strategy for Kruger National Park, to manage the park in an ever changing environment. It is widely accepted that emphasis be placed on the major role river systems play in biodiversity, and hence their high priority in conservation.



Nwambe Pan within the Luvuvhu River floodplain, Ramsar Makuleke Wetland System

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LIST OF ACRONYMS

ARC	Agricultural Research Council
CCA	Canonical Correspondence Analysis
CESVI	Cooperazione e sviluppo
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
GIS	Geographical Information System
GLTP	Greater Limpopo Transfrontier Park
IUCN	International Union for the Conservation of Nature
JMB	Joint Management Board
KNP	Kruger National Park
LNP	Limpopo National Park
SANBI	South African National Biodiversity Institute
SANPARKS	South African National Parks Board
TSS	Total Suspended Solids
TWQR	Target Water Quality Range
UNEP	United Nations Environment Programme

1. INTRODUCTION

1.1 Overview

The Kruger National Park (KNP) in the lowveld of northeastern South Africa is the largest formally protected area in the country. The park's mission statement is "to maintain biodiversity in all its natural facets and fluxes and to provide human benefits in keeping with the mission of SANParks in a manner which detracts as little as possible from the wilderness qualities of the Kruger National Park" (Mabunda et al., 2003, p18). Six major rivers flow through the KNP, all of which originate to the west, outside of the park's boundaries and are highly utilised (Venter and Deacon, 1995). Protected areas, such as the KNP, face major management challenges, of which ensuring a healthy flow of rivers through the park is one of the most important for the conservation of many of the unique environments within the KNP (Venter and Deacon, 1995; Pollard et al., 2011).

The Makuleke Wetland is a system of inland pans that are situated within the floodplains of the Limpopo and Luvuvhu rivers in the extreme north-eastern region of the KNP. The wetland system is contained within the Makuleke Contractual Park, a concession area within KNP, and is bordered by Zimbabwe to the north and Mozambique to the east (Deacon, 2007) (Figure 1). The Makuleke Contractual Park aims to integrate conservation with the interests of rural people through cooperation between the Makuleke Community, the South African National Parks Board (SANParks) and the South African government. To this effect, the area is used for ecotourism, which generates an income for the community but has minimal conflict with the conservation objectives of SANParks (Pollard et al., 2003; Peace Parks Foundation, 2007).

In May 2007, The Makuleke Wetlands were declared a Ramsar site. The Ramsar Convention on Wetlands (Ramsar, Iran, 1971) is an intergovernmental treaty that "embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the wise use, or sustainable use, of all of the wetlands in their territories" (Ramsar, 2010: www.ramsar.org, accessed 9 April 2010). The Makuleke area is known for its high biodiversity which can be attributed to the geographic location as well as the diversity of landscape features (River Health Programme, 2001). The pan system comprises a number of land cover types including riverine forest, riparian floodplain forest, floodplain grassland, river channels and pans, which create a variety of habitats for an abundance of plant, animal and bird species (Deacon, 2007; Griffin, 2012). The riverine forest system in the area provides food, shelter and nesting sites for the largest number of bird species found within the Kruger National Park (Newman, 1987). Furthermore, the pan system provides an important stopover for many migratory water birds (Griffin, 2012). High densities of nyala (*Tragelaphus angasii*) occur in the area, as well as Hippopotamus (*Hippopotamus amphibious*, listed by IUCN as vulnerable), Nile crocodile (*Crocodylus niloticus*, SA Red Data Species and listed as vulnerable) and African Rock Python (*Python sebae*, SA Red Data Species and listed as vulnerable) (Deacon, 2007).

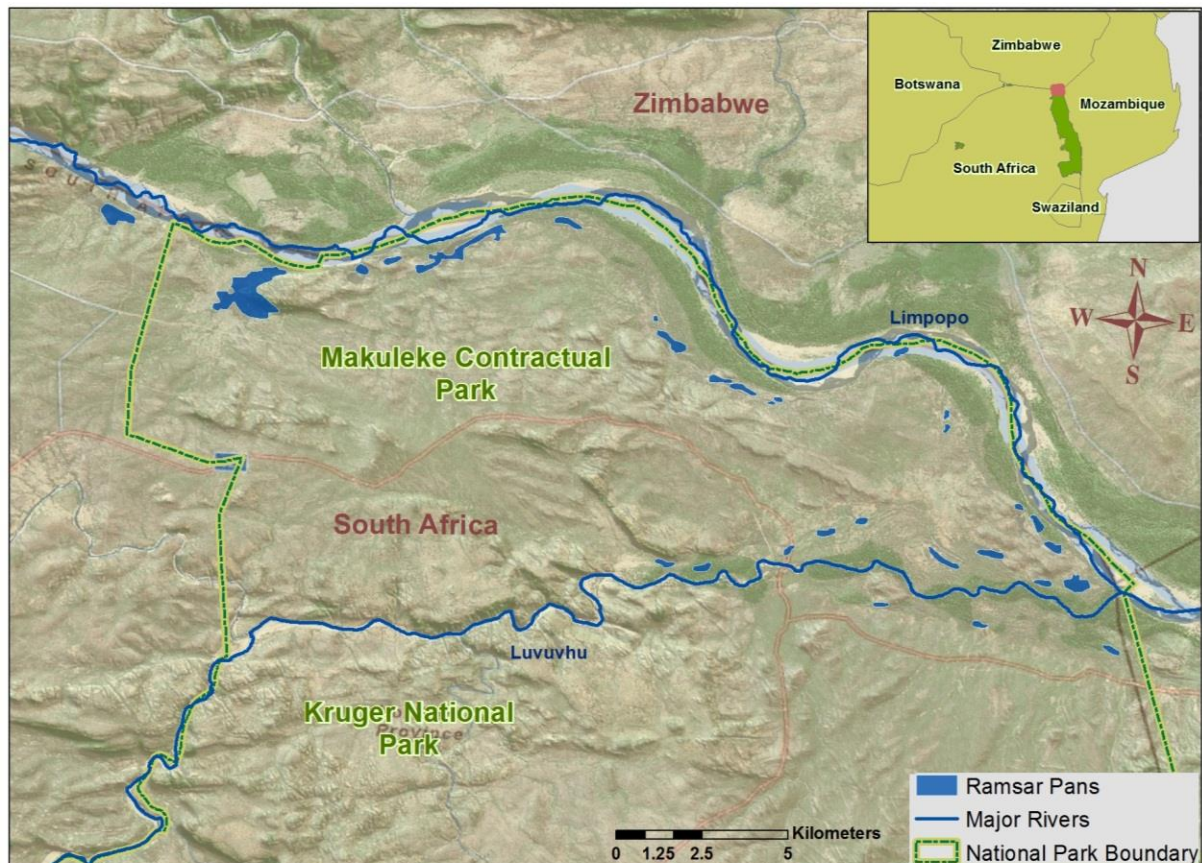


Figure 1: The Makuleke Wetlands within The Makuleke Contractual Park

Increasing water demand from sectors upstream of the Makuleke region has resulted in reduced flow in both the Luvuvhu and Limpopo rivers in recent years, the latter of which now rarely has surface flow during the dryer months (Kleynhans, 1996). However, some of the pans within the floodplain hold water well into the dry season when the Limpopo may not be flowing. They therefore provide important refuge areas and sources of drinking water for wildlife during the dry months (Deacon, 2007). The predicted increase in variability of future climatic conditions may also have a negative impact on natural habitats, especially aquatic ecosystems such as the Makuleke Wetlands, and consequently on wildlife relying on the system (New et al., 2001; Boko et al., 2007; Kingsford et al., 2011).

Comparatively little research has been conducted on the rivers in the extreme north of the KNP, relative to the Crocodile, Sabie and Olifants Rivers to the south (O'Keeffe and Rogers, 2003; Kingsford et al., 2011). Similarly, many studies have focused on the usage by mammals, and the ecological effects thereof, of artificial water sources in the KNP, particularly in the dryer northern regions (Gaylard et al., 2003; Smit et al., 2007a and Reardon, 2012). However, no water usage studies on the natural surface water sources within the Makuleke Wetland system have previously been undertaken, even though the area is considered one of the high biodiversity areas in the KNP and South Africa as a whole (Environmental Resources Management, 2011).

This MSc research study focuses on the seasonal usage of the perennial pans and rivers within the Makuleke Wetland System by mammal species. Environmental characteristics such as ground cover (vegetation cover), canopy cover, water quality and human activity at each water source is assessed to determine what influence these environmental variables may have on drinking site selection. This information will aid in gaining a better understanding of the reliance certain, potentially endemic, vulnerable or endangered, mammals have on the pan system. Mammal usage information from the pans and rivers will aid decision makers from both SANParks and the Makuleke Community when prioritising pans for conservation or tourism/recreational uses. Given that the wetland is listed under the Ramsar Convention, up-to-date monitoring and assessments are required to better understand, and therefore sustainably conserve the wetland system. The most recent Ramsar report for the Makuleke Wetland was compiled by Deacon in 2007. Information from more recent studies can therefore be used to update and add to the knowledge within the existing Ramsar report.

1.2 Aims and Objectives

Water is a fundamental requirement for animal life, and water requirements have implications for mammal distributions, ecology and conservation. Despite this, there has been very little research conducted on the use of water in free-ranging wildlife populations (Hayward and Hayward, 2012). Mammal species also have different strategies for predator and human avoidance, and as a result, different species may have different preferences or tolerances for water quality, camouflaging vegetation and human activity. Much research has focused on KNP's southern, heavily utilised, rivers and on the provision of artificial water points across the park (O'Keeffe and Rogers, 2003; Gaylard et al., 2003; Smit et al., 2007a; Reardon, 2012). The natural pans along the Luvuvhu and Limpopo Rivers in the north have not been extensively studied. Improved knowledge of the wetland system may thus improve the ecotourism potential in the area and aid in conservation decision making.

1.2.1 Aims

This study aims to establish how perennial pan and river characteristics (water quality, surrounding land cover and extent of human activity) in the Makuleke Wetland System influence pan usage by mammal species in the area.

1.2.2 Objectives

The objectives of the study are to:

1. Determine the seasonal usage of each perennial pan and river by different mammal species.
2. Determine the finer scale (daily and hourly) temporal usage of each perennial pan and river by different mammal species.
3. Determine what environmental factors (water quality and vegetation cover) and anthropogenic factors (distance to tourist roads and park boundaries) influence mammals' selection of drinking sources.

4. Determine which are the key pans within the wetland system with regards to the extent and diversity of mammal usage, and therefore determine which pans are of greatest conservation priority for mammal species in the area.

1.3 Hypotheses and Questions

The hypotheses are that the usage of the pans will increase during the dry season and that different mammal species will demonstrate different drinking site preferences according to perceived safety and better water quality (lower concentrations of minerals, low EC and TDS) at perennial water sources within the Makuleke Wetland System.

Key Research Questions:

- Does water quality influence the usage of the inland pans by mammals?
- Which mammal species are most reliant on the pan system?
- To what extent does camouflaging vegetation cover influence mammal species' usage of the pans?
- To what extent does human activity (as a result of location) influence the usage of the pans and rivers by mammal species?

2. LITERATURE REVIEW

2.1 Resource Use by Wildlife

Central to the study of animal ecology is the usage an animal makes of its environment. This is predominantly with regards to the types of food it consumes and the variety of habitats it occupies (Johnson, 1980; Millspaugh, 2006). Three concepts are fundamental to understanding and studying resource selection by animals: use, availability and selection. The usage of a resource is the quantity of (or time spent within) that resource utilised by the consumer over a fixed period of time (Johnson, 1980; Thomas and Taylor, 2006). Availability refers to the accessibility of a resource to the consumer, whilst selection refers to the behavioural choice of a component by a consumer (Johnson, 1980; Buskirk and Millspaugh, 2006). Many analytical procedures have been developed to assess data on the usage of such resources by individuals and populations (Johnson, 1980; Millspaugh, 2006; Thomas and Taylor, 2006).

Wildlife research often compares the relative use and availability of resources. When resources are used by animals disproportionately to availability, use is said to be selective (Alldredge and Ratti, 1986; Alldredge et al., 1998). One can then determine an animal's or population's "preference". A component is generally termed "preferred" if usage exceeds availability, or "avoided" if availability exceeds usage (Johnson, 1980). Preference is ordinarily stated to be independent of availability, but it is generally defined by reference to the choice made at equal availabilities (Johnson, 1980).

Resources can include a broad range of items ranging from matter that is directly taken up by the animal, and which affects fitness positively, to the absence of something negative such as predators. Selection is often a trade-off; for example animals may not necessarily select for an area with the most forage, but may instead prefer an area with less competition (Buskirk and Millspaugh, 2006). Furthermore, resources may be consumed, in the case of food or water, or simply visited, in the case of habitats. Vegetation for example can be assumed a resource to different animals for different reasons. To some animals, vegetation is a food source and provides nutritional value, whereas for others it may provide shelter or a refuge (Alldredge et al., 1998). An important assumption made in resource-selection studies is that animals optimise fitness through behaviour. In most cases one does not know whether behavioural choices made in fact result in optimised fitness. We only know that animals have an evolutionary predisposition to choose correctly within certain constraints to optimise their chance of survival (Buskirk and Millspaugh, 2006). Resource selection is affected by the abundance and diversity of resources in an animal's environment. Many resources used by free-ranging animals occur heterogeneously across the landscape and resource selection is therefore closely linked to use of space (Buskirk and Millspaugh, 2006).

In arid and semi-arid environments worldwide, the availability of surface water largely determines the behaviour, distribution and abundance of animals. As a consequence, the distribution and quality of water are factors that influence carrying capacities of protected areas in such environments such as the KNP, South Africa (Thrash et al., 1995; Chamaille-Jammes et al., 2007;

Smit and Grant, 2009; Valeix et al., 2009). Surface water availability depends on rainfall, which varies greatly between and within years in arid and semi-arid environments, with most of the annual precipitation falling within only a few months each year (Mares, 1999). The successful management of semi-arid and arid ecosystems therefore requires an understanding of surface water quality, quantity and distribution, as surface water is closely associated with animal distributions (Redfern et al., 2005).

2.1.1 Water Availability and its Effects on Resource Use by Wildlife

Water is available to animals from three different sources: free water (streams, puddles, water holes and rivers); preformed water (water contained in food), and oxidative and metabolic water (water produced metabolically as a product of the oxidation of organic compounds containing hydrogen) (Wolff, 2001). Highly seasonal rainfall patterns directly determine the water levels in water holes and rivers (free water) and cause seasonal changes in the availability of food, which, in return leads to changes in the availability of preformed water in forms such as fruit pulp and fresh leaf material. Furthermore, water requirements and the availability of preformed water vary substantially among species and are strongly influenced by basal metabolic rates, diet, body size, and activity patterns (Robbins, 1993). Differing water contents of food indirectly influence the dependence of animals on free water. In general, water requirements are highest for herbivores, intermediate for omnivores and lowest for carnivores. Diurnal animals generally also have greater water requirements, as higher ambient temperatures during the day result in greater evaporation rates (Wolff, 2001).

Animals may survive in water-limited environments by concentrating in areas with relatively constant supplies of water, through dormancy, by having a high degree of tolerance to low-water conditions, or through other behavioural and physiological adaptations (Robbins, 1993; Smit and Grant, 2009). Although physiological adaptations to water restricted environments have been documented in a variety of taxa, many other more widespread, generalist species such as zebra (*Equus quagga*) and blue wildebeest (*Connochaetes taurinus*), rely exclusively on behavioural strategies, such as migration or remaining close to water sources, to avoid dehydration (Smit and Grant, 2009). For example, the seasonal movement of medium- to large-sized vertebrates to areas with a higher abundance of free water is a commonly observed behavioural strategy during the dry season (Western 1975; Thrash et al. 1995; Smit and Grant 2009).

The abundance of free water alone, however, does not affect wildlife distribution patterns. Many studies conducted in arid environments have shown that water quality (mineralisation) and perceived predation risk may also influence animal water usage or consumption patterns (Ayeni, 1977; Casey and Meyer, 2000; Bleich et al., 2006; Valeix et al., 2009; Periquet et al., 2010). In arid and semi-arid areas, ground water is often highly mineralised, thus affecting the quality of water sources fed by groundwater (Ayeni, 1977; Parris, 1984; Bleich et al., 2006). The mineral composition of water bodies varies seasonally as rainwater dilutes surface water available to animals, whereas increased evaporation rates may increase mineral concentrations (Ayeni, 1977).

Although studies have shown that animals tend to choose the least saline (mineralised) water sources available, it is thought that herbivores may augment a low mineral status within their diets by drinking from more mineralised waterholes during the dry season (Ayeni, 1977; Parris, 1984; Redfern et al., 2005; Wanke and Wanke, 2007). However, this is within water quality limitations, above which certain mineral concentrations may become detrimental to animal health (Casey and Meyer, 2000). The quality of water supplied to wildlife in private or national reserves and parks is often not monitored and little is known about the behavioural or physiological influence of water quality on wildlife health (Wanke and Wanke, 2007; Strauch, 2013). This can be problematic as groundwater in drylands, such as the Kalahari Desert, contains a wide variety of salts and the levels of these can occur, at least locally, in toxic concentrations (Wanke and Wanke, 2007). In a study published by Dreyer (1989), it was concluded that 49% of the water troughs in the Kalahari Gemsbok National park were considered non-potable, with possible negative health effects for domestic stock (Brain et al., 1995). Water-dependent wildlife in drylands such as in the Kalahari Desert, however, is forced to consume the provided water regardless of its quality, simply because no other water sources are available (Wanke and Wanke, 2007). Studies have also suggested that water quality may be a factor in the migratory behaviour of wildebeest in the Serengeti, as poor quality water can have significant health consequences for ungulates, including depressed milk production and reduced food conversion (Strauch, 2013).

Surface and groundwater runoff collects impurities that are characteristic of the types of bedrock, soils and land uses within a catchment. Thus, by the time the water enters the river or wetland, its quality has changed from that of rainwater, to water that reflects the nature of the catchment (Bosch et al., 1986). In general, this change in quality will be least near the source of the river. This is because the rocks of a mountain or source-area will be hard and resistant to leaching, and land disturbance in such areas will be minimal. The lower reaches of the river, however, are usually associated with a greater change in quality from rainwater as the ground is softer and more leaching takes place. The quality of water will continuously change along the length of the river, varying in adjacent and upstream areas, where it exerts an influence upon the river (Bosch et al., 1986). Chemical reactions that occur when rocks are in contact with water, aid in weathering as minerals are released from the rocks and transported by the water towards the river. As a general rule, the main cations in water are derived from the chemical weathering of bedrock, whilst anions are derived mainly from non-geological sources (Bosch et al., 1986).

Supplementing surface water has become a contentious issue, particularly in the KNP, with increasing concern regarding the effects of artificial water sources on ecosystem processes, productivity, resilience, stability and biodiversity (Smit et al., 2007a). When the KNP was established in 1898, animals concentrated during the dry months along the five perennial rivers and remaining pools within the larger seasonal rivers (Gaylard et al., 2003). As early as 1930, the KNP started a "water stabilising programme" which gained momentum in the 1960's. The aim of the programme was to make larger areas of the park accessible to water dependent herbivores, preventing particularly zebra and blue wildebeest from attempting to migrate out of the park and gathering along the fencelines during the dry season. It was also hoped that the programme would

increase the populations of rare antelope species such as roan antelope (*Hippotragus equinus*), sable (*Hippotragus niger*) and tsessebe (*Damaliscus lunatus*), which were confined to the drier northern areas of the park (Smit et al., 2007a, Reardon, 2012). Initially the programme seemed to be successful but during the drought of the 1980s problems emerged. The high density of permanent water was thought to be responsible for many, starvation-induced, mortalities during drought years. It was also hypothesised that the provision of artificial water had in fact reduced herbivore diversity by expanding the distribution of common water dependent species such as zebra and blue wildebeest, and as a result lion, at the expense of the rare antelope species (Gaylard et al., 2003; Smit et al., 2007a, Reardon, 2012). Changes in vegetation (forage) and its inability to recover under constant herbivory was also blamed on the presence of the artificial waterholes (Smit et al., 2007a). Consequently, the former policy is now being reversed with the closing of more than half of the artificial waterholes within the park. This indicates a shift in KNP management from the past paradigm of suppressing variability, towards maintaining the spatial and temporal fluctuations now believed to be essential for sustaining biodiversity and ecosystem processes (Gaylard et al., 2003).

With the exception of KNP's water stabilising program, there has been very little quantification of the relative waterhole use by African fauna (Hayward and Hayward, 2012). Valeix et al. (2007) studied the effects of African elephants (*Loxodonta africana*) on competition for water amongst the herbivores of Hwange National Park, Zimbabwe. It was found that most herbivores, except elephants, were predominantly diurnal, whereas elephant waterhole use peaked at dusk. Hayward and Hayward (2012) used existing webcams to compare water usage by wildlife at certain waterholes in the KNP and Pilanesberg. They concluded that hippopotamus (*Hippopotamus amphibius*), warthog (*Phacochoerus africanus*) and blue wildebeest have the highest water requirements, while lion (*Panthera leo*), spotted hyaena (*Crocuta crocuta*), kudu (*Tragelaphus strepsiceros*) and springbok (*Antidorcas marsupialis*) all appear to have relatively low water requirements. They also determined that, overall, animals were observed near waterholes significantly more during the day than at night. This, they attributed to the diurnality of ungulates, while their potential predators were significantly more nocturnal. The medium-sized grazing ungulates exhibited a high degree of overlap in waterhole use and little evidence of distinct periods of drinking. Unlike the observations made by Valeix et al. (2007) in Hwange, elephants in the KNP and Pilanesberg showed a distinct peak in the middle of the day, whereas impala (*Aepyceros melampus*) waterhole use peaked earlier in the day. Medium-sized browsing ungulates generally steadily increased their waterhole use throughout the day. Eland (*Tragelaphus oryx*) was the only herbivore regularly observed accessing waterholes at night (Hayward and Hayward, 2012).

2.1.2 Predation Risk and its Effects on Resource Use by Wildlife

Just as wildlife may select water sources according to water quality, they may also select drinking locations according to perceived predation risk (Wakefield and Attum, 2006; Valeix et al. 2009; Periquet et al., 2010). Predation risk can therefore strongly influence the patch use and resource selection of animals (Meyer and Valone, 1999). To reduce the risk of predation, prey make behavioural decisions to decrease the probability of encounter, attack and capture, as well as the

time spent being vulnerable to predation (Lima and Dill, 1990). As foraging behaviour can be altered considerably by perceived predation risk, it may lead to habitat partitioning in species differing in susceptibility to predation (Hughes et al., 1994). Predator-prey interaction studies have shown that predators may affect the habitat use, food use, group size and overall activity of their prey without instantaneously affecting their population numbers. Behavioural effects of predators on prey may further affect the availability of their prey's resources, and thus total community and ecosystem dynamics (Persson, 1993).

Waterholes can be particularly dangerous places for herbivores. Prey animals are often ambushed here as predators may be familiar with the location of the waterhole and the activity patterns of their prey (Wakefield and Attum, 2006; Periquet et al., 2010). Many African savanna herbivores need to access critical water resources on an almost daily basis, with the dependence being strongly influenced by seasonal rainfall differences (Valeix et al. 2009; Crosmar et al., 2012). Predators take advantage of this dependence, especially during the dry season when water sources are limited (Valeix et al., 2009). Behavioural responses to predation may include the avoidance of risky environments and the selection of specific habitat types and features where prey species feel safer (Creel et al., 2005). Smaller, more vulnerable species, for example, may prefer water sources that provide better vegetation cover for concealment, whereas large herbivores such as zebra may prefer more open water sources where they feel they are less likely to be ambushed by predators such as lion (Periquet et al., 2010). Giraffe, for example, are particularly vulnerable to predators because of the splay-legged posture used when drinking. They may therefore prefer more open water sources which allow them to see predators well in advance (Valeix et al., 2007). Water sources located in certain vegetative environments may therefore be more important to, or more frequently accessed by, specific species.

2.1.3 *The Effect of Human Activity on Resource Use by Wildlife*

Human traffic and activity in natural areas can also have an effect on the resource use of resident wildlife (Griffiths and van Schaik, 1993; Klein, 1993). Increased human activity may lead to animals selecting to leave an area, become more nocturnal or more arboreal, or avoid using trails on which humans are likely to travel, and thus go unnoticed without making major behavioural changes (Griffiths and van Schaik, 1993; Wakefield and Attum, 2006). Increased poaching activity in an area can also cause animals to move out of an area or utilise an area more selectively. Large species (such as zebra and wildebeest) without refuge tend to move out of areas with high human traffic. Certain species, however, may also remain unaffected or become habituated to the presence of humans. Intensive ecotourism can thus potentially lead to local ecological change by resulting in the population increase of habituated or unaffected species, to the potential detriment of their competitors (Griffiths and van Schaik, 1993).

All the mentioned factors that drive resource use usually interact additively, negatively or synergistically to influence the use of resources by wildlife (Hughes et al., 1994). It is therefore important that conservation and wildlife management practices take into account these drivers, and their interactions, to better understand resource selection and use by various species. In arid

and semi-arid environments, the components driving wildlife to select critical water sources may have a huge impact on the distribution of animals and levels of biodiversity within a protected area (Redfern et al., 2005). Gaining an understanding of how drivers such as water availability, quality (possibly affected by soil and geology), vegetation cover, predation-risk, competition and human activity influence wild animals' selection of water sources, allows for more informed management decisions to be made, resulting in more successful conservation practices.

2.2 Rivers in the Kruger National Park

Many of the world's protected areas include freshwater ecosystems, some specifically declared for freshwater protection. These freshwater ecosystems, however, are often supplied by rivers which flow outside of the protected area boundaries (Kingsford et al., 2011). The Kruger National Park is no exception with its six major rivers originating to the west of the park boundary and flowing eastwards across the park (Venter and Deacon, 1995). If the length of rivers or the areas of the catchments that fall within the KNP are examined, then the linkages and vulnerability of the park to external influences become starkly apparent, with almost all the associated catchment areas falling largely outside of the KNP (Pollard et al., 2011). Consequently, these rivers and their dependent freshwater aquatic ecosystems are inextricably interlinked with human livelihoods, forming complex socio-ecological systems. Reflecting this, the world's freshwater ecosystems and their dependent biota are in a sharp decline, more so than other biomes, largely due to extraction and the regulation of river flow, pollution and the spread of invasive species (Griscom, 2010; Kingsford et al., 2011). The state of main river ecosystems in South Africa is considered to be dire, with 54% considered to be in a critically endangered state (Nel et al., 2007). Although 61% of the Luvuvhu River catchment, for example, falls within the KNP, this accounts for only 34% of the river's length. The portion of the river which flows through the KNP is a wilderness area with outstanding features resulting in it being regarded as one of the most unique features of the park (Kleynhans, 1996). The reaches of the river to the west of the KNP, however, are influenced by various activities which impact on the habitat integrity of the river. The upper reaches are used for commercial farming practices resulting in abstraction for irrigation, as well as agricultural chemicals entering the system (Kleynhans, 1996; Pollard et al., 2011). Before the river enters the park, it flows through areas of subsistence farming practices which are associated with considerable river mismanagement, resulting in issues such as overgrazing, removal of riparian vegetation, erosion and sedimentation. The Tshikondeni Coal Mine, and its potential risks to water quality, is also situated within the Luvuvhu catchment, just west of the park boundary (Kleynhans, 1996; Mining, Minerals and Sustainable Development, 2001).

All of the major river systems flowing eastwards across the KNP, like the Luvuvhu, ultimately flow into Mozambique. Under international obligations, South Africa is required to honour certain flow volumes within the rivers through into Mozambique. Therefore, on one hand the KNP is the victim of upstream use and abuse of its rivers and, on the other, it acts as a buffer for Mozambique downstream through partly securing the water demands which will flow on into the country (Pollard et al., 2011). Thus, the successful management of freshwater ecosystems in protected areas needs to occur over large spatial scales, beyond the boundaries of protected areas, to

include the holistic ecosystem management of the catchment (Nel et al., 2007; Kingsford et al., 2011). It has previously been highlighted by Pollard and Du Toit (2008), that the KNP therefore plays an important role as the “watchdog” or the first agency to alert water managers and society in general of a problem in the rivers. This is essential to ensure functional feedback loops. Today the KNP has adopted a “strategic adaptive management” framework and participates in fora that cover all major rivers entering the park and plays an important role in stating its positions and interests in water resource decisions (Pollard et al., 2011). A study conducted by Turpie and Joubert (2001), calculated that R41m (30%) of KNP revenues and R80m of overall expenditure by tourists could be attributed to rivers for the whole of the KNP. Appearance of the riverscape had the greatest influence on recreational use value, followed by water bird diversity, aquatic megafauna and riparian tree density (Turpie and Joubert, 2001). It is, therefore, essential for park management to try and reduce the negative impacts of upstream users on the rivers flowing through the park, not only for biodiversity conservation and ecological integrity, but also for tourism satisfaction and associated revenue (Turpie and Joubert, 2001; Kingsford et al., 2011).

2.3 Riparian Wetland Systems

The Makuleke wetland system can also be described as a riparian zone or wetland. According to Rogers (1995, p42), “Riparian wetlands are open ended systems which occur adjacent to river and stream channels where plant species distribution and growth is determined by, at least intermittent, soil saturation or inundation as a consequence of fluctuations in flow”. Riparian areas often provide a contrast to the surrounding uplands of a landscape in terms of vegetative structure, topography, microclimate, soils and productivity due to fluctuating water levels (Kauffman and Krueger, 1984; Naiman et al., 2005; Pettit and Naiman, 2007). They are biologically diverse and structurally complex habitats that support a diversity of plant, bird and animal species (Lussier et al., 2006).

Riparian zones are recognised as boundaries between terrestrial landscapes and aquatic ecosystems, and can be considered ecotones, and hence highly heterogeneous systems (Rogers, 1995; Naiman et al., 2005; Pettit and Naiman, 2007). They create well-defined habitat zones within the much drier surrounding landscape and create conditions such as cover from predators, perches and shading (Kauffman and Krueger, 1984; Rogers, 1995). Because riparian zones link aquatic and terrestrial habitats, they can support species-rich communities, which integrate both terrestrial and aquatic processes. The high biodiversity and productivity of riparian systems are therefore largely attributed to biotic and nutrient exchanges between the aquatic and upland (terrestrial) ecosystems (Kauffman and Krueger, 1984; Croonquist and Brooks, 1991; Larsen et al., 2010). This high productivity and nutrient status also makes them favoured sites for grazing and browsing animals, especially during the dry season (Rogers, 1995). Furthermore, the river corridor as a whole acts as an important migratory route for many species and forms an important biophysical link between various wetlands within a catchment. The state of the riparian zone is therefore a major determinant of the ability of the river corridor to provide this function (Rogers, 1995). A common thread in the literature regarding riparian wetlands is the emphasis placed on

the major role these systems play in biodiversity, and hence their high priority in conservation (Bosch et al., 1986; Rogers, 1995; Lussier et al., 2006; Larsen et al., 2010). Kröger and Rogers (2005), for example, suggest that ephemeral wetland boundaries provide important, nutrient rich, grazing areas for the rare roan antelope (*Hippotragus equinus equinus*) in the northern regions of KNP.

2.3.1 *Effects of Riparian Systems on Water Quality*

Water pollution in riverine systems occurs because of human activities such as agriculture, deforestation, mining and urbanization in river catchments. These activities alter the structure of the landscape and increase the quantities of substances like sediments, nitrogen, phosphorous and other elements that are washed into the river system (Anbumozhi et al., 2005).

It is widely believed that forest buffer zones, or riparian zones, are effective in reducing the nutrient concentrations in water that passes through them (Anbumozhi et al., 2005). The use of riparian management zones is relatively well established as a best management practice for water quality improvement and control of nonpoint source pollution, especially within forestry practices (Lowrance et al., 1997). Wetlands slow the movement of water and materials downstream, especially during flooding, and increase the overall system efficiency for nutrient processing (Whigham et al., 1988). There is little doubt that freshwater wetlands can significantly improve water quality and, with few exceptions, most have been shown to perform this function. Wetlands have been proven to aid, most effectively, in the retention of sediment particles and in acting as nitrogen and phosphorous sinks. Their effects on water quality, however, do depend on the type of wetland and its position within the landscape. Multiple wetlands within a catchment can also have a cumulative effect on water quality. However, numerous questions regarding the relationship between wetlands and water quality are still unanswered, as many types of freshwater wetlands have not been adequately studied (Whigham et al., 1988).

2.3.2 *Threats to Riparian Systems*

Riparian wetlands are considered among the most productive and valuable natural systems on earth, but many have been degraded or altered by human activities (Croonquist and Brooks, 1991). In southern Africa, land owners, planners and developers have mostly regarded riparian zones as a hinderance to efficient water use. They have thus paid little attention to the value and land use functions of these wetland systems in the landscape. Thus, many, if not most of southern African riparian wetlands have been lost or badly degraded (Begg, 1988; Rogers, 1995; Holmes et al., 2005).

Conversely, the potentially high productivity of these systems has also led to extensive destruction. Livestock exhibit a strong preference for riparian zones for a number of the same reasons other animals prefer and use these areas- mainly the availability of water, shade and the quality and variety of forage (Kauffman and Krueger, 1984). Inappropriate livestock management in rural areas results in the overuse and subsequent degradation of riparian ecosystems. This can

severely impact terrestrial wildlife habitat, causing a decrease in wildlife abundance and diversity (Kauffman and Krueger, 1984).

Another threat to riparian zones has been that general management decisions are concerned with large landscape units and not with the boundaries or ecotones between them (Rogers, 1995). As transitional areas between terrestrial and aquatic systems, their degradation or fragmentation affects the quality of both systems, along with their associated plants and wildlife (Kauffman and Krueger, 1984; Croonquist and Brooks, 1991). Additionally, because of the high edge-to-area ratio, riparian habitats are particularly sensitive to changes in the surrounding landscape (Larsen et al., 2010). Riparian zones are of utmost importance in river conservation in general, as they form part of the catchment which has a direct effect on the river ecosystem, and water quantity and quality. As rivers are longitudinal systems, their condition at any point is a reflection of all upstream activities, as well as activities in the adjacent catchment, and likewise will have an effect on systems further downstream (Bosch et al., 1986).

In South Africa, it is very much the exception to find areas where a riparian system is specifically conserved or managed. Conservation is usually incidental when larger land tracts are proclaimed for conservation (Rogers, 1995). Riparian habitats in many parts of South Africa are severely degraded, particularly by invasive alien plants. These invasions reduce water yields from catchments and affect riverine functioning and biodiversity (Holmes et al., 2005). South Africa is considerably far behind other countries, specifically developed countries, with regards to riparian management and research (Rogers, 1995). The South African National Biodiversity Institute's (SANBI) National Spatial Biodiversity Assessment produced the most recent wetland inventory for South Africa in 2006 (SANBI, 2009). The need for wetland rehabilitation in South Africa is considerable (Ellery et al., 2011). The loss and degradation of wetlands have been great and national policy and legislation now provides clear direction and support for their rehabilitation. The rehabilitation of wetlands, however, is often costly and complicated as wetlands have complex links with communities (Ellery et al., 2011).

A further global threat placing pressure on wetlands and other aquatic ecosystems is that of climate change. The evaluation of how future climate change may impact natural habitats has become increasingly important in the study of the long-term maintenance of biodiversity worldwide (Halpin, 1997). According to the Department of Environmental Affairs and Tourism (DEAT), the US "Country Studies Project" predicts that climate change will cause a mean temperature increase across South Africa of between 1°C and 3°C by the middle of the 21st century (DEAT, 2005). A broad decrease in annual rainfall in the range of 5%-10% has also been projected for the summer rainfall region of the country. This is expected to be accompanied by a greater variability in rainfall and an increased occurrence of both droughts and floods, with prolonged dry spells followed by intense storms (DEAT, 2005; Boko et al., 2007). Based on the International Panel on Climate Change's (IPCC) scenario A1 (which assumes a more integrated world with rapid global economic growth, a global population of 9 billion by 2050 and the quick spread of new and efficient technologies), the northern section of South Africa in which the Makuleke Contractual Park

is situated, is expected to experience a decrease in available surface water of at least 20% by 2050 (Figure 2) (UNEP, 2008).

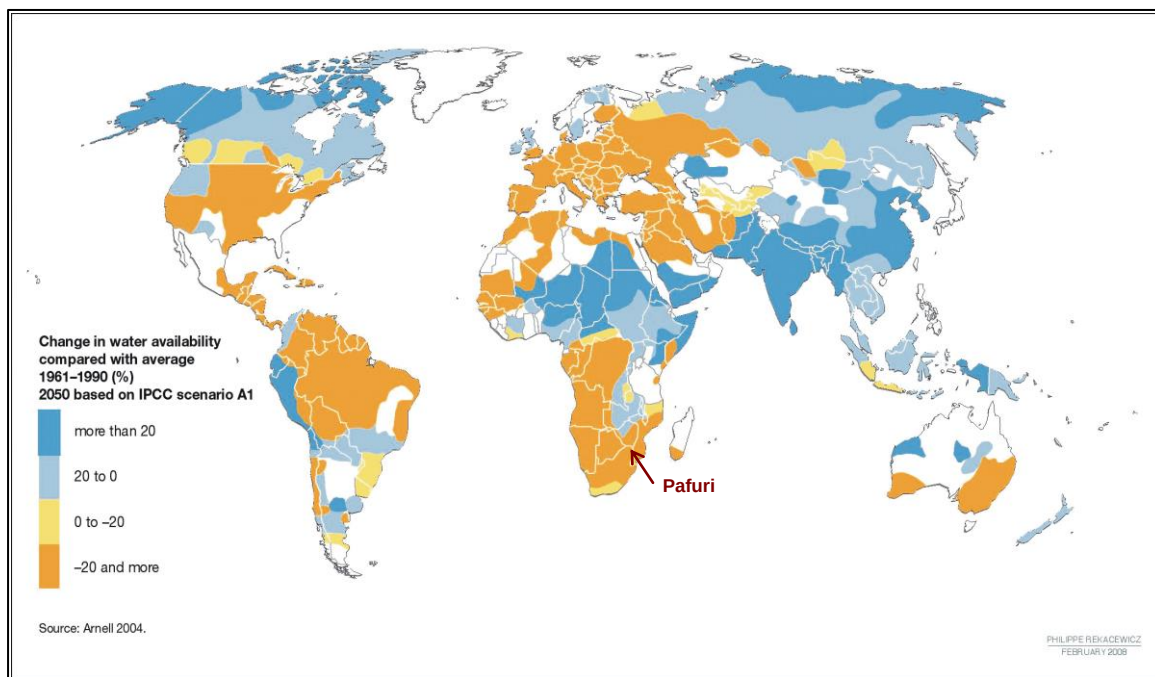


Figure 2: Predicted percentage change in global water availability for 2050 compared to 1961-1990 based on IPCC scenario A1 (UNEP, 2008)

Climatic conditions, particularly rainfall and temperature, influence the variability of surface water availability and quality across the landscape at the inter-annual scale. Very few studies, however, have quantified this effect, especially with regard to how climate fluctuations translate into changes in surface water availability and quality (Chamaille-Jammes et al., 2007; Boko et al., 2007). This lack of knowledge prevents a full understanding of how these ecosystems will respond to future global climate change, which projects even greater variability in rainfall for the southern African region (New et al., 2001; IPCC, 2001; Pittock et al., 2008; Kingsford et al., 2011).

South Africa is one of 160 member countries of the Ramsar Convention on Wetlands of International Importance, which is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources (Ramsar, 2010). The Convention's mission is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world" (Ramsar, 2010: www.ramsar.org, accessed 9 April 2010). The convention was developed and adopted by participating nations at a meeting in Ramsar on February 2, 1971, and came into force on December 21, 1975. South Africa's list of wetlands of international importance now includes 21 sites (known as *Ramsar Sites*), covering approximately 554,136 hectares. Of this, the Makuleke Wetland System makes up 7,757 hectares within the northern Limpopo province (Ramsar, 2010). Gaining a better understanding of these wetland ecosystems and their importance in the landscape

will better prepare ecologists, managers and planners to sustainably protect these systems, both currently as well as into a climatically variable future.

2.4 Current Conservation Status of the Makuleke Wetland System

According to the SANBI and the Council for Scientific and Industrial Research (CSIR), the Luvuvhu River, and many of its tributaries, are considered to be endangered (Figure 3) (Driver et al., 2004). A river is considered to be endangered when its intact length is still greater than the set conservation target (10% of the total length). However, the ecosystems have lost significant amounts of their original habitat, so their functioning is compromised (Driver et al., 2004). The Limpopo River is considered to be a critically endangered river (Figure 3). A river is considered by SANBI and CSIR to be critically endangered when its intact length is less than the set conservation target (10% of the river's total length). These ecosystems have lost so much of their original natural habitat that ecosystem functioning has broken down and species associated with the ecosystem have been lost, or are likely to be lost (Driver et al., 2004). The ecological status of the Luvuvhu and Limpopo Rivers improves as they flow through the KNP. This could be as a result of the well-established and undisturbed riparian zone along the edge of the rivers within the KNP, which helps to improve water quality (Lowrance et al., 1997; Anbumozhi et al., 2005). From the confluence of the Luvuvhu and Limpopo Rivers, and for approximately 10km upstream, the ecological status of the two rivers improves from critically endangered and endangered status respectively, to vulnerable (Figure 3). A vulnerable ecological status means that these ecosystems have lost some of their original natural habitat and their functioning will be compromised if they continue to lose natural habitat (Driver et al., 2004).

The network of pans situated along the Limpopo and Luvuvhu rivers is known as the Makuleke Wetland System and is a typical example of a riparian wetland type known as a floodplain vlei (Rogers, 1995; Deacon, 2007). It is considered to be the only true floodplain in the KNP (Venter et al., 2003). The pans are depressions in the floodplain which are intermittently filled from floods, rains and groundwater seepage. Although most pans are seasonal, some hold water into the dry season and are of great importance in the ecosystem, as they create a refuge for wildlife and water birds during both summer and winter months (Deacon, 2007). The floodplains and pans also attenuate floods, resulting in reduced flood damage in downstream areas of Mozambique, and are important for groundwater recharge which helps to maintain riparian and floodplain vegetation (Deacon, 2007).

As a result of its important role in the landscape, the Makuleke Wetland System was declared a Ramsar site in May 2007, and acknowledged for being one of South Africa's 21 wetlands of international importance (Ramsar, 2010).

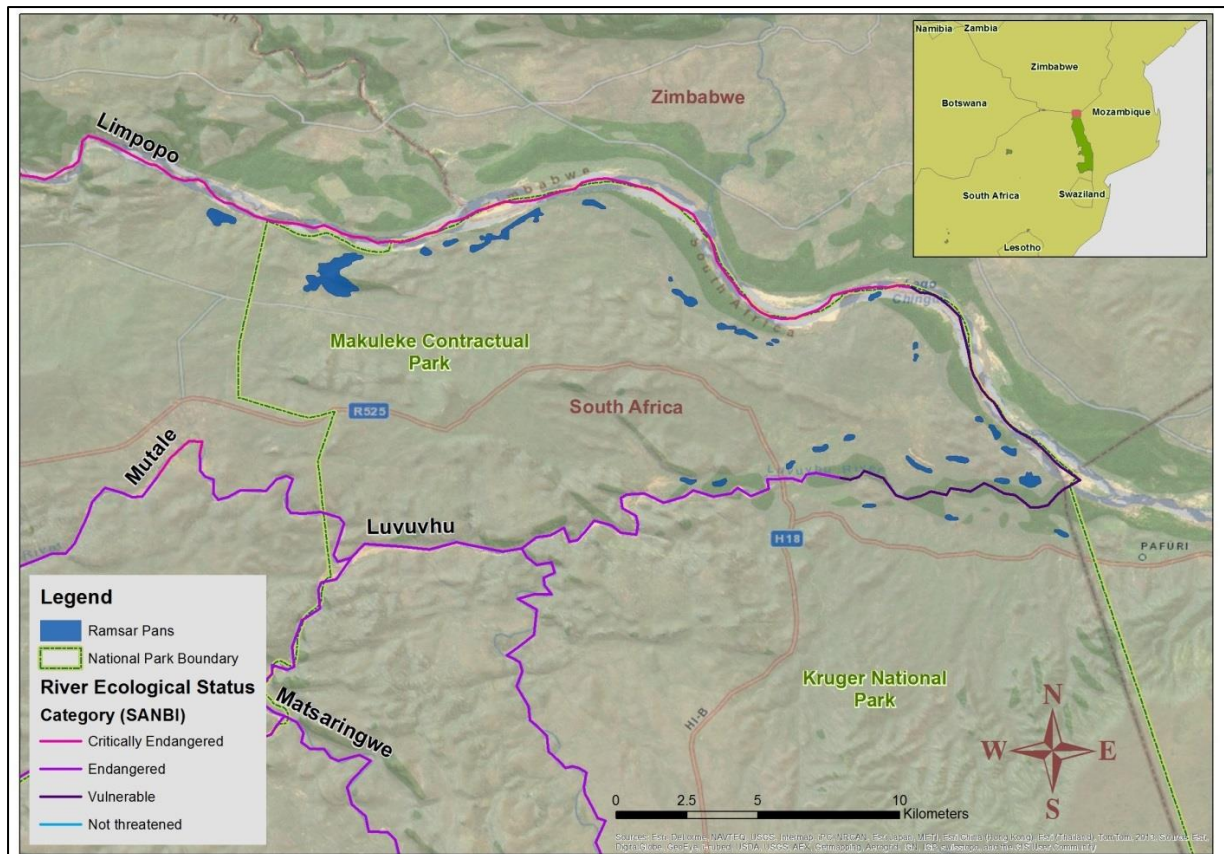


Figure 3: The river ecological status of The Luvuvhu and Limpopo Rivers

(Ecological status shapefiles obtained from <http://bgis.sanbi.org>)

2.4.1 Great Limpopo Transfrontier Park

The Great Limpopo Transfrontier Park (GLTP), consisting of the Limpopo National Park (LNP), Kruger National Park (KNP), Gonarezhou National Park (GNP) and the areas linking the GNP to the KNP (Sengwe Corridor), was established in 2002 through an international treaty signed by the Heads of the States of Mozambique, South Africa and Zimbabwe (Figure 4) (International Conservation Services et al., 2008). The joint conservation areas cover 36 000km² (Mabunda et al., 2003). The three governments established the GLTP for the purpose of “conservation, socio-economic development and for public enjoyment”. The signing of the GLTP Treaty established a Joint Management Board (JMB) with representatives from all three countries to help run the transfrontier park (International Conservation Services et al., 2008; Mabunda et al., 2003). The six treaty objectives are to:

- Foster trans-national collaboration and co-operation among the parties which will facilitate effective ecosystem management in the area comprising the Transfrontier Park;
- Promote alliances in the management of biological natural resources by encouraging social, economic and other partnerships among the Parties, including the private sector, local communities and non-governmental organisations;

- Enhance ecosystem integrity and natural ecological processes by harmonising environmental management procedures across international boundaries and striving to remove artificial barriers impeding the natural movement of wildlife;
- Facilitate the establishment and maintenance of a sustainable sub-regional economic base through appropriate development frameworks, strategies and work plans;
- Develop trans-border eco-tourism as a means of fostering regional socioeconomic development; and
- Establish mechanisms to facilitate the exchange of technical, scientific and legal information for the joint management of the ecosystem (International Conservation Services et al., 2008).

The area on the Zimbabwean side of the Limpopo River is Sengwe Communal Land, which is currently not formally protected, but owned by the Sengwe community (CESVI, 2002; Ramutsindela, 2007). The south-western half of the Sengwe Communal Land lies adjacent to the northern border of the KNP (along the Limpopo) (Figure 4). The north-eastern edge of the Sengwe Communal Land forms the western boundary of Gonarezhou National Park in Zimbabwe (CESVI, 2002). It was agreed that a “wildlife strip” be set aside in the Sengwe Communal Land along the Limpopo River, free of settlement, cultivation and livestock. This strip of riverine forest varies between 0.6km and 2.3km wide and runs the whole length of the border with the KNP (Figure 5) (CESVI, 2002). In February 2005, the Sengwe Corridor was also established to allow for animal movements between the KNP and GNP in Zimbabwe, as part of the Great Limpopo Park Transfrontier Conservation initiative (CESVI, 2002; Ramutsindela, 2007) (Figure 5). Although these strips or corridors have been set aside, according to the Sengwe-Tchipise Wilderness Corridor Local Development Plan Report (2005), the local community still rely heavily on income generated from trophy hunting in the region (Combination Local Plan Preparation Authority, 2005). Trophy hunting in the area is largely run through the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE), a community-based natural resource management programme in which Rural District Councils, on behalf of communities on communal land, are granted the authority to market access to wildlife in their district to safari operators (Frost and Bond, 2008). According to the Sengwe Corridor Concept Paper produced by CESVI (2002), the majority of hunting in the Sengwe Communal Land occurs along and even within the Limpopo River (Figure 5). Essentially, the hunting is based on the overflow of wildlife from the KNP. In the 2002 concept paper, multiple incidents of buffalo (*Syncerus caffer*), elephant, lion, leopard (*Panthera pardus*) and spotted hyaena being shot for trophies were recorded (Figure 5). CAMPFIRE revenues go towards funding infrastructure developments and household dividends in the local community (CESVI, 2002). Particularly during the dry season when the Limpopo is dry, it is easy for animals and people to move between Zimbabwe and the KNP, as well as Mozambique further downstream. Occasional reports and signs of people crossing over from Zimbabwe into the Makuleke area were noted during research trips in the field.

2.4.2 *The Makuleke Contractual Park*

The Makuleke Contractual Park falls within the northern Pafuri region of the KNP, in the Limpopo province, South Africa. The region is bordered by Zimbabwe to the north and Mozambique to the east (Deacon, 2007). The Makuleke community, claiming ancestry in the area back to at least the middle of the 18th century, remained in the Pafuri area until 1969. They were then relocated by the government to Ntlaveni and what was then the Pafuri Game Reserve was incorporated into the KNP. In 1995 the Makuleke community launched a successful land claim. They are now co-managing biodiversity conservation and ecotourism in the area, with SANParks and the South African government, as the Makuleke Contractual Park (Pollard et al., 2003). Since majority rule in 1994, contractual national parks have been seen as a model through which the country's conservation, social and development objectives can be met, particularly where landowners are previously disadvantaged communities, such as the Makuleke People (Reid, 2001; Pollard et al., 2003).

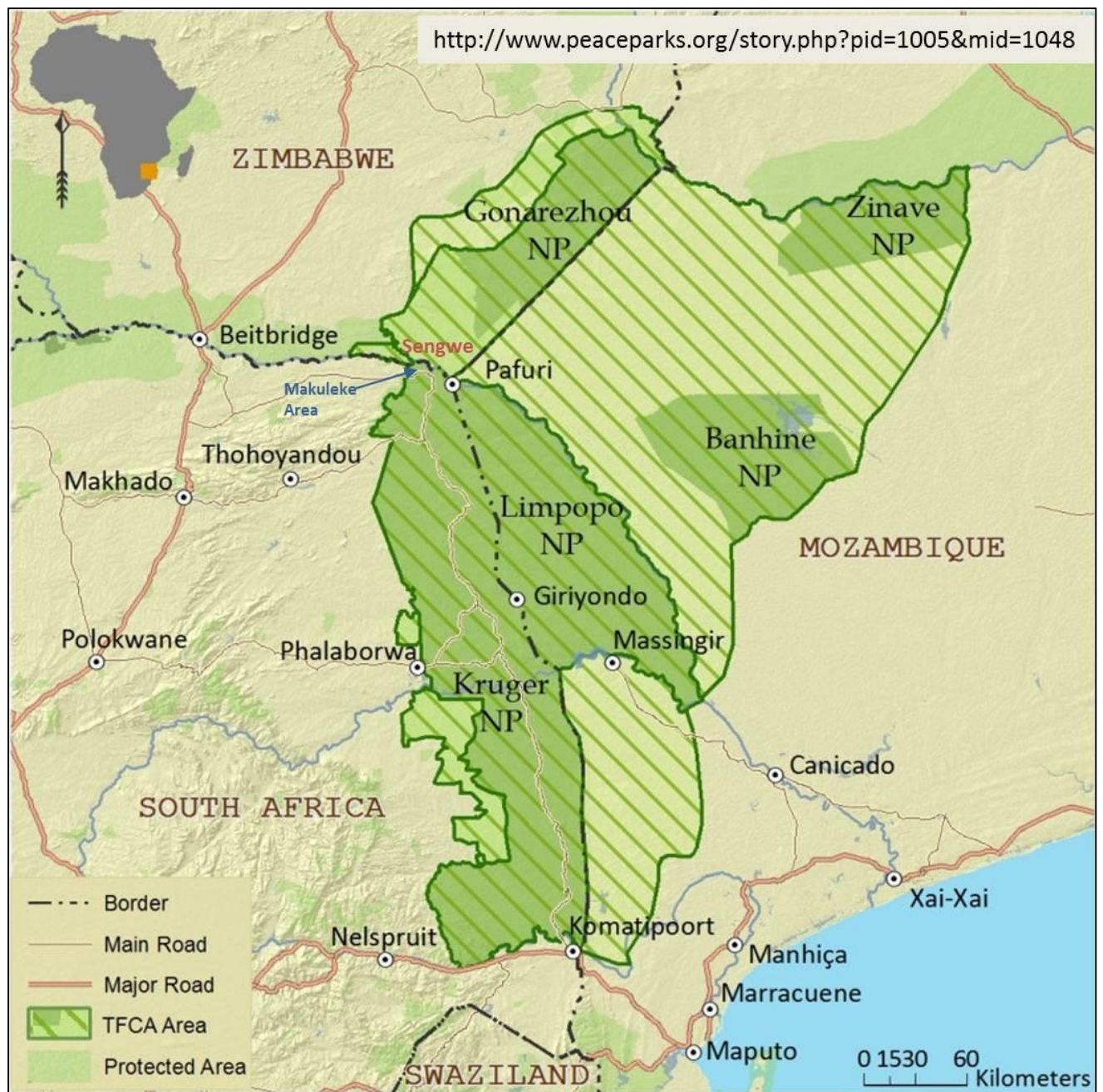


Figure 4: Protected areas contributing to The Great Limpopo Transfrontier Park

(Adapted from www.peaceparksfoundation.net, accessed May 2013)

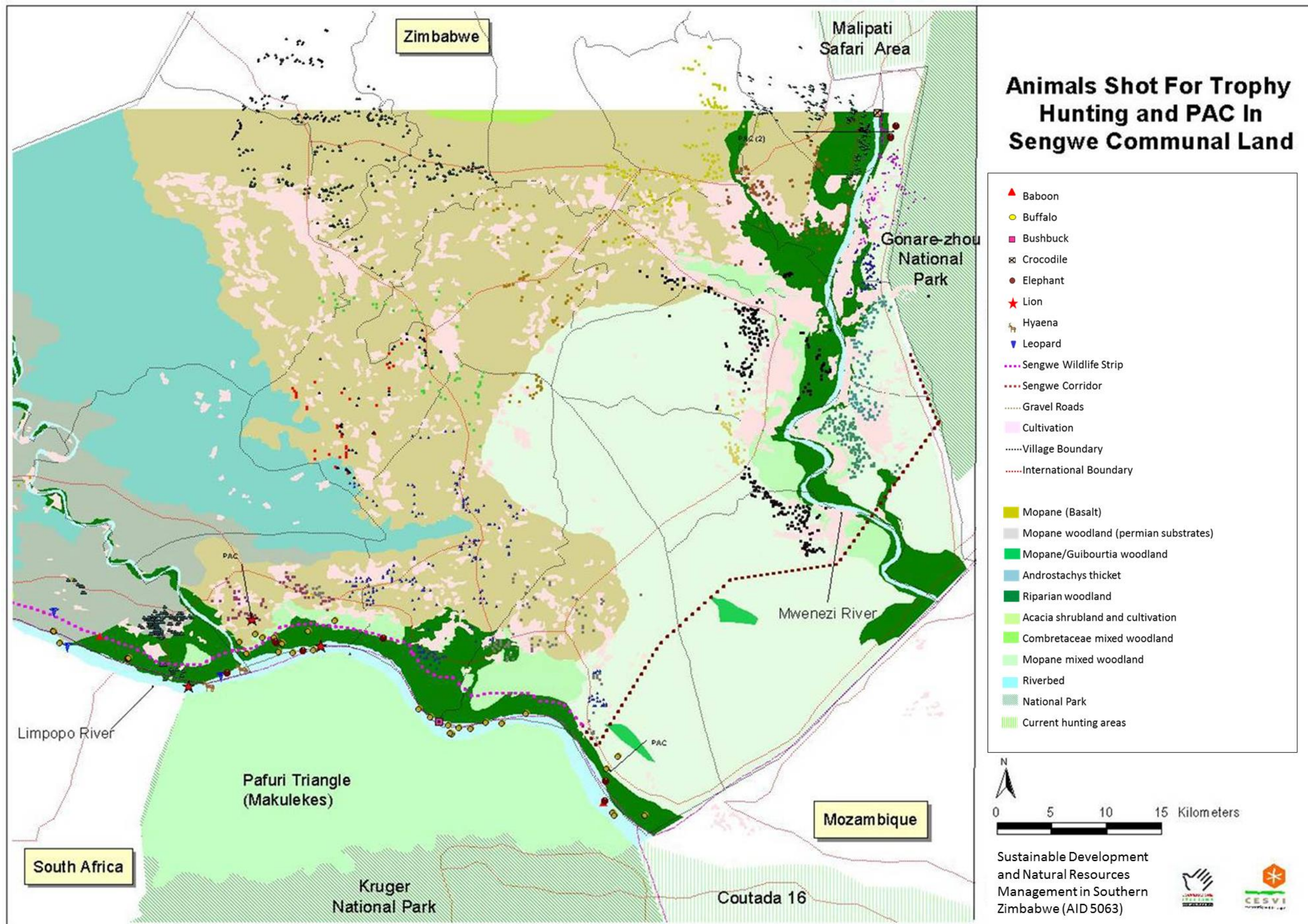


Figure 5: Recorded animals shot for trophy hunting in Sengwe Communal Land (CESVI, 2002)

3. STUDY SITE DESCRIPTION

Five perennial pans, as well as sites along both the Limpopo and Luvuvhu rivers, within the Makuleke Wetland System, have been selected for this study (Figure 6). The five selected pans are: Nwambe, Mapimbi, Nhlanguwe, Jachacha and Lakangwa. These specific pans were selected as they are the only pans known to hold water throughout the dry season.

Mean annual rainfall for the Pafuri area is low (375–420 mm/year) and highly variable with an inter-annual coefficient of variation of rainfall of 35% (Venter et al., 2003; Gillson and Ekblom, 2009). The region is characterised by undulating plains, comprised of a range of sedimentary and volcanic rocks (and their associated soils), as well as alluvial floodplains (Venter et al., 2003). The underlying geology and hydrology provides a template for a variety of landscape features including riverine forests, riparian floodplain forests, floodplain grasslands, river channels and flood pans (Venter et al., 2003; Deacon, 2007).

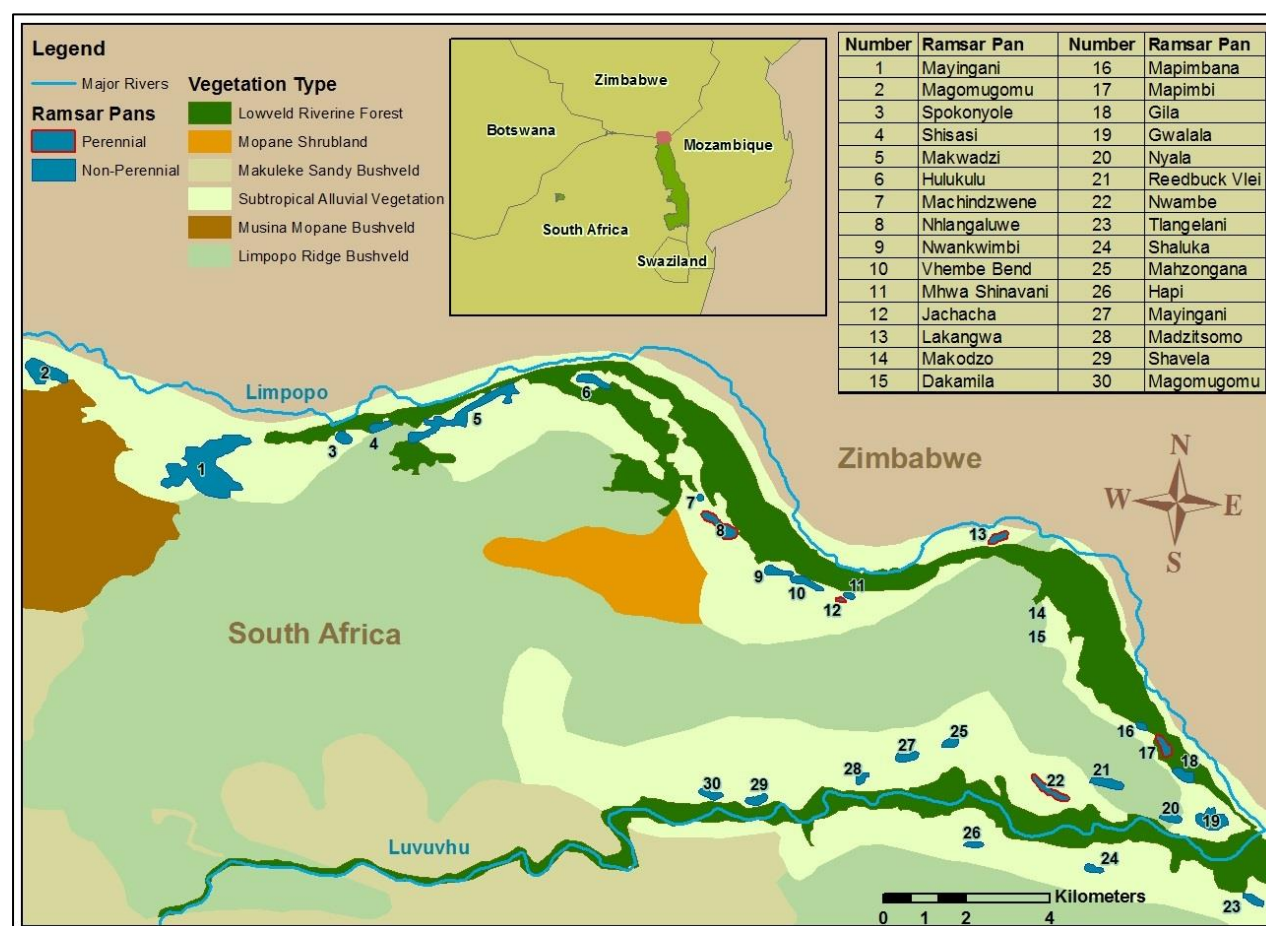


Figure 6: The Makuleke Wetland System and perennial pans and rivers studied

The false colour composite image produced by Claire Knight (2011), assigns different colours to the bands in the SPOT 321 image. This colour combination (as seen in Figure 7) shows vegetation in shades of red, based on the high reflectance in the NIR band, with the shade depending on the types and conditions of the vegetation. Less healthy vegetation and bare areas are displayed in shades of green. The almost white areas represent sand banks, whilst rivers and pans are displayed as dark blue. The image taken in the

summer of 2010 (Figure 7) shows the most densely vegetated areas as those in close proximity to the rivers (the riverine vegetation), along the small tributaries, and along the valleys in the area. The area between the two rivers is characterised by sparse vegetation and bare areas, as seen from the varying shades of green.

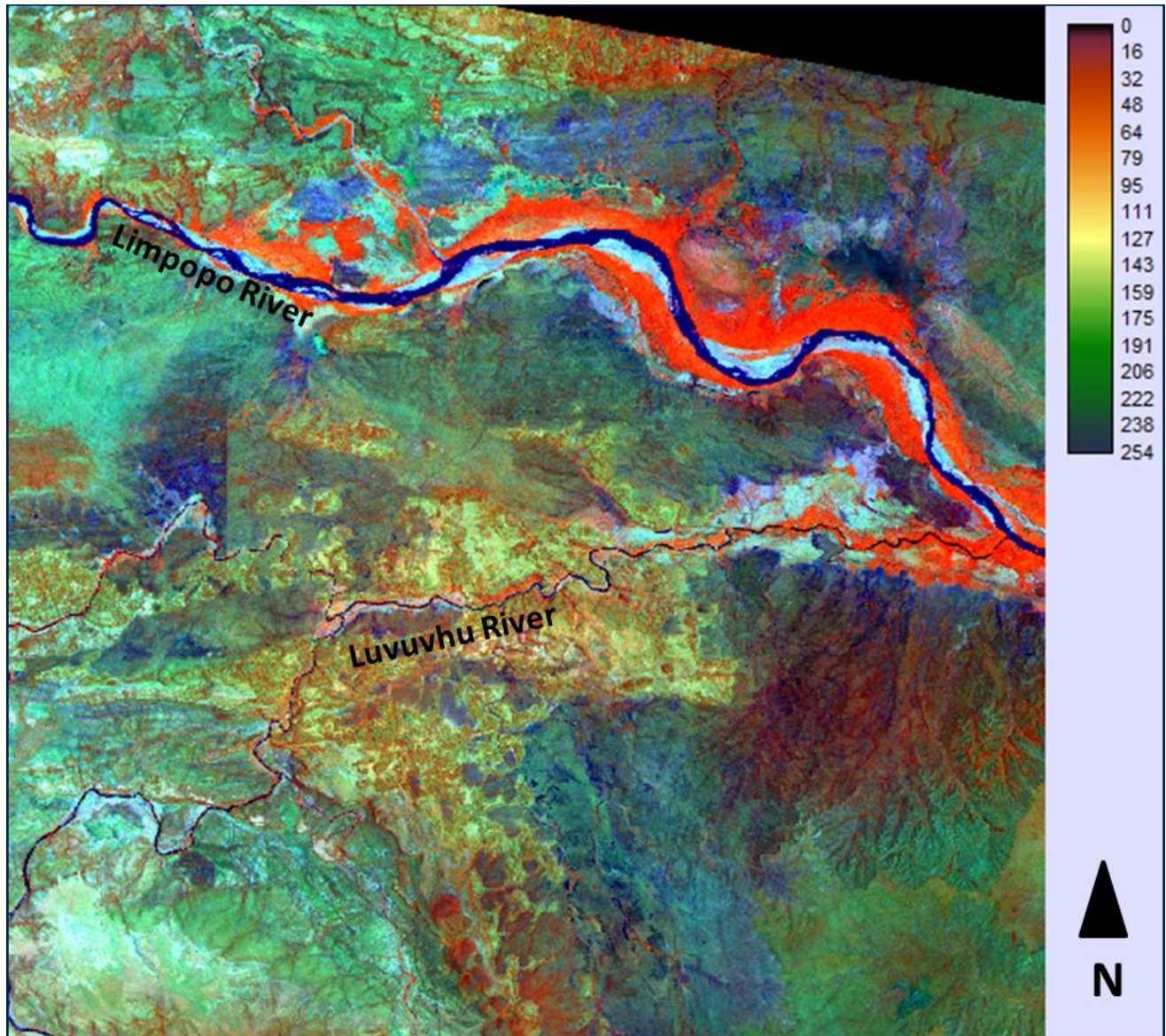


Figure 7: False colour composite image for 2010 (Knight, 2011)

The broad vegetation type classes surrounding each water source were determined using satellite imagery, aerial photography and the classes as produced from the supervised FISHER module run in IDRISI (Knight, 2011). The supervised FISHER model groups the vegetation into 13 classifications (Table 1; Figure 8). The supervised vegetation classification image shows belts of denser riverine vegetation along the river fringes made up largely of species such as *Acacia xanthophloea* (fever tree), *Diospyros mespiliformis* (jackalberry tree) and *Salvadora persica* (mustard tree). The floodplain between the two rivers is made up of less dense stands of mixed vegetation communities comprises species such as

Colophospermum mopane (mopane trees), *Sporobolus Pyramidalis* (dropseed grass) and *Hyphaene coriacea* (lala palms) (Figure 8).

Table 1: Vegetation Classifications used in the supervised FISHER model (Knight, 2011)

Common Name	Scientific Name	Common Name	Scientific Name
Butter and Cheese	<i>Abutilon sonneratianum</i>	Three-thorned acacia	<i>Acacia Senegal</i>
Ana Tree	<i>Faidherbia albida</i>	Dropseed Grass	<i>Sporobolus pyramidalis</i>
Lala Palm	<i>Hyphaene coriacea</i>	Knobthorn Tree	<i>Acacia nigrescens</i>
Jackalberry Tree	<i>Diospyros mespiliformis</i>	Mopane Tree/Shrub	<i>Colophospermum mopane</i>
Mustard Tree	<i>Salvadora persica</i>	Anasotis Shrub	<i>Anasotis</i>
Needle Bush	<i>Azima tetracantha</i>	Fever Tree	<i>Acacia xanthophloea</i>
Umbrella Thorn	<i>Acacia tortilis</i>		

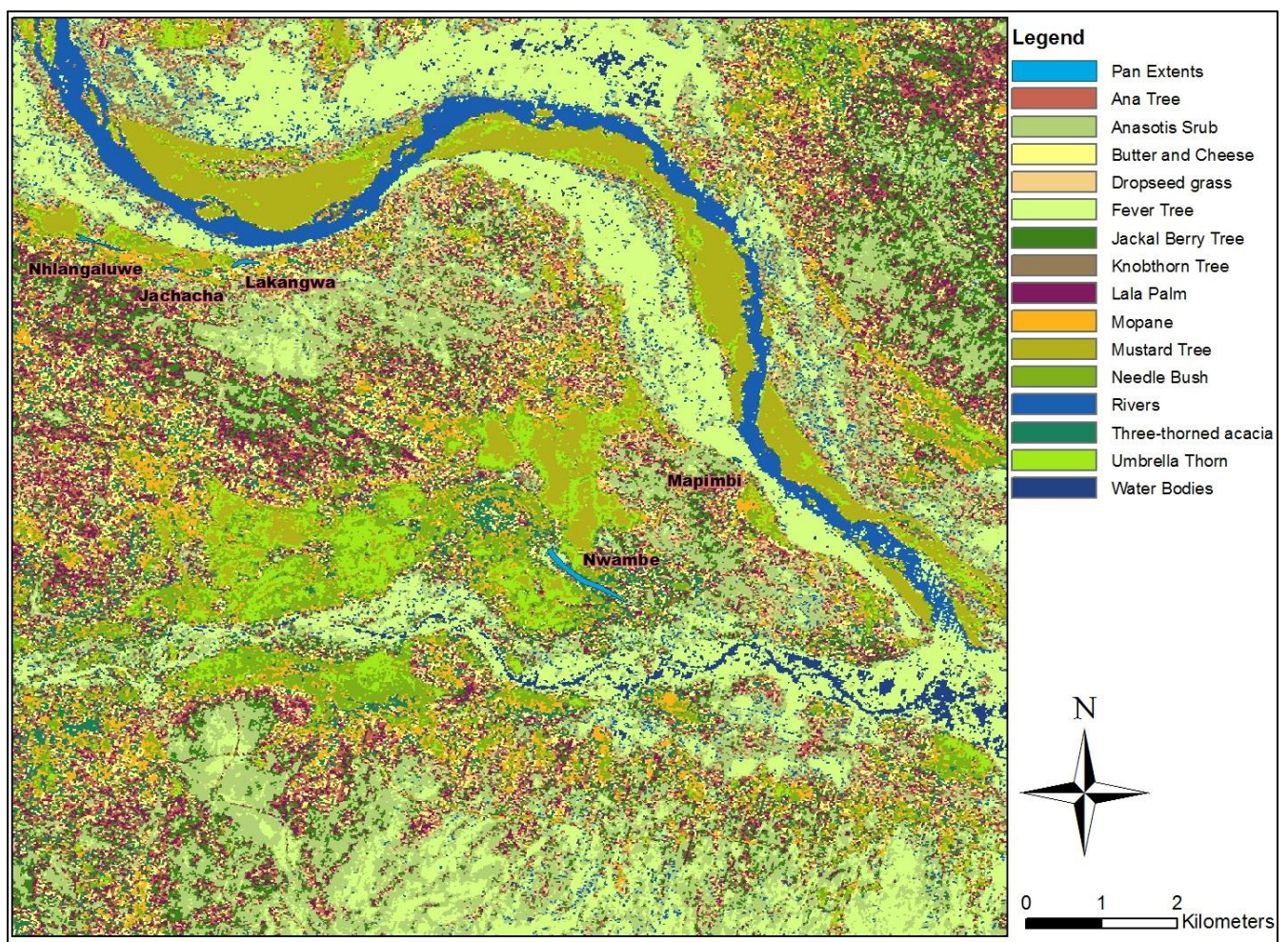


Figure 8: FISHER supervised classification image for 2010 of the Makuleke area (adapted from Knight, 2011)

3.1 Pan and River Descriptions and Characteristics

This section briefly describes the characteristics of the five perennial pans studied and the Limpopo and Luvuvhu rivers, within the floodplains of which the pans occur. The location, size, surrounding vegetation, bank gradient and accessibility to humans are described. Pan surface areas were calculated by Gina Martin (2011) who used GIS software to digitise the pan extents from 2008 aerial photography. The risk of poaching is determined by the distance to the National Park's closest boundary, which in this case is the border with Zimbabwe along the Limpopo River, along which there is no boundary fence.

Vegetation Classes

The broad vegetation type classes surrounding each water source were determined using satellite imagery, aerial photography and the classes as produced from the supervised FISHER module run in IDRISI (Knight, 2011).

Vegetation Structure

Vegetation structure at the edge of each pan was calculated by averaging the vegetation cover and height classes within plots recorded along 50m transects away from the edge of each pan. Cover and height classes were recorded for grass, shrubs and trees along each transect (see Methodology Section 4.4) (Zoghby, 2011).

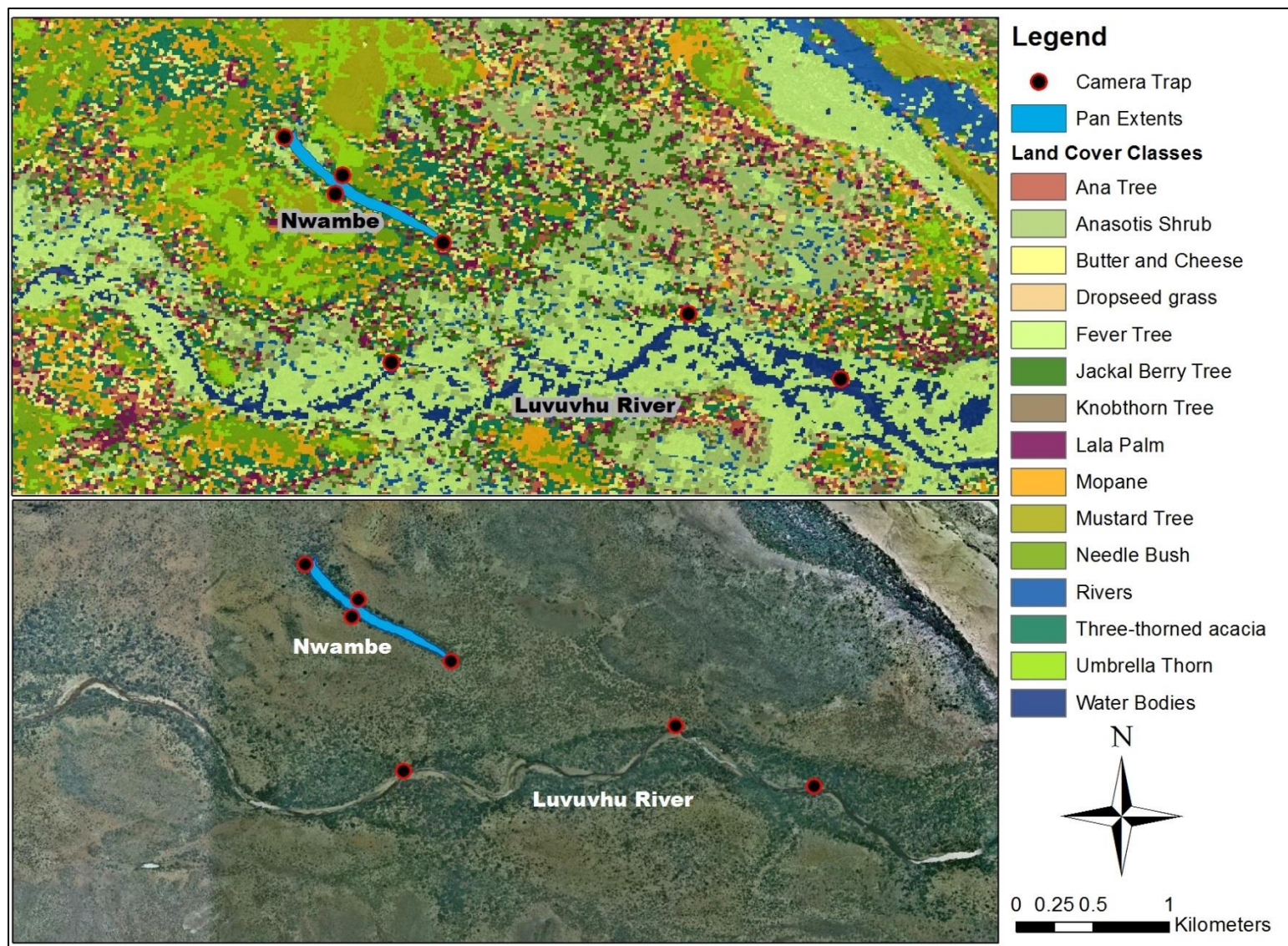
3.1.1 Luvuvhu River Floodplain

3.1.1.1 Luvuvhu River (22°25'44.8"S; 31°15'29.43"E)

The Luvuvhu River flows from west to east across the northern KNP until its confluence with the Limpopo at Crook's Corner at the border of South Africa, Mozambique and Zimbabwe. The Luvuvhu channel is not as wide as that of the Limpopo and in many places the Luvuvhu has high, steep banks as a result of historical large flood events (Figure 9). Within the KNP, the Luvuvhu River flows through a major gorge and then exits out onto a wide floodplain before it joins the Limpopo River at Crook's Corner (O'Keeffe and Rogers, 2003). The Luvuvhu River sediments are characterised by deep red silt (Venter et al., 2003). The three camera traps were therefore set up along known access points recommended by field guides that have worked in the area for a number of years. All the access points monitored along the Luvuvhu can only be accessed on foot. Although the water level in the Luvuvhu drops during the dry season, unlike the Limpopo, the river does not usually dry up completely with the exception of very dry years (Figure 9). The Luvuvhu River is the only river within the KNP with a well-defined forested floodplain (O'Keeffe and Rogers, 2003). The riparian vegetation along the length of the river where the camera traps were situated is dominated by well-established riverine forest consisting of ana trees (*Faidherbia albida*), fever trees (*Acacia xanthophloea*) and jackalberry trees (*Diospyros mespiliformis*) (Figure 10).



Figure 9: The Luvuvhu River depicting the riparian forest vegetation along its banks and the seasonal variation in water levels



3.1.1.2 Nwambe Pan (22°24'57.33"S; 31°15'35.78"E)

Nwambe is the only perennial pan within the Luvuvhu floodplain (pers. communication Walter Jubber, 2011) and is located on the edge of the floodplain woodland along the Luvuvhu River, which is dominated by fever trees (*Acacia xanthophlea*). Nwambe can only be accessed on foot and the closest area with high levels of human activity is Pafuri Lodge, 3.1km to the west. The border with Zimbabwe (the Limpopo River) is 3.1km east of the pan. It is assumed that Nwambe receives its water from both surface runoff after rainfall events, as well as from ground water recharge. Nwambe's southernmost position is situated ~790m from the Luvuvhu River. There is also an inlet stream linking Nwambe directly to the Luvuvhu River during high discharge events. Nwambe Pan has the greatest surface area (~95043m²) of all the perennial pans sampled in the Makuleke Concession. According to the study conducted by Gina Martin in 2011, assessing the percentages of water cover within the Makuleke pans between 1963 and 2008 using aerial photography, Nwambe retains annual water even into very dry years when other pans dry up. Although Nwambe retains water throughout the year, during the dry season the shallow pan's extent decreases considerably (Figure 12) (Martin, 2011). It is a large and relatively shallow pan with flat banks for game to access it, with the exception of areas along the northern bank which is relatively steep (Nwambe camera trap site 4). The riparian vegetation immediately surrounding the pan consists of large riverine forest trees, similar to the riparian forests bordering the Luvuvhu and Limpopo Rivers, interspersed with large fever trees (Deacon, 2007) (Figure 11). Although there are large trees surrounding the pan, there is very little ground cover around the pan edge (Figure 11). The water in Nwambe Pan is usually red/orange in colour, indicating a high silt load from the surrounding red soils (Figure 11 and Figure 12) (Venter et al., 2003). Four camera traps were set up to monitor Nwambe Pan, given its large size. The traps were set up to monitor game paths accessing the pan from the northern, southern, western and eastern edges (Figure 13).



Figure 11: Nwambe Pan depicting the large riparian trees and the shallow gradient of the banks



Figure 12: Nwambe Pan at the end of the dry season (2011) when the extent water had been substantially reduced



Figure 13: Aerial photograph of Nwambe Pan (SANParks, 2008)

3.1.2 Limpopo River Floodplain

3.1.2.1 Limpopo River (22°22'17.89"S; 31°13'30.8"E)

The Limpopo River forms the border between Zimbabwe and South Africa along the northern boundary of the KNP. Discharge within the Limpopo fluctuates significantly between seasons. During the dry season of 2011 the river dried up completely, leaving stagnant pools within the channel (Figure 14). During the wet season, however, the river is transformed into a fast flowing, wide channel of water (Figure 14). According to The Department of Water Affairs' (DWA) station data for station A7H008 along the Limpopo at Beit Bridge, just upstream of the study area, flow fluctuated in 2011 from a monthly peak flow of 1439.5m³/s in January 2011 to a peak flow of 1.6m³/s in October 2011 before the rains (DWA, 2012). Some areas along the Limpopo have steep, undercut banks and many areas are difficult to access due to thick riverine vegetation. The sediments flanking the Limpopo River are mostly sandy (Venter et al., 2003). The camera trap sites selected along the Limpopo were therefore selected according to ease of accessibility and the bank gradient being appropriate for fauna to access the river. Game paths were used to detect areas of high activity along the river. All three sites selected along the Limpopo are accessible by vehicles, with roads within 30m of where traps were set up (Figure 15).

The riverine forest along the edge of the Limpopo is broad and consists of species such as brack thorns (*Acacia robusta*), fever trees (*Acacia xanthophlea*), common cluster figs (*Ficus sycamorus*), and apple leaf (*Philenoptera violacea*) among others (Deacon, 2007). In places, particularly surrounding the pans, lala palms (*Hyphaene coriacea*) are present (Figure 15). The Limpopo camera trap site directly east of Mapimbi Pan (Trap 1) is situated within the fever tree dominated riparian zone along the Limpopo River. The two camera trap sites along the Limpopo to the south of Mapimbi Pan are also situated within the riparian zone along the Limpopo River, however, this area is not as dominated by fever trees, but other large riparian species such as jackalberry (*Diospyros mespiliformis*) and mustard trees (*Salvadora persica*) occur (Figure 15).

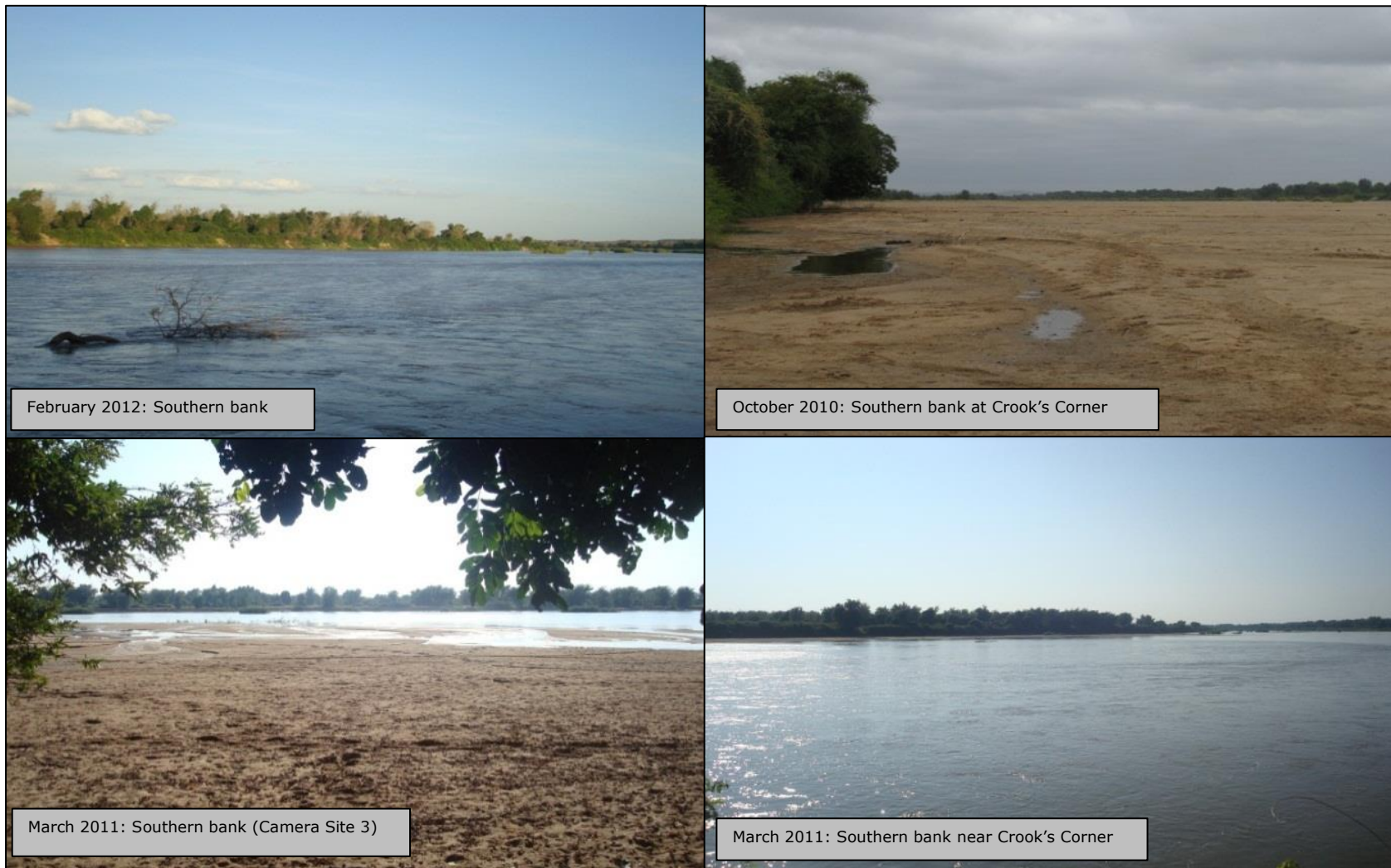
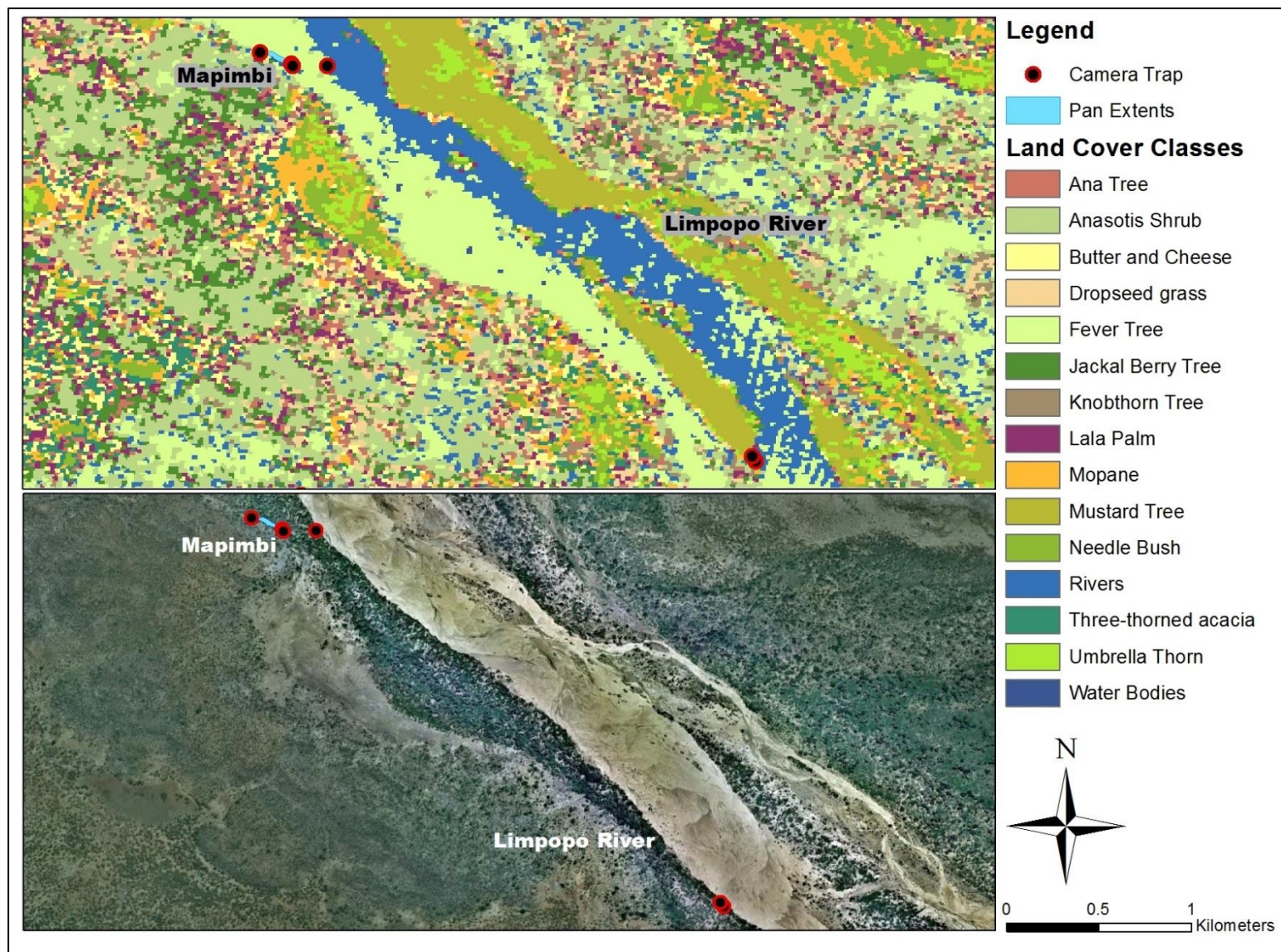


Figure 14: The Limpopo River depicting the broad river bed which almost dries up completely towards the end of the dry season



3.1.2.2 Mapimbi Pan (22°24'8.61"S; 31°16'45.84"E)

Mapimbi Pan is situated within the riparian forest along the southern bank of the Limpopo River, ~177m from the Limpopo channel. The eastern bank of the pan is accessible by vehicles from the lodges within the concession. The pan's surface area does not fluctuate greatly throughout the year and it has a maximum extent of ~4167m² (Figure 16 and Figure 17). Due to the pan's close proximity to the Limpopo, it is thought that it is primarily fed through groundwater seepage from the channel (Figure 15). The majority of Mapimbi's banks are fairly steep, with a slightly more gradual access on the south-eastern bank and a flat access area along the north-western bank (Figure 16). Evidence of crocodile activity was often observed during field work at Mapimbi. As the pan is situated less than 200m from the Limpopo, crocodiles can easily move between the two water sources; particularly during the dry season (when the Limpopo is dry), Mapimbi Pan is likely an important refuge for Limpopo River crocodiles.

The FISHER supervised image and satellite image of Mapimbi Pan shows that the pan is situated just within the riparian zone along the Limpopo River (Figure 15). This stretch of the riparian zone is largely dominated by large fever trees (*Acacia xanthophlea*), with scattered jackalberry trees (*Diospyros mespiliformis*) along the pan's edge. Like Nwambe Pan, Mapimbi Pan supports a riparian zone of well established trees within a landscape consisting largely of shrubs, dropseed grass (*Sporobolus Pyramidalis*), mopane shrub and woodland (*Colophospermum mopane*) and scattered lala Palms (*Hyphaene coriacea*) (Figure 15).

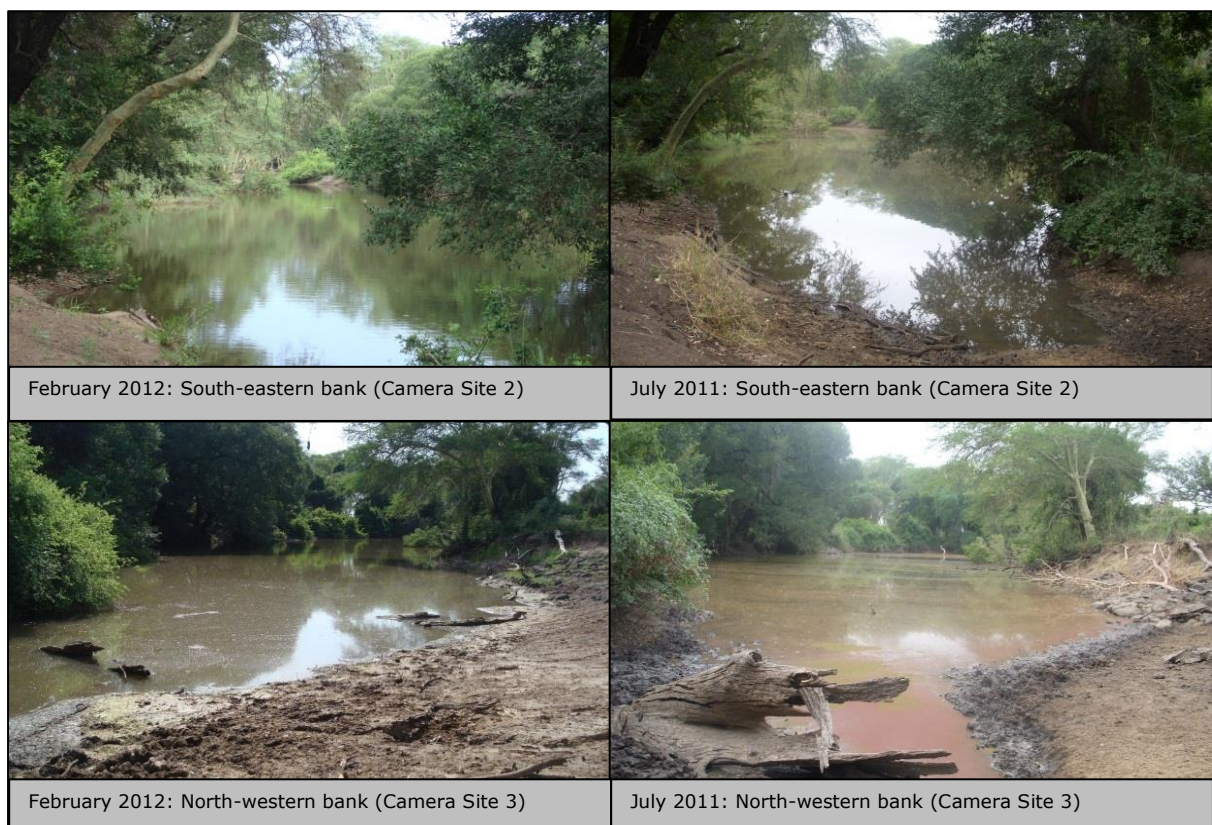


Figure 16: Mapimbi Pan is surrounded by large riparian forest trees and has steep banks with the exception of the south-eastern and north-western banks

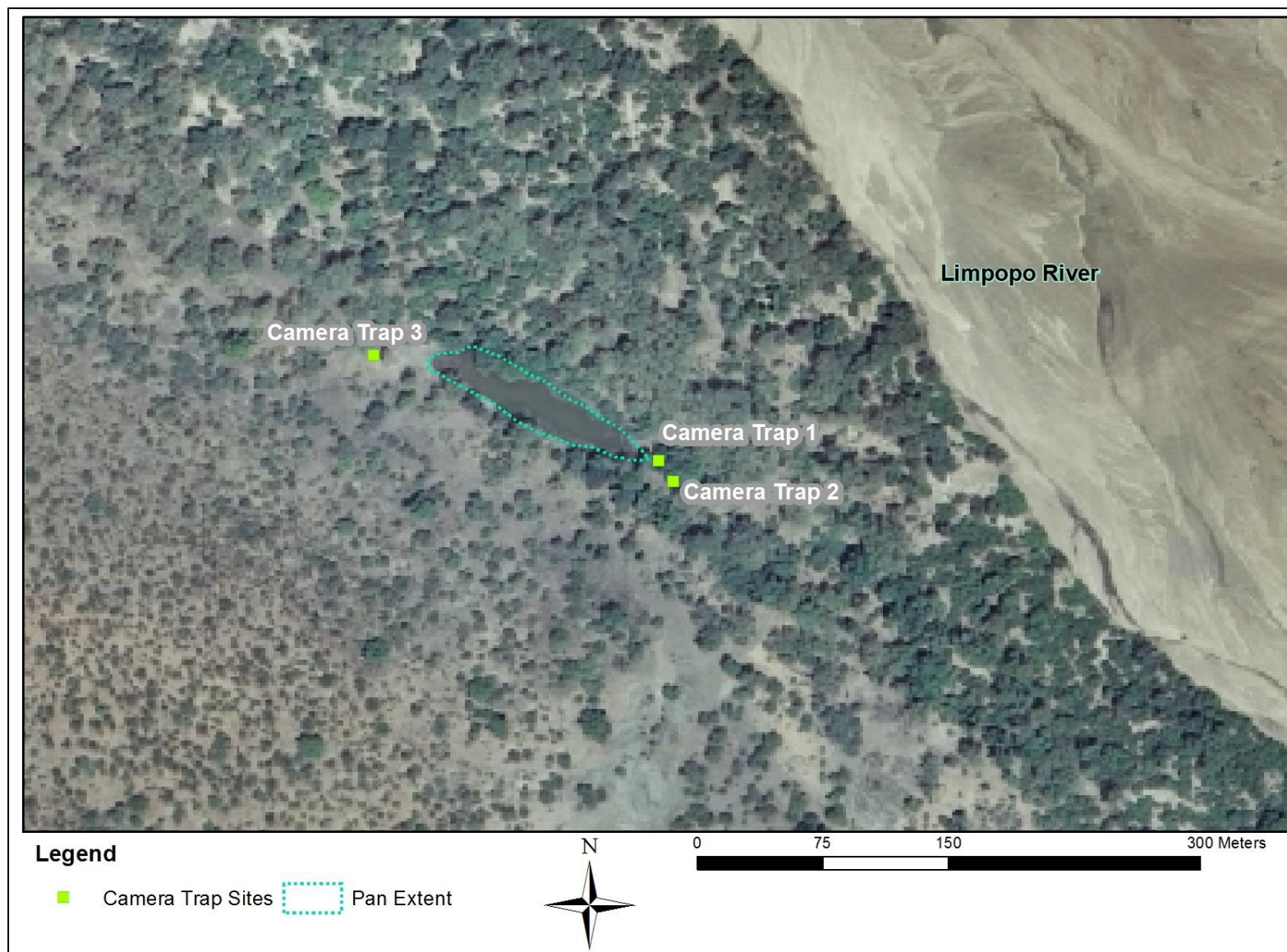


Figure 17: Aerial photograph of Mapimbi Pan (SANParks, 2008)

3.1.2.3 Lakangwa Pan (22°22'44.1"S; 31°13'14.01"E)

Nhlangaluwe, Jachacha and Lakangwa Pans, like Mapimbi Pan, are also situated within the Limpopo River floodplain. However, these three pans are not situated directly within the riparian belt along the river, but rather within the floodplain grassland (Deacon, 2007) (Figure 18 and Figure 19). Lakangwa Pan is situated ~180m south of the Limpopo channel. As it is situated within the floodplain grassland, the majority of Lakangwa's margins are covered in thick grass cover with no clear game paths accessing the pan (Figure 18 and Figure 20). Lakangwa Pan is only accessible on foot and is roughly 330m from the closest road in the concession (Figure 20). The pan has a maximum extent of 17442m²; however, during the year of data acquisition (2011/2012), Lakangwa's extent did not fluctuate greatly between the wet and dry seasons (Figure 18). The banks of this pan are fairly flat with a slight gradient along the southern bank, against a ridge (Figure 20). The northern, western and eastern banks were unfavourable for setting up of camera traps as there were no trees to secure the traps to, no obvious game paths to monitor, and the grass would have continuously triggered the traps as it blew in the wind (Figure 18). The only bank that is easily accessible is the southern bank which is located against a ridge which is covered in floodplain woodland vegetation dominated by knob thorn trees (*Acacia nigrescens*), lala palms (*Hyphaene coriacea*), gardenia shrubs (*Gardenia spatulifolia*) and baobab trees (*Adansonia digitata*) (Deacon, 2007) (Figure 19). The southern bank has multiple game paths which are used to access the pan. The four camera traps were thus set up along these paths on the southern bank where trees were available (Figure 20).

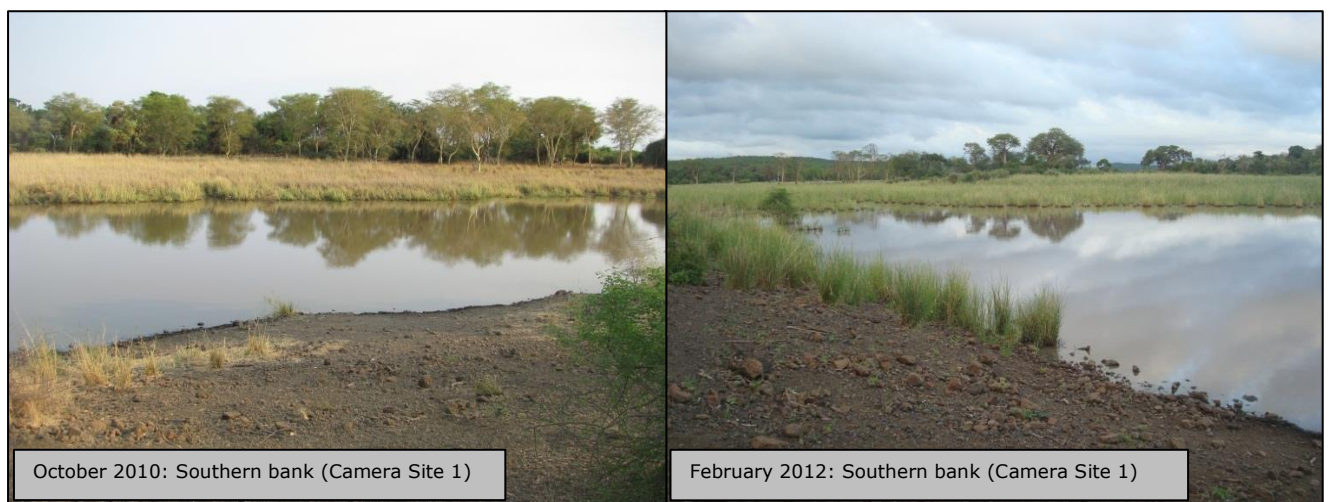
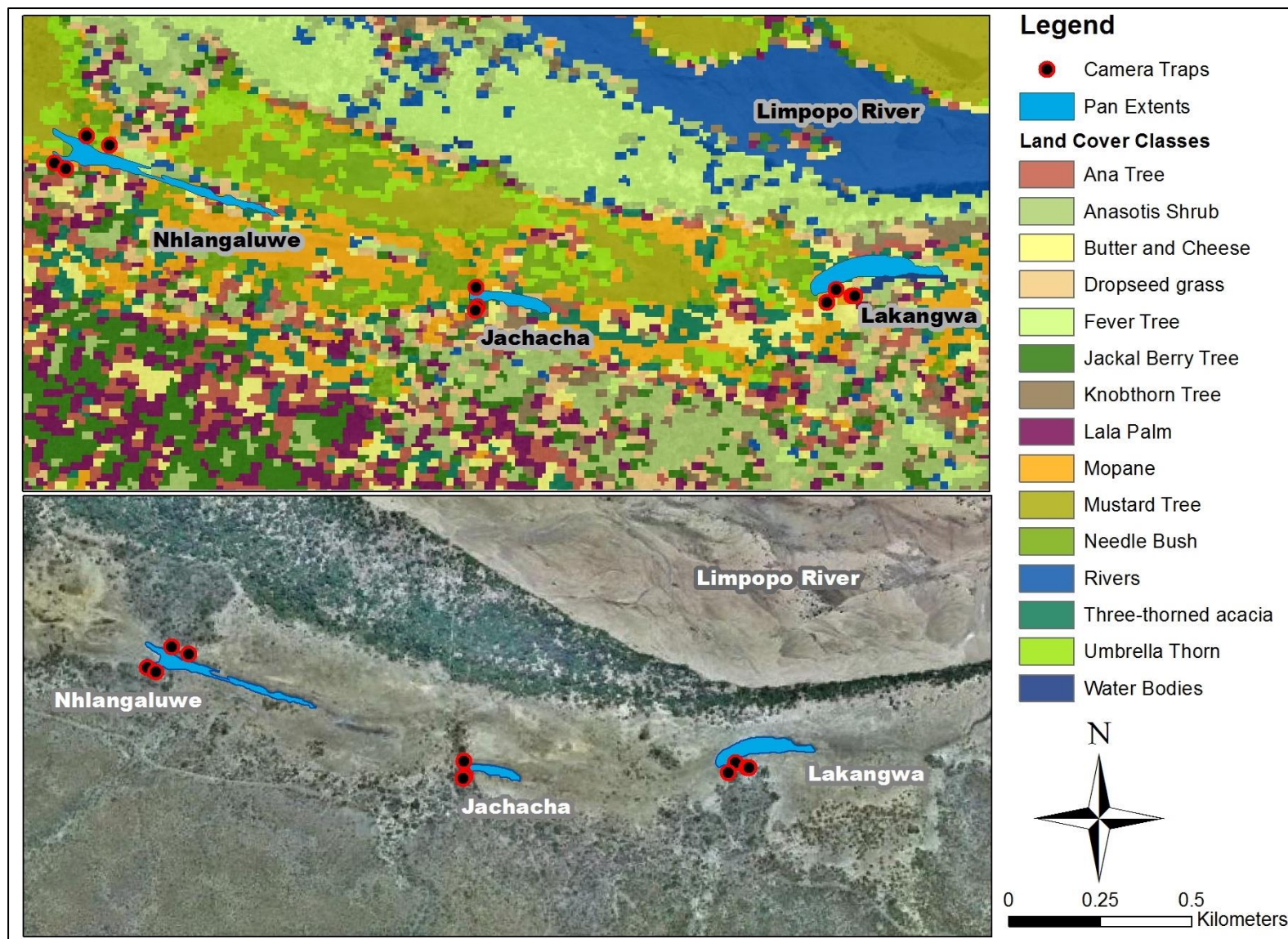


Figure 18: Lakangwa Pan is situated within the Limpopo River floodplain grassland, resulting in grass covered northern, eastern and western banks. The large trees in the background depict the riparian forest bordering the Limpopo River



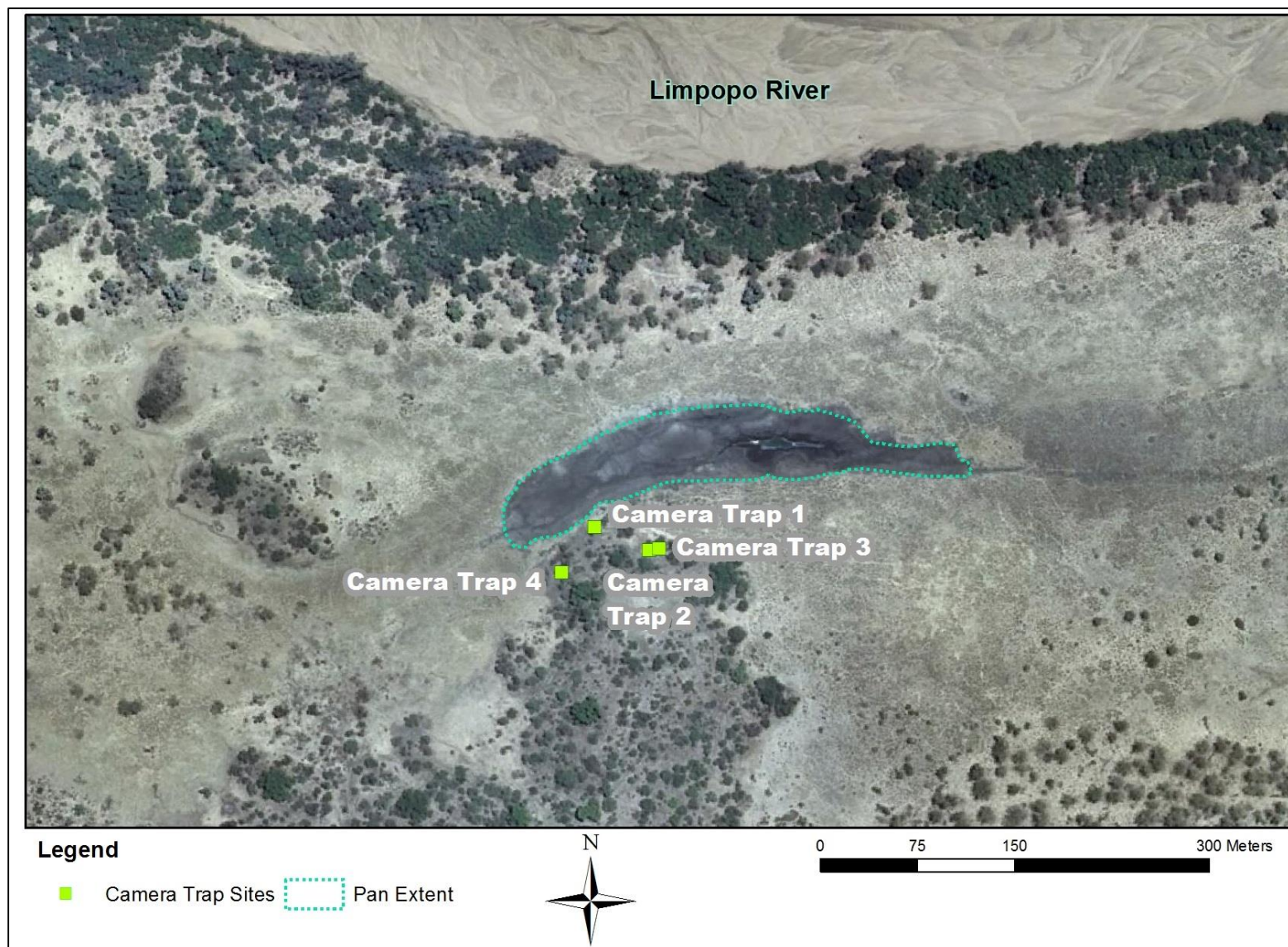


Figure 20: Aerial photograph of Lakangwa pan within the Limpopo River floodplain (SANParks, 2008)

3.1.2.4 Jachacha Pan (22°22'46.55"S; 31°12'40.67"E)

Jachacha Pan is situated approximately 645m from the Limpopo River channel. Like Lakangwa, Jachacha Pan is also located within the Limpopo floodplain grassland and the majority of the banks are covered in thick grass cover (Figure 21 and Figure 22). The western bank of the pan can be accessed by vehicles along a dirt road (Figure 22). Jachacha has a maximum extent of 6075m² and the pans' extent did not fluctuate greatly during the year of study (Figure 21). The western side of Jachacha Pan occurs between two ridges (one north and one south of the pan) (Figure 22). These ridges are not as densely grass covered and are covered by floodplain woodland vegetation supporting, amongst other species, knob thorn trees (*Acacia nigrescens*), fever trees (*Acacia xanthophlea*) and lala palms (*Hyphaene coriacea*) (Figure 19 and Figure 22) (Deacon, 2007). Jachacha's grassland banks are very flat with very slightly inclined banks up against the ridges towards the west of the pan. The three camera traps were therefore set up within the woodland vegetation at the water's edge and along well used game paths.



Figure 21: Jachacha Pan set within the floodplain grassland of the Limpopo River

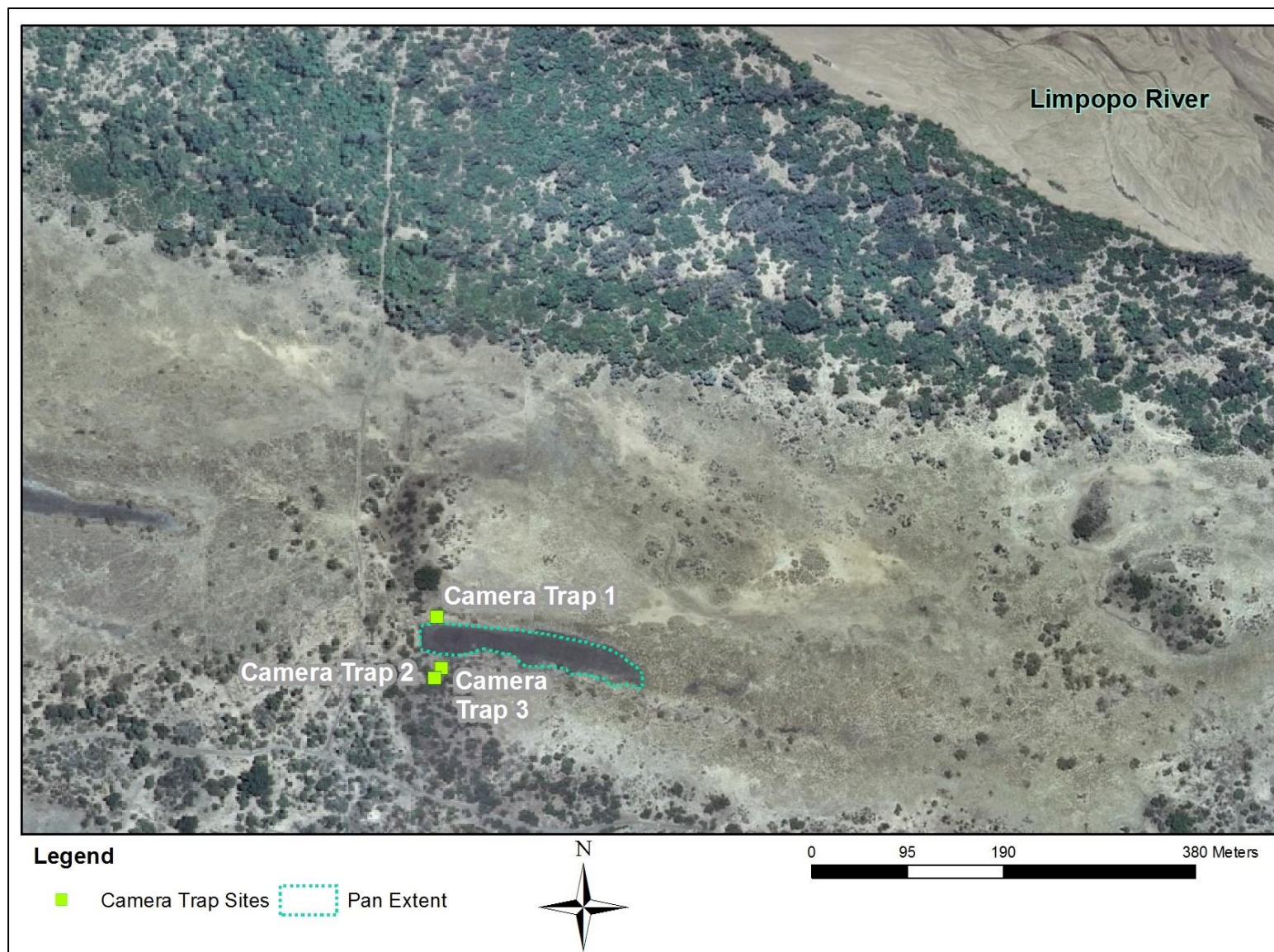


Figure 22: Aerial photograph of Jachacha Pan within the Limpopo River floodplain (SANParks, 2008)

3.1.2.5 Nhlangaluwe Pan (22°22'33.92"S; 31°12'05.12"E)

Nhlangaluwe Pan is situated within the Limpopo floodplain approximately 817m south of the river channel. The pan is only accessible on foot and is ~287m from the closest road on the concession. Nhlangaluwe is a large pan with a maximum extent of ~9506m²; however the extent of the pan fluctuates greatly between seasons (Figure 23 and Figure 24). During very wet years (such as 1999 and 2004), Nhlangaluwe tends to merge into Nwankwimbi and Vhembe Bend pans which are located alongside it, creating one large coalesced pan (Figure 24) (Martin, 2011). The northern and southern banks are fairly steep, but the gradient shallows eastwards and westwards along the pan and into the grasslands. It is also situated within the floodplain grassland with ridges of floodplain woodland vegetation to the north and south of the pan (Figure 19 and Figure 24). As the pan is situated within the grasslands, much of the banks are covered by thick grass cover (Figure 23). The FISHER image shows that the pan is largely surrounded by floodplain vegetation made up of mopane trees (*Colophospermum mopane*), lala palms (*Hyphaene coriacea*) and fever trees (*Acacia xanthophloea*) (Figure 19). Two camera traps were set up on the northern bank, and two on the southern bank within the woodland vegetation. Camera traps were either facing the water's edge where animal activity was evident or along well used game paths (Figure 24).

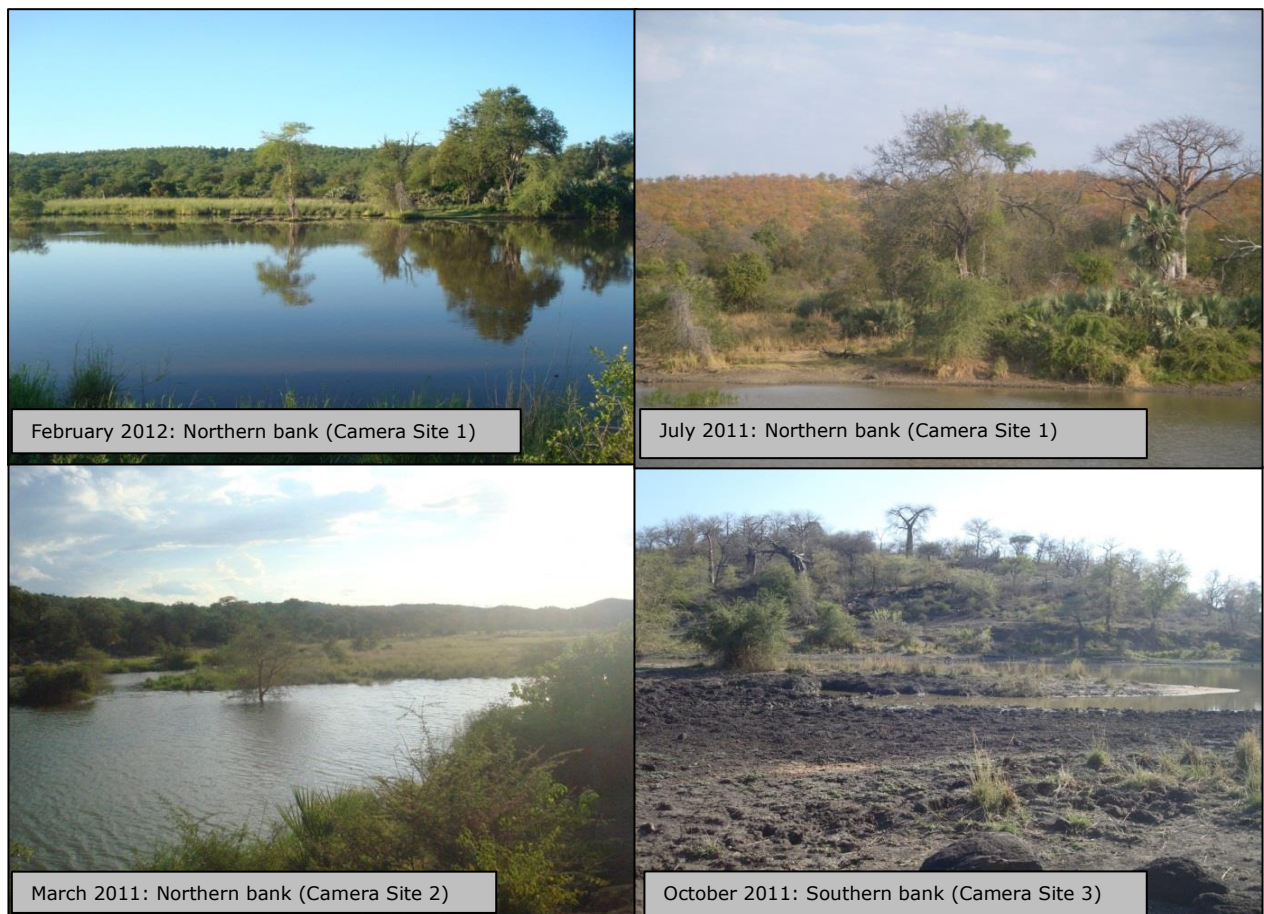


Figure 23: Nhlangaluwe Pan within the Limpopo floodplain, showing the ridges running along either side of the pan which flatten into floodplain grassland

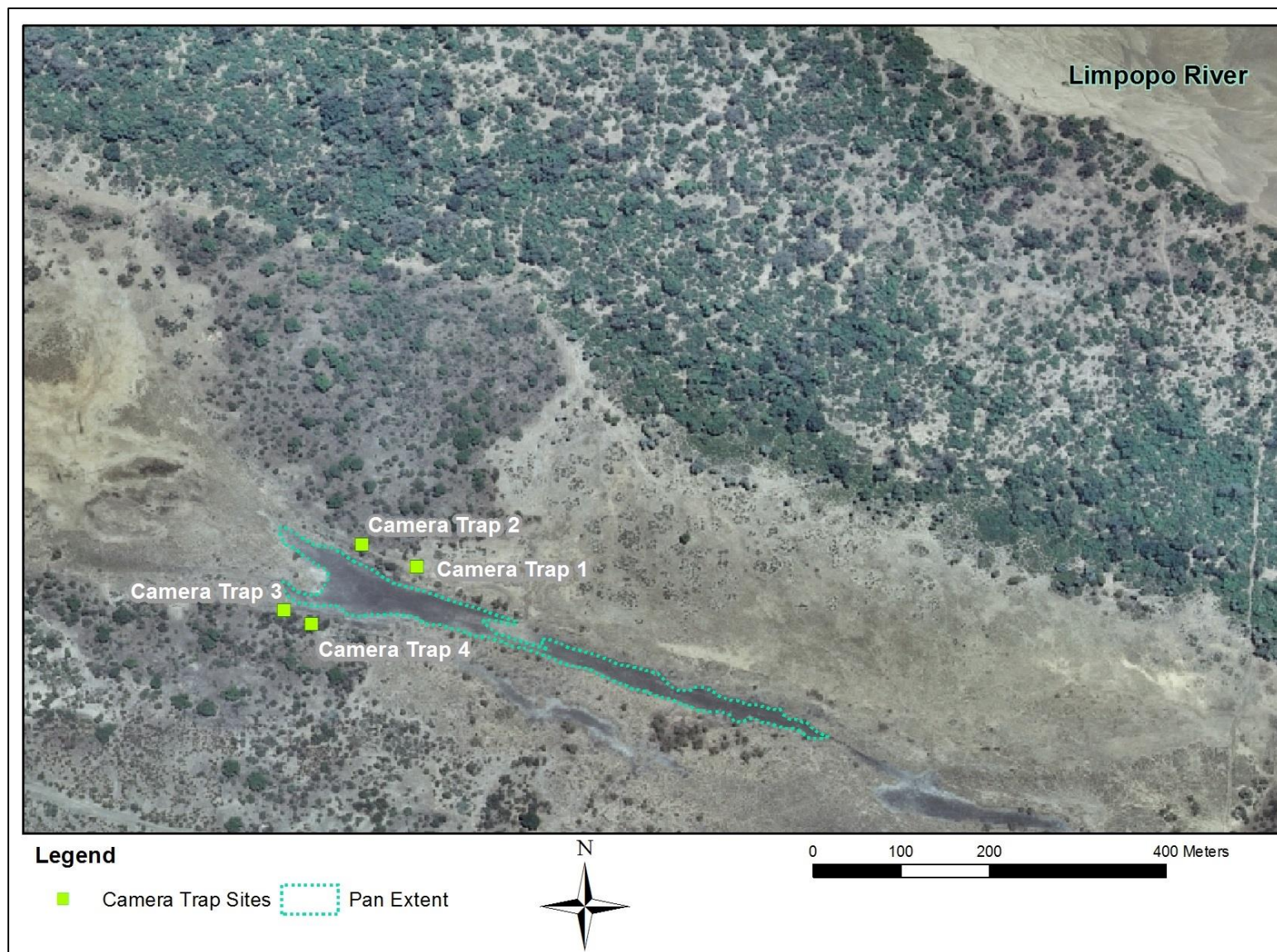


Figure 24: Aerial photograph of Nhlanguwe Pan within the Limpopo River floodplain (SANParks, 2008)

4. METHODOLOGY

Water quality and usage data were collected seasonally (four times throughout the year) in three month intervals: at the end of the rainy season (March 2011); during the dry season (July 2011); at the end of the dry season (October 2011) and at the start of the rainy season (late January/early February 2012). These data were supplemented with vegetation data from previous studies conducted in the area, and distances measured from tourist and access roads within the concession and Zimbabwean border.

4.1 Water Quality

The four seasonal surface water samples were taken from the five perennial pans (Jachacha, Lakangwa, Nhlangaluwe, Mapimbi and Nwambe), as well as from a selected site along both the Limpopo and Luvuvhu Rivers within the Makuleke Wetland System (Figure 6).

The surface samples (500ml) were taken from near the banks as this is where mammals would be obtaining their drinking water from. The water samples were then sent to the laboratory at the Council for Geoscience to have their mineral composition analysed (anion and cation analyses). Samples were analysed for concentrations of lithium (Li), beryllium (Be), boron (B), sodium (Na), magnesium (Mg), aluminium (Al), potassium (K), calcium (Ca), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd), lead (Pb), uranium (U), chlorine (Cl), fluorine (F), nitrites (NO_2^-), nitrates (NO_3^-), phosphates (PO_4^-) and sulphates (SO_4^-). The Major and Trace Method was used to analyse cation concentrations as it is more accurate than a semi-quantitative scan. Additionally, total suspended solids (TSS) analysis was also conducted to obtain an indication of sediment load within each pan and river.

The composition of each sample was then compared to published Department of Water Affairs and Forestry (DWAF) water quality standards recommended for livestock (Table 1). Where available, as they are rarely published, water quality standards for wildlife were also applied. As a matter of policy, the Department of Water Affairs and Forestry (DWAF) has undertaken to strive to maintain the quality of South Africa's water resources within the "No Effect Range". The No Effect Range in the *South African Water Quality Guidelines* is referred to as the Target Water Quality Range (TWQR) and any concentrations greater than these values are considered to have chronic health effects for livestock if consumed habitually (DWAF, 1996).

Water temperature, pH and electrical conductivity (EC) were measured on site as these variables are sensitive to changing environments. pH, EC and temperature were measured using a Eutech Instruments' Multi-Parameter PCSTestr 35 meter. Three readings were taken from each water sample and an average was taken for pH, EC and temperature. The overall mineral composition of the water within the pans and rivers was assessed seasonally, as concentrations of minerals are affected by water temperatures, rainfall and evaporation rates.

Table 1: Water quality guidelines for livestock watering

Element		Unit	Livestock Watering Guideline			Comments
			*DWAF	DWA	Other	
Acidity	pH		NA		<5.5 or >8.5	Source: University of Missouri (Pfoest et al.)
Electrical Conductivity	EC	µS/cm		9000		
Total Dissolved Solids	TDS	mg/l	1000			Dairy, Pigs & Poultry
			2000			Cattle & Horses
Lithium	Li	mg/l	NA			
Beryllium	Be	mg/l	NA			
Boron	B	mg/l	5			
Sodium	Na	mg/l	2000	2000		
Magnesium	Mg	mg/l	500	500		
Aluminium	Al	mg/l	5			
Potassium	K	mg/l	NA			
Calcium	Ca	mg/l	1000	1000		
Vanadium	V	mg/l	1			
Chromium	Cr	mg/l	1			
Manganese	Mn	mg/l	10			
Iron	Fe	mg/l	10			
Cobalt	Co	mg/l	1			
Nickel	Ni	mg/l	1			
Copper	Cu	mg/l	1			Cattle
			5			Horses, Pigs & Poultry
Zinc	Zn	mg/l	20			
Arsenic	As	mg/l	1			
Selenium	Se	mg/l	0.05			
Cadmium	Cd	mg/l	0.01			
Lead	Pb	mg/l	0.1			Other livestock
			0.5			Pigs
Uranium	U	mg/l	NA			
Chloride	Cl	mg/l	1500			Monogastrics & Poultry
			3000	3000		Other livestock
Flouride	F	mg/l	2			Other livestock
			3	6		Ruminants
Nitrite	NO2	mg/l	10			
Nitrate	NO3	mg/l	100			
Phosphate	PO4	mg/l	NA			
Sulphate	SO4	mg/l	1000	1500		

DWAF: Department of Water Affairs and Forestry (1996)

DWA: Department of Water Affairs, Namibia (1991, as cited in Wanke and Wanke, 2007)

*Maximum Target Water Quality Range (TWQR) values are given; values exceeding this may be harmful to animal health.

The chemical water quality data enabled the determination and assessment of the differences in water quality among the five perennial pans and the Limpopo and Luvuvhu rivers, and how this varied seasonally. This gave an indication of the quality of surface water available for animals to drink within a given season within the Makuleke Wetland System.

4.2 Rainfall

Rainfall and temperature data were obtained from the weather station located at the Wilderness Safaris Pafuri camp along the Luvuvhu River. These data were used to determine rainfall

seasonality and water availability during the study period, as a proxy of the amount of rainfall received within the previous month (last 30 days). The information was used to control for the influence weather has on mammal water requirements.

4.3 Water Level

An indication of the water level in each water source was determined using an index. Guides working in the Pafuri area were consulted during field trips to determine the relative water levels in the studied water sources.

Table 2: Water level index used

Index	Water Level
5	Flooded
4	Full
3	Three quarters full
2	Half-full
1	Less than half-full
0	Dry

4.4 Vegetation Data

Vegetation data were obtained with the help of honours research students, Claire Knight and Blaire Zoghby, who conducted their research in the area during the same period.

Land cover data were obtained for the edge of each pan and access points to the rivers by using a Geographical Information System (GIS) and aerial photographs to determine broad vegetation classes. A SPOT 321 image of the Makuleke area was classified, and land cover types identified, based on the unique and distinguishable spectral responses of the different geographic features and vegetation types. Feature classification was completed by Claire Knight (2011) for her honours dissertation, using the supervised classification method. The supervised classification process involves selecting areas of known land cover type, called training sites, and assigning them a unique identifier. For this analysis, a total of fifteen training site types were used. These sites were based on ground truthing points and vegetation analysis conducted in the field (Knight, 2011).

The general vegetation structure at the edges of the pans was determined by averaging structural vegetation data obtained by Blair Zoghby at the pans in 2011. Zoghby (2011) collected structural vegetation data from plots measuring 5m x 4m along 50m transects away from the pan edge. Within each plot, the grass, shrub and tree average cover and height were recorded. A cover and height category system was used to increase efficiency in the field. The category system was based on a range of potential measurements where, for example, an estimated cover of 40% would fall within the range 26-50% and therefore be assigned a cover category 3, whilst an estimated height of 2.5m would fall within the range 2.1-3 m, and therefore be assigned a height category 4 (Table 3). The class scores for both cover and height per plot were then averaged to

determine the average grass, shrub and tree cover and height at the edges of each pan. The overall vegetation structure value was then calculated by adding the average cover class and height class at the edge of the pan (Appendix B).

In addition to Zoghby's (2011) data, the distance to the closest vegetation cover at the water's edge, at each camera trap site, was measured. The percentage of canopy cover around the water source was also estimated and recorded (Appendix B).

Table 3: Vegetation cover and height categories (Zoghby, 2011)

Cover (%)	Cover Category	Height (m)	Height Category
0-10	1	<0.5	1
11-25	2	0.6-1	2
26-50	3	1.1-2	3
51-70	4	2.1-3	4
76-100	5	>3.1	5

Different vegetation types and the extent of cover (e.g. floodplain vs. riparian forest) may govern the usage of pans by certain species. More vulnerable or secretive species, for example, may prefer water sources that provide better vegetation cover for concealment close to the water's edge, whereas large herbivores such as zebra may prefer more open water sources where they are more likely to see predators in advance (Periquet et al., 2010).

4.5 Anthropogenic Impact

The influence of human activity on each site was determined as a function of the sites location. Using GIS, the direct distance of each water source to the closest tourist road and the boundary of the park (border with Zimbabwe) was determined. It was also noted whether the water source could be accessed only on foot or whether road networks accessed the water source.

4.6 Study Design to Monitor Water Usage

Water usage by mammal species was monitored by installing Bushnell Trophy Cam camera traps. The five pans known to be perennial and hold water throughout the dry season and the two rivers (Limpopo and Luvuvhu) within the wetland system were selected to be monitored. The Camera traps were installed at previously identified positions around each pan and river site using animal signs as indicators, such as along visible game paths accessing the pans and rivers (Figure 25) (Trolle and Kéry, 2005; Sanderson, 2008; Crosmar, 2012). This was done to ensure the maximum capture of approaching game. For details on the camera trap positions please refer to the aerial maps (Figures 10, 13, 15, 17, 20, 22 and 24) in Section 3.1. The GPS coordinates of the position of each camera trap was captured to ensure that during the following season, the same sites were used. Camera traps are increasingly being used in studies to make more accurate estimates of species diversity and richness, total mammalian biomass, and spatial and seasonal

variations of species, activity patterns, and seasonal changes in populations (Chavez-Leon, 2005; Trolle and Kéry, 2005; Stein et al., 2008; Sanderson, 2008). It was decided not to utilise spoor data to complement the camera trap data for a number of reasons. Firstly, it was found that the spoor data after a 48 hour period were often obscured either by a large herd of animals such as buffalo or impala, thus disturbing and covering all previous spoor on a given path. The lengths of ground that could be raked to allow for spoor collection also varied greatly among the water sources, so set lengths could not be smoothed relative to the perimeter of a given pan. 24 Hour waterhole counts were not conducted either because of time restraints and reserve restrictions which required an armed warden or guide to be present during counts.

For each mammal sighting recorded, the species, time and date (season) were recorded (Figure 26 and Figure 27). Camera trap data consisted of a positive sighting of a particular species, and any questionable sightings were discarded. Numbers and group dynamics were not taken into account as this was often difficult to determine from still images; often only partial photographs were taken, or only a portion of a herd was visible. The camera traps were set up to take three photos in quick succession, once triggered by an animal's movement, and then to have a 10 second delay so as not to waste memory if the wind or a large herd of animals were to repeatedly trigger the camera trap. Comments were recorded regarding group dynamics when visible.

The Bushnell Trophy Cam camera traps installed use motion sensors to trigger the camera, with a trigger time of 1.024 seconds. Advanced Passive Infrared Technology senses motion up to 15m away. When a subject walks into range, a photo or video clip is instantly captured. Night vision LEDS, rather than a flash, were utilised so as not to disturb animals coming to drink, therefore allowing for 24hour surveillance. Each camera housed a 2 gigabyte memory card that was removed and inserted into a laptop to download pictures. The key advantage of a camera trap system is that it also allows for the unobtrusive monitoring of secretive and often unobservable species in their natural habitat (Locke et al., 2005). Camera trapping has provided robust records on mammal and bird diversity differences in adjacent habitats and can ultimately be incorporated into long-term monitoring programmes (Stein et al., 2008).



Figure 25: Bushnell Trophy Cam camera traps were installed at previously identified positions around each pan and river site using animal signs as indicators

Time constraints of field trips meant that two water sources needed to be monitored at any given time. The seven available camera traps were therefore distributed such that three camera traps were placed at access points to the two rivers and at the smaller two pans (Mapimbi and Jachacha) (see Section 3.1 for further detail). Four camera traps were used to cover each of the three larger pans (Nwambe, Nhlanguwe and Lakangwa) (Figure 28). The positioning and installation of the camera traps had its limitations, such as a lack of suitable trees on which to set up, resulting in a limited area being captured. It is also challenging to set camera traps to capture such a great range in animal sizes, from smaller mongoose species to large herbivores such as elephant. The lower one sets the trap, the more likely it is to be triggered by smaller animals, but it then only obtains partial images of larger animals, often making species identification problematic. The camera traps were set up, as described above, to monitor each water source for a continuous period of 48 hours during each of the four monitoring seasons.

The camera trap information was used to establish differences in pan and river usage by various species, and the quality of water these species are prepared to drink. This information was also captured and analysed seasonally as animals' drinking habits may have changed according to temperature, water quality and availability.



Figure 26: Examples of day time images captured by the Bushnell Trophy Cam camera traps



Figure 27: Examples of night images captured by the Bushnell Trophy Cam camera traps

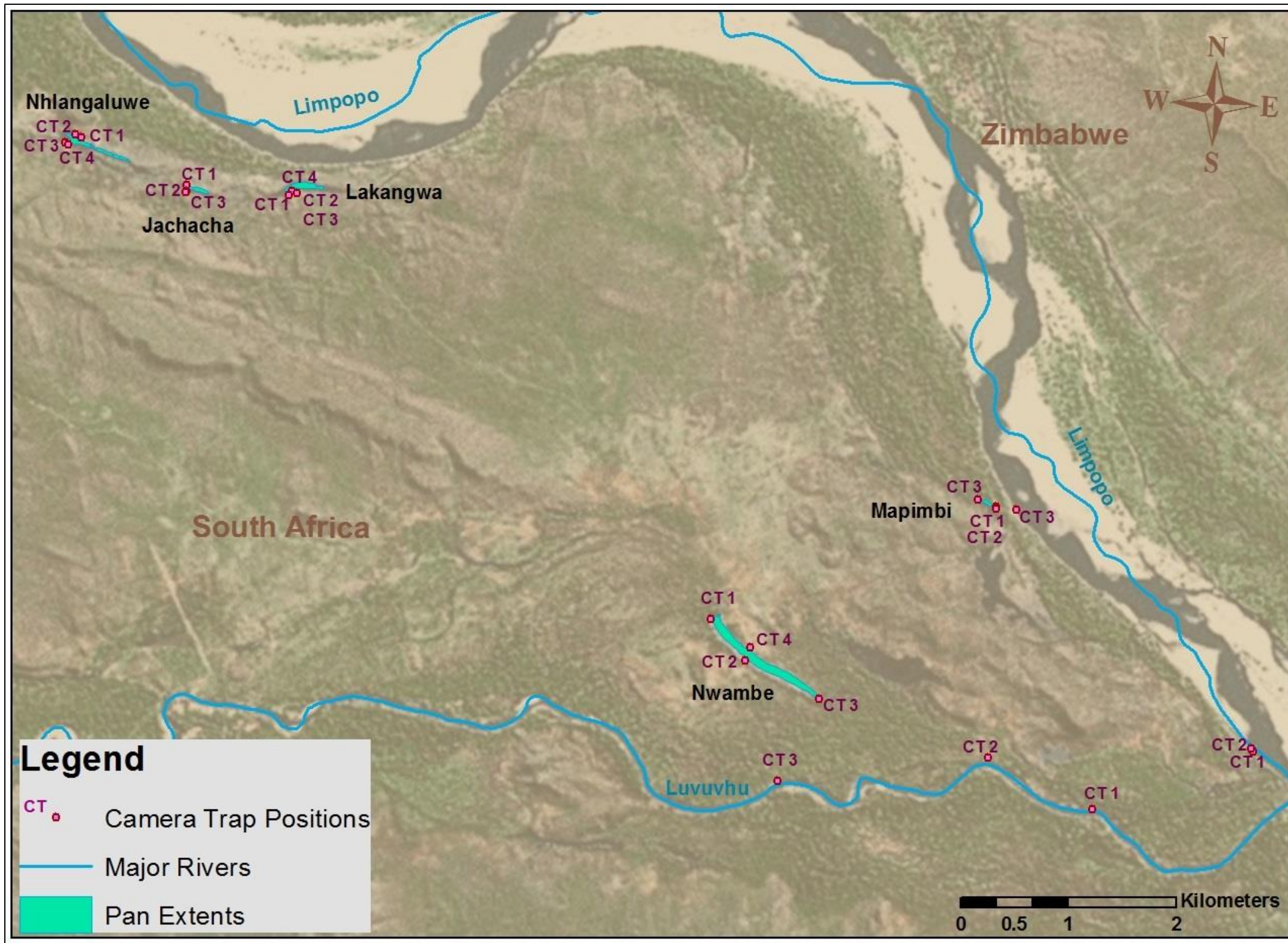


Figure 28: Overview of the camera trap setup positions throughout the study

4.7 Data Analysis

The hypothesis is testing whether certain species' (dependant variable) selection of drinking sites is influenced by the various environmental variables being tested (water quality, vegetation cover and human disturbance) (independent variables).

The mammal species documented from images captured by the camera traps during the study were categorised firstly into feeding classes (herbivores, primates and carnivores) and then into size classes (small, medium and large mammals), as different feeding classes and sized mammals have different water requirements (Redfern et al., 2003) (Table 4). As similar studies were found to focus on either a particular species or a handful of focus species, none included the same or similar species diversity, the mammal groupings were therefore determined according to each mammal's diet and size (mass and height), as described in Skinner and Chimimba (2005), "The Mammals of the Southern African Subregion". Usage trends could then be determined for each of the classes. The raw data recorded from the camera trap images were then used to determine the spatial (using ArcView 10 GIS) and temporal drinking preferences of the observed mammal species (Section 5.3 and 5.4).

Table 4: Mammal classes used to categorise mammal sighting records

Feeding Group	Size Class	Common Name	Scientific Name
Carnivore	Small (up to ~13kg)	African Civet	<i>Civettictis civetta</i>
		Small Spotted Genet\	<i>Genetta genetta\ Genetta</i>
		Large Spotted Genet	<i>tigrina</i>
		White-tailed Mongoose	<i>Ichneumia albicauda</i>
		Slender Mongoose	<i>Galerella sanguinea</i>
	Large (up to ~190kg)	Banded Mongoose	<i>Mungos mungo</i>
		Spotted Hyena	<i>Crocota crocuta</i>
		Leopard	<i>Panthera pardus</i>
		Lion	<i>Panthera leo</i>
Herbivore	Small (up to ~79kg)	Common Duiker	<i>Sylvicapra grimmia</i>
		Scrub Hare	<i>Lepus saxatilis</i>
		Warthog	<i>Phacochoerus africanus</i>
		Bushbuck	<i>Tragelaphus scriptus</i>
		Bushpig	<i>Potamochoerus larvatus</i>
		Porcupine	<i>Hystrix africaeaustralis</i>
	Medium (up to ~227kg)	Impala	<i>Aepyceros melampus</i>
		Plains Zebra	<i>Equus quagga</i>
		Kudu	<i>Tragelaphus strepsiceros</i>
		Nyala	<i>Tragelaphus angasii</i>
		Blue Wildebeest	<i>Connochaetes taurinus</i>
		Waterbuck	<i>Kobus ellipsiprymnus</i>
	Large (up to ~6000kg)	African Elephant	<i>Loxodonta Africana</i>
		African Buffalo	<i>Syncerus caffer</i>
		Eland	<i>Tragelaphus oryx</i>
		Hippopotamus	<i>Hippopotamus amphibius</i>
Primates (Omnivores)	All	Chacma Baboon	<i>Papio ursinus</i>
		Vervet Monkey	<i>Cercopithecus pygerythrus</i>
		Thicktailed Bushbaby	<i>Otolemur crassicaudatus</i>

4.7.1 Canonical Correspondence Analysis

A Canonical Correspondence Analysis (CCA) or ordination was conducted using Environmental Community Analysis 1.37 software (Pisces Conservation Ltd. 2000). A CCA was conducted to determine whether any of the species compositions recorded could be explained by the environmental variables being measured. For the purpose of this analysis, each camera trap in each season was considered a site. For example, a "site" could be camera trap 1 set up at Nwambe pan during the dry season (refer to Section 3.1.1.2, Figure 13) (Appendix C and D). Ordination methods geometrically arrange sites so that distances between them in the diagram represent their ecological distances (Kindt and Coe, 2005). The result of an ordination is typically viewed as a two dimensional graph. Sites are plotted to show the chi-square distance among sites on the graph. Sites that plot close together are interpreted as being similar in species composition; the further apart the sites in the graph, the more different their species compositions (Kindt and Coe, 2005). In CCA the ordination is constrained by the environmental variables shown in the environmental matrix. The CCA axes are constrained to be linear combinations of the environmental variables being tested for. The relationships with these environmental variables to all sites and species are illustrated by vectors within the plot that are assigned to each environmental variable, around which sites and species are plotted. The significance test is based on permutation, if $P < 0.001$ it indicates that the observed relationship between environmental variables and ecological distance is not due to chance (Kindt and Coe, 2005).

Only species that accounted for at least 2% of the overall 981 sightings recorded were used in the CCA, as it was felt that species sightings which accounted for less than this did not have enough data to influence meaningful trends. The omitted species' sightings were incorporated into the mammal groupings data which were also analysed. Various environmental variables were also removed from the analysis, initially due to multicollinearity. Vegetation variables, for example, are intercorrelated and therefore only the combined grass, shrub and tree structures were utilised in the analysis. Other multicollinearity was found between: seasons and water temperature; human access and distance from roads; and water quality measurements. After running the first CCA, variables showing the greatest influence were chosen to represent all of the closely related groups of variables. The overall variables removed were: seasons, camera trap distance from the water's edge, human access, grass cover, grass height, tree cover, tree height, shrub cover, shrub height, water temperature, electrical conductivity of the water, pH of the water and rain recorded within the previous month. The CCA was then run again using the following remaining environmental variables:

1. Distance to Cover (m)
2. Canopy cover (%)
3. Distance to the Zimbabwe border (m)
4. Distance to closest road (m)
5. Combined grass structure at water's edge
6. Combined shrub structure at water's edge
7. Combined tree structure at water's edge
8. Water level

9. Maximum daily air temperature (°C)
10. Total Suspended Solids (TSS) (mg/l)

4.7.2 K-Means Cluster Analysis

A K-Means cluster analysis was also run using the same cleaned environmental variables and mammal sightings data, using Clustan Graphics software (Thuiller et al., 2006). This was because it was felt that species sightings which accounted for less than 2% did not have enough data to influence meaningful trends, and would therefore only “dilute” the cluster analysis. Two cluster analyses were run, one using the individual mammal species observed and the second using the species groupings as classified in Table 4. This was done to determine whether certain species appeared to be selecting for certain environmental variables, as well as whether certain mammal groupings showed trends in their selection for, or avoidance of, certain environmental characteristics of perennial drinking sites.

The number of clusters used was subjective; however, there was a clear aim of producing ecologically interpretable patterns (Thuiller et al., 2006). According to Mardia et al. (1979), the best way to determine an indication of the number of clusters to be run, is to take the square root of half the number of samples (sites). In this case there were 96 sites or samples, half of which is 48, the square root of which is 6.92. Clustering was therefore run with many different numbers of clusters slightly greater and smaller than 6.92, ranging from five to 10 clusters. It was determined that five clusters of camera trap locations was the most meaningful to interpret for the mammal species data, and that seven clusters was the most meaningful to interpret for the mammal groupings data. The clusters were then plotted spatially in a GIS using ArcView 10, to determine how the clusters were positioned across the study area, and thus to establish any further spatial trends.

4.7.3 Pearson’s Correlation

Pearson’s correlations were also run to determine the direct relationship between the various aspects being tested at each of the five water sources. The relationship between the various water quality elements and the total animal sightings recorded was analysed using Pearson’s Correlation.

5. RESULTS

The results obtained during the four seasonal site visits are analysed and summarised in this section. Water quality data obtained from the seven water sources for each of the four seasons are analysed and compared to the DWAF quality guidelines for livestock drinking water to determine whether the water quality in the area is suitable for mammal consumption throughout the year. The mammal sightings data obtained using the camera traps are then analysed. The overall species richness and diversity is analysed at each of the rivers and pans. The temporal and spatial use of the pans and rivers is then summarised. Statistical analyses are then performed on all the combined data in the form of a Canonical Correspondence Analysis and a Cluster Analysis in order to try and tease out the pan characteristics which may influence mammal species' selection for a water source.

5.1 Water Quality

The overall water quality data are recorded seasonally for each pan in Appendix A. The seasonal water pH, EC, TSS and temperature signatures for each pan and river are analysed. The total amount of rainfall received in the previous 30 days (previous month) from the date of sampling is also plotted on each graph to show the dilution effect from rainwater in each case. A total of 28 water samples were taken (one from each of the seven water sources for each of the four seasons).

5.1.1 pH Values

According to the South African Agricultural Research Council (ARC), the Makuleke area supports soils with a natural pH ranging from 6.5-7.4 (Figure 30). Overall, the pH values in the pans and rivers range from 7.03 (Nwambe at the end of the wet season) to 8.87 (Nhlangaluwe in the dry season). The pH values recorded fluctuate seasonally between these values. According to the University of Missouri's Guidelines (Pfoest et al., 2001), the pH of drinking water for livestock should be between 5.5-8.5. Lakangwa, Jachacha, Mapimbi and Nhlangaluwe pans occasionally exceed the 8.5 limit, particularly during the dry season. The only pan, however, with a prolonged high pH value is Lakangwa, which exceeds 8.5 in all seasons except the wet season (Figure 29). The Limpopo River has a spike in pH at the end of the wet season (8.713), which also exceeds the recommended limit (Figure 29). The pans and rivers tend to become more alkaline as the amount of rainfall decreases (Figure 29). A Pearson's Correlation between pH and the amount of rainfall recorded in the previous month confirms this negative relationship and shows that it is a significant relationship with 99% confidence ($r_{\text{calc}}=0.5792$; $P=0.01$; $r>0.2617$). It can thus be expected that the pans and rivers generally become more alkaline as the dry season progresses (Figure 29).

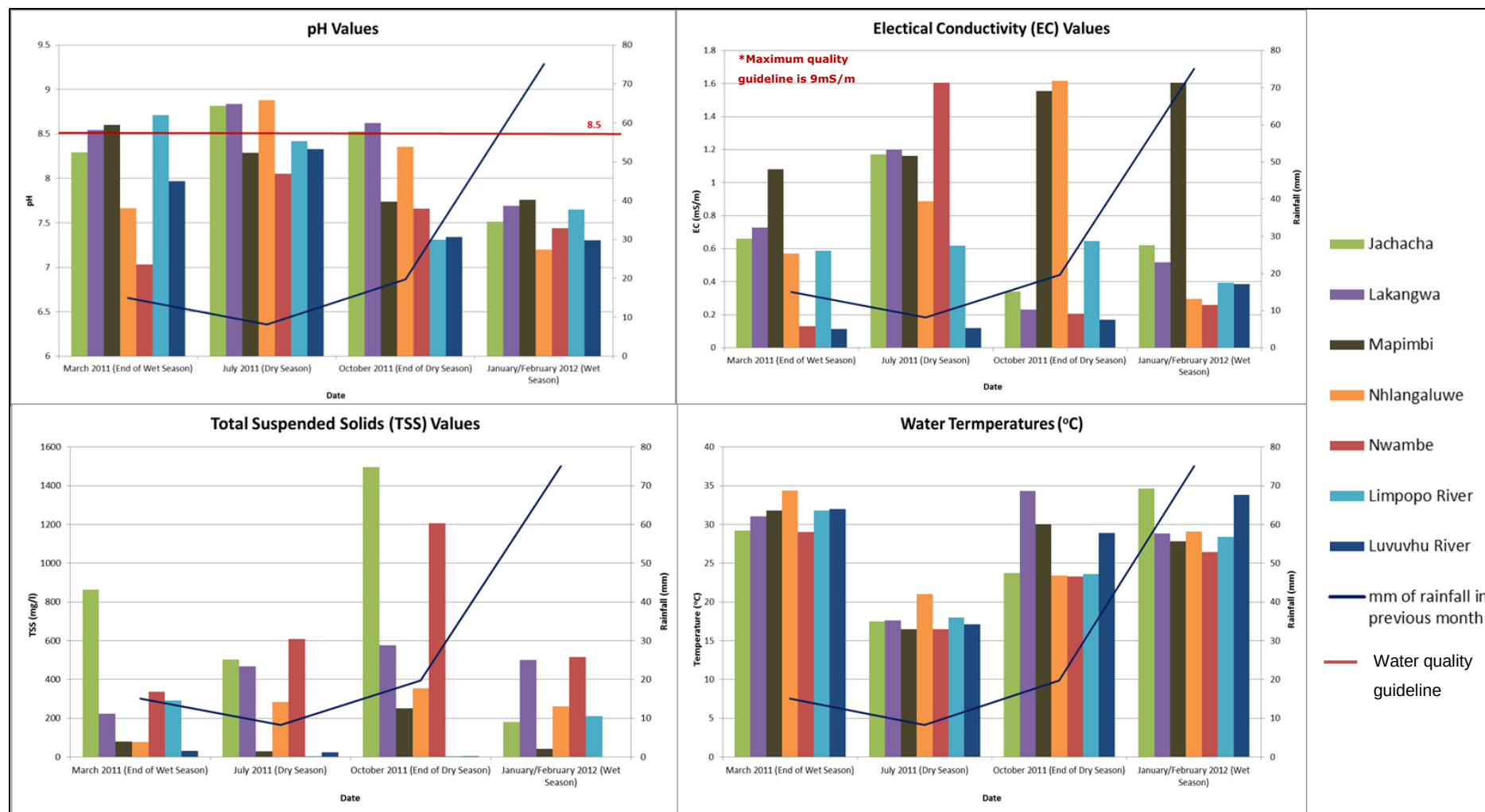


Figure 29: Seasonal pH, electrical conductivity, total suspended solids and temperature values recorded within the Makuleke Wetland System

*pH Guideline maximum limit for livestock of 8.5 from The University of Missouri (Pfoet et al., 2001).

**EC Guideline maximum limit for livestock from DWAF Guidelines, 1996

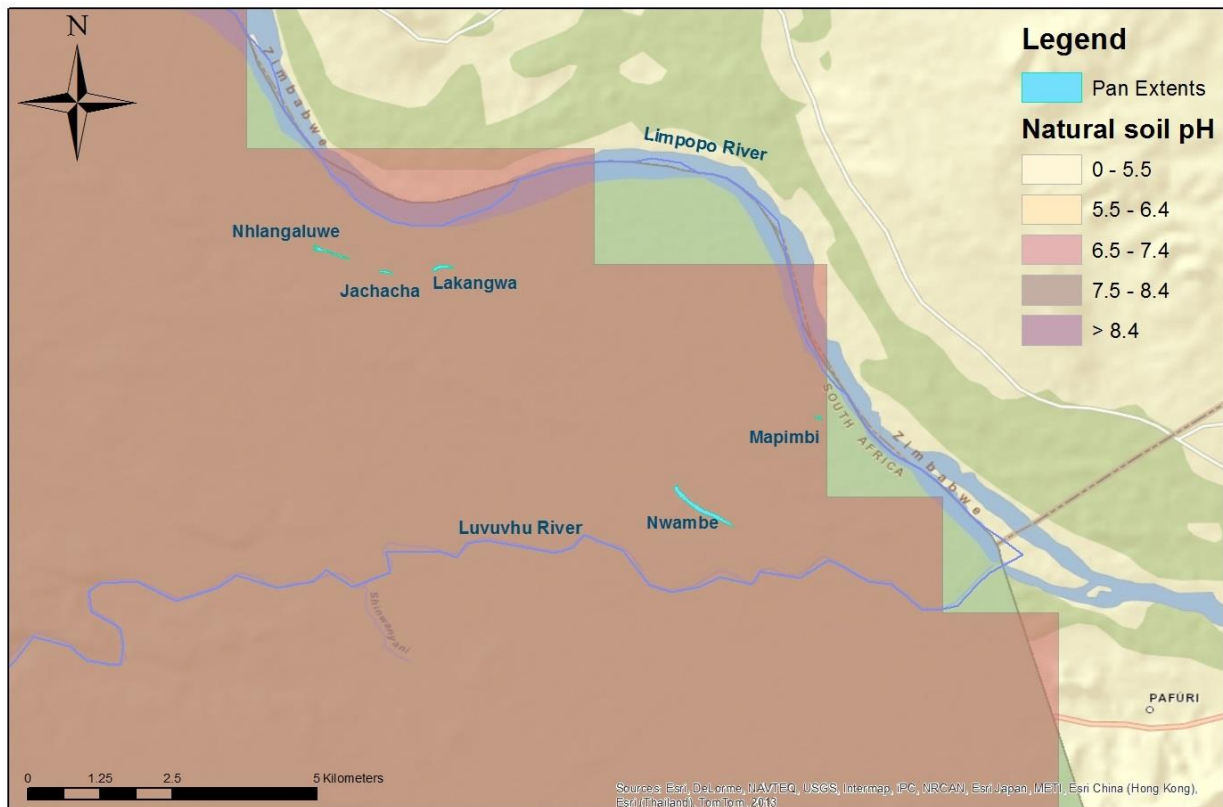


Figure 30: The natural soil pH within the Makuleke Concession area (ARC: AGIS 2012).

5.1.2 EC Values

Electrical conductivity (EC) is related to the amount of total dissolved solids in solution and gives an indication of the salinity of the water body. All the EC values measured during this study fall well below the DWAF guideline of 9mS/m for livestock drinking water (Figure 29). The EC values range between 0.114mS/m (Luvuvhu at the end of the wet season) and 1.617mS/m (Nhlangaluwe at the end of the dry season). Overall EC values are highest at the end of the dry season when the previous month's rainfall is the lowest (8.2mm) (Figure 29). A Pearson's Correlation between EC and the amount of rainfall recorded in the previous month confirms this negative relationship and indicates that it is a significant relationship with 95% confidence ($r_{\text{calc}}=0.2273$; $P=0.05$; $r>0.201$). Despite the correlation results, Mapimbi Pan depicts an unusual EC signature which, unlike any of the other water sources, remains above 1mS/m across all four seasons, with the highest EC recorded (1.6mS/m) during the wet season (Figure 29). This could be owing to Mapimbi being less dependent on rainwater than the other pans and more reliant on seepage water from the Limpopo River, which is then subject to evaporation, particularly during the hot wet season. With the exception of the wet season, the Luvuvhu River depicts the lowest EC values across the year (average of 0.19mS/m). Nwambe Pan depicts the lowest EC of all five pans (average of 0.55mS/m) with the exception of the dry season when it peaks at 1.6mS/m.

5.1.3 TSS Values

Total suspended solids (TSS) provide an indication of the sediment concentration in the water (muddiness). The overall TSS values range between 0mg/l (Limpopo during the wet season) and 1497mg/l (Jachacha at the end of the dry season). Overall, the rivers show much lower TSS values than the pans (Figure 29). Jachacha's TSS value fluctuates the greatest between the seasons from 1497mg/l during the dry season to 180.67mg/l during the wet season. This is most likely due to increased disturbance of the sediment by animals along the edge and within the pan as access levels increases during the dry season (Laporte and Behrensmeyer, 1980; Hubbard et al., 2004). TSS values generally increased during the dry season when there is more drinking activity at the water sources and less water to dilute the sediment, however, there is no significant relationship between TSS and the amount of rainfall received ($r_{\text{calc}}=0.095$; $P=0.05$; $r<0.201$). This could be due to increased animal activity along the edges of the pans during the dry season, which may increase TSS values as they churn up sediment when they access the pans to drink. Heavy rainfalls causing erosion may also wash sediment into the water bodies, thus increasing TSS values during the wet season (Figure 31). According to the ARC's database, Nhlangaluwe, Jachacha, Lakangwa and Mapimbi pans within the Limpopo floodplain, are surrounded by "land with moderate to high water or wind erosion hazard, containing soils with a low to moderate erodibility". In contrast, Nwambe pan, within the Luvuvhu floodplain, occurs in an area of "low to moderate water and wind erosion potential" but with soils that may have "low to very high erodibility" (Figure 31) (ARC:AGIS, 2012: www.agis.agric.za, accessed 20 June 2012).

5.1.4 Temperature Values

As the Makuleke Wetland System falls within a summer rainfall area it would be expected that the water temperatures would be highest during the wet season (maximum 34.4°C) and lower during the dry season (minimum 16.5°C), as indicated in Figure 29. During the dry season (winter) cooler air temperatures (average minimum temperature of 4.8°C and maximum of 27.1°C) and reduced insolation values result in cooler water temperatures (Figure 29). A significant correlation ($P=0.01$) between rainfall received and water temperatures is thus recorded ($r_{\text{calc}}=0.285$; $r>0.2617$).

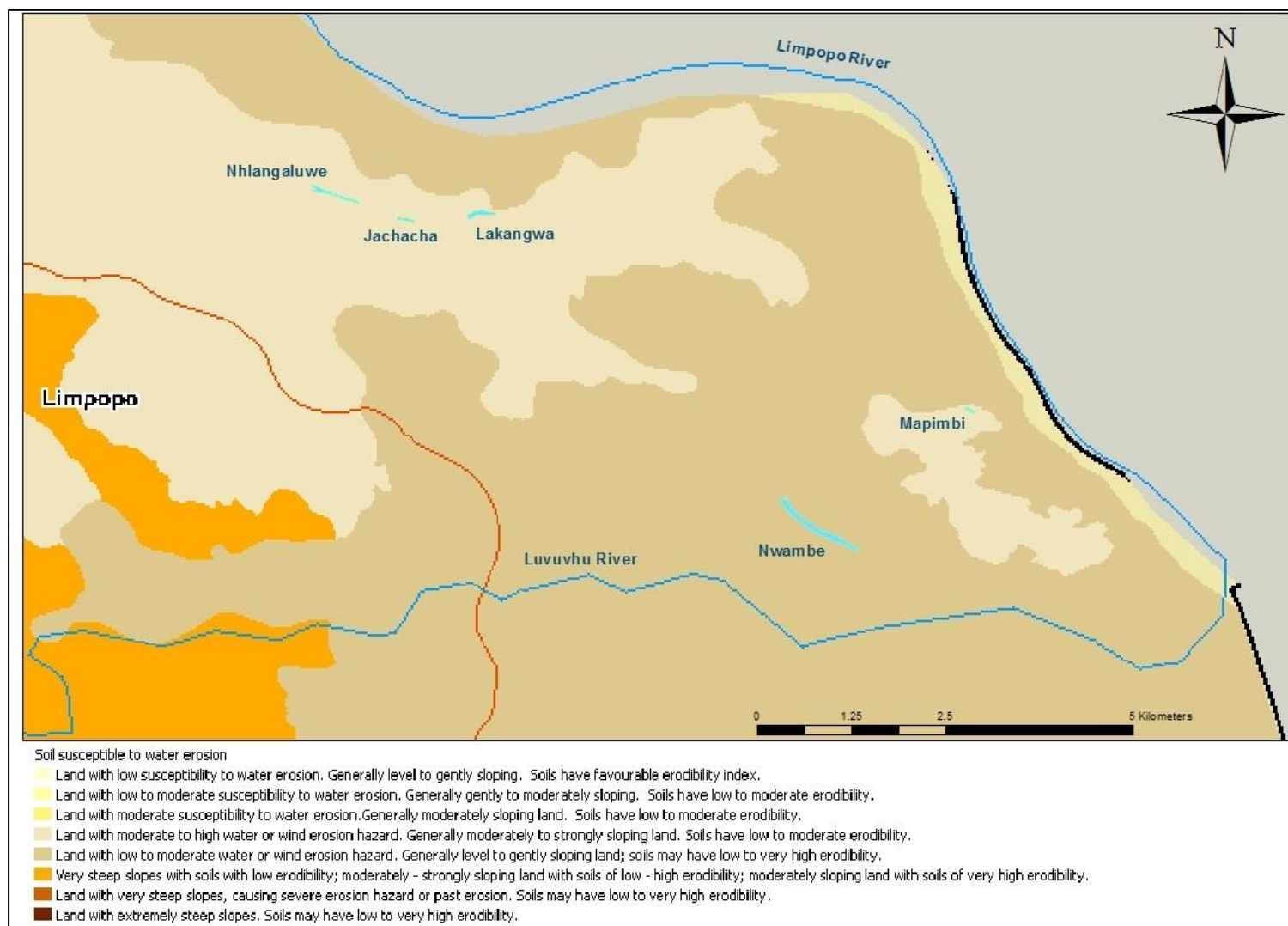


Figure 31: Soil susceptibility to erosion within the Makuleke Wetland System (ARC: AGIS, 2012 : www.agis.agric.za, accessed 20 June 2012).

5.1.5 Anion Concentrations

The concentrations of anions (negative ions) in the seasonal water samples were all below the recommended guidelines for livestock drinking, with the exception of one sample. The sample taken from Nhlanguwe Pan during the wet season (February 2012) shows a peak in nitrite concentration of 53mg/l. All other samples from the other water sources that season are below 0.34mg/l and the recommended limit for livestock is 10mg/l. Nitrates and nitrites occur together in the environment and interconversion readily occurs. Under oxidising conditions, nitrite is converted to nitrate, which is the most stable positive oxidation state of nitrogen and far more common in the aquatic environment than nitrite (DWAF,1996). The source of this unusual increase in nitrite concentration is unknown. A significant source of nitrates and nitrites in natural water results from the oxidation of vegetable and animal matter and of animal excrement (DWAF, 1996; Hubbard et al., 2004). The elevated nitrites could therefore have originated from animal faeces, such as from a herd of elephant or buffalo, either as they accessed the pan, or alternatively may have been washed into the pan during a high rainfall event (previous month's total rainfall of 75.1mm). Increased crocodile or hippopotamus activity within the pan may also have yielded higher nitrite values. This increase in nitrite concentration occurred during the wet season so it could also be a consequence of the decomposition of flooded vegetation along the pan margins due to increased water levels. During the wet season, particularly the eastern and western grass covered banks of Nhlanguwe pan became inundated with water (Figure 32). Mineral deposits of nitrates/nitrites are very rare and are therefore an unlikely source (DWAF, 1996).



Figure 32: Nhlanguwe Pan's grass covered banks were inundated during the wet season of 2011/2012

5.1.6 Cation Concentrations

Iron (Fe), aluminium (Al) and cadmium (Cd) were the only cation concentrations to exceed the recommended guidelines for livestock drinking during the study period (Appendix A). The water sources did not maintain detrimentally high levels of these cations across all four seasons or sampling periods. However, Nwambe pan recorded iron concentrations above the DWAF (1996) recommended limit of 10 000ppb for livestock during three of the four sampling seasons. The only

sample below the recommended limit was taken at the end of the wet season when the water was probably sufficiently diluted to reduce the iron concentration. Nwambe pan is situated within very red soils which indicates the presence of iron (DWAF, 1996), and is thus the likely source of the pan's high iron concentrations (Figure 33).



Figure 33: Nwambe Pan indicating the iron containing red soils

Similarly, Lakangwa Pan recorded high concentrations of aluminium, exceeding the DWAF recommended limit of 5000ppb, in three of the four sampling seasons. The end of the rainy season was again the only season that did not exceed this limit. These high values are probably also due to the soil in the area as aluminium is considered to be the most common metal in the earth's crust (DWAF, 1996). Aluminium does not appear to be an essential nutrient for animals and is for all practical purposes nontoxic, as aluminium salts are not normally absorbed from food and water and are readily excreted. The cadmium concentrations in Jachacha and Lakangwa pans peak to 15.6ppb and 15.06ppb respectively during the dry season, exceeding the DWAF (1996) recommended limit of 10ppb. This spike is probably due to the evaporation of water within the pans during the dry season and the high alkalinity of the water within these pans at that time (pH values exceeding 8.8), as cadmium has a low solubility under alkaline conditions. Cadmium is highly toxic as it bio-accumulates in organisms, yet toxicity is not often observed due to the low absorption of cadmium (DWAF, 1996).

5.1.7 Water Quality and Mammal Water Utilisation

A Pearson's Correlation was performed to determine whether there were any significant relationships between the water quality parameters tested for and the animal usage of water sources, based on data obtained from the camera traps. This was conducted to determine whether mammals are selecting for or against water sources with particular water quality characteristics. The results of the correlation are presented in Table 5. Primate sightings are negatively correlated

with the concentration of calcium in the water sources. Primate sightings are significantly lower as the calcium concentration in the water increases, with 95% confidence ($P=0.05$) (Table 5). Calcium can influence the aesthetic taste of water, which may be why primates select against using these water sources (Tordoff, 1996). Herbivore sightings are positively correlated with boron concentration in the drinking water, with a 95% confidence level ($P=0.05$). Sulphate concentration in the drinking water had a significant ($P=0.05$) negative correlation with the total number of animal sightings recorded, and the overall herbivore sightings at each pan or river (Table 5). However, none of the water quality ions tested for show any significant correlations to mammal sightings with a 99% confidence level.

The water quality within the Makuleke Wetland System does not seem to be notably compromised by human activities such as mining and agriculture, upstream along the Limpopo and Luvuvhu rivers, so as to negatively affect mammal species drinking from the system. The only noticeable impact was that the Limpopo River was reduced to a couple of stagnant pools during the dry months which may be exacerbated by extraction practices upstream (Deacon, 2007). Anion and cation concentrations were therefore excluded from the Canonical Correspondence Analysis (CCA) and Cluster Analysis.

Table 5: Pearson's correlation table showing relationships between mammal sightings and water quality data within the Makuleke Wetland System

	pH	EC	Temp	Li (7)	Be (9)	B (10)	Na (23)	Mg (24)	Al (27)	K (39)	Ca (43)	V (51)	Cr (52)	Fe (54)	Mn (55)	Co (59)	Ni (60)	Cu (63)
Primate sightings per trap	-0.37114	-0.22883	0.316788	0.0802	-0.25863	-0.18336	-0.23945	-0.24585	-0.15672	-0.27406	-0.40251	-0.13552	-0.2024	-0.10225	-0.13204	-0.09891	-0.27019	-0.1383
Average Number of species per Camera Trap	-0.21821	0.142767	-0.3554	-0.19165	0.199812	0.064176	-0.02489	0.081959	0.027121	-0.06328	-0.01022	0.012535	0.046151	0.127873	0.13443	0.09685	0.089298	0.143124
Carnivore sightings per trap	0.013493	-0.00494	-0.18552	-0.0159	0.16059	-0.01114	-0.08242	0.010233	0.093301	0.086119	-0.12521	0.016188	0.096656	0.161294	0.033087	0.187832	0.059913	0.16309
Large Herbivores	-0.05307	-0.35348	-0.26729	-0.36598	0.205702	0.039692	-0.13862	-0.28139	0.018587	-0.30312	-0.24177	0.021085	-0.00378	0.147808	-0.19983	0.07102	0.045477	0.209825
Total Sightings per trap	-0.21727	-0.08757	-0.07094	-0.12373	0.132175	-0.00815	-0.10486	-0.1449	0.192028	0.034538	-0.08801	0.048208	0.150788	0.280046	0.118023	0.203968	0.018286	0.235315
Herbivore sightings per trap	-0.15139	-0.04581	-0.15336	-0.16945	0.211795	0.037495	-0.05549	-0.11288	0.257132	0.100658	0.008658	0.090295	0.221286	0.340149	0.169134	0.249661	0.089032	0.298051

	Zn (66)	As (75)	Se (82)	Cd (111)	Te (128)	Ba (137)	Tl (205)	Pb (208)	Bi (209)	U (238)	F-	Cl-	NO2-	Br-	NO3-	PO43-	SO42-	TSS
Primate sightings per trap	-0.30388	-0.36519	-0.11606	-0.35192	-0.25941	-0.0946	-0.27785	-0.30948	-0.26305	-0.10101	0.106973	-0.27587	-0.10985	0.05949	-0.03318	-0.11005	-0.33377	-0.18361
Average Number of species per Camera Trap	0.149804	0.087971	0.23659	-0.09342	0.25455	0.253039	0.245461	0.277283	0.25394	0.125992	0.094929	0.057207	0.012184	0.268498	0.247798	0.104216	-0.1095	-0.07898
Carnivore sightings per trap	0.116408	0.036865	0.078429	-0.18331	0.150376	0.256308	0.162486	0.209055	0.17096	0.012177	0.003112	-0.08676	-0.00912	0.107342	0.107089	0.008093	0.031158	0.100663
Large Herbivores	0.090405	0.029357	0.069129	0.100363	0.155097	0.209144	0.145527	0.201215	0.152935	-0.01058	-0.03267	-0.23765	-0.13459	0.033687	-0.12616	-0.10296	-0.27404	0.104006
Total Sightings per trap	-0.02473	-0.0881	0.186135	0.027448	0.019704	0.339308	-0.02469	0.029267	-0.01252	-0.02149	0.059085	-0.17297	-0.13654	0.150045	0.027198	0.092544	-0.39961	0.190448
Herbivore sightings per trap	0.045295	-0.0076	0.235446	0.134704	0.083325	0.398785	0.035289	0.10393	0.04586	0.001187	0.041886	-0.12914	-0.12791	0.151083	0.03471	0.135169	-0.37702	0.262063

*Green cells indicate r values that exceed the r value of 0.374 when P=0.05; df=26

5.2 Overall Species Richness and Diversity

A total of 27 mammal species were recorded at the selected pans and rivers in the Makuleke Wetland System during the study. These species are all listed along with their grouping and their conservation status according to the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species in Table 6 (IUCN Red List, 2013). Herbivorous species make up the majority of the sightings recorded, with nyala being the most abundant species making up 25.69% of the total 981 mammal sightings recorded (Figure 34). Carnivores make up the smallest percentages recorded with banded mongoose (*Mungos mungo*), slender mongoose (*Galerella sanguinea*), thick-tailed bushbaby (*Otolemur crassicaudatus*) and blue wildebeest (rare in this region of the KNP) making up the smallest percentage with 0.1% of the total sightings each (Figure 34). Vervet monkeys (*Cercopithecus pygerythrus*) and chacma baboon (*Papio ursinus*), common primate species in the area, make up 8.97% and 12.64% of the total mammal sightings respectively (Figure 34).

Table 6: Mammal species recorded during the study in Makuleke Concession area, listed taxonomically according to Skinner and Chimimba (2007) and their Red Data List status (IUCN: www.iucnredlist.org, accessed January 2013)

Scientific Name	Species' Common Name	Grouping	IUCN Red Data List Category	Population Trend (IUCN)
<i>Loxodonta Africana</i>	African Elephant	Herbivore	Vulnerable	Increasing
<i>Lepus saxatilis</i>	Scrub Hare	Herbivore	Least concern	Decreasing
<i>Hystrix africaeaustralis</i>	Porcupine	Herbivore	Least concern	Stable
<i>Otolemur crassicaudatus</i>	Thick-tailed Bushbaby (Galago)	Primate	Least concern	Stable
<i>Papio ursinus</i>	Chacma Baboon (Baboon)	Primate	Least concern	Stable
<i>Cercopithecus pygerythrus</i>	Vervet Monkey	Primate	Least concern	Stable
<i>Crocuta crocuta</i>	Spotted Hyaena	Carnivore	Least concern	Decreasing
<i>Panthera pardus</i>	Leopard	Carnivore	Near threatened	Decreasing
<i>Panthera leo</i>	Lion	Carnivore	Vulnerable	Decreasing
<i>Civettictis civetta</i>	African Civet	Carnivore	Least concern	Unknown
<i>Genetta genetta</i>	Small-spotted/ Common Genet	Carnivore	Least concern	Stable
<i>Genetta tigrina</i>	Large-spotted Genet	Carnivore	Least concern	Unknown
<i>Galerella sanguinea</i>	Slender Mongoose	Carnivore	Least concern	Stable
<i>Ichneumia albicauda</i>	White-tailed Mongoose	Carnivore	Least concern	Stable
<i>Mungos mungo</i>	Banded Mongoose	Carnivore	Least concern	Stable
<i>Equus quagga</i>	Plains Zebra	Herbivore	Least concern	Stable
<i>Potamochoerus larvatus</i>	Bushpig	Herbivore	Least concern	Stable
<i>Phacochoerus africanus</i>	Warthog	Herbivore	Least concern	Stable
<i>Hippopotamus amphibius</i>	Hippopotamus	Herbivore	Vulnerable	Decreasing
<i>Syncerus caffer</i>	African Buffalo	Herbivore	Least concern	Decreasing
<i>Tragelaphus strepsiceros</i>	Kudu	Herbivore	Least concern	Stable
<i>Tragelaphus angasii</i>	Nyala	Herbivore	Least concern	Stable
<i>Tragelaphus scriptus</i>	Bushbuck	Herbivore	Least concern	Stable
<i>Tragelaphus oryx</i>	Eland	Herbivore	Least concern	Stable
<i>Connochaetes taurinus</i>	Blue Wildebeest	Herbivore	Least concern	Stable
<i>Sylvicapra grimmia</i>	Common Duiker	Herbivore	Least concern	Stable
<i>Kobus ellipsiprymnus</i>	Waterbuck	Herbivore	Least concern	Decreasing
<i>Aepyceros melampus</i>	Impala	Herbivore	Least concern	Stable

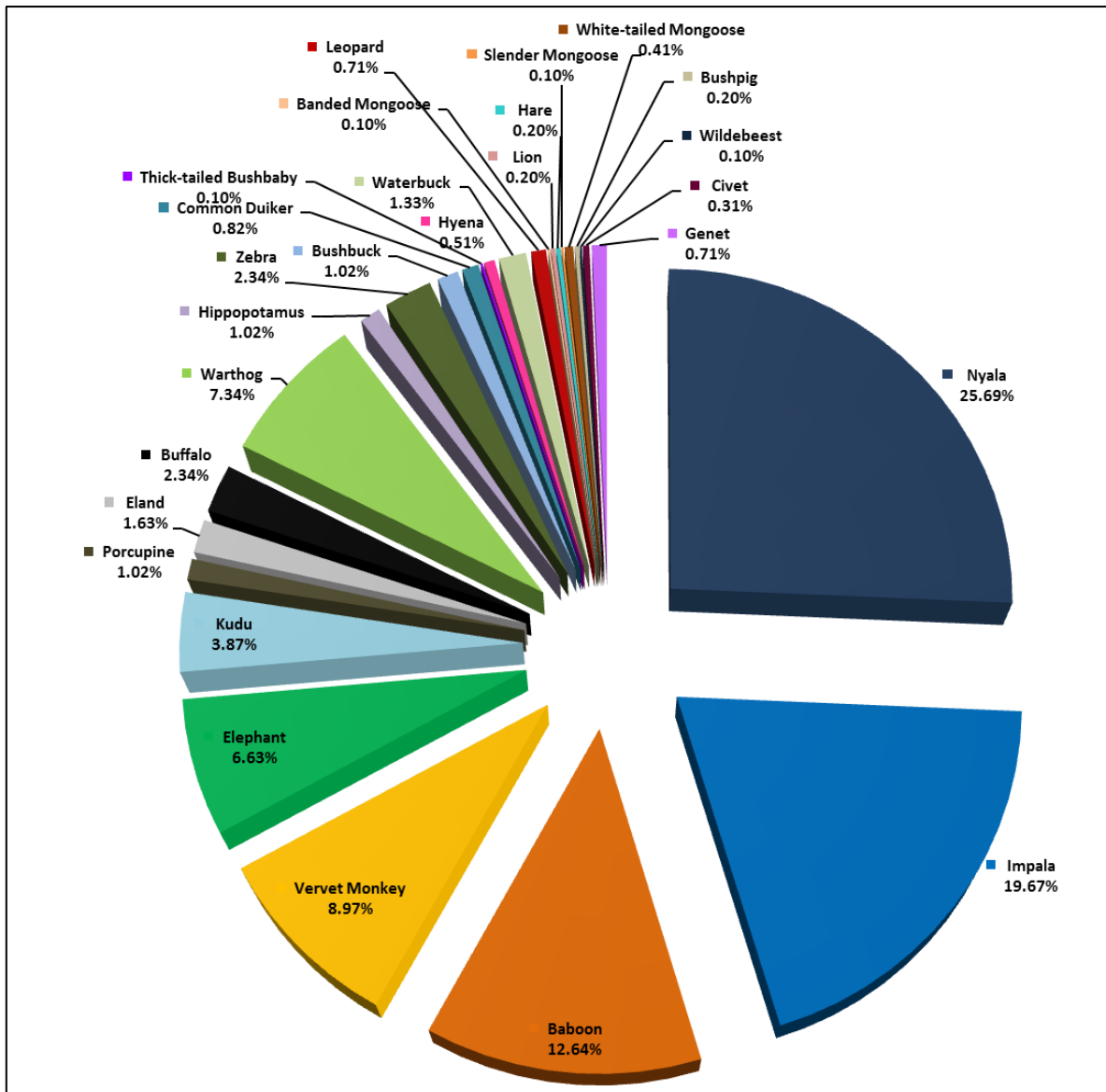


Figure 34: Percentage of total sightings per species

The mammal species are organised into their groupings as explained in the methodology and then plotted according to the season in which the sightings were recorded (Figure 35). It is evident that the greatest overall usage of the water sources studied occurred at the end of the dry season (351 mammal sightings) when surface water is least widespread and less accessible to mammals (Figure 35). The second highest number of sightings occurred during the dry season (283 mammal sightings), followed by the wet (176 mammal sightings) and end of the wet season (171 mammal sightings). Although primate numbers do not fluctuate greatly between the seasons, herbivore and carnivore sightings do (Figure 35). Large herbivore sightings fluctuate the most from one sighting during the wet season to 54 sightings at the end of the dry season. Large carnivores (lion, leopard and spotted hyaena) also show variation with one sighting recorded at the end of the wet season and seven during the dry season (Figure 35). Small carnivores show low numbers across all four seasons but show a similar pattern with one sighting recorded at the end of the wet season and six sightings recorded at the end of the dry season.

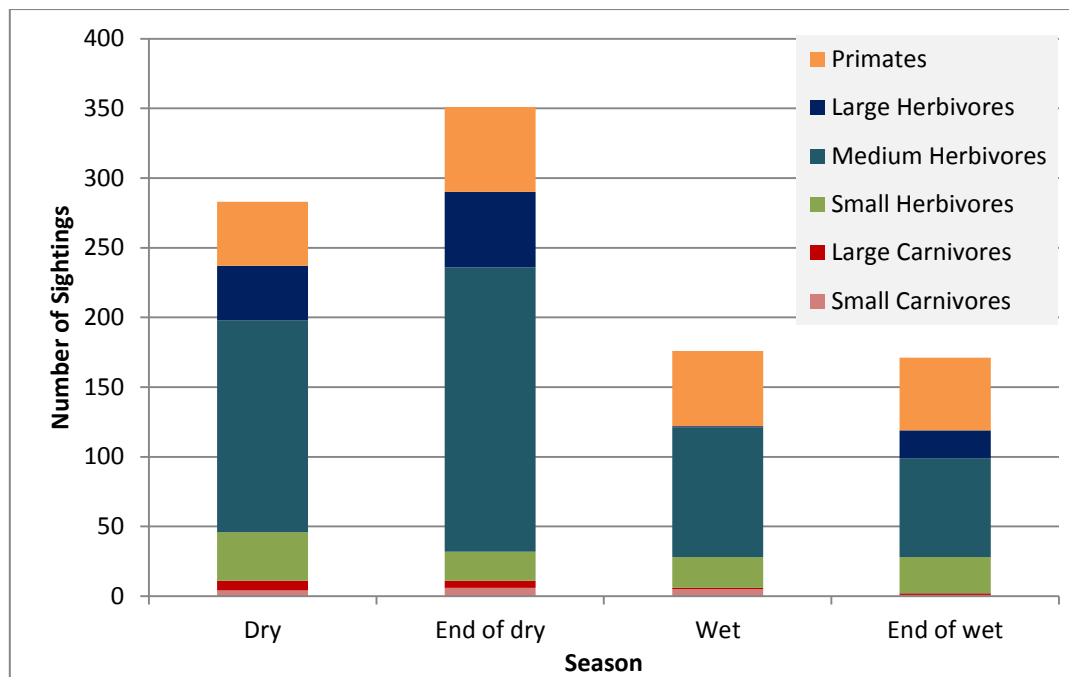


Figure 35: Seasonal sightings per species grouping

When the total species richness is examined across the seven water sources, it is evident that Nwambe pan shows the greatest overall species richness, particularly during the dry season (15 mammal species) and end of the wet season (11 mammal species) (Figure 36). The Limpopo River shows the lowest overall species richness (Figure 36). Nhlanguwe pan shows the highest richness during the end of the dry season (12 mammal species) and the wet season (nine mammal species). As the water sources were monitored by either three or four camera traps, depending on the size, a correlation was run to determine whether the number of camera traps set up had a significant impact on the species richness recorded at a water source. There was no significant correlation between the number of camera traps set up and the species richness recorded at each water source ($r_{\text{calc}}=0.3625$; $P=0.05$; $r<0.3739$). A scatter plot (Figure 37) further illustrates the relationship between the species richness recorded at each of the seven water sources for each of the four seasons, while also illustrating the number of camera traps used at each pan. Again, it is evident that Nwambe Pan shows the overall greatest species richness and that the Luvuvhu River displays greater species richness than the Limpopo River across all four seasons.

Nwambe Pan is the only perennial pan within the Luvuvhu floodplain, as the others usually only hold water temporarily during the wet season. The camera trap results thus indicate that the Luvuvhu River and its associated pan within its floodplain are sources of water for a greater diversity of species, when compared to the water sources associated with the Limpopo floodplain.

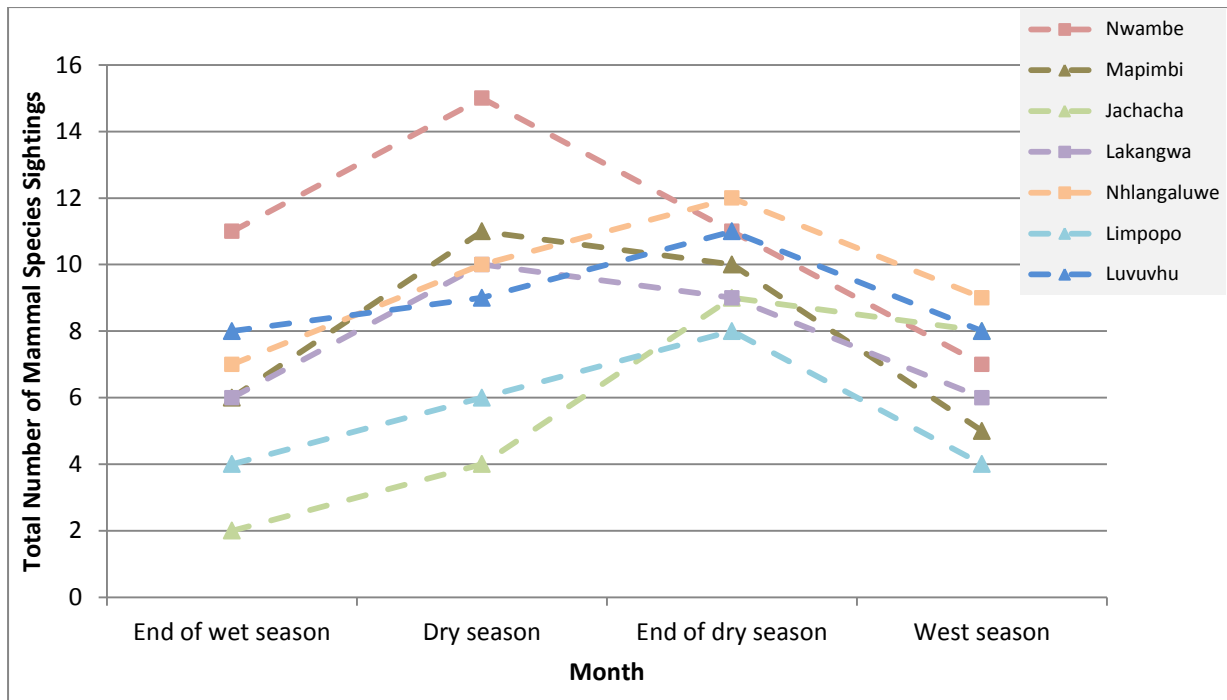


Figure 36: Total Seasonal species richness at the pans and rivers

*Dotted lines are used to indicate trends as solid lines imply that there can be fractions/portions of a sighting.

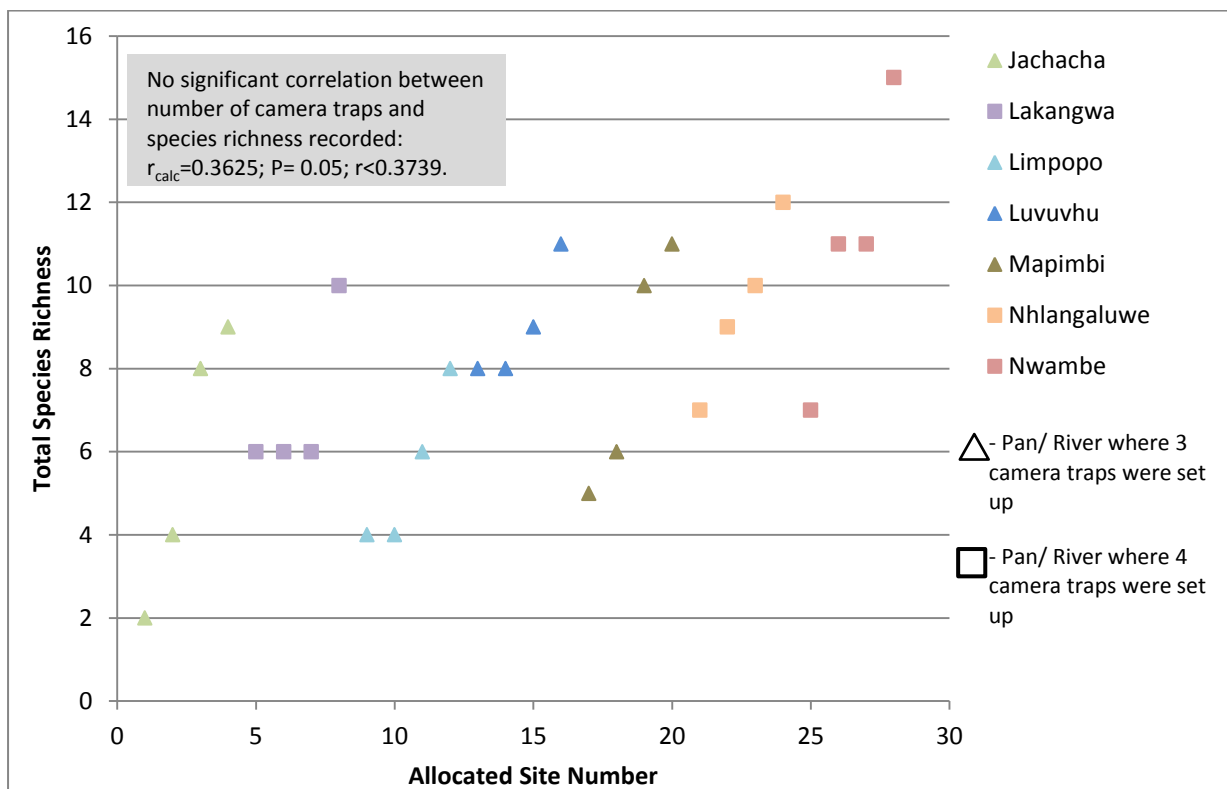


Figure 37: Species richness recorded at each of the water sources for the four seasons studied

5.3 Temporal Drinking Trends

Over the length of the study, camera trap data were collected for a total of 4 608 hours. The time of day that each species was photographed at each water source was recorded. Due to the wide range of mammal species being studied, it was not possible to select time categories according to known species' behaviour. The day was therefore divided into broad five hour intervals: early morning (04:00-09:00), midday (09:00-14:00) and late afternoon (14:00- 19:00). From 19:00 until 04:00 was considered "night". The percentage of overall mammal sightings recorded for each of the four time intervals, for each of the seven water sources was recorded (Figure 38). In general, the majority of the sightings were recorded during midday and late afternoon. Lakangwa, Nhlanguwe and Jachacha pans within the Limpopo floodplain grasslands show similar trends with the highest activity during midday, with at least 49% of their total sightings recorded then (Figure 38). The Luvuvhu River also shows the highest percentage of sightings during the midday period (44%). Mapimbi pan and the Limpopo River show the highest percentage of sightings recorded during the late afternoon (44% and 39% respectively) (Figure 38). Nwambe pan shows the highest percentage of sightings at both midday (36%) and in the late afternoon (35%). The Limpopo River shows the highest percentage of sightings, of all the water sources, during the night time period (17%). This is possibly due to the fact that the Limpopo River forms the border with Zimbabwe. The Zimbabwean side of the border is not formally protected and trophy and subsistence hunting is known to be conducted here (Crosmary et al., 2012). Animals may therefore feel safer accessing this area after nightfall.

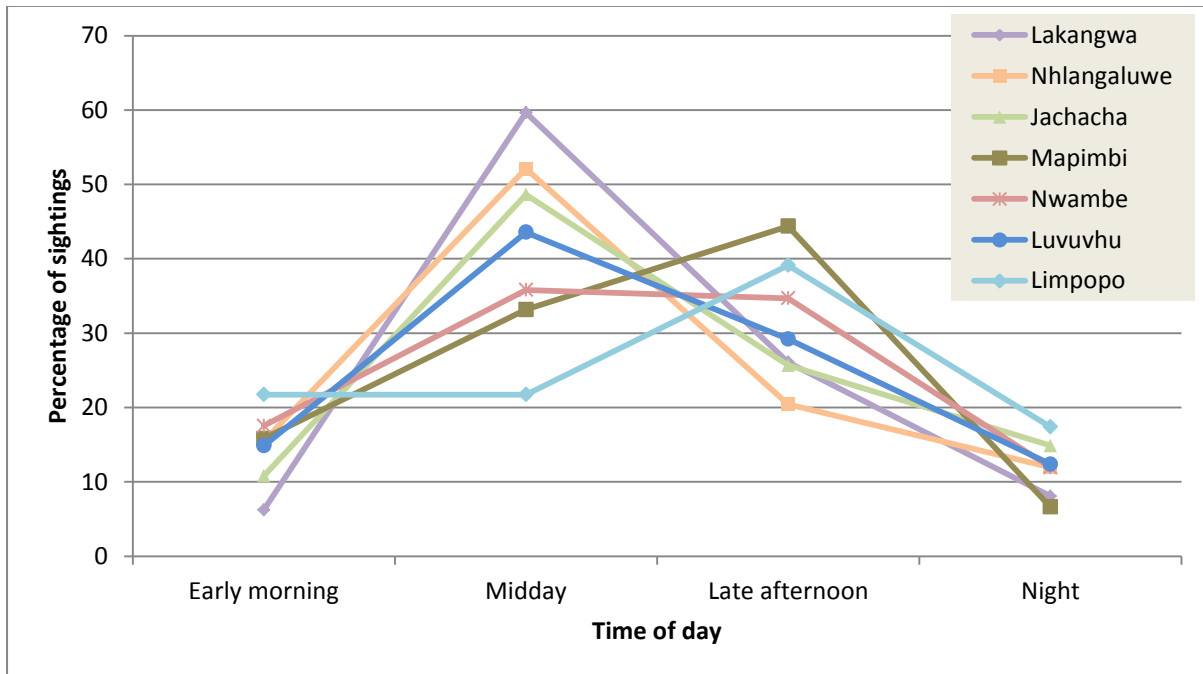


Figure 38: Percentage of overall mammal sightings recorded during each time interval at each water source

The total species sightings data was separated into hourly intervals over 24 hours (Figure 39), as well as being separated into the four seasons (Figure 40). The time period with the most sightings

overall is between 13:00 and 14:00. Sightings then decrease gradually on either side of 13:00 until 05:00 and 19:00. This pattern is repeated across all four sample seasons. There is considerably less activity at the water sources from 19:00 in the evening until 05:00 in the morning. As discussed in Section 5.2, it is again evident that the greatest species richness was recorded at the end of the dry season, followed by the dry season (Figure 40). A greater variety of species, as well as numbers of mammals, therefore appear to rely on the perennial water sources during the dry seasons.

Due to logistics, moon phases were not controlled for during each of the four sampling sessions. A Pearson's correlation of the number of sightings recorded between 19:00 and 04:00, and the recorded moon phase, however, shows that for the data set used, moon phase, including sampling during full moon, did not have a significant impact on the overall number of mammal sightings recorded ($r_{\text{calc}}=0.3625$; $P=0.05$; $r<0.3739$). Moon phase did not appear to have a significant impact on the number of sightings of primates ($r_{\text{calc}}=0.0196$; $P=0.05$; $r<0.5529$), herbivores ($r_{\text{calc}}=0.2566$; $P=0.05$; $r<0.3961$) or carnivores ($r_{\text{calc}}=-0.1558$; $P=0.05$; $r<0.4821$) recorded. No vervet monkey or baboon sightings are recorded between 20:00 and 05:00 as these diurnal primates tend to roost in trees at night for safety (Skinner and Chimimba, 2005). Very few antelope species were recorded at watersources overnight, with the exception of nyala, which were recorded occasionally, and common duiker (*Sylvicapra grimmia*), which were recorded across the 24 hours (Figure 39). Elephant and buffalo were recorded accessing the water sources throughout the day and night and do not appear to have preferential drinking times (Figure 39). Night time access did, however, increase during the dry seasons (Figure 40). Zebra were recorded accessing watersources during daylight as well as between 20:00 and 23:00 at night (Figure 39). Vervet monkeys and chacma baboons accessed the water sources throughout the day, across all four seasons (Figure 40). Carnivores accessed the water sources more frequently during the dry seasons, which would be expected as they are considered to be the least water dependent of the mammal groupings (Wolff, 2001) (Figure 40). Carnivore sightings were all recorded between 18:00 in the evening and 08:00 in the morning, which is expected as most carnivore species are nocturnal (Skinner and Chimimba, 2005). However, this shows that predators and prey are accessing the water sources at very different times of the day, with the majority of medium and large herbivores and primates accessing water sources during the midday period, whilst large carnivores are predominantly accessing the water sources during the night (Figure 39).

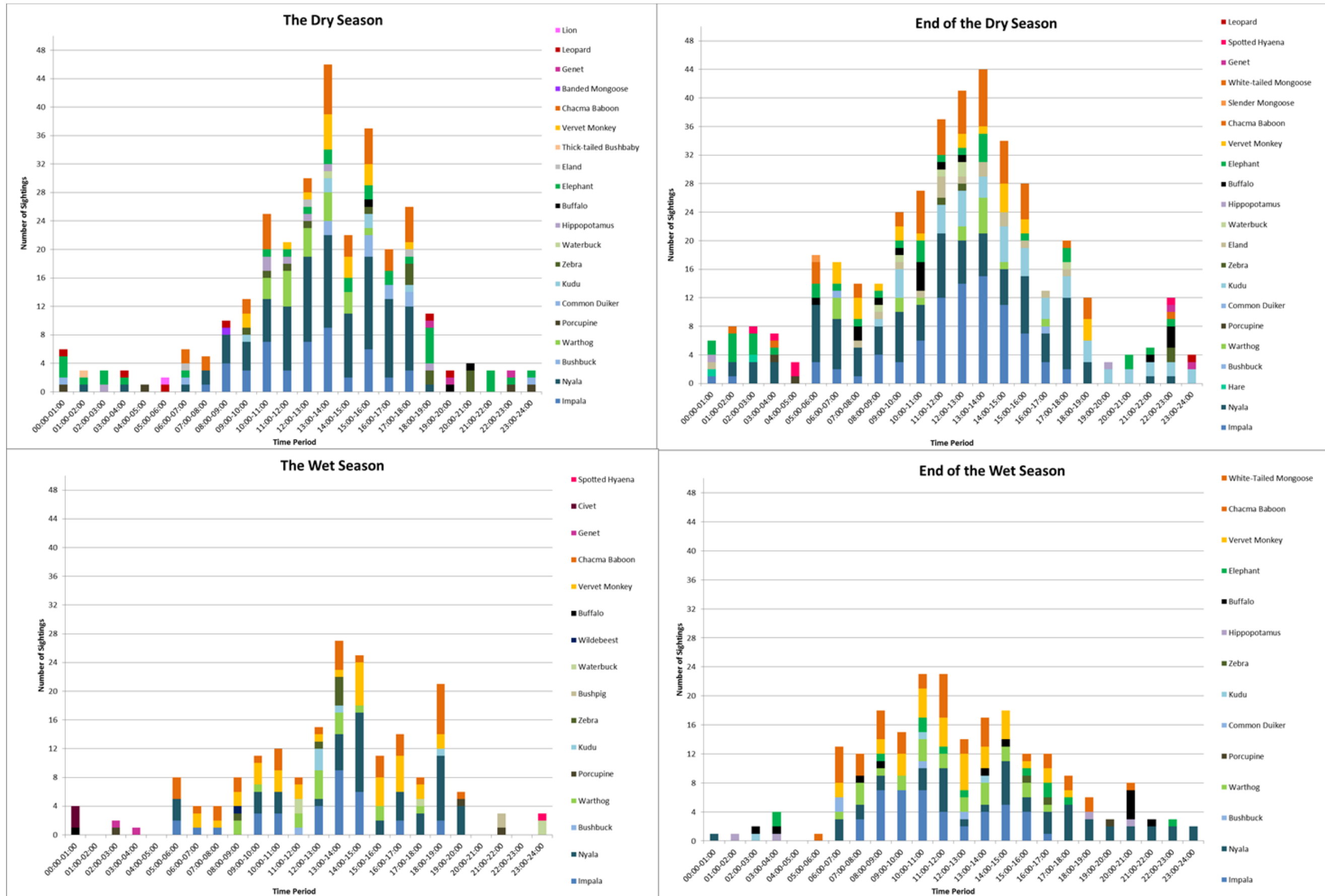


Figure 40: Seasonal numbers of species sightings recorded accessing water sources during each hourly interval over 24 hours

5.4 Spatial Drinking Patterns (Site Preferences)

The species sightings data recorded, as well as the mammal groupings, were plotted spatially using ArcView 10, for each of the four study seasons. The majority of species showed an increase in sightings at the water sources during the dry season and at the end of the dry season. Species which displayed interesting spatial drinking patterns, and which are associated with sufficient sightings recorded to display trends are discussed.

Elephant

Elephant sightings were recorded throughout the study area at both the pans and rivers (Figure 41). Sightings, however, were at their highest during the dry season and end of the dry season, particularly along the Luvuvhu River (the maximum number of elephant sightings recorded on one camera trap in 48 hours was 10) (Figure 41). Interestingly, of the total 65 elephant sightings recorded at the various water sources, no sightings were recorded during the wet season. Five elephant sightings were recorded along the Limpopo River, but notably all five sightings were recorded after dark. This suggests that the elephants in the area are avoiding the Limpopo and are choosing only to access or cross the river at night. Of the pans, Nwambe Pan was the most popular with multiple elephant sightings during the dryer seasons.

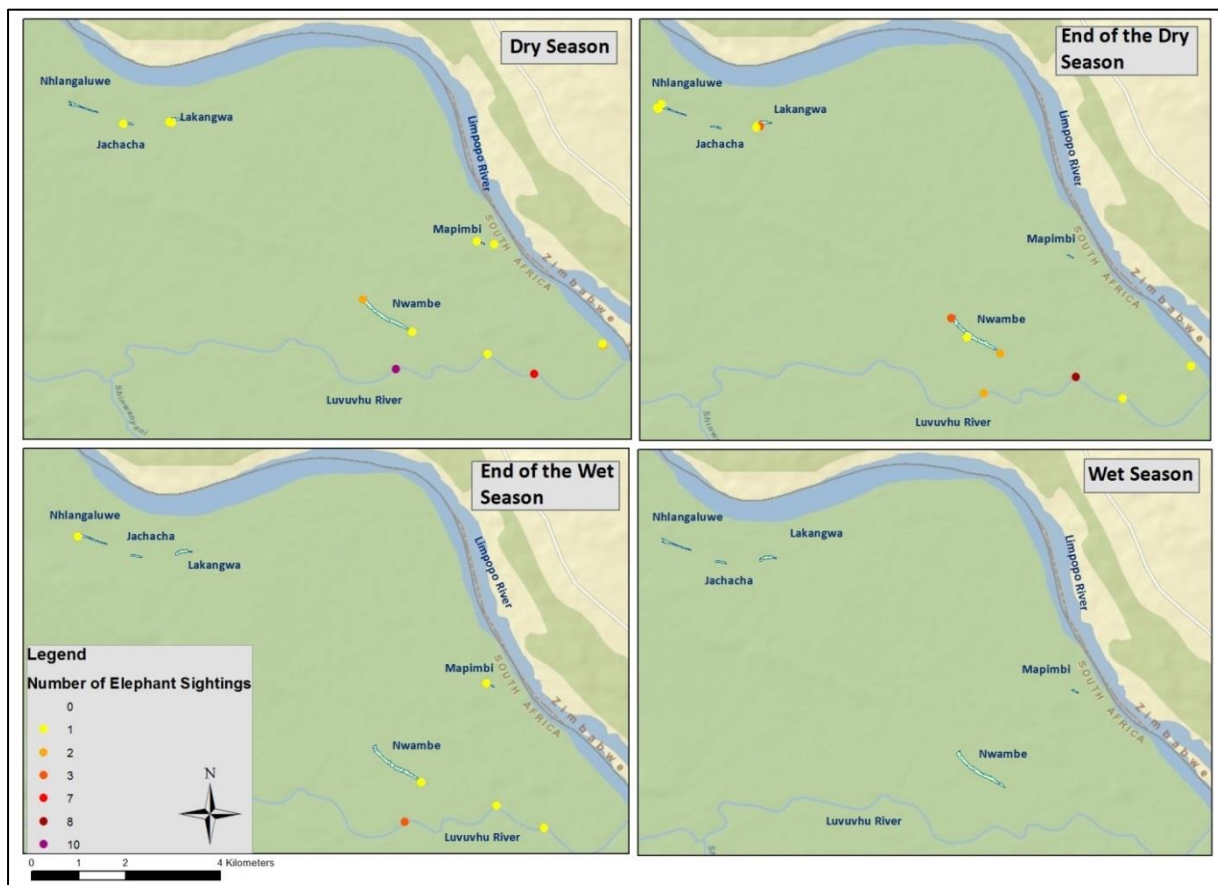


Figure 41: Seasonal distribution of elephant sightings recorded using camera traps at perennial water sources

Buffalo

Buffalo were recorded making use of all five of the studied pans as well as along the Luvuvhu River (Figure 42). No sightings were recorded and no personal observations were made of buffalo along the banks of the Limpopo River throughout the study. The most consistent sightings of buffalo throughout the seasons were made along the Luvuvhu River and Nwambe and Mapimbi pans, suggesting that they are selecting for this area (Figure 42). Sightings further north at the pans within the Limpopo grassland floodplain were only recorded during the end of the dry season, suggesting that the buffalo in the region only utilise these water sources when other water sources are scarce (Figure 42). Buffalo are water dependant animals and are known to preferentially select areas near water (within 1km), but may range further during the dry season for higher-quality food (Ryan et al., 2006; Hunter, 1996). This explains why they were recorded at all of the available water sources at the end of the dry season. It may also explain the relatively high number of buffalo sightings at the water sources during the end of the wet season as there is enough high-quality food in close proximity to the water sources; the buffalo are not required to move far from their preferred water sources (the Luvuvhu River and Nwambe and Mapimbi pans).

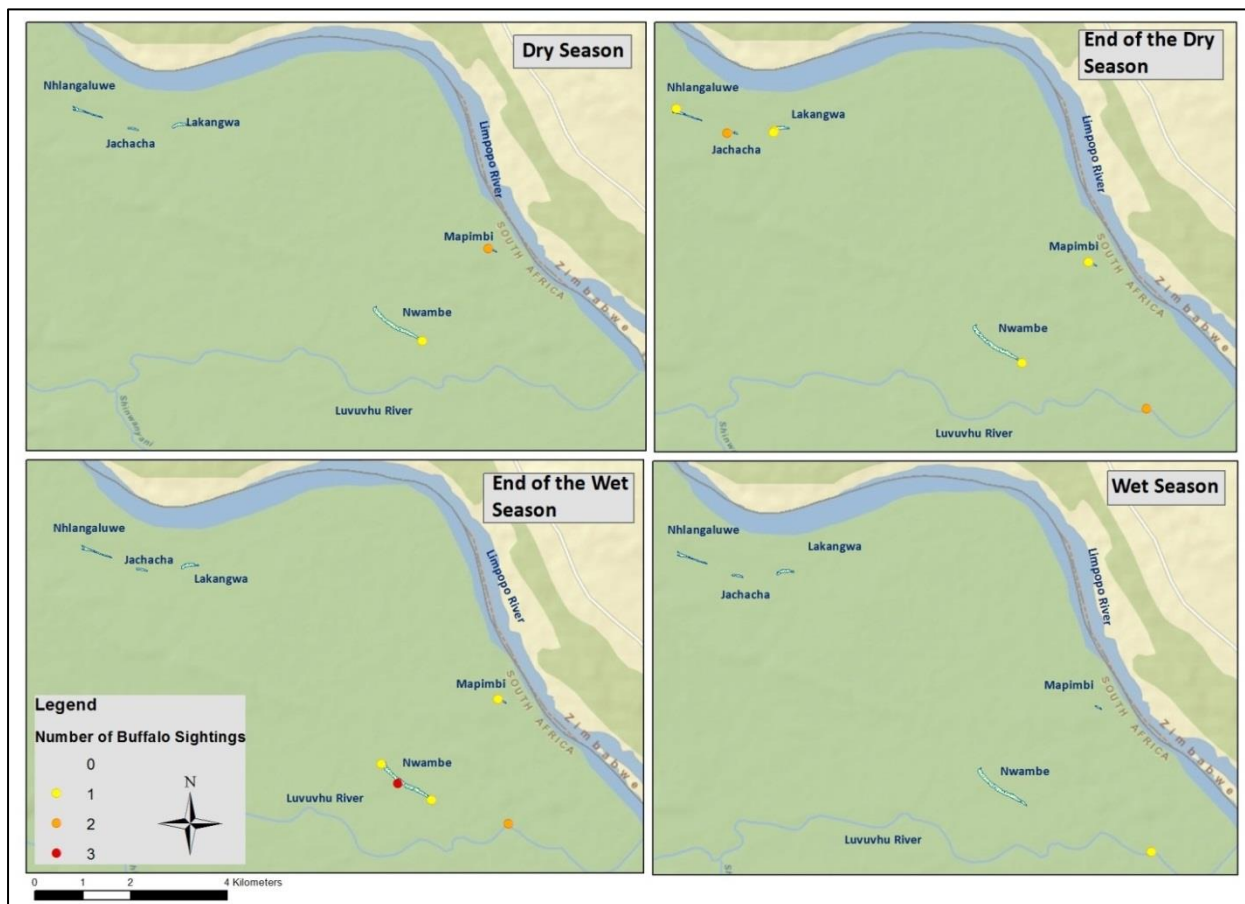


Figure 42: Seasonal distribution of buffalo sightings recorded using camera traps at perennial water sources

Nyala

A total of 252 sightings of nyala were recorded. Multiple nyala sightings were recorded across the Makuleke region at the pans and rivers for all four seasons studied (Figure 43). Sightings were greatest during the dry seasons (36% of nyala sightings recorded) and lowest during the end of the wet season (11% of nyala sightings recorded). The highest numbers were recorded at Mapimbi Pan and along the Luvuvhu River (Figure 43). This is most likely because nyala select for the well-established riparian vegetation along the banks of the Luvuvhu River and Mapimbi Pan (refer to Sections 3.1.1.1 and 3.1.2.2) (Grant et al., 2002). Nyala are a fairly rare antelope species in the southern section of the Kruger National Park and the pans and rivers in the Makuleke area provide an important habitat for this species, which is utilised throughout the year.

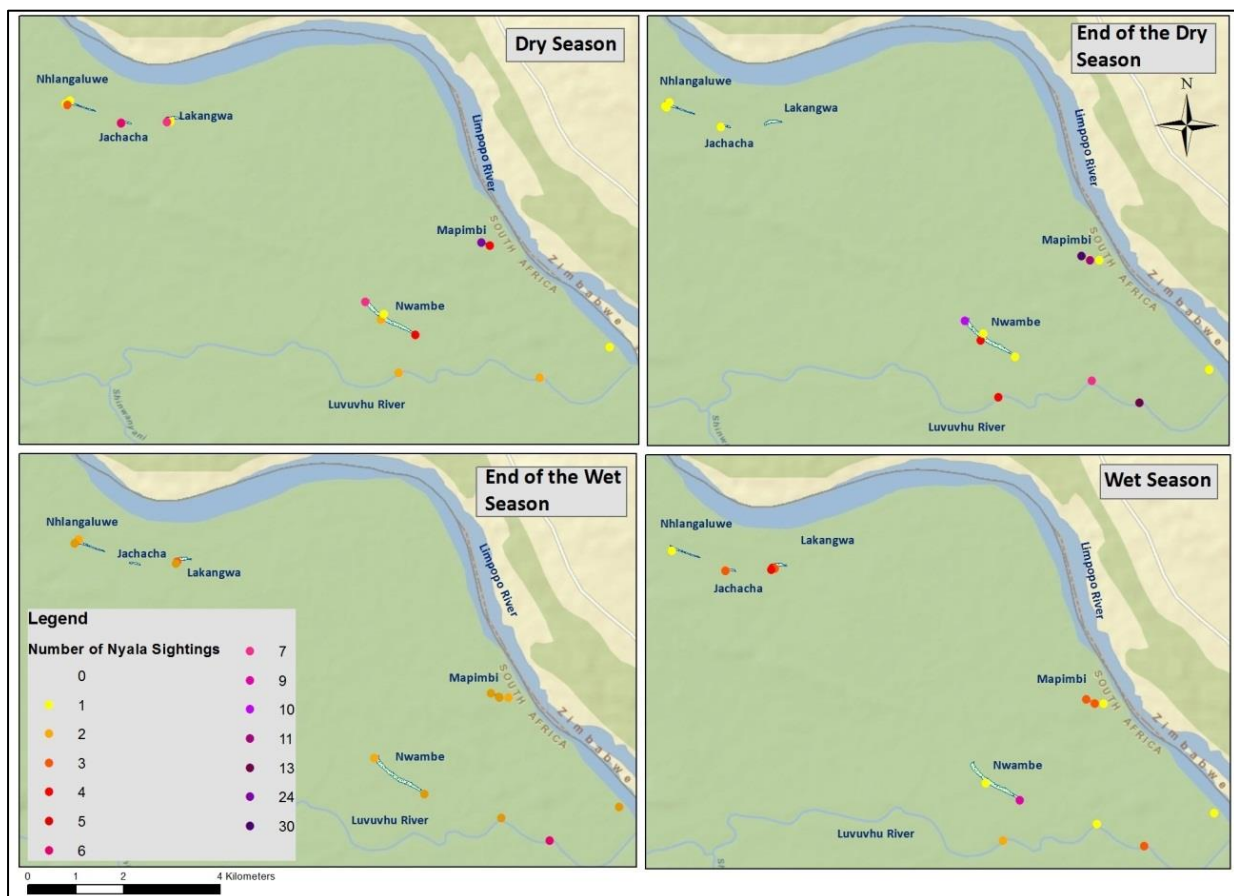


Figure 43: Seasonal distribution of nyala sightings recorded using camera traps at water sources

Eland

A total of 16 eland sightings were recorded at the perennial water sources. Three of the 16 sightings (19%) were recorded during the dry season and 13 sightings (81%) were recorded during the end of the dry season (Figure 44). Of the total 16 sightings, 12 (75%) were recorded at Nwambe Pan alone at the end of the dry season. Eland thus appear to rely more on the perennial water sources studied during the dry months, as no eland sightings were recorded during the two wet season study periods (Figure 44). Nwambe Pan in particular, appears to be a popular water source for eland during the dry seasons.

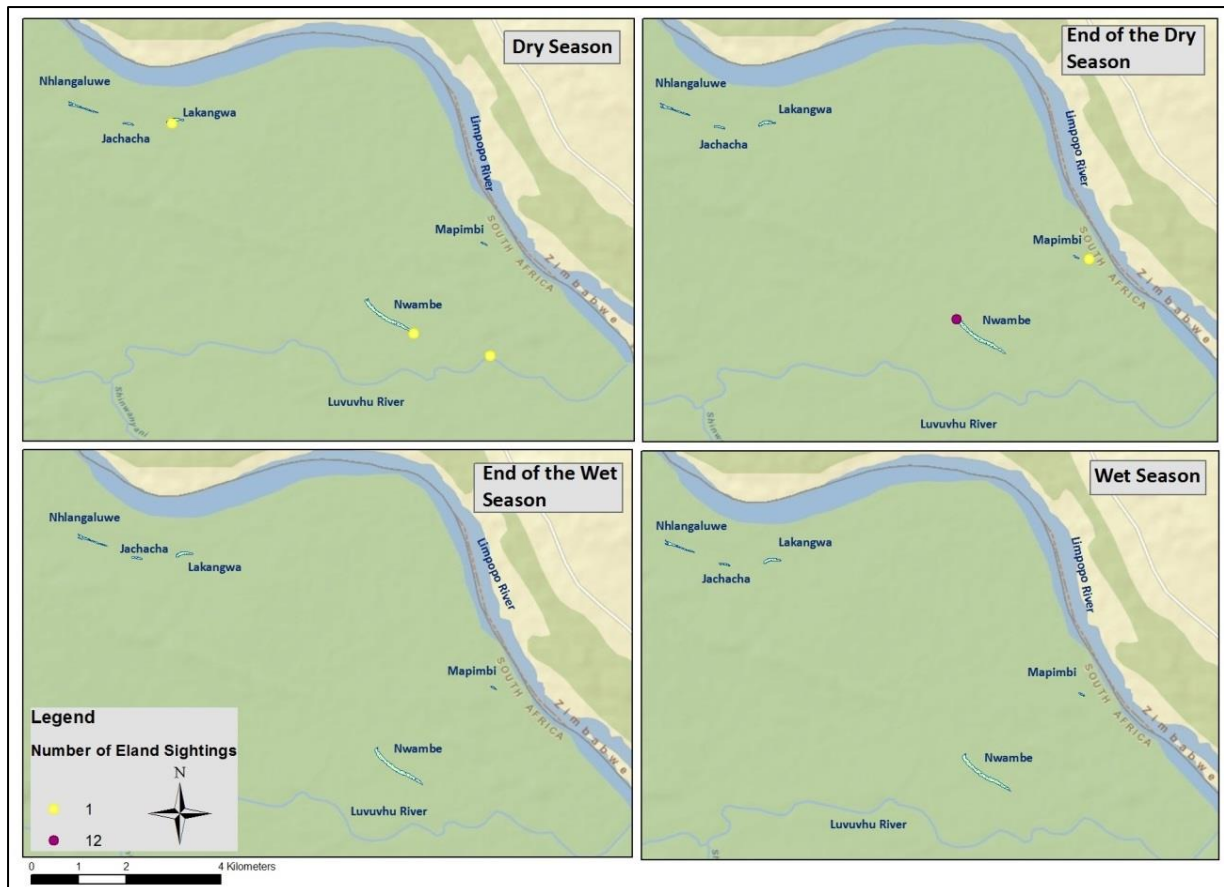


Figure 44: Seasonal distribution of eland sightings recorded using camera traps at perennial water sources

Kudu

A total of 38 kudu sightings were recorded at the studied water sources. The majority of these (25 sightings or 66%) were recorded at the end of the dry season (Figure 45). By far the highest number of kudu sightings (10 sightings) recorded within a 48 hour period was at Nwambe Pan at the end of the dry season (Figure 45). In general, kudu seemed to prefer the pans over the rivers with 34 of the overall 38 sightings (89%) being made at pans, and most consistently within the Limpopo floodplain. This is probably due to the fact that kudu prefer the more open savannah habitat, which supports their preferred acacia species, associated with the Limpopo floodplain to the dense riparian vegetation along the rivers.

Zebra

A total of 23 zebra sightings were recorded. Zebra were most widely distributed and recorded (12 sightings) during the dry season (Figure 46). No sightings of zebra were recorded at either of the two rivers in the study area (Figure 46). Zebra therefore appear to select to drink at the pans, particularly those within the Limpopo grassland floodplain (83% of total sightings).



Figure 45: Seasonal distribution of kudu sightings recorded using camera traps at perennial water sources

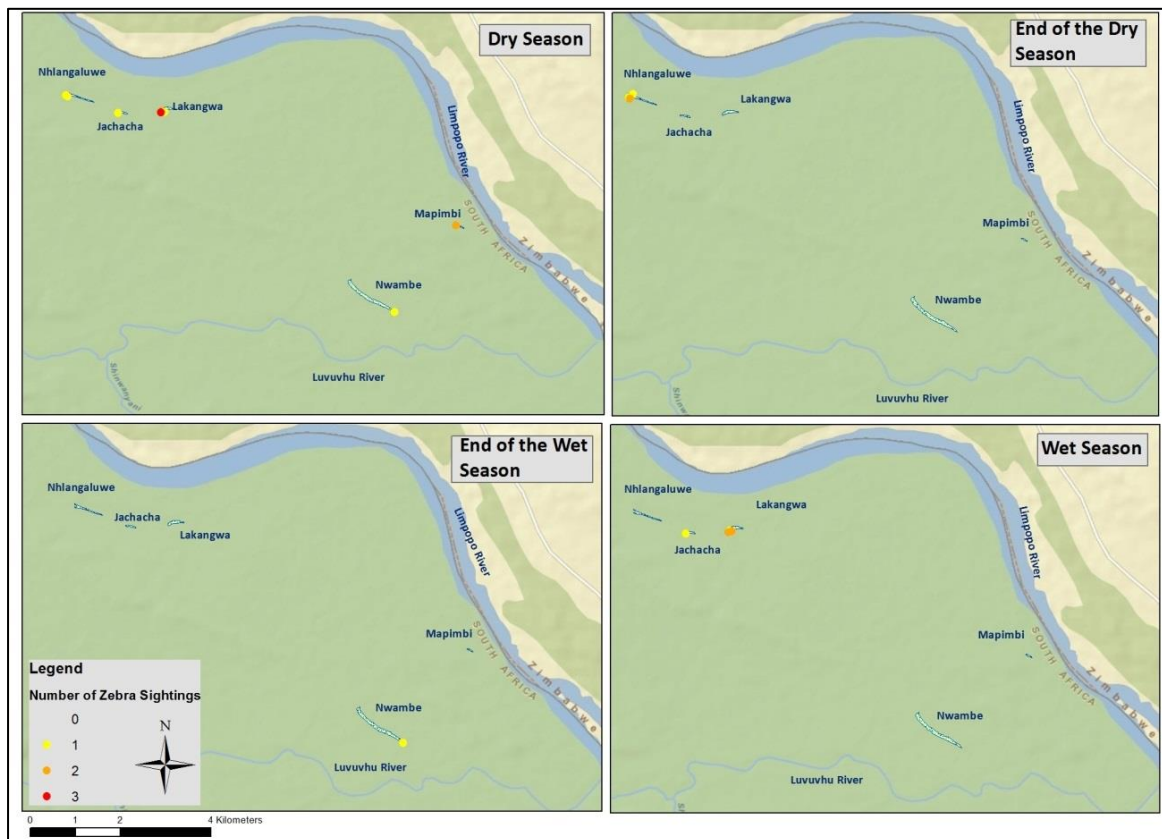


Figure 46: Seasonal distribution of zebra sightings recorded using camera traps at water sources

Warthog

A total of 72 warthog sightings were recorded. The number of warthog sightings recorded was fairly evenly distributed across the four seasons. A total of 20 sightings were recorded during the dry season, 15 sightings at the end of the dry season, 16 sightings in the wet season and 21 sightings at the end of the wet season (Figure 47). Warthogs are considered to be highly water dependent, which would explain their fairly consistent abundances throughout the year (Hayward and Hayward, 2012). Warthogs were recorded at all water sources studied, with the exception of the Limpopo River. The highest number of sightings was recorded at Nwambe and Mapimbi pans. The highest numbers of warthog sightings (19 sightings) recorded in a 48 hour period were recorded at Nwambe Pan at the end of the wet season (Figure 47). Of the total warthog sightings, 51% were recorded at Nwambe Pan.

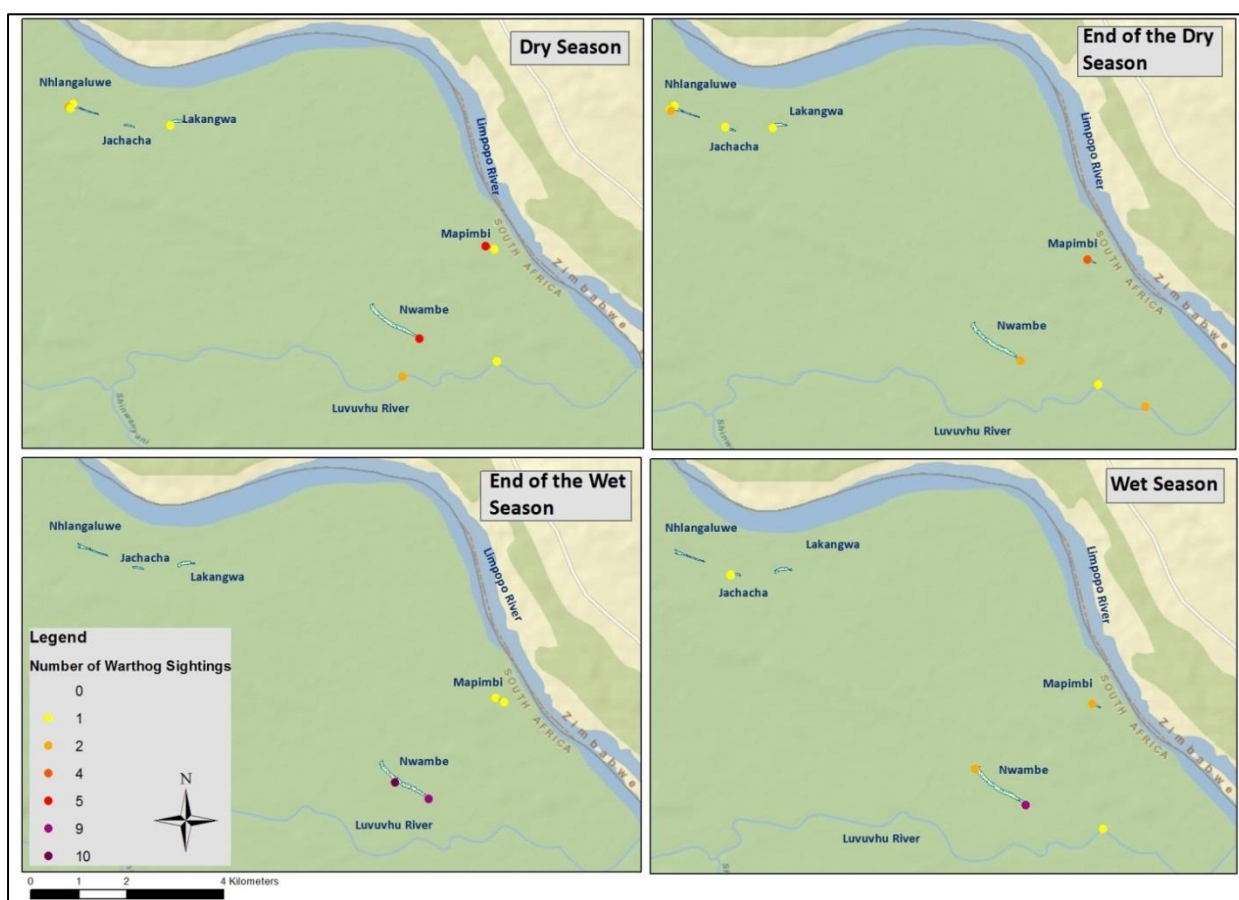


Figure 47: Seasonal distribution of warthog sightings recorded using camera traps at perennial water sources

Vervet Monkey

Overall, 88 sightings of vervet monkeys were recorded. Vervet monkey sightings were recorded utilising all seven studied water sources throughout the study area (Figure 48). The highest number of vervet monkey sightings recorded in a 48 hour period was at Mapimbi Pan during the dry season (9 sightings). In general, higher numbers of sightings were recorded at Mapimbi Pan and within the Luvuvhu floodplain (Luvuvhu River and Nwambe Pan). This is probably because they prefer established riparian vegetation (higher density of trees) within the Luvuvhu floodplain and at Mapimbi Pan (refer to Sections 3.1.1 and 3.1.2.2). Interestingly, the highest numbers of

overall sightings were recorded during the wet season (27 sightings) and at the end of the wet season (24 sightings). This is possibly because during the wet seasons, vervet monkeys are not forced to move as far to find good quality forage and can therefore spend more time in their preferred habitat along the rivers and around the pans.

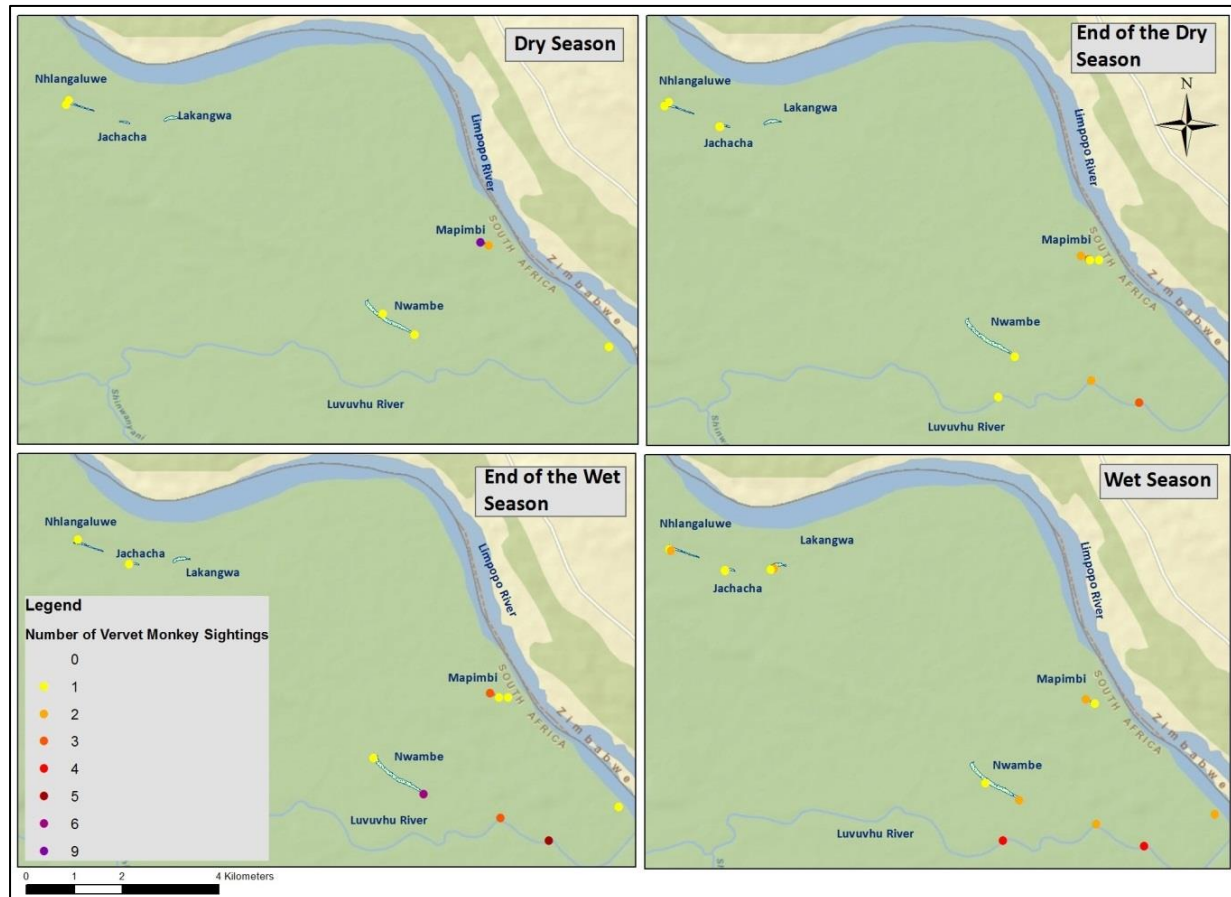


Figure 48: Seasonal distribution of vervet monkey sightings recorded using camera traps at water sources

Chacma Baboon

A total of 124 baboon sightings were recorded using camera traps. Baboons were recorded at all seven water sources, along the rivers and at the perennial pans (Figure 49). The greatest number of sightings was recorded at the end of the dry season (40 sightings), as fewer surface water sources were available. Throughout the year, both the pans and the rivers appear to be an important source of water for the baboons in the Makuleke area.

Leopard

Throughout the study a total of seven leopard sightings were recorded. Six of the seven sightings (86%) were recorded during the dry season at Nhlanguwe Pan and along the Luvuvhu River (Figure 50). The seventh sighting was recorded at Mapimbi Pan at the end of the dry season. No leopard sightings were recorded during the wet season or at the end of the wet season at any of the studied water sources (Figure 50). The water sources thus seem to be a more important source of water for leopards during the dry months of the year. Other species of large carnivores

(lion and spotted hyaena) were not recorded in sufficient numbers (five sightings and less) to display any meaningful trends.



Figure 49: Seasonal distribution of chacma baboon sightings recorded using camera traps at water sources

Genet (Large and Small Spotted)

Genets (*Genetta genetta* and *Genetta tigrina*) were the most abundant small carnivores recorded, with a total of seven sightings documented. Large and small spotted genet sightings were grouped together as photograph quality, especially at night, was often not clear enough to distinguish with certainty between the two species. Genet sightings were recorded throughout much of the year, with the exception of the end of the wet season (Figure 51). Four of the seven sightings (57%) were recorded at Mapimbi pan, two along the Luvuvhu River and one at Nwambe Pan. Genets thus appear to be selecting for sites within well-established riparian vegetation. Other species of small carnivores ((civet (*Civettictis civetta*), slender mongoose, banded mongoose and white-tailed mongoose) were not recorded in sufficient numbers (four sightings and less) to display any meaningful trends.

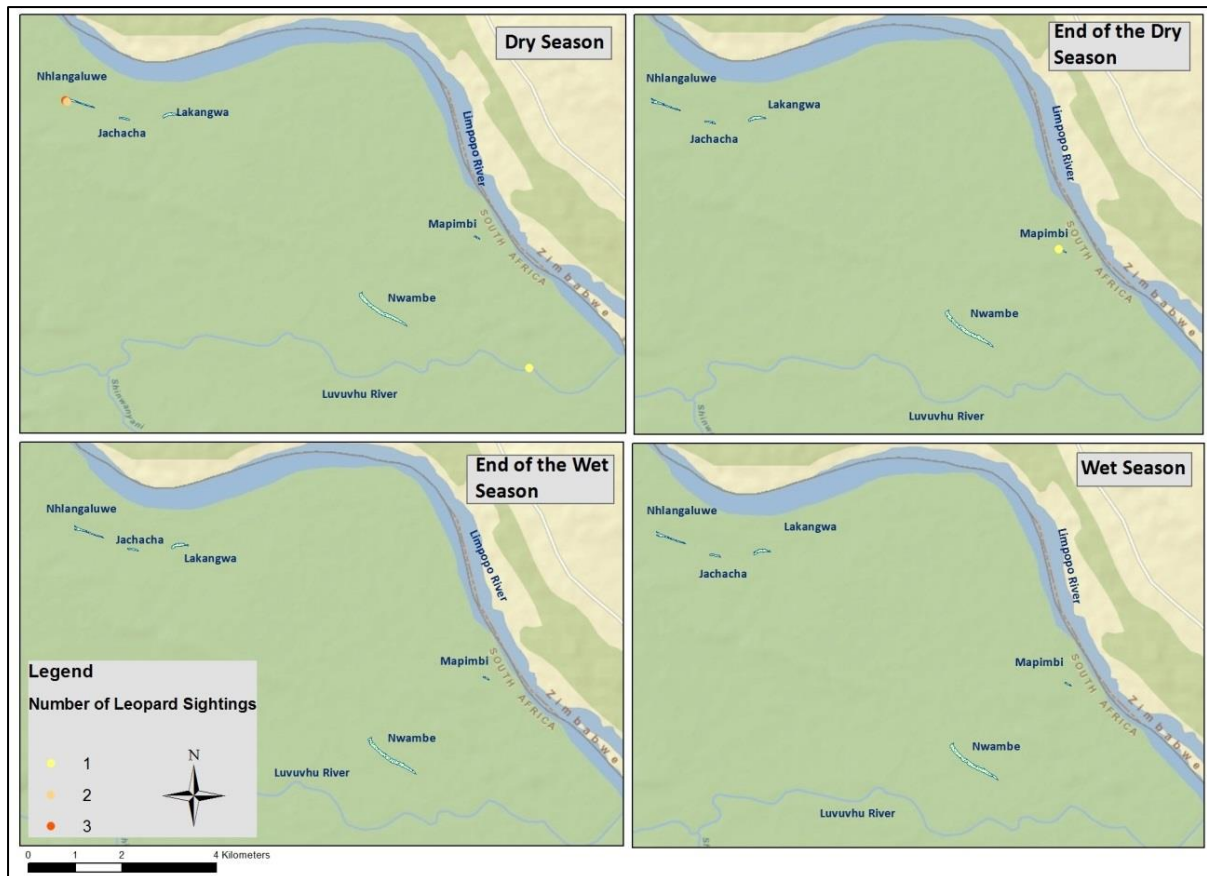


Figure 50: Seasonal distribution of leopard sightings recorded using camera traps at water sources

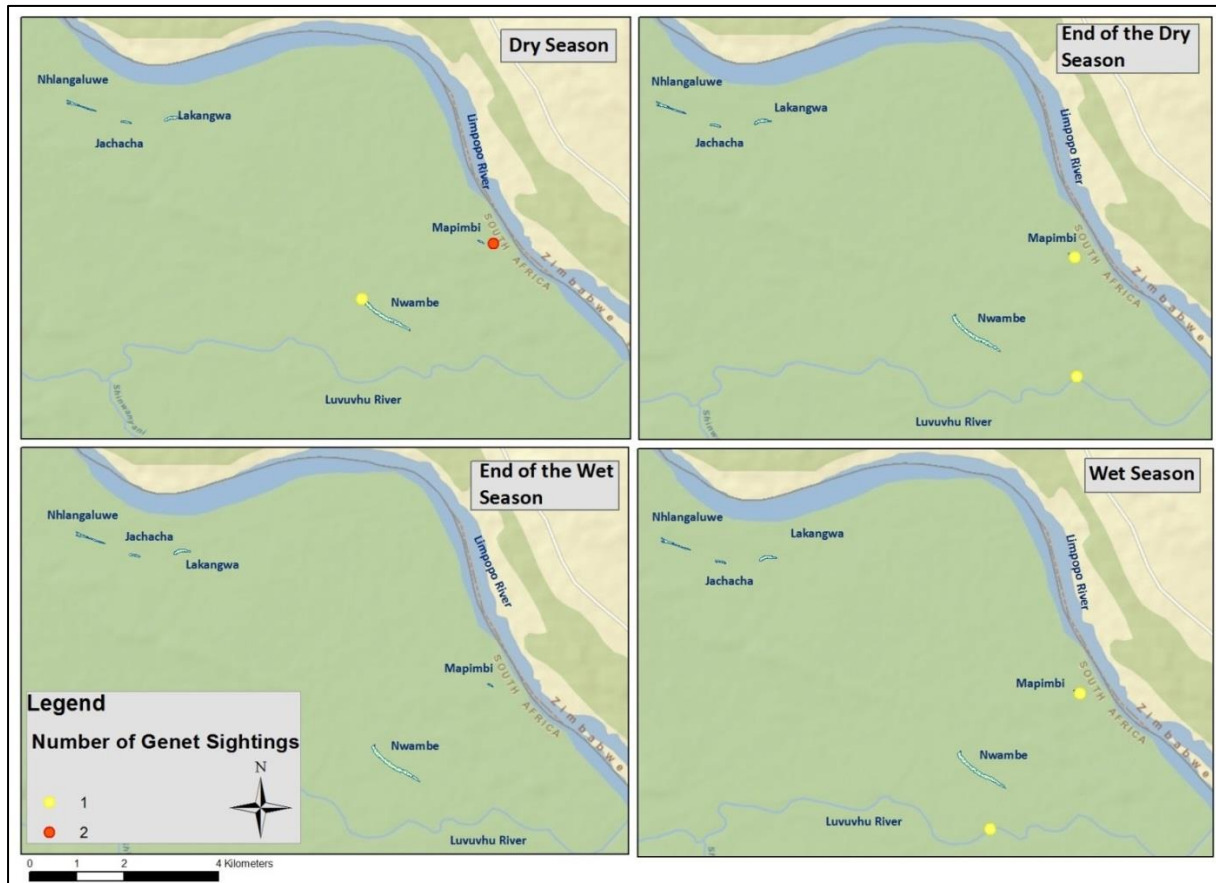


Figure 51: Seasonal distribution of genet sightings recorded using camera traps at perennial water sources

5.5 Effect of Environmental Variables on Mammal Drinking Site Selection

The CCA produced an ordination plot (Figure 52). The CCA results are weak as they show that the ten environmental variables explain only a very small portion of the variance in the species data. The two main axes explain a cumulative percentage variance of 17% (Table 7). All ten environmental variables show a cumulative percentage variance of 28.41% (Table 7). These variables therefore only explain 28% of the overall species variance in the data set, suggesting that there are other factors likely influencing water source usage by mammal species in the study area. The CCA, however, helps to tease out which environmental variables have more influence than others (Figure 52). Although the ten environmental variables analysed only explain a portion of species' variance, they are significant as the first six axes produced by the CCA show a highly significant Pearson's correlation ($P=0.01$) between species and environmental scores ($r>0.2687$) (Table 7).

The biplot (Figure 52) shows that TSS is the dominant variable on Axis 1 and that several large mammal species (kudu, large carnivores, zebra and buffalo) plot along this axis. Muddy water therefore does not deter these species from selecting a drinking site. Alternatively, the primate species all plot directly opposite TSS, indicating that primates may be selecting for drinking sources with cleaner, less muddy water (Figure 52). Primate species (vervet monkey and chacma baboon) and small carnivores plot along the percentage canopy cover axis, which has the second highest biplot score after TSS. This is, therefore, also probably a key driver as primates and small carnivores are selecting drinking sites with more canopy cover as many of these species are fairly arboreal and rely on climbing trees to escape danger (such as genets, vervet monkeys and bushbaby species) (Figure 52) (Skinner and Chimimba, 2005). Along the Y Axis (Axis 2), tree and shrub structure have the highest biplot scores. Elephant sightings plot directly opposite the combined shrub and tree structure axes, showing a negative relationship. Elephants are therefore using water sources with less shrub and tree cover. However, it cannot be determined from this whether elephants are selecting for water sources with less tree and shrub cover at the water's edge, or whether there is less overall tree and shrub cover at water sources where elephants frequent as a consequence of their feeding behaviour (Franz et al., 2010).

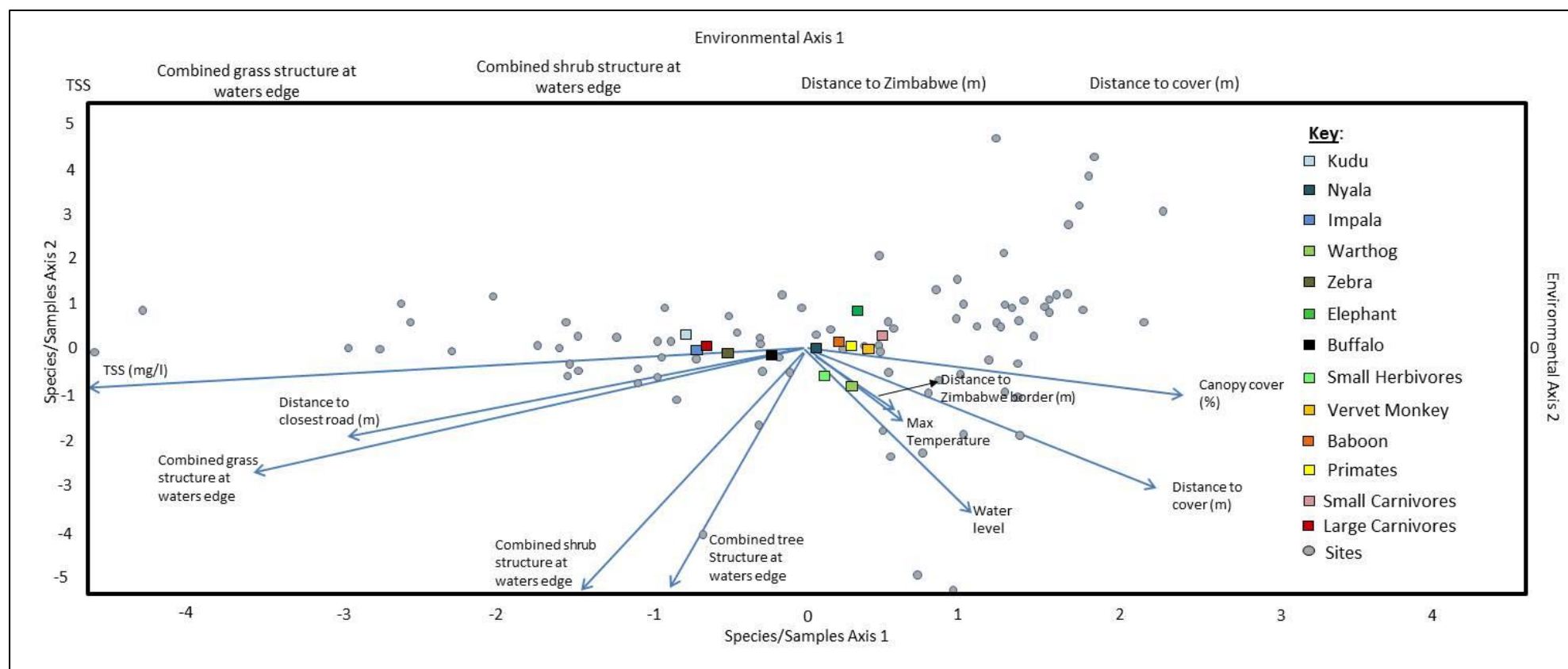


Figure 52: Ordination plot displaying relationships between mammal species and environmental variables at water sources

Table 7: Statistics summary of the Canonical Correspondence Analysis

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6	Axis 7	Axis 8	Axis 9	Axis 10
Canonical Eigen value	0.1535	0.1121	0.0641	0.0522	0.0309	0.0168	0.0049	0.0028	0.0009	0.0004
% variance explained	9.9390	7.2610	4.1520	3.3800	2.0010	1.0860	0.3195	0.1828	0.0576	0.0287
Cumulative % variance	9.9390	17.2000	21.3500	24.7300	26.7300	27.8200	28.1400	28.3200	28.3800	28.4100
Pearson correlation species/environment scores	0.8697	0.8133	0.6974	0.6890	0.4901	0.5567	0.2598	0.2493	0.0558	0.0910

5.6 Clustering of Drinking Sites According to Environmental Variables and Species' Preferences

To further tease out the relationships between environmental variables and mammal species preferences for water sources, cluster analyses were undertaken. Two cluster analyses were run; the first of which was conducted to determine preferences of specific mammal species recorded (Section 5.6.1). The second analysis was to determine trends that mammal groupings may show concerning environmental characteristics of water sources (Section 5.6.2).

5.6.1 Clusters Using Mammal Species

Five clusters were found to be the most manageable and interpretable number of clusters using the recorded species data (Thuiller et al., 2006). The following five clusters in Table 8 were produced:

Table 8: Cluster summary of the five clusters produced showing relationships between environmental variables and mammal species sightings at the studied water sources

Cluster	Size	Distance to cover (m)				Canopy cover (%)				Distance to Zimbabwe (m)				Distance to closest road (m)			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	26	16.58	31.19	0	100	29.23	23.65	0	80	1482.04	1326.47	0	3242	371.27	361.6	3	1243
2	7	75	42.72	10	100	50	15.28	20	70	2054.6	1436.59	177	3160	441.1	378.77	154	1243
3	33	11.12	23.55	0	100	24.85	23.47	0	80	1351.76	1204.45	0	3242	367.48	362.27	3	1243
4	18	35.5	46.95	2	100	92.2	11.66	70	100	98.33	90.5	0	177	40.78	51.28	15	181
5	12	7.75	7.61	0	20	18.3	16.97	0	40	480.58	319.48	180	817	303.83	85.08	76	375
All	96	21.41	35.71	0	100	39.69	33.16	0	100	1094.38	1209.53	0	3242	304.67	325.79	3	1243
Cluster	Size	Water level				Maximum Temperature (°C)				TSS (mg/l)				Total mammal sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	26	2.46	0.58	1	3	32.5	4.13	26	38	565.85	498.06	3	1497	8.15	6.3	0	26
2	7	2.86	0.9	2	4	34.43	6.08	26	44	420.9	413.12	3	1205	43.71	16.32	24	71
3	33	4.12	0.55	3	5	41.4	2.45	38	44	273.44	242.6	0	864	5.97	4.9	0	18
4	18	3.22	1.06	1	4	37	5.6	27	44	107.24	108.48	3	290	5.83	3.5	0	15
5	12	3	0.74	2	4	34.08	4.7	26	40	419.47	86.25	284	502	13.42	4.06	8	20
All	96	3.27	0.98	1	5	36.73	5.55	26	44	350.48	354.66	0	1497	10.22	11.6	0	71
Cluster	Size	Nyala sightings				Impala sightings				Baboon sightings				Vervet Monkey sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	26	1.65	2.21	0	7	1.54	2.18	0	7	1.08	1.52	0	7	0.42	0.76	0	3
2	7	13.1	10.3	2	30	8.86	9.15	2	29	4	1.63	2	7	3.29	3.15	0	9
3	33	1	1.41	0	6	1.36	2.04	0	9	0.88	1.17	0	4	0.97	1.36	0	5
4	18	2.11	2.45	0	11	0.11	0.32	0	1	1.5	0.92	0	3	0.94	1	0	3
5	12	3.83	3.21	1	11	3.67	2.15	0	8	1	1.54	0	4	0.42	0.51	0	1
All	96	2.62	4.53	0	30	2.01	3.63	0	29	1.29	1.51	0	7	0.92	1.46	0	9
Cluster	Size	Elephant sightings				Kudu sightings				Buffalo sightings				Warthog sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	26	1.65	2.64	0	10	0.27	0.53	0	2	0.27	0.53	0	2	0.38	0.64	0	2
2	7	1	1	0	3	2.43	3.6	0	10	1	0.82	0	2	4.86	3.34	0	9
3	33	0.18	0.58	0	3	0.18	0.46	0	2	0.21	0.65	0	3	0.45	1.77	0	10
4	18	0.22	0.43	0	1	0.11	0.32	0	1	0.06	0.24	0	1	0.28	0.57	0	2
5	12	0.42	0.51	0	1	0.5	0.8	0	2	0.08	0.29	0	1	0.67	0.78	0	2
All	96	0.68	1.57	0	10	0.4	1.18	0	10	0.24	0.58	0	3	0.75	1.83	0	10
Cluster	Size	Zebra sightings				* Red values indicate the cluster with the highest values for each variable and green values indicate the values in the cluster with the lowest values for each variable.											
		Mean	Standard Deviation	Min	Max												
1	26	0	0	0	0												
2	7	0.57	0.79	0	2												
3	33	0.03	0.17	0	1												
4	18	0	0	0	0												
5	12	1.5	0.67	1	3												
All	96	0.24	0.59	0	3												

Figure 53 and Figure 54 show the composition of the five clusters when the mean for each environmental variable is taken. Figure 55 shows the composition of the five clusters in terms of the mean number of sightings of the nine most common mammal species.

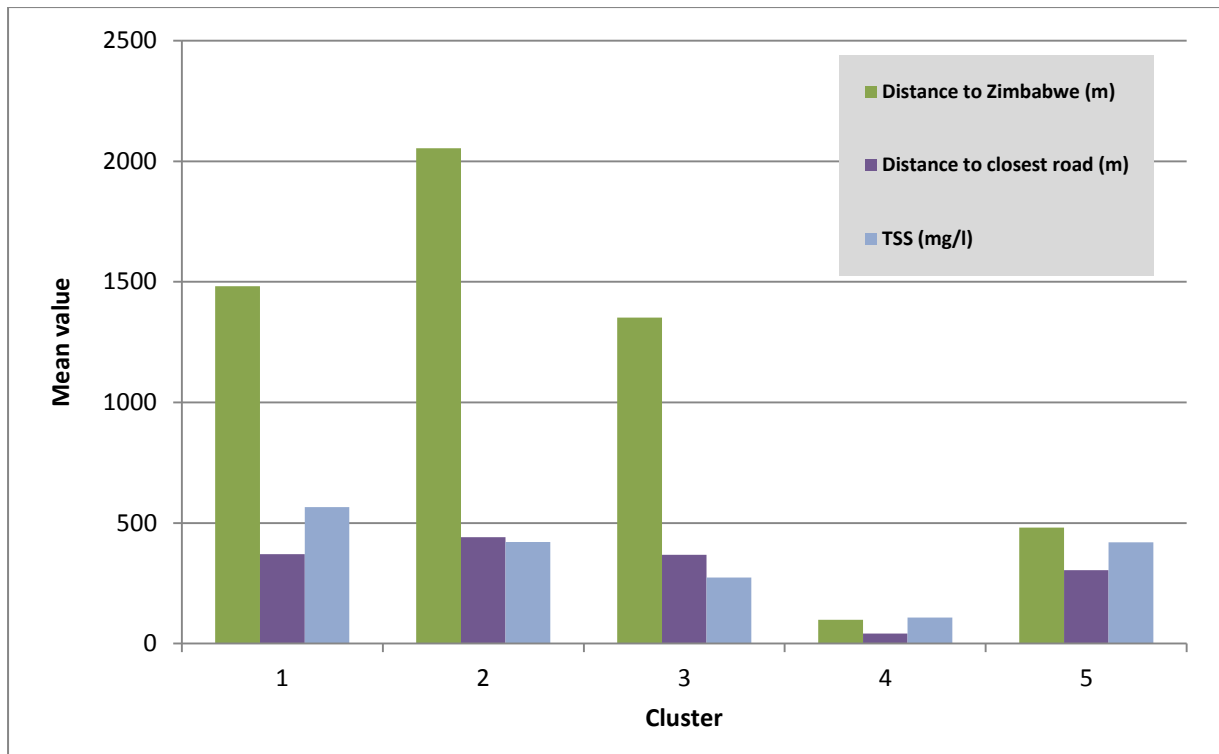


Figure 53: Mean distance to Zimbabwe, distance to the closest road and TSS for species clusters 1 to 5

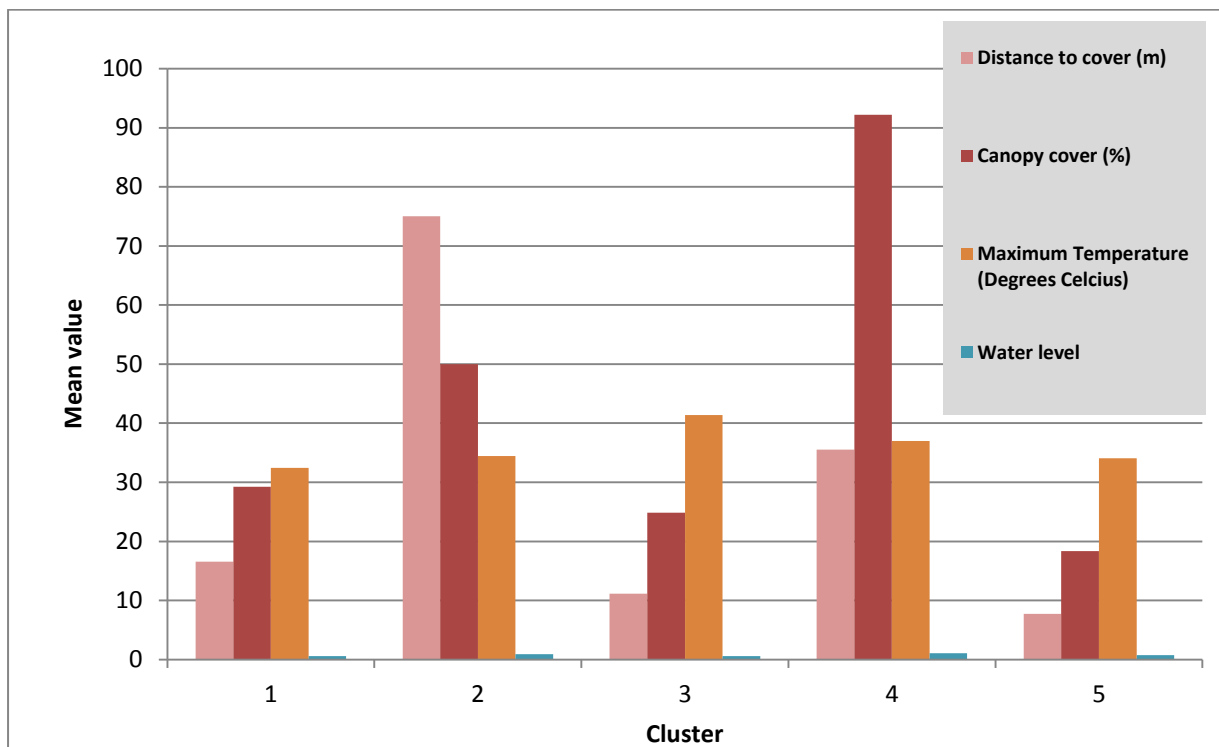


Figure 54: Mean distance to cover, percentage canopy cover, maximum daily temperature and water level for species clusters 1 to 5

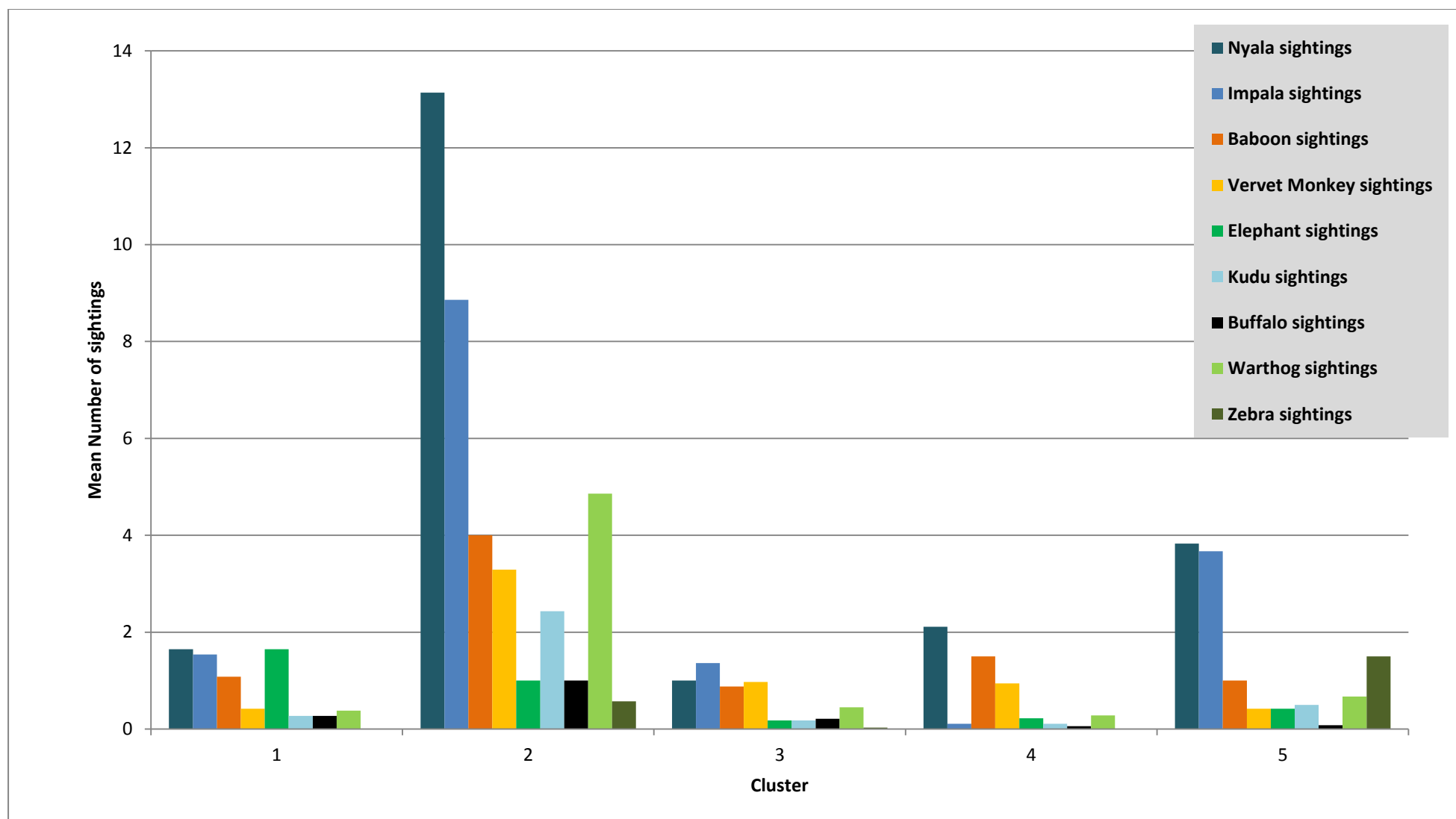


Figure 55: Mean number of sightings of the nine most common mammal species making up clusters 1 to 5

The dendrogram, or tree diagram, illustrates the arrangement of the 5 clusters produced by hierarchical clustering (Figure 56). Indicating how the clusters are “related” helps to tease out which environmental variables are driving the formation of the various clusters and as a result which mammal species are selecting for or against those variables. The left row of nodes represents data (individual camera trap observation sites), and the remaining nodes represent the clusters to which the data belong, with the lines representing the distance (dissimilarity). The height of each node in the plot is proportional to the value of the intergroup dissimilarity between its two daughters. Clusters 1 and 5 are “similar” showing average distances to access roads and relatively low maximum average ambient temperatures (Table 8). Clusters 3 and 4 are “similar” showing low overall mammal sightings. These four clusters are then linked and cluster 2 is least like any of the other four recording the highest overall number of mammal sightings (Figure 56).

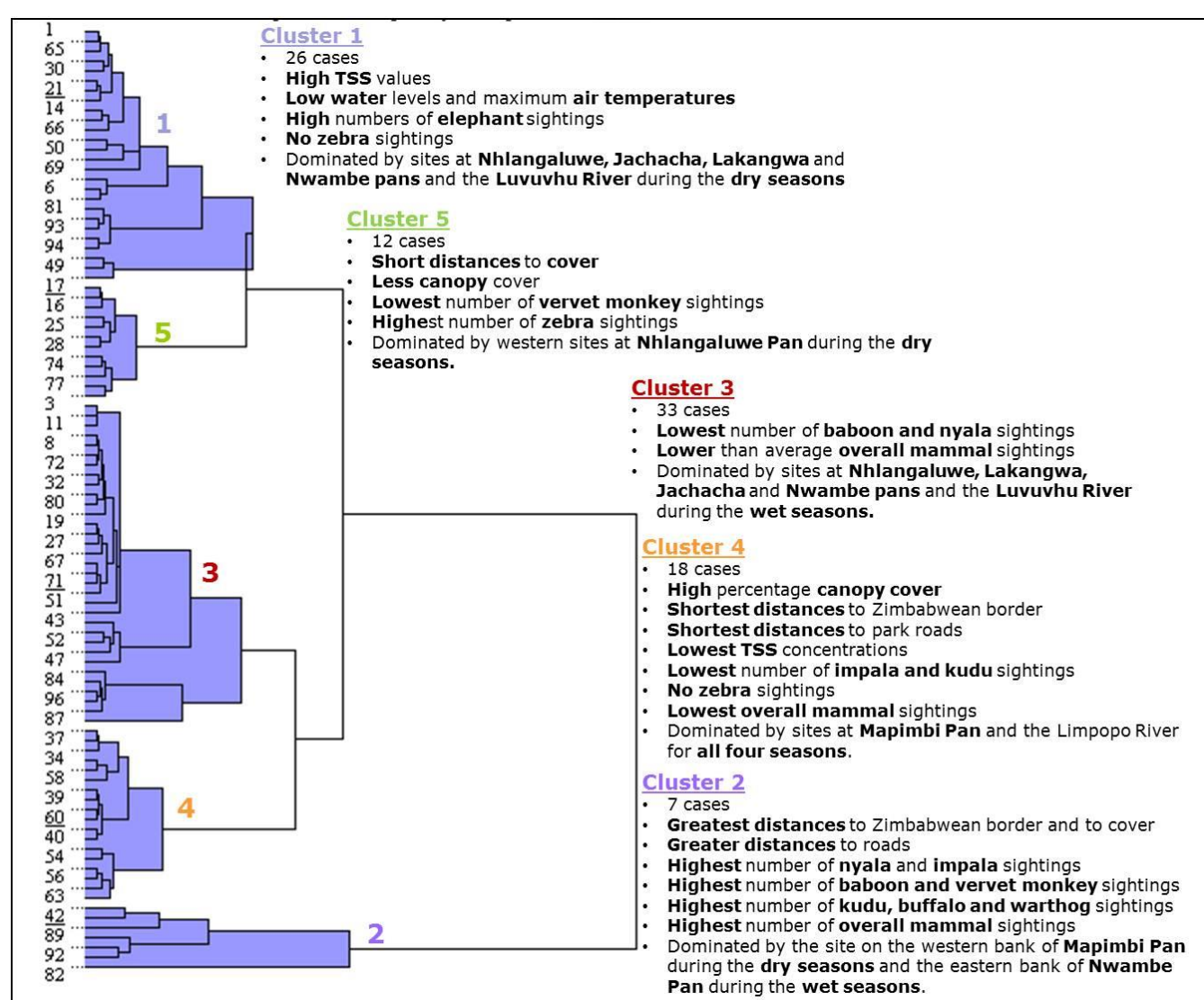


Figure 56: Dendrogram (tree diagram) showing the relationships among clusters 1 to 5

Cluster 1:

Cluster 1 consists of 26 sites and is characterised by the highest TSS values recorded (mean of 565.9mg/l and a maximum of 1497mg/l) (Table 8 and Figure 53). This cluster is also characterised by low water levels (mean of a category 2.46) and relatively low maximum daily ambient air temperatures (mean of 32.5°C) (Table 8 and Figure 54). This indicates that the majority of the sites in this cluster were recorded in the dry (winter) season. This cluster is also characterised by high numbers of elephant sightings (mean of 1.65 sightings per site and a maximum of 10 sightings at one site), yet no zebra sightings were recorded in this cluster (Table 8 and Figure 55).

Elephants, particularly herds, are very water dependant and are known to select for clean water where possible (Singh and Chowdhury, 1999; Matson, 2006; Smit et al., 2007b), so it is interesting that this cluster also shows the highest TSS concentrations. However, during the dry season higher TSS concentrations would be expected as there is no rainfall to dilute the water sources. Reduced water availability means the remaining water sources are used more often, resulting in the churning up of sediment by animals while drinking and wallowing, particularly in the pans. Within this cluster, the Luvuvhu River records the highest numbers of elephant sightings, which would be expected as the river water is cleaner (lower TSS concentrations, Section 5.1.3). It also shows that during the dry season, the elephants do not have access to as many water sources, as the Limpopo and many of the seasonal pans are dry. Elephants may therefore be forced to drink from water sources with a higher TSS concentration than they would usually select for. Specifically within the more stagnant pans, the elephants themselves may contribute to the increased TSS values if they wade through or wallow in the water. This cluster indicates that Jachacha, Nhlanguwe, Lakangwa and Nwambe pans and the Luvuvhu River are probably important sources of water for elephants during the dry season. This is evident as a Pearson's two-tailed correlation indicates the significant negative correlation between the overall elephant sightings and maximum daily air temperature ($P=0.01$) ($r_{\text{calc}}=0.269$; $r>0.261$). The absence of zebra sightings does not appear to be due to the season or high TSS, as neither correlate significantly with the overall zebra sightings recorded.

Cluster 2:

Cluster 2 is least like any of the other four clusters (Figure 56). The cluster consists of only seven sites which are characterised by greater distances to the Zimbabwean border (mean of 2054.6m) and greater distances to roads within the area (mean distance of 441.1m to the closest road) (Table 8 and Figure 53). The cluster is also associated with the greatest distances to cover (mean 75m). This cluster indicates the highest number of nyala sightings (mean of 13.1 sightings and a maximum at one site of 30 sightings); the highest number of impala sightings (mean of 8.86 sightings at each site); the highest number of baboon sightings (mean of 4 sightings); the highest number of vervet monkey sightings (mean of 3.29 sightings); the highest number of kudu sightings (mean of 2.43 sightings); the highest number of buffalo sightings (mean of 1 sighting per site); as well as the highest record of warthog sightings (mean of 4.86 sightings per site) (Table 8 and Figure 55). Consequently, cluster 2 records the highest number of total mammal

sightings (mean of 43.7 sightings and a maximum of 71 sightings at one camera trap site at Nwambe pan) (Figure 55 and Figure 57).

The high numbers of sightings of the species associated with this cluster indicates that these species are selecting for the same water sources. A Pearson's two-tailed correlation of the full dataset indicates that overall, mammal species are selecting to use water sources that are at greater distances from the Zimbabwe border, as Cluster 2 suggests ($P=0.05$; $r_{\text{calc}}=0.2029$; $r>0.201$). There is a highly significant (99% confidence) positive relationship between the distance to cover and the overall mammal sightings recorded ($P=0.01$, $r_{\text{calc}}=0.3703$; $r>0.2610$). Mammals generally seem to be selecting to drink at sites where there is greater distance to cover, most likely to reduce their chances of being ambushed by predators while accessing the water or drinking (Wakefield and Attum, 2006; Periquet et al., 2010). Although cluster 2 suggests that animals are also selecting to drink from areas that are at greater distances from the roads, this relationship is not significant ($P=0.05$; $r_{\text{calc}}=0.1508$; $r<0.201$). The seven sites within this cluster are located at Mapimbi (2 sites) and Nwambe pans (4 sites), and the Luvuvhu River (1 sites), all of which are associated with exposed earth near the water's edge (large distances to cover) (Figure 57). The fact that the smallest cluster (fewest sites) consists of the greatest number of sightings, suggests that mammals are selecting to drink at Mapimbi and Nwambe pans and the Luvuvhu River during the dry seasons and Nwambe Pan during the wet seasons.

Cluster 3:

Cluster 3 is the largest cluster, consisting of 33 camera trap sites (Table 8). These sites are characterised by high water levels (mean of 4.12) and high maximum daily temperatures (mean of 41.4°C) (Table 8 and Figure 54). This indicates that the majority of the sites in this cluster were recorded during the wet (summer) season. This cluster shows the lowest number of nyala (mean of 1 sighting per site) and baboon sightings (mean of 0.88 sightings per site). When compared to the other clusters, this cluster shows lower than average overall mammal sightings (mean of 5.97 mammal sightings per site) (Table 8 and Figure 55).

Baboon and nyala sightings show a significant correlation ($P=0.01$; $r_{\text{calc}}=0.2664$; $r>0.2617$), indicating that they are selecting for and against the same water sources (Figure 55). The overall low mammal sightings in this cluster is most likely due to the fact that this cluster is dominated by data collected during the wet season when there is more surface water available for mammals to choose from. This is evident as there is a significant negative correlation between total mammal sightings and water level ($P=0.01$; $r_{\text{calc}}=0.2650$; $r>0.2617$), as well as mammal sightings and maximum daily temperature ($P=0.05$; $r_{\text{calc}}=0.2055$; $r>0.2006$).

Cluster 4:

Cluster 4 consists of 18 camera trap sites. This cluster is associated with high percentages of canopy cover (mean of 92% cover), the shortest distances to the Zimbabwean border (mean of 98.33m) and the shortest distances to the closest road within the area (mean of 40.78m) (Table 8, Figure 53 and Figure 54). The lowest TSS concentrations are recorded in this cluster (mean of

107.2mg/l). The lowest number of impala (mean of 0.11 sightings) and kudu sightings (mean of 0.11 sightings), and no zebra sightings were recorded in this cluster. The cluster is associated with the lowest overall mammal sightings with a mean of 5.83 sightings per site (Table 8 and Figure 55).

Kudu and impala sightings are significantly correlated ($P=0.01$; $r_{\text{calc}}=0.7879$; $r>0.2617$), indicating that they are selecting for similar drinking sites. The low overall mammal sightings in this cluster could be attributed to the short distances to the Zimbabwean border, as there is a significant negative correlation between mammal sightings and the distance to the border, as was also indicated in cluster 2 ($P=0.05$; $r_{\text{calc}}=0.2029$; $r>0.201$).

Cluster 5:

Cluster 5 consists of 12 camera trap sites. This cluster is associated with shorter distances to cover (mean of 7.75m) and low percentages of canopy cover (mean of 18.3%) (Table 8, Figure 53 and Figure 54). The lowest number of vervet monkeys was recorded in this cluster (mean of 0.42 sightings), but the highest recorded number of zebra sightings (mean of 1.5 sightings and a maximum of 3 sightings at one site) (Figure 55 and Table 8).

Vervet monkeys appear to be selecting for sites with trees and a greater percentage of canopy cover, as there is a significant correlation between vervet monkey sightings and tree cover at the edge of the pans ($P=0.01$; $r_{\text{calc}}=0.3757$; $r>0.3017$). Clusters 1 and 5 are closely “related” on the dendrogram (Figure 56), however, cluster 1 records no zebra sightings and cluster 5 records the highest number of zebra sightings. Zebras are therefore probably selecting for the pan characteristics evident in Cluster 5 that are not present in cluster 1, such as less canopy cover. Zebras show a significant positive correlation with the amount of grass cover at the edge of each pan ($P=0.01$; $r_{\text{calc}}=0.3165$; $r>0.3017$) and a significant negative correlation with tree height at the edge of the pans ($P=0.05$; $r_{\text{calc}}=0.2967$; $r>0.2319$). This cluster is dominated by sites on the western bank of Nhlanguwe Pan, which falls within the Limpopo floodplain grassland, and suggests that this may be the zebras preferred habitat in the area.

Spatial and seasonal distribution of mammal species clusters 1 to 5:

Figure 57 depicts the spatial and seasonal distribution of clusters 1 to 5 across the seven water sources studied within the Makuleke region. The dry season and end of the dry season, when there is less surface water available in the region, are dominated by cluster 1 along the Luvuvhu River, Nwambe Pan, and the pans within the Limpopo floodplain grassland (Figure 57). Cluster 1 is associated with high numbers of elephant sightings and no zebra sightings. During the dry seasons, Mapimbi Pan and the sites along the Limpopo River are dominated by cluster 4, which is associated with low overall mammal sightings and shorter distances to the Zimbabwean border (Figure 57). The western bank of Mapimbi Pan, however, is associated with cluster 2 during the dry seasons (Figure 57). This cluster shows the highest number of recorded mammal sightings. Nhlanguwe Pan is associated with cluster 5 during the dry seasons, which shows the lowest number of vervet monkey sightings, but the highest number of zebra sightings.

During the wet season and at the end of the wet season, when there is the most surface water available to mammals, the region is dominated by cluster 3 (Figure 57). Sites in cluster 3 are found along the Luvuvhu River, Nwambe Pan and the pans within the Limpopo floodplain grassland. Cluster 3 is associated with lower than average overall mammal sightings and particularly low nyala and baboon sightings. During the wet season, Mapimbi Pan and the Limpopo River are associated with cluster 4, indicating very low overall mammal sightings and shorter distances to the Zimbabwean border (Figure 57). Across all four seasons, Nwambe Pan is associated with a site in cluster 2 which indicates high numbers of overall mammal sightings and greater distances to the Zimbabwean border (Figure 57).

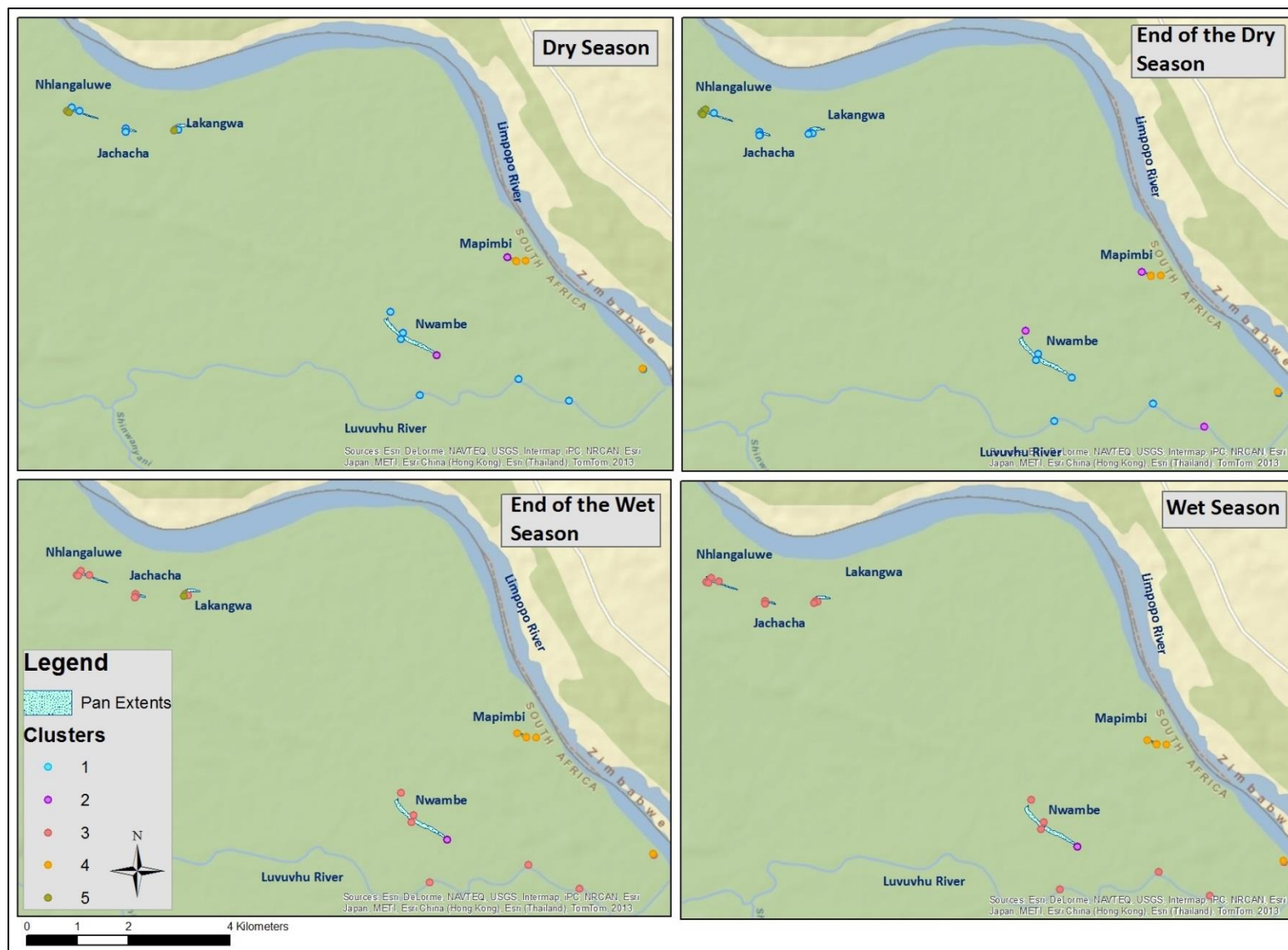


Figure 57: Spatial and seasonal distribution of species clusters 1 to 5

5.6.2 Clusters Using Mammal Groupings

In order to include all the data captured and to determine whether certain animal groupings showed any relationships with environmental factors, a cluster analysis was run, including mammal groupings, but excluding specific species. Seven clusters were found to be the most manageable and interpretable number of clusters using the available data (Thuiller et al., 2006). Seven clusters as per Table 9 were produced.

Table 9: Cluster summary of the seven clusters produced showing relationships between environmental variables and mammal groupings sightings at the studied water sources

Cluster	Size	Distance to cover (m)				Canopy cover (%)				Distance to Zimbabwe (m)				Distance to closest road (m)			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	29	9.03	18.47	0	100	25.17	22.93	0	80	1114.45	1191.82	0	3242	325.45	300.35	3	1078
2	8	30.13	43.47	1	100	60	37.03	20	100	1653.25	1532.67	0	3242	402.25	532.57	15	1243
3	15	35.47	47.25	2	100	90.67	12.23	70	100	106.2	89.76	0	177	45	55.47	15	181
4	3	35	56.31	1	100	20	26.46	0	50	1598	1352.73	817	3160	326.67	100.75	268	443
5	6	85	36.74	10	100	48.33	16.02	20	70	1870.33	1480.35	177	3160	307.5	148.76	154	443
6	1	15	0	15	15	60	0	60	60	3160	0	3160	3160	1243	0	1243	1243
7	34	11.47	23.21	0	100	24.41	22.72	0	80	1139.59	1130.41	0	3242	348.5	318.63	3	1243
All	96	21.41	35.71	0	100	39.69	33.16	0	100	1094.38	1209.53	0	3242	304.67	325.79	3	1243
Cluster	Size	Water level				Maximum Temperature (°C)				TSS (mg/l)				Total mammal sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	29	2.52	0.57	1	3	32.9	3.74	26	38	534.79	445.97	3	1497	8.1	5.49	0	20
2	8	2.5	0.93	1	4	35.12	6.24	26	44	194.88	229.28	0	608	12.5	7.41	4	26
3	15	3.47	0.92	1	4	37.53	5.53	27	44	111.62	106.11	3	290	5.67	3.66	0	15
4	3	2.67	0.58	2	3	28.33	4.04	26	33	591	531.74	284	1205	14	2	12	16
5	6	3	0.89	2	4	34.67	6.62	26	44	290.22	247.68	3	608	39.17	12.07	24	53
6	1	2	0	2	2	33	0	33	33	1205	0	1205	1205	71	0	71	71
7	34	4.15	0.5	3	5	41.24	2.39	38	44	299.53	242.11	0	864	6.26	5.06	0	18
All	96	3.27	0.98	1	5	36.73	5.55	26	44	350.48	354.66	0	1497	10.22	11.6	0	71
Cluster	Size	Small carnivore sightings				Large carnivore sightings				Total carnivore sightings				Small herbivore sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	29	0.03	0.19	0	1	0.03	0.19	0	1	0.07	0.26	0	1	0.59	0.73	0	2
2	8	1.25	0.46	1	2	0	0	0	0	1.25	0.46	1	2	1	1.6	0	4
3	15	0.13	0.35	0	1	0	0	0	0	0.13	0.35	0	1	0.47	0.64	0	2
4	3	0	0	0	0	2.67	0.58	2	3	2.67	0.58	2	3	2.33	0.58	2	3
5	6	0.17	0.41	0	1	0.17	0.41	0	1	0.33	0.52	0	1	6.67	2.94	2	10
6	1	0	0	0	0	2	0	2	2	2	0	2	2	0	0	0	0
7	34	0.06	0.24	0	1	0.06	0.24	0	1	0.12	0.33	0	1	0.74	1.75	0	10
All	96	0.17	0.43	0	2	0.15	0.54	0	3	0.31	0.65	0	3	1.08	2.03	0	10
Cluster	Size	Medium herbivore sightings				Large herbivore sightings				Total herbivore sightings				Primate sightings			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
1	29	4.55	4.69	0	17	1.59	2.35	0	10	6.72	5.09	0	19	1.31	1.69	0	8
2	8	4.75	4.23	0	13	2	2.62	0	8	7.75	7.59	1	22	3.5	2.56	1	8
3	15	2.47	2.83	0	12	0.27	0.59	0	2	3.2	2.88	0	12	2.33	1.45	0	6
4	3	5.33	1.53	4	7	1	1.73	0	3	8.67	0.58	8	9	2.67	1.53	1	4
5	6	22	12.76	6	41	2.5	1.76	0	5	31.17	11.14	18	47	7.67	3.33	3	12
6	1	49	0	49	49	15	0	15	15	64	0	64	64	5	0	5	5
7	34	3.41	3.99	0	14	0.44	1.11	0	5	4.59	4.38	0	14	1.56	1.69	0	6
All	96	5.42	7.97	0	49	1.19	2.32	0	15	7.69	10.07	0	64	2.22	2.4	0	12

* Red values indicate the cluster with the highest values for each variable and green values indicate the values in the cluster with the lowest values for each variable.

Figures 58 to 60 show the composition of the seven clusters when the mean values for each environmental variable and mammal grouping in each cluster is used.

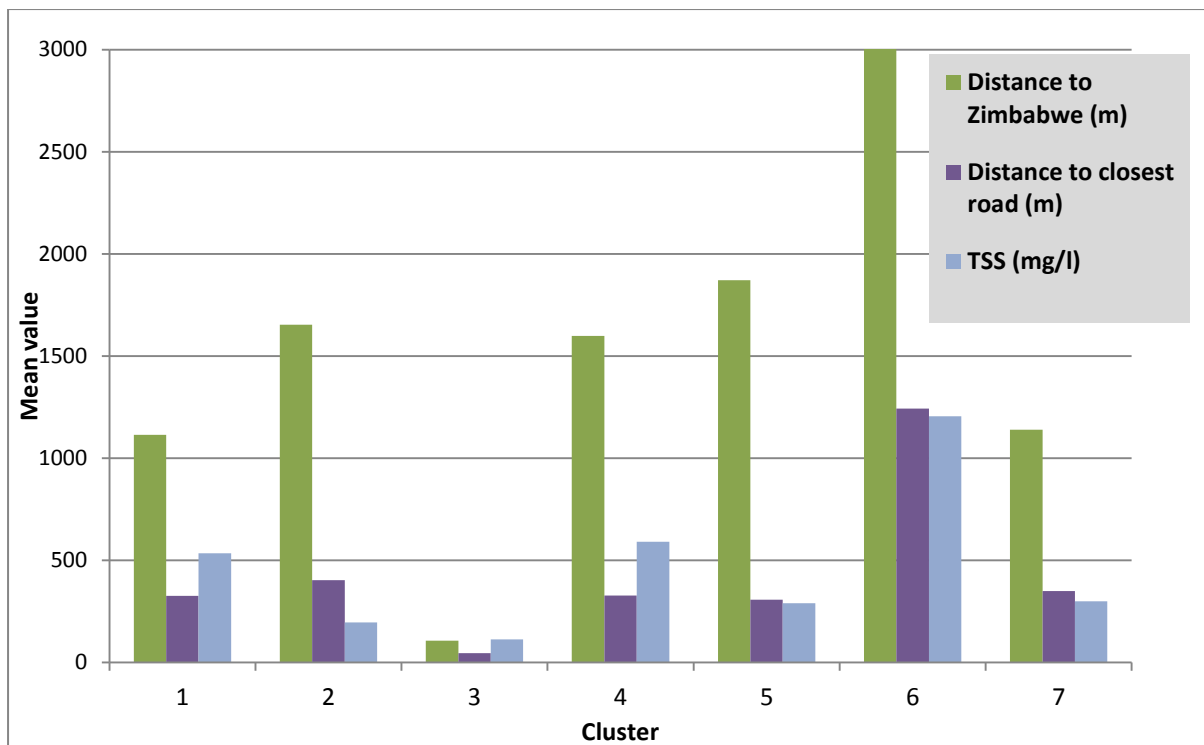


Figure 58: Mean distance to Zimbabwe, distance to the closest road and TSS for clusters 1 to 7

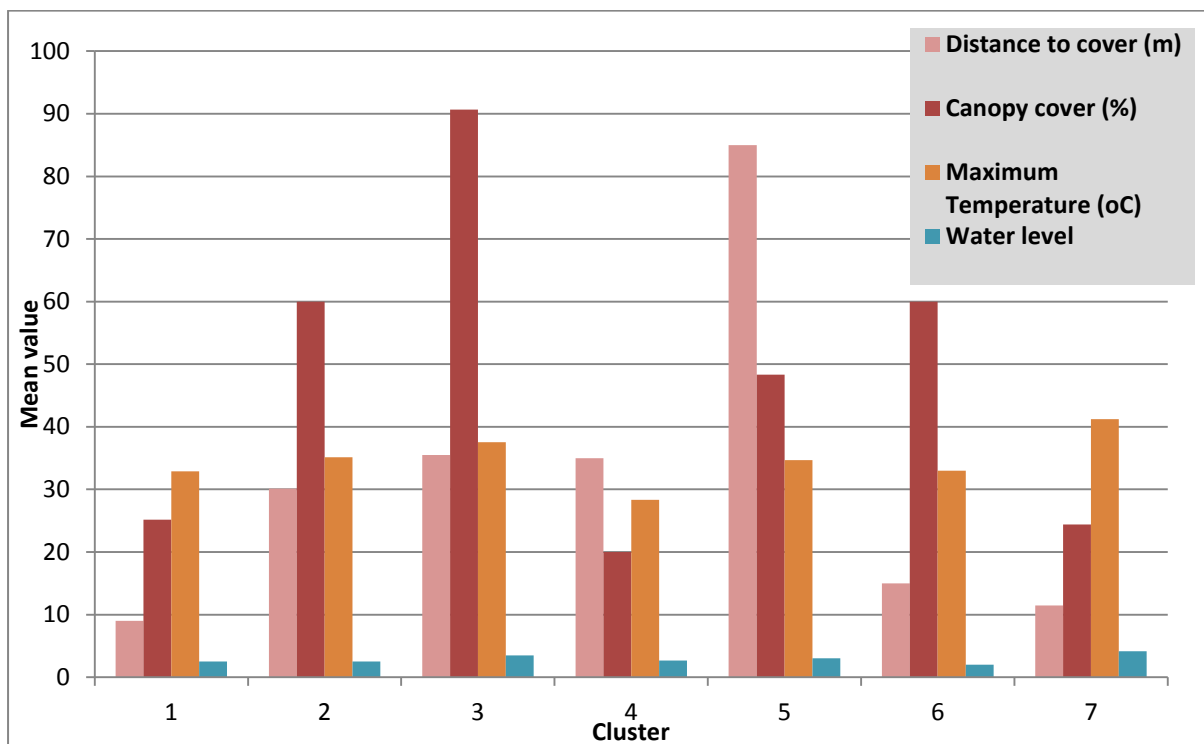


Figure 59: Mean distance to cover, percentage canopy cover, maximum daily temperature and water level for clusters 1 to 7

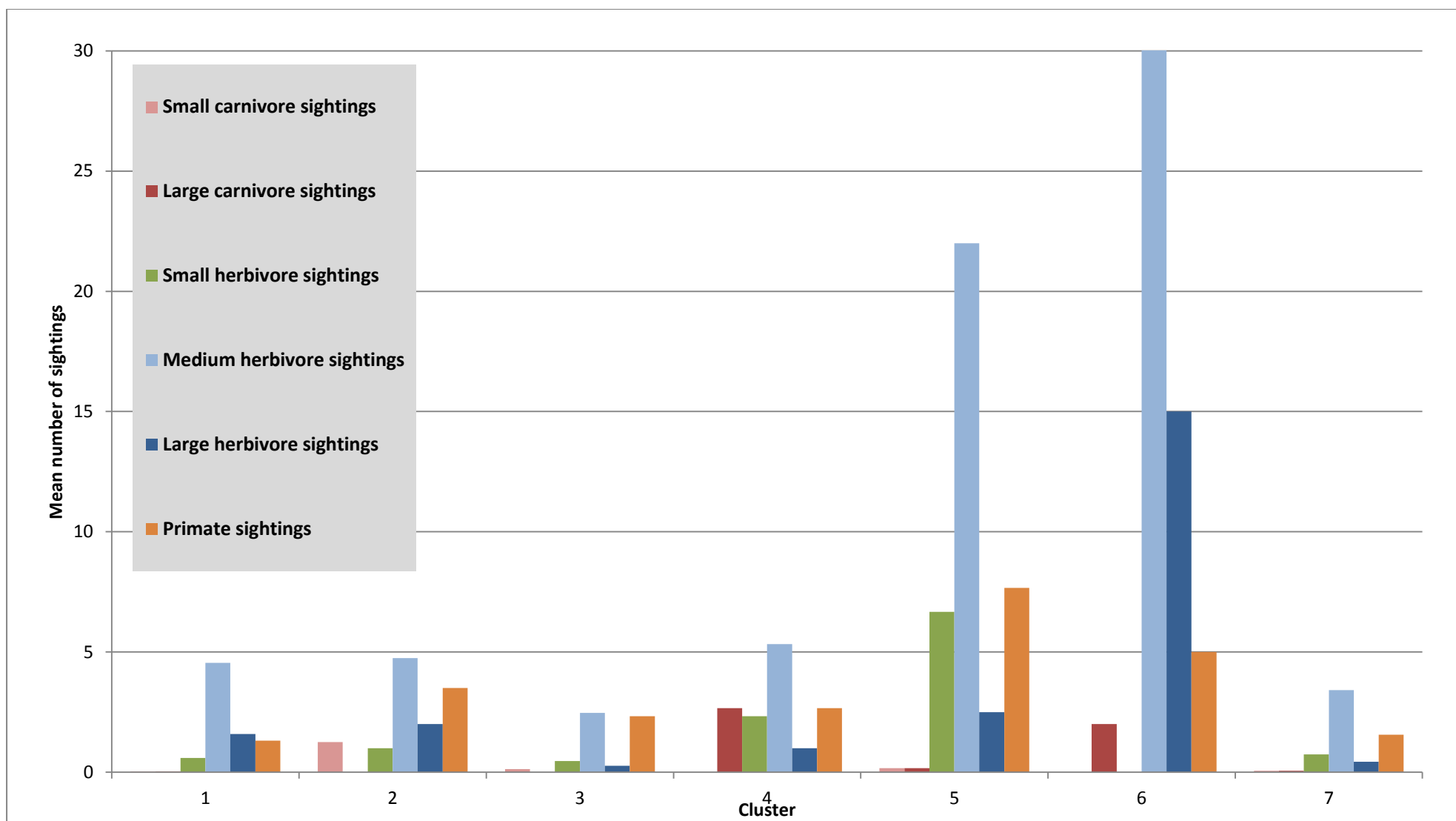


Figure 60: Mean number of sightings for each mammal grouping making up clusters 1 to 7

The dendrogram, or tree diagram, illustrates the arrangement of the 7 clusters produced by the hierarchical clustering of the mammal grouping data (Figure 61). The left row of nodes represents data (individual camera trap observation sites), and the remaining nodes represent the clusters to which the data belong, with the lines representing the distance (dissimilarity). The height of each node in the plot is proportional to the value of the intergroup dissimilarity between its two daughters. Clusters 3 and 7 are “similar” and both show low overall numbers of mammal sightings (Figure 56). Cluster 1 represents low numbers of primate sightings and is then most similar to clusters 3 and 7. Clusters 2 and 4 are “branched” together and show the highest number of small carnivore sightings and no small carnivore sightings respectively. Clusters 5 and 6 are then grouped together, but are least like any of the other 5 clusters. Clusters 5 and 6 show the highest numbers of overall mammal sightings (Figure 56).

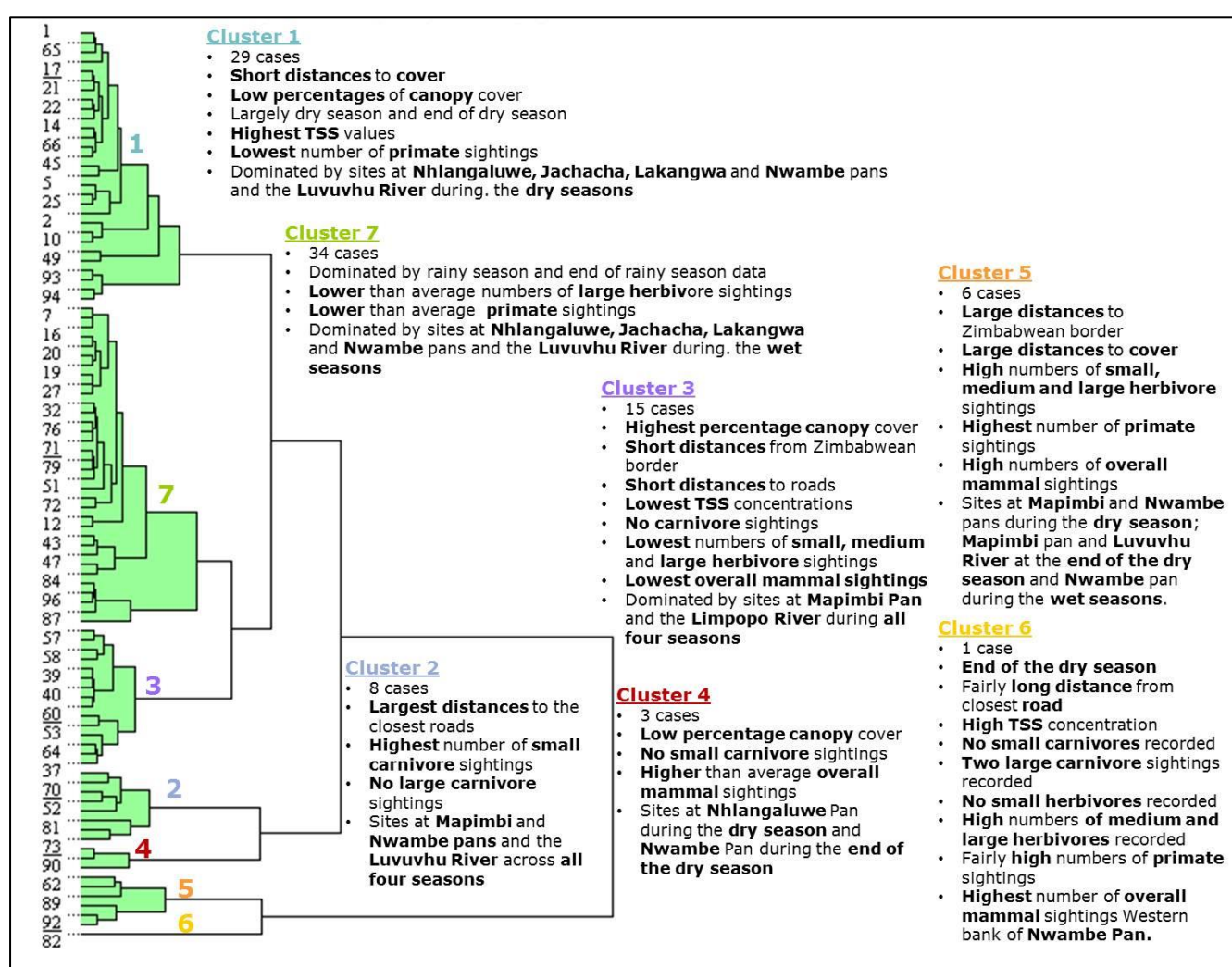


Figure 61: Dendrogram (tree diagram) showing the relationships among clusters 1 to 7

Cluster 1:

Cluster 1 consists of 29 camera trap sites and is characterised by relatively short distances to cover (mean of 9m) and a fairly low percentage of canopy cover (mean of 25%) (Figure 58 and Figure 59). This cluster has low water levels (mean of a category 2.5), which is indicative that the cluster is dominated by sighting records from the dry, and end of dry, season. This cluster shows the highest TSS values (mean of 535mg/l) and is associated with the lowest number of primate sightings (mean of 1.31) (Figure 60).

Primate species such as vervet monkeys may be selecting against these sites with shorter distances to cover as they prefer accessing water sources from more open areas where they are less likely to be ambushed by predators such as leopard (Pasternak, 2009). Primates may also be selecting against the sites in cluster 1 as they prefer areas with more trees (greater percentage canopy cover) in which they can scout for and escape from predators (Pasternak, 2009). This is also evident as there is a significant ($P=0.05$) relationship between primates and combined tree structure ($r_{\text{calc}}=0.271$; $r>0.232$). Primates may also be selecting against the sites in cluster 1 as they are selecting for cleaner water. A Pearson's two-tailed correlation indicates a negative correlation between primates and TSS as significant ($P=0.05$) and suggests that primates are selecting for cleaner, less muddy water ($r_{\text{calc}}=0.208$; $r>0.201$) (Figure 52).

Cluster 2:

Cluster 2 is made up of eight sites and is characterised by the largest average distance (402m) to the closest road utilised by lodges within the Pafuri concession (Figure 58). Cluster 2 has the highest number of sightings of small carnivores at any given site, with an average of 1.25 sightings per site across the eight sites. Although this cluster has the highest number of small carnivore sightings, no large carnivore sightings were recorded in this cluster (Figure 60).

Small carnivores such as genet are often shy and nocturnal (Skinner and Chimimba, 2005). Such species may therefore be selecting for water sources with less daily disturbance from human activity, such as sources that are a greater distance from the road networks and can only be accessed on foot. The fact that no large carnivores were recorded at the sites where most small carnivore sightings occurred, could also suggest that small carnivores may be selecting for areas that are not commonly utilised by larger carnivores, such as lions and leopards, to minimise their chances of dangerous, or even fatal encounters. Similar behaviour was observed by Fedriani et al. (2000) in North America, and by Kamler et al. (2012) in South Africa, between carnivore species with overlapping distributions.

Cluster 3:

Cluster 3 is made up of 15 of the total 96 sites. This cluster shows the highest average percentage of canopy cover ranging between 70% and 100%, with an average of 90.7% at the sites within this cluster (Figure 59). This cluster is also characterised by shorter distances from the Zimbabwean border (mean of 106m), as well as shorter distances from roads on the concession (mean of 45m) (Figure 58). Cluster 3 has the lowest TSS values (mean of 111mg/l) as well as the

lowest number of large carnivore (0 sightings), small herbivore (mean of 0.47 sightings), medium sized herbivore (mean of 2.47 sightings) and large herbivore sightings (mean of 0.27 sightings) (Figure 60). Thus, cluster 3 shows the lowest overall mammal sightings of the 7 clusters, with a mean of 5.7 sightings.

Cluster 3 indicates that the majority of mammals are not selecting for dense canopy cover where they choose to drink. It also implies that mammals are selecting against drinking sites that are in close proximity to the Zimbabwean border. With the exception of small carnivores and primates, all the mammal groupings showed low sighting numbers in this cluster. A Pearson's two-tailed correlation indicates the negative correlation between total mammal sightings and distance to the Zimbabwean border is significant ($P=0.05$), and suggests that mammals possibly associate Zimbabwe with danger as it is not a formally protected area ($r_{\text{calc}}=0.2029$; $r>0.201$). Although the sites in cluster 3 have the cleanest water (lowest TSS values), this does not seem to be an important enough driver to encourage mammals to select for these water sources.

Cluster 4:

Cluster 4 is only made up of 3 sites. These sites are characterised by low percentages of canopy cover ranging from 0% to 50% (Figure 59). Relatively low daily maximum temperatures ranging from 26°C to 33°C are associated with these sites, which suggests that the data were recorded during the dry season (winter). No small carnivore sightings occur within this cluster, however, the overall number of mammal sightings is higher than the mean of all the combined clusters (mean of 14 sightings per site) (Figure 60).

The relatively high number of overall mammal sightings is probably largely due to the fact that these three sites were recorded during the dry season when there is less surface water readily available for wildlife to drink from. The fact that no small carnivores were recorded in this cluster may be due to the low percentage canopy cover as most small carnivores select for cover as they take refuge in trees and shrubs during the day (Skinner and Chimimba, 2005); however, this relationship is not found to be significant ($P=0.05$, $r_{\text{calc}}=0.199$; $r<0.2319$).

Cluster 5:

Cluster 5 consists of six sites and is characterised by greater distances to the Zimbabwean border (mean of 1870m) and greater distances to cover (mean of 85m) relative to the other clusters (Figure 58). This cluster displays high numbers of small, medium and large herbivores (mean sightings of 6.67, 22 and 2.5 respectively), as well as the highest recorded primate numbers (mean of 7.67 and a max of 12 sightings) (Figure 60). With the exception of cluster 6, cluster 5 displays the highest overall number of mammal sightings, with a mean of 39.17 sightings and a maximum of 53 sightings at one site.

This cluster again suggests that herbivores and primates are selecting for water sources that have greater distances to cover at the water's edge (see cluster 1). This is possibly due to the fact that they prefer to be able to see greater distances when drinking as they are less likely to be

ambushed by predators when they are most vulnerable (Wakefield and Attum, 2006; Periquet et al., 2010). Cluster 5 also emphasises the results of cluster 3, which suggests that mammals are selecting for water sources at greater distances from the Zimbabwean border, along which there is more human activity and trophy hunting (CESVI, 2002) (see cluster 3).

Cluster 6:

Cluster 6 only comprises one site which was positioned at Nwambe Pan at the end of the dry season (Figure 62) and has very high numbers of mammal sightings, unlike any of the other 95 sites (Figure 60). This site is a considerable distance (1243m) from the closest road, as Nwambe Pan can only be accessed on foot. The low water level (2) supports the fact that this site was recorded during the dry season (Figure 59). This site shows a high TSS value (1205mg/l). No small carnivores were recorded at this site, yet two sightings of large carnivores were recorded. Although no small herbivores were recorded, high numbers of medium (49 sightings) and large herbivores (15 sightings) were recorded (Figure 60). Fairly high numbers of primates were also sighted (5 sightings). The overall total mammal sightings at this site (cluster 6) is the highest recorded at 71 sightings (Figure 60). Nwambe Pan is therefore an important source of water for mammals in the Makuleke area during the dry season and the muddy water (high TSS) does not deter them from using the pan and may in fact be a result of disturbance due to higher drinking activity at the pan.

Cluster 7:

Cluster 7 is the largest cluster consisting of 34 sites. This cluster is characterised by relatively high water levels (mean of 4.15) and maximum daily temperatures (mean of 41.24°C) (Figure 59). This implies that the majority of the sites making up this cluster were recorded during and towards the end of the rainy season. Cluster 7 also has lower than average sightings of large herbivores (mean of 0.44 sightings) and a lower than average number of primate sightings (mean of 1.56) (Figure 60).

This cluster does not show particularly high numbers of any mammal grouping. This is probably because during the wet season, mammals rely less on the perennial pans in the Makuleke area, as there is more surface water available in the non-perennial pans and streams. Primates may also obtain more moisture from their diets, which probably comprise of more fruits in the rainy season (Skinner and Chimimba, 2005; McDougall et al., 2010). Large herbivore sightings decreased during the rainy season, particularly with regard to elephant sightings.

Spatial and seasonal distribution of mammal groupings for clusters 1 to 7:

Figure 62 depicts the spatial and seasonal distribution of mammal grouping clusters 1 to 7. The dry seasons are dominated by sites associated with cluster 1, particularly around the pans within the Limpopo floodplain grassland, and the northern and southern banks of Nwambe Pan. Cluster 1 is indicative of short distances to cover, low percentages of canopy cover and the lowest number of primate sightings. During the wet seasons, the area is dominated by cluster 7. Cluster 7 is indicative of low numbers of large herbivore sightings, lower than average numbers of primate

sightings and relatively low overall mammal sightings. Cluster 5, which is associated with the highest number of overall sightings, is associated with Nwambe Pan in both the dry and wet seasons, and the western bank of Mapimbi Pan, and the eastern-most locality along the Luvuvhu River during the dry seasons. During the end of the dry season, the western bank of Nwambe Pan forms cluster 6. This cluster only consists of one site which recorded the highest number of overall mammal sightings throughout the study (Table 9). This is therefore an important source of drinking water during the end of the dry season for many mammal species.



Figure 62: Spatial and seasonal distribution of mammal grouping clusters 1 to 7

6. DISCUSSION

A total of 27 mammal species were recorded utilising the perennial water sources within the Makuleke Wetland System, during this study (Appendix D). Overall, 981 mammal sightings were recorded during 4 608 hours of camera trap surveillance. From these results, the possible influence of pan characteristics such as water quality, vegetation structure and cover, and the extent of human access and activity are discussed, and the most popular perennial water sources for mammals within the Makuleke Concession area are determined.

6.1 Seasonal Variations in Water Quality and Mammal Water Quality Preferences

The quality of the perennial surface water sources in the Makuleke study area fluctuates seasonally. The pans in particular, as they are less influenced by rainfall in the greater catchment and activities upstream, tend to get more alkaline and have higher TSS and EC concentrations during the dry season (Figure 29). Nwambe Pan and the Luvuvhu River never exceeded the recommended pH limit for livestock during the study period, whereas other water sources exceeded the limit, mostly during the dry season. The DWAF recommended EC limit for livestock drinking was never reached at any of the studied water sources during the study area. The only studied ions that ever exceeded the DWAF recommended maximum limit for livestock drinking were iron (Fe), aluminium (Al), cadmium (Cd) and nitrites (NO_2^-). These concentration limits were only ever exceeded within the pan system, never within the rivers, and can all be explained through natural processes. The concentrations of ions are likely to become higher within the pans, as the pans are relatively stagnant systems, especially during the dry season when rainfall, baseflow and surface channels linking flow from the rivers are reduced (Ayeni, 1977).

According to SANBI (2004), the Luvuvhu River is considered to be “endangered” and the Limpopo River is considered to be “critically endangered” (Driver et al., 2004). It is therefore encouraging that, even in these lower river reaches of the Limpopo and Luvuvhu, there was no evidence of harmful concentrations of any of the ions analysed that may have been caused by human activities, such as agriculture and mining upstream of the Makuleke region. The Tshikondeni Coal Mine, for example, is located just upstream of the KNP, along the Luvuvhu River. While the mine is operational, unwanted water is pumped out of the coal workings. It will therefore be interesting to monitor what impact the coal mine has on the Luvuvhu River water quality when pumping ceases, once the mine has closed and the risk of acid mine drainage becomes greater (Mining, Minerals and Sustainable Development, 2001). The cessation of surface flow within the Limpopo River in the study area during the dry season is debatably due, at least partly, to the amount of extraction by human activities upstream (Deacon, 2007). In this regard, human activities upstream have an impact on the surface water sources within the study area, in terms of availability. This baseline water quality information on the Makuleke Wetland System is therefore important as it is essential for park management to monitor and try to reduce the negative impacts of upstream users on the rivers flowing through the park, not only for biodiversity conservation and ecological integrity, but

also for tourism satisfaction and associated revenue (Turpie and Joubert, 2001; Kingsford et al., 2011).

None of the water quality ions tested for, show any significant correlations to mammal sightings, at a 99% confidence level. Primate sightings were significantly lower with an increase in calcium concentration in the water (with 95% confidence). Herbivore sightings are positively correlated with boron concentration in the drinking water (with a 95% confidence level). Perhaps then, as previous studies have suggested (Aveni, 1977; Redfern, 2005 and Wanke and Wanke, 2007), herbivores may augment a low mineral status (e.g. boron) within their diets by drinking from mineralised sources, particularly during the dry season. The cluster analyses also indicate that primates may be selecting for less muddy drinking sites (lower TSS values) where possible. Sulphate concentration in the drinking water had a significant negative correlation with the total number of mammal sightings recorded, and the overall herbivore sightings at each pan or river. Sulphates have an adverse effect on the palatability of water, even below the concentration that causes acute toxic effects. Sulphates often cause diarrhoea in stock that are not adapted to sulphate waters (DWAF, 1996). It is thus possible that mammals generally, but specifically herbivores, are selecting against water sources with raised sulphate concentrations, as it affects the taste of the water (Table 5). Apart from the associations listed above, mammal species do not appear to be strongly (none with 99% confidence) selecting for or against any particular elements or ions within the water sources. This may be influenced by the fact that during the dry season, when water within the study site is most mineralised, the studied perennial pans are the only water sources available for mammal species to use. The cluster analyses indicate that sites with the least muddy water (lowest TSS values) are often associated with the lowest overall numbers of mammal sightings. This association, however, is likely due to the activity of the mammals themselves (particularly herbivores) while drinking along the edges of the water sources, thus disturbing the sediment and increasing the TSS (Laporte and Behrensmeier, 1980; Hubbard et al., 2004). The turbidity produced by higher levels of activity, however, does not appear to deter mammals from utilising the more popular water sources. Although the trends indicate that mammals, particularly primates, may prefer to select for cleaner water as hypothesised, it is not a significant relationship. This is probably because clean water is not as easily accessible during the dry season, and that other environmental pressures such as predation and human disturbance, may play a more significant role in mammals' water source choices.

6.2 The Influence of Vegetation Cover at Pan Edges on Mammal Drinking Site Selection

The ordination (CCA), as well as the cluster analyses, suggest that both small carnivores and primates select for drinking sites with greater percentages of canopy cover (tree cover). This would be expected as many small carnivores (such as genets) take refuge in trees during the day, and primates (such as bushbabies, vervet monkeys and chacma baboons) take refuge in trees at night (Skinner and Chimimba, 2005). All of these species are known to be fairly arboreal and rely on climbing trees to escape danger, so would therefore select drinking sites with more trees

around the edges, enabling them with a means to escape from danger (predators or humans) (Lima and Dill, 1990; Skinner and Chimimba, 2005). Vervet monkeys in particular, seem to show a negative relationship with a decrease in canopy cover (species cluster 5), indicating that they are selecting for drinking sites with greater percentages of canopy cover. Primates in general are selecting for sites with less ground cover, but more canopy cover (cluster 1). Primates like trees to use as vantage points for sentinels and to escape danger. However, they are also selecting against sites with shorter distances to cover, as once on the ground, they prefer accessing water sources from more open areas where they are less likely to be ambushed by predators such as leopard (Pasternak, 2009). As suggested by Lima and Dill (1990), primates are selecting water sources and making behavioural decisions that decrease the probability of encounter, attack and capture, as well as time spent vulnerable to predation. Primates therefore appear to prefer water sources with large trees along the edges, but with little ground cover. Sites along the Luvuvhu and Limpopo rivers, as well as at Mapimbi and Nwambe pans, best fit the criteria and are most popular among primate species. Groupings cluster 5 also suggests that all herbivore size groupings and primates are selecting for water sources that have greater distances to cover at the water's edge. This is again probably due to the fact that these mammals prefer to be able to see greater distances when they have their heads down drinking, as they are less likely to be ambushed by predators when they are vulnerable (Wakefield and Attum, 2006; Periquet et al., 2010).

Interestingly however, the cluster analyses indicate that with the exception of primates and small carnivores, the sites with highest percentages of canopy cover are associated with the lowest overall number of mammal sightings. Small, medium and large herbivores and large carnivore species are therefore selecting for drinking sites with reduced canopy cover. Overall, however, mammals appear to be selecting for drinking sites with increased distances to ground cover. This conforms with Valeix et al. (2007) and Periquet et al. (2010) who suggest that prey species may select drinking sites where they are less likely to be ambushed by predators and they are more likely to see predators in advance.

Zebra are selecting for sites within the Limpopo floodplain grasslands with a greater percentage of grass cover and reduced tree cover. As would be expected, this indicates that the grasslands, as opposed to the well-established riparian vegetation areas, is the zebras preferred habitat within the Makuleke Concession area (Skinner and Chimimba, 2005).

The CCA also suggests that elephant sightings are associated with a reduction in shrub and tree cover. It cannot be determined from the plot, however, whether elephants are selecting for water sources with less tree and shrub cover at the water's edge, or if their use of those water sources is causing a reduction in tree and shrub cover. It is likely to be the latter, as camouflage from predators should not be a requirement for elephants (Franz et al., 2010; Reardon, 2012). Elephant herds were largely recorded at more open water sources, particularly along the Luvuvhu River, and may therefore select water sources that have larger open drinking points to accommodate a group, as they prefer to drink together.

6.3 The Influence of Human Access and Activity at Water Sources on Mammal Drinking Site Selection

One of the original research objectives was to determine to what extent human activity (as a result of location) influences the usage of pans and rivers by mammal species in the Makuleke Concession area. The cluster analyses strongly suggest that the distance to the Zimbabwean border (along the Limpopo River) may influence mammal drinking site selection. Species cluster 2 records the highest overall mammal sightings (in particular the highest numbers of nyala, impala, chacma baboon, vervet monkey, kudu, buffalo and warthog sightings) in conjunction with greater distances to Zimbabwe as well as increased distances from tourist roads within the concession. When a correlation was run on the entire data set, the distance to tourist roads was not found to have a significant effect on the number of mammal sightings recorded. However, an increase in the distance of a site from the Zimbabwean border does appear to have a significant effect on the number of mammal sightings recorded by that camera trap. Similarly, species cluster 4 indicates that the shortest distances to the Zimbabwean border and to roads in the area was associated with the lowest numbers of overall mammal sightings.

As discussed in Section 2.4.1, there are no fences separating the KNP in South Africa with the Sengwe Corridor in Zimbabwe. Animals are required to cross the Limpopo River, which during the dry months is easily accomplished due to highly reduced flow. The land on the Zimbabwean side is not formally protected and is accessed by local communities to obtain resources. Mammals therefore appear to be avoiding drinking sites with a higher risk of human activity (Wakefield and Attum, 2006). The local communities have agreed to set aside a strip of land parallel to the Limpopo River, free of villages, cultivation and livestock (CESVI, 2001). However, this strip along the river is known to be accessed for trophy hunting purposes (Section 2.4.1, Figure 5). During field work during this study, several fishermen were also found to have crossed the border to access pans along the Limpopo. There is thus evidence for some human activity along this border.

Groupings cluster 3 again indicated that sites closest to Zimbabwe were associated with the lowest overall numbers of mammal sightings, particularly with regards to small, medium and large herbivores and large carnivores. With the exception of small carnivores and primates, all species groupings sightings were lower when in closer proximity to the park boundary with Zimbabwe. There thus seems to be a strong case to suggest that herbivores and large carnivores in particular (most likely as they are the species most at risk from hunting), are selecting to use water sources that are further away from the Zimbabwean border (Limpopo River). It should also be taken into account that the only five elephant sightings (none of which were herds) recorded along the Limpopo during the study were all recorded after dark. This suggests that if elephants do choose to utilise or cross the Limpopo River into the Sengwe Corridor in Zimbabwe, they are choosing to do so under the cover of darkness when they possibly feel safer from human disturbance or trophy hunters. This behavioural change as a result of human activity was also previously observed in Kenya, where the elephants monitored spent more time at night than during the day, in areas under land use that presented a risk of mortality associated with human occupation (Graham et

al., 2009). Similarly, no buffalo sightings were recorded along the Limpopo River during the study period. This may also be due to buffalo avoiding the risks associated with Zimbabwe.

The cluster analysis (groupings cluster 2) associates increased distances to the closest tourist or access road with increased small carnivore sightings. Small carnivores, which are often shy, nocturnal creatures such as genets and civets, are possibly selecting water sources which are less frequently accessed by humans, and if so, those only on foot. This cluster is also associated with no large carnivore sightings. Avoidance of large carnivores may therefore also play a role in small carnivores' water source selection (Crosmar et al., 2012; Skinner and Chimimba, 2005).

6.4 Seasonal, Spatial and Temporal Drinking Preferences within the Makuleke Wetland System

The majority (36%) of mammal sightings recorded at the perennial water sources, within the Makuleke Wetland System, were recorded at the end of the dry season. Of the total mammal sightings, 29% were recorded during the dry season, with 18% and 17% of sightings being recorded during fieldwork conducted during the wet season and end of the wet season respectively. This pattern would be expected as during the wetter months, despite higher daily temperatures, other water sources also become available to mammals in the form of non-perennial pans and puddles. The water content available to herbivores and primates in their daily forage (preformed water) would also increase during the wet season (Wolff, 2001). Although mammals clearly depend more heavily on the perennial water sources during the dry seasons (combined 65% of sightings), they still utilise the water sources during the wetter seasons (combined 35% of sightings), confirming the year-round importance of this pan network.

The number of primate sightings (largely vervet monkeys and chacma baboons) did not fluctuate greatly between seasons (Figure 35). Their fairly regular usage of the pans and rivers suggests that they are a consistently important source of water, refuge and forage for primate species throughout the year. Similarly, herbivore species such as warthog and nyala seem to rely on the perennial pans and rivers all year round (Figure 43). Certain medium sized herbivore species such as kudu and zebra utilised the pans, particularly during the dry seasons, and appear to select for the pans as drinking sources over the rivers. It appears that zebra, in particular, are selecting for grass cover and reduced shrub and tree cover found at the pans, mostly within the Limpopo floodplain (as discussed in section 6.2). The highest numbers of kudu sightings were clustered with the highest number of overall mammal sightings associated with greater distances to cover, the Zimbabwean border and park roads (species cluster 2).

The perennial pans and rivers appear to be a significant water source during the dry months to large herbivore and large carnivore species, which display the greatest seasonal fluctuations. Only one large carnivore sighting (of the 14 sightings in total) was recorded during the wet season, and one at the end of the wet season accessing the selected water sources. Eland were only recorded utilising the perennial water sources during and at the end of the dry season. Buffalo are water

dependent and were recorded all year round, showing the greatest utilisation of perennial water sources at the end of the dry season and at the end of the wet season.

Elephants show the greatest demand for water during the dry seasons, with only eight of the 65 sightings (12%) recorded at the end of the wet season and not one elephant sighting recorded during the wet season. Elephants are known to be heavily water dependent, needing to drink every 48 hours, with bulls known to drink up to 200 litres a day (Reardon, 2012). Unlike the findings of Hayward and Hayward (2012) in the KNP and Pilanesberg, the elephants in the Makuleke region did not display a peak in drinking times at dusk. Elephants accessed the perennial water sources throughout the day and night. During the dry season, the amount of protein available from grasslands is reduced and elephants are known to seek out woody vegetation to supplement their nutritional requirements (van de Koppel and Prins 1998; Codron et al., 2006). In the KNP, elephants are known to congregate towards riparian areas during the dry season where both forage and water requirements are met (Young et al., 2009; Reardon, 2012). This study supports this pattern described by Young et al. (2009) and Reardon (2012). These seasonal migrations allow some time for the environment to recover between seasons of high elephant densities (Young et al., 2009; Reardon, 2012). This would explain the higher densities of elephants recorded within the Makuleke Wetland System during the dry seasons. According to research being conducted by the "Save the Elephants" organisation, movements out of the Makuleke concession area in the wet season are poorly understood, but it is assumed that the elephants move both southward within the KNP and northward into Zimbabwe (Henley et al., 2012). Elephant movement into Zimbabwe is obviously of relevance to the design of the Sengwe Corridor and the successful development of the Great Limpopo Transfrontier Park (Henley et al., 2012). The Makuleke Wetland System, and in particular the perennial water sources, therefore provide an important dry season refuge for the elephant population in northern KNP and the GLTP.

The majority of mammal sightings were recorded during the midday period (09:00-14:00) and late afternoon (14:00-19:00). The hour within the day that experienced the most mammal activity overall was between 13:00 and 14:00 in the afternoon. The number of mammal sightings then tends to gradually decrease hourly on either side of 13:00 and 14:00. The least mammal activity was recorded between 19:00 and 05:00 at the perennial pans and rivers. This supports Hayward and Hayward's (2012) findings elsewhere in the KNP and Pilanesberg. The Limpopo River recorded the highest percentage of sightings at night (17% of sightings), which again suggests that mammals are selecting to use or cross the Limpopo River after dark when they feel less at risk from human activities on the Zimbabwean side of the border (Section 6.3) (Griffiths and van Schaik, 1993; Wakefield and Attum, 2006). As discussed in section 6.3, elephants in particular appear to choose to only access the Limpopo River after dark.

Predators and prey in general appear to be accessing the water sources at very different times of the day. This again supports the findings of Hayward and Hayward (2012) who attributed this to the diurnal behaviour of the prey species and the largely nocturnal behaviour of their predators. The majority of medium and large herbivores, as well as primates, access water sources during

the midday period, whereas large carnivores mostly access the water sources during the night (Figure 39). Herbivore species may therefore intentionally be accessing water sources during the heat of the day to reduce their chances of encountering predators, as previously hypothesised (Périquet et al., 2010). The pans and rivers may thus not be important hunting sites for the large carnivores in the area.

6.5 Key Perennial Water Sources within the Makuleke Wetland System

Mammal sightings were recorded at all seven selected perennial water sources throughout the study year. All the selected water sources, however, displayed an increase in mammal usage during the dry seasons (Figure 63). Nwambe and Mapimbi Pans, in particular, showed the highest overall sightings during the dry seasons and represented the more elusive mammal species such as genets and thick-tailed bushbabies. During the end of the dry season, 93 mammal sightings were recorded at Nwambe Pan within the observed 48 hour period and 78 sightings at Mapimbi Pan (Figure 63). As previously mentioned, the Luvuvhu River displays higher numbers of sightings than the Limpopo River. As discussed in section 6.3, mammals (in particular medium and large herbivores and large carnivores) are probably selecting against using the Limpopo River as a water source as the area of Zimbabwe across the river is not formally protected. Mammals may thus feel less secure utilising and crossing the Limpopo River. The results indicate that the Luvuvhu River and its associated pan (Nwambe) within its floodplain are sources of water for the greatest diversity of species when compared to the water sources associated with the Limpopo floodplain.

Certain species appear to prefer and rely more heavily on particular water sources. Zebra appear to have a preference for the pans within the Limpopo grassland floodplain (Lakangwa, Jachacha and Nhlanguwe pans), with 82% of zebra sightings recorded there. Eland display a preference for Nwambe Pan during the dry months (81% eland sightings). Warthogs, although recorded utilising all perennial water sources except the Limpopo, also display a preference for Nwambe Pan, with 51% of the total warthog sightings recorded there. Elephants utilised the entire Makuleke Wetland System, particularly during the drier months, however, they display a preference for the Luvuvhu River, with 52% of the total elephant sightings recorded along the Luvuvhu. This is not surprising as elephants are known to select for cleaner water, which the Luvuvhu offers (Section 5.1 and Figure 29). The Luvuvhu River is also the boundary across which elephants move in and out of the greater KNP (Henley et al., 2012). Vervet monkeys were recorded across the Makuleke area, but display a preference for Nwambe and Mapimbi pans and the Luvuvhu River. This is most likely due to the well-developed riparian vegetation and reduced ground cover which is associated with these water sources. Genet sightings display a similar preference for Mapimbi and Nwambe pans and the Luvuvhu River. Chacma baboons appear to be less selective and throughout the year both the perennial pans and the rivers appear to be an important source of water for the baboons in the Makuleke area. During the study period, only 7 leopard, 2 lion and 5 hyaena sightings were recorded. Sightings of these large carnivore species

were not numerous enough to determine any preferences the species may have towards drinking sites.

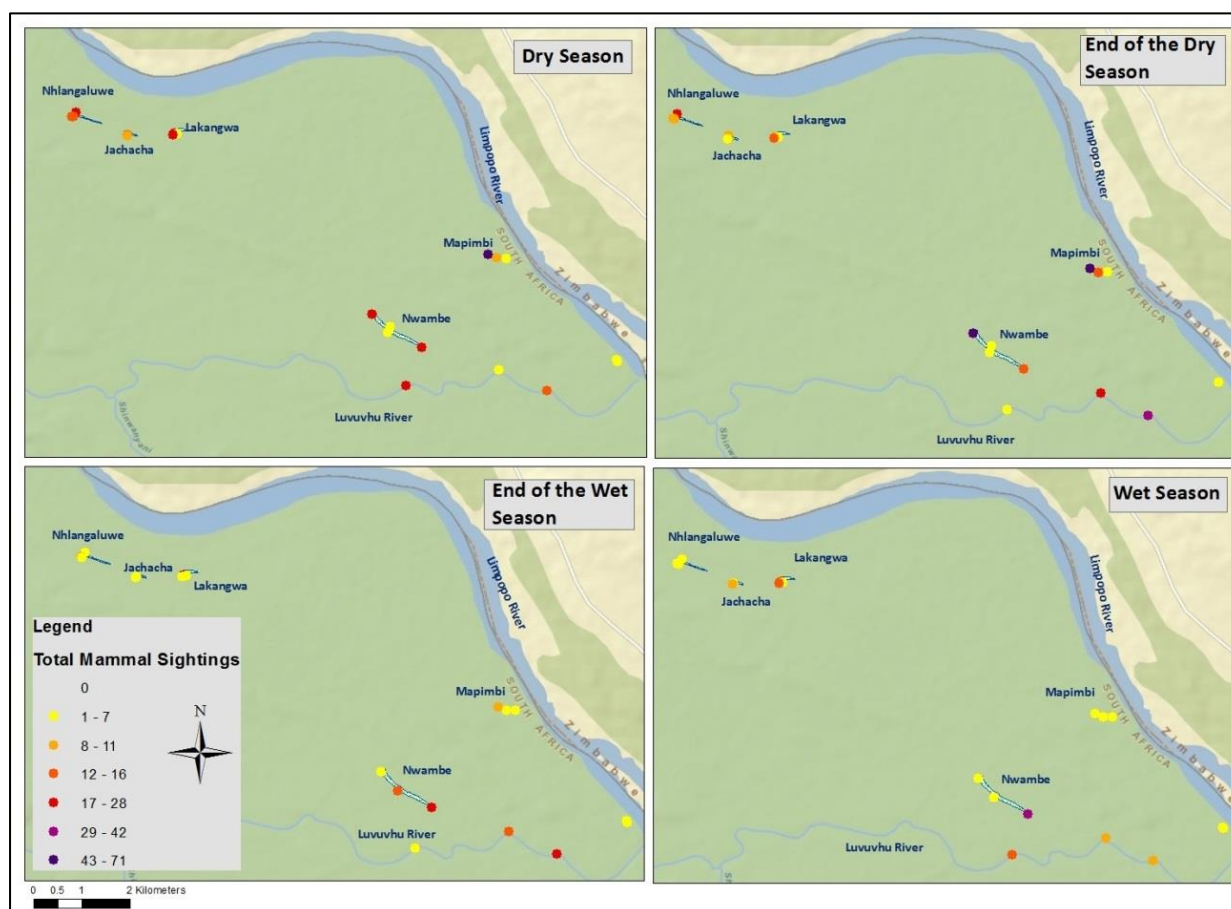


Figure 63: Total number of mammal sightings recorded seasonally at each perennial water source within The Makuleke Wetland System

6.6 Summary of Findings Associated with Each Water Source

If all the combined data variables assessed are summarised for the seven water sources, in order of overall drinking preference to mammals, the following summary is obtained:

1. Nwambe Pan

Nwambe Pan is the only perennial pan situated within the Luvuvhu floodplain and was observed to have the highest total overall number of mammal sightings as well as the greatest diversity of mammal species observed. Nwambe Pan displayed the lowest EC values measured at any of the pans, however it does not represent the cleanest water source within the wetland system with regards to Total Dissolved Solids (muddiness). Nwambe is not associated with dense low vegetation cover around its banks but is associated with large riverine trees creating a dense canopy around the pan. The pan at its closest point is ~443m from the closest tourist road and is the water source located furthest from the Zimbabwean border (3160m). The results associated with Nwambe Pan suggest that although mammals might select against high EC values in water sources, a high TDS or turbidity of the water does not deter them. Mammals selecting to drink at

Nwambe also appear to be selecting to drink at a source with reduced low vegetation cover, although a dense canopy, possibly to improve visibility of their surroundings while drinking to reduce the risk of predation.

2. Nhlangaluwe Pan

Nhlangaluwe Pan, within the Limpopo floodplain, displayed the second highest number of total sightings and species richness. Nhlangaluwe is associated with low shrubs and grass cover around its banks with an average distance to vegetation cover of 4m from the water's edge. The percentage of canopy cover is 20% and the pan is 268m from the closest tourist road and can only be accessed on foot. Nhlangaluwe is also the second furthest (817m) pan from the Zimbabwean border after Nwambe.

3. Luvuvhu River

The Luvuvhu River is associated with the lowest EC values recorded at any water source. The distance to vegetation cover along the Luvuvhu ranges from 10m to 100m and the distance of the three sites from the closest tourist road is ~200m. All three sites along the Luvuvhu are located more than 2000m from the Zimbabwe border.

4. Mapimbi Pan

Mapimbi Pan is the pan situated closest to the Limpopo River and the Zimbabwe border (177m). The pan has very little ground cover around its edges which in places is up to 100m from the waters edge. Although there is little ground cover, it is associated with large riparian trees with 80% canopy cover around its banks. Mapimbi can be accessed by tourist roads and displayed the highest EC concentrations recorded throughout the year.

5. Lakangwa Pan

Lakangwa Pan within the grassy Limpopo Floodplain is located ~180m from the Limpopo River and border with Zimbabwe. The pan can only be accessed on foot and is ~375m from the closes tourist road within the concession. The grass covered northern bank of Lakangwa has grass cover right up to the water's edge whereas the southern bank has ground cover varying from 2-5m from the water's edge and is associated with 10-15% canopy cover.

6. Limpopo River

The Limpopo River forms the border of the Kruger National Park with Zimbabwe to the north and was reduced from a fast flowing, wide river during the wet season to a few pools within the wide riverbed, by the end of the dry season. The three sites chosen to monitor along the river range from 3-22m from the nearest tourist road. When the river is flowing the distance to cover is only 2-5m from the river's edge, however during the dry season if animals access the pools within the otherwise dry riverbed the distance to cover can be well over 100m from the water. The banks of the Limpopo are associated with large riparian trees creating up to 100% canopy cover at the sampling sites.

7. Jachacha Pan

With the exception of the Limpopo River during the dry season, Jachacha Pan was the least popular drinking source for mammals. Jachacha is situated within the grassy Limpopo Floodplain and therefore has grass cover within close proximity to the water's edge around the entire pan and only 10-30% canopy cover along the southern bank. Tourist vehicles can access to within 66m of the pan from the road and the pan is ~602m from the Zimbabwe border.

Overview

When the water sources are listed in order of general preference to mammal species and their environmental characteristics are assessed, it would appear that a greater distance to the Zimbabwean border as well as an increased distance to cover (increased visibility) would be the greater drivers influencing mammalian water source preferences. Water sources with low vegetation cover close to the water's edge were overall the least popular water sources. The accessibility of the area by tourist vehicles may influence mammals preferences slightly as the three most popular water sources can only be accessed on foot. This, however, is not a significant driver as Mapimbi Pan (4th most popular) is easily accessible by vehicles. Water quality does not appear to play a major role in drinking site selection for mammals within the Makuleke region, although sites with the lowest EC values were listed within the three most popular drinking sources. It must be noted, however, that all EC values recorded, throughout the year, were well within the suggested guidelines for livestock drinking.

6.7 Management Implications

Understanding how ecological drivers such as water availability, quality, vegetation cover, predation risk and human activity influence mammal selection of important water sources, allows for more informed management decisions to be made and may result in more successful ecotourism ventures. Information from this study may aid SANParks management with their "adaptive management" strategy for KNP, which promotes "learning by doing", based on the best available knowledge, as the most appropriate tool to manage the park in an ever changing environment (Mabunda et al., 2003). It is widely accepted that emphasis be placed on the major role these river systems play in biodiversity, and hence their high priority in conservation (Bosch et al., 1986; Rogers, 1995; Lussier et al., 2006; Larsen et al., 2010). This is particularly true in the drier, northern KNP where many previous artificial water-sources have been removed (Gaylard et al., 2003; Smit et al., 2007a) and mammals thus rely heavily on natural perennial water sources.

Eco-tourism, measured here by distance to roads within the concession area, does not appear to have a significant impact on drinking site selection, with the exception of possibly shy, nocturnal, small carnivore species such as genets and civets. The construction of future tourist camps, lodges or hides can therefore be placed at popular water sources within the Makuleke concession to increase tourist sightings without significantly impacting on mammals drinking patterns, if the current levels of activity and traffic volumes are maintained. During field trips, a large diversity and quantity of wildlife was witnessed utilising the Luvuvhu River in front of the Pafuri Camp. As

this study has shown, the Luvuvhu is a popular water source for mammals within the area, and the presence of the camp does not seem to have significantly impacted on mammal river usage. Tour operators and guides may also learn from the drinking times recorded during this study, as to when the best time to access water sources would be to view specific species, or the widest variety of species. The data gained from this study may therefore aid SANParks in making decisions which adhere to the park's mission statement which is "To maintain biodiversity in all its natural facets and fluxes and to provide human benefits in keeping with the mission of SANParks in a manner which detracts as little as possible from the wilderness qualities of the Kruger National Park" (Mabunda et al., 2003, p18). Game count censuses are expensive operations and often do not shed light on populations of smaller or nocturnal species such as civets, genets and leopards. Camera trap data, such as those obtained in this study, can therefore be used together with census data to obtain a more holistic view of animal populations and distributions within protected areas such as the KNP.

The water quality data obtained in this study should be used as baseline information for the Ramsar site, allowing authorities to monitor and compare future changes in water qualities due to droughts, flooding events or activities upstream. The baseline information, for example, can be used to determine changes in water quality and mammal usage of water sources as a result of the recent extreme flood event experienced in the region in January 2013. The Luvuvhu River and the pan associated with its floodplain (Nwambe Pan) have been shown in this study to serve the greatest mammal species richness, of the perennial water sources studied within the Makuleke Wetland System, particularly during the dry seasons. The Luvuvhu River and Nwambe Pan should therefore be of conservation importance and authorities should ensure that the Luvuvhu River remains in good condition and continues to flow throughout the dry season, unlike the Limpopo River which no longer flows during the dry months as a result of upstream demands (O'Keeffe and Rogers, 2003). Promoting integrated catchment management systems with users outside the KNP is therefore of vital importance (O'Keeffe and Rogers, 2003). Considering that the Makuleke Wetland System is considered a wetland of international importance (Ramsar), South Africa is obliged to conserve and protect it and its associated biodiversity (Deacon, 2007).

As stated in the Sengwe Corridor Concept Paper (CESVI, 2002), hunting within the Sengwe area of Zimbabwe across the Limpopo River, is essentially based on overflow of wildlife from KNP. If trophy hunting continues without consultation with SANParks, hunting may have detrimental effects on the KNP wildlife populations. Should male lions, for example, continually be targeted and hunted, this may have major effects on the northern KNP population. Future territorial males of the KNP and important breeding males may be continuously removed from the system (Whitman et al., 2004; Loveridge et al., 2007). The fact that considerably fewer mammals, particularly large mammal species, were recorded along the Limpopo River, with the exception of a few elephant bulls after dark, implies that animals are not comfortably using the Sengwe Corridor to migrate to and from GNP. One of the GLTP's six treaty goals is to "enhance ecosystem integrity and natural ecological processes by harmonising environmental management procedures across international boundaries and striving to remove artificial barriers impeding the natural movement of wildlife"

(International Conservation Services et al., 2008, p2). In order to accomplish this goal, the GLTP needs to encourage ecotourism initiatives in Zimbabwe to replace the current trophy hunting which is contributing to local incomes, as the "artificial barriers impeding the natural movement of wildlife" have not really been removed if animals do not feel safe and "free" to disperse. Zimbabwe's political climate, particularly with regards to issues of land redistribution, does not make it an easy task, but if conservation and economic objectives of the GLT are to be met (see Section 2.4.1), animals need to feel safe to use the corridors linking the protected areas (CESVI, 2002; International Conservation Services et al., 2008, p2).

7. CONCLUSION

7.1 Limitations to the Study

As this study was conducted for a masters research dissertation, financial, time and logistical constraints limited the scope of this study.

It was not possible to take into account every possible environmental characteristic of the water sources studied. Only the characteristics that were thought to be most influential, or where data could be obtained within the timeframe of the study or from fellow students' studies within the area, were taken into account. According to the CCA, only 28.4% of the variance in mammal site selection could be accounted for by the environmental factors tested for in this study. Other environmental influences such as the inclination of the bank, or distance to suitable or preferred forage, or territories, as well as competition may also influence wildlife's decisions when selecting a drinking site.

It was only possible to set up between three and four camera traps to survey each water source for a 48 hour period, regardless of the length or perimeter of the river or pan. Camera traps were set up wherever possible along well used game paths or areas along the water's edge which displayed signs of high animal activity. However, mammals could easily have accessed the pans, and especially the rivers, at points not covered by a camera trap. Spoor data proved difficult to keep consistent among the water sources as substrates and amount of vegetation cover at the water's edge differed between sites, making it impossible to compare sites without bias. It was also found that if a large herd of animals such as buffalo accessed a water source during the surveillance period, they would often destroy any existing spoor, laid previously by other species. Although spoor data were recorded at each site (along with the camera trap data), it was decided not to include the spoor data in the analysis as such data were not consistent enough between the sites, and would therefore possibly lead to biased results.

The camera traps were found to be far less sensitive to movement at night. When using infrared after dark, the cameras' field of view is not as deep. Nocturnal sighting numbers may therefore not be as accurate as the numbers recorded during the day. This would have a particular influence on the accuracy in the numbers of carnivore sightings (both large and small) recorded, as many of these species are nocturnal and were only recorded at night. Small carnivores are less likely to trigger the camera trap while moving around at night, unless they move close enough the trap sensor. Having said this, a similar study by Hayward and Hayward (2012) using webcam observations, did not record any small, nocturnal carnivores. Ungulate and large carnivore trends seem to be similar, suggesting that camera traps are a viable method of observing animal drinking behaviour where 24 hour webcams may not be available.

In terms of water quality data, point samples as taken during this study, only represent the water quality at a particular position and time. This is particularly true for the rivers which are continuous systems and are influenced by rainfall patterns and human influences upstream (O'Keeffe and

Rogers, 2003). Water quality within these systems may therefore change daily. The water quality data used in this study are thus merely an indication of the broad seasonal changes in the quality of water available to mammals in the area. An in depth and continuous analysis of the seasonal changes in water quality within the Makuleke Wetland System would be a study in its own right.

This study only provides an indication of mammals' usage patterns at perennial water sources within the Makuleke Wetland System. Data were only collected during four fieldwork sessions in 2011 and 2012, and for 48hour periods at each water source. Rainfall can vary greatly between years and data collected over a longer period may display slightly different trends. In January 2013, for example, once field work for this study was complete, the Makuleke region experienced the worst flood event since the floods of 2000 (Wilderness Safaris, 2012). Flooding of the Limpopo and Luvuvhu River floodplains is likely to alter the pan network, covering foraging areas with silt, possibly silting up pans, or breaking through and linking pans together. Such events would impact mammal usage of the system. Follow up studies in the region to determine how the floods may have influenced the regions mammal distributions and water sources could build on the trends presented in this study.

The four original objectives of the study were met in varying degrees of success. The seasonal, as well as the finer scale (daily and hourly) temporal usage of each water source by different mammal species was determined successfully through the use of the camera traps. The environmental and anthropogenic factors investigated, however, only partially explain the drivers influencing mammalian preferences for drinking sources. This indicates that other environmental pressures such as forage or intraspecific competition are also likely to influence drinking site selection. The key perennial water sources, with regards to the extent and diversity of mammal usage, were determined for the study area, however, this is only part of the overall picture as the majority of the pans within the wetland system are non-perennial and this is not necessarily consistent between years, depending on rainfall received. For a more comprehensive view of the conservation importance of the various water resources within the Makuleke region, data should be obtained across a number of years with varying rainfall values received.

7.2 Conclusion to the Study

The perennial pans and rivers making up the Ramsar Makuleke Wetland System in northern Kruger National Park provide an important water source for mammal species in the area, particularly during the dry season. Environmental aspects, such as vegetation type and perceived threat from predators and human activity, appear to influence how mammal species in the area select for drinking sites and times to access these sites. Water quality in the pans and rivers does not appear to have a significant (with 99% confidence) impact on mammals' water preferences. This is probably because clean water is not as easily accessible during the dry season, and that other environmental pressures such as predation and human disturbance, may play a more significant role in water source choices.

Small carnivores and primates select for drinking sites with greater percentages of canopy cover (tree cover). Small, medium and large herbivores and large carnivore species, however, are selecting for drinking sites with reduced canopy cover. Overall, mammals appear to be selecting for drinking sites with increased distances to ground cover where they are more likely to see predators in advance. Zebra select for sites within the Limpopo floodplain grasslands, their preferred habitat, with a greater percentage of grass cover and reduced tree cover. Elephants are associated with a reduction in shrub and tree cover and herds were largely recorded at more open water sources, particularly along the Luvuvhu River, where they could all be accommodated and drink together as a herd.

Mammal species appear to be avoiding the Zimbabwean border as a result of human activity along the Zimbabwean side of the GLTP. Overall, mammals select for drinking sites further from the Zimbabwean border along the Limpopo River. Elephants also appear to alter their behaviour along the Zimbabwe border, only accessing the Limpopo River after dark, so as to avoid human activity in Zimbabwe. Similarly, small carnivores which are often shy and nocturnal creatures, are selecting for water sources which are less frequently accessed by humans.

The perennial pans and rivers appear to be a significant water source during the dry months to large herbivore and large carnivore species, which display the greatest seasonal fluctuations. The majority of mammals access the perennial water sources during the midday period (09:00-14:00) and late afternoon (14:00-19:00). Elephants show the greatest demand for water during the dry seasons and access the perennial water sources throughout the day and night. The Makuleke wetland system, and in particular the perennial water sources, provide an important dry season refuge for the northern Kruger National Park and the Greater Limpopo Transfrontier Park elephant population.

The Luvuvhu River and its associated pan (Nwambe), within its floodplain, are sources of water for the greatest diversity and richness of species when compared to the water sources associated with the Limpopo floodplain, within the Makuleke Wetland System. A better understanding of how ecological drivers such as water availability, quality, vegetation cover, predation risk and human activity, influence mammalian selection of important water sources within the wetland system, allows for more informed management decisions to be made which in turn may result in more successful ecotourism ventures within the Makuleke Contractual Park.

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Appendix A: Water Quality Data

Table A: Water quality data obtained during the study and the guideline maximum concentrations published for livestock

ELEMENT		pH	EC	Temp	TDS	Li (7)	Be (9)	B (10)	Na (23)	Mg (24)	Al (27)	K (39)	Ca (43)	V (51)	Cr (52)	Fe (54)	Mn (55)	Co (59)	Ni (60)	Cu (63)	Zn (66)	Ga (69)	As (75)	Se (82)	Rb (85)	Sr (88)	Mo (95)	Ag (107)	Cd (111)	Te (128)	Ba (137)	Tl (205)	Pb (208)	Bi (209)	U (238)	F ⁻	Cl ⁻	NO ₂ ⁻	Br ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	TSS				
UNIT		mS/cm			mg/l	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb			
GUIDELINES	DWAF				1000 2000	NA	NA	5000	2 000 000	500 000	5 000	NA	1 000 000	1000	1000	10 000	10 000	1000	1000	1000	1000	5000	20 000		1000	50				10																	
	DWA		9						2 000 000	500 000			1 000 000																																		
	OTHER	5.5 - 8.5																																													
	PAN	SAMPLE																																													
Mar-11	Jachacha	JAC 02	8.29	0.661	29.2		1.3451	< 0.2	141.866	116884.738	13737.445	1023.747	8713.177	17009.933	24.643	6.099	1839.974	250.525	0.342	15.681	10.324	< 60	3.541	9.231	2.685	3.213	240.544	2.613	< 0.2	< 0.2	< 0.2	102.232	< 0.2	< 6	< 0.2	1.651	0.183	43.946	< 0.05	< 0.09	< 0.07	3.233	3.346	864.000			
	Lakangwa	LAK 02	8.546	0.727	31		2.8044	< 0.2	154.129	138256.642	16157.427	3638.048	8842.684	19214.492	44.743	22.030	6741.418	328.328	6.857	72.391	24.523	< 60	5.041	8.340	2.980	5.564	226.968	1.652	< 0.2	< 0.2	< 0.2	122.164	< 0.2	< 6	< 0.2	3.125	0.816	49.386	< 0.05	< 0.09	< 0.07	3.149	3.680	224.000			
	Limpopo	LIMP 02	8.713	0.589	31.8		11.083	< 0.2	84.423	46832.867	14197.371	229.296	4975.356	29537.065	11.800	2.553	301.470	27.182	< 0.2	< 10	12.143	< 60	1.889	< 4	1.521	2.350	190.199	1.407	< 0.2	3.636	< 0.2	61.039	< 0.2	6.396	< 0.2	0.974	1.299	66.957	< 0.05	< 0.09	< 0.07	< 0.2	28.491	290.000			
	Luvuvhu	LUV 02	7.97	0.114	32		< 0.4	< 0.2	< 40	6312.573	3334.749	247.611	802.814	6023.294	3.972	1.029	834.170	39.738	0.243	< 10	15.633	< 60	1.174	< 4	1.136	1.321	42.662	< 0.2	< 0.2	< 0.2	33.969	< 0.2	< 6	< 0.2	< 0.4	1.045	6.752	< 0.05	< 0.09	< 0.07	< 0.2	< 0.1	30.000				
	Mapimbi	MAP 02	8.6	1.08	31.8		1.276	< 0.2	78.585	103949.908	30459.683	891.341	8473.574	44431.265	19.709	4.452	1329.156	386.579	< 0.2	13.087	8.481	< 60	4.174	< 4	3.199	4.481	391.353	1.687	< 0.2	< 0.2	< 0.2	125.304	< 0.2	< 6	< 0.2	4.091	0.395	123.301	< 0.05	< 0.09	2.872	< 0.2	23.216	78.000			
	Nhlangaluwe	NHL 02	7.663	0.571	34.4		1.2279	< 0.2	121.633	86055.175	16234.756	791.681	10109.101	22178.438	31.673	5.211	1209.033	161.893	1.076	13.699	14.251	< 60	1.904	8.660	1.093	3.259	294.100	2.138	< 0.2	1.214	< 0.2	49.755	< 0.2	< 6	< 0.2	1.572	0.481	27.955	< 0.05	< 0.09	< 0.07	4.471	2.073	76.000			
	Nwambe	NWA 02	7.033	0.1302	29		0.8602	0.444	< 40	7320.737	5685.846	3774.477	8613.894	9099.135	34.890	18.271	9324.209	426.314	7.789	28.039	36.978	< 60	5.600	< 4	0.923	5.849	125.350	< 0.2	< 0.2	< 0.2	130.816	< 0.2	< 6	< 0.2	< 0.4	1.345	4.923	< 0.05	< 0.09	2.218	< 0.2	1.715	337.000				
Jul-11	Jachacha	JAC 03	8.813	1.171	17.5		3.6699	1.485	243.465	249544.856	27844.814	6781.811	11143.104	59933.882	115.562	46.364	10704.550	484.880	13.268	64.331	40.640	436.836	8.108	33.617	< 2	10.110	380.678	2.403	< 1	15.607	< 1	153.376	< 1	< 30	< 1	10.163	0.515	103.830	< 0.35	< 0.64	< 0.48	8.496	12.901	502.000			
	Lakangwa	LAK 03	8.836	1.2	17.6		4.4464	< 1	287.816	267665.193	18828.044	5531.183	8396.986	133651.006	85.710	34.763	8632.723	346.872	11.076	< 50	39.194	461.756	6.799	28.369	3.775	7.829	308.544	1.907	< 1	15.058	1.163	129.030	< 1	< 30	< 1	8.593	0.481	102.900	< 0.35	< 0.64	4.383	4.588	9.629	467.000			
	Limpopo	LIMP 03	8.42	0.62	18		7.0371	< 1	< 200	63459.393	18621.626	480.420	4624.475	39807.479	6.307	6.858	939.007	35.220	11.923	< 50	25.007	464.347	3.165	< 20	< 2	2.209	234.083	1.382	< 1	1.212	< 1	79.606	< 1	< 30	< 1	< 2	0.459	92.660	< 0.35	< 0.64	< 0.48	< 1.61	50.852	3.000			
	Luvuvhu	LUV 03	8.33	0.1206	17.1		< 2	< 1	< 200	13862.171	6021.005	432.462	1296.261	9738.777	4.990	< 5	882.020	59.937	1.808	< 50	< 20	< 300	2.189	< 20	< 2	1.724	68.247	< 1	< 1	8.886	< 1	55.420	< 1	< 30	< 1	< 2	< 0.17	10.237	< 0.35	< 0.64	< 0.48	< 1.61	0.924	24.000			
	Mapimbi	MAP 03	8.286	1.162	16.5		< 2	< 1	< 200	150940.482	49839.946	476.528	8069.665	47522.010	13.051	< 5	762.210	573.803	2.489	< 50	< 20	< 300	5.387	< 20	< 2	2.928	491.298	1.572	< 1	< 1	< 1	151.462	< 1	< 30	< 1	4.332	< 0.34	181.342	< 0.7	< 1.27	4.565	< 3.22	12.123	28.000			
	Nhlangaluwe	NHL 03	8.876	0.889	21		2.3172	< 1	< 200	161496.587	29964.910	5029.572	10569.136	29928.956	75.861	31.280	8109.476	484.776	11.320	< 50	34.457	< 300	7.021	24.778	< 2	7.220	411.606	1.385	< 1	< 1	< 1	146.155	< 1	< 30	< 1	6.913	0.452	57.146	< 0.35	< 0.64	3.904	< 1.61	3.949	284.000			
	Nwambe	NWA 03	8.053	1.605	16.5		< 2	1.346	< 200	8677.601	7081.005	6708.508	9194.134	9703.659	69.090	34.701	18202.677	343.000	16.923	< 50	63.375	< 300	12.072	< 20	< 2	6.940	143.765	< 1	< 1	1.155	< 1	261.006	< 1	< 30	< 1	< 2	< 0.17	7.832	< 0.35	< 0.64	3.876	< 1.61	2.723	608.000			
Oct-11	Jachacha	JAC 04	8.53	0.341	23.7		24.082	2.363	765.693	789586.775	61349.781	20285.724	18576.960	50776.385	362.403	116.339	35819.240	1001.530	40.960	180.283	102.432	101.317	18.242	36.738	11.359	20.054	686.035	9.037	< 0.2	0.264	0.303	344.464	< 0.2	18.494	< 0.2	75.641	< 2.4	380.773	< 5	< 9.1	35.439	< 23	52.251	1497.000			
	Lakangwa	LAK 04	8.623	0.231	34.3		15.007	0.861	607.468	499129.366	23569.931	6979.830	10139.654	22370.818	239.885	37.150	11533.454	567.845	15.284	61.166	51.117	< 60	7.083	23.423	4.918	9.133	289.377	6.106	< 0.2	< 0.2	0.443	159.375	< 0.2	8.290	< 0.2	29.049	< 1.2	186.947	< 2.5	< 4.55	< 3.45	< 11.5	19.381	576.000			
	Limpopo	LIM 04	7.31	0.646	23.6		10.353	< 0.2	60.618	52973.905	21096.703	19.293	3280.247	39402.203	5.190	2.127	107.522	378.726	0.534	< 10	< 4	< 60	3.741	< 4	6.449	1.170	252.991	1.069	< 0.2	< 0.2	0.215	135.003	< 0.2	< 6	< 0.2	1.789	< 0.34	74.486	< 0.7	< 1.27	< 0.97	< 3.22	31.937	3.000			
	Luvuvhu	LUV 04	7.34	0.171	28.9		8.0491	< 0.2	158.050	11338.133	7362.462	238.967	1339.562	9762.063	4.649	2.071	650.906	35.896	1.221	< 10	6.162	< 60	1.503	< 4	3.632	1.819	80.876	< 0.2	< 0.2	< 0.2	< 0.2	48.353	< 0.2	< 6	< 0.2	< 0.4	< 0.17	13.418	< 0.35	< 0.64	< 0.48	< 1.61	< 0.69	3.000			
	Mapimbi	MAP 04	7.74	1.555	30		14.318	0.270	184.787	188394.683	59893.098	2703.694	15446.419	51925.718	33.399	12.755	4703.212	792.082	5.598	20.529	16.458	< 60	8.159	<																							

Appendix B: Vegetation Structure Data

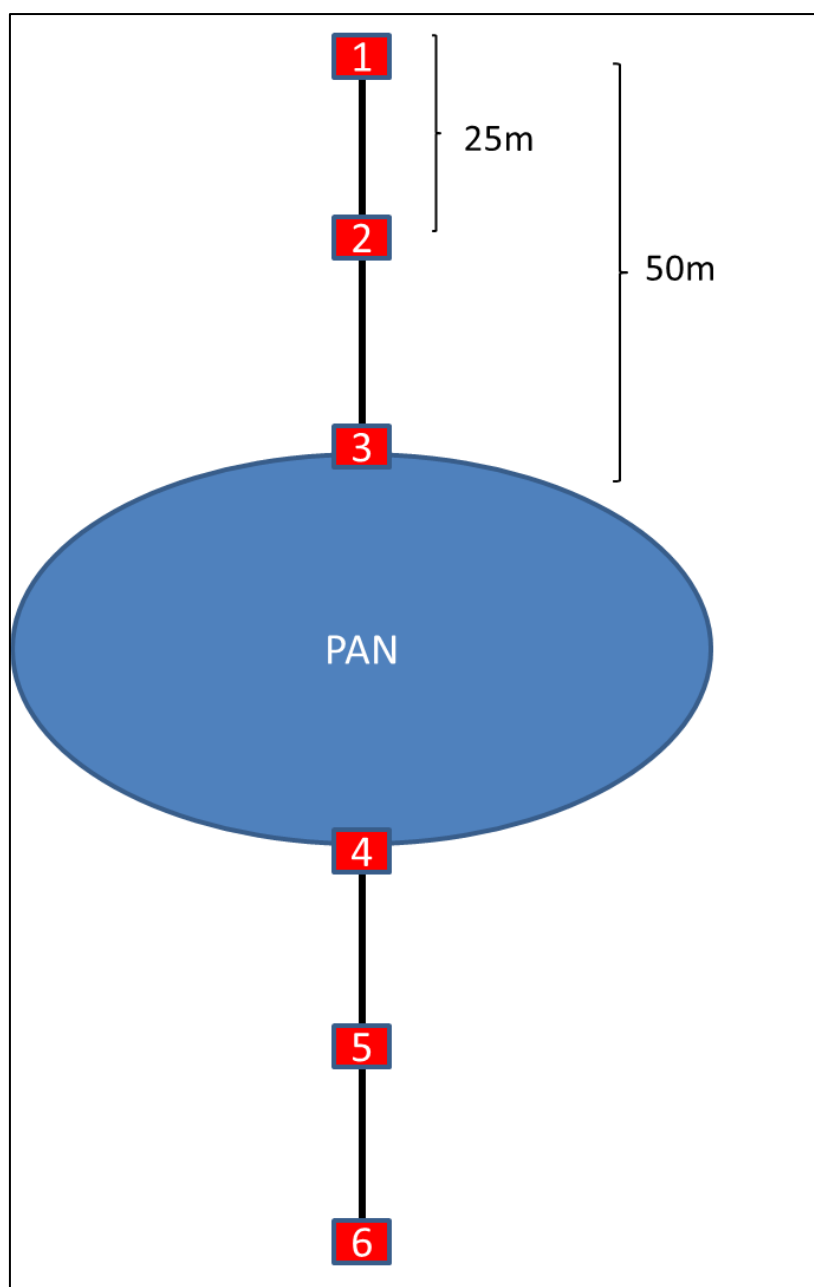


Image B: Diagram showing the position and layout of the vegetation transects (Zhogby, 2011)

Table B: Vegetation structure data obtained at the five perennial pans (Zoghby, 2011)

Nwambe						
Point Along Transect	Av. Grass Cover	Av. Grass Height	Av. Shrub Cover	Av. Shrub Height	Av. Tree Cover	Av. Tree Height
1	4	2	1	2	1	4
2	2	2	2	3	2	4
3	2	2	3	2	5	5
4	2	2	4	3	5	5
5	3	2	3	3	3	5
6	3	2	2	2	1	5
Average	2.67	2.00	2.50	2.50	2.83	4.67
Lakangwa						
Point Along Transect	Av. Grass Cover	Av. Grass Height	Av. Shrub Cover	Av. Shrub Height	Av. Tree Cover	Av. Tree Height
1	5	3	1	1	1	1
2	5	3	1	1	1	1
3	5	3	1	1	1	1
4	5	3	1	1	2	5
5	3	2	2	2	3	5
6	3	2	2	3	5	5
Average	4.33	2.67	1.33	1.50	2.17	3.00
Nhlangaluwe						
Point Along Transect	Av. Grass Cover	Av. Grass Height	Av. Shrub Cover	Av. Shrub Height	Av. Tree Cover	Av. Tree Height
1	2	1	2	2	5	5
2	3	1	1	1	4	5
3	5	3	1	1	1	3
4	5	3	1	1	1	3
5	4	3	1	1	3	5
6	2	1	2	2	5	5
Average	3.50	2.00	1.33	1.33	3.17	4.33
Jachacha						
Point Along Transect	Av. Grass Cover	Av. Grass Height	Av. Shrub Cover	Av. Shrub Height	Av. Tree Cover	Av. Tree Height
1	2	2	2	4	5	5
2	2	2	2	4	5	5
3	2	2	1	3	4	5
4	5	3	1	1	1	1
5	4	3	1	1	2	4
6	4	3	1	1	3	5
Average	3.17	2.50	1.33	2.33	3.33	4.17
Mapimbi						
Point Along Transect	Av. Grass Cover	Av. Grass Height	Av. Shrub Cover	Av. Shrub Height	Av. Tree Cover	Av. Tree Height
1	3	2	2	2	5	5
2	3	2	2	2	5	5
3	3	2	1	2	5	5
4	3	2	2	2	5	5
5	4	2	3	2	5	5
6	3	2	2	2	5	5
Average	3.17	2.00	2.00	2.00	5.00	5.00

Appendix C: Combined Independent Variable Data

Site Number	Site ID	X	Y	Season	Season Number	Distance to Cover (m)	% Canopy Cover	Distance to Zimbabwe border (m)	Distance to closest road (m)	Combined Grass Structure at water's edge	Combined Shrub Structure at water's edge	Combined Tree Structure at water's edge	Water Level	Max Air Temp	Rain previous month (mm)	Human Access	Human Access ID	TSS
1	JacT1D	22.37940	31.21115	dry	1	0	10	602	66	6	3	5.5	3	33	8.2	Vehicle	1	502
2	JacT1ED	22.37940	31.21115	end of dry	2	0	10	602	66	6	3	5.5	2	35	19.7	Vehicle	1	1497
3	JacT1EW	22.37940	31.21115	end of wet	3	0	10	602	66	6	3	5.5	4	44	15	Vehicle	1	864
4	JacT1W	22.37940	31.21115	wet	4	0	10	602	66	6	3	5.5	5	38	75.1	Vehicle	1	180.67
5	JacT2D	22.37986	31.21120	dry	1	0	0	602	76	6	3	5.5	3	33	8.2	Vehicle	1	502
6	JacT2ED	22.37986	31.21120	end of dry	2	1	20	602	76	6	3	5.5	2	35	19.7	Vehicle	1	1497
7	JacT2EW	22.37986	31.21120	end of wet	3	0	10	602	76	6	3	5.5	4	44	15	Vehicle	1	864
8	JacT2W	22.37986	31.21120	wet	4	0	0	602	76	6	3	5.5	5	38	75.1	Vehicle	1	180.67
9	JacT3D	22.37994	31.21114	dry	1	1	30	602	73	6	3	5.5	3	33	8.2	Vehicle	1	502
10	JacT3ED	22.37994	31.21114	end of dry	2	3	0	602	73	6	3	5.5	2	35	19.7	Vehicle	1	1497
11	JacT3EW	22.37994	31.21114	end of wet	3	1	10	602	73	6	3	5.5	4	44	15	Vehicle	1	864
12	JacT3W	22.37994	31.21114	wet	4	1	30	602	73	6	3	5.5	5	38	75.1	Vehicle	1	180.67
13	LakT1D	22.37945	31.22000	dry	1	6	10	180	375	8	2	4.5	3	33	8.2	Foot	2	467
14	LakT1ED	22.37945	31.22000	end of dry	2	6	10	180	375	8	2	4.5	3	38	19.7	Foot	2	576
15	LakT1EW	22.37945	31.22000	end of wet	3	6	10	180	375	8	2	4.5	4	44	15	Foot	2	224
16	LakT1W	22.37945	31.22000	wet	4	6	10	180	375	8	2	4.5	4	40	75.1	Foot	2	499.2
17	LakT2D	22.37960	31.22038	dry	1	15	40	180	365	8	2	4.5	3	33	8.2	Foot	2	467
18	LakT2ED	22.37960	31.22038	end of dry	2	15	40	180	365	8	2	4.5	3	38	19.7	Foot	2	576
19	LakT2EW	22.37960	31.22038	end of wet	3	15	40	180	365	8	2	4.5	4	44	15	Foot	2	224
20	LakT2W	22.37960	31.22038	wet	4	15	40	180	365	8	2	4.5	4	40	75.1	Foot	2	499.2
21	LakT3D	22.37960	31.22045	dry	1	10	50	180	373	8	2	4.5	3	33	8.2	Foot	2	467

Site Number	Site ID	X	Y	Season	Season Number	Distance to Cover (m)	% Canopy Cover	Distance to Zimbabwe border (m)	Distance to closest road (m)	Combined Grass Structure at water's edge	Combined Shrub Structure at water's edge	Combined Tree Structure at water's edge	Water Level	Max Air Temp	Rain previous month (mm)	Human Access	Human Access ID	TSS
22	Lakt3ED	- 22.37960	31.22045	end of dry	2	10	50	180	373	8	2	4.5	3	38	19.7	Foot	2	576
23	Lakt3EW	- 22.37960	31.22045	end of wet	3	10	50	180	373	8	2	4.5	4	44	15	Foot	2	224
24	Lakt3W	- 22.37960	31.22045	wet	4	10	50	180	373	8	2	4.5	4	40	75.1	Foot	2	499.2
25	Lakt4D	- 22.37976	31.21977	dry	1	20	40	180	323	8	2	4.5	3	33	8.2	Foot	2	467
26	Lakt4ED	- 22.37976	31.21977	end of dry	2	20	40	180	323	8	2	4.5	3	38	19.7	Foot	2	576
27	Lakt4EW	- 22.37976	31.21977	end of wet	3	20	40	180	323	8	2	4.5	4	44	15	Foot	2	224
28	Lakt4W	- 22.37976	31.21977	wet	4	20	40	180	323	8	2	4.5	4	40	75.1	Foot	2	499.2
29	LimT1D	- 22.42201	31.30267	dry	1	4	0	0	3	Null	Null	Null	3	33	8.2	Vehicle	1	3
30	LimT1ED	- 22.42201	31.30267	end of dry	2	4	0	0	3	Null	Null	Null	1	38	19.7	Vehicle	1	3
31	LimT1EW	- 22.42201	31.30267	end of wet	3	4	0	0	3	Null	Null	Null	4	44	15	Vehicle	1	290
32	LimT1W	- 22.42201	31.30267	wet	4	4	0	0	3	Null	Null	Null	4	38	75.1	Vehicle	1	210.46
33	LimT2D	- 22.42179	31.30250	dry	1	5	100	0	27	Null	Null	Null	3	27	8.2	Vehicle	1	3
34	LimT2ED	- 22.42179	31.30250	end of dry	2	5	100	0	27	Null	Null	Null	1	38	19.7	Vehicle	1	3
35	LimT2EW	- 22.42179	31.30250	end of wet	3	5	100	0	27	Null	Null	Null	4	42	15	Vehicle	1	290
36	LimT2W	- 22.42179	31.30250	wet	4	5	100	0	27	Null	Null	Null	4	36	75.1	Vehicle	1	210.46
37	LimT3D	- 22.40283	31.28188	dry	1	2	100	0	22	Null	Null	Null	3	27	8.2	Vehicle	1	3
38	LimT3ED	- 22.40283	31.28188	end of dry	2	5	100	0	22	Null	Null	Null	1	38	19.7	Vehicle	1	3
39	LimT3EW	- 22.40283	31.28188	end of wet	3	2	100	0	22	Null	Null	Null	4	42	15	Vehicle	1	290
40	LimT3W	- 22.40283	31.28188	wet	4	2	100	0	22	Null	Null	Null	4	36	75.1	Vehicle	1	210.46
41	LuvT1D	- 22.42750	31.28950	dry	1	10	20	1388	154	Null	Null	Null	2	29	8.2	Foot	2	24
42	LuvT1ED	- 22.42750	31.28950	end of dry	2	10	20	1388	154	Null	Null	Null	2	33	19.7	Foot	2	3

Site Number	Site ID	X	Y	Season	Season Number	Distance to Cover (m)	% Canopy Cover	Distance to Zimbabwe border (m)	Distance to closest road (m)	Combined Grass Structure at water's edge	Combined Shrub Structure at water's edge	Combined Tree Structure at water's edge	Water Level	Max Air Temp	Rain previous month (mm)	Human Access	Human Access ID	TSS
43	LuvT1EW	-22.42750	31.28950	end of wet	3	10	20	1388	154	Null	Null	Null	4	44	15	Foot	2	30
44	LuvT1W	-22.42750	31.28950	wet	4	10	20	1388	154	Null	Null	Null	3	40	75.1	Foot	2	0
45	LuvT2D	-22.42367	31.28058	dry	1	100	20	2670	205	Null	Null	Null	2	29	8.2	Foot	2	24
46	LuvT2ED	-22.42367	31.28058	end of dry	2	100	20	2670	205	Null	Null	Null	2	33	19.7	Foot	2	3
47	LuvT2EW	-22.42367	31.28058	end of wet	3	100	20	2670	205	Null	Null	Null	4	44	15	Foot	2	30
48	LuvT2W	-22.42367	31.28058	wet	4	100	20	2670	205	Null	Null	Null	3	40	75.1	Foot	2	0
49	LuvT3D	-22.42653	31.26314	dry	1	3	20	3242	98	Null	Null	Null	2	29	8.2	Foot	2	24
50	LuvT3ED	-22.42653	31.26314	end of dry	2	3	20	3242	98	Null	Null	Null	2	33	19.7	Foot	2	3
51	LuvT3EW	-22.42653	31.26314	end of wet	3	3	20	3242	98	Null	Null	Null	4	44	15	Foot	2	30
52	LuvT3W	-22.42653	31.26314	wet	4	3	20	3242	98	Null	Null	Null	3	40	75.1	Foot	2	0
53	MapT1D	-22.40274	31.28013	dry	1	100	100	177	15	5	3.5	10	3	29	8.2	Vehicle	1	28
54	MapT1ED	-22.40274	31.28013	end of dry	2	100	100	177	15	5	3.5	10	2	38	19.7	Vehicle	1	250
55	MapT1EW	-22.40274	31.28013	end of wet	3	100	100	177	15	5	3.5	10	4	44	15	Vehicle	1	78
56	MapT1W	-22.40274	31.28013	wet	4	100	100	177	15	5	3.5	10	4	38	75.1	Vehicle	1	42.47
57	MapT2D	-22.40286	31.28020	dry	1	2	80	177	29	5	3.5	10	3	29	8.2	Vehicle	1	28
58	MapT2ED	-22.40286	31.28020	end of dry	2	2	80	177	29	5	3.5	10	2	38	19.7	Vehicle	1	250
59	MapT2Ew	-22.40286	31.28020	end of wet	3	2	80	177	29	5	3.5	10	4	44	15	Vehicle	1	78
60	MapT2W	-22.40286	31.28020	wet	4	2	80	177	29	5	3.5	10	4	38	75.1	Vehicle	1	42.47
61	MapT3D	-22.40218	31.27860	dry	1	100	70	177	181	5	3.5	10	3	29	8.2	Foot	2	28
62	MapT3ED	-22.40218	31.27860	end of dry	2	100	50	177	181	5	3.5	10	2	38	19.7	Foot	2	250
63	MapT3EW	-22.40218	31.27860	end of wet	3	100	70	177	181	5	3.5	10	4	44	15	Foot	2	78

Site Number	Site ID	X	Y	Season	Season Number	Distance to Cover (m)	% Canopy Cover	Distance to Zimbabwe border (m)	Distance to closest road (m)	Combined Grass Structure at water's edge	Combined Shrub Structure at water's edge	Combined Tree Structure at water's edge	Water Level	Max Air Temp	Rain previous month (mm)	Human Access	Human Access ID	TSS
64	MapT3W	-	31.27860	wet	4	100	70	177	181	5	3.5	10	4	38	75.1	Foot	2	42.47
65	NhIT1D	-	21.20303	dry	1	4	0	817	371	8	2	4	3	26	8.2	Foot	2	284
66	NhIT1ED	-	21.20303	end of dry	2	1	10	817	371	8	2	4	2	35	19.7	Foot	2	355
67	NhIT1EW	-	21.20303	end of wet	3	4	0	817	371	8	2	4	4	41	15	Foot	2	76
68	NhIT1W	-	21.20303	wet	4	4	0	817	371	8	2	4	5	40	75.1	Foot	2	260.71
69	NhIT2D	-	31.20161	dry	1	1	20	817	370	8	2	4	3	26	8.2	Foot	2	284
70	NhIT2ED	-	31.20161	end of dry	2	1	20	817	370	8	2	4	2	35	19.7	Foot	2	355
71	NhIT2EW	-	31.20161	end of wet	3	1	20	817	370	8	2	4	4	41	15	Foot	2	76
72	NhIT2W	-	31.20161	wet	4	1	20	817	370	8	2	4	5	40	75.1	Foot	2	260.71
73	NhIT3D	-	31.20082	dry	1	4	0	817	268	8	2	4	3	26	8.2	Foot	2	284
74	NhIT3ED	-	31.20082	end of dry	2	4	0	817	268	8	2	4	2	35	19.7	Foot	2	355
75	NhIT3EW	-	31.20082	end of wet	3	4	0	817	268	8	2	4	4	41	15	Foot	2	76
76	NhIT3W	-	31.20082	wet	4	4	0	817	268	8	2	4	5	40	75.1	Foot	2	260.71
77	NhIT4D	-	31.20110	dry	1	1	10	817	269	8	2	4	3	26	8.2	Foot	2	284
78	NhIT4ED	-	31.20110	end of dry	2	1	10	817	269	8	2	4	2	35	19.7	Foot	2	355
79	NhIT4EW	-	31.20110	end of wet	3	1	10	817	269	8	2	4	4	41	15	Foot	2	76
80	NhIT4W	-	31.20110	wet	4	1	10	817	269	8	2	4	5	40	75.1	Foot	2	260.71
81	NwaT1D	-	31.25803	dry	1	15	60	3160	1243	4	6	10	3	26	8.2	Foot	2	608
82	NwaT1ED	-	31.25803	end of dry	2	15	60	3160	1243	4	6	10	2	33	19.7	Foot	2	1205
83	NwaT1EW	-	31.25803	end of wet	3	15	60	3160	1243	4	6	10	4	44	15	Foot	2	337
84	NwaT1W	-	31.25803	wet	4	15	60	3160	1243	4	6	10	4	38	75.1	Foot	2	515.32

Site Number	Site ID	X	Y	Season	Season Number	Distance to Cover (m)	% Canopy Cover	Distance to Zimbabwe border (m)	Distance to closest road (m)	Combined Grass Structure at water's edge	Combined Shrub Structure at water's edge	Combined Tree Structure at water's edge	Water Level	Max Air Temp	Rain previous month (mm)	Human Access	Human Access ID	TSS
85	NwaT2D	- 22.41665	31.25984	dry	1	10	50	3160	885	4	6	10	3	26	8.2	Foot	2	608
86	NwaT2ED	- 22.41665	31.25984	end of dry	2	10	50	3160	885	4	6	10	2	33	19.7	Foot	2	1205
87	NwaT2EW	- 22.41665	31.25984	end of wet	3	10	50	3160	885	4	6	10	4	44	15	Foot	2	337
88	NwaT2W	- 22.41665	31.25984	wet	4	10	50	3160	885	4	6	10	4	38	75.1	Foot	2	515.32
89	NwaT3D	- 22.41950	31.26618	dry	1	100	50	3160	443	4	6	10	3	26	8.2	Foot	2	608
90	NwaT3ED	- 22.41950	31.26618	end of dry	2	100	50	3160	443	4	6	10	2	33	19.7	Foot	2	1205
91	NwaT3EW	- 22.41950	31.26618	end of wet	3	100	50	3160	443	4	6	10	4	44	15	Foot	2	337
92	NwaT3W	- 22.41950	31.26618	wet	4	100	50	3160	443	4	6	10	4	38	75.1	Foot	2	515.32
93	NwaT4D	- 22.41554	31.26025	dry	1	0	80	3160	1078	4	6	10	3	26	8.2	Foot	2	608
94	NwaT4ED	- 22.41554	31.26025	end of dry	2	0	80	3160	1078	4	6	10	2	33	19.7	Foot	2	1205
95	NwaT4EW	- 22.41554	31.26025	end of wet	3	0	80	3160	1078	4	6	10	4	44	15	Foot	2	337
96	NwaT4W	- 22.41554	31.26025	wet	4	0	80	3160	1078	4	6	10	4	38	75.1	Foot	2	515.32

Appendix D: Combined Dependent Variable Data

Site Number	Site ID	Nyala	Impala	Baboon	Vervet Monkey	Elephant	Kudu	Porcupine	Eland	Buffalo	Warthog	Hippopotamus	Zebra	Bushbuck	Common Duiker	Thick-tailed Bushbaby	Hyena	Waterbuck	Leopard	Banded Mongoose	Lion	Hare	Slender Mongoose	White-tailed Mongoose	Bushpig	Wildebeest	Civet	Genet	Total Sightings	Small Carnivores	Large Carnivores	Carnivores	Small Herbivores	Medium Herbivores	Large Herbivores	Herbivores	Primates
1	JacT1D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	JacT1ED	0	4	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	8	1	0	1	1	5	0	6	1
3	JacT1EW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	JacT1W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	JacT2D	7	5	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	13	1	14	0	0
6	JacT2ED	1	4	0	1	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	7	1	8	1	1
7	JacT2EW	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2	0	2	1	1
8	JacT2W	2	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	7	1	0	1	1	4	0	5	1	1
9	JacT3D	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	8	0	8	0	0
10	JacT3ED	0	1	0	1	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	2	2	5	1	1
11	JacT3EW	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	4	0	0
12	JacT3W	3	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	10	1	0	1	1	6	0	7	2	2
13	LakT1D	11	4	0	0	1	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	1	17	1	19	0	0
14	LakT1ED	0	5	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	1	5	2	8	1	1
15	LakT1EW	3	9	4	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	1	13	0	14	4	4
16	LakT1W	5	8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	14	0	14	0	0
17	LakT2D	4	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	7	1	8	0	0
18	LakT2ED	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	1	1
19	LakT2EW	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	1	2	1	1
20	LakT2W	1	4	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	7	0	7	1	1
21	LakT3D	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	2	1	1	4	0	0
22	LakT3ED	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	0	0	0	1	3	4	2	2
23	LakT3EW	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
24	LakT3W	3	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	5	0	5	2	2
25	LakT4D	7	6	1	0	0	1	0	0	0	1	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	2	17	0	19	1	1
26	LakT4ED	0	6	4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	6	2	8	4	4
27	LakT4EW	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6	0	6	0	0
28	LakT4W	4	3	0	1	0	2	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	1	11	0	12	1	1
29	LimT1D	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	2	1	1
30	LimT1ED	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	LimT1EW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0
32	LimT1W	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
33	LimT2D	1	0	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	1	1	3	3	3
34	LimT2ED	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	1	1	3	1	1
35	LimT2EW	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	2	0	2	2	2
36	LimT2W	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	1	0	1	0	1	0	1	0	1	3
37	LimT3D	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	2	0	2	0	0	1	1	1	1
38	LimT3ED	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	1	0	1	0	2	1	3	2	2
39	LimT3EW	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	1	3	3
40	LimT3W	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	1	2	2

Site Number	Site ID	Nyala	Impala	Baboon	Vervet Monkey	Elephant	Kudu	Porcupine	Eland	Buffalo	Warthog	Hippopotamus	Zebra	Bushbuck	Common Duiker	Thick-tailed Bushbaby	Hyena	Waterbuck	Leopard	Banded Mongoose	Lion	Hare	Slender Mongoose	White-tailed Mongoose	Bushpig	Wildebeest	Civet	Genet	Total Sightings	Small Carnivores	Large Carnivores	Carnivores	Small Herbivores	Medium Herbivores	Large Herbivores	Herbivores	Primates
41	LuvT1D	2	0	1	0	7	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	13	0	1	1	0	2	9	11	1
42	LuvT1ED	13	7	4	3	1	3	0	0	2	2	2	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	42	0	0	0	2	28	5	35	7
43	LuvT1EW	6	5	0	5	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	1	11	1	13	5
44	LuvT1W	3	1	2	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	4	1	5	6
45	LuvT2D	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	1	1	2	4	1
46	LuvT2ED	7	4	1	2	8	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	26	1	0	1	1	13	8	22	3
47	LuvT2EW	2	0	2	3	1	0	0	0	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	1	2	5	8	5
48	LuvT2W	1	1	3	2	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	9	0	0	0	1	3	0	4	5
49	LuvT3D	2	0	2	0	1	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	17	0	0	0	2	3	10	15	2
50	LuvT3ED	4	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	4	2	6	1
51	LuvT3EW	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	3	3	2
52	LuvT3W	2	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	12	1	0	1	0	3	0	3	8
53	MapT1D	4	0	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	1	4	0	5	4
54	MapT1ED	1	1	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	1	0	1	0	3	0	3	6
55	MapT1EW	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2	0	2	1
56	MapT1W	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1	0	1	0	2	0	2	1	
57	MapT2D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	MapT2ED	11	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	12	0	12	3
59	MapT2Ew	2	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	1	2	0	3	2
60	MapT2W	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	3	0	3	2
61	MapT3D	24	2	3	9	1	0	0	0	2	5	0	2	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	52	1	0	1	8	28	3	39	12
62	MapT3ED	30	8	3	2	0	3	0	0	1	4	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	53	0	1	1	5	41	1	47	5
63	MapT3EW	2	0	3	3	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	1	2	2	5	6
64	MapT3W	3	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	2	3	0	5	2
65	NhIT1D	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	3	0	4	0
66	NhIT1ED	0	0	1	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	2	2	4
67	NhIT1EW	0	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	3	0	4	2
68	NhIT1W	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	2	0	0	2	0
69	NhIT2D	1	7	7	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	1	9	0	10	8
70	NhIT2ED	1	3	4	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	17	2	0	2	3	5	2	10	5
71	NhIT2EW	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	2	0	2	2
72	NhIT2W	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	3	0	1	1	1	0	0	1	1
73	NhIT3D	1	5	4	0	0	0	0	0	0	2	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	16	0	3	3	2	7	0	9	4
74	NhIT3ED	1	2	2	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	1	4	1	6	3
75	NhIT3EW	2	5	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	8	1	9	1
76	NhIT3W	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	0	0	0	1	3	0	4	1
77	NhIT4D	3	0	0	1	0	1	2	0	0	1	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	12	0	3	3	3	5	0	8	1
78	NhIT4ED	1	2	1	0	1	2	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	2	7	1	10	1
79	NhIT4EW	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	2	0	2	2

[illegible]