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University of the Witwatersrand

School of Geography, Archaeology, and Environmental Sciences

Faunal Occurrence at Naturally-Forming Waterholes in Shamwari Private Game Reserve, Eastern Cape, South Africa

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Kathleen Frances Vowles

Student Number: 672837



Dissertation submitted to the Faculty of Science in fulfilment of the requirements for the degree of Masters of Science

Johannesburg, July 2018

Declaration

I, Kathleen Frances Vowles (672837) hereby declare that this research project for my Master`s qualification in the division of Geography at the University of the Witwatersrand, is my original work. I declare that some information was withheld from this research project to protect rhino and elephants in Shamwari Private Game Reserve at the request of the reserve, as the threat of rhino and elephant poaching is unfortunately a reality in South Africa.



Kathleen Frances Vowles

20/07/2018

Date

Abstract

This research examines the influence of surface water availability, which depends on rainfall, and temperature on faunal occurrence patterns at naturally-forming waterholes in Shamwari Private Game Reserve, Eastern Cape, South Africa. The objectives assess the occurrence and diversity of species at three naturally-forming waterholes and to examine the implications that rainfall and temperature have on species visitation patterns at naturally-forming waterholes. On a local scale, this research makes use of camera trap images activated by motion sensor, capturing at 10 second intervals to establish the faunal occurrence patterns and to determine wallowing activity of elephants, white rhino, and warthog at the waterholes over a short-time scale (June 2016 to November 2016). The frequencies of mammal species visiting times per hour were grouped into daily and monthly periods. Monthly data were examined, as this was a short-term study, hence shifts in faunal activity could be easily identified with local weather conditions monthly rather than seasonally (as seasonality was not the focus of the study). The occurrence of different species per hour at the waterholes was established over a period of six months (June to November). Distribution curves were created to determine species peak visitation times per hour, both daily and monthly, and pie charts were produced to determine shifts in individual species abundance each month. Local weather data were statistically analysed (Pearson`s correlation coefficient and cross-correlation) with faunal occurrence to determine the influence of these local weather conditions on faunal behaviour.

Species-specific occurrences (daily and monthly) were established for all species that visited the three selected waterholes. Herbivore visitation occurred predominantly during diurnal hours and carnivores were observed during nocturnal hours. Temperature influenced species visitation times at these waterholes. As temperatures peaked (T_{max} and T_{min}), there was a decrease in species sighted at the waterholes. However, surface water availability, which is influenced by rainfall, was the crucial variable that drove faunal occurrence at the naturally-forming waterholes. More species were observed at the waterholes after rainfall events, compared to before rainfall. A delay in faunal occurrence was evident at the waterholes, two weeks after rainfall events. This lag exists due to the surface water, which was made available after rainfall events. Surface water availability and temperatures were, however, not the only factors that drove the occurrence of species at these waterholes. Other factors such as predator-prey relationships, tourist presence, cloud cover, inter- and intra-species competition, vegetation, soil type, and waterhole morphology influenced faunal occurrence patterns.

Other objectives were to establish wallowing activity at the naturally-forming waterholes and to determine if there is a relationship between local weather variables and wallowing behaviour. As elephants, white rhino, and warthog are sparsely haired mammals, it is essential that they wallow for means of thermoregulation. Wallowing activity of these species only occurred during diurnal hours. In Shamwari at the three naturally-forming waterholes, warthogs wallowed more frequently than elephants and white rhino. Local weather variables influenced the wallowing behaviour of these species. An increase in temperature corresponded with an increase in wallowing activity. In addition, peak wallowing activity occurred at midday, when temperatures were at their highest. However, this depended on whether there was surface water available in these waterholes. A significant two week interval occurred between rainfall and wallowing activity (cross correlation function = 0.75), where the quantity of rainfall directly influenced the presence of surface water available in these waterholes. Without rainfall, the three naturally-forming waterholes remained dry and species did/could not undergo wallowing activity.

It is essential to understand faunal visitation patterns and wallowing behaviour in relation to local weather variables, in particular with projected climate change scenarios. This study contributes to the knowledge necessary for the management decisions that ensure sustainability of wildlife in protected areas in South Africa. This can provide essential information for the construction of artificial waterholes, which should mimic natural waterholes and faunal distribution.

Keywords: Naturally-forming waterholes, temperature, surface water availability, faunal occurrence, wallowing activity.

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Chapter 1

Introduction



1.1 Introduction

Since life first began on the planet, organisms have evolved in response to environmental change (Davies, 2012; Davies *et al*., 2012). Organisms have the ability to alter their behaviour to adapt to the changing environments around them, as a behavioural change is the first response to changing local environmental conditions (Owen-Smith, 2002; Brown, 2012; Davies *et al*., 2012). This is known as behavioural ecology, which is the study of behavioural strategies that animals have evolved to enhance their survival and to increase their reproductive success (Owen-Smith, 2002; Alcock, 2009; Davies *et al*., 2012). To understand the behavioural ecology of an animal, studies that examine the link between behaviour, evolution, and ecology are required (Owen-Smith, 2002; Woodroffe, 2003; Brown, 2012; Davies *et al*., 2012). Behavioural ecology is an interdisciplinary field of study, since many factors contribute to changing environmental conditions, which are all integrated (Caro, 1999). For example, organisms have the ability to change the state of their local environments and the local environment can change the state of organisms. This presents a close link between landscape, ecosystem, and climate that, in turn, alters animal behaviour (Anon, 2014).

Understanding animal behaviour through research is part of the solution to solving both wildlife conservation and management problems. The key characteristic of wildlife management is that animal species are not the same and will react differently to changing environmental conditions, even at an individual level (Owen-Smith, 2002; Festa-Bianchet & Apollonio, 2003). Understanding species' physiological constraints is one aspect in determining their potential for adaptation to environmental change (Brown, 2012; Buchanan & Partecke, 2012), as physiological constraints are factors (i.e. stabilising selection) which make faunal populations resistant to evolution (Blomberg & Garland, 2002). This shows that interdisciplinary studies are needed to fully understand animal behaviour and the consequences of changing environmental conditions (Owen-Smith, 2002; Bigwood, 2011; Davies, 2012; Engvall, 2013). Thus, research of this nature is important as it provides broad knowledge of animal behaviour, which can improve conservation by refining our ability to manage wildlife (Festa-Bianchet & Apollonio, 2003; Gosling, 2003; van Wilgen *et al*., 2015). In particular, our predictions concerning population responses to environmental change (Gosling, 2003; Woodroffe, 2003; Wieren & Bakker, 2008; Blumstein, 2012; Chaine & Clobert, 2012).

Much work has been carried out on the relationship between wildlife, climate, and local weather variables (e.g. Jeltsch, 1997; Hawkins *et al*., 2003; Ogutu *et al*., 2008; Simpson *et al*., 2011; Hayward & Hayward, 2012; Halidu *et al*., 2013; Maraschin; 2016; Trent, 2016). One such example is the relationship between rainfall and temperature, and how these variables have the ability to control species richness gradients (Hawkins *et al*., 2003). Water and vegetation affects the distribution and

abundance of animals, thus, making the availability of surface water, which is influenced by rainfall, a regional constraint (Owen-Smith, 2002; Georgiadis *et al*., 2003; Chamaillé-Jammes *et al*., 2007a; van Wilgen *et al*., 2015). Most mammals live in close association with water, since water is essential for their survival (Rosenstock *et al*., 1999). Consequently, areas around surface water have zoogeomorphic impacts on the environment, e.g. compaction and trampling (Viles, 1988; Chamaillé-Jammes *et al*., 2007a; Archer & Predick, 2008; Fey *et al*., 2010; Bigwood, 2011; Vanschoenwinkel *et al*., 2011). The African Savannah is one habitat where large numbers of different mammal species live in close association with water sources such as rivers, ponds, lakes, naturally-forming waterholes, and artificial waterholes (Owen-Smith, 2002; Skead, 2007; Bigwood, 2011; Davidson *et al*., 2013; Trent, 2016). Hence, it is essential to understand how surface water availability influences animal behaviour, in particular semi-arid regions which make up bioregions in southern Africa. This understanding is required to determine whether species are able to adapt to changes in environmental conditions, otherwise extinction of species could be the result (Festa-Bianchet & Apollonio, 2003; Hannah *et al*., 2007). Furthermore, research of this nature will aid in predicting how animals will respond to future climate change scenarios (Gaillard *et al*., 2008; Brown, 2012).

In South Africa, many protected areas provide supplementary water for their associated wildlife, including the South African National Parks, private game reserves, and private game farms (Knight, 1995; Epaphras *et al*., 2008; Smit & Grant, 2009; Davidson *et al*., 2013; Maraschin, 2016; Trent, 2016). Water is a crucial resource, in particular arid and semi-arid environments where many of these protected areas are located (Thomas, 1998). These regions – and the animals within them – are exposed to varying temperatures and a seasonal shift in rainfall, which affects the availability of naturally occurring surface water (Simpson *et al*., 2011; van Wilgen *et al*., 2015). Furthermore, successful management of African protected areas requires an understanding of the relationship between animal populations and water sources, so that a better understanding between the biotic and abiotic elements can be established (Hannah *et al*., 2007; Halidu *et al*., 2013). Knowledge and monitoring of variable surface water availability can improve our understanding of the functioning of the natural ecosystem with all the related effects (e.g. floods and droughts).

1.2 Rationale: Contribution to Existing Research

Extensive research has been conducted on faunal utilisation at waterholes in conservation areas in southern Africa (Ayeni, 1975; Hayward & Hayward, 2012; Maraschin, 2016; Trent, 2016). However, there are still many gaps regarding faunal water-source utilisation in different bioregions of southern Africa, in particular wallowing at naturally-forming waterholes. Different regions in southern Africa

have likely different responses to the effects of climate and local weather variability and climate change (Chamaillé-Jammes *et al*., 2007a; van Wilgen *et al*., 2015). There is a gap in literature on how species assemblages and the distribution of southern African species within different regions are related to climatic variables, predominantly rainfall as it influences the amount of surface water available (Jeltsch, 1997; Ogutu *et al*., 2008). Mammal responses will therefore vary depending on fluctuations in the naturally occurring surface water and local temperature (Hitchcock, 1996). Furthermore, rainfall and temperature changed over the past century in South Africa, and temperatures have increased in recent years in many protected areas (Hitchcock, 1996; van Wilgen *et al*., 2015). Hence, ongoing research is essential to determine how such climatic changes will affect species survival and adaptive responses (Hitchcock, 1996; van Wilgen *et al*., 2015).

Daily and monthly visitation of species to naturally-forming waterholes is the focus of this research as the availability of surface water influences faunal utilisation of water sources. Seasonal variability for predicting species richness is better than annual climatic variables. However, due to time constraints a short-term study was conducted where monthly data were examined, hence, shifts in faunal activity could be easily identified with local weather conditions monthly rather than seasonally (as seasonality was not the focus of the study) (Hawkins *et al*., 2003; Chamaillé-Jammes *et al*., 2007b; Simpson *et al*., 2011). Therefore, monthly visitation patterns were analysed to observe the short-term changes in faunal visitation at the naturally-forming waterholes (Chamaillé-Jammes *et al*., 2007b; Simpson *et al*., 2011) because even short-term changes in climate can alter animal behaviour (Brown, 2012).

The understanding of faunal occurrence at naturally-forming waterholes becomes important in facilitation of management decisions to achieve a 'desired ecosystem state' at supplementary waterholes (e.g. artificial waterholes) (Venter *et al*., 2008). An ecosystem state refers to the conservation of specified processes desirable for stability in a system (i.e. species composition and abundance) (Venter *et al*., 2008). Artificial waterholes need to mimic natural systems to ensure that they are not only utilised for drinking but also wallowing (Butler, 1995; Venter *et al*., 2008; Bracke, 2011). Wallowing is the coating of the animal's body surface with mud, a mud like substance or water (Jarman, 1972; Bigwood, 2011, Bracke, 2011; Vanschoenwinkel *et al*., 2011). Likewise, over-provision of water points could lead to decline in some species populations during drought periods, and artificial waterholes can alter the natural balance of an area (James *et al*., 1999).

In the Kruger National Park, supplementation of water with artificial waterholes resulted in the unintended loss of roan antelope (*Hippotragus equinus*) during the drought period of 1982 - 1983 (Harrington *et al*., 1999). Burchell`s zebra (*Equus burchellii*) and wildebeest (*Connochaetes taurinus*)

increased in environments, which roan antelope favoured for grazing on tall grasses. With Burchell`s zebra and wildebeest encroachment into the roan antelope niche, it resulted in an increased grazing and a decline of tall grass cover. Affecting the amount of resources available for roan antelope and increased vulnerability of roan antelope calves (Harrington *et al*., 1999). An increase in mammals drinking at artificial waterholes can result in increased predation and transference of disease (Rosenstock *et al*., 1999; Epaphras *et al*., 2008). Areas where water points are more widely distributed (which mimic natural waterholes), suffered very little reduction of species populations during drought periods (Owen-Smith, 2002).

Faunal species do not only utilise waterholes for drinking, but also wallowing. African elephants (*Loxodonta africana*), white (Square-Lipped) rhinoceros (*Ceratotherium simum*) – often abbreviated as rhino – and warthogs (*Phacochoerus aethiopicus*) will be focal species of wallowing activity in this research as they are known to wallow frequently (Jarman, 1972; Vanshoenwinkel *et al*., 2011). Much literature exists on wallowing activity in National Parks and game reserves in Africa, this includes: Etosha National Park (Namibia) (Berger & Cunningham, 1998), Hwange National Park (Zimbabwe) (Flint & Bond, 1968), Middle Zambezi Biosphere Reserve (Zimbabwe) (Jarman, 1972), Malilangwe (Zimbabwe) (Vanshoenwinkel *et al*., 2011), Tembe Elephant Park (Maputuland) (Bigwood, 2011; Engvall, 2013), Ruaha National Park (Tanzania) (Barnes, 1983), Liwande National Park (Malawi) (Dudley, 1997), Umfolozi-Hluhluwe Game Reserve (South Africa) (Owen-Smith, 1974; Pienaar, 1994), Kalahari Gemsbok National Park (South Africa) (Weir, 1969; Maraschin, 2016), Kruger National Park (South Africa) (Trent, 2016), and Addo Elephant National Park (South Africa) (Engvall, 2013). Gaps are still present with regards to wallowing activity in the Eastern Cape of South Africa and further research on wallowing behaviour is needed in this specific region.

Elephants, white rhino, and warthog are sparsely haired mammals, which makes them more likely to wallow than other mammal species (Parker *et al*., 2009; Bracke, 2011; Stuart & Stuart, 2015). Limited research has been conducted into wallowing activity of these species in relation to local weather variables, in particular the white rhino and warthog. Only these three species wallowing behaviour was explored in this investigation, as no wallowing activity was observed by other species at the naturally-forming waterholes. For the purpose of this investigation, a wallowing event will be considered when animals enter naturally-forming waterholes and cover their body surface with mud, other substances (dust), or water (Jarman, 1972; Bigwood, 2011; Bracke, 2011; Vanshoenwinkel *et al*., 2011). Elephants are known to spray mud, dust, or water onto themselves, which can be conducted outside waterholes, therefore this will be excluded as a wallowing event

(Jarman, 1972). Thus, comparable wallowing events (entering the waterhole and rolling in mud, other substances, and water) are explored for all three species.

There is limited research into how the availability of surface water and temperature affects the wallowing behaviour of these species (Jarman, 1972; Butler, 1995; Cumming & Cumming, 2003). Wallowing is a behavioural response to increased temperatures, as wallowing species are unable to thermoregulate their body temperatures effectively (*section 2.7*) (Brown, 2012). Thus, it is essential to understand wallowing behaviour to determine what management strategies can be put in place to aid in these species wallowing activity with increased temperatures and decreased surface water availability. Wallowing species will be negatively affected by climate change, as thermoregulation influences the visitation times that these species drink or wallow at water sources (Hewitson & Crane, 2006; Kruger, 2006; Valeix *et al*., 2007a; Huey *et al*., 2012). It was noted by Huey *et al*. (2012) that behavioural thermoregulation (e.g. wallowing) acts as a buffer to increased temperatures. Therefore, increased wallowing frequency will take place by elephants, white rhino, and warthogs to cope with increased temperatures. Warthogs are highly vulnerable during periods of low rainfall, as warthogs are known to be the first species to decline during droughts, as they are vulnerable to changes in water and food availability (Walker *et al*., 1987; Mason, 1990; Owen-Smith, 2002). Thus, behavioural and physiological constraints become a necessity to investigate, and to establish species-specific water-requirements and how it is influenced by climate change (Bellard *et al*., 2012).

1.2.1 Research Aim

This research aims to investigate how daily and monthly variations in local weather conditions affect the occurrence and wallowing behaviour of faunal species at naturally-forming waterholes in Shamwari Private Game Reserve, Eastern Cape, South Africa.

1.2.2 Objectives

1. To establish the daily and monthly faunal occurrence at naturally-forming waterholes in Shamwari Private Game Reserve for a six-month period (June – November 2016).
2. To identify any relationship between faunal occurrence patterns and local daily weather conditions (rainfall and temperature) over the same six-month period.
3. To establish the number of wallowing events both daily and monthly at naturally-forming waterholes for a six-month period.
4. To identify if there is a relationship between local weather conditions (rainfall and temperature) and wallowing behaviour over a six-month period or to determine if wallowing is an event driven process.

Chapter 2

Literature Review



2. Literature Review

2.1 Natural Waterholes

The generic definition of a natural waterhole is a naturally formed depression on the surface of the landscape that is filled with water for an extended period of time (Butler, 1995; Ng *et al*., 2001). It is known as a zoogenous pool, which is a pool originated or produced by animals rather than plants (Jarman, 1972). Literature reveals the formation of natural waterholes to be highly localised to specific environmental conditions, climatic conditions, species present in the environment, and other influences by animal action in the landscape (Bracke, 2011). Typically, the area surrounding waterholes often comprises of game trails that lead directly to and away from the waterholes, in particular if the waterhole is located in the thicket biome as it enables an easier gradient for animals to descend (Jarman, 1972; Hall *et al*., 1999; Skead, 2007; Mucina & Rutherford, 2011; Jones, 2012). Waterholes may even form along these game paths during the wet season (Bracke, 2011). However, limited research has been conducted on non-perennial natural waterholes or naturally-forming waterholes; literature predominantly focuses on perennial water sources and artificial waterholes for animal utilisation and behaviour.

2.2 Origin of Natural Waterholes

2.2.1 Natural Forming Waterholes

Waterholes can form in various ways, for instance, some waterholes are a consequence of natural shallow depressions or as deflation basins in dry seasons (Flint & Bond, 1968; Weir, 1969; Jarman, 1972; Ng *et al*., 2001; Makhabu *et al*., 2002; Bracke, 2011; Vanshoenwinkel *et al*., 2011; Etosha, 2015; Stommel *et al*., 2016). Natural shallow depressions in the landscape can retain water for an extended period. This allows for the formation of mud or a mud-like substance and therefore the ability to hold water, which forms a waterhole (Ng *et al*., 2001; Bracke, 2011; Vanshoenwinkel *et al*., 2011; Etosha, 2015; Stommel *et al*., 2016). However, these naturally-forming waterholes have spatial and temporal variability due to various climatic and hydrogeological factors (Cronje *et al*., 2005). For instance, some waterholes have endorheic drainage, which is a closed hydrological drainage system, such as a pan, while other waterholes have an open hydrological drainage system, such as a waterhole in a dry riverbed (Parris, 1976; Hillyard *et al*., 2015). Therefore, the type of drainage can influence the ability of the waterhole to retain water or to disperse throughout the dry season (Weir, 1969; Jarman, 1972; Yair, 1972; Makhabu *et al*., 2002). In addition, waterholes can form during the dry periods as deflation basins, which are shallow clay-lined depressions that can extend to at least

1.5 km in diameter (Weir, 1969; Jarman, 1972). These types of waterholes contain high clay content making it an appropriate waterhole for wildlife to wallow in (*section 2.7*), as clay has high water retention capability (Flint & Bond, 1968; Weir, 1969; Jarman, 1972; Yair, 1995; Makhabu *et al*., 2002).

Natural waterholes are predominantly located in wet areas, however, availability of these areas is due to fluctuations in surface water according to the season (Allan *et al*., 1995). During the wet season, ephemeral (rain-fed) waterholes host an abundance of water for wildlife, however, in the dry season; the ephemeral water source evaporates and at times is unable to support water (Jarman, 1972; Davidson *et al*., 2013; Stommel *et al*., 2016). Therefore, the transient nature of these ephemeral waterholes as a water source is revealed (Jarman, 1972; Chamaillé-Jammes *et al*., 2007a; Davidson *et al*., 2013; Stommel *et al*., 2016). However, one should acknowledge that the deeper waterholes could provide a permanent water source throughout the dry season, despite high evaporation rates (Gaylard *et al*., 2003). On the other hand, after heavy rains, some waterholes may hold water despite the decline in water volume of permanent rivers in the dry season (Gaylard *et al*., 2003; Davidson *et al*., 2013). The exception to this is in periods of extreme droughts, making naturally-forming waterholes dependent on preceding catchment-level rainfall (Flint & Bond, 1968; Mason *et al*., 1999; Gaylard *et al*., 2003; Davidson *et al*., 2013). In river beds, when there is a decline in water capacity of permanent rivers resulting from the dry season, there is waterhole formation in dry sand riverbeds, which animals use to drink or wallow. An example of these waterholes is found in alluvial riverbeds of Kruger National Park (Jarman, 1972; Goudie & Wells, 1995; Makhabu *et al*., 2002; Etosha, 2015; Stommel *et al*., 2016).

Natural waterholes can form because of where a surface depression meets the water table (usually located in valleys) (Jarman, 1972; Shaw & Thomas, 1997; Bracke, 2011; Etosha, 2015; Stommel *et al*., 2016). Furthermore, waterholes can be located on the side of ridges, manipulating the connecting fractures in the geology creating waterways (Alistoun, 2012). However, the availability of water in the waterholes varies depending on the season and the size and depth of the waterhole, with exceptions to this pattern in years that experience intense drought or a significant decrease in the water table (Flint & Bond, 1968; Jarman, 1972; Alistoun, 2012; Etosha, 2015).

2.2.2 Zoogenous Waterholes

There are many reasons as to why waterholes exist; literature reveals the origin of natural waterholes is by trampling, drinking, rooting, and geophagy by animals, which is then called a zoogenous pool/waterhole (Jarman, 1972; Butler, 1995; Viles, 1988; Bigwood, 2011; Bracke, 2011; Vanshoenwinkel *et al*., 2011) (*Figure 2.1*). Trampling is also an origin of a waterhole by animal

activity, as trampling creates an impermeable clay seal, allowing for greater water retention (Butler, 1995, Thomas, 1998, Bigwood, 2011). Waterholes can be the consequence of digging by elephants, rhino, Burchell`s zebra, and warthogs. In times when there are inadequate water sources (where the water table cannot be accessed) or poor quality of water and mud present, is when digging into the ground by these animals occurs (Flint & Bond, 1968; Weir, 1969; Jarman, 1972; Ng *et al*., 2001; Skead, 2007; Haynes, 2012; Jones, 2012; Stommel *et al*., 2016). With repeated use, the wet soil is trampled and a certain volume of the sediment is removed, finally forming a waterhole (Jarman, 1972; Bigwood, 2011; Engvall, 2013). If there is a presence of pigs in the environment, they are the main creators of waterholes in many natural settings (Bracke, 2011), and warthogs are the main cause of zoogenous waterholes in Africa (Flint & Bond, 1968). Warthogs are known to produce holes from rooting, which then expand to form waterholes over a given period of time (Flint & Bond, 1968; Bracke, 2011). However, contradictory evidence suggests elephants are the most observed species that dig waterholes, as they are able to access water at depths (Weir, 1969; Jarman, 1972 & Stommel *et al*., 2016). Bioturbation within waterholes control these water sources, as it plays a predominant role in the structure and function of the waterholes (Yair, 1995). Literature on why, where, and when animals dig to access water to drink or wallow is lacking and investigations into this behaviour is important to understand, in particular times of drought when there is less natural surface water available.

Once a hole or depression is created from animal activity, it becomes enlarged by animals drinking, wallowing, entering and exiting waterholes, and geophagy (Haynes, 2012). Engineer species at waterholes cause formation and decay of the environment within and around waterholes, and can cause geomorphological change in the waterhole structure (Weir, 1969; Jarman, 1972; Parker *et al*., 2009, Bigwood, 2011; Jones, 2012). The waterhole can be changed by an individual species or a variety of species. Once a waterhole has been formed, it can be subject to deterioration by physical (wind, rain, and runoff), and biological/zoogeomorphic forces (Goudie & Wells, 1995; *Fey et al.*, 2010; Alistoun, 2012).

Waterholes may be abandoned, but they can be re-engineered by animal species to conserve energy, as it is a more efficient ecological constraint then starting a waterhole anew (Jones, 2012). Shifts in waterhole density are a result of ecological factors, such as abiotic resources and conditions, resources and interactions, positive and negative feedbacks, and intrinsic density-dependent regulations. Understanding the ecological feedbacks becomes central to understanding to connection between geomorphology, climate, and faunal interactions in all landscapes (Jones, 2012).

2.2.3 Salt-Lick Zoogenous Waterholes

Waterholes are also created because of certain species' needs to consume saline-rich soils for mineral supplementation, known as salt-licks which occur in various areas (*Figure 2.1*) (Weir, 1969; Jarman, 1972; Butler, 1995). Salt-licks have high concentrations of water-soluble sodium, which animals require for their daily nutritional requirements (Haynes, 2012). In addition, the soils also have significant concentrations of calcium, magnesium, and potassium and are usually located on grassy plains (Weir, 1969; Parris, 1976). To consume the saline-rich soil, animals either paw, lick, or use horns, forefoot, tusks, trunks, antlers, or digging tools to obtain the saline-rich soil (Flint & Bond, 1968; Weir, 1969; Butler, 1995; Haynes, 2012; Engvall, 2013). Wallowing is also a method, to loosen the soil for ingestion around salt licks. Once the soil is actively removed, it creates a cavity that fills with water, creating a waterhole that can be used for further faunal utilisation (Weir, 1969; Engvall, 2013). In addition, salt-licks can form during dry periods, where evaporation rates can increase water salinity, leading to the surrounding soils becoming salt rich (Alistoun, 2012; Engvall, 2013). This could potentially cause an ephemeral waterhole to become a salt rich waterhole; however, this is very environmentally specific (i.e. pan) (Yair, 1995; Clutton-Brock, 2001; Stommel *et al*., 2016).

To emphasise further the connection of waterholes and waterways, salt-licks are known to be found in a chain along a line segment on a surface or subsurface waterway into larger waterholes (Weir, 1969; Ng *et al*., 2001; Alistoun, 2012). This makes it essential to consider drinking sites, in combination with wallowing and salt-licks (Weir, 1969; Jarman, 1972; Engvall, 2013). All waterholes develop through a range of stages of expansion and infilling (Jarman, 1972; Skead, 2007). The diagram is a summary of the formation of naturally-forming waterholes and was created using all of the previous information in *section 2.2*, which includes the origin of natural, zoogenous, and salt-lick zoogenous waterholes (*Figure 2.1*).

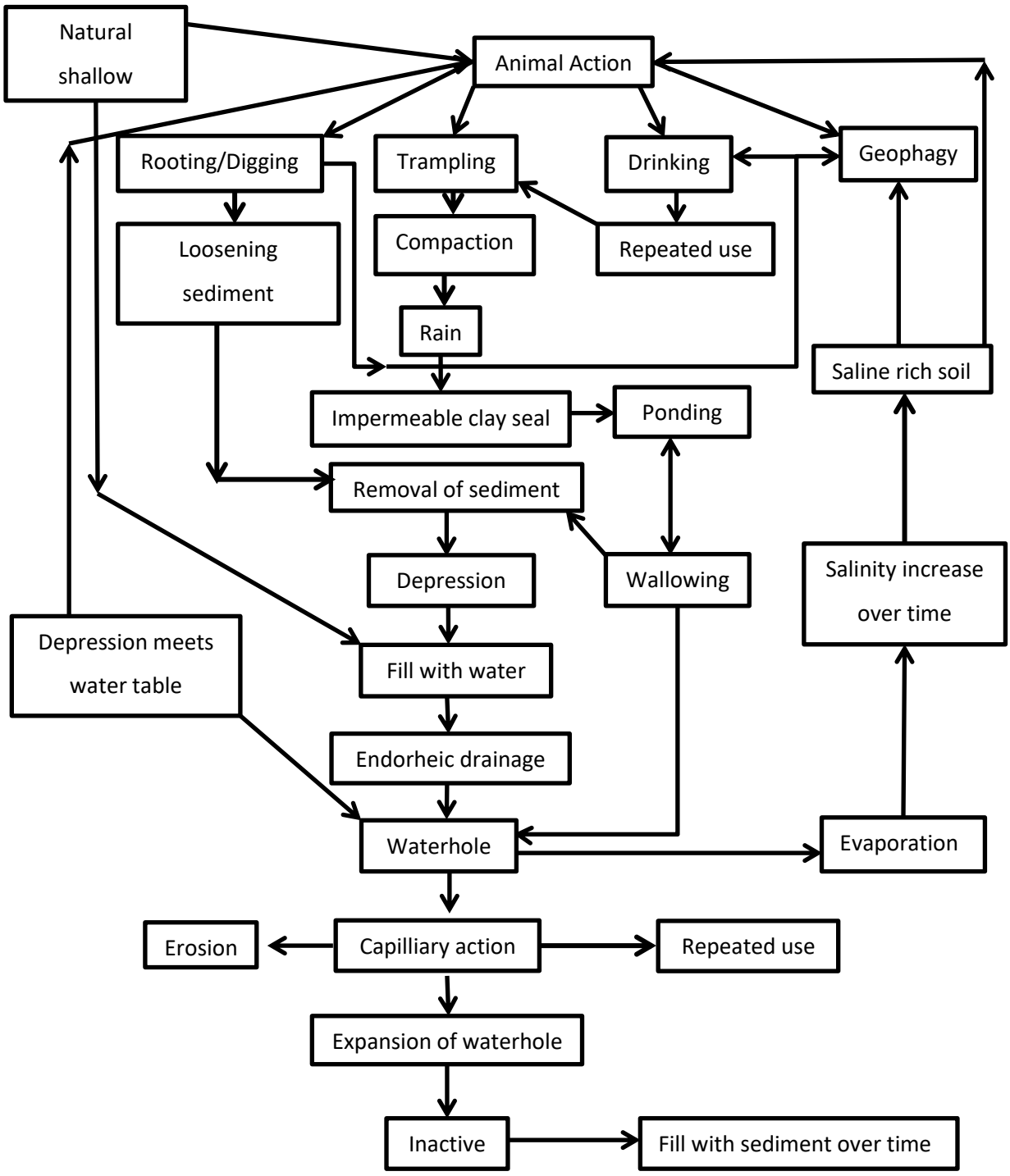


Figure 2. 1: Model of the formation of naturally-forming waterholes.

2.3 Introduction to Climate, Weather, and Water Sources

Climate has constantly been changing since the earth first formed, and on every timescale there have been fluctuations of the earth's surface conditions. The first step one has to take to determine how the climate varies is to distinguish between weather and climate. Weather is what you get and climate is what we expect. Therefore, climate change is concentrated around the statistics of the weather phenomena that have provided evidence into long-temporal changes in the overall warming and cooling of the global climate (Burroughs, 2007). Thus, past climate changes are etched on the landscape, and has therefore influenced the evolution of life forms (Beever & Belant, 2012).

Water is an essential resource for animals to survive (Rosenstock *et al*., 1999) and thus most mammals live in close association with water (Chamaillé-Jammes *et al*., 2007a). Many species are known to migrate over vast distances to find adequate water sources (quality and availability), to either drink or wallow (Crowe, 1995; Clutton-Brock, 2001; Vanschoenwinkel *et al*., 2011; Birkett *et al*., 2012; Engvall, 2013). Therefore, the availability of water sources influences the distribution, abundance, and occurrence of fauna (Owen-Smith, 2002; Chamaillé-Jammes *et al*., 2007a). Climate variables, namely rainfall and temperature, are important in explaining the patterns of species diversity and richness patterns as they influence the availability of water (Bergstrom & Skarpe, 1999; Hawkins *et al*., 2003; Chamaillé-Jammes *et al*., 2007a; Bigwood, 2011). Other climatic variables are important (e.g. humidity, wind, cloud cover), but they are not examined here due to time and funding constraints.

The global distribution of rainfall has a stronger correlation to species diversity and richness than temperature (Hawkins *et al*., 2003). Similarly, Ogutu *et al*. (2008) state that the dominant climatic factor influencing herbivore dynamics in the African environment is rainfall. Several authors (Owen-Smith, 2002, 2008; Georgiadis *et al*., 2003; Chamaillé-Jammes *et al*., 2007; Prins & Fritz, 2008) have revealed that rainfall limits the carrying capacity of herbivore species. This is because it constrains the distribution and abundance of water-dependent and large body sized herbivore species in landscapes, since they have greater water requirements compared to less-water-dependent and smaller body sized herbivores (Owen-Smith, 2002, 2008; Chamaillé-Jammes *et al*., 2007a; Ogutu *et al*., 2008; Davies *et al*., 2012; Hawkins *et al*., 2013). In addition, rainfall directly affects the food availability for herbivore species, making rainfall patterns important for natural food production (Chamaillé-Jammes *et al*., 2007a; Ogutu *et al*., 2008; Owen-Smith, 2008; Davies *et al*., 2012; Hawkins *et al*., 2013), and the recycling and formation of water sources that these species depend upon (Jarman, 1972; Chamaillé-Jammes *et al*., 2007a; van Wilgen *et al*., 2015).

Water sources are a major limiting factor that influences faunal occurrence, when it comes to wildlife distribution and abundance, in particular the savannah regions (Owen-Smith, 2002; Chamaillé-Jammes *et al*., 2007a). There are different water sites that are available to animals as water sources, including free water (i.e. streams, rivers, puddles, lakes), preformed water (i.e. water within food), and oxidative, or metabolic water (i.e. this is water that is produced as a product of the oxidation of organic compounds containing hydrogen) (Alex, 2011). Effective management and monitoring are needed for these different water sources, as it is necessary for species survival, in particular the dry seasons, during periods of drought, and under the effects of climate change (Halidu *et al*., 2013). An ecological drought is a shortfall of rainfall over a long-temporal scale, which effects large areas for one to several seasons or a year resulting in reduction of primary production in the natural ecosystem (Hounam *et al*., 1975: 127). During times of drought, lack of rainfall will negatively affect plant growth, therefore, affecting the ecosystem and food availability for animal species (Redfern *et al*., 2005; Chamaillé-Jammes *et al*., 2007a; Owen-Smith, 2008). In addition, there has been a loss of species due to construction of fences blocking migratory routes for species to access water sources outside protected areas, making supplementary water sources essential for species to fulfil their water requirements (Williamson *et al*., 1988; Kalikawa, 1990; Butler, 1995; Shroyer *et al*., 2001; Owen-Smith, 2002, 2008; Woodroffe, 2003). Hence, ongoing research into species-specific water requirements is necessary; particularly to determine if water requirements change under differing climatic conditions (Kerley *et al*., 2003).

The increase in drought events, evaporation rates, temperature, and decrease in precipitation reduces the availability of surface water in protected areas and thus, there is a need for additional water sources (Trent, 2016). Thus, this research aims to determine whether species have the ability to adapt to these climatic changes in fragmented fenced settings or when it is necessary for management to implement adaptive management decisions (Owen-Smith, 2002; Gosling, 2003; Woodroffe, 2003; Hannah *et al*., 2007; Chaine & Clobert, 2012; van Wilgen *et al*., 2015). Furthermore, this research provides information on how daily local weather patterns influence faunal behaviour, which is valuable for future management decisions (Gaillard *et al*., 2008; van Wilgen *et al*., 2015). Thus, research on faunal behaviour can be used to determine how future climatic changes (e.g. temperature extremes) will influence faunal behaviour. Therefore, the impacts associated with climatic changes can be detected early and adaptive management solutions can be put in place to deal with the consequences (van Wilgen, 2015).

2.4 Impacts of Climate and Weather on Wild Fauna

National Parks and protected areas in southern Africa are essential for conservation of wildlife and require effective management to ensure their sustainability. South African conservation areas are typically affected by climate and local weather changes, as many areas are in water scarce regions and are predicted to become more arid due to changing rainfall patterns, also due to their fragmented fenced setting (Magadza, 1994; Wanke & Wanke, 2007; Owen-Smith & Ogutu, 2012). Over the past century, there has been a decreasing rainfall volume across southern Africa (Hoofman & Vogel, 2008; Derry & Dougil, 2008; Reddy *et al*., 2010; Hetem *et al*., 2014). The southeastern parts of the country (Eastern Cape) have been predicted to increase in summer rainfall (Hewitson & Crane, 2006; Kruger, 2006; van Wilgen *et al*., 2015), which differs from the western and northern parts of South Africa where a decrease in rainfall is predicted (IPCC, 2014). The Cape Floristic Region is predicted to have dryer conditions, and will warm approximately by 1.8°C by mid-century (Kerley *et al*., 2003; Midgley *et al*., 2003). A projected decrease of 5 to 10% of rainfall is possible in the next five decades for South Africa (Madzwamuse, 2010; van Wilgen *et al*., 2015). Moreover, it is projected that temperature is expected to increase by 1°C to 3°C in South Africa generally, over the next five decades (Madzwamuse, 2010) and to increase by 0.5°C to 2.0°C in semi-arid regions (i.e. Kruger National Park) (Eriksen *et al*., 2008; Hoffman & Vogel, 2008; Hughes *et al*., 2011). These projected increases in temperature and evaporation rates, combined with a decrease in rainfall, will affect surface water availability (Hulme *et al*., 2001; Davis, 2010). Therefore, monitoring protected areas to determine all the factors that threaten these conservation areas, in particular climate and local weather changes are becoming increasingly more important, in particular with additional stress to water resources (Caro, 1999; Jury, 2013).

Predicted changes in precipitation will increase vulnerability of certain species and may lead to species extinction (Tews *et al*., 2004; Meadows, 2006; IPCC, 2007; Willis *et al*., 2009). It has been estimated that 69% of all mammals alive today will be extinct by 2050 (Hetem *et al*., 2014). The Kruger National Park (South Africa) may lose 66% of animal species resulting from potential climate change by 2050 (Meadows, 2006). Already, tsessebe (*Damaliscus lunatus lunatus*) populations have declined because of rainfall-induced weather changes, as natural food availability is altered in the dry season (Dunham *et al*., 2004). In Zimbabwe (from 1985 to 2005), large herbivore populations were negatively affected due to a decrease in the availability of surface water as they have a greater need to fulfil water requirements compared to smaller body sized species (Chamaillé-Jammes *et al*., 2007b).

Climate and weather changes affect the patterns of habitat utilisation, due to water availability and environmental change (Blumstein, 2012; Halidu *et al*., 2013). Species undergo behavioural and

physiological adaptations to cope with climate and weather changes (i.e. daily and seasonal shift in utilisation of resources or migration) (Bellard *et al*., 2012; Brown, 2012). In Australia, the presence of surface water influences the number of species present in a habitat (Williams & Wells, 1986). In the African savannah ecosystem, an increase in rainfall has a direct correlation with an increase in most ungulate species (Owen-Smith, 2008). Thus, seasonality affects when fauna utilise waterholes with regard to water requirements, food intake, and wallowing; which is often neglected in literature.

There is a need to understand the basic ecological mechanism of naturally-forming waterholes for park management and other conservation practices, in particular with the effects of climate and weather variability being a reality (Halidu *et al*., 2013). Longer-term applications will be beneficial in protected areas and not short-term solutions, as adaptation management practices of protected areas become a necessity (i.e. artificial waterholes) with the effects of climate change (Ritter & Bednekoff, 1995; Islam & Uyeda, 2007; Tefempa *et al*., 2008; Madzwamuse, 2010). With monitoring techniques, one can establish specific faunal distribution and behavioural patterns in each protected area (Trent, 2012).

2.5 Water Dependency

Water requirements are different for every species, either water-dependent or less-water dependent based on how regularly species need water to either drink or wallow. Physiological adaptations, diet, and the ability of species to prevent water loss all influence water dependency (Redfern *et al*., 2005; Cain *et al*., 2012). Water-dependent species are those that require large quantities of water on a daily basis (e.g. warthog) (Redfern *et al*., 2005). Water-dependent species may drink water every one to two days (e.g. white rhino) (Young, 1970). Grazers are water-dependent species and need greater access to water sources, as their food source has low moisture content (e.g. grass) (Knight, 1995; Owen-Smith, 2002; Derry, 2004; Derry & Dougill, 2008). Furthermore, grazers usually have larger body sizes to browsers; therefore, they have to drink more regularly to reach their daily water requirements (Owen-Smith, 2002; Prins & Fritz, 2008). Less-water dependent species can go an extended period – up to three or four days – without regular water intake (e.g. giraffe [*Giraffe camelopardalis*]) (Tefempa *et al*., 2008). Succulent leaves, and fruits obtained by some species make up their water intake to meet their daily water requirements (Western, 1975; Derry, 2004; Owen-Smith, 2008; Halidu *et al*., 2013). For example, Kudu (*Tragelaphus strepsiceros*), a less-water-dependent species, reach their daily water requirements through eating succulent leaves (e.g. spekboom [*Portulacaria afra*]) as they are browsers (Western, 1975; Owen-Smith, 2002; Derry, 2004). Impala (*Aepyceros melampus*) are known to remain in areas

around permanent water sources; however, they are mixed feeders and vary their dependency on the availability of water and appropriate water-bearing foraging resources (Young, 1972; Owen-Smith, 2002, 2008; Brown, 2012). Carnivores are less-water dependent species, as carnivores obtain their water requirements from animal tissue and bodily fluids (e.g. lion [*Panthera leo*]) (Western, 1975; Trent, 2016).

Understanding these water requirements for different species is important, so that a loss of water-dependent species does not occur during times of drought or during the dry season (Ayeni, 1975, Knight, 1995; Owen-Smith, 2002; Bobich *et al*., 2014; Trent, 2016). Water-dependent species are not able to survive without a permanent (perennial) water sources and fencing constricts their ability to move to different permanent water sources (Ayeni, 1975, Shroyer *et al*., 2001; Chamaillé-Jammes *et al*., 2007c). In the Amboseli region (Kenya) some 80–90% of water-dependent species are found within 4 km of water sources in the dry season (Owen-Smith, 2002) as animals drink more frequently in the dry season to meet body water requirements, in particular antelope species (Halidu *et al.,* 2013). Furthermore, some species' physiology, which is unique to each species, does not allow species to adapt to environmental conditions in the dry season unless they have water available; hence, these species are considered the most water-dependent. This includes the blue wildebeest, hippopotamus (*Hippopotamus amphibious*), waterbuck (*Kobus ellipsiprymnus*), and warthogs to name a few; which are considered the greatest water-dependent species in Africa (Nagy & Knight, 1994; Auer, 1997; Schmidt-Nielsen, 1997; Owen-Smith, 2008; Hayward & Hayward, 2012; Huey *et al*., 2012; Okello *et al*., 2015). It is important to understand water needs for different water-dependent species, in particular those species that undergo wallowing as means of thermoregulation, because wallowing species can be even more vulnerable in the dry season or during drought periods (Owen-Smith, 2002; Juarez *et al*., 2013). Furthermore, water requirements for water-dependent species influence competition over territory around water sources (Ritter & Bednekoff, 1995; Valeix *et al*., 2007b; Blumstein, 2012).

Species-specific water requirements are thus linked to daily and seasonal migration patterns (Knight, 1995; Shresta *et al*., 2012; Gienapp, 2012; Gandiwa, 2013). These factors determine how far species will migrate to find an adequate water source to drink or wallow. Not surprisingly, there are different seasonal acclimatisation responses that species undergo for their water and energy requirements (Haim *et al*., 1990). A gap in research exists regarding species-specific water requirements for wild free-ranging animals making it important to study faunal occurrence and utilisation at water sources, to improve the general understanding of faunal behaviour and their

impacts at water sources (e.g. zoogeomorphic), also with the added pressures of climate change (Peck *et al*., 2009).

2.6 Faunal Occurrence Patterns at Waterholes

Surface water is an important resource for the water supply in wildlife populations, in particular arid and semi-arid regions (Strauch, 2013). Fauna in southern Africa are often exposed to conditions ranging from arid to semi-arid, which include increased temperature and decreased rainfall due to climate and weather changes, which alter species waterhole occurrence and utilisation patterns (Davidson *et al*., 2013). Some regions are more vulnerable to changes in weather and climate change compared to others (e.g. Kruger National Park) (Gillson *et al*., 2013; van Wilgen *et al*., 2015). The supply of surface water depends on seasonality, which influences mammal distribution and migration in protected area, which fencing has altered (Knight, 1995; Epaphras *et al*., 2008; Smit & Grant, 2009). Hence, localised environmental conditions can lead to localised faunal occurrence, utilisation, and wallowing behaviour at these water sources (Trent, 2016).

In addition, many other factors play a role in the abundance and diversity of species present at the water sources, such as vegetation, predation, body size, soil type, geology, morphology of the waterhole, topography, food preference, habitat preference, and climatic variables. The visitation, utilisation, and behaviour of species at waterholes therefore vary over different temporal scales and in different environments. Individual species must respond to changing conditions daily, seasonally, and annually.

2.6. 1 Daily Faunal Patterns

Several studies have been conducted to document the daily temporal drinking patterns of different mammal species (Cronje *et al*., 2005; Smit, 2011; Trent, 2016, Maraschin, 2013, 2016). Understanding species-specific water requirements is crucial for future conservation of biodiversity, in particular research in relation to species body size and carrying capacity with respect to rainfall variability (Chamaillé-Jammes *et al*., 2007a; Jeltsch *et al*., 1997; IPCC, 2007; Hetem *et al*., 2014). Peak herbivore occurrence at water sources occurred at midday, when temperatures were at their peak (Hayward & Hayward, 2012). By contrast, research by Lindstedt & Boyce (1985) and Troost *et al.* (2009) reveals that lightest body size has a crucial influence of daily temporal drinking patterns, where smaller species are observed utilising waterholes more frequently during the day (e.g. warthog). Alternatively, the larger body sized species (e.g. elephants) are observed utilising waterholes in the evening (Ayeni, 1975; Skinner & Chimimba, 2005; Valeix *et al*., 2007a). With the increase in temperature, smaller body sizes will be favoured as smaller animals dissipate heat more

readily than larger body sized animals (Haim *et al*., 1990; Riek & Geiser, 2013; Boutin & Lane, 2014). Hence, the smaller body sized species have the ability to utilise waterholes during the day, when temperatures are at their peak. Large animals accumulate large amounts of heat during the day and slowly dissipate this heat at night, therefore, the larger body sized species utilise waterholes during nocturnal hours, as these conditions are more favourable for their thermoregulation (Lindstedt & Boyce, 1985; Riek & Geiser, 2013).

2.6.1.1 Sunrise and Sunset

An animal`s daily behaviour follows a 24-hour cyclic pattern, which is regulated by external factors such as light intensity, ambient temperature, or the sun's position in the sky, and are thus associated with sunrise and sunset (Nouvellet *et al*., 2011). Animal behaviour at water sources is known to follow variations in sunrise and sunset times (Nouvellet *et al*., 2011). Diurnal animal behaviour is adjusted seasonally, this is related to the changing sunrise and sunset times causing a variation in day length and the availability of light (Hill *et al*., 2003; Nouvellet *et al*., 2011; Beauchamp, 2015). Nocturnal species are also influenced by sunrise and sunset times, as they adjust their active hours before sunrise and after sunset (Hill *et al*., 2003; Beauchamp, 2015). Most herbivore (prey) species are restricted by light availability in contrast to carnivores, as the seasonal variation in day length influences their daily activity patterns (Hill *et al*., 2003; Nouvellet *et al*., 2011).

2.6.2 Seasonal Patterns

Surface water availability affects the distribution of wildlife diversity and abundance within a habitat, which are influenced by seasonal conditions (Williams & Wells, 1986; Cronje *et al*., 2005; Epaphras *et al*., 2008; Stapelberg *et al*., 2008; Bellard *et al*., 2012; Shresta *et al*., 2012; Gandiwa, 2013; Gandiwa *et al*., 2013; Fuller *et al*., 2014). In the wet season, large quantities of surface water are available for species to utilise throughout the landscape, thus, fauna become dispersed (Phillipson, 1975). As a result, certain waterholes are utilised less frequently, when more pools are widely distributed (Western, 1975; Thrash *et al*., 1995; Owen-Smith, 1996; Leggett *et al*., 2003, 2004; Legget, 2006a, 2006b; Chamaillé-Jammes *et al*., 2007c; Smit *et al*., 2007; Valeix *et al*., 2008a; Blumstein, 2012). Corresponding to a decrease in abundance of species that congregate around artificial waterholes as they are spread across a larger number of natural water sources (Owen-Smith, 2002; Nangula & Oba, 2004; Maraschin, 2016; Trent, 2016). In the dry season, many natural waterholes dry up and the only water available in the landscape is present at permanent water sources such as perennial rivers and supplementary waterholes (Dudley, 1997; Owen-Smith, 2002; Valeix *et al*., 2009a; Valeix, 2011; Davidson *et al*., 2013).

Vegetation growth is seasonal, which influences the nutritional quality of the food and its availability (Owen-Smith, 2002, 2003, 2008; Prins & Fritz, 2008; Searle & Shipley, 2008; Davies *et al*., 2012). Therefore, faunal visitation patterns are influenced by shifting rainfall patterns and consequential food availability (Owen-Smith, 2002, 2008; Lewison, 2007; Searle & Shipley, 2008; Davies *et al*., 2012). The dry season has an effect on local vegetation structure and composition (Barnes, 1983; Cumming & Cumming, 2003; Harrison & Bargdgett, 2008; Owen-Smith, 2008), as a decrease in precipitation and over-grazing around waterholes could lead to expansion of the piosphere (Owen-Smith, 2002; Wieren & Bakker, 2008). A piosphere is a zone of influence resulting from regular grazing of vegetation around a water source (Washington-Allen *et al*., 2013). The piosphere is often cleared of vegetation for a distance between 10 to 35 m around the margins of waterholes (Thrash *et al*., 1993; Ng *et al*., 2001; Parker *et al*., 2009; Franz *et al*., 2010; Kasiringua, 2010; Mukaru & Mapaure, 2012; Engvall, 2013). This loss in vegetation in the dry season results in a decrease in abundance of herbivore species and the number of individuals that utilise the piosphere around waterholes, due to the vegetation change from the drier conditions (Barnes, 1983; Owen-Smith, 2002, 2008; Skarpe & Hester, 2008; Wieren & Bakker, 2008; Kasiringua, 2010; Blumstein, 2012; Engvall, 2013). Fundamentally, land utilisation within the piosphere is determined by the adequacy of food availability, which is dependent on the wet season. Thus, foraging behaviour is adapted to the local environmental conditions for species to meet their nutritional requirements through seasonal cycles, which is influenced by rainfall (Owen-Smith, 2002, 2003, 2008; Prins & Fritz, 2008; Searle & Shipley, 2008).

The ecosystem response varies depending on the differing communities of herbivores in a certain environment, which is influenced by seasonality. Differing faunal communities can affect the long-term sustainability and resilience of the greater herbivore community that congregate and rely on a water source, in particular the dry seasons (Goudie & Thomas, 1985; Clutton-Brock, 2001). For example, four female elephants weigh apparently the same as a herd of 50 sable antelope, but each community will have a different effect on the environment. Thus, understanding the diversity and abundance of species utilising water sources during different seasons is essential, as they have differing effects on the ecosystem.

2.6.3 Predation Effects on Waterhole Use

Predator-prey dynamics affect the density of herbivore species that utilise waterholes, causing a predator-prey shift (Berger *et al*., 2003; Hoover & Tylianakis, 2012; Blumstein *et al*., 2015). Predator-prey shifts are caused by seasonal shifts in diets that may result in the increased presence of predators around water sources (Owen-Smith, 2002; Blumstein, 2012; Jones, 2012; Davidson *et al*.,

2013; Peterson *et al*., 2014). For instance, when there is a decrease in the abundance of prey, this has an influence on their corresponding predators. Predators typically seek their prey when they are weakened, thus during months when there is a deficit of rainfall or during drought periods, kills by predators increase. For example, during the dry season in the Kruger National Park 40% of kudu kills occur, whereas during years of above average rainfall kudus have a high survival rate (Owen-Smith, 2002). Thus, variations in predation are related to rainfall, which influences the forage availability and hence diet quality of the kudu (Owen-Smith, 2002).

In addition, herbivores are vulnerable to predation at permanent water sources in particular during dry season, as many naturally-forming waterholes dry up (Blumstein, 2012; Davidson *et al*., 2013). Predation typically occurs within a 2 km distance from waterholes in the dry season (Davidson *et al*., 2013), whereas in the wet season predation occurs at greater distances (Rosenstock *et al*., 1999; Owen-Smith, 2002; Dolan, 2006; Valeix *et al*., 2009c; Simpson *et al*., 2011; Crosmary *et al*. 2012; Davidson *et al*., 2013). Lions in the Kruger National Park are known to kill 2-4 km away from water sources in the dry season, where the varying distance of a kill is dependent on the season (Valeix *et al*., 2009c; Davidson *et al*., 2013). Thus, herbivores are more evenly dispersed in the wet season when natural surface water is abundant in the landscape, compared to the dry season when water is predominantly present in permanent water sources and artificial waterholes (Davidson *et al*., 2013).

Consequently, vegetation can affect the occurrence and drinking times of herbivore species at waterholes. Open areas will have higher numbers of herbivore species, thus allowing them to drink for longer periods as there is a greater chance to detect predators (Gaillard *et al*., 2008; Owen-Smith, 2008; Périquet *et al*., 2010; Stankowich & Reimers, 2015). This sense of security is a result of limited opportunity for ambush techniques by predators, as prey can spot predators at a greater distance (Owen-Smith, 2002; Périquet *et al*., 2010; Davies *et al*., 2012; Engvall, 2013; Stankowich & Reimers, 2015). Burchell`s zebras are an example of species that favour certain drinking sites in open areas for this reason (Périquet *et al*., 2010). Species will have longer drinking times at water sources when there is a larger abundance of species, as this reduces individual vigilance responsibility and decreases the opportunity for predation by prey dilution and confusion (Bruger & Gochfeld, 1992; Périquet *et al*., 2010; Blumstein, 2012; Davies *et al*., 2012; Beauchamp, 2015; Blumstein *et al*., 2015; Stankowich & Reimers, 2015). Thus, faunal abundance, vegetation, water requirements, and predation influence the occurrence and utilisation of fauna at the water sources.

2.7 Wallowing

Wallowing is the coating of the animal's body surface with mud, a mud-like substance or water (Jarman, 1972; Bigwood, 2011, Bracke, 2011; Vanschoenwinkel *et al*., 2011). Wallowing is the natural behaviour of pigs (*Suidae* spp), warthogs (*Phacochoerus aethiopicus*), wild boar (*Sus scrofa*), rhino (*Rhinocerotidae*), elephants (*Elephantidae*), elephant seals (*Mirounga*), American bison (*Bison bison*), giant tortoises (*Testudinidae*), crocodile (*Crocodylinae*), buffalo (*Syncerus caffer*), deer (*Cervidae*), and occasionally hippopotamus (*Hippopotamus amphidae*) (Jarman, 1972; Dudley, 1997; Bigwood, 2011; Bracke, 2011; Vanschoenwinkel *et al*., 2011; Jones, 2012; Engvall, 2013). Small rodents are also known to sometimes wallow (e.g. yellow marmots [*Marmota flaviventris*]) (Butler, 1995). Animals that have no fur or are sparsely haired are more likely to wallow frequently than other mammal species (Skinner & Smithers, 1990; Bigwood, 2011; Bracke, 2011; Vanshoenwinkel *et al*., 2011). The animal's need to wallow is associated with thermoregulation and using mud as sun protector. Wallowing is also related to skin care and grooming, for removing biting insects or ectoparasite repellent and health by disinfection of wounds. Lastly, fauna wallow for scent-marking, resting, play and pleasure, and a social centre for animals by either drinking or wallowing related to sexual behaviour (Weir, 1969; Dudley, 1997; Ng *et al*., 2001; Bracke, 2011; Vanshoenwinkel *et al*., 2011; Haynes, 2012; Engvall, 2013; Stuart & Stuart, 2015). Thus, wallowing is a basic ethological need.

Wallowing activity is particularly prominent in pigs and pig-like animals (Butler, 1995; Bracke, 2011). Pigs lack functional sweat glands and wallowing in mud is an effective behavioural control mechanism to prevent hyperthermia (Bracke; 2011). Wallowing is a pig's adaptation for humid environments; as such, warthogs undergo wallowing activity when temperatures are at their peak to cope with the heat (Bracke, 2011). Hence, wallowing is necessary for thermoregulation and is important for the welfare of these species (Vanshoenwinkel *et al*., 2011). Pigs also wallow after consuming food as food intake elevates their body temperature (Bracke, 2011). Research has indicated that as pigs wallow, it reduces their body temperature by 2°C, however the variation in body temperature for elephants, rhino, and warthogs after wallowing is not known (Bracke, 2011).

2.7.1 Zoogeomorphic Effect of Wallowing

Wallowing activity has direct geomorphic consequences on the landscape, as was explained by Butler (1995). Butler (1995, 2006) suggests that wallowing is a direct effect that animals can create on a landscape (Bigwood, 2011). Butler`s (2006) diagram, portrays the host of geomorphic consequences associated with animal action on the landscape, and the consequences associated with it (*Figure 2.2*). However, there is still a gap in literature on wallowing and the effects this animal

action has on the landscape. The formation of natural waterholes because of wallowing activity has many consequences on the landscape, such as compaction, trampling, transportation and deposition of sediments, and erosion (Butler, 1995; Viles, 1988; Bigwood, 2011; Engvall, 2013; Stommel *et al*., 2016).

The predominant sediment in natural waterholes consists of thick viscous clay, which can be easily attached to an animal's body (Ng *et al*., 2001; Bracke, 2011; Vanschoenwinkel *et al*., 2011). Furthermore, the loosening of surface material is a consequence of the activity in the waterholes, resulting from natural excavation and wallowing activities (Thomas, 1998). The sediment that is transported from the waterhole is typically redeposited outside of the waterhole (Flint & Bond, 1968; Bigwood, 2011). Consequently, the utilisation of a waterhole can lead to localized soil erosion, which typically leads to filling of waterholes with coarser sand over a period of time (Weir, 1969; Skead, 2007; Stommel *et al*., 2016). In addition, the regular compaction of soil surrounding waterholes and trampling of vegetation enhances erosion at the waterhole edge, which leads to the expansion of the waterhole (Butler, 1995; Harrison & Bardgett, 2008; Wieren & Bakker, 2008; Bigwood, 2011; Engvall, 2013; Stommel *et al*., 2016). This expansion of the waterhole contributes to the ability of the waterhole to hold an increased amount of water (Engvall, 2013). Moreover, rhino and warthogs practice excavation at waterhole edges, which can change the consistency of the mud (Bracke, 2011).

In addition, a factor to consider with waterholes is how the sediment changes during wet and dry periods (Allan *et al*., 1995). There is mechanical separation of coarse and fine material into separate areas when water is present, which could affect where animals are wallowing, as certain sediment types are more desirable than others for wallowing (Weir, 1969; Stommel *et al*., 2016). Hence, the type of sediment transported out of the waterholes in the different areas, because of separation, is significant as it influences the utilisation of waterholes (Weir, 1969). During the wet season, sediment such as coarse silt and clay may wash into waterholes and accumulate, resulting in more ideal waterholes for wallowing (Weir, 1969; Alistoun, 2012). Sediment can also be blown into these waterholes by wind action (Weir, 1969). In the dry season, transport of sediment is influenced more by wind action rather than by water, as water is limited or absent (Weir, 1969; Alistoun, 2012). If a sufficient amount of sediment is neither removed nor present, this will make the waterholes less ideal for wallowing and utilisation, therefore they are less likely to be maintained and remain active (Flint & Bond, 1968; Weir, 1969; Thomas, 1998; Parker *et al*., 2009; Engvall, 2013).

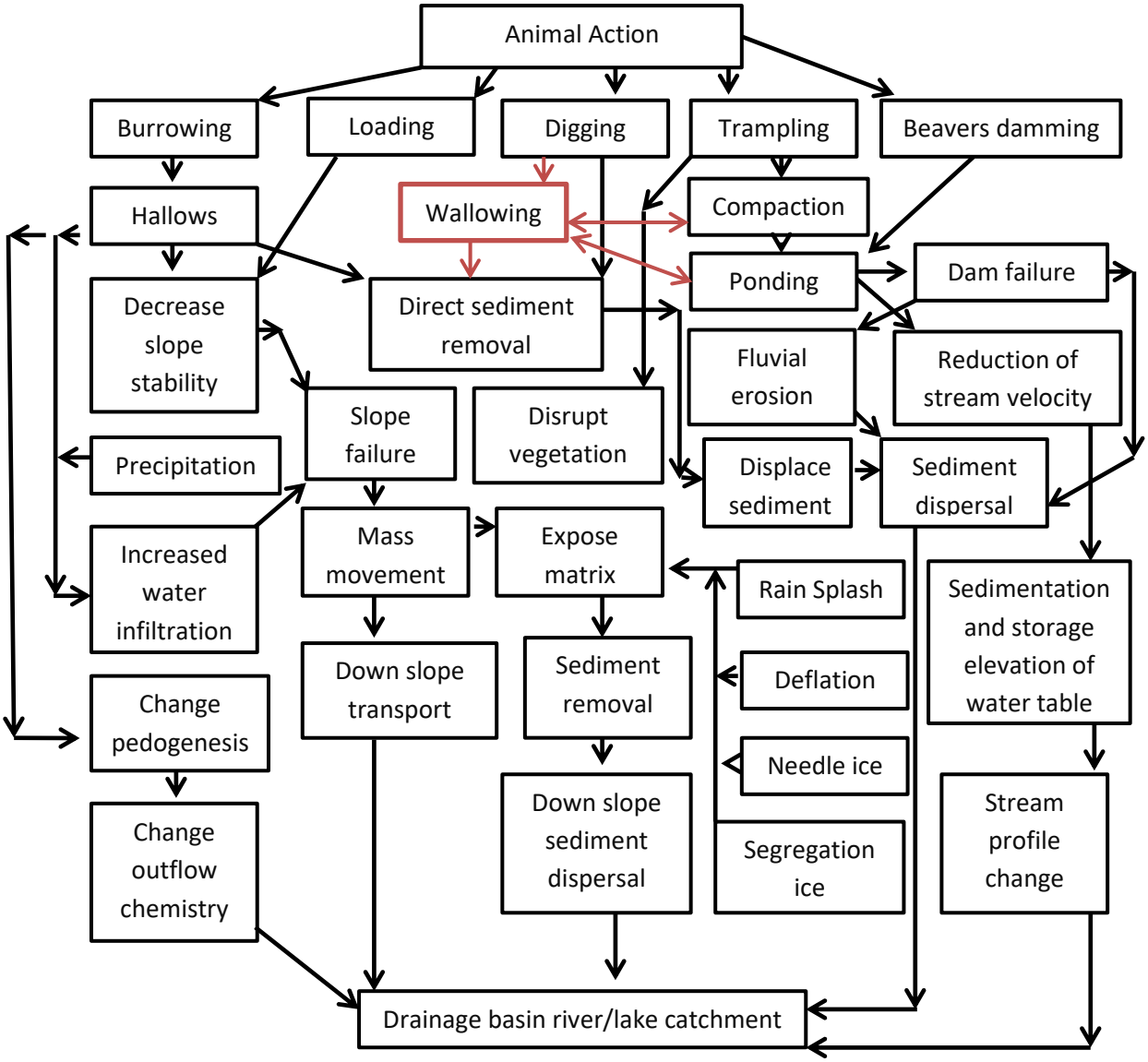


Figure 2. 2: Incorporation of wallowing activity into Butler`s (2006) model of animal action. Wallowing was incorporated as it has a direct geomorphic consequence on the landscape.

The entire behaviour of wallowing by animals still needs to be investigated; as literature reveals very little on the consequences wallowing has on the landscape (*Figure 2.2*), in particular regarding warthogs and rhino. Furthermore, there is also a gap in the literature related to wallowing frequency and duration of wallowing mammals, in particular warthogs, and how climatic and local weather factors affect the wallowing behaviour of different species (Bracke, 2011).

2.8 Monitoring Methods

Interpreting animal behaviour and observing the interactions animals have in their natural environment is vital when investigating faunal occurrence around natural waterholes. Animal behaviour and occurrence patterns can be observed by many methods including, but not limited to:

GPS collars, direct observations from a hide or motor vehicle (direct counts), spoor and dropping counts, aircraft monitoring, radio-telemetry, and photographic/video recording techniques (Lord *et al*., 1962; Ayeni, 1975; Wilson *et al*., 1996; Caro, 1999; Galanti *et al*., 2000; Owen-Smith, 2003; Gaillard *et al.* 2008; Cromsigt *et al*., 2009; Funston *et al*., 2010; Kays *et al*., 2011a; Rowcliffe *et al*., 2011; Hayward & Hayward, 2012). Each method has its advantages and limitations, for instance traditional monitoring methods (for example direct counts by observation) are labor intensive (Ayeni, 1977; Cromsigt *et al*., 2009; Handcock *et al*., 2009). Other limitations include time constraints, cost, and negative effects on faunal behavior from the presence and impact of human activity (Weir *et al*., 2009: Verstaeten *et al*., 2010). New monitoring techniques have emerged with technological advances which have become popular and address many past limitations (i.e camera traps and webcams) (Wawerla *et al*., 2009: Verstaeten *et al*., 2010).

Camera traps are a useful non-invasive method that do not require the capturing and handling of animals (Roberts *et al*., 2006; Marnewick *et al*., 2008; Porter *et al*., 2010; Kays *et al*., 2011a; Ancrenaz *et al*., 2012; Hayward & Hayward, 2012; Engvall, 2013). Camera traps have aided research as it allows for more precise, accurate, and reliable monitoring strategies; and there is no influence of human activity on animal behaviour (Roberts *et al*., 2006; Marnewick *et al*., 2008; Rowcliffe & Cabone, 2008; Porter *et al*., 2010; Kays *et al*., 2011a; Kays *et al*., 2011b; Ancrenaz *et al*., 2012; Hayward & Hayward, 2012; Engvall, 2013). In addition, the use of camera traps allows for safe monitoring of animals at night, where predation is high, and traditional methods were generally limited to a 12-hour observation period (during daylight hours) (Kays *et al*., 2011a; Ancrenaz *et al*., 2012; Crosmary *et al*., 2012).

Webcam monitoring can also be used in research as it is advantageous over camera traps because of live monitoring (Eulerian approach) in real time (Hayward & Hayward, 2012; Trent, 2012; Maraschin, 2013). An Eulerian approach is when a particular area is monitored and any species moving into the area is recorded in real time (Kays *et al*., 2011a). In South Africa, specific locations in different game reserves can be viewed online through live video streaming (webcams), such as the website Africam.com and the SANParks website, to view species drinking from water sources in Addo Elephant National Park, Kgalagadi National Park, and Kruger National Park (Pettorelli *et al*., 2010; Kamphof, 2011; SANParks, 2012). Some advantages are that webcam monitoring can be low-cost and can acquire continuous high frequency imagery without regular maintenance, check-ups, battery replacements, or various technical expertise (Bradley *et al*., 2010). Solar panels provide continuous recharge capabilities for the webcam and because of the live monitoring method (in real time); one can determine the proper function of the webcams without check-ups in the field (Culter

& Swann, 1999; Locke *et al*., 2005). Webcams are more beneficial over camera traps, however, the advantage of both is that the data can be viewed and stored for future investigations (Cutler & Swann, 1999; Verstraeten *et al*., 2010; Bradley & Clarke, 2011). These photographic/video recording techniques are valuable methods to monitor wildlife to discover future threats to their populations and ensure survival and management of species in conservation areas (Pettorelli *et al*., 2010).

2.9 Summary

Water sources are a major limiting factor that influences animal behaviour, in particular when it comes to wildlife distribution and abundance, predominantly in savannah regions (Owen-Smith, 2002; Chamaillé-Jammes *et al*., 2007a). Climate and weather changes affect faunal utilisation at water sources, due to the changes in natural surface water, which is influenced by rainfall, and environmental change (Blumstein, 2012; Halidu *et al*., 2013). Species undergo behavioural and physiological adaptations to cope with climate and weather changes (i.e. daily and seasonal shift in utilisation of resources or migration) (Bellard *et al*., 2012; Brown, 2012). Hence, localised environmental conditions can lead to localised faunal occurrence, utilisation, and wallowing behaviour at these water sources (Trent, 2016). Therefore, there is a need to understand the basic ecological mechanism of naturally-forming waterholes for park management and other conservation practices, in particular with the effects of climate change being a reality (Halidu *et al*., 2013).

Wallowing at waterholes is necessary for animal thermoregulation and is important for the welfare of sparsely haired species (Vanshoenwinkel *et al*., 2011). The predominant sediment in natural waterholes is thick viscous clay, which can be easily attached to an animal's body (Ng *et al*., 2001; Bracke, 2011; Vanschoenwinkel *et al*., 2011). There is a gap in the literature related to wallowing frequency and duration of wallowing mammals, in particular warthogs, and how climatic and local weather factors affect wallowing behaviour (Bracke, 2011). Thus, research of this nature can provide knowledge of animal behaviour around waterholes, and can improve wildlife management (Festa-Bianchet & Apollonio, 2003; Gosling, 2003; van Wilgen *et al*., 2015). Behavioural research can enhance our understanding of population responses to environmental change and providing sufficient supplementary waterholes in which fauna can utilise for drinking and wallowing (Gosling, 2003; Woodroffe, 2003; Wieren & Bakker, 2008; Blumstein, 2012; Chaine & Clobert, 2012).

Chapter 3

Study Area



3. Study Area

3.1 Introduction

Shamwari Private Game Reserve is located in the Eastern Cape, South Africa (*Figure 3.1*) and covers an area of 25 000 ha. Shamwari is the chosen location to achieve the aims and objectives of this study as it has a diverse ecosystem, with rich biodiversity (Anon, 2015). A large variety of southern African species are present in Shamwari, including buffalo, giraffe, lion, cheetah (*Acinonyx jubatus*), leopard (*Panthera pardus*), caracal (*Felis caracal*), brown hyena (*Hyaena brunnea*), black-backed jackal (*Canis mesomelas*), bat-eared fox (*Otocyon megalotis*), yellow mongoose (*Cynictis penicillata*), honey badger (*Mellivora capensis*), elephants, white rhinoceros, black rhinoceros (*Diceros bicornis*), hippopotamus, a variety of nocturnal species, leopard tortoise (*Geochelone pardalis*), and a wide variety of birds and insects (Anon, 2015). Other species have been reintroduced to the region and conserved such as the red-billed ox-pecker (*Buphagus erythrorhynchus*); conservation of Cape Mountain zebra (*Equus zebra zebra*), and the flightless dung beetle (*Circellium bacchus*). Shamwari also have conservation and reintroduction programmes (Anon, 2015).

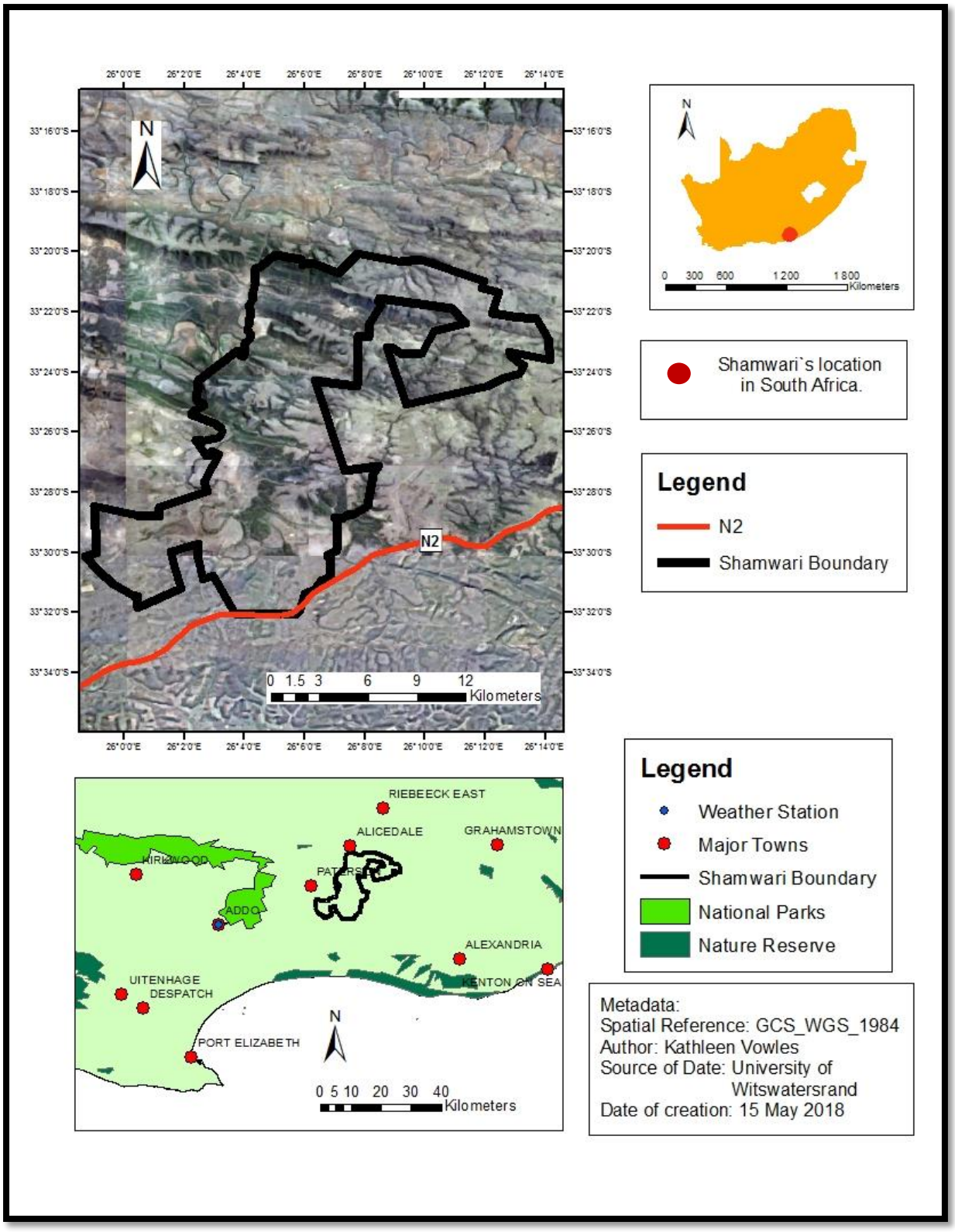


Figure 3. 1: Location of Shamwari Private Game Reserve in the Eastern Cape, South Africa.

3.2 Climate and Habitat

3.2.1 Climate

Shamwari is located in a semi-arid region with an average annual rainfall of approximately 425-620 mm (Whitehouse *et al*., 2008; Parker *et al*., 2009). In semi-arid regions, variability in seasonal rainfall is a central characteristic (Knight, 1995; Epaphras *et al*., 2008; Smit & Grant, 2009; Hetem *et al*., 2014). Lowest rainfall occurs in the winter months (dry season) from May to August and summer months of December and January. On the other hand, the highest rainfall is in the spring months of October and November and the autumn month of March, thus these are typically the wet seasons (*Figure 3.2*). March receives an average of 43 mm of rainfall the highest for any month (*Figure 3.2*). Seasonal rainfall is an important influence in the amount of surface water available in the reserve in particular natural surface water in naturally-forming waterholes (Ogutu & Owen-Smith, 2003; Birkett *et al*., 2012; Davidson *et al*., 2013).

African semi-arid regions typically experience fluctuations in temperature, both seasonally and diurnally, with hot days and cool nights (Van Rooyen *et al*., 2008; Mills & Mills, 2013). In Shamwari, the average minimum temperature ranges from 6°C to 16°C and average maximum temperature ranges from 20°C to 29°C annually (*Figure 3.2*). The hottest temperatures are experienced in December, January, and February (*Figure 3.2*) (Schulze, 2007). July and June are the coolest months.

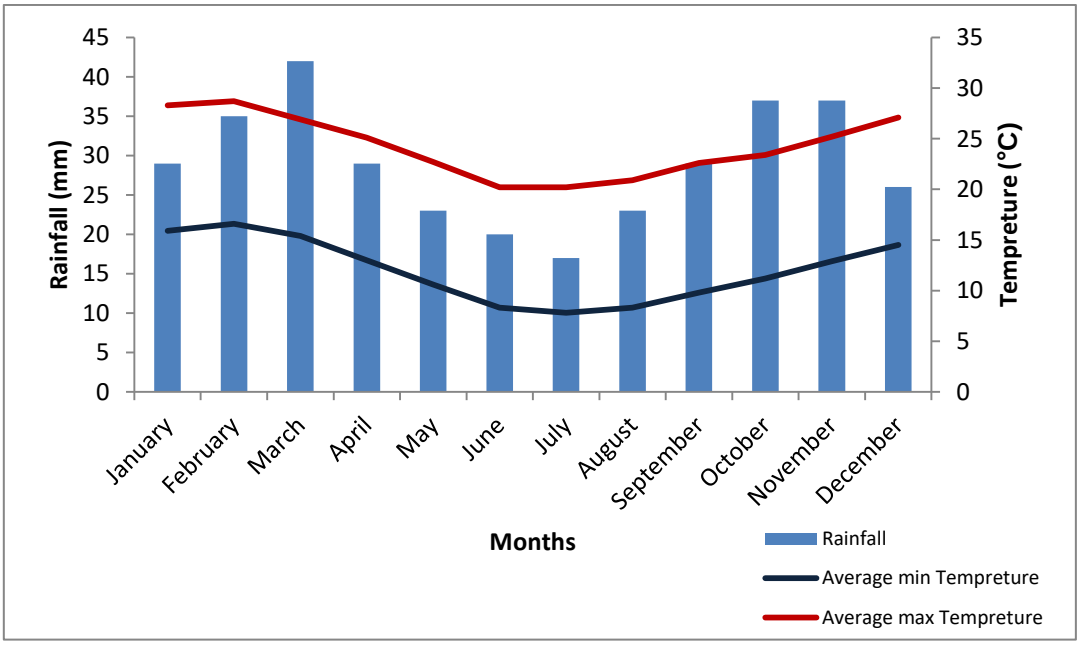


Figure 3. 2: Monthly average climate variables calculated over 25 years in Shamwari Private Game Reserve (Schulze, 2007).

3.2.2 Geology

Shamwari Private Game Reserve is located on two different lithologies. The lower-altitude parts of the reserve are associated with coastal sediment, connected with long periods of stability on the Post-African I erosion surface (McCarthy & Rubidge, 2005; Maud, 2008). These deposits formed the Alexandria Formation (marine limestone) and Nanaga Formation (aeolian dunes) which are overlain by a red soil; these are part of the Algoa basin hosting the Uitenhage Group (*Figure 3.3*) (McCarthy & Rubidge, 2005; Norman & Whitfield, 2006; Maud, 2008). The Uitenhage Group predominantly comprise of greenish-grey coloured and reddish mudstone, which are claylike materials (McCarthy & Rubidge, 2005; Norman & Whitfield, 2006; Addo Elephant National Park, 2016). Other sediments associated with the Algoa basin consist of calcareous sandstone, sandy limestone, conglomerate, and coquinite (Norman & Whitfield, 2006; Maud, 2008). The higher-altitude parts of Shamwari are located on the marine Algoa Group of soft Cretaceous sediments present from when the world`s sea level rose causing marine deposits to cover these coastal plains (*Figure 3.4*) (McCarthy & Rubidge, 2005; Maud, 2008).

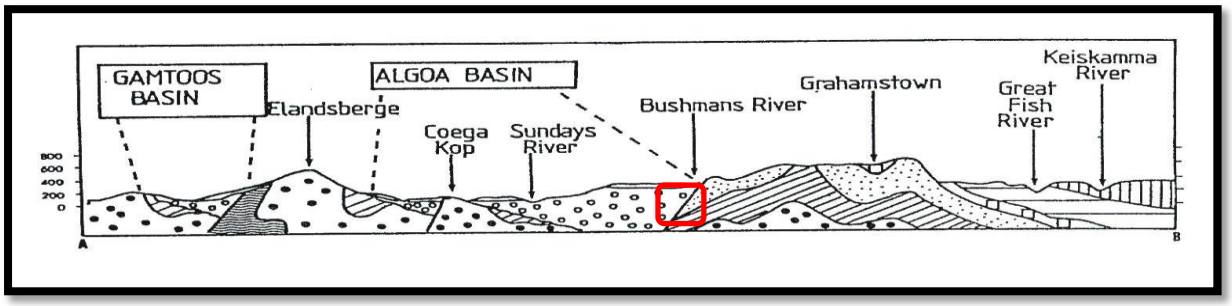


Figure 3. 3: Cross section from the Gamtoos Basin to beyond the Fish River (Büttner *et al.*, 2015). Research site indicated by red square, legend for this figure provided below in *Figure 3.4*.

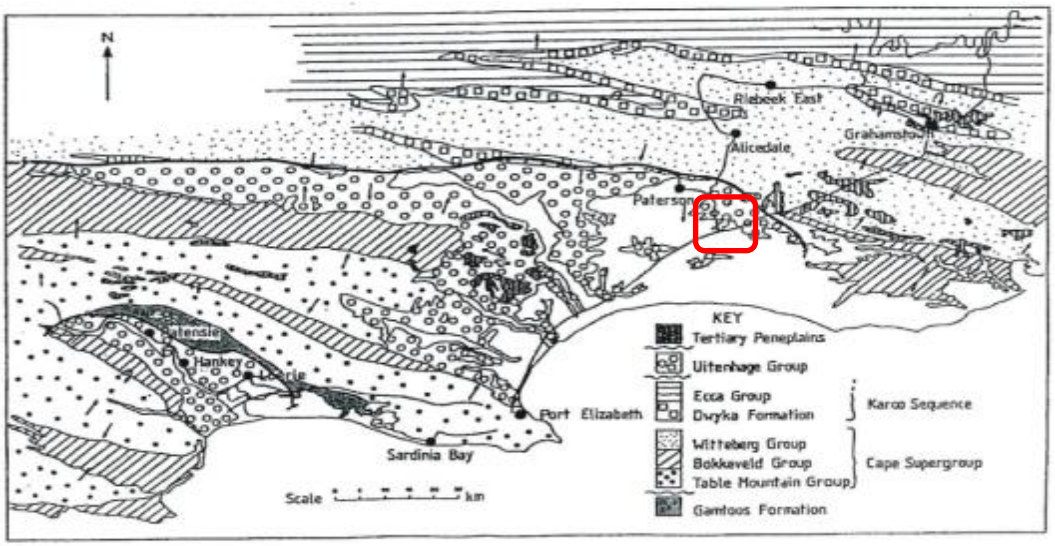


Figure 3. 4: Geological map of Eastern Cape region (Büttner *et al.*, 2015). The red square indicates the study site (Shamwari Private Game Reserve).

3.2.3 Vegetation and Habitat

3.2.3.1 Vegetation

The most dominant natural vegetation present in Shamwari Private Game Reserve is the Eastern Cape succulents (Mucina & Rutherford, 2011). Shamwari is located in the Kowie Thicket vegetation unit, which is dominated by the succulents euphorbias and aloes, there are thorny shrubs, woody lianas (*Capparis, Secamone, Rhoicissus, Aloe*), and shrubby succulents (*Crassulaceae, Asphodelaceae*) (Vlok & Euston-Brown, 2002; Mucina & Rutherford, 2011). The Kowie Thicket unit comprises the Albany Valley Thicket, which dominates Shamwari vegetation. The Albany Thicket is the second smallest biome in South Africa, making up 3.3% of the total land area (Pote *et al*., 2006).

Albany Valley Thicket consists of well-developed woody vegetation, with succulents and spinescence that are relatively poorly developed (Shackleton *et al*., 2007). Woody semi-succulents consist of thorny vegetation types have an average height of 2-3 m (Vlok & Euston-Brown, 2002; Mucina & Rutherford, 2011). Many species present in the Albany Valley thicket biome are endemic to this region, thus, it is identified as a biodiversity hotspot as it harbours a large number of rare and threatened species (Vlok & Euston-Brown, 2002; Kerley *et al*., 2003; Mucina & Rutherford, 2011). In the past, clearing for agricultural land and extensive pastoralism occurred resulting in open areas (savannah biome) in this thicket biome (Kerley *et al*., 2003; Skead, 2007; Parker *et al*., 2009; Mucina & Rutherford, 2011). In total, 92% of the Albany Thicket biome in the Eastern Cape was degraded (Mucina & Rutherford, 2011). Today, however, the Albany Thicket Biome is highly transformed, but still has high levels of degradation (Kerley *et al*., 2003; Skead, 2007; Parker *et al*., 2009).

Shamwari Private Game Reserve vegetation also consists of the Sundays thicket and Coega Bontveld (Mucina & Rutherford, 2011). Sundays thicket is dominated by Spekboom (*Portulacaria afra*) which is known as Sundays Spekboomveld. The Sundays Spekboomveld has high structural heterogeneity in this vegetation unit (Vlok & Euston-Brown, 2002; Mucina & Rutherford, 2011). Spekboom is one of the most important food sources for mega-herbivores (e.g. elephants and rhino) (Skead, 2007; Whitehouse *et al*., 2008). In areas where spekboom was removed, *Acacia karoo* may be found (Mucina & Rutherford, 2011). There are also annual grasses (e.g. *Aristida congesta*, *Cynodon dactylon* and *Enneapogon desvauxii*) present and resilient herbaceous species (e.g. *Sanseveieria aethioppica*), where spekboom was once removed (Mucina & Rutherford, 2011). Coega Bontveld has a mixture of species such as grasses (wide stretches) and succulent Karoo elements; the fynbos biome is also present in the Coega Bonteveld (Vlok & Euston-Brown, 2002; Mucina & Rutherford, 2011). A wide variety of aloes are located in Shamwari Private Game Reserve (Smith, 2003), these aloes are classified under the Grass Ridge Bonteveld (Vlok & Eustin, 2002). Grass Ridge Bonteveld

species are restricted to outcrops of limestone, which only occur along the Nanaga Formation of the Uitenhage Group (*section 3.2.2*).

3.2.3.2 Permanent Water Sources

There are very few artificial waterhole sites in Shamwari, as the main water source that runs through the reserve is the Bushman's River (Boesmansrivier), which extends inland (Skead, 2007). Other water sources that are utilised by wildlife are naturally-forming waterholes (non-perennial water sources), which are present throughout the Shamwari landscape (Skead, 2007). These waterholes are, however, only utilised when there is surface water availability. Three naturally-forming waterholes (A–C) are examined in this study (*Figures 3.5, 3.6 & 3.7*).

3.3 Site A

Site A is a naturally-forming waterhole located on a low gradient (1:20), at an altitude of 210 m a.s.l and is located on alluvial deposits (*Appendix 1*). Locations (GPS coordinates) of the waterholes will not be divulged at the request of Shamwari Private Game Reserve, as unfortunately the effects of poaching in South Africa are a reality. In the past, site A was cleared of the Albany Thicket vegetation and transformed to agricultural land and pasturage (Skead, 2007). Currently the land has been rehabilitated and is dominated by a variety of grasses and other vegetation that is present, including scattered Sweet thorn (*Acacia Karoo*) and Royal carpet (*Lobularia maritima*) (Skead, 2007). The Bushman's River is located approximately 100 m away from the waterhole (*Figure 3.5*). Multiple game trails are found in a radial pattern surrounding the waterhole (*Figure 3.5*), predominantly leading to and from the Bushman's River.

This naturally-forming waterhole has few bare soil patches; therefore, less opportunity for runoff as the grass restricts the free movement of surface water, thereby the waterhole acts as a sink and captures the transported water and sediment from surrounding area (Parker *et al*., 2009). The centre of the waterhole is the deepest depression of this naturally-forming waterhole (*Table 3.1*). The waterhole at site A has a length of approximately 22.5 m, depth of 0.5 m, and a width of 17.5 m (*Table 3.1*). The overall shape of site A waterhole is irregular to circular (*Figure 3.5*). Site A waterhole is the smallest waterhole in this study (*Table 3.1*). These parameters are not exact measurements due to the irregular shape of the naturally-forming waterholes and constantly changing morphology of these waterholes; hence, they are given as an approximation.

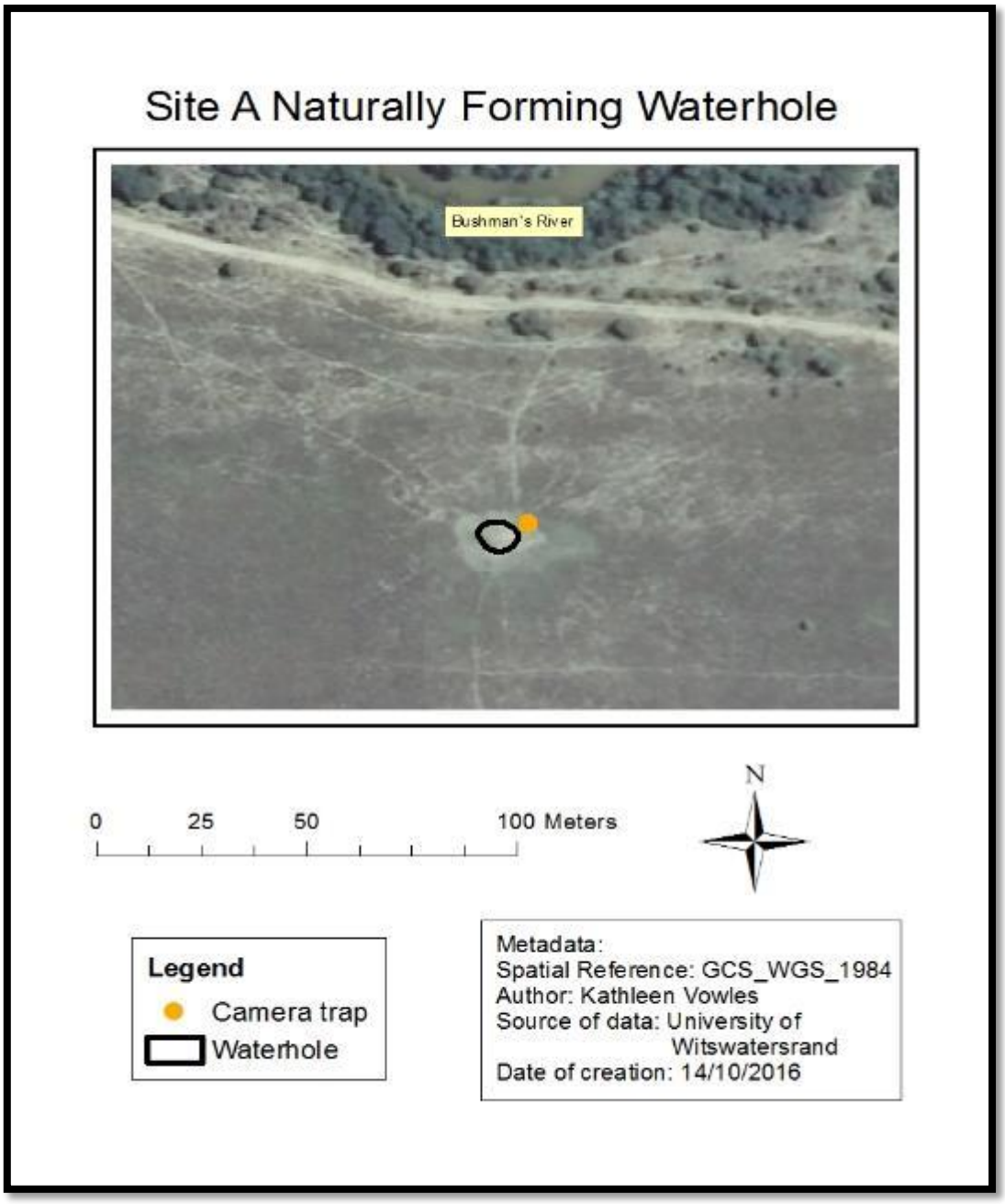


Figure 3. 5: Aerial photograph of Site A`s location and surroundings in Shamwari Private Game Reserve. Latitude and longitude were withheld due to the unfortunate reality of poaching in South Africa.

Table 3. 1: Naturally-forming waterhole approximation parameters of each site.

Average	Site A waterhole	Site B waterhole	Site C waterhole
Length (m)	20 - 25	54 - 60	10 - 14
Width (m)	15 - 20	22 - 26	1 - 4
Depth (m)	0.5 - 1	0.2 - 1	0.5 - 1

3.4 Site B

The naturally-forming waterhole, site B, is located on a low gradient (1:20) area in Shamwari, with an altitude between 218 and 219 m a.s.l and is located on alluvial deposits (*Appendix 1*). Site B waterhole falls within both the Savannah and Thicket Biomes (*Figure 3.6*). The Savannah area was previously agricultural land and is now rehabilitated natural land, located south and west of the waterhole. The Thicket Biome is located north and east of the waterhole (*Figure 3.6*). The different vegetation types located in close proximity to the waterhole include Sweet thorn (*Acacia Karoo*), Needle bush (*Azuma tetracantha*), Common Spike thorn (*Gymnosporia buxifolia*), Milkwood (*Syderaxyan inerme*), Blue-bush (*Dipspyros lycioides*), and Puzzle bush (*Ehretia rigida*). Multiple game trails are present radially around the waterhole and lead directly to the waterhole from various directions in Shamwari, predominantly to the waterholes deepest depressions (*Figure 3.6*). The deepest and widest depression in this waterhole is where the greatest faunal utilisation and wallowing activity takes place, as this is where water collects. Site B was the largest of the waterholes in this investigation with a length of 57 m and width of 22.5 m (*Table 3.1*). Site B had a flat morphology, except for the central depression in the waterhole. This central depression was deepest at 0.6 m. Overall, this waterhole had an irregular kidney shape (*Figure 3.6*).

3.5 Site C

Site C is located on a low gradient (1:20), with an altitude of 210 m a.s.l. in the Thicket biome (*Figure 3.7*). Vegetation surrounding the waterhole includes Sweet thorn (*Acacia Karoo*), Needle bush (*Azuma tetracantha*), Common Spike thorn (*Gymnosporia buxifolia*), Milkwood (*Syderaxyan inerme*), Blue-bush (*Dipspyros lycioides*), Puzzle bush (*Ehretia rigida*), Spekboom (*Portulacaria afra*), and Karoo Num Num (*Carissa haematocarpa*). Multiple game trails lead to the waterhole, forming a radial pattern (*Figure 3.7*). Site C has relatively more bare soil, compared to site A and B, with just thicket vegetation surrounding the waterhole; therefore, there is less regulation of runoff at site C compared to the other two waterholes. Site C is the deepest waterhole in this investigation at 0.75 m (*Table 3.1*), and the surrounding vegetation, north and south, influenced this waterholes morphology. The west and east of the waterhole consists of the deepest depressions, whereas the centre is raised, due to the presence of thicket vegetation of the waterhole edges at these locations (*Figure 3.7*). Site C had the shortest length at 12 m and width of 2.5 m (*Table 3.1*). Site C presents itself as a highly irregular hour-glass shape (*Figure 3.7*).

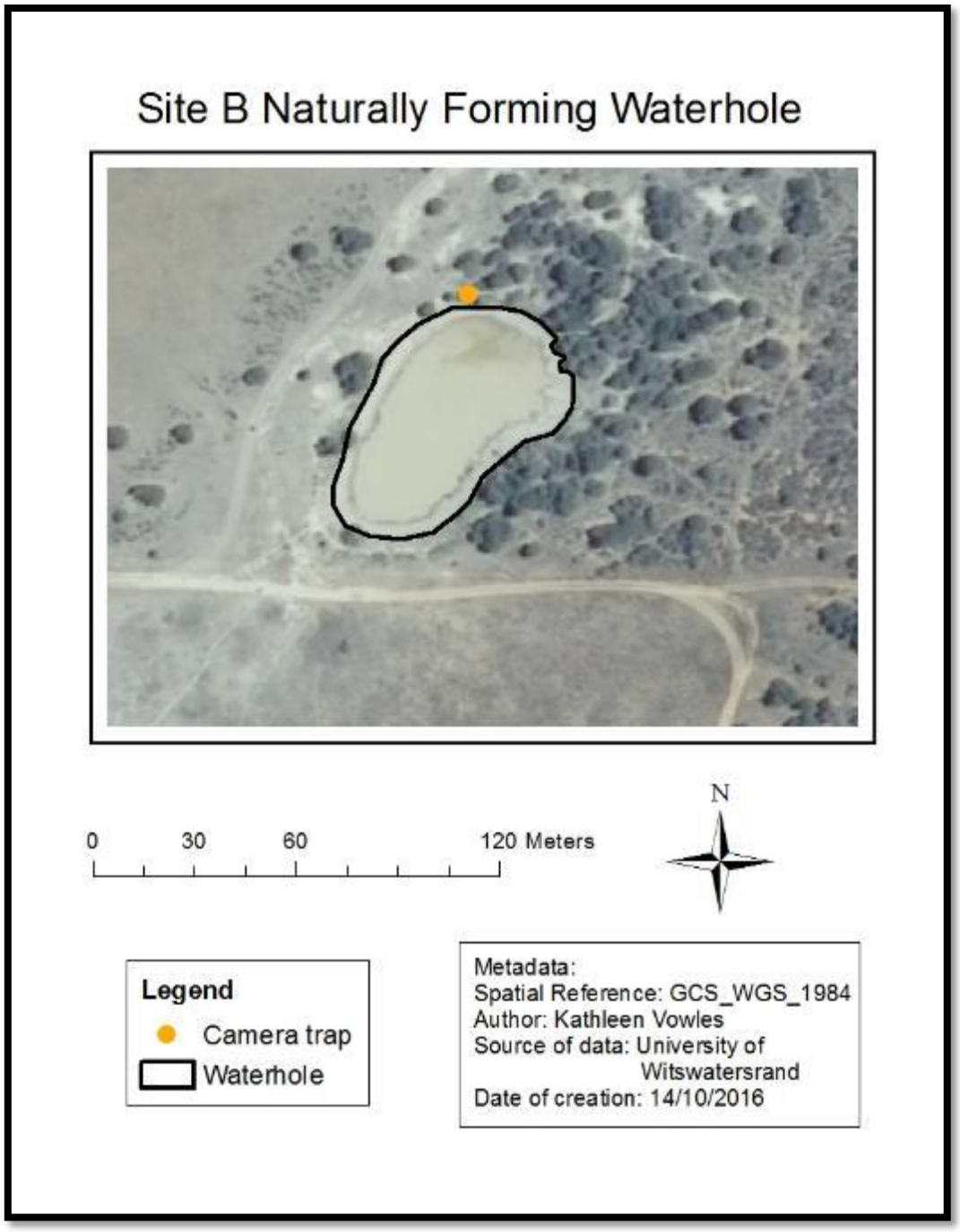


Figure 3. 6: Aerial photograph of Site B`s location and surroundings in Shamwari Private Game Reserve. Latitude and longitude were withheld due to the unfortunate reality of poaching in South Africa.

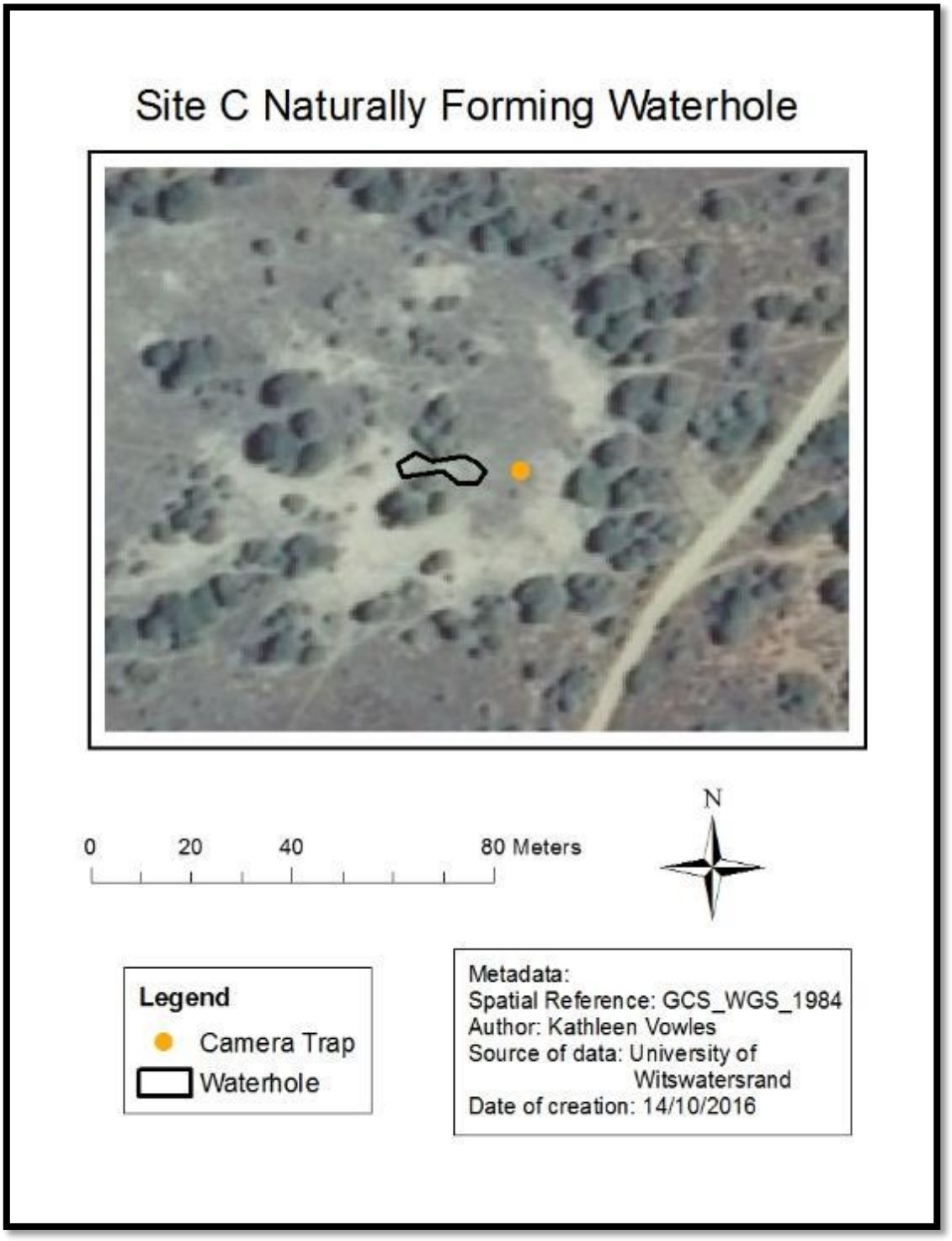


Figure 3. 7: Ariel photograph of Site C`s location and surroundings in Shamwari Private Game Reserve. Latitude and longitude were withheld due to the unfortunate reality of poaching in South Africa.

3.6 Summary

Shamwari Private Game Reserve in the Eastern Cape, South Africa (*Figure 3.1*), has a diverse ecosystem with rich biodiversity and is the chosen location to achieve the aims and objectives of this study. The low rainfall regime and the sole river water source of the Bushman's River means that naturally-forming waterholes are an important non-perennial water source. Faunal activity around three waterholes (A-C) are examined in this study.

Chapter 4

Methodology



4. Methods

This project focuses on local daily weather influence on the occurrence of faunal species observed at the chosen naturally-forming waterholes. Bushnell Trophy camera trap high-resolution imagery from June 2016 to November 2016 in Shamwari Private Game Reserve was used to achieve the desired aim and objectives (*section 1.2*). The research project was only conducted for a short time period (six months) because of the timeframe of Masters study. Rainfall, surface water availability, and temperature [average (T_{avg}), maximum (T_{max}), and minimum (T_{min})] all potentially influence faunal visiting times (duration and frequency) and species behaviour. This chapter describes the data collection methods and the specifics of how data gathering and analysis took place. Following this, there is a discussion on the methodology used to analyse camera trap images and local short-term daily weather patterns.

4.1 Field Data Collection

4.1.1 Site Selection

Naturally-forming waterholes are widely spread throughout the Shamwari landscape (Skead, 2007). Three naturally-forming waterholes were chosen in this investigation. The GPS coordinates and detailed locations of each waterhole site were documented, but this information was withheld at the request of the game reserve. To make sure these waterholes were adequate to achieve the aims and objectives mentioned (*section 1.2*); certain factors mentioned below were taken into consideration.

First, the naturally-forming waterholes needed to be active (in use) over the time frame of the investigation. Waterholes that are excavated by wildlife affect site selection, as some waterholes will be utilised at different periods, ranging from a few days to two weeks. In addition, others are only utilised in the wet season (Jarman, 1972; Halidu *et al*., 2013; Stommel *et al*., 2016). It was important to note that during the dry season, some species may locate to different areas in Shamwari to find adequate water sources, and therefore waterholes could potentially become inactive during the dry months.

Second, the three wallowing species investigated (elephant, white rhino, and warthogs) needed to visit each waterhole and undergo wallowing at these waterhole sites. This information was provided from the knowledge of the game rangers who observed these specific wallowing mammal species at each waterhole site.

Lastly, the waterholes needed to be away from areas with high tourist activity as it negatively affects faunal behaviour. Behaviour is disrupted due to noise levels of vehicles and tourists, which in turn leads to increased vigilance behaviour of fauna at the waterholes before drinking and wallowing (Kamanda *et al*., 2008; Stankowich & Reimers, 2015). For this reason, the chosen sites are relatively isolated and away from tourist hotspots.

4.1.2 Waterhole Parameters

Average waterhole parameters were measured at the start of the data collection (June 2016) for each naturally-forming waterhole site. Average waterhole parameters included estimated length (m), width (m), and depth (m) of each waterhole (*Table 3.1*). Mean waterhole parameters of each site were established, as parameters such as depth was difficult to measure, due to the waterholes' irregular shape and morphological change by animal action and environmental factors such as wind and water. Thus, the waterhole parameters are not spatially uniform.

4.1.3 Camera Traps

With the presence of inquisitive elephants in Shamwari, a metal camera casing was designed and manufactured to protect the camera traps in the field (Ancrenaz *et al*., 2012). The camera trap casings were tested at Johannesburg Zoo (in the elephant enclosure) to determine if any modifications were needed for the casing or if other elephant deterrents were needed to protect them (*Appendix 2*). The casings were commendable for use in environments with elephant presence, without any extra modifications or deterrents. As a result, the Bushnell Trophy camera traps and casings were placed at each waterhole site in Shamwari without modifications. Bushnell Trophy camera traps are digital passive camera traps, with a capture quality of eight megapixels.

The camera traps were placed at the waterhole sites for a six-month period (June–November 2016), ensuring a large dataset were available for analysis. Camera traps were placed approximately 10 m away from the waterhole, ensuring the entire waterhole would be captured. Another important aspect regarding camera placement was sun exposure. Camera traps were placed facing a southeast or southwest direction to ensure sun exposure did not interfere with photos, by creating blanks in the image (Ancrenaz *et al*., 2012). The same parameters were set for each camera at each site, enabling comparability of data. Each camera was to take an image quality of five megapixels, as was the recommended setting. For the purpose of this investigation, the camera traps were set to motion sensor and set to take an image every 10 seconds once the motion sensor was activated (Stommel *et al*., 2016). Field scan (monitoring edges of waterhole sites) was set at each site to take images from 00:00 until 23:59 (24-hours). Camera traps were able to take images for 24-hours over a six-month period once the motion sensor was activated. A time stamp was set up on each of the

camera traps, so each image contained the date/time of when the image was captured, allowing for easy recording and counting of individuals at the waterholes. The camera traps have a built in LED that functions as a flash (white flash), so the camera trap could take acceptable photos at night by capturing the faunal species that activated the motion sensor. Additional equipment was needed to ensure adequate and efficient running of camera traps, this included: spare AA size Lithium batteries; memory cards; cloth for cleaning the camera traps (when changing batteries and checking camera traps regularly); GPS unit and data storage facilities; and a portable hard drive for storage and back-up (Ancrenaz *et al*., 2012).

The limitations with using camera traps are that smaller species may not be captured (i.e. small rodents) (Pollock *et al*., 2002). In addition, if the movement of animals triggered the motion sensor, the 10 second delay may not capture the entirety of the animal movement, in particular if the animals crossed the field of view in less than 10 seconds (Ancrenaz *et al*., 2012).

4.1.4 Camera Trap Checking Procedure

It was essential to check on the camera traps, to ensure that they were working optimally, and were in the correct position (Ancrenaz *et al*., 2012). Before leaving the camera in the field, a two-week pilot project was conducted to ensure the camera traps were functioning properly in the environment and were in appropriate positions. The camera traps were checked regularly, every 2 weeks, to change the memory cards and batteries, where necessary. Checking procedures may have influenced faunal utilisation on the day, as faunal behaviour is disrupted due to noise levels of vehicles and human activity, therefore, less fauna could have visited the waterholes on these days (Kamanda *et al*., 2008; Stankowich & Reimers, 2015). In addition, the presence of elephants in Shamwari resulted in more regular check-ups of the camera traps to ensure no destruction and shift of the camera trap position, resulting from their curiosity (Ancrenaz *et al*., 2012).

4.2 Organisation of Data

From all the species recorded by the camera traps (*Table 4.1*), reptilian and avian species were excluded from this investigation, as this research focuses on mammalian species.

Table 4. 1: Reptilian and avian species observed at naturally-forming waterholes in Shamwari but excluded from analysis, as the focus of this study was on mammalian species.

Species not analysed during study period	
Scientific Name	**Common Name**
Corvus capensis	Pied Crow
Falco naumanni	Rock (Common) Kestrel
Sagittarius serpentarius	Secretary bird
Streptopelia capicola	Cape turtle dove
Lamprotornis nitens	Glossy starling
Anthropoides paradiseus	Blue crane
Bostrychia hagedash	Hadeda Ibis
Ardea cinerea	Grey heron
Numida meleagris	Helmeted Guineafowl
Alopochen aegyptiacus	Egyptian Goose
Geochelone pardalis	Leopard tortoise

4.2.1 Camera Trap Image Data Organisation

At each site (*Table 4.2*), species were identified and the numbers of individuals of each species present at the waterholes, alongside the relevant date and time of their presence. Faunal waterhole visitations were recorded in *Microsoft Excel 2010* spreadsheets. Once individuals first appeared at the waterhole, the species and number of individuals were recorded. A zero was allocated when the same individual was present at the waterhole in the next camera trap images (Trent, 2016). Individuals were identified by visual markings or recognisable traits. Over- or underestimation may, however, occur as some individuals do not have easily visually identifiable traits. If the same individuals revisited the waterhole later in the day (such as morning and evening), they were re-recorded as species are known to utilise the same waterholes throughout the day. Species visitation per hour was grouped into daily and monthly periods to investigate correlations between visiting times and wallowing activity with local weather variables. Monthly data were examined as this was a short-term study, hence, shifts in faunal activity could be easily identified with local weather conditions monthly rather than seasonally (as seasonality was not the focus of the study).

Table 4. 2: Camera trap details of total images from June 2016 – November 2016. Discrepancy is number of days captured is explained as a limitation in the Discussion section.

Site	Study Period	No. of days captured	No. of camera trap images archived
Site A	14th June – 29th November 2016	141	1236
Site B	14th June – 29th November 2016	169	1897
Site C	14th June – 29th November 2016	169	1156

4.2.2 Climate Data

Local climate data were obtained from the South African National Weather Service (SAWS) and were used to explore a relationship between temporal differences in species' visitation times at the waterholes, compared to local daily rainfall and temperature. Rainfall and temperature data, during the same time period of the study, was obtained from the Addo Elephant National Park weather station (station = 0055447A7). This station was chosen as it is the closest reliable weather station to Shamwari (23 km) and is in the same climatic zone as Shamwari (*Figure 3.1*). The Addo Elephant Park weather was also the only available reliable weather data for this investigation. It was important having rainfall records which are appropriate, as rainfall variability of the area of studies varies temporally, spatially, and in terms of intensity (Ayeni, 1977; Hayward & Hayward, 2012).

4.3 Data Analysis

All statistical analysis of faunal observations was conducted using *Microsoft Excel 2010* and *Statistica*. The faunal occurrence data were used to determine species-specific visitation patterns (either diurnal or nocturnal) at the waterholes. With the help of camera traps, factors that influenced the diversity and density of species at these waterholes were revealed (i.e. grass growth and surface water availability). These images, which were relevant to this investigation, were stored so they could be used for further analysis and discussion of results.

4.3.1 Short-Term Temperature and Rainfall Analysis (June – November 2016)

The average daily and monthly temperature (T_{min}, T_{max}, T_{avg}) and rainfall (mm) were calculated over the study period (June–November 2016), to determine which days and months experienced the highest and lowest temperatures and the greatest and least rainfall (mm) totals.

4.3.2 Camera Trap Imagery

The total (n) faunal occurrence and total (n) individuals per species at each waterhole was calculated for each hour (00:00–23:59) over the study period (*section 4.2.1*). Then daily visitation patterns of each species were averaged over a six-month period to determine the peak visitation intervals (morning [00:00-09:00], afternoon [09:00-15:00], late afternoon [15:00-18:00], and evening [18:00-24:00]). Peak sightings at the waterholes were classified as the period in which the greatest frequency by a particular species occurred over the study period (June–November 2016). After this, average counts per species were separated into monthly hour occurrence data over the study period. Distribution curves were analysed to determine monthly patterns for different species at the waterholes. Totals (n) were used in this analysis of the number of individuals of each species within the different hours and months throughout the study period.

4.3.3 *Peak Faunal Activity*

The mean hourly data from June to November were used to analyse temporal occurrence patterns of each species at the waterhole sites. Hourly percentages for each species were calculated from the hourly data. Then the separate species were grouped according to their visitation intervals (morning, afternoon, late afternoon, and evening), so that the peak time for each species observed could be established. These results were statistically analysed with the use of Principal Components Analysis (PCA) and cluster analysis. PCA and cluster are suitable for this statistical analysis as they can enable isolation of specific groups of species that have similar peak occurrence at the waterholes. Euclidean methods were used to test occurrence of unclustered analysis. Ward's D method was used to calculate distance between each species, based on the hourly percentages for each species (Manly, 2009). Time was classified as a vector, then species were grouped according to overlapping waterhole visitation times driven by specific time vectors. The statistical analyses using PCA and clusters were then compared to waterhole occurrence patterns.

Differences in sunrise and sunset were considered, as the sunrise and sunset differed each month over the study period, altering the light available in each month (*Table 4.3*). The sun's position in the sky (time of sunrise and sunset) cause variations each month in the daylight hours available, which is known to influence faunal behaviour (Nouvellet *et al*., 2011). Sunrise ranged from 05:00-08:00 and sunset from 17:00-20:00 over the study period (*Table 4.3*).

Table 4. 3: Sunrise and sunset times grouped into hourly categories for each month over the study period (June - November 2016).

	Sunrise	Sunset
June	07:00 - 08:00	17:00 - 18:00
July	07:00 - 08:00	17:00 - 18:00
August	06:00 - 07:00	17:00 - 18:00
September	06:00 - 07:00	18:00 - 19:00
October	05:00 - 06:00	18:00 - 19:00
November	05:00 - 06:00	19:00 - 20:00

4.3.4 *Monthly Faunal Activity*

To establish monthly waterhole occurrence patterns for each species, the hourly visitations which were calculated per species, were divided into different monthly hourly means of the study period (June–November 2016). Monthly data were examined as this was a short-term study, hence, shifts in faunal activity could be easily identified with local weather conditions monthly, as seasonality was not the focus of the study. Graphs were produced so that monthly differences in species occurrence

at the waterholes could be identified. Species that have similar visitation times were grouped together according to monthly preferential waterhole occurrence. Faunal species were also categorised according to their food preference (feeding guilds – grazers, browsers, mixed feeders, insectivores, and carnivores). This was to determine in which month certain species with different food preferences occurred at the waterholes, as food preference is associated with water-dependency (Ayeni, 1975; Western, 1975).

4.3.5 Local Weather Conditions and Faunal Activity Relationships

Local weather conditions, such as temperature and rainfall, affect visiting times and wallowing activity of species (Skiles & Hanson, 1994; Thuiler, 2007). Temperature thresholds of each individual species and the amount of available surface water present in the landscape following rainfall events, also affect faunal behaviour (Mills & Retief, 1984; Thouless, 1998; Fuller *et al*., 2014). Monthly means for both temperature and rainfall were explored throughout the study period (*Appendix 3*). This was to determine when rainfall quantity was sufficient to form surface water and to produce an adequate amount of water for faunal utilisation, and suitable conditions to allow species to undergo wallowing activity. Thus, rainfall influences faunal occurrence patterns at waterholes, as rainfall affects both water availability and distribution in Shamwari. Therefore, the number of species visiting the waterholes is likely to be influenced by daily and monthly rainfall patterns in the region, which is explained below (*section 4.3.7 - 4.3.9*) (Valeix *et al*., 2008a).

4.3.6 Temperature and Faunal Activity

To determine if there was a relationship between temperature and faunal activity at the waterholes, mean daily faunal sightings were used. These were plotted against average daily temperature (T_{avg}) over the study period, to determine if a pattern exists. Pearson's Correlation Coefficient was used to statistically analyse this relationship (*Appendix 3*). The relationships between T_{max}, T_{min}, and faunal activity were identified. The relationship between T_{max}, T_{min}, and faunal activity is important as different species have different temperature thresholds and are active during different times of the day under different local weather conditions. Monthly relationships were determined between occurrence per species and temperature. Average monthly activity for each species was correlated with average monthly temperature (T_{avg}). Thus, species–specific daily and monthly patterns with temperature over the study period could be determined.

4.3.7 Rainfall and Faunal Activity

A relationship between faunal sightings and rainfall (before rainfall, during rainfall, and immediately after rainfall) was determined. The mean number of sightings was organised in response to rainfall categories. This included one day before a rainfall event or two days before a rainfall event, on the

day of a rainfall event, and one day after a rainfall event or two days after a rainfall event. To determine if a relationship existed between rainfall and these rainfall categories, the Pearson's Correlation Coefficient was used, with rainfall data and the mean faunal sightings during these rainfall events (*Appendix 3*). A cross-correlation was completed to determine the similarity of rainfall relative to faunal sightings and to determine if there is displacement (lag) between rainfall and the number of faunal sightings over the study period. The cross-correlation was conducted with average weekly faunal sighting at the waterholes, as it was more effective than daily faunal sightings, to detect a change in faunal occurrence patterns in relation to rainfall.

4.3.8 Faunal Activity in Relation to Quantity of Rainfall

The quantity of rainfall affects species occurrence at waterholes. Different quantities of daily rainfall were categorised during the study period: 1-9 mm; 10-19 mm; 20-29 mm; and ≥ 30 mm. Rainfall events < 1 mm were excluded from this analysis due to its inconsequential quantity. The mean of faunal sightings were established for each rainfall category. This was completed to determine the effects that different quantities of rainfall have on faunal occurrence at the waterholes.

4.3.9 Faunal Activity and Surface Water Availability

Rainfall drives faunal occurrence patterns at waterholes, as rainfall affects both water availability in waterholes and distribution of water throughout the landscape (Valeix *et al*., 2008b). A relationship between faunal sightings and surface water availability in the naturally-forming waterholes was established and displayed graphically. This was accomplished by categorising the waterholes each day over the study period from the camera trap images, as either: dry; muddy; or water. Dry was when there was no mud or water present in the waterholes. Muddy was when the waterholes appeared to be wet but clearly no puddles of water could be seen and mud was present. Lastly, water was when the waterholes were filled with water or contained puddles in the depressions of the waterholes.

4.3.10 Peak Wallowing Activity

The hourly data were used to analyse temporal patterns of wallowing by elephant, white rhino, and warthogs at each waterhole. The total (n) number of wallowing events was calculated for each species per hour over the study period and were grouped according to their time periods, so that the peak time of wallowing activity could be established per wallowing species. These results were statistically analysed with PCA and cluster analysis, and Pearson Correlation Coefficient to determine if there is a significant difference in wallowing activity for each species (*Appendix 3*).

4.3.11 Monthly Wallowing Activity

To establish monthly wallowing activity for each wallowing species, the percentage of wallowing activity that was calculated for each species was divided into different months. This was used to determine in which months the greatest and least wallowing activity took place. Species that had similar wallowing activities were grouped together. To determine if there was a shift in monthly wallowing activity, the total (n) wallowing events per hour for each species during these months were graphed.

4.3.12 Wallowing Activity and Temperature

To determine if there is a relationship between temperature and peak wallowing activity at the waterholes, daily wallowing patterns were calculated using the total (n) wallowing activity. Daily average temperatures (T_{avg}) were then plotted against peak wallowing activity. The Pearson's Correlation Coefficient was used to determine if a relationship exists between T_{avg}, T_{max}, and T_{min} and peak wallowing activity per wallowing species (*Appendix 3*).

4.3.13 Wallowing Activity and Rainfall

To determine a relationship between wallowing activity and rainfall events, total (n) wallowing activity and rainfall (before rainfall, during rainfall, and immediately after rainfall) was established. Wallowing activity was organised according to rainfall categories; one day before a rainfall event or two days before a rainfall event, on the day of the rainfall event, and one day after a rainfall event or two days after the rainfall event. Pearson's Correlation Coefficient and cross-correlation was used to examine these relationships (*Appendix 3*). A cross-correlation were conducted with weekly averages as it was more effective to detect a change in wallowing activity in relation to rainfall, as daily wallowing activity may not take place at all of the waterholes.

4.3.14 Wallowing Activity after Rainfall Events

The quantity of rainfall affects wallowing activity of elephants, white rhino, and warthogs. The total (n) wallowing activity for each species was established for each rainfall category, to determine if the different quantities of rainfall influenced wallowing activity of these wallowing species at the waterholes. Different quantities of rainfall were categorised during the study period, as described above.

4.3.15 Wallowing Activity and Surface Water Availability

It is important to establish a relationship between surface water availability and wallowing activity. Wallowing is the coating of animal's body surface with mud, a mud-like substance, or water, thus, surface water needs to be present to allow wallowing events to take place (Jarman, 1972; Bigwood,

2011, Bracke, 2011; Vanschoenwinkel *et al*., 2011). This was accomplished by the methods described in *section 4.3.9*.

4.4 Summary

Data at the three waterholes were collected by means of motion sensor-triggered camera traps. At each site, the species were identified and the numbers of individuals of each species present at the waterholes, alongside the relevant date and time of their presence. Species occurrence per hour was grouped into daily and monthly periods to investigate correlations between visiting times with local weather variables. Data analysis was based on the total faunal occurrence and total individuals per species at each waterhole for each hour (00:00–23:59). The total number of wallowing events was calculated for each species per hour over the study period and were grouped according to time periods, so that the peak time of wallowing activity could be established per wallowing species. These faunal activity patterns were then compared with climate variables of temperature and precipitation, using Pearson's correlation coefficient.

Chapter 5

Results



5. Results

5.1 Short-Term Temperature and Rainfall (June–November 2016)

5.1.1 Temperature

Over the course of the study period (June–November 2016), June and July experienced the coldest mean monthly temperatures, with the absolute lowest daily temperature recorded in July (-1.1 °C). The absolute highest daily temperature were recorded in August (40.1 °C) (*Figure 5.1 & Table 5.1*). Due to the short period of this study, predominantly winter month data were collected, therefore not all seasons were explored.

Table 5. 1: Six-month average (duration of study period) for T_{avg}, T_{max}, T_{min}, and rainfall (mm).

Six-month average for T_{avg}, T_{max}, T_{min}, and rainfall (mm)				
	T_{avg}	T_{max}	T_{min}	Rainfall (mm)
Average (x)	16.80 °C	25.27 °C	8.17 °C	0,58 mm
Sample size (n)	169	169	169	49
Range	18.45	25.8	14.6	14.2
Variance (σ)	14.21 °C	26.63 °C	19.45 °C	3.61 mm

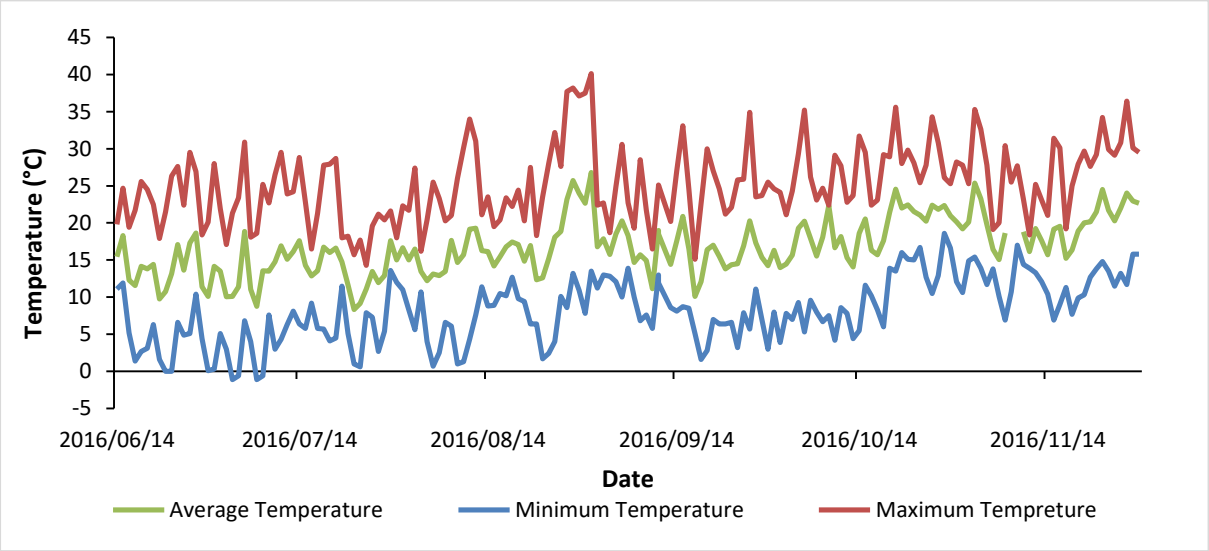


Figure 5. 1: Daily average, maximum, and minimum temperature over the study period (June–November 2016).

5.1.2 Rainfall

In the region, the highest rainfall (mm) was measured in July, with 32.4 mm of rainfall (*Figure 5.2*). During the year when the research was conducted, June recorded only 7 mm. November followed with the second lowest of 10 mm (*Figure 5.2*).

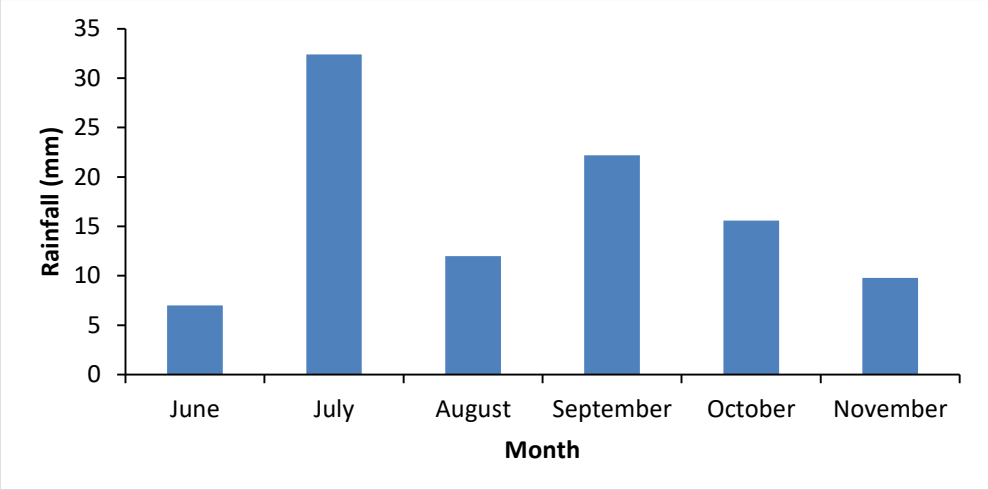


Figure 5. 2: Monthly precipitation (mm) over the study period.

Over the course of the study period, the 25th of July recorded the highest daily rainfall (mm) of 14.2 mm. On the 3rd of September, the second highest of 12 mm was measured (*Figure 5.3*). More rain fell during the dry season then wetter season, which may have been due to the weak development of La Niña towards the wet season, causing below average rainfall (mm) (SAWS, 2016b). Over the course of the study period, Shamwari experienced moderately dry conditions (SAWS, 2016a) and below average rainfall (mm). From September to November 2016, Shamwari experience below average rainfall causing severely dry conditions (*Figure 5.3*) (SAWS, 2016a).

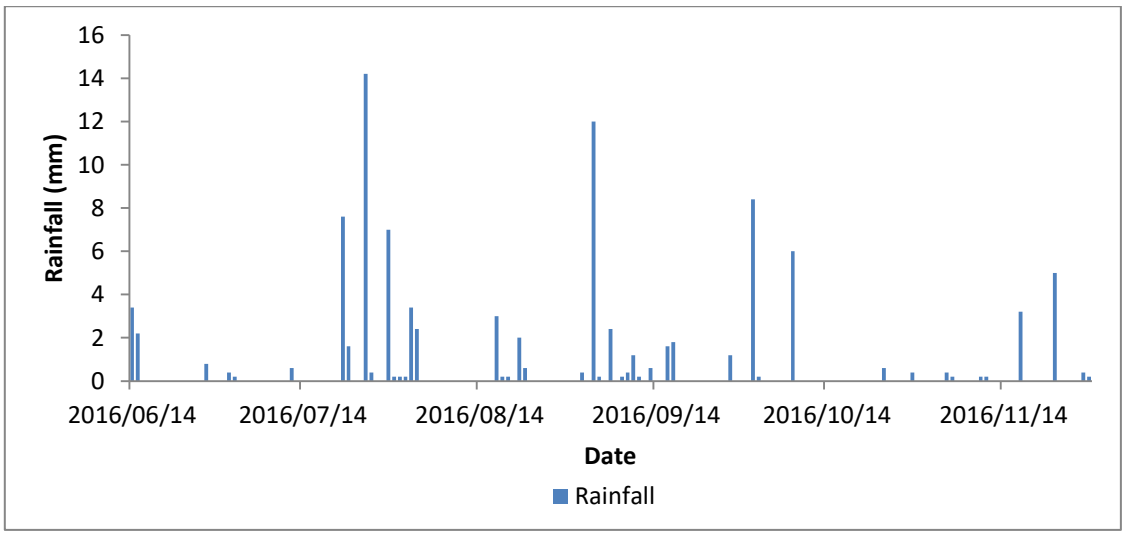


Figure 5. 3: Daily precipitation (mm) over the study period.

5.2 Faunal Occurrence at Waterholes

There were 27 species observed at the waterholes over the study period (*Table 5.2*), these were both diurnal and nocturnal species (*Table 5.2, 5.5, 5.6 & 5.7*).

Table 5. 2: Faunal species observed at the naturally-forming waterholes during the study period, demonstrating water dependency of these species in the Shamwari Private Game Reserve.

Common Name	Scientific Name	Water-dependency	Feeding preference
		(Sources: Western, 1975; Derry, 2004; Owen-Smith, 2008; Davidson *et al*., 2013; Stuart & Stuart, 2015).	
Diurnal species			
Family Bovidae			
Red Hartebeest	*Alcelaphus buselaphus*	Water-dependent	Mixed Feeder
Springbok	*Antidorcas marsupialis*	Less water-dependent	Grazer
Impala	*Aepyceros melampus*	Water-dependent	Mixed Feeder
Blesbok	*Damaliscus dorcas phillipsi*	Water-dependent	Mixed Feeder
Waterbuck	*Kobus ellipsiprymnus*	Water-dependent	Grazer
Gemsbok	*Oryx gazella*	Less water-dependent	Mixed Feeder
Eland	*Taurotragus oryx*	Less water-dependent	Mixed Feeder
Greater Kudu	*Tragelaphuc strepsiceros*	Less water-dependent	Browser
Family Giraffidae			
Giraffe	*Giraffa camerlopardalis*	Less water-dependent	Browser
Family Equidae			
Burchell zebra	*Equus burchellii*	Water dependent	Grazer
Black Rhino	*Diceros bicornis*	Water-dependent	Browser
White Rhino	*Cerathotherium simum*	Water-dependent	Grazer
Family Elephantidae			
African Elephant	*Loxodonta africana*	Water-dependent	Mixed Feeder
Family Hippopotamidae			
Hippopotamus	*Hippopotamus amphibius*	Water-dependent	Grazer
Family Suidae			
Warthog	*Phacochoerus aethiopicus*	Water-dependent	Grazer
Family Cercopithecidae			
Vervet Monkey	*Ceropithecus aethiops*	Water-dependent	Mixed Feeder
Chacma Baboon	*Papio ursinus*	Water-dependent	Mixed Feeder
Nocturnal Species			
Family Hystricidae			
Porcupine	*Hystrix africaeaustralis*	Less water-dependent	Mixed Feeder
Family Felidae			
Lion	*Panthera leo*	Less water-dependent	Carnivore
Family Hyaenidae			
Brown hyena	*Hyaena brunnea*	Less water-dependent	Carnivore
Family Canidae			
Black-Backed jackal	*Canis mesomelas*	Less water-dependent	Carnivore
Bat-eared fox	*Otocyon megalotis*	Less water-dependent	Insectivore
Family Leporidae			
Scrub Hare	*Lepus saxatilis*	Less water-dependent	Grazers
Family Mustelidae			
Honey Badger	*Mellivora capensis*	Less water-dependent	Mixed Feeder
Family Suidae			
Bush Pig	*Potamochoerus porcus*	Water-dependent	Mixed Feeder
Family Bovidae			
Common Duiker	*Sylvicapra grimmia*	Less water-dependent	Browser
Bushbuck	*Tragelaphus scriptus*	Water-dependent	Browser

5.3 Camera Trap Monitoring at Each Naturally-Forming Waterhole.

This section analyses species observed over a 24-hour (00:00-23:59) period each day when the camera traps were active in the field over the study period. The 24-hour period was divided into hourly time categories (*Table 5.3*).

Table 5. 3: Time categories over the 24-hour period.

	Time Category		Time Category
1	00:00 - 00:59	**13**	12:00 - 12:59
2	01:00 - 01:59	**14**	13:00 - 13:59
3	02:00 - 02:59	**15**	14:00 - 14:59
4	03:00 - 03:59	**16**	15:00 - 15:59
5	04:00 - 04:59	**17**	16:00 - 16:59
6	05:00 - 05:59	**18**	17:00 - 17:59
7	06:00 - 06:59	**19**	18:00 - 18:59
8	07:00 - 07:59	**20**	19:00 - 19:59
9	08:00 - 08:59	**21**	20:00 - 20:59
10	09:00 - 9:59	**22**	21:00 - 21:59
11	10:00 - 10:59	**23**	22:00 - 22:59
12	11:00 - 11:59	**24**	23:00 - 23:59

The observed species over the study period revealed 27 species at the waterholes (*Table 5.4*). Site B had the highest number of individuals sighted at the waterhole (n= 2067), followed by site C (n= 1022), with the lowest number of individuals observed at site A (n= 988). Warthogs had the highest occurrence at site A (n= 186) and site C (n= 262), and springbok had the highest occurrence at site B (n = 583) (*Table 5.4*).

5.4 Peak Faunal Activity

Species were recorded over the 24-hour period each day during which camera trap images were available. The most frequent species to visit site A waterhole over the study period were warthogs (n=186), with 12:00-13:00 as the peak hour in which warthogs were most frequently sighted (n=40) (*Table 5.4, 5.5*). Burchell's zebra were the second most frequent species (n=181) (*Table 5.4*). The peak hour for Burchell's zebra activity was between 11:00-12:00 (*Table 5.5*). Springbok (n=583) were the most frequently sighted at the site B waterhole (*Table 5.4, 5.6*). The springbok's peak activity occurred between 12:00-13:00 (n=104). The second most frequently sighted species at site B was

impala (n=457) (*Table 5.6*), with 17:00-18:00 as the peak hour of activity. Warthogs were the most frequently sighted species at site C (n=262) with peak activity between 11:00-12:00 (n=46) (*Table 5.4, 5.7*). Kudu were the second most frequently sighted species at site C (n=145) with peak activity between 10:00-11:00 (*Table 5.7*).

Table 5. 4: Total (n) faunal sightings over a 6 month period at each naturally-forming waterhole site. Asterisk (*) has been marked on the highest number of sightings per species.

Common Name	Scientific Name	Site A	Site B	Site C
Diurnal species				
Family Bovidae				
Red Hartebeest	*Alcelaphus buselaphus*	0	13	7
Springbok	*Antidorcas marsupialis*	174	*583	2
Impala	*Aepyceros melampus*	121	457	95
Blesbok	*Damaliscus dorcas phillipsi*	15	244	0
Waterbuck	*Kobus ellipsiprymnus*	40	0	70
Gemsbok	*Oryx gazella*	0	0	13
Eland	*Taurotragus oryx*	18	16	0
Greater Kudu	*Tragelaphuc strepsiceros*	30	62	145
Family Giraffidae				
Giraffe	*Giraffa camerlopardalis*	31	51	7
Family Equidae				
Burchell zebra	*Equus burchellii*	181	126	95
Black Rhino	*Diceros bicornis*	0	3	9
White Rhino	*Cerathotherium simum*	0	10	77
Family Elephantidae				
African Elephant	*Loxodonta africana*	37	53	22
Family Hippopotamidae				
Hippopotamus	*Hippopotamus amphibius*	6	3	3
Family Suidae				
Warthog	*Phacochoerus aethiopicus*	*186	239	*262
Family Cercopithecidae				
Vervet Monkey	*Ceropithecus aethiops*	9	1	4
Chacma Baboon	*Papio ursinus*	0	1	15
Nocturnal Species				
Family Hystricidae				
Porcupine	*Hystrix africaeaustralis*	10	0	11
Family Felidae				
Lion	*Panthera leo*	0	1	1
Family Hyaenidae				
Brown hyena	*Hyaena brunnea*	2	3	4
Family Canidae				
Black-backed jackal	*Canis mesomelas*	9	12	5
Bat-eared fox	*Otocyon megalotis*	0	0	2
Family Leporidae				
Scrub Hare	*Lepus saxatilis*	8	0	7
Family Mustelidae				
Honey Badger	*Mellivora capensis*	1	0	1
Family Suidae				
Bush Pig	*Potamochoerus porcus*	0	0	1
Family Bovidae				
Common Duiker	*Sylvicapra grimmia*	11	29	68
Bushbuck	*Tragelaphus scriptus*	0	0	14
Total (n)		**988**	**2067**	**1022**

Table 5. 5: Total faunal species over the study period per time category at site A. Asterisk (*) has been marked on the hour with the largest number of sightings per species. Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Time Category	Black-Backed Jackal	Blesbok	Brown Hyena	Burchell`s Zebra	Common Duiker	Eland	Elephant	Giraffe	Hippopotamus	Honey Badger	Impala	Kudu	Porcupine	Scrub Hare	Springbok	Vervet Monkey	Warthog	Waterbuck	Unknown
00:00 - 01:00	1	0	*1	0	1	0	0	0	0	0	0	0	0	*2	0	0	0	0	1
01:00 - 02:00	0	0	0	0	0	0	1	0	0	*1	13	0	1	0	1	0	0	0	3
02:00 - 03:00	0	0	0	0	0	0	6	0	0	0	13	0	1	0	0	0	0	0	6
03:00 - 04:00	0	0	0	0	2	0	1	0	*1	0	0	0	*2	1	0	0	0	0	1
04:00 - 05:00	1	0	0	0	1	0	0	1	*1	0	0	0	1	*2	0	0	0	0	0
05:00 - 06:00	0	0	0	0	1	3	0	0	0	0	15	0	0	0	2	0	0	1	5
06:00 - 07:00	0	0	0	0	0	2	0	0	0	0	2	4	0	0	2	0	0	0	2
07:00 - 08:00	0	0	0	0	0	2	0	0	0	0	3	4	0	0	9	0	10	4	5
08:00 - 09:00	1	0	0	29	0	0	0	1	0	0	6	*5	0	0	19	0	4	0	3
09:00 - 10:00	*2	2	0	17	0	0	0	0	0	0	10	1	0	0	12	0	18	0	8
10:00 - 11:00	0	*6	0	36	0	0	2	1	0	0	8	*5	0	0	18	0	28	1	*15
11:00 - 12:00	0	5	0	*44	0	0	5	1	0	0	17	0	0	0	13	2	36	0	11
12:00 - 13:00	0	2	0	40	0	*7	*18	0	0	0	*18	4	0	0	*33	*5	*40	*16	7
13:00 - 14:00	0	0	0	8	0	3	0	*10	0	0	0	1	0	0	20	1	18	9	9
14:00 - 15:00	0	0	0	1	0	0	0	7	0	0	0	2	0	0	0	1	22	0	2
15:00 - 16:00	0	0	0	0	0	0	0	1	0	0	1	0	0	0	21	0	8	5	3
16:00 - 17:00	1	0	0	0	0	1	1	0	0	0	4	4	0	0	1	0	2	2	0
17:00 - 18:00	1	0	0	3	0	0	0	1	0	0	2	0	0	0	9	0	0	0	2
18:00 - 19:00	1	0	0	0	0	0	0	0	*1	0	6	0	0	0	7	0	0	2	2
19:00 - 20:00	0	0	0	0	1	0	1	5	*1	0	3	0	0	0	0	0	0	0	1
20:00 - 21:00	1	0	*1	3	0	0	0	0	1	0	0	0	*2	1	0	0	0	0	4
21:00 - 22:00	0	0	0	0	0	0	2	0	0	0	0	0	1	1	2	0	0	0	0
22:00 - 23:00	0	0	0	0	2	0	0	0	*1	0	0	0	*2	0	2	0	0	0	1
23:00 - 24:00	0	0	0	0	*3	0	0	3	0	0	0	0	0	1	3	0	0	0	8
Total	**9**	**15**	**2**	**181**	**11**	**18**	**37**	**31**	**6**	**1**	**121**	**30**	**10**	**8**	**174**	**9**	***186**	**40**	**99**

Table 5. 6: Total faunal species over the study period per time category at site B. Asterisk (*) has been marked on the hour with the largest number of sightings per species. Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Time Category	Black-Backed Jackal	Black Rhino	Blesbok	Brown Hyena	Burchell`s Zebra	Chacma Baboon	Common Duiker	Eland	Elephant	Giraffe	Hippopotamus	Impala	Kudu	Lion	Red Hartebeest	Springbok	Vervet Monkey	Warthog	White Rhino	Unknown
00:00 - 01:00	0	*2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	6	*3	5
01:00 - 02:00	0	0	0	0	0	0	1	0	0	0	0	17	0	0	*5	2	0	6	0	4
02:00 - 03:00	0	0	7	0	10	0	1	0	0	0	0	18	0	0	0	3	0	5	0	11
03:00 - 04:00	0	0	14	0	0	0	0	0	0	0	0	5	0	0	0	18	0	0	0	1
04:00 - 05:00	0	0	12	0	0	0	0	0	0	0	0	3	0	0	0	11	0	0	0	0
05:00 - 06:00	0	0	8	0	0	0	0	0	0	0	0	18	0	0	0	28	0	11	0	3
06:00 - 07:00	0	0	13	0	13	0	1	0	0	0	0	33	0	0	0	21	0	1	0	6
07:00 - 08:00	0	0	*49	0	27	0	2	0	13	0	0	19	8	0	0	27	0	8	0	*29
08:00 - 09:00	*8	0	8	*1	*40	0	2	0	1	4	1	12	7	0	0	10	0	10	0	12
09:00 - 10:00	3	0	15	*1	4	*1	1	0	0	0	0	12	*9	0	0	24	0	*52	1	22
10:00 - 11:00	0	0	5	0	4	0	3	0	1	*19	0	21	7	0	1	*51	*1	15	2	1
11:00 - 12:00	0	0	32	0	0	0	0	0	0	0	0	39	5	0	0	30	0	23	0	7
12:00 - 13:00	0	1	3	0	0	0	0	*16	0	0	0	14	0	0	0	27	0	19	2	1
13:00 - 14:00	0	0	23	0	1	0	2	0	1	2	0	*61	0	*1	4	45	0	11	0	13
14:00 - 15:00	0	0	24	0	0	0	1	0	0	0	0	42	1	0	0	7	0	2	0	6
15:00 - 16:00	0	0	5	0	0	0	0	0	0	0	0	35	4	0	0	44	0	13	0	3
16:00 - 17:00	0	0	2	0	0	0	0	0	*24	0	0	17	1	0	0	1	0	1	0	10
17:00 - 18:00	0	0	2	0	6	0	1	0	8	1	0	26	4	0	0	6	0	1	0	9
18:00 - 19:00	1	0	1	0	0	0	1	0	5	7	0	8	0	0	0	35	0	4	0	2
19:00 - 20:00	0	0	0	0	0	0	1	0	0	1	*1	6	0	0	0	0	0	0	0	2
20:00 - 21:00	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	1	0	0
21:00 - 22:00	0	0	1	0	0	0	1	0	0	3	0	5	0	0	0	2	0	4	2	2
22:00 - 23:00	0	0	0	0	0	0	0	0	0	0	*1	17	6	0	1	17	0	0	0	1
23:00 - 24:00	0	0	20	*1	21	0	*11	0	0	14	0	27	*9	0	0	2	0	46	0	10
Total	**12**	**3**	**244**	**3**	**126**	**1**	**29**	**16**	**53**	**51**	**3**	**457**	**62**	**1**	**13**	***583**	**1**	**239**	**10**	**160**

Table 5. 7: Total faunal species over the study period per time category at site C. Asterisk (*) has been marked on the hour with the largest number of sightings per species. Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Time Category	Bat-Eared Fox	Black-Backed Jackal	Black Rhino	Brown Hyena	Burchell's Zebra	Bushbuck	Bush Pig	Chacma Baboon	Common Duiker	Elephant	Gemsbok	Giraffe	Hippopotamus	Honey Badger	Impala	Kudu	Lion	Porcupine	Red Hartebeest	Scrub Hare	Springbok	Vervet Monkey	Warthog	Waterbuck	White Rhino	Unknown
00:00 - 01:00	0	0	*3	0	0	1	0	0	4	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	1	4
01:00 - 02:00	0	0	0	*3	2	0	0	0	2	0	0	0	0	0	1	0	0	*3	0	1	0	0	0	0	1	4
02:00 - 03:00	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	*3	0	0	0	0	0	0	2	0
03:00 - 04:00	0	0	0	1	0	1	0	0	2	3	0	0	0	0	5	1	0	1	0	0	0	0	0	0	1	3
04:00 - 05:00	0	*2	0	0	0	0	0	0	10	0	0	1	1	*1	3	1	0	0	0	0	0	0	0	0	0	1
05:00 - 06:00	0	0	0	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	2
06:00 - 07:00	0	0	0	0	8	0	0	0	2	0	0	*2	0	0	11	0	0	0	0	*2	0	0	1	0	1	1
07:00 - 08:00	0	0	0	0	0	0	0	0	4	0	*2	1	0	0	1	10	0	0	0	1	0	0	15	0	1	4
08:00 - 09:00	0	0	0	0	10	0	0	0	0	0	0	*2	0	0	*13	5	0	0	1	0	0	0	17	10	5	5
09:00 - 10:00	0	0	0	0	3	0	0	0	1	0	*2	0	0	0	3	7	0	0	1	0	0	0	20	7	6	5
10:00 - 11:00	0	0	0	0	*24	1	0	0	0	0	1	0	0	0	6	*26	*1	0	0	0	0	*2	41	0	2	2
11:00 - 12:00	0	0	0	0	9	0	0	0	0	4	1	0	0	0	10	13	0	0	1	0	0	1	*46	1	5	*7
12:00 - 13:00	0	0	0	0	12	0	0	*15	0	0	1	0	0	0	9	11	0	0	0	0	*1	0	36	2	7	6
13:00 - 14:00	0	0	0	0	3	0	0	0	0	0	1	0	0	0	3	5	0	0	0	0	0	0	34	0	2	2
14:00 - 15:00	0	0	0	0	8	0	0	0	0	0	1	0	0	0	6	7	0	0	0	0	*1	0	16	2	2	2
15:00 - 16:00	0	*2	0	0	2	0	0	0	0	0	2	0	0	0	5	0	0	0	0	0	0	1	26	7	*12	5
16:00 - 17:00	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	9	1	6	0
17:00 - 18:00	0	0	0	0	11	0	0	0	0	0	1	0	0	0	5	6	0	0	*3	0	0	0	1	*19	9	*7
18:00 - 19:00	0	0	0	0	0	0	0	0	7	1	0	0	0	0	5	9	0	0	1	0	0	0	0	3	8	1
19:00 - 20:00	0	0	0	0	0	1	0	0	*15	2	0	0	0	0	0	12	0	1	0	1	0	0	0	14	4	6
20:00 - 21:00	0	0	0	0	0	*3	0	0	10	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	4	6
21:00 - 22:00	0	0	1	0	0	2	*1	0	2	*7	0	0	0	0	0	10	0	0	0	0	0	0	0	4	0	6
22:00 - 23:00	0	1	1	0	0	*3	0	0	1	5	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	1
23:00 - 24:00	*2	0	1	0	0	1	0	0	3	0	0	1	*2	0	0	19	0	0	0	1	0	0	0	0	1	2
Total	**2**	**5**	**6**	**4**	**95**	**14**	**1**	**15**	**68**	**22**	**13**	**7**	**3**	**1**	**95**	**145**	**1**	**11**	**7**	**7**	**2**	**4**	***262**	**70**	**80**	**82**

5.5 Monthly Faunal Activity

The total number of individuals for each faunal species were analysed for each month as the faunal activity differs month to month over the study period. The number of individuals for each species was used to determine which species had the highest occurrence at each waterhole in the different months of the study period.

5.5.1 Site A

In the month of June, springbok had the highest number of individuals sighted (31.9%), the second highest species sightings being warthogs (19.2%). In July, springbok (47.9%) were the most frequently sighted species, with the second highest being impala (11.5%) (*Figure 5.4*). In August, the highest sighted species were Burchell's zebra (47.1%), yet June and July had no sightings of Burchell's zebra, with the second most frequently sighted species being warthogs (21.4%). In September, warthogs (32.5%) were the most frequently sighted species with the second being springbok (14.1%) (*Figure 5.4*). In October, the most frequently sighted species were impala (34.8%), with the second being waterbuck (13.7%). Lastly, in November, warthog (29.7%) were the most frequently sighted species, with the second being springbok (25.3%) (*Figure 5.4*).

5.5.2 Site B

In June, at site B waterhole the most frequently sighted species was impala (29.3%), with the second being warthog (24.1%) (*Figure 5.5*). No carnivores were sighted in June, only herbivorous species. In July, the most frequently sighted species were springbok (21.5%), with the second being blesbok (21.1%) (*Figure 5.5*). In August, the most frequently sighted species were warthog (29.8%), with the second being springbok (15.7%). A high percent of 16.2% were unknown species observed in August at this waterhole, these species could not be identified due to many factors (this is explained in limitations (*section 6.9*)) (*Figure 5.5*). In September, the most frequently sighted species were springbok (30.9%), with the second being impala (21.1%) (*Figure 5.5*). In October, the most frequently species sighted were impala (35.7%), with the second being springbok (25.5%) (*Figure 5.5*). Lastly, in November, the most frequently sighted species were springbok (52.3%), with the second being warthog (13.9%) (*Figure 5.5*). There were no carnivore sightings in the first three months of the study period and an increase in carnivore sightings occurred in the last three months at site B waterhole.

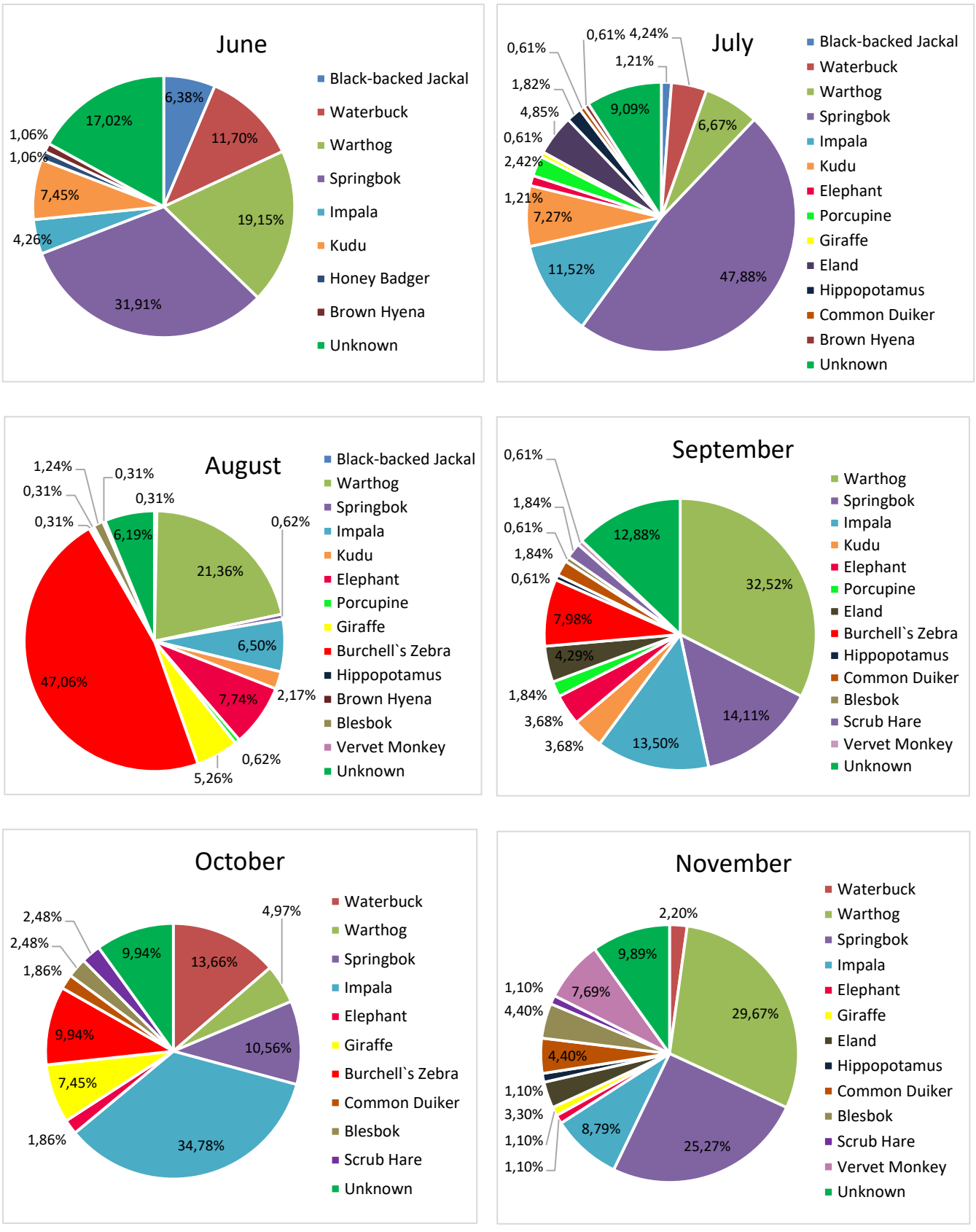


Figure 5. 4: Percentage composition of the total number of faunal species sighted at site A waterhole in each month over the study period.

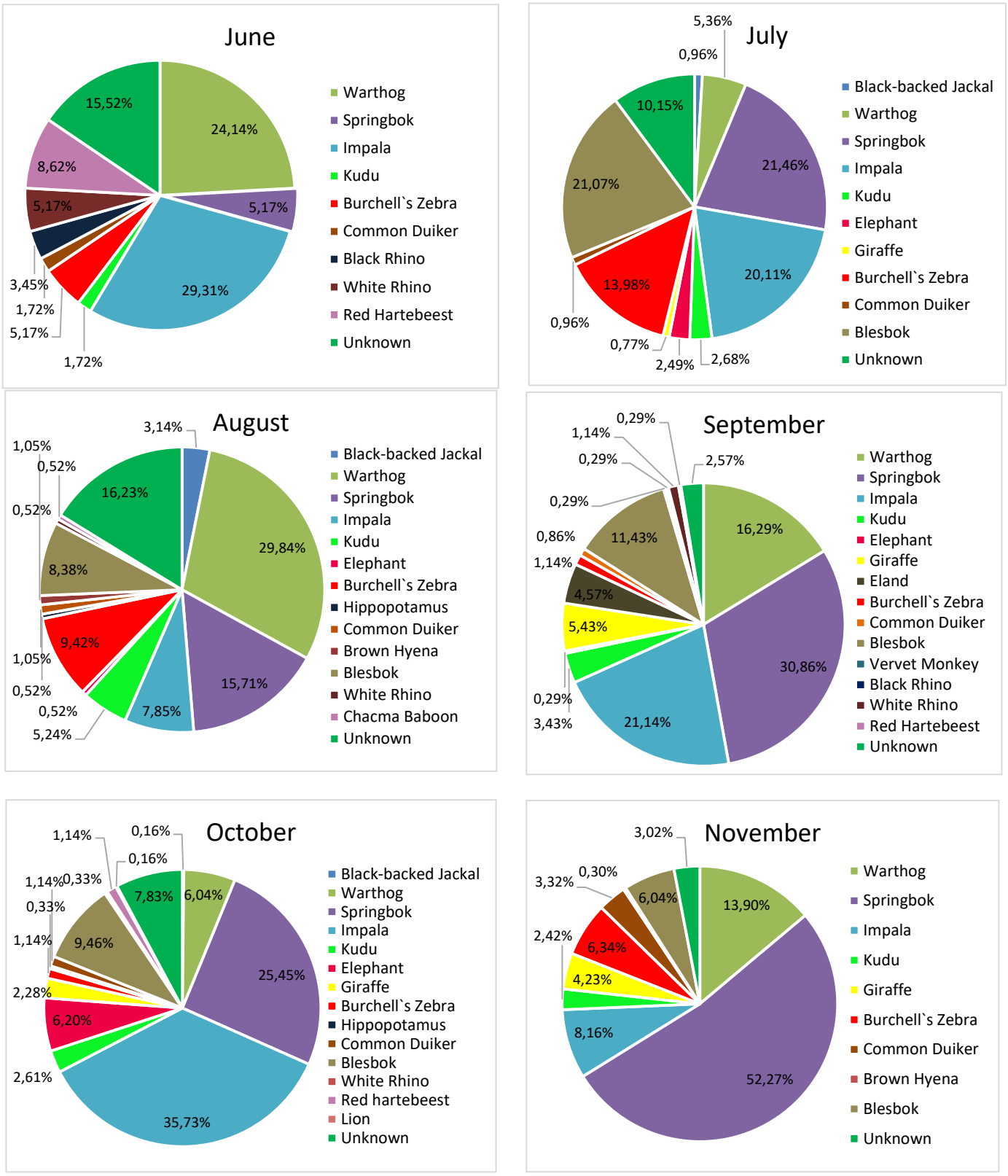


Figure 5. 5: Percentage composition of the total faunal species sighted at site B waterhole over the study period.

5.5.3 Site C

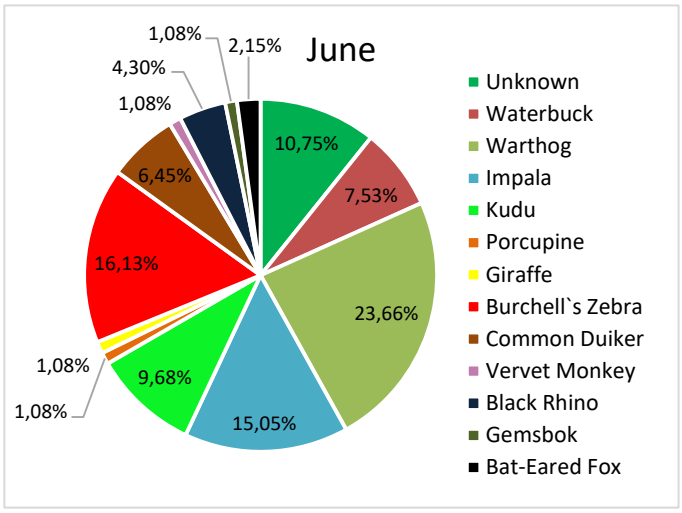
At the site C waterhole in June, the most frequently sighted species were warthog (23.7%), with the second most frequently sighted species being Burchell's zebra (16.1%) (*Figure 5.6*). In July, the most frequently sighted species were Burchell's zebra (17.7%), with the second being kudu (17%) and waterbuck (17%) (*Figure 5.6*). In August, the most frequently sighted species were warthog (27.2%), with the second being white rhino (15%), these are both wallowing mammals (*Figure 5.6*). In September, the most frequently sighted species were warthog (34.6%), with the second being kudu (17.8%) (*Figure 5.6*). In October, the most frequently sighted species were warthog (33.9%), with the second being common duiker (17.9%) (*Figure 5.6*). Lastly, in November, the most frequently sighted species were kudu (30.5%), with the second being warthog (18.6%) (*Figure 5.6*).

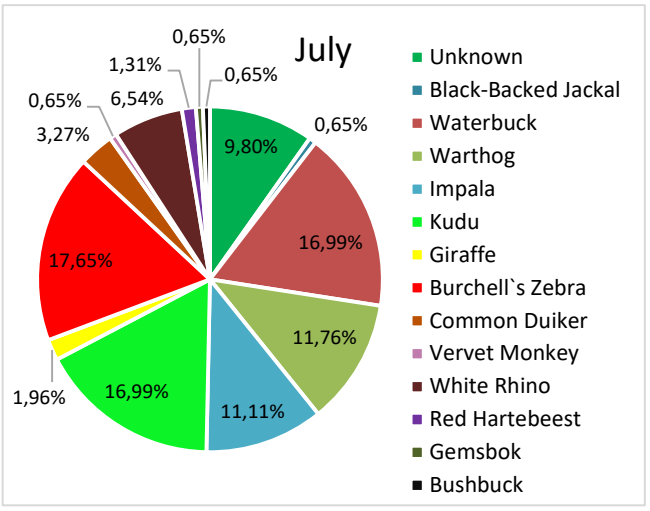
5.6 Different Feeding Guilds Monthly Activity

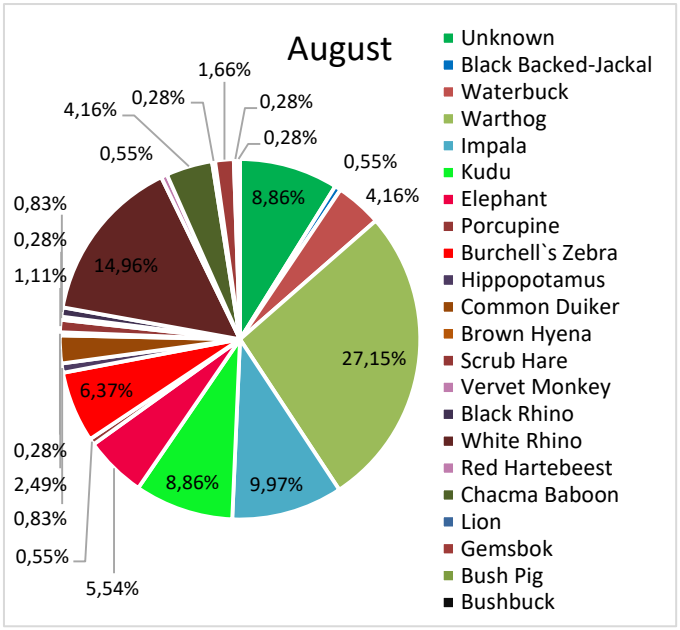
Faunal species have different food preferences (feeding guilds – grazers, browsers, mixed feeders, and carnivores). Different food preferences are associated with water-dependence and influences the occurrence of faunal species at the waterholes (Ayeni, 1975; Western, 1975). Herbivore populations are known to disperse into different habitats within a landscape where there is food availability, in particular after rainfall events (Owen-Smith, 2002; Gaillard *et al.* 2008; Prins & Fritz, 2008; Valeix *et al*., 2010; Davies *et al*., 2012). This makes it important to understand monthly faunal species distribution in relation to feeding guilds.

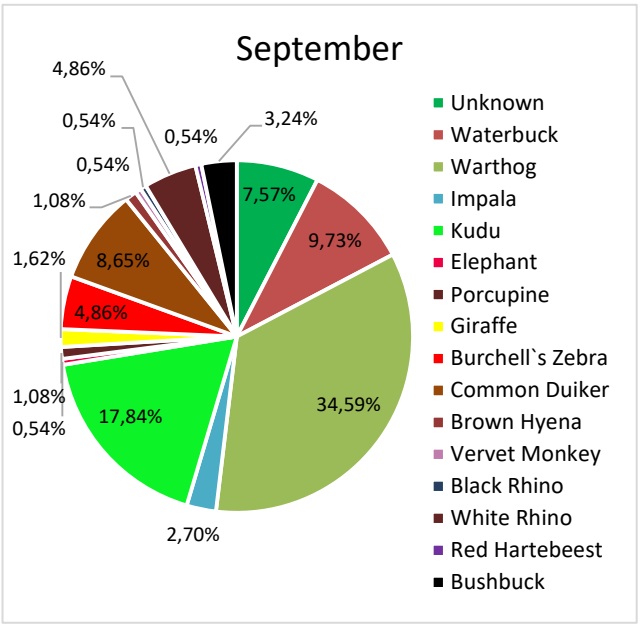
5.6.1 Site A

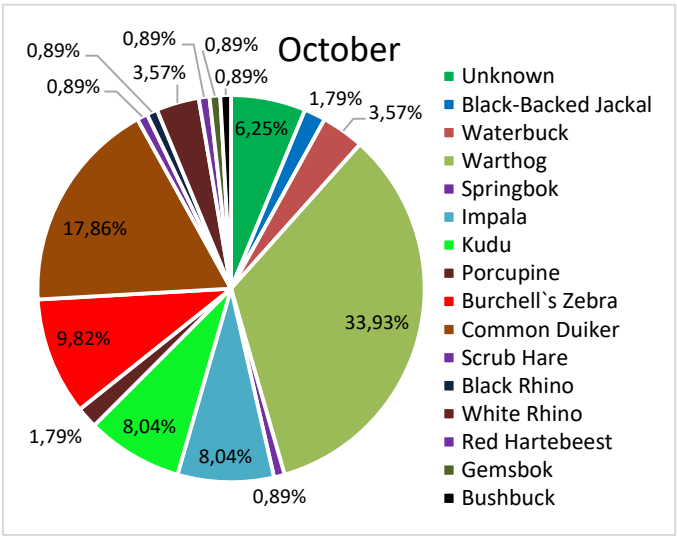
Grazers occurred every month at the waterhole and it is evident that they were the most frequently sighted feeding guild. However, this could be due to their overall large numbers in Shamwari, compared to the other feeding guilds. The most frequent sightings of grazers (69.4%) occurred in August, with the least being in October (41.6%) (*Figure 5.7*). The number of grazers sighted, increased in August and decreased again in September and October. Springbok were the most frequently sighted grazers at site A waterhole in June (31.9%) and July (47.9%) (*Figure 5.4*). In August, Burchell's zebra (47.1%) were the most frequently sighted grazers. In September (32.5%) and November (29.7%), warthog were the most frequently sighted grazers (*Figure 5.4*). In October, waterbuck (13.7%) were the most frequently sighted grazers (*Figure 5.4*). Browsers (9.3%) were most frequently sighted in October, with the least sighted in June (5.5%) (*Figure 5.7*). In June, the only browsers sighted at the waterhole were kudu (7.5%). In July (7.3%) and September (3.7%), the most frequently sighted browsers were kudu (7.3%). In August (5.3%) and October (7.5%), the most











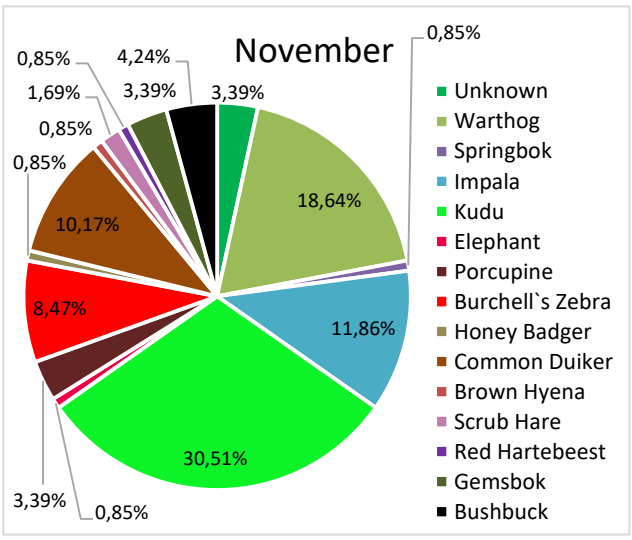


Figure 5. 6: Percentage composition of the mammal species sighted at site C naturally-forming waterhole over the study period.

frequently sighted browsers were giraffe (*Figure 5.4*). Lastly, in November, the most frequently sighted browsers were common duiker (4.4%) (*Figure 5.4*).

Mixed feeders were sighted at site A waterhole, October had the most frequent sightings of mixed feeders (39.1%), with the least in June (5.3%) (*Figure 5.7*). In October, when grazers were least sighted the least in October, mixed feeders had their highest number of sightings at the waterhole during this month (*Figure 5.7*). In June (4.3%), July (11.5%), September (13.5%), October (34.8%), and November (8.8%) the most frequently sighted mixed feeders were impala (4.3%) (*Figure 5.4*). However, in August, the most frequently sighted mixed feeders were elephants (7.7%) (*Figure 5.4*).

Carnivore species were sighted at site A waterhole in the months of June, July, and August and were absent in September, October, and November. June had the most frequent sightings of carnivore species (7.5%) at the waterhole (*Figure 5.7*).

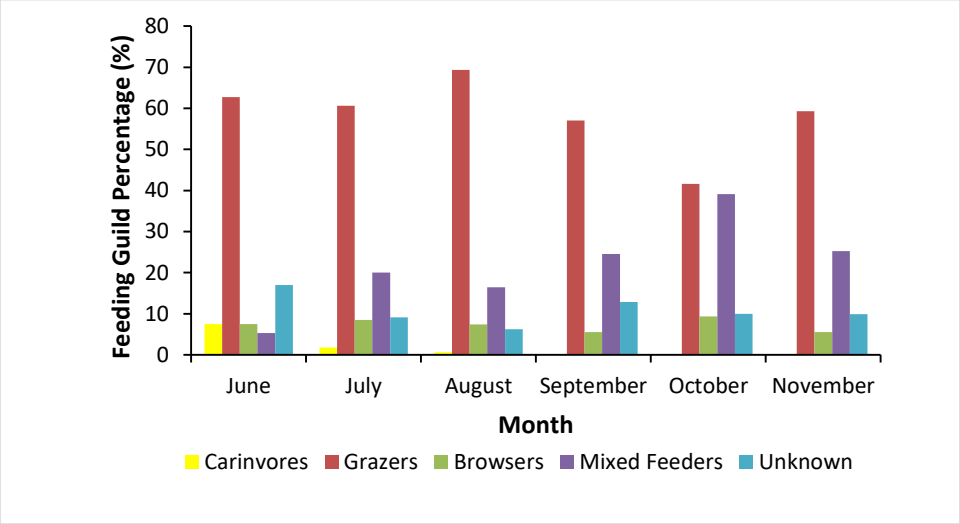


Figure 5. 7: Percentage (%) of the total faunal sightings of species with different feeding guilds (grazers, browsers, mixed feeders, and carnivores) at site A waterhole over study period.

5.6.2 Site B

Grazers were sighted most frequently at the waterhole than any other feeding guild in each month, except in the month of October; with mixed feeders being the most frequently sighted. Grazers were most frequently sighted in November (74.1%) and August (59.4%), with the least in October (39.1%) and June (39.7%) (*Figure 5.8*). In June (24.1%) and August (29.8%), the most frequently sighted grazers were warthog. In July (20.1%), September (30.9%), October (24.5%), and November (52.3%), the most frequently sighted grazers were springbok (*Figure 5.5*).

Browsers were most frequently sighted in November (9.4%) and September (9%), with the least in July (3.6%) and October (5.5%) (*Figure 5.8*). In June, the most frequently sighted browsers were black rhino (3.5%). In July (2.7%), August (5.2%), and October (2.6%), the most frequently sighted browser were kudu (*Figure 5.5*). In September (5.4%) and November (4.2%), the most commonly sighted browsers were giraffe (*Figure 5.5*).

October (48%) and June (37.9%) had the most frequent sightings of mixed feeders, with the least in November (13.4%) and August (15.9%) (*Figure 5.8*). In June (29.3%), September (21.1%), October (35.7%), and November (8.2%), the most frequently sighted mixed feeders were impala. In July (21.1%) and August (8.4%), the most frequently sighted mixed feeders were blesbok (21.1%) (*Figure 5.5*). Carnivores were sighted at site B waterhole in July, August, October, and November. Carnivores (4.2%) were most frequently sighted in August and absent in June and September (*Figure 5.8*).

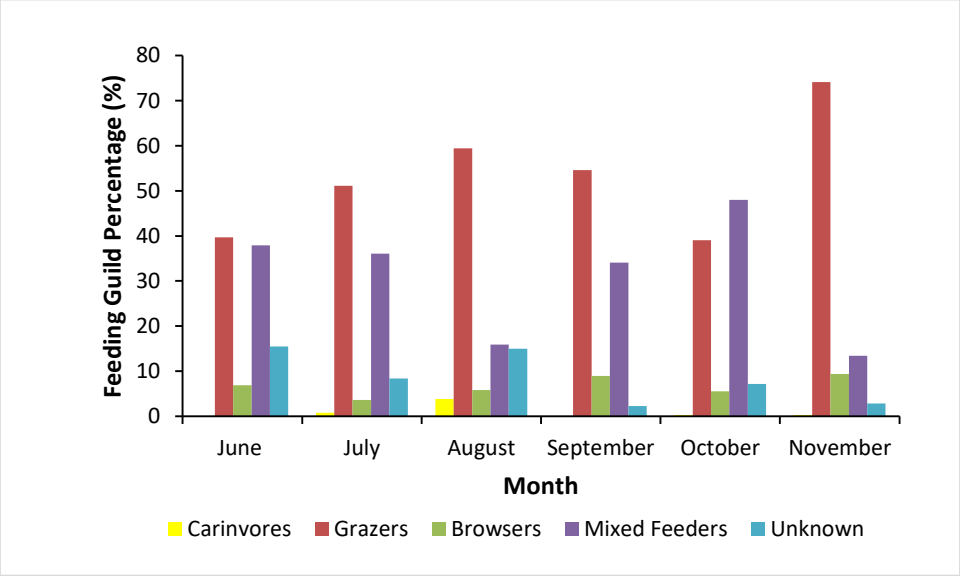


Figure 5. 8: Percentage (%) of the total faunal sightings of species with different feeding guilds (grazers, browsers, mixed feeders and carnivores) at site B waterhole over study period.

5.6.3 Site C

Grazers were sighted most frequently in August (54.9%) and September (54.1%), with the least being in November (29.7%) and June (47.3%) (*Figure 5.9*). Grazers were again the most predominant feeding guild at the waterhole, except in November, browsers were the most frequent feeding guild during this month. In June (23.7%), August (27.2%), September (34.6%), October (33.9%), and November (18.6%), the most frequently sighted grazers at the site C waterhole were warthogs. In July, the most frequently sighted grazers were Burchell's zebra (17.6%) (*Figure 5.6*).

Browsers were most frequently sighted in November (44.9%) and September (54.1%), with the least in August (12.5%) and June (21.5%) (*Figure 5.9*). In June (9.7%), July (17%), August (8.9%), September (17.8%), and November (30.5%), the most frequently sighted browsers at the waterhole were kudu. In October, the most frequently sighted browsers were common duiker (17.9%) (*Figure 5.6*).

Mixed feeders were most frequently sighted at the waterhole in August (21.7%) and November (21.2%), with the least in September (5.4%) and October (11.6%) (*Figure 5.9*). In all months, impala were the most frequently sighted mixed feeders at site C waterhole: June (15.1%), July (11.1%), August (10%), September (2.7%), October (8%), and November (11.9%) (*Figure 5.6*).

Carnivores were only absent from site C waterhole in June and present every other month over the study period. Carnivores were sighted most frequently in October (1.8%) and August (1.1%) (*Figure 5.9*). Species-specific visitation patterns at the waterholes are due to multiple factors such as feeding preference, physiology of different species, predator-prey interactions, and body size differences. Some of these factors will be explained further in the discussion (*Chapter 6*).

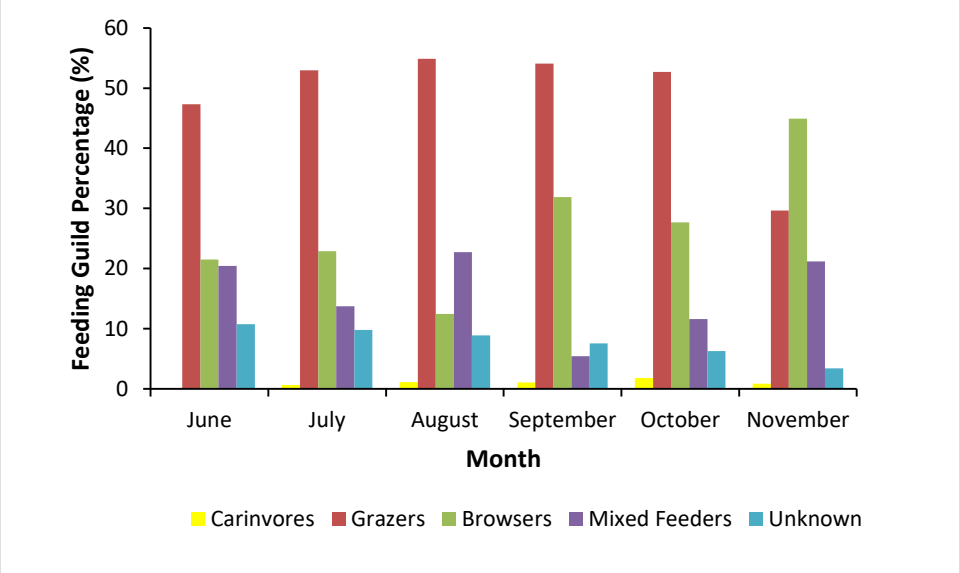


Figure 5. 9: Percentage (%) of the total faunal sightings of species with different feeding guilds (grazers, browsers, mixed feeders and carnivores) at site C waterhole over study period.

5.7 Monthly Faunal Activity

The total faunal sightings at the waterholes were analysed monthly for each species, to determine if there was a shift in faunal activity monthly over the study period. Some species that were sighted at the waterholes had small visitation frequencies, and therefore these species were excluded from the monthly analysis. The following species were excluded: red hartebeest, blesbok, gemsbok, waterbuck, eland, common duiker, giraffe, black rhino, hippopotamus, vervet monkey, chacma baboon, porcupine, lion, brown hyena, black-backed jackal, bat-eared fox, scrub hare, honey badger, bush pig, and bushbuck. The following species were included in the analysis: springbok, impala, kudu, Burchell's zebra, white rhino, elephant, and warthog.

5.7.1 Monthly Faunal Activity of Each Species

Faunal behaviour is known to follow cyclical patterns over the day, which is a result of external factors such as light availability (sunrise and sunset). The different faunal species have a preference in visitation times (e.g. diurnal or nocturnal) (Nouvellet *et al*., 2011). Thus, seasonality causes variations of sunrise and sunset over the study period, and an animal's behaviour follows this light availability (*Table 4.3*) (Nouvellet *et al*., 2011).

5.7.1.1 Family Bovidae Diurnal Species

5.7.1.1.1 Springbok

Springbok were sighted every month at the waterhole over the study period and had predominantly diurnal visitation patterns at the waterhole. June and August both had unimodal peaks in springbok hourly visitation times and July, September, October, and November had multimodal peaks at the waterholes (*Figure 5.10*). June and September had peak sightings in the afternoon, June (13:00-14:00) and September (14:00-15:00). July and October had peak sightings later in the day (late afternoon and evening), July (16:00-17:00) and October (17:00-18:00). August and November had peak springbok sightings between 12:00-13:00 (midday), June and July had a peak in hourly springbok sightings during midday (*Figure 5.10*). Springbok visitation patterns show a variation with sunrise and sunset, due to light availability at the waterholes (*Figure 5.10; Table 4.3*). From September to November there was an increase in springbok sightings later and earlier in the day, this shift occurred with the variation in light available during these months, due to earlier sunrises and later sunsets (*Figure 5.10*).

5.7.1.1.2 Impala

Impala show predominantly diurnal activity at the waterholes; however, they were sighted regularly during nocturnal hours. Over the study period, impala show multimodal peaks in visitation patterns at the waterholes (*Figure 5.11*). Impala had peak sightings during nocturnal hours (23:00-24:00) in

June. July had a shift in impala sightings to later in the morning between 09:00-11:00. August and September sightings were later in the day, August (11:00-12:00) and September (10:00-11:00) (*Figure 5.11*). Lastly, October and November, also had a shift in impala visitation times to even later in the day, October (17:00-18:00) and November (15:00-16:00). August, September, and November impala sightings vary with sunrise and sunset at the waterhole, however June, July, and October do not show a variation with light availability at the waterholes (*Figure 5.11*).

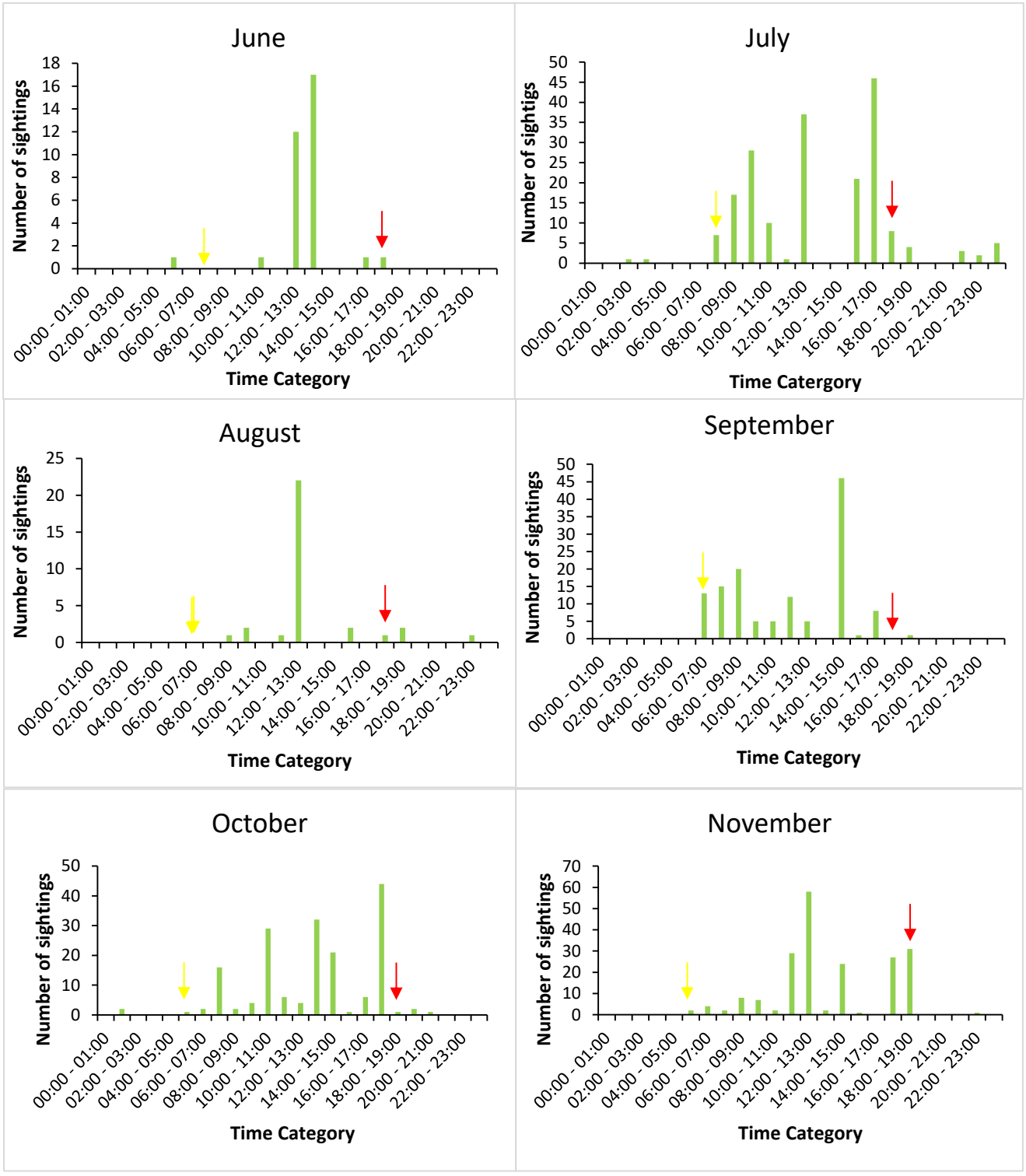


Figure 5. 10: Springbok monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

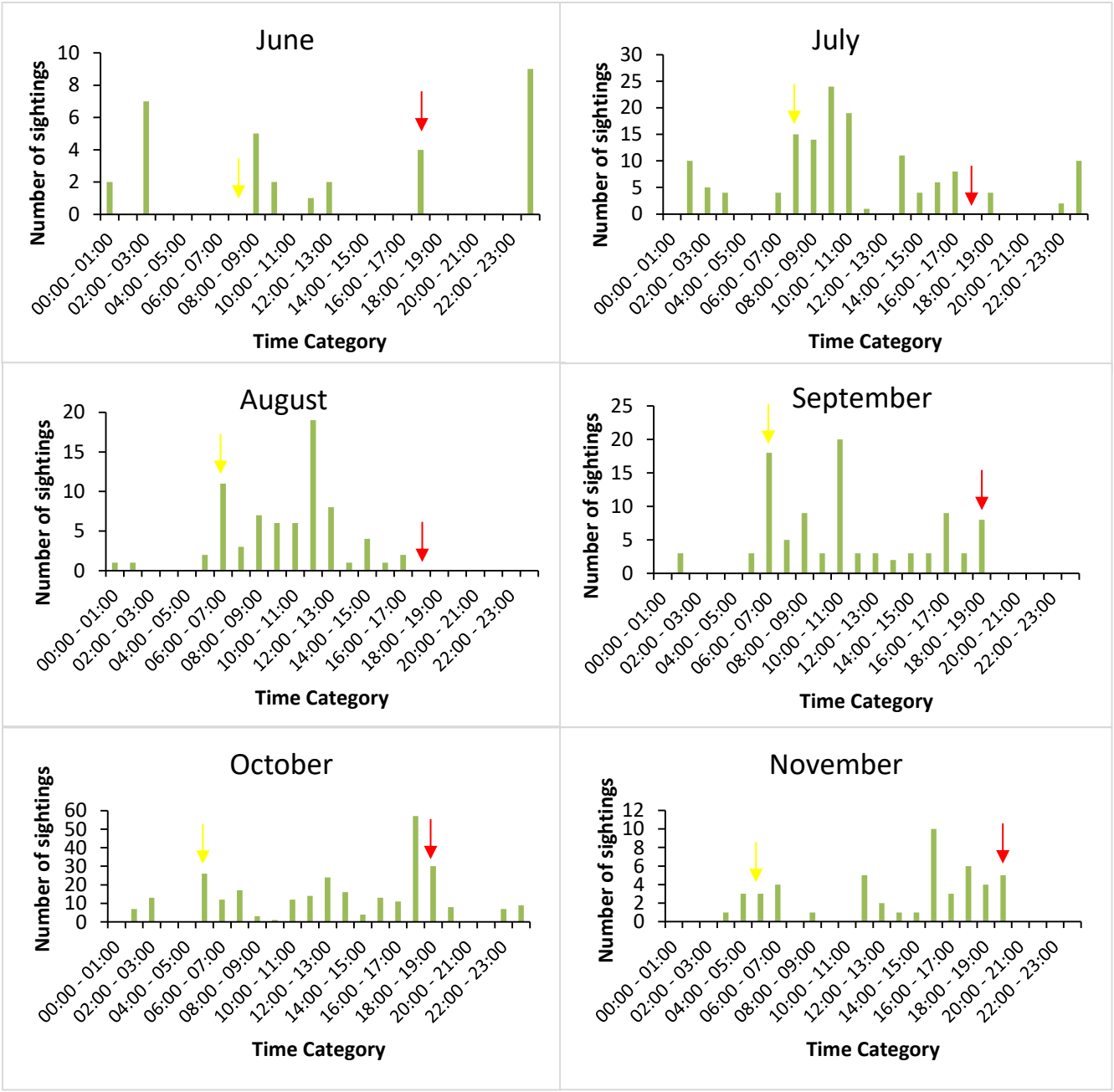


Figure 5. 11: Impala monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.7.1.1.3 Kudu

Kudus which were sighted at the waterholes did not show strictly diurnal activity, as kudu were sighted during nocturnal hours over the study period. In June and July, peak activity occurred between 23:00-24:00, during nocturnal hours. In August, there was a shift in visitation times to 22:00-23:00 (*Figure 5.12*). There was also an hourly peak between 10:00-11:00; September had a peak in kudu sightings between 10:00-11:00 (*Figure 5.12*). October was the only month with a peak in the morning (07:00-08:00) over the study period. Lastly, kudu had peak sightings between 18:00–

20:00 in November (*Figure 5.12*). Kudu do not show a variation in activity at the waterholes with light availability (sunrise and sunset). However, the exception is the month of September and November, which shows kudu behaviour following the sunrise and sunset (light availability) at the waterholes (*Figure 5.12; Table 4.3*).

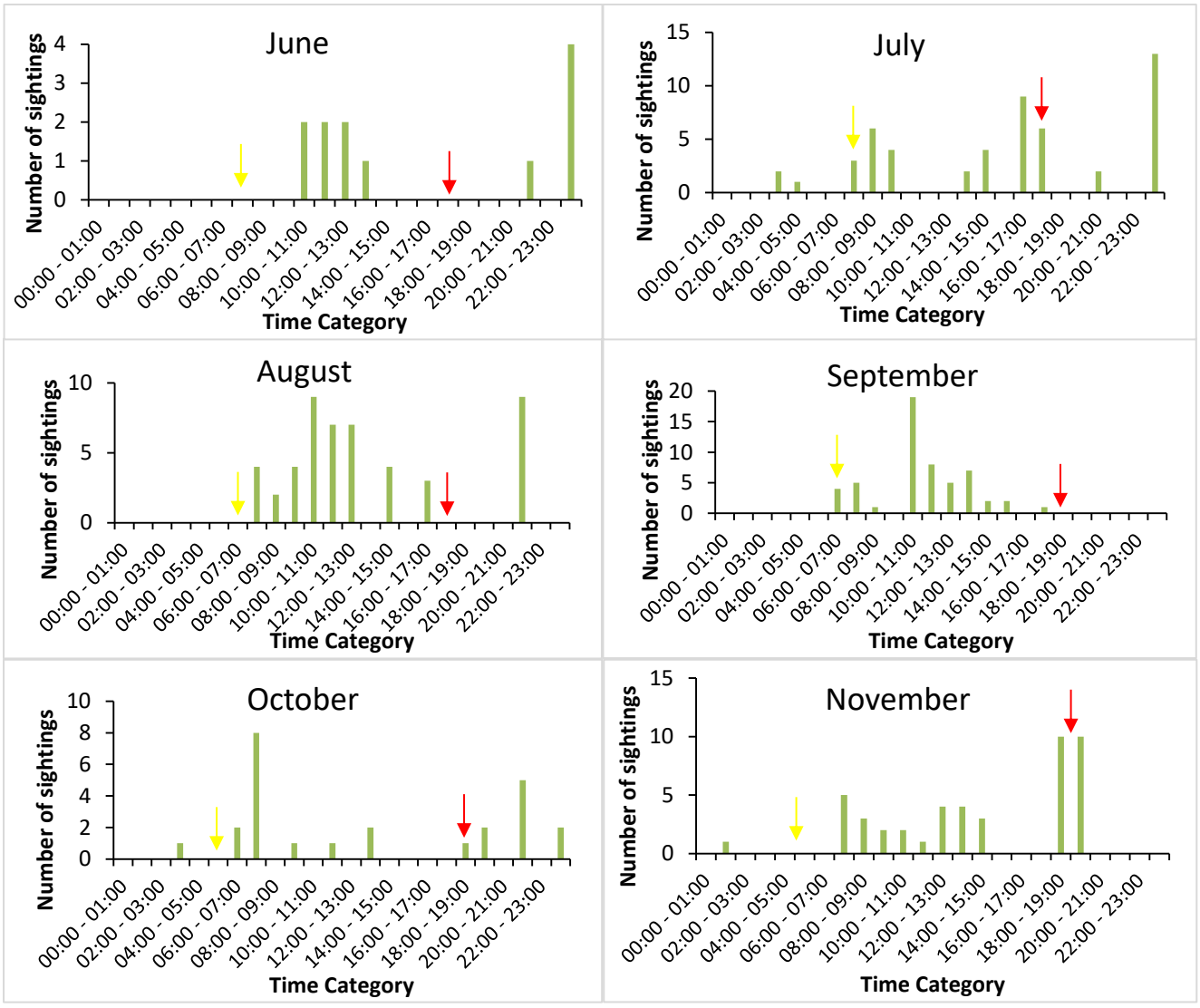


Figure 5. 12: Kudu monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.7.1.2 Family Equidae Diurnal Species

5.7.1.2.1 Burchell's Zebra

Burchell's zebra were sighted at the waterholes every month over the study period. In June there were three peaks in activity at the waterhole from 10:00–13:00, all peak activity occurred in the afternoon at the waterhole (*Figure 5.13*). Peak sightings in July were between 10:00-11:00, and in August to between 11:00-12:00 (*Figure 5.13*). September and November showed it earlier in the day

(06:00-07:00 for September, 08:00-09:00 for November) (*Figure 5.13*). Burchell's zebra visitation patterns over the course of the study period, revealed strict diurnal activity as a result of light availability (sunrise and sunset) (*Figure 5.13; Table 4.3*). October is an exception as Burchell's zebra were sighted at the waterhole during nocturnal hours, but still had peak activity during diurnal hours during this month (*Figure 5.13*).

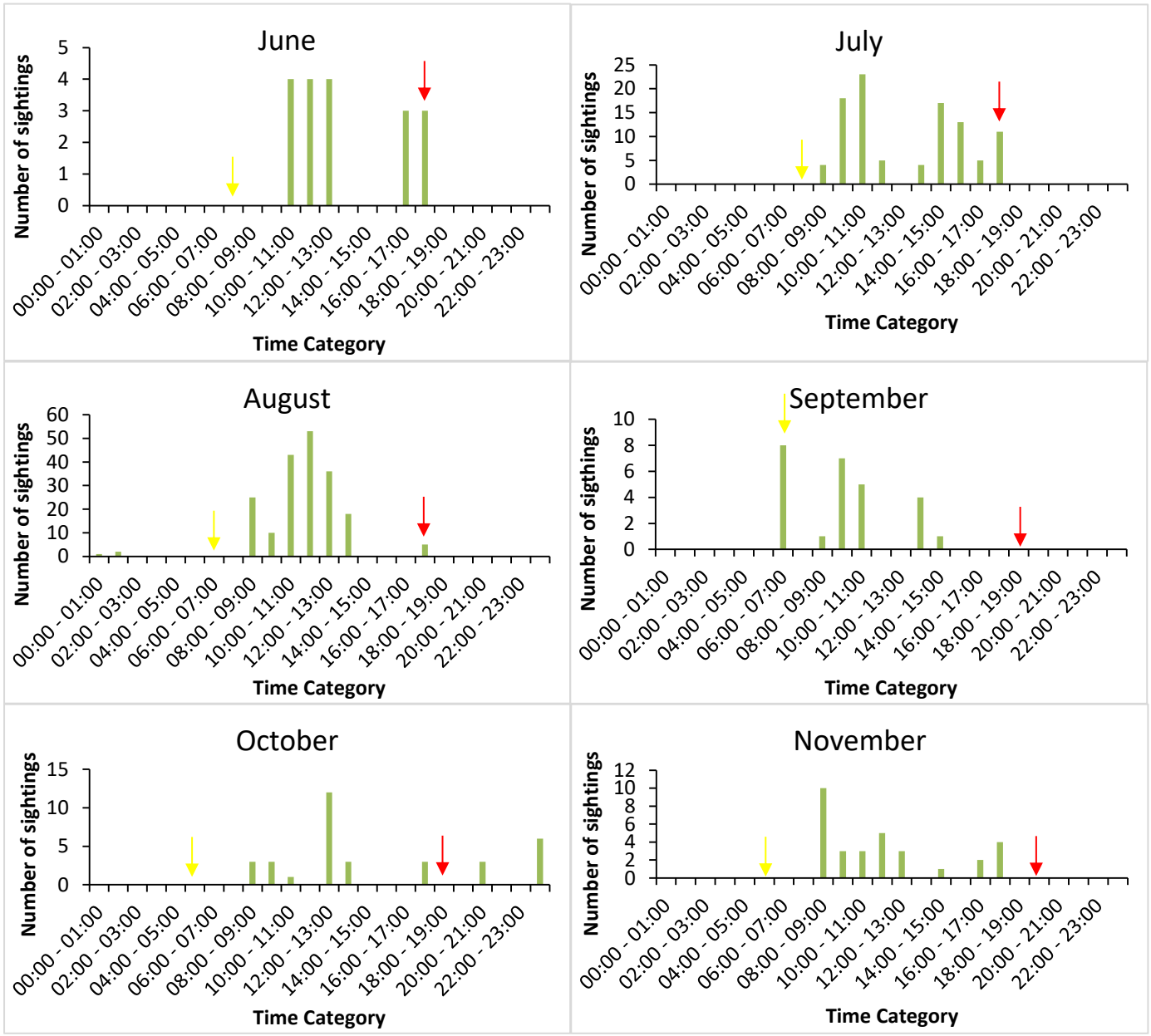


Figure 5. 13: Burchell's zebra monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.7.1.2.2 White Rhino

White rhino were sighted at the waterholes during both diurnal and nocturnal hours over the course of the study period. In June, July, August, and September white rhino peak sightings occurred at different times (June 09:00-10:00; July 12:00-13:00; August 15:00-16:00; September 14:00-15:00) (*Figure 5.14*). From August to September, there was a shift in peak white rhino activity at the waterhole to later in the day. In October, peak white rhino sightings occurred between 18:00-19:00, but white rhino were not sighted at the waterholes in November (*Figure 5.14*). Visitation patterns reveal predominantly diurnal activity at the waterholes, between sunrise and sunset (*Table 4.3*). However, there are cases where white rhino have high numbers of sightings during nocturnal hours, so it is not clear whether white rhino activity at the waterholes follow the light availability of sunrise and sunset (*Figure 5.14*).

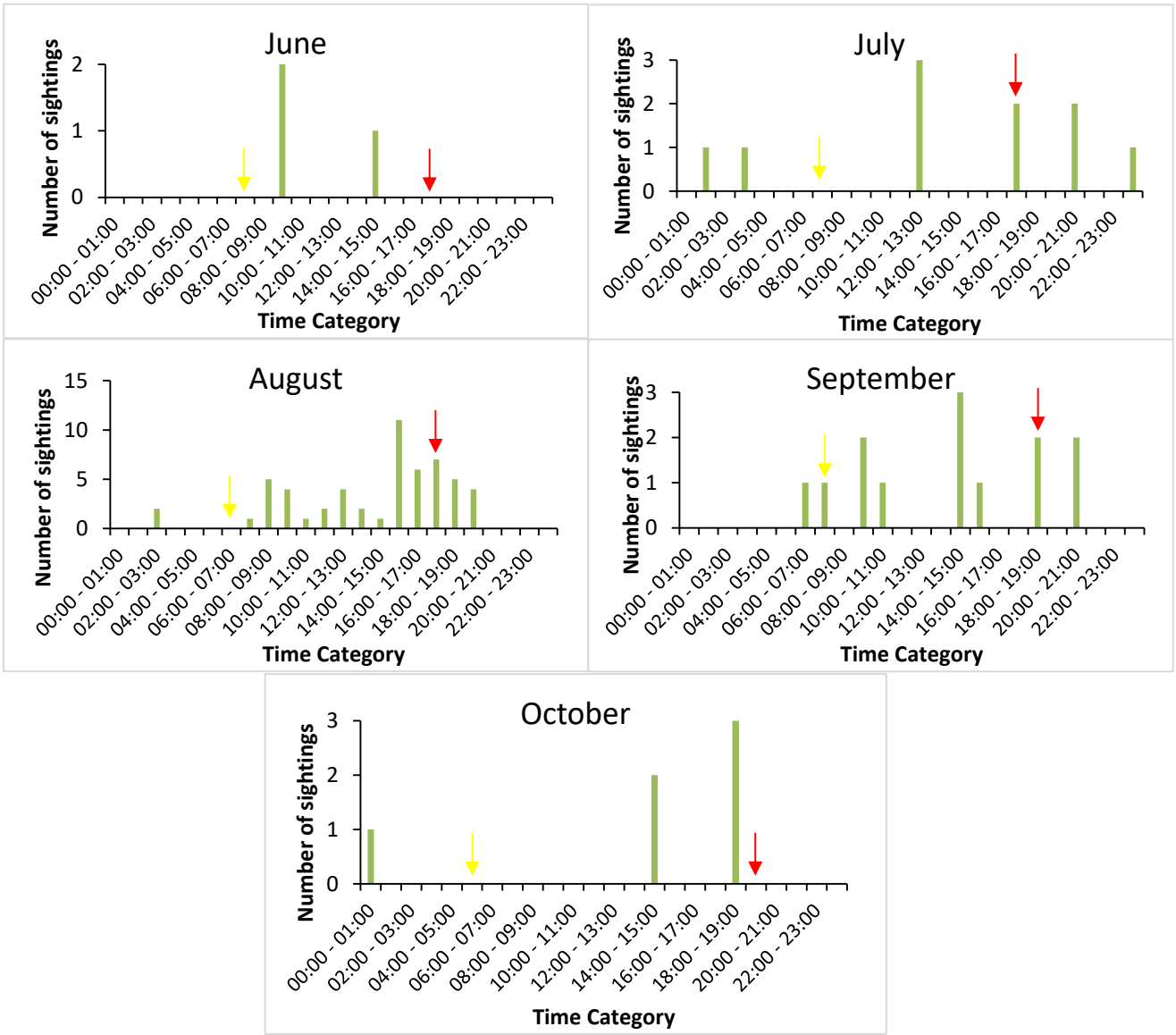


Figure 5. 14: White rhino monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.7.1.3 Family Elephantidae Diurnal Species

5.7.1.3.1 Elephant

Elephant were not sighted at the waterholes every month over the course of the study period, as they were absent in June. However, when sighted, elephant peak activity patterns were predominantly during nocturnal hours (*Figure 5.15*). July, October, and November had peak elephant sightings between 01:00-02:00. November had a peak in elephant sightings between 19:00-20:00 (*Figure 5.15*). September had an activity peak at 02:00–03:00 (*Figure 5.15*), and August's peak was between 12:00-13:00 (midday).

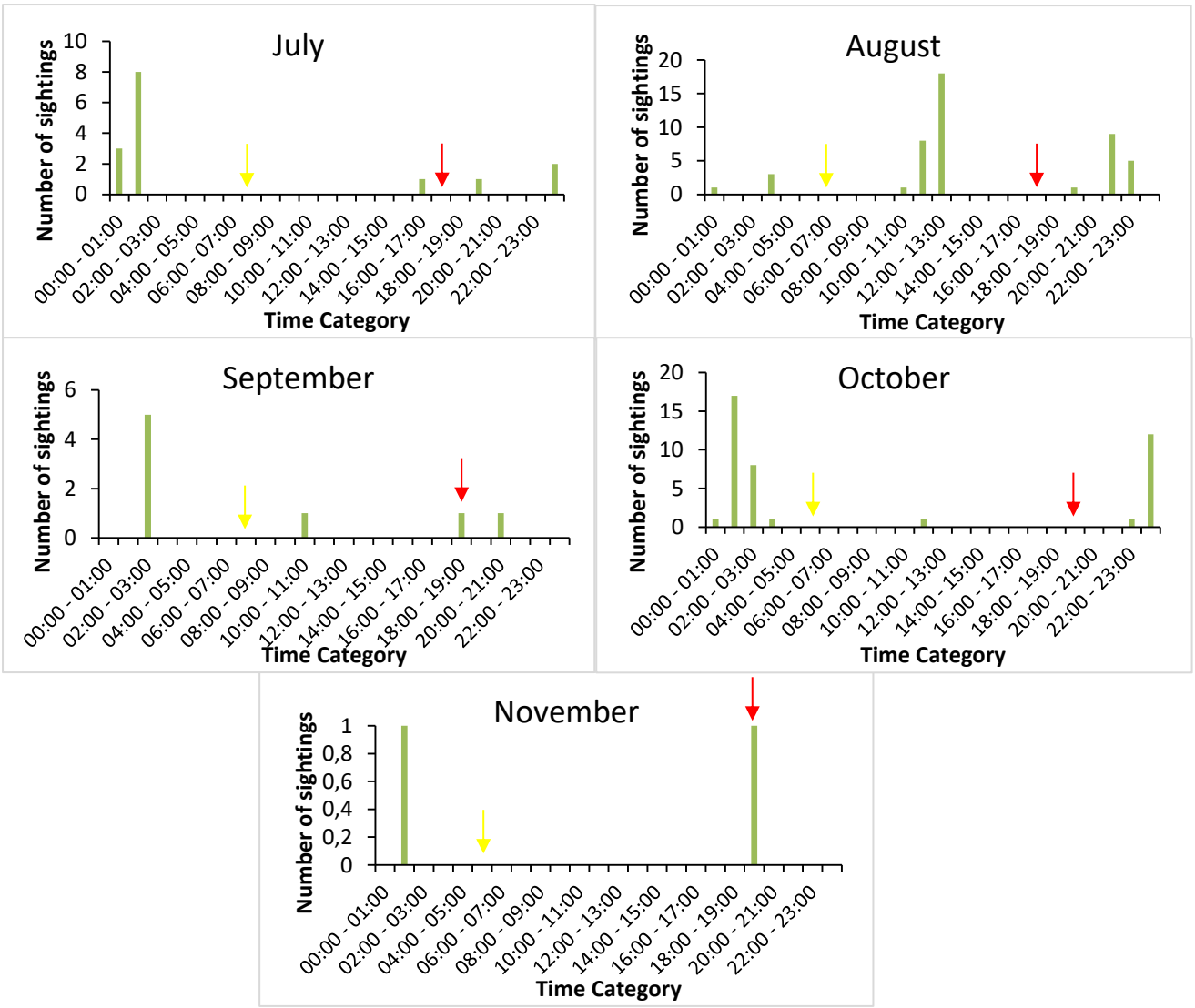


Figure 5. 15: Elephant monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.7.1.4 Family Suidae Diurnal Species

5.7.1.4.1 Warthog

Warthogs were sighted at the waterholes every month over the study period, which showed strictly diurnal visitation patterns and were not sighted during nocturnal hours. In June, warthog had peak sightings between 12:00-13:00 (midday) (*Figure 5.16*). In July and August, this was between 10:00-11:00, and October and November between 07:00-08:00 (*Figure 5.16*). Warthog visitation behaviour follows the cyclical patterns of sunrise and sunset (light availability) at the waterholes (*Table 4.3*).

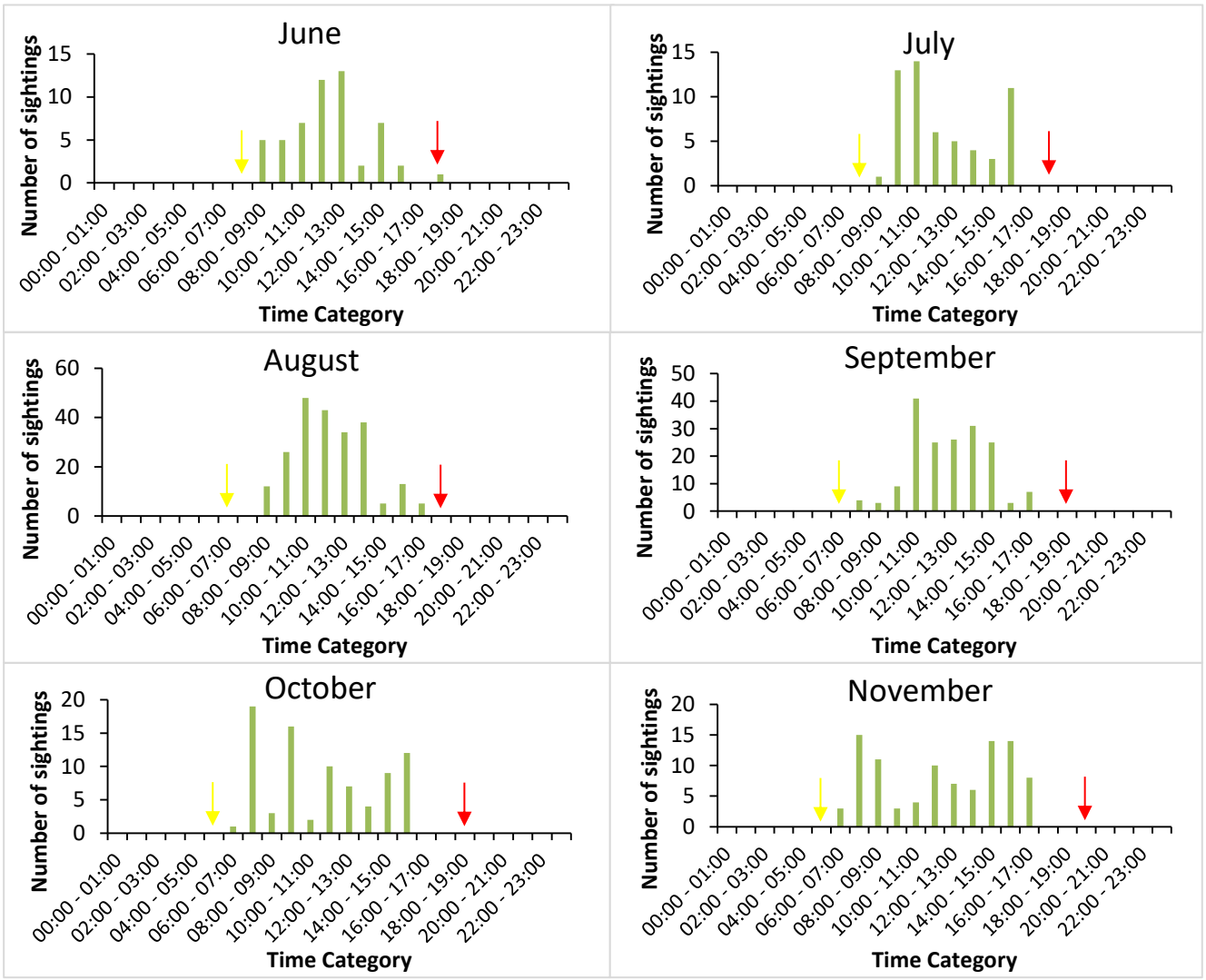


Figure 5. 16: Warthog monthly visitation patterns over the study period. Yellow arrow indicates sunrise, red arrow indicates sunset.

5.8 Statistical Cluster Analysis and Principal Component Analysis (PCA)

5.8.1 Site A

Cluster analysis at site A of all species sighted over the study period was performed. Cluster analysis was based on the visitation times of all species to the waterhole. Species were grouped when the timing of sightings at the waterholes were similar. Scrub hare and common duiker were grouped together as they were sighted during the same visitation times. Hippopotamus and porcupine were also grouped together (*Figure 5.17*). All of these species were grouped into a different sub-group, as they are nocturnal species, and had strictly nocturnal visitation patterns. Honey badger and brown hyena are nocturnal species, but visitation times at the waterhole differed from other nocturnal species (*Figure 5.17*). The statistical cluster dendrogram reveals statistical similarities in visitation times between Burchell's zebra, warthog, impala, and springbok at site A waterhole (*Figure 5.17*). It is evident that there is a clear division in grouping between nocturnal and diurnal species. All species with clear diurnal visitation times were grouped together, which are majority herbivore species. However, there is no clear division between carnivore and herbivore species visitation times, as black-backed jackal had peak sightings at the waterhole during the day, while brown hyena had strictly nocturnal visitation times at the waterhole (*Figure 5.17*).

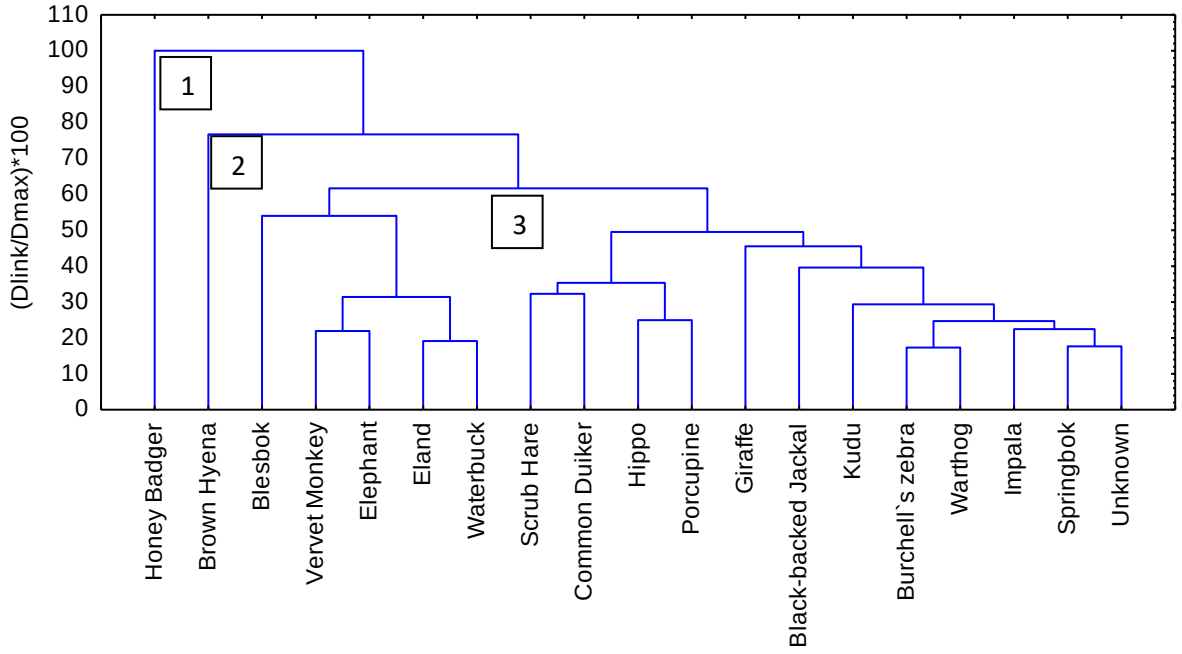


Figure 5. 17: Cluster analysis (dendrogram) of mammal species grouped according to the occurrence times at site A.

Principal component analysis (PCA) was performed on the sightings of species at site A waterhole over the study period. PCA was performed as it is a more statistically significant analysis of the visitation times of the species which occurred at the waterholes, compared to cluster analysis. PC1 is the division between nocturnal and diurnal species. The first separation of PC1 is porcupine, common duiker, brown hyena, scrub hare, and hippopotamus. The second separation in PC1 is honey badger and black-backed jackal (*Figure 5.18*). PC2 is the division of species into different time categories (*Figure 5.18*). The species are thus divided into 5 groups (A–F). Group A includes porcupine, hippopotamus, common duiker, scrub hare, and brown hyena. Group B only includes honey badger. Group C only includes black-backed Jackal. Group D includes waterbuck, eland, elephant, and vervet monkey. Group E only includes giraffe. Group F includes springbok, warthog, impala, Burchell's zebra, kudu, and blesbok (*Figure 5.18*). Black-backed jackal, honey badger, and giraffe are grouped independently as their visitation times have no similarities with other species visitation times at the waterhole; therefore, they are not clustered with other species (*Table 5.8*). Both axes of PC1 and PC2 demonstrate a separation of late morning to afternoon hours (*Figure 5.18*). Group A species are grouped into evening and morning peak visitation times. Group D species are grouped together as their peak visitation times occur in the morning and afternoon (*Table 5.8*). Lastly, group F species were grouped together as the peak visitation times occurred in the afternoon (*Table 5.8*).

Species that are at 90 degrees from one another in the PCA have mutually exclusive visitation times at the waterhole; therefore, they do not visit the waterhole at the same time. The PCA demonstrates that nocturnal species do not visit the waterhole at the same time as diurnal species (*Figure 5.18*). The carnivore black-backed jackal is mutually exclusive to the nocturnal herbivore (prey) species, and the diurnal herbivore species. This is since the carnivore black-backed jackal will not occur at the same time as prey species (*Figure 5.18*). The brown hyena is mutually exclusive to diurnal herbivore (prey) species; however, scrub hare, porcupine, and common duiker have the same visitation times to the brown hyena, as they are nocturnal species (*Figure 5.18*).

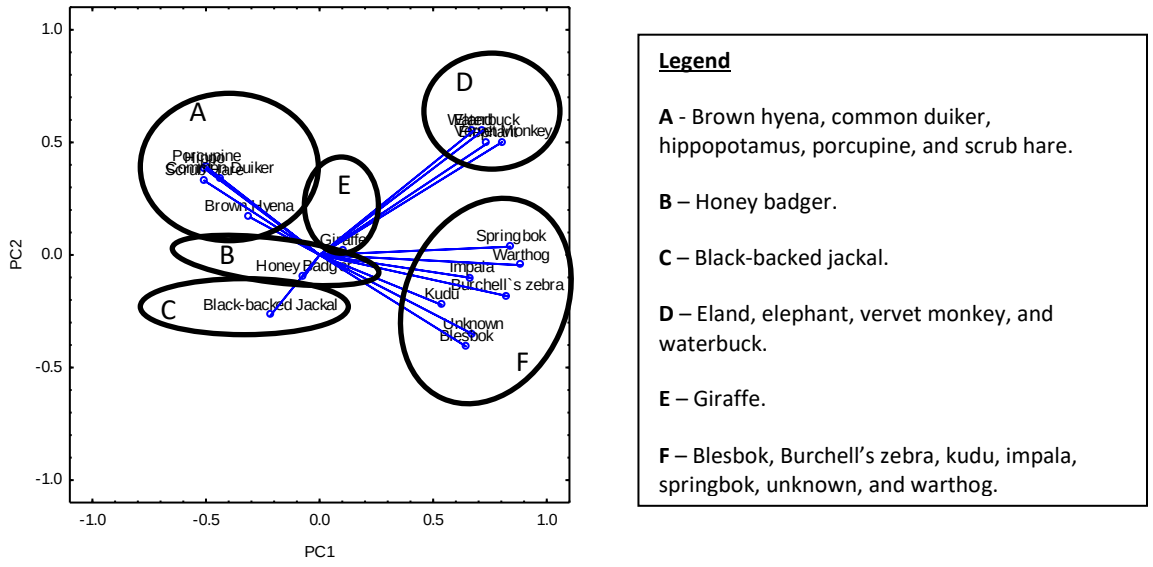


Figure 5. 18: PCA analysis demonstrating time vectors, which drives occurrence of species at site A.

5.8.2 Site B

A cluster analysis was performed for site B waterhole, to determine statistical differences and similarities of species visitation times over the study period of all species sighted at the waterhole. Brown hyena, hippopotamus, and black rhino have similarities in visitation times, as they all have nocturnal visitation patterns at the waterhole. Elephants were grouped with these species as their peak visitation times were during nocturnal hours (*Figure 5.19*). Lion was grouped independently, as lions had no similarities in visitation times with other species. Vervet monkeys and chacma baboons were grouped together (both primates) as they both have strictly diurnal visitation patterns (*Figure 5.19*). Blesbok, springbok, Burchell's zebra, warthog, giraffe, kudu, and impala are grouped together as their peak visitation times are in the afternoon (*Figure 5.19; Table 5.9*). These species which have similar visitation times are all diurnal herbivore species. Blesbok and springbok are grouped, Burchell's zebra and warthog are grouped, giraffe and kudu are grouped together as they have similar visitation times at the waterhole (*Figure 5.19*). Red hartebeest and white rhino are grouped together as they have similar visitation times in the afternoon and morning (*Table 5.9*). Black-backed jackal and common duiker are grouped in the same sub-group as they have similarities in visitation times (*Figure 5.19*). Both these species have similar visitation times during nocturnal hours in the early morning and evening, however the black-backed jackal has peak visitation patterns during the day, whereas, the common duiker has strictly nocturnal visitation patterns (*Figure 5.19*). Eland have no similarities in visitation patterns with other species, and therefore were grouped independently (*Figure 5.19*).

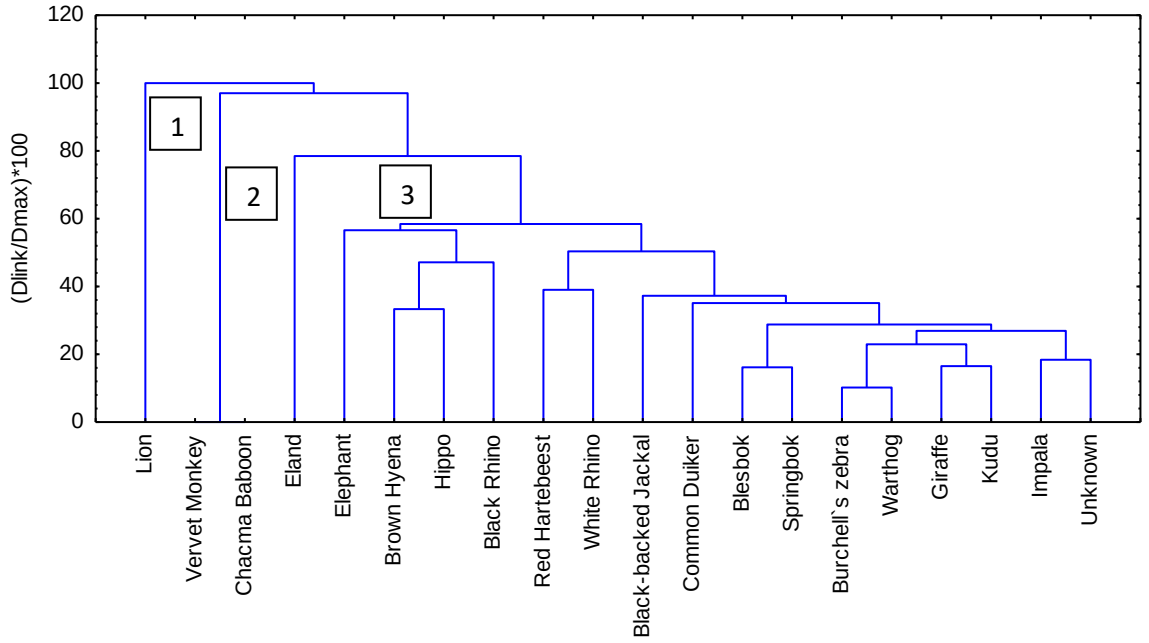


Figure 5. 19: Cluster analysis (dendrogram) of mammal species grouped according to the occurrence times at site B.

Principal component analysis (PCA) was performed of all species sighted at site B waterhole over the study period. PC1 is the division of diurnal and nocturnal groups. The first separation is group A which includes black-backed jackal, blesbok, white rhino, red hartebeest, eland, springbok, and impala. These species are grouped together as their peak visitation times occur in the afternoon and late afternoon (*Figure 5.20 & Table 5.9*). Group B consists of giraffe, warthog, Burchell's zebra, and kudu (*Figure 5.20*). These species were sighted at the waterhole in the morning and afternoon, therefore were grouped because of similar visitation times. Group C includes vervet monkey and chacma baboon. Both these primates have the same peak visitation times at the waterhole in the afternoon between 13:00-14:00 (*Table 5.9*). Group D are all nocturnal species, with the exception of elephant and hippopotamus. These species were grouped together as peak visitation patterns occurred in the evening and morning at the waterhole (*Table 5.9*). Lion and brown hyena are both carnivores and have the same visitation times at the waterhole in the evening, as they are both nocturnal species (*Figure 5.20*). Carnivore species (lion and brown hyena) are 90 degrees to herbivore (prey) species, except for common duiker as it is a nocturnal species, thus, they have mutually exclusive visitation patterns at the waterhole. The PC1 first separation are all diurnal species and the second separation are all nocturnal species. All diurnal and nocturnal species are mutually exclusive from one other; therefore, they do not visit the waterhole at the same time

(*Figure 5.20*). White rhino and elephants are mutually exclusive to each other; therefore, they do not visit the waterhole at the same time.

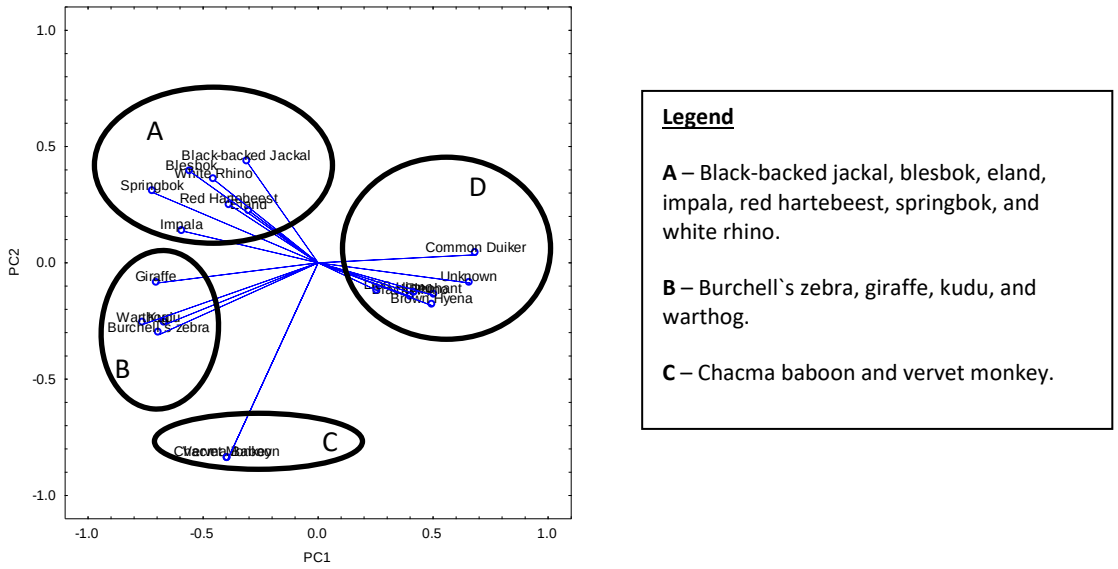


Figure 5. 20: PCA analysis demonstrating time vectors, which drives occurrence of species at site B.

5.8.3 Site C

A cluster analysis was preformed of the visitation times for all species sighted at site C waterhole, to determine the similarities and differences in visitation times of these species. Honey badger and black-backed jackal are grouped together as they have similar nocturnal visitation times. Springbok and chacma baboon are grouped together as they have similar diurnal visitation times. Hippopotamus and bat-eared fox are grouped together as they have similar nocturnal visitation times (*Figure 5.21*). Brown hyena are grouped independently as they have no similar visitation times to other species sighted at site C. Elephant, black rhino, porcupine, bushbuck, and common duiker are grouped together as their peak visitation times at the waterholes occur during nocturnal hours (*Figure 5.21*). Elephant and black rhino are grouped together as their peak visitation is in the evening and morning (nocturnal hours). Bushbuck and common duiker are grouped together as they have similar visiting times in the evening and early morning (*Figure 5.21*). Scrub hare and giraffe are grouped together, scrub hare are strictly nocturnal, whereas, giraffe have no preference but have similar peak visitation times as the scrub hare at site C. Diurnal species are grouped into two sub-groups (*Figure 5.21*). Gemsbok, warthog, kudu, impala, and Burchell's zebra are grouped together and red hartebeest, waterbuck, and white rhino are all grouped together. Gemsbok, warthog, kudu, impala, and Burchell's zebra are grouped together as their peak visitation times occurs in the

afternoon. Whereas, red hartebeest, white rhino, and waterbuck are grouped together as their peak visitation times occurred in the late afternoon (*Figure 5.21 & Table 5.10*).

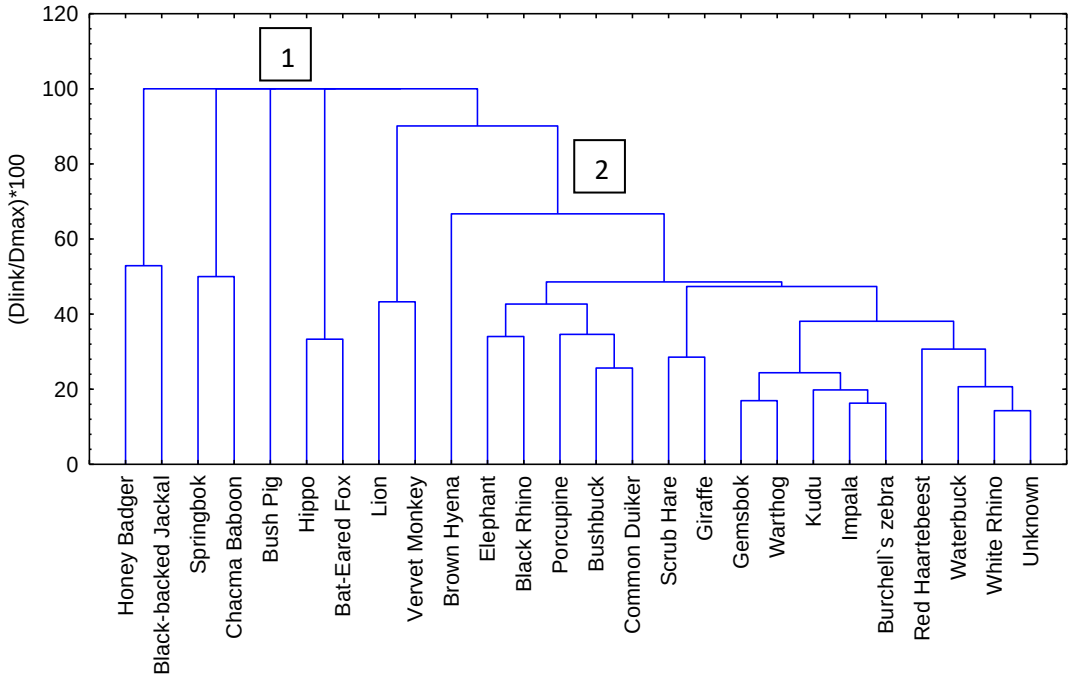
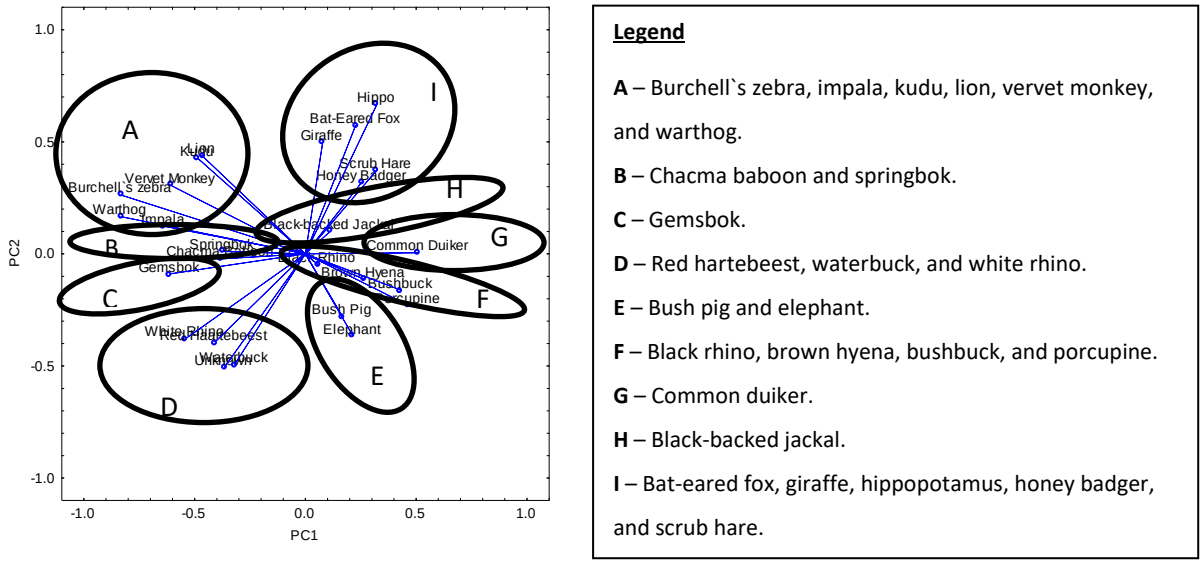


Figure 5. 21: Cluster analysis (dendrogram) of mammal species grouped according to the occurrence times at site C.

Principal component analysis (PCA) was performed for all species sighted at site C waterhole over the study period. PC1 separates nocturnal and diurnal species at the waterhole. The first separations are the diurnal species and the second separations are all the nocturnal species, with an exception of lion that was sighted during diurnal hours. Each cluster was grouped (A–I) according to their peak visitation times at the waterhole. Group A consists of lion, kudu, vervet monkey, Burchell's zebra, warthog, and impala (*Figure 5.22*). These species are grouped together as their peak visitation times occurred in the afternoon (*Table 5.10*). Group B include springbok and chacma baboon as these species had the same visitation times between 12:00-13:00. Gemsbok was grouped independently in group C as their peak visitation times ranges from morning, afternoon, and late afternoon, predominantly in the afternoon (*Table 5.10*). Group D includes white rhino, red hartebeest, and waterbuck (*Figure 5.22*). These species are grouped together as their peak visitation times occurred in the late afternoon (*Table 5.10*). Group E includes elephant and bush pig (*Figure 5.22*). These species are grouped together as their peak visitation times occurred in the evening (*Table 5.10*). Group F includes bushbuck, porcupine, brown hyena, and black rhino as these species occurred at the waterhole during similar times (*Figure 5.22*). These species are all grouped together as they are

nocturnal species and were sighted in the evening and morning (*Table 5.10*). The common duiker was grouped independently in group G (*Figure 5.22*), as it did not have similar visitation times to the other species that were sighted at the waterhole. The common duiker had peak visitation times in the evening and morning (*Table 5.10*). Group H only includes the black-backed jackal as this species peak visitation times were throughout the day in the morning, afternoon, and evening (*Table 5.10*). Group I includes hippopotamus, bat-eared fox, giraffe, scrub hare, and honey badger as these species are grouped together as their peak visitation times are all during nocturnal hours (*Figure 5.22*). These species are grouped as their peak visitation times occurred in the late evening and in the morning (*Table 5.10*).

Elephant, white rhino, hippopotamus, and giraffes which are all megaherbivores are all mutually exclusive from one other (90 degrees from each other), therefore they do not occur at the waterhole at the same time (*Figure 5.22*). The brown hyena was mutually exclusive from all diurnal herbivore (prey) species. Lion, however, were not mutually exclusive to herbivore species, as lion occurred during diurnal hours at site C (*Figure 5.22*). All diurnal species are mutually exclusive to nocturnal species at the waterhole. Kudu, vervet monkey, elephant, and waterbuck are exceptions as they are not 90 degrees from nocturnal species. Elephants, giraffe, and kudu, however, are excluded form nocturnal and diurnal analysis, as they have peak visitation times both diurnally and nocturnally hours (*Figure 5.22*).



Legend

A – Burchell`s zebra, impala, kudu, lion, vervet monkey, and warthog.

B – Chacma baboon and springbok.

C – Gemsbok.

D – Red hartebeest, waterbuck, and white rhino.

E – Bush pig and elephant.

F – Black rhino, brown hyena, bushbuck, and porcupine.

G – Common duiker.

H – Black-backed jackal.

I – Bat-eared fox, giraffe, hippopotamus, honey badger, and scrub hare.

Figure 5. 22: PCA analysis demonstrating time vectors, which drives occurrence of species at site C.

Table 5. 8: Percentage of each species sightings during the morning, afternoon, and evening at site A. Percentage peaks are highlighted: dark orange (peak hour), orange (second highest peak hour) and lighter orange (third highest peak hour). Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Peak	Time Category	Black-Backed Jackal	Blesbok	Brown Hyena	Burchell`s Zebra	Common Duiker	Eland	Elephant	Giraffe	Hippopotamus	Honey Badger	Impala	Kudu	Porcupine	Scrub Hare	Springbok	Vervet Monkey	Warthog	Waterbuck	Unknown
Morning	00:00 - 01:00	11.11	0.00	50.00	0.00	9.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	1.01
	01:00 - 02:00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.00	100.00	10.74	0.00	10.00	0.00	0.57	0.00	0.00	0.00	3.03
	02:00 - 03:00	0.00	0.00	0.00	0.00	0.00	0.00	16.22	0.00	0.00	0.00	10.74	0.00	10.00	0.00	0.00	0.00	0.00	0.00	6.06
	03:00 - 04:00	0.00	0.00	0.00	0.00	18.18	0.00	2.70	0.00	16.67	0.00	0.00	0.00	20.00	12.50	0.00	0.00	0.00	0.00	1.01
	04:00 - 05:00	11.11	0.00	0.00	0.00	9.09	0.00	0.00	3.23	16.67	0.00	0.00	0.00	10.00	25.00	0.00	0.00	0.00	0.00	0.00
	05:00 - 06:00	0.00	0.00	0.00	0.00	9.09	16.67	0.00	0.00	0.00	0.00	12.40	0.00	0.00	0.00	1.15	0.00	0.00	2.50	5.05
	06:00 - 07:00	0.00	0.00	0.00	0.00	0.00	11.11	0.00	0.00	0.00	0.00	1.65	13.33	0.00	0.00	1.15	0.00	0.00	0.00	2.02
	07:00 - 08:00	0.00	0.00	0.00	0.00	0.00	11.11	0.00	0.00	0.00	0.00	2.48	13.33	0.00	0.00	5.17	0.00	5.38	10.00	5.05
	08:00 - 09:00	11.11	0.00	0.00	16.02	0.00	0.00	0.00	3.23	0.00	0.00	4.96	16.67	0.00	0.00	10.92	0.00	2.15	0.00	3.03
Afternoon	09:00 - 10:00	22.22	13.33	0.00	9.39	0.00	0.00	0.00	0.00	0.00	0.00	8.26	3.33	0.00	0.00	6.90	0.00	9.68	0.00	8.08
	10:00 - 11:00	0.00	40.00	0.00	19.89	0.00	0.00	5.41	3.23	0.00	0.00	6.61	16.67	0.00	0.00	10.34	0.00	15.05	2.50	15.15
	11:00 - 12:00	0.00	33.33	0.00	24.31	0.00	0.00	13.51	3.23	0.00	0.00	14.05	0.00	0.00	0.00	7.47	22.22	19.35	0.00	11.11
	12:00 - 13:00	0.00	13.33	0.00	22.10	0.00	38.89	48.65	0.00	0.00	0.00	14.88	13.33	0.00	0.00	18.97	55.56	21.51	40.00	7.07
	13:00 - 14:00	0.00	0.00	0.00	4.42	0.00	16.67	0.00	32.26	0.00	0.00	0.00	3.33	0.00	0.00	11.49	11.11	9.68	22.50	9.09
	14:00 - 15:00	0.00	0.00	0.00	0.55	0.00	0.00	0.00	22.58	0.00	0.00	0.00	6.67	0.00	0.00	0.00	11.11	11.83	0.00	2.02
Late Afternoon	15:00 - 16:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.23	0.00	0.00	0.83	0.00	0.00	0.00	12.07	0.00	4.30	12.50	3.03
	16:00 - 17:00	11.11	0.00	0.00	0.00	0.00	5.56	2.70	0.00	0.00	0.00	3.31	13.33	0.00	0.00	0.57	0.00	1.08	5.00	0.00
	17:00 - 18:00	11.11	0.00	0.00	1.66	0.00	0.00	0.00	3.23	0.00	0.00	1.65	0.00	0.00	0.00	5.17	0.00	0.00	0.00	2.02
Evening	18:00 - 19:00	11.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67	0.00	4.96	0.00	0.00	0.00	4.02	0.00	0.00	5.00	2.02
	19:00 - 20:00	0.00	0.00	0.00	0.00	9.09	0.00	2.70	16.13	16.67	0.00	2.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01
	20:00 - 21:00	11.11	0.00	50.00	1.66	0.00	0.00	0.00	0.00	16.67	0.00	0.00	0.00	20.00	12.50	0.00	0.00	0.00	0.00	4.04
	21:00 - 22:00	0.00	0.00	0.00	0.00	0.00	0.00	5.41	0.00	0.00	0.00	0.00	0.00	10.00	12.50	1.15	0.00	0.00	0.00	0.00
	22:00 - 23:00	0.00	0.00	0.00	0.00	18.18	0.00	0.00	0.00	16.67	0.00	0.00	0.00	20.00	0.00	1.15	0.00	0.00	0.00	1.01
	23:00 - 24:00	0.00	0.00	0.00	0.00	27.27	0.00	0.00	9.68	0.00	0.00	0.00	0.00	0.00	12.50	1.72	0.00	0.00	0.00	8.08

Table 5. 9: Percentage of each species sightings during the morning, afternoon, and evening at site B. Percentage peaks are highlighted: dark orange (peak hour), orange (second highest peak hour) and lighter orange (third highest peak hour). Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Peak	Time Category	Black-backed Jackal	Black Rhino	Blesbok	Brown Hyena	Burchell's Zebra	Chacma baboon	Common Duiker	Eland	Elephant	Giraffe	Hippopotamus	Impala	Kudu	Lion	Red Hartebeest	Springbok	Vervet Monkey	Warthog	White Rhino	Unknown
Morning	00:00 - 01:00	0.00	0.00	0.00	0.00	0.79	0.00	6.90	0.00	9.43	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.50
	01:00 - 02:00	0.00	0.00	0.00	33.33	0.00	0.00	6.90	0.00	47.17	0.00	0.00	1.53	1.61	0.00	0.00	0.17	0.00	0.00	0.00	11.88
	02:00 - 03:00	8.33	0.00	0.00	0.00	0.00	0.00	17.24	0.00	13.21	0.00	0.00	2.63	0.00	0.00	0.00	0.17	0.00	0.00	0.00	6.88
	03:00 - 04:00	16.67	0.00	0.00	0.00	0.00	0.00	17.24	0.00	0.00	0.00	0.00	0.00	3.23	0.00	0.00	0.17	0.00	0.00	0.00	5.63
	04:00 - 05:00	0.00	0.00	0.00	0.00	0.00	0.00	6.90	0.00	0.00	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.38
	05:00 - 06:00	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.84	0.00	3.50	0.00	0.00	0.00	0.34	0.00	0.00	0.00	7.50
	06:00 - 07:00	0.00	0.00	5.33	0.00	0.00	0.00	3.45	0.00	0.00	5.88	0.00	7.88	3.23	0.00	23.08	2.92	0.00	1.26	0.00	4.38
	07:00 - 08:00	33.33	0.00	2.46	0.00	0.00	0.00	0.00	93.75	0.00	19.61	0.00	7.88	17.74	0.00	0.00	5.32	0.00	5.44	10.00	1.88
	08:00 - 09:00	8.33	0.00	1.23	0.00	3.17	0.00	0.00	6.25	0.00	9.80	0.00	4.38	3.23	0.00	0.00	4.97	0.00	5.86	0.00	1.25
Afternoon	09:00 - 10:00	0.00	0.00	1.64	0.00	16.67	0.00	0.00	0.00	0.00	15.69	0.00	5.03	4.84	0.00	0.00	5.83	0.00	14.23	20.00	2.50
	10:00 - 11:00	0.00	0.00	0.82	0.00	15.08	0.00	0.00	0.00	0.00	1.96	0.00	9.41	1.61	0.00	38.46	4.97	0.00	19.67	0.00	1.88
	11:00 - 12:00	0.00	0.00	0.41	0.00	11.11	0.00	0.00	0.00	0.00	0.00	0.00	3.50	9.68	0.00	0.00	6.17	0.00	10.04	0.00	2.50
	12:00 - 13:00	0.00	0.00	6.56	0.00	2.38	0.00	0.00	0.00	0.00	9.80	0.00	2.63	4.84	0.00	0.00	17.84	0.00	6.69	0.00	3.75
	13:00 - 14:00	0.00	0.00	3.69	0.00	14.29	100.00	0.00	0.00	0.00	13.73	0.00	6.13	16.13	0.00	0.00	5.32	100.00	13.81	0.00	1.25
	14:00 - 15:00	8.33	0.00	18.03	0.00	7.94	0.00	0.00	0.00	0.00	9.80	0.00	2.19	6.45	0.00	38.46	15.44	0.00	10.46	50.00	1.88
Late Afternoon	15:00 - 16:00	0.00	0.00	11.07	0.00	8.73	0.00	0.00	0.00	0.00	0.00	0.00	5.91	3.23	0.00	0.00	0.86	0.00	8.79	0.00	1.25
	16:00 - 17:00	0.00	0.00	21.72	0.00	5.56	0.00	0.00	0.00	0.00	1.96	0.00	5.91	11.29	0.00	0.00	10.29	0.00	3.77	0.00	2.50
	17:00 - 18:00	25.00	0.00	19.67	0.00	9.52	0.00	0.00	0.00	0.00	1.96	0.00	13.79	1.61	0.00	0.00	12.35	0.00	0.00	0.00	3.75
Evening	18:00 - 19:00	0.00	0.00	6.97	0.00	0.00	0.00	3.45	0.00	0.00	1.96	0.00	7.66	3.23	0.00	0.00	5.49	0.00	0.00	20.00	1.88
	19:00 - 20:00	0.00	0.00	0.41	0.00	0.00	0.00	10.34	0.00	0.00	0.00	0.00	2.19	0.00	0.00	0.00	0.34	0.00	0.00	0.00	0.63
	20:00 - 21:00	0.00	0.00	0.00	0.00	0.00	0.00	10.34	0.00	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	2.50
	21:00 - 22:00	0.00	0.00	0.00	33.33	0.00	0.00	3.45	0.00	0.00	0.00	33.33	0.00	8.06	0.00	0.00	0.17	0.00	0.00	0.00	8.75
	22:00 - 23:00	0.00	33.33	0.00	33.33	0.00	0.00	10.34	0.00	1.89	0.00	33.33	1.53	0.00	0.00	0.00	0.34	0.00	0.00	0.00	1.88
	23:00 - 24:00	0.00	33.33	0.00	0.00	4.76	0.00	3.45	0.00	26.42	0.00	0.00	6.13	0.00	100.00	0.00	0.34	0.00	0.00	0.00	11.88

Table 5. 10: Percentage of each species sightings during the morning, afternoon, and evening at site C. Percentage peaks are highlighted: dark orange (peak hour), orange (second highest peak hour) and lighter orange (third highest peak hour). Sunrise times are highlighted in yellow, sunset times are highlighted in red over the study period.

Peak	Time Category	Bat-Eared Fox	Black Backed-Jackal	Black Rhino	Brown Hyena	Burchell`s Zebra	Bush Buck	Bush Pig	Chacma Baboon	Common Duiker	Elephant	Gemsbok	Giraffe	Hippopotamus	Honey Badger	Impala	Kudu	Lion	Porcupine	Red Hartebeest	Scrub Hare	Springbok	Vervet Monkey	Warthog	Waterbuck	White Rhino	Unknown
Morning	00:00 – 01:00	0.00	0.00	50.00	0.00	0.00	7.14	0.00	0.00	5.88	0.00	0.00	0.00	0.00	0.00	2.11	0.00	0.00	9.09	0.00	0.00	0.00	0.00	0.00	0.00	1.25	4.88
	01:00 – 02:00	0.00	0.00	0.00	75.00	2.11	0.00	0.00	0.00	2.94	0.00	0.00	0.00	0.00	0.00	1.05	0.00	0.00	27.27	0.00	14.29	0.00	0.00	0.00	0.00	1.25	4.88
	02:00 – 03:00	0.00	0.00	0.00	0.00	0.00	7.14	0.00	0.00	1.47	0.00	7.69	0.00	0.00	0.00	0.00	0.00	0.00	27.27	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00
	03:00 – 04:00	0.00	0.00	0.00	25.00	0.00	7.14	0.00	0.00	2.94	13.64	0.00	0.00	0.00	0.00	5.26	0.69	0.00	9.09	0.00	0.00	0.00	0.00	0.00	0.00	1.25	3.66
	04:00 – 05:00	0.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00	14.71	0.00	0.00	14.29	33.33	100.00	3.16	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22
	05:00 – 06:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88	0.00	0.00	0.00	0.00	0.00	3.16	0.00	0.00	0.00	0.00	14.29	0.00	0.00	0.00	0.00	0.00	2.44
	06:00 – 07:00	0.00	0.00	0.00	0.00	8.42	0.00	0.00	0.00	2.94	0.00	0.00	28.57	0.00	0.00	11.58	0.00	0.00	0.00	0.00	28.57	0.00	0.00	0.38	0.00	1.25	1.22
	07:00 – 08:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.88	0.00	15.38	14.29	0.00	0.00	1.05	6.90	0.00	0.00	0.00	14.29	0.00	0.00	5.73	0.00	1.25	4.88
	08:00 – 09:00	0.00	0.00	0.00	0.00	10.53	0.00	0.00	0.00	0.00	0.00	0.00	28.57	0.00	0.00	13.68	3.45	0.00	0.00	14.29	0.00	0.00	0.00	6.49	14.29	6.25	6.10
Afternoon	09:00 – 10:00	0.00	0.00	0.00	0.00	3.16	0.00	0.00	0.00	1.47	0.00	15.38	0.00	0.00	0.00	3.16	4.83	0.00	0.00	14.29	0.00	0.00	0.00	7.63	10.00	7.50	6.10
	10:00 – 11:00	0.00	0.00	0.00	0.00	25.26	7.14	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	6.32	17.93	100.00	0.00	0.00	0.00	0.00	50.00	15.65	0.00	2.50	2.44
	11:00 – 12:00	0.00	0.00	0.00	0.00	9.47	0.00	0.00	0.00	0.00	18.18	7.69	0.00	0.00	0.00	10.53	8.97	0.00	0.00	14.29	0.00	0.00	25.00	17.56	1.43	6.25	8.54
	12:00 – 13:00	0.00	0.00	0.00	0.00	12.63	0.00	0.00	100.00	0.00	0.00	7.69	0.00	0.00	0.00	9.47	7.59	0.00	0.00	0.00	0.00	50.00	0.00	13.74	2.86	8.75	7.32
	13:00 – 14:00	0.00	0.00	0.00	0.00	3.16	0.00	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	3.16	3.45	0.00	0.00	0.00	0.00	0.00	0.00	12.98	0.00	2.50	2.44
	14:00 – 15:00	0.00	0.00	0.00	0.00	8.42	0.00	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	6.32	4.83	0.00	0.00	0.00	0.00	50.00	0.00	6.11	2.86	2.50	2.44
Late Afternoon	15:00 – 16:00	0.00	40.00	0.00	0.00	2.11	0.00	0.00	0.00	0.00	0.00	15.38	0.00	0.00	0.00	5.26	0.00	0.00	0.00	0.00	0.00	0.00	25.00	9.92	10.00	15.00	6.10
	16:00 – 17:00	0.00	0.00	0.00	0.00	3.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	0.69	0.00	0.00	0.00	0.00	0.00	0.00	3.44	1.43	7.50	0.00
	17:00 – 18:00	0.00	0.00	0.00	0.00	11.58	0.00	0.00	0.00	0.00	0.00	7.69	0.00	0.00	0.00	5.26	4.14	0.00	0.00	42.86	0.00	0.00	0.00	0.38	27.14	11.25	8.54
Evening	18:00 – 19:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.29	4.55	0.00	0.00	0.00	0.00	5.26	6.21	0.00	0.00	14.29	0.00	0.00	0.00	0.00	4.29	10.00	1.22
	19:00 – 20:00	0.00	0.00	0.00	0.00	0.00	7.14	0.00	0.00	22.06	9.09	0.00	0.00	0.00	0.00	0.00	8.28	0.00	9.09	0.00	14.29	0.00	0.00	0.00	20.00	5.00	7.32
	20:00 – 21:00	0.00	0.00	0.00	0.00	0.00	21.43	0.00	0.00	14.71	0.00	0.00	0.00	0.00	0.00	0.00	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	7.32
	21:00 – 22:00	0.00	0.00	16.67	0.00	0.00	14.29	100.00	0.00	2.94	31.82	0.00	0.00	0.00	0.00	0.00	6.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.71	0.00	7.32
	22:00 – 23:00	0.00	20.00	16.67	0.00	0.00	21.43	0.00	0.00	1.47	22.73	0.00	0.00	0.00	0.00	2.11	0.00	0.00	18.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22
	23:00 – 24:00	100.00	0.00	16.67	0.00	0.00	7.14	0.00	0.00	4.41	0.00	0.00	14.29	66.67	0.00	0.00	13.10	0.00	0.00	0.00	14.29	0.00	0.00	0.00	0.00	1.25	2.44

5.9 Temperature and Faunal Activity

Fauna in southern Africa are often exposed to conditions of increased temperature, due to climate and weather changes (Davidson *et al*., 2013). This makes research relevant for species-specific water requirements, as temperature influences how regularly a species utilises waterholes for either drinking or wallowing (Owen-Smith, 2002; Gosling, 2003; Woodroffe, 2003; Hannah *et al*., 2007; Chaine & Clobert, 2012; van Wilgen *et al*., 2015).

The daily number of species sighted at the waterhole was plotted against T_{avg} experienced daily over the study period. This was done to determine if there was a relationship between temperature and the number of species sighted at the waterholes (*Figure 5.23*). As temperature increases there is a decrease in faunal sightings at the waterhole (*Figure 5.23*). When temperature is at its lowest there is a decrease in faunal sightings at the waterholes (*Figure 5.23*). However, it is relevant to note that lowest sightings may correspond with the time of day rather than temperature, thus, a more in-depth (hourly) analysis is necessary. The time series indicates a decrease in the number of faunal sightings over the course of the study period (*Figure 5.23*). T_{avg} shows an increase in temperature over the study period (*Figure 5.23*).

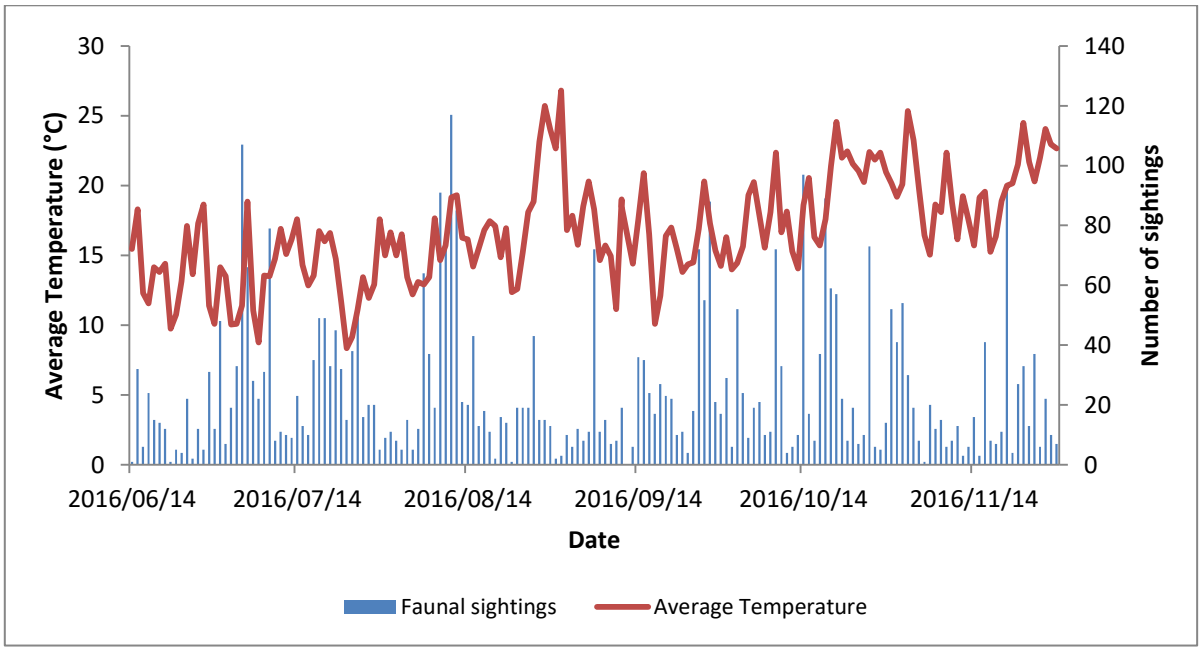


Figure 5. 23: Total number of daily faunal sightings in relation to average temperature at waterholes over the study period.

Pearson's correlation coefficients were used to determine a relationship between daily T_{avg}, T_{max}, and T_{min}, and the daily total of all fauna sighted at the waterholes over the study period. A positive correlation indicates that as temperature increases, the number of fauna sighted at the waterholes increases and a negative correlation indicates that as temperature increases the number of fauna

sighted at the waterholes decreases. T_{avg} and T_{max} show an increase in faunal sightings with the increase in temperature, but this is a very weak relationship (*Table 5.11*). However, with T_{avg} there is no significant relationship ($p > 0.05$) between temperature and faunal sightings, but there is a significant relationship ($p < 0.05$) between T_{max} and the number of faunal sightings (*Table 5.11*). T_{min} indicates that as T_{min} increases there is a decrease in faunal sightings at the waterholes, which shows a statistically significant relationship ($p < 0.05$) (*Table 5.11*). Therefore, as temperatures decrease so does the faunal sightings at the waterholes.

Table 5. 11: Pearson's correlation coefficient of temperature (T_{avg}, T_{max}, and T_{min}) in relation to the number of fauna sighted at the waterholes over the study period. Negative correlations are marked in green. Statistically significant correlations are marked by asterisk (*).

Temperature	Average Temperature	Maximum Temperature	Minimum Temperature
Pearson`s correlation coefficient	0.06	*0.18	*-0.17

5.9.1 Temperature and Faunal Activity of Each Species

Water requirements are different for every species, either water-dependent, or less-water-dependent based on how regularly species need water to either drink or wallow. Temperature influences how regularly species utilise the waterholes, which makes research into species-specific water requirements important (Owen-Smith, 2002; Gosling, 2003; Woodroffe, 2003; Hannah *et al*., 2007; Chaine & Clobert, 2012; van Wilgen *et al*., 2015). As stated in *section 5.7,* some species that were sighted at the waterholes had small visitation frequencies, and therefore these species were excluded from the analysis.

Springbok show an increase in the number of sightings at the waterholes when temperatures (T_{avg}, T_{max}, & T_{min}) increased (*Figure 5.24*). There appears to be a decrease in kudu, Burchell's zebra, white rhino, and warthog sightings at the waterholes when the temperature increased. However, Burchell's zebra, white rhino, elephant, and warthog appear to have peak sightings at the waterholes in August, when the temperature peaked (T_{max}). Elephants have a peak in the number of sightings in October when temperature started to increase (*Figure 5.24*).

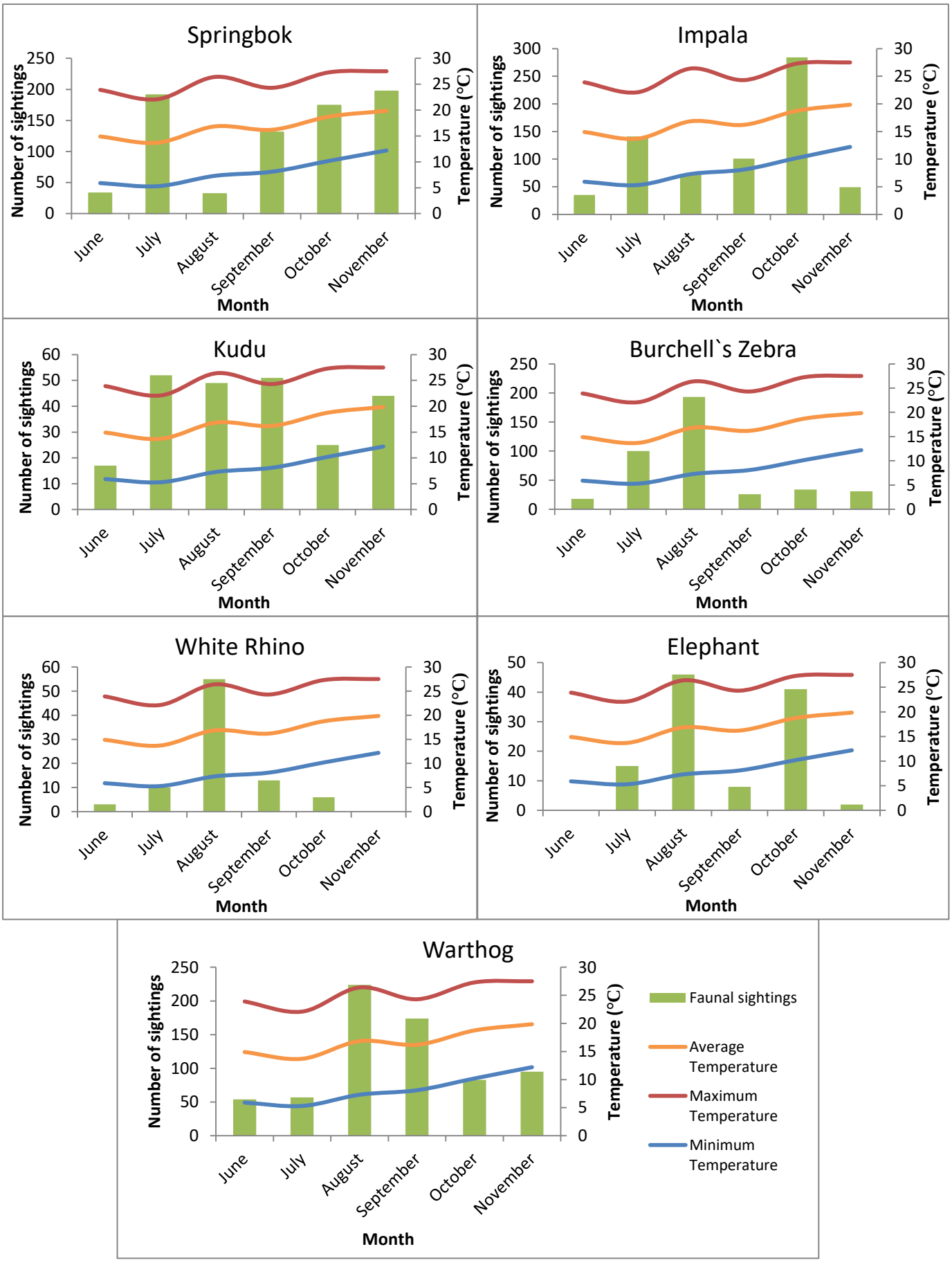


Figure 5. 24: Monthly average of number of sightings for individual species in relation to the monthly T_{avg}, T_{max}, and T_{min} over the study period.

Pearson correlation coefficients were used to determine whether there was a positive or negative correlation with the number of sightings per species and temperature (T_{avg}, T_{max}, and T_{min}). Weak positive correlations exist between T_{avg} and the number of elephant, impala, springbok, and warthog sightings (*Table 5.12*). A weak positive correlation exists between T_{max} and the number of Burchell's zebra, elephant, impala, springbok, warthog, and white rhino sightings (*Table 5.12*). Lastly, a weak positive correlation exists between T_{min} and the number of elephant, impala, springbok, and warthog sightings (*Table 5.12*). However, these positive correlations did not show any statistical significance. Weak negative correlations exist between T_{avg} and the number of elephant, impala, springbok, and warthog sightings (*Table 5.12*). A weak negative correlation exists between T_{max} and the number of kudu sightings at the waterholes. Lastly, there is a weak negative correlation between T_{min} and the number of Burchell's zebra, kudu, and white rhino sightings (*Table 5.12*). However, these negative correlations show no statistical significance.

Table 5. 12: Correlation of monthly number of sightings and temperature (T_{avg}, T_{max}, and T_{min}) and rainfall (mm). Negative correlations are highlighted in green. Statistically significant correlations are marked by an asterisk (*).

Species	Average Temperature	Maximum Temperature	Minimum Temperature	Rainfall
Burchell's zebra	-0,19	0,00	-0,34	0,14
Elephant	0,21	0,40	0,03	0,03
Impala	0,19	0,19	0,18	0,37
Kudu	-0,10	-0,18	-0,03	0,60
Springbok	0,32	0,08	0,49	0,52
Warthog	0,18	0,30	0,07	-0,10
White rhino	-0,09	0,13	-0,27	-0,05

5.10 Rainfall and Faunal Activity

The dominant climatic factor which influences faunal behaviour in the African environment is rainfall (Ogutu *et al*. 2008). Rainfall affects food availability for species, making rainfall patterns important for natural food production (Chamaillé-Jammes *et al*., 2007a; Ogutu *et al*., 2008; Owen-Smith, 2008; Davies *et al*., 2012; Hawkins *et al*., 2013). According to Hawkins *et al*. (2003), rainfall has a stronger correlation to species diversity and richness when compared to temperature, therefore rainfall has a stronger influence on faunal visitation patterns at the waterholes. The time series over the study period reveals that both rainfall and the number of faunal sightings are decreasing (*Figure 5.25*). The time series indicates that as rainfall increases, there is a decrease in the number of faunal sightings at the waterholes (*Figure 5.25*). Pearson's correlation coefficient was completed to determine if a

negative or positive correlation exists between rainfall and the number of faunal sightings at the waterholes. A very weak negative correlation (r=-0.018, p > 0.05) exists between rainfall (mm) and the number of faunal sightings, however, this was not statistically significant (p > 0.05). In the time series a pattern is evident, when there are large quantities of rainfall (mm) there is a lagged peak in the number of fauna sighted after these rainfall events at the waterholes (*Figure 5.25*).

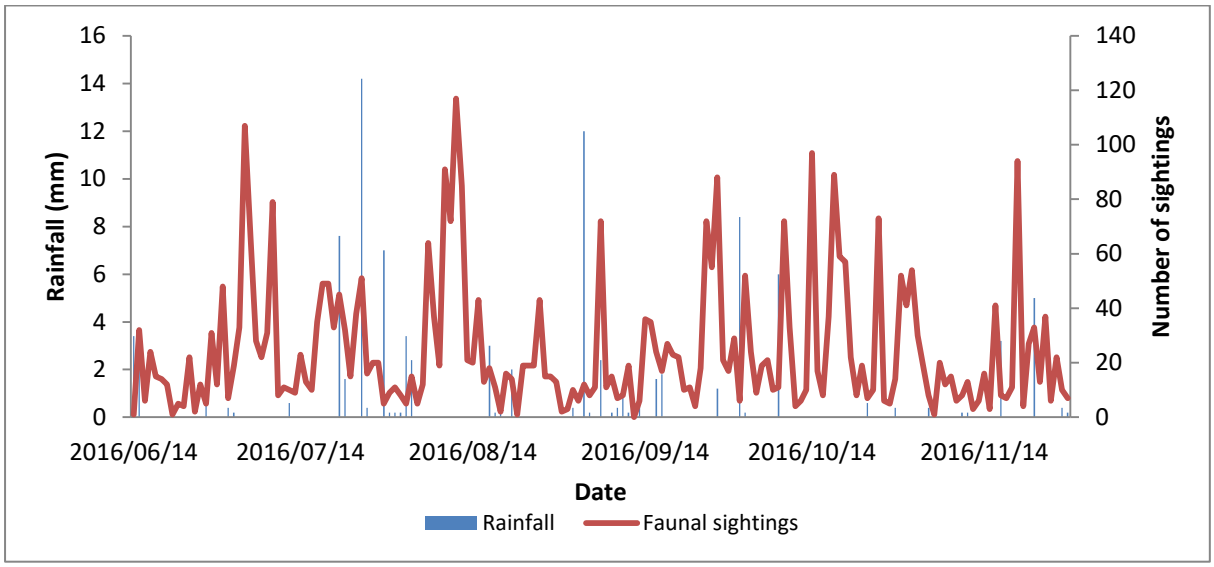


Figure 5. 25: Total number of faunal sightings in relation to rainfall (mm) at waterholes over the study period.

5.10.1 Rainfall and Faunal Activity of Each Species

As stated in *sections 5.7* and *5.9.1*, some species sighted at the waterholes had low visitation frequencies, and were excluded from analysis. Results indicate that when peak rainfall occurs in July (32.4 mm), there is a peak in the number of springbok (n=119) and kudu (n=52) sightings at the waterholes (*Figure 5.26*). Burchell's zebra (n=193), white rhino (n = 55), elephant (n = 46), and warthog (n=224) all show peaks in August, a month after the largest quantity of rainfall fell (August experienced low quantities of rainfall at 12 mm) (*Figure 5.26*). Elephant (n=41) showed a peak in October, a month after a peak quantity of rainfall (22.2 mm) (*Figure 5.26*). Lastly, when there were small quantities of rainfall (June, October, and November), there is a decrease in the number of Burchell's zebra, white rhino, and warthog (*Figure 5.26*). Impala had a peak in the number of sightings in October, a month after a peak in rainfall in September, but also showed a peak in the number of sightings in July when there was a peak in rainfall quantity. Therefore, there is no clear relationship between rainfall and impala sightings at the waterholes (*Figure 5.26*).

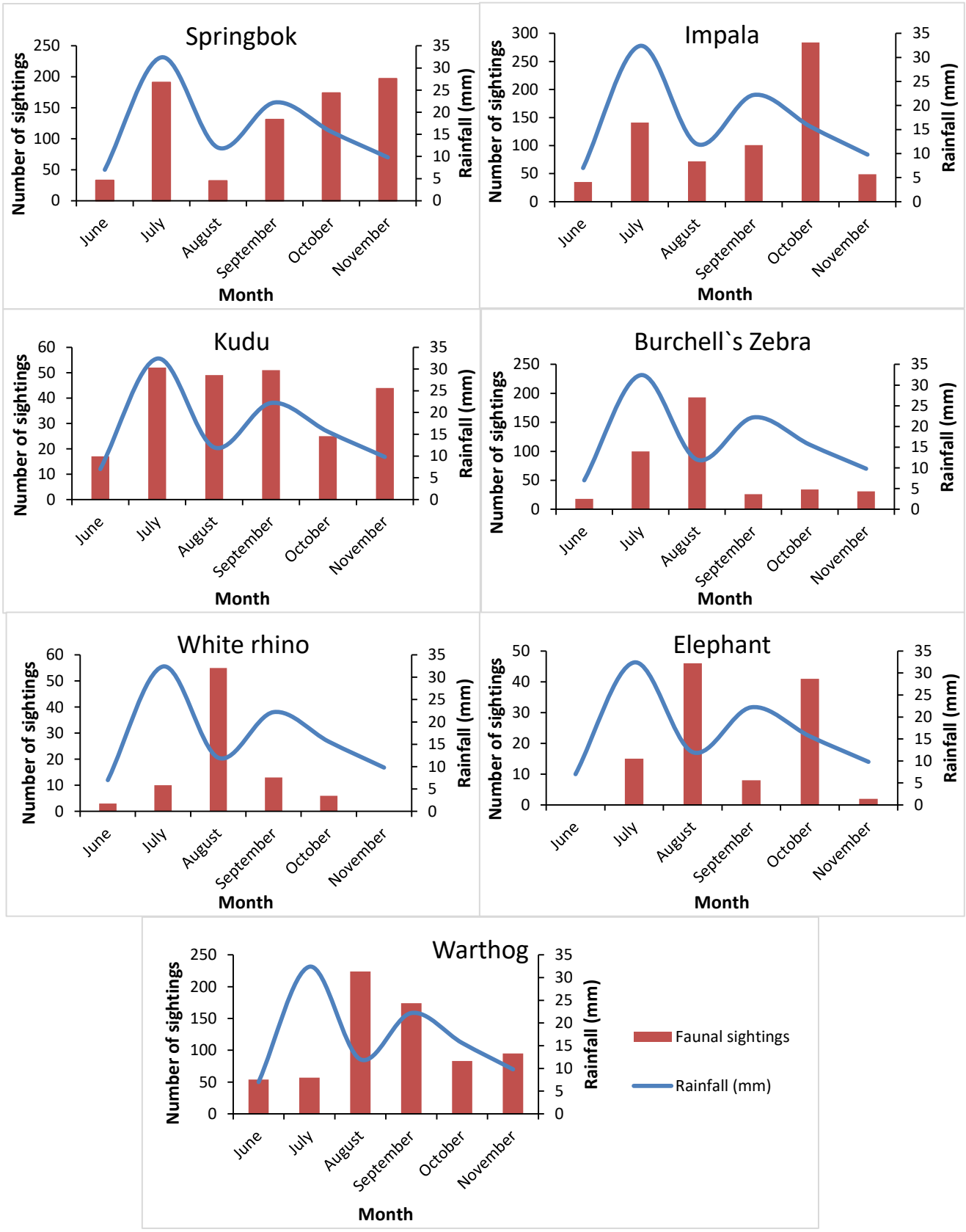


Figure 5. 26: Monthly average of number of sightings for individual species and the monthly rainfall (mm) over the study period.

Pearson correlation coefficients were used to determine whether there was a positive or negative correlation with the number of sightings per species and rainfall (mm). A positive correlation indicates that as rainfall (mm) increases the number of fauna sighted at the waterholes increases, and a negative correlation indicates that as rainfall (mm) increases the number of fauna sighted at the waterholes decreases. A weak positive correlation exists between Burchell's zebra, elephant, and impala sightings and rainfall (mm) (*Table 5.12*). A moderate positive correlation exists between kudu and springbok sightings and rainfall (mm) (*Table 5.12*). A weak negative correlation exists between warthog and white rhino sightings and rainfall (mm) (*Table 5.12*). However, the correlations have no statistical significance ($p > 0.05$) (*Table 5.12*).

5.10.2 Faunal Activity in Relation to Rainfall Events

A lag between the number of faunal sightings at the waterholes and rainfall (mm) is apparent in *Figure 5.25*, therefore analysing different rainfall events and the number of faunal sightings was necessary. Days were divided into different groups (two days before, one day before, on the day, one day after and two days after rainfall events); this was conducted to determine when peak faunal sightings at the waterholes occurred in relation to rainfall events. The least number of faunal sightings at the waterhole occurred before rainfall events, in particular two days before (n=269) rainfall events (*Table 5.13*). On the day of rainfall events, there were the greatest faunal sightings (n=781) at the waterholes (*Table 5.13*). After the rainfall events, depending on the quantity of rainfall, there was a decline in faunal sightings (*Table 5.13*). Therefore, a relationship between faunal sightings and rainfall at the waterholes does exist, but this relationship is not statistically significant (*Figure 5.27*).

Table 5. 13: Total faunal sightings in association with rainfall events at the waterhole over the study period. Asterisk (*) has been marked on the largest number of sightings per species.

Days before or after rainfall event	Faunal sightings
Two days before	269
One day before	411
On the day	*781
One day after	467
Two days after	494

A cross-correlation analysis was conducted to determine whether there was a lagged correlation between faunal sightings and rainfall at the waterholes over the study period (*Figure 5.27*). Lag numbers from 0 to -7 were ignored in this analysis, as this would be predicted faunal sightings at the waterhole, before rainfall events even occur. The cross-correlation indicates a 2-week lag (cross

correlation function [CCF]) in faunal sightings at the waterholes after rainfall events (*Figure 5.27*). Therefore, the number of faunal sightings increases 2 weeks after a rainfall event, but this is not statistically significant (CCF < 0.5) (*Figure 5.27*). Thus, post-rainfall surface water availability has a greater influence on the number faunal sightings at the waterholes compared to rainfall (mm).

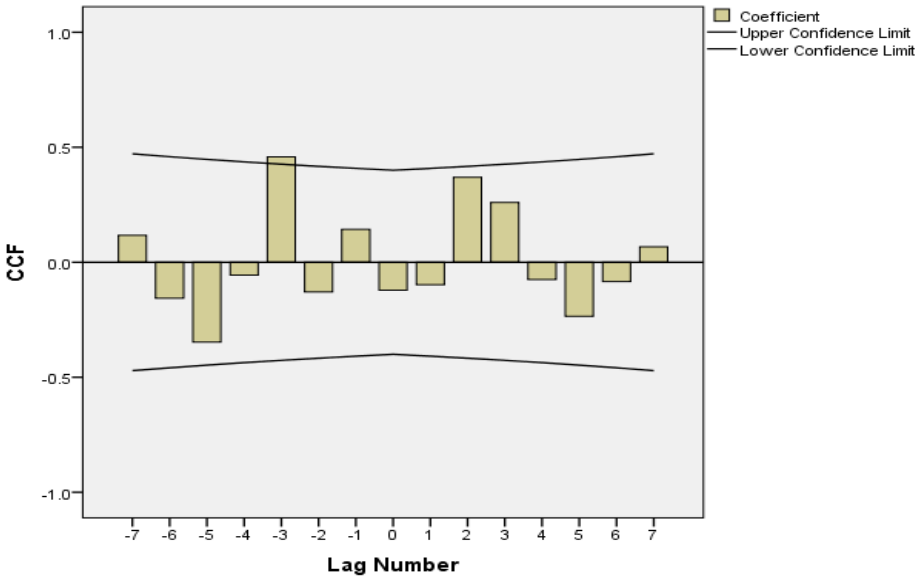


Figure 5. 27: Cross-correlation between rainfall and faunal sightings at the waterholes over the study period.

5.10.3 Faunal Activity in Relation to Rainfall Quantity

Rainfall quantity (mm) influences the amount of surface water that is available in the waterholes and the surrounding areas, for faunal species to utilise. At the waterholes there were more faunal sightings between 1-9 mm (n=3994) of rainfall, than 10-19 mm (n=119) (*Table 5.14*). As there were more rainfall events which fell into the category of 1-9 mm rainfall quantity (n=43) than 10-19 mm (n=2) (*Table 5.14*). 1-9 mm and 10-19 mm were the only rainfall categories explored as no rain fell > 19 mm. However, when comparing averages (the number of faunal sightings within each rainfall category), more faunal sightings occurred at the waterhole with 10-19 mm (average = 23.80) even with its small dataset (*Table 5.14*). Therefore, higher rainfall volumes resulted in an increase in the number of faunal sightings at the waterholes, as there are greater quantities of surface water available for species to utilise. A longer-temporal study is needed to determine how an increase in rainfall quantity > 19 mm influences the number of faunal sightings at the waterholes.

Table 5. 14: Total faunal sightings at the waterhole in relation to rainfall quantity (mm) over the study period.

Rainfall quantity (mm)	Number of faunal sightings	Average number of sightings per rainfall event	Number of rainfall events
1 - 9	3994	24.35	43
10 - 19	119	23.80	2

5.11 Faunal Activity and Surface Water Availability

The presence of surface water influences the number of species present in a given habitat (Williams & Wells, 1986). Both the occurrence of water-dependent and less water-dependent species at water sources are influenced by the availability of surface water (Trent, 2012, 2016). The time series of site A waterhole indicates a significant positive correlation with the number of faunal sightings and surface water availability ($r=0.015$; $p < 0.05$) (*Figure 5.28*). Therefore, as surface water increases, there is an increase in the number of faunal sightings at the waterhole. However, in the time series there are also peaks in the number of faunal sightings at the waterhole, when the waterhole is dry (*Figure 5.28*).

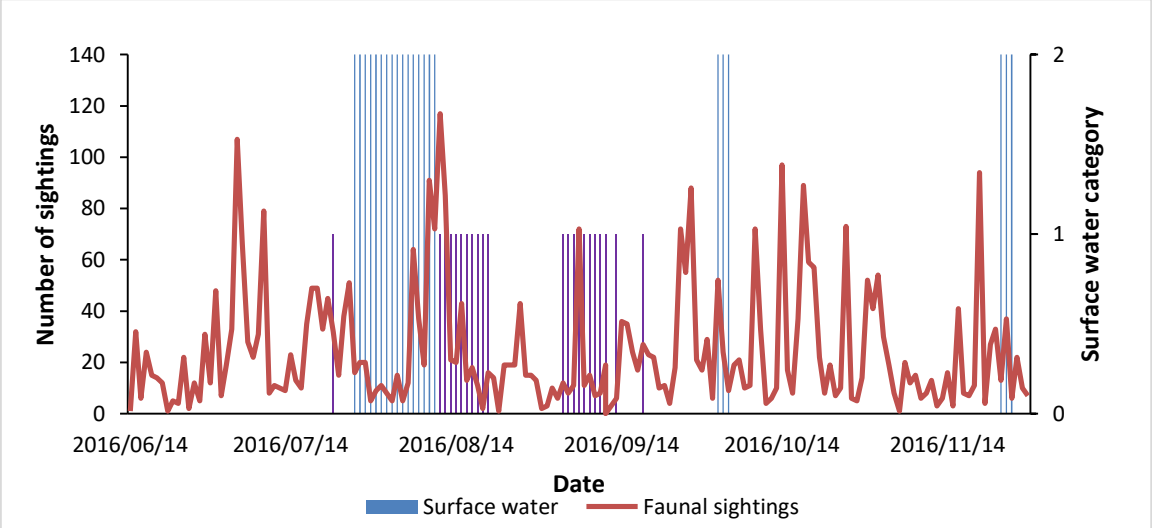


Figure 5. 28: Total number of faunal sightings in relation to surface water available at site A waterhole over the study period. Different surface water categories are represented by 0=Dry, 1=Muddy (purple), 2=Water (blue).

The time series of site B waterhole indicates a significant negative correlation with the number of faunal sightings and surface water available in the waterhole ($r= -0.17$; $p < 0.05$) (*Figure 5.29*). As the surface water increases, there is a decrease in the number of faunal sightings at the waterhole. This could be a consequence of increased surface water available throughout Shamwari in temporary pools, after large quantities of rainfall (*Figure 5.29*). The time series, however, reveals a peak in the

number of faunal sightings at the waterhole when it was dry, and a significant decrease in faunal sightings when there was surface water available, except in September (*Figure 5.29*).

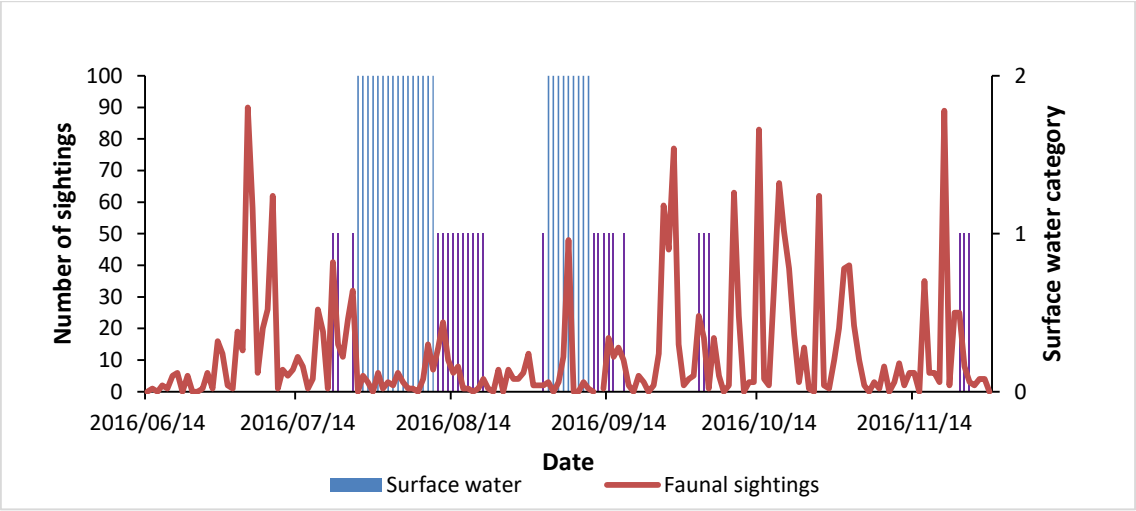


Figure 5. 29: Total number of faunal sightings in relation to surface water available at site B waterhole over the study period. Different surface water categories are represented by 0=Dry, 1=Muddy (purple), 2=Water (blue).

The times series of site C waterhole indicates a significant positive correlation with the number of faunal sightings and surface water available ($r=0.31$; $p < 0.05$) (*Figure 5.30*). Therefore, as surface water increases, the number of faunal sightings increases. The time series reveals a peak in faunal sightings when surface water had a muddy consistency in the waterhole. It displays that there was an increase (peak) in faunal sightings when there was water and mud present compared to when the waterhole was dry, which differs from the other two waterholes (*Figure 5.30*).

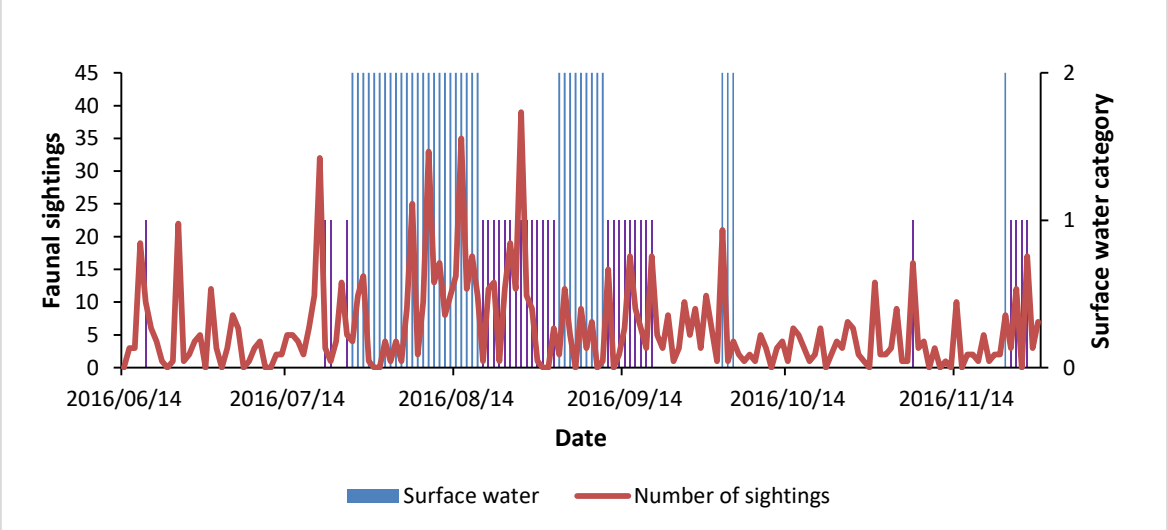


Figure 5. 30: Total number of faunal sightings in relation to surface water available at site C waterhole over the study period. Different surface water categories are represented by 0=Dry, 1=Muddy (purple), 2=Water (blue).

5.12 Peak Wallowing Activity

Wallowing is the coating of an animal's body surface with mud, a mud-like substance, or water (Jarman, 1972; Bigwood, 2011; Bracke, 2011; Vanschoenwinkel *et al*., 2011). For the purpose of this investigation, a wallowing event was considered when elephants, white rhino, and warthogs enter the waterholes and cover their body surface with mud, other substances (dust), or water (Jarman, 1972; Bigwood, 2011; Bracke, 2011; Vanshoenwinkel *et al*., 2011). Elephants are known to spray mud, dust, or water onto themselves (Jarman, 1972), which can be conducted outside waterholes, therefore this was excluded as a wallowing event. Thus, comparable wallowing events (entering the waterhole and rolling in mud, other substances, and water) are explored for all three species.

Analysis of hourly wallowing activity for each wallowing species (elephant, white rhino, and warthog) was conducted to determine when peak wallowing activity took place. Warthog preformed wallowing activity at all the waterholes in this investigation. Warthog had peak wallowing activity at site A between 12:00-14:00 and at site B between 11:00-12:00 (*Figure 5.31*). Wallowing activity at both these sites occurred during the afternoon, whilst temperatures were at their peak. At site C, wallowing activity of warthog occurred between 15:00-16:00 (late afternoon) (*Figure 5.31*). Site C had the highest number of wallowing events of warthog (n=7) compared to sites A (n=6) and B (n=5). Wallowing events of elephants were only sighted at site A (n=11), in this investigation. Elephant peak wallowing activity took place between 12:00-13:00 when temperatures were at their peak (*Figure 5.31*). Wallowing events of white rhino were sighted at sites B and C. White rhino peak wallowing activity (n=2) at site B occurred between 14:00–15:00 (afternoon) (*Figure 5.31*). Wallowing events (n=3) of white rhino were distributed throughout diurnal hours at site C waterhole. Peak wallowing activity of white rhino occurred between 08:00-09:00 (morning), 13:00-14:00 (afternoon), and 16:00-17:00 (late afternoon) (*Figure 5.31*). Therefore, determining the hour in which white rhino prefer to wallow was inconclusive. At site A there is no significant difference ($p > 0.05$) between elephant and warthog wallowing activity, as peak wallowing activity occurred during similar times. Sites A and B both showed no significant difference ($p > 0.05$) between warthog and white rhino wallowing activity at the waterholes. In addition, all wallowing events occurred during diurnal hours and no wallowing activity occurred during nocturnal hours.

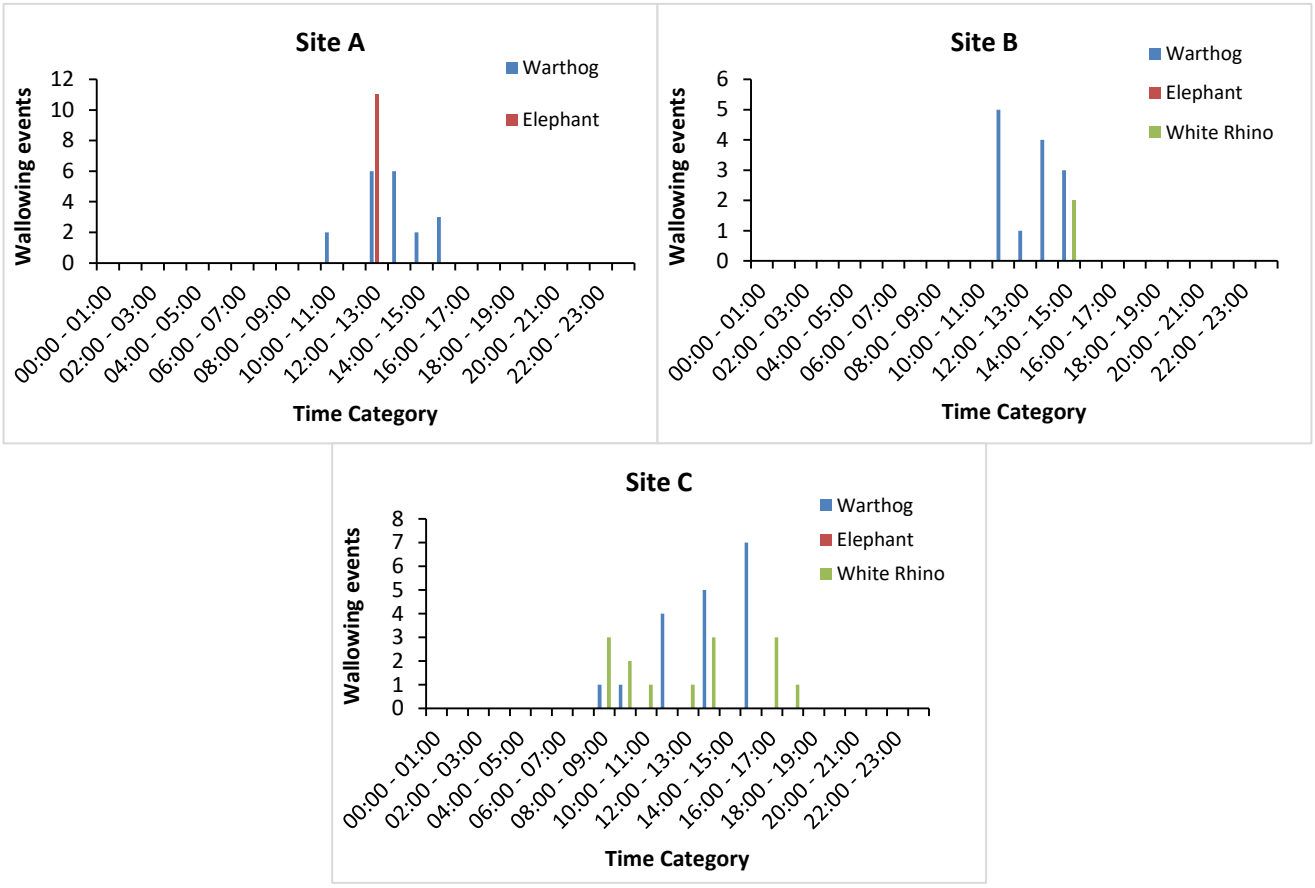


Figure 5. 31: Peak wallowing activity at each site over the study period.

5.13 Statistical Cluster Analysis and Principal Component Analysis (PCA)

5.13.1 Cluster Analysis

A cluster analysis was performed of the wallowing activity of elephant, white rhino, and warthog at the waterholes, to determine the similarities and differences in wallowing activity over the study period. Elephants were grouped independently as wallowing activity only occurred at site A (*Figure 5.31*) between 12:00-13:00 (*Figure 5.32*). White rhino and warthog were grouped together as their wallowing activity occurred at similar times at the waterholes (*Figures 5.31 & 5.32*).

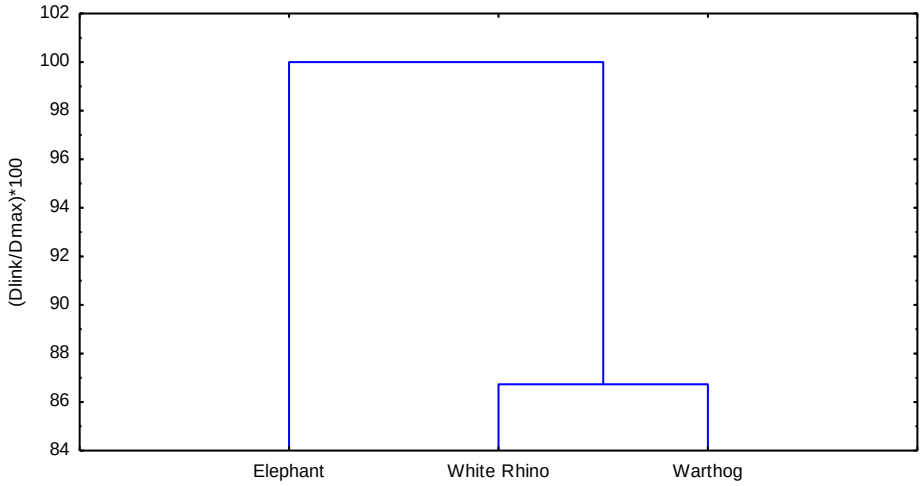


Figure 5. 32: Cluster analysis (dendrogram) of wallowing activity at waterholes over the study period.

5.13.2 Principal Component Analysis (PCA)

A principal component analysis (PCA) was conducted to determine whether there were similarities or differences in wallowing activity of elephants, white rhino, and warthogs. Each wallowing species was grouped (A–C) into independent clusters, as the wallowing activity of these three species differ (*Figure 5.33*). Group A only consists of elephant wallowing activity, as wallowing events of elephants only took place at midday at site A waterhole (*Figures 5.31 & 5.33*). Warthogs are in group B as their wallowing activity ranges from the early morning to late afternoon, warthog peak wallowing activity takes place in the afternoon (*Figures 5.31 & 5.33*). Group C consists of white rhino; white rhino are clustered independently as wallowing activity ranges from the late morning to late afternoon. Predominantly, white rhino wallowing activity takes place in the late afternoon which differs from both elephant and warthog (*Figures 5.31 & 5.33*).

Elephant and white rhino wallowing activity are mutually exclusive from one another, as elephants and white rhino are grouped 90 degrees from each other. Therefore, these two species will not appear or wallow at the waterholes at the same time (*Figure 5.33*). Warthog wallowing activity is not mutually exclusive to elephants and white rhino. Therefore, warthogs will be present at the waterhole at the same time as elephants and white rhino. Furthermore, warthog wallowing activity can occur at the same time as elephants and white rhino (*Figure 5.33*).

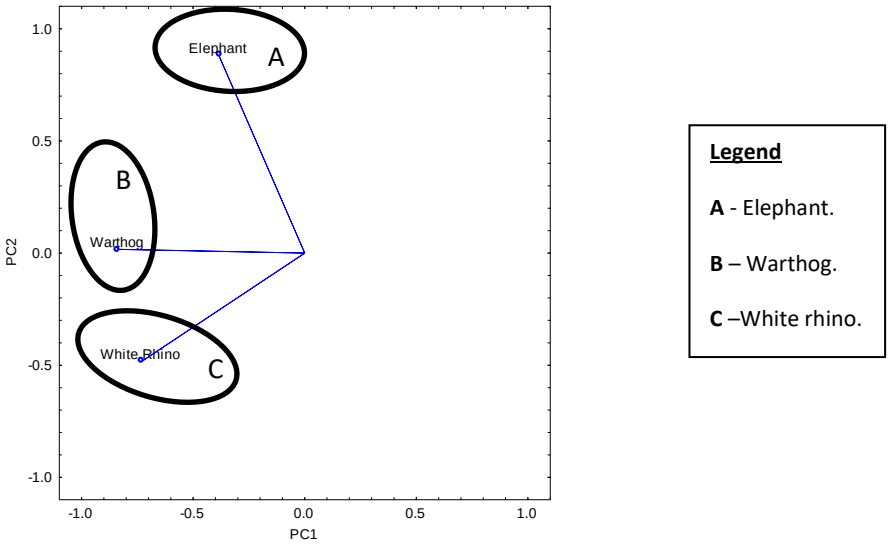


Figure 5. 33: PCA analysis demonstrating time vectors, which drives wallowing activity at all sites for wallowing species over the study period.

5.14 Monthly Wallowing Activity

Wallowing activity differs monthly for elephants, white rhino, and warthogs at the waterholes. Warthog had the most wallowing events in September (n=19) and August (n=15) (*Figure 5.34*). Warthogs had wallowing events in June (n=2), October (n=1), and November (n=11). Elephant were only sighted wallowing in August (n=11) and white rhino were sighted wallowing in August (n=13) and September (n=2) (*Figure 5.34*). August consisted of the most wallowing events (n=39) compared to all other months over the study period. June (n=2) and October (n=1) had very few events and July had no wallowing events (*Figures 5.28, 5.29, 5.30, 5.34*).

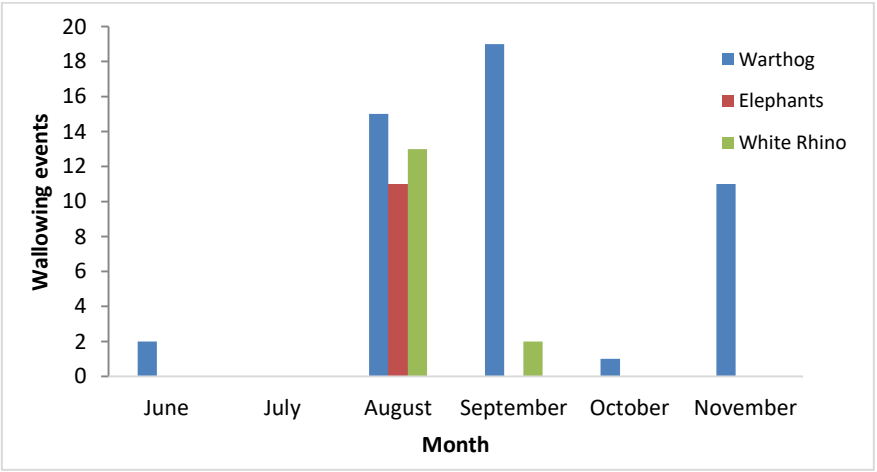


Figure 5. 34: Total monthly wallowing activity at the waterholes over the study period.

Monthly wallowing activity was analysed to determine if there was a shift in monthly wallowing activity over the study period. Wallowing activity of warthogs predominantly occurred in the afternoon. In August, wallowing activity of warthogs occurred at midday, whilst at site C wallowing activity occurred between 08:00-09:00 (morning) and 13:00–14:00 (afternoon) (*Figure 5.35*). In October, no wallowing activity occurred at site A, whilst wallowing activity occurred between 12:00-15:00 (midday) at site B and between 15:00-16:00 (late afternoon) at site C (*Figure 5.35*). Lastly, in November, wallowing activity of warthogs was observed at site A and not at sites B and C, wallowing activity shifted earlier in the day between 10:00-11:00 (morning) (*Figure 5.35*). The only wallowing activity observed by elephants occurred at site A in August between 12:00-13:00 (midday) (*Figure 5.35*). No wallowing activity of white rhino was observed at site A, only at sites B and C (*Figure 5.35*). In August, peak wallowing activity of white rhino was observed between 08:00-09:00 (morning) and 14:00-15:00 (afternoon). However, wallowing activity at site C is distributed throughout the diurnal hours (08:00-16:00). In September, wallowing activity of white rhino was observed between 13:00-15:00 (afternoon) (*Figure 5.35*).

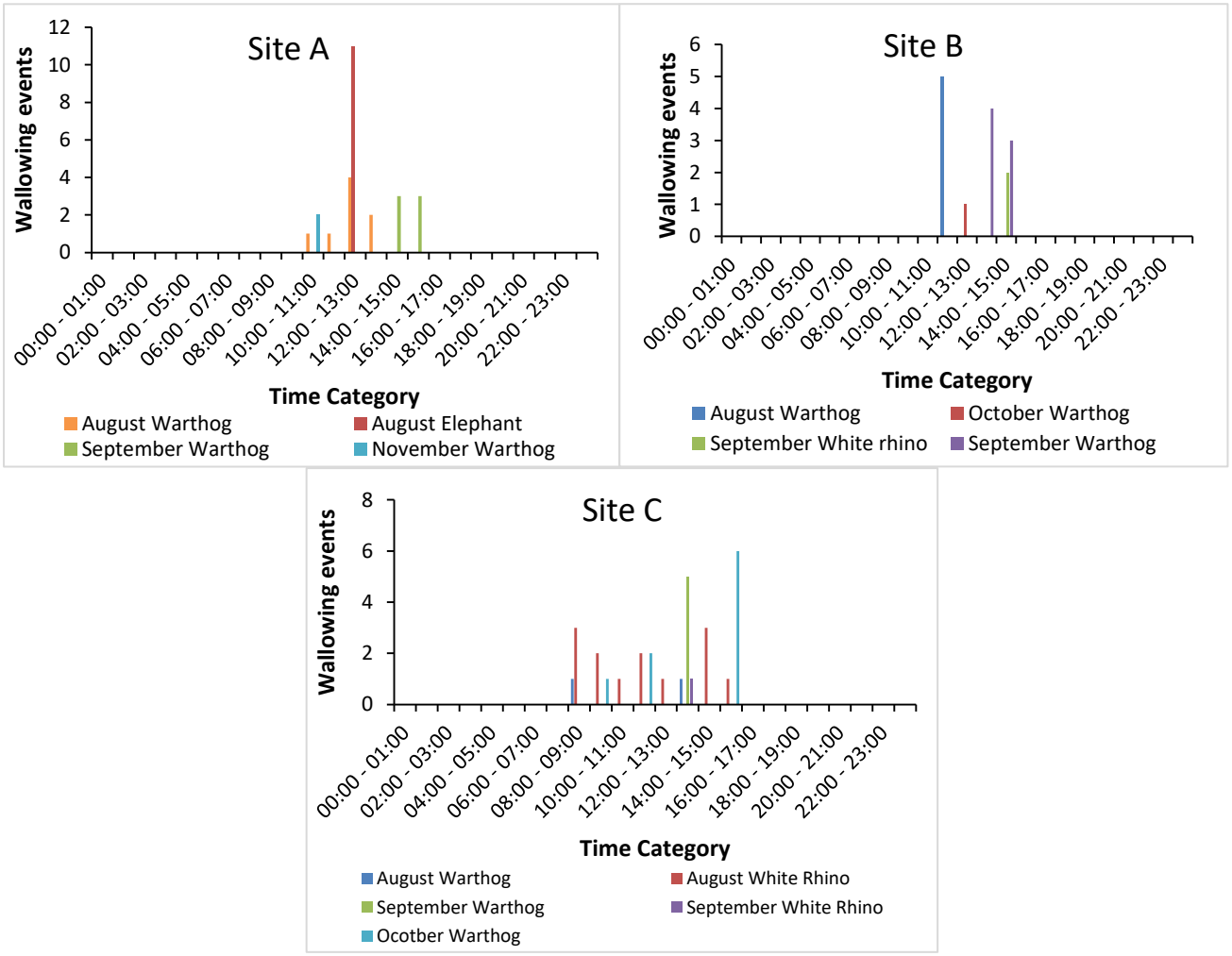


Figure 5. 35: Monthly wallowing activity per hour at the waterholes over the study period.

5.15 Temperature and Wallowing Activity

When analysing wallowing activity in relation to temperature, it is evident that as temperature increases, wallowing activity increases at the waterholes (*Figure 5.36*). Peaks in wallowing activity took place in August and September 2016. August experienced the highest temperatures (40.1°C) during this study period and this is when peak wallowing occurred for elephant and white rhino (*Figure 5.34*). When temperature increased in October and November, there was a decline in the number of wallowing events, even though T_{avg} increased during this time (*Figure 5.36*).

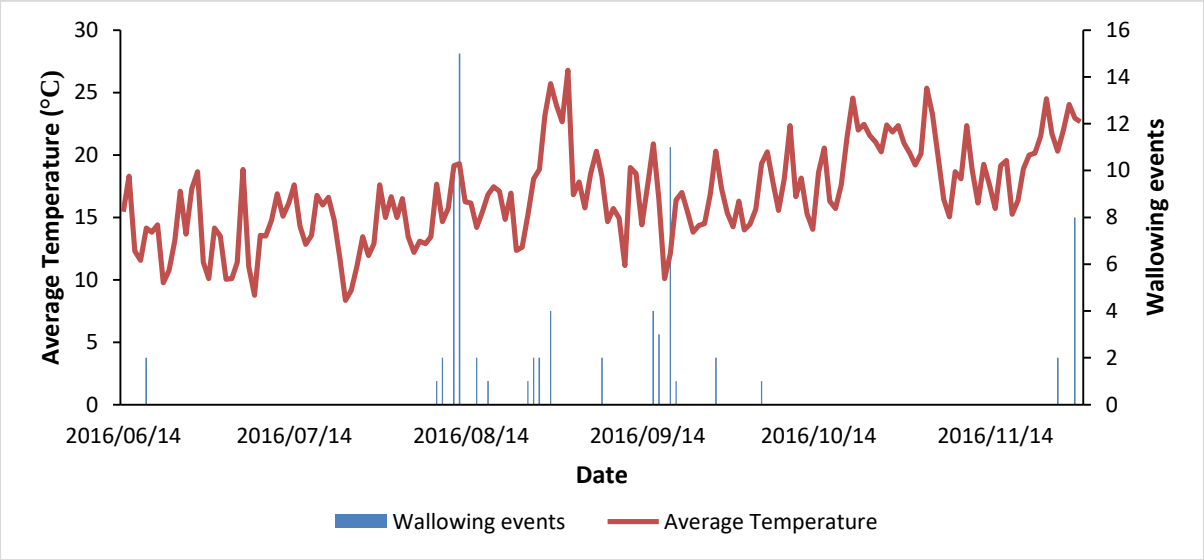


Figure 5. 36: Daily average temperature (°C) in relation to the total number of wallowing events at the waterholes over the study period.

Pearson's correlation coefficients were conducted to determine a relationship between T_{avg}, T_{max}, and T_{min}, and the number of wallowing events at the waterholes over the study period. A positive correlation indicates that as temperature increases the number wallowing events increases and a negative correlation indicates that as temperature increases the number of wallowing events decreases. T_{avg} and T_{max} show an increase in wallowing events as the temperature increases, however, this is a very weak relationship (*Table 5.15*). T_{avg} has no statistically significant relationship ($p > 0.05$) with wallowing events, but there is a statistically significant relationship ($p < 0.05$) between T_{max} and the number of wallowing events (*Table 5.15*). T_{min} reveals a weak negative correlation with wallowing events at the waterholes. Thus, as temperature decreases so does the number of wallowing events, however, this is not statistically significance ($p > 0.05$) (*Table 5.15*).

Table 5. 15: Pearson's correlation coefficient of temperature (T_{avg}, T_{max}, and T_{min}) in relation to the number of wallowing events at the waterholes over the study period. Negative correlations are marked in green. Statistically significant are marked by asterisk (*).

Temperature	Average Temperature	Maximum Temperature	Minimum Temperature
Pearson`s correlation coefficient	0,10	*0,19	-0,05

5.15.1 Temperature and Monthly Wallowing Activity of Each Species

As temperature increases over the study period, there is an increase in wallowing events at the waterholes. In August when temperatures peak, there is peak wallowing activity of elephant (n=11) and white rhino (n=13) at the waterholes. When temperatures were at their lowest in July, no wallowing activity took place at the waterholes. Warthog do not show a preference for wallowing activity in association with temperature. Warthogs were observed wallowing in June (n=2), when temperatures were cooler, and in August (n=15) and November (n=10) when temperatures were at their highest. Warthog had peak wallowing activity in September (n=19) when temperatures did not peak (T_{max} and T_{min}). However, available surface water may have been a limiting constraint in the amount of wallowing activity that occurred, which will be analysed in *section 5.17*.

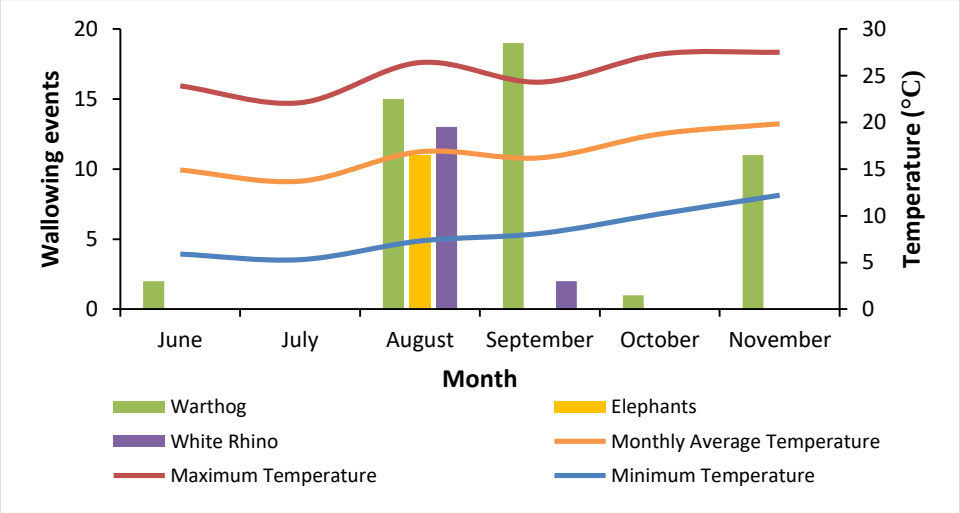


Figure 5. 37: Monthly total of number wallowing events for each wallowing species in relation to monthly average, maximum and minimum temperature (T_{avg}, T_{max}, and T_{min}) over the study period.

Pearson correlation coefficients were conducted to determine whether there was a negative or positive correlation with the number of wallowing events for each wallowing species and T_{avg}, T_{max}, and T_{min}. There is a weak positive correlation with the number of wallowing events for all wallowing species and T_{avg} and T_{max} (*Table 5.16*). A weak positive correlation exists between the number of warthog wallowing events and T_{min} (*Table 5.16*). Lastly, there is a weak negative correlation that

exists between elephants and white rhino wallowing events and T_{min}. All correlations which were conducted for each wallowing species wallowing events and T_{avg}, $T_{max,}$ & T_{min} showed no statistical significance ($p > 0.05$) (*Table 5.16*).

Table 5. 16: Pearson's correlation coefficient of temperature (T_{avg}, T_{max}, and T_{min}) and rainfall in relation to monthly number of wallowing events for each species at the waterholes over the study period. Negative correlations are marked in green. Statistically significant correlations are marked by asterisk (*).

Species	Average Temperature	Maximum Temperature	Minimum Temperature	Rainfall (mm)
Warthog	0,27	0,27	0,26	-0,14
Elephants	0,03	0,26	-0,16	-0,23
White Rhino	0,01	0,23	-0,17	-0,19

5.16 Rainfall and Wallowing Activity

Short-term changes in rainfall (mm) alter animal behaviour in any given habitat (Brown, 2012). The short-term changes in the number of wallowing events, is a response to the quantity of rainfall. When comparing rainfall and the number of wallowing events at the waterholes over the study period, it appears that there is no relationship between the two (*Figure 5.38*). A Pearson's correlation coefficient was used to determine if a relationship does exist between rainfall and the number of wallowing events. A weak negative correlation exists between rainfall and wallowing events, however, this is not statistically significant ($r=-0.05$, $p > 0.05$). However, in the times series it was evident that the number of wallowing events was lagged behind rainfall. In July, when there was a peak in rainfall (14 mm), a lagged peak of wallowing events (n=15) occur after this rainfall event, as possibly more surface water was available for species to utilise for wallowing activity (*Figure 5.38*).

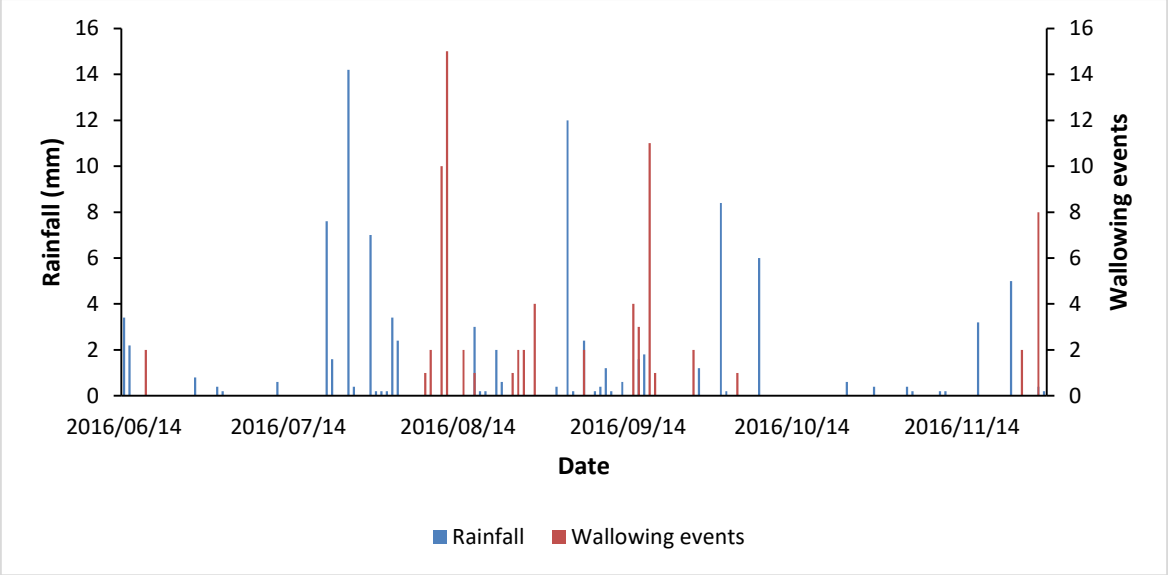


Figure 5. 38: The number of wallowing events in relation to rainfall (mm) at the waterholes over the study period.

5.16.1 Rainfall and Monthly Wallowing Activity of Each Species

July received the greatest quantity of rainfall (32.4 mm) over the study period, however, no wallowing activity took place during July (*Figure 5.39*). Elephant (n=11) and white rhino (n=13) had the highest number of wallowing activity in August, a month after the greatest quantity of rainfall (*Figure 5.39*). September had the second greatest quantity of rainfall (22.2 mm), and the highest number of warthog wallowing events (n=19) took place during this month (*Figure 5.39*). Therefore, the number of wallowing events that occur at the waterholes is indirectly related to rainfall (mm) and possibly directly related to surface water availability in the waterholes.

Pearson correlation coefficients were used to determine whether there was a negative or positive correlation with the number of wallowing events for each wallowing species and rainfall (mm). There is a weak negative correlation between the number of wallowing events for each species and rainfall (mm), all correlations which were conducted showed no statistical correlation ($p > 0.05$) (*Table 5.16*).

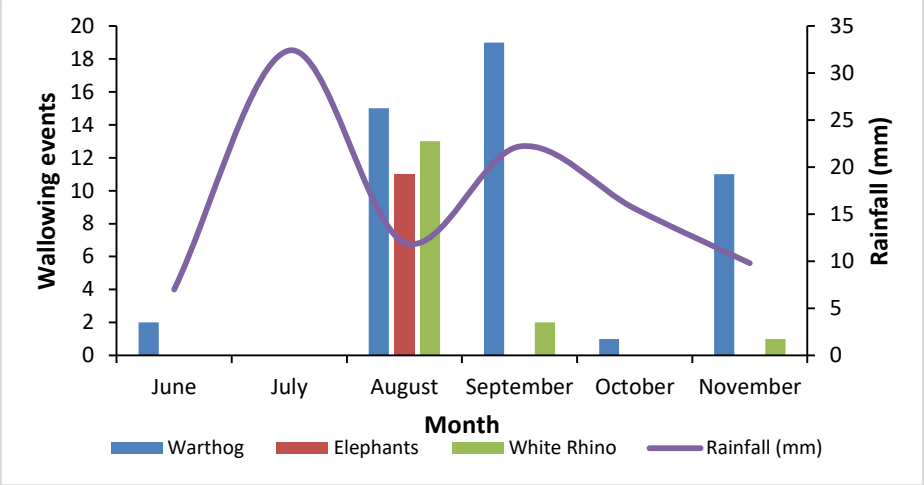


Figure 5. 39: Monthly total of number wallowing events for each wallowing species in relation to monthly rainfall (mm) over the study period.

5.16.2 Wallowing Activity in Relation to Rainfall Events

A lag between the number of wallowing events at the waterholes and rainfall (mm) is apparent in *Figure 5.38*. Further analysis reveals that the highest number of wallowing events take place more than two days after a rainfall event (n=40) (*Table 5.17*). Therefore, wallowing species are possibly utilising the waterholes when other surface water sources, which were available after rainfall events, have dried up (Epaphras *et al*., 2008; Rudee, 2011; Valeix, 2011; Maraschin, 2016; Trent, 2016). The second highest number of wallowing events takes place on the day of the rainfall event (n=14) (*Table 5.17*). Therefore, wallowing species take advantage of the surface water which was made available in the waterholes on the day of the rainfall events, as previously the waterholes were dry. This is why no wallowing events take place before a rainfall event, as there was no surface water or mud present for wallowing species to utilise in the waterholes (*Table 5.17*). Lastly, there is a decline in wallowing events at the waterholes one day after a rainfall event (*Table 5.17*).

Table 5. 17: Total number of wallowing events in association with rainfall events at the waterhole over the study period. Asterisk (*) has been marked on the largest number of wallowing events.

Days before or after rainfall event	Wallowing events
Two days before	2
One day before	0
On the day	14
One day after	0
Two days after	3
>2 days after rainfall event	*40

A cross-correlation was conducted to determine a weekly lag between rainfall (mm) and wallowing events at the waterholes over the study period, which was revealed in *Figure 5.38*. Lag numbers 0 to -7 were ignored in this analysis as it would be predicted wallowing events at the waterhole, before rainfall events occur. The cross-correlation indicates a 2-week lag (cross correlation function; CCF) in the number of wallowing events at the waterholes after rainfall events (*Figure 5.40*). Therefore, the number of wallowing events increases two weeks after a rainfall event, which is statistically significant (CCF > 0.05) (*Figure 5.40*). Therefore, surface water availability has a greater influence on the number of wallowing events at the waterholes compared to rainfall (mm).

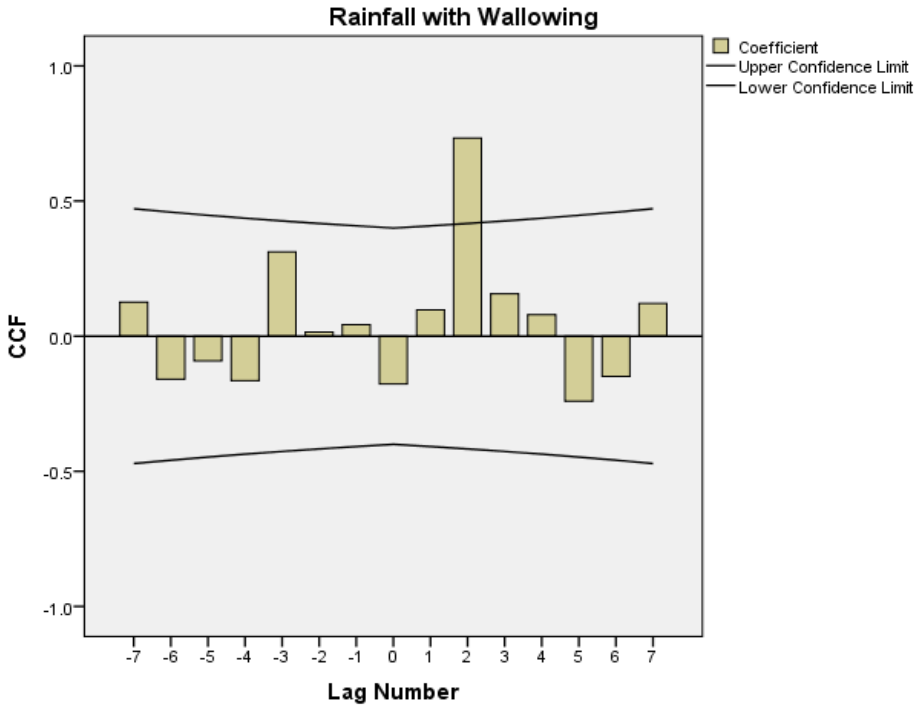


Figure 5. 40: Cross-correlation between rainfall and the number of wallowing events weekly at the waterholes over the study period.

5.16.3 Wallowing Activity in Relation to Rainfall Quantity

As stated earlier, faunal responses at the waterholes are influenced by the fluctuations of rainfall quantity, making it important to understand how different quantities of rainfall influence wallowing behaviour (Hitchcock, 1996). At the waterholes there were more wallowing events (n=76) after 1-9 mm rainfall quantity, then 10-19 mm (n=0) (*Table 5.18*). As there were more rainfall events which fell into the category of 1-9 mm rainfall quantity (n=43) then 10-19 mm (n=2) (*Table 5.18*). It is clear that there is a lag peak in the number of wallowing events after 14 mm rainfall at the waterholes (*Figure 5.38*), which falls into the category 10-19 mm (*Table 5.18*). Therefore, wallowing activity by

elephant, warthog, and white rhino are influenced by rainfall quantity (mm). As it determines the amount of surface water available in waterholes, and surrounding areas in which these wallowing species can utilise for wallowing activity. A longer-temporal study is needed to determine how an increase in rainfall quantity greater than > 19 mm influences the number of wallowing events at the waterholes.

Table 5. 18: The total number of wallowing events at the waterholes in relation to rainfall quantity (mm) over the study period.

Rainfall quantity (mm)	Number of wallowing events	Average number of wallowing events	Rainfall Events
1 - 9	76	0.46	43
10 - 19	0	0	2

5.17 Wallowing Activity and Surface Availability

The presence of surface water in naturally-forming waterholes influences the wallowing behaviour of elephant, warthog, and white rhino. Each waterhole and its relation between surface water and wallowing activity was explored independently, due to differing waterhole morphologies, infiltration, and evaporation rates, and potentially differing soil properties (*Figure 5.41, 5.42, & 5.43*). Wallowing events at all sites only take place when there is water or the waterholes had a muddy consistency, and no wallowing took place in the waterholes when they were dry (*Figure 5.41, 5.42, & 5.43*). Therefore, surface water influences the number of wallowing events that take place at the waterholes. Pearson correlation coefficients were used to determine if there was a relationship between surface water and number of wallowing events at the waterholes. Sites A and C has a weak positive relationship between surface water and the number of wallowing events, however, these are statistically significant relationships ($r=0.2$, $p < 0.05$; $r=0.16$, $p < 0.05$; respectively). Site B has a weak positive relationship with surface water and the number of wallowing events, which is not a statistically significant relationship ($r=0.11$, $p > 0.05$).

The type of surface water in the waterholes influenced the number of wallowing events. At site A, peak wallowing activity took place when water was present in the waterhole (*Figure 5.41*). Sites B and C showed peak wallowing activity when the waterholes had a muddy consistency (*Figure 5.42 & 5.43*). When comparing wallowing events with surface water in the waterholes, there is an increase in rainfall events over a consecutive amount of days an increased surface water was available in the waterholes, therefore more wallowing events took place (*Figure 5.38, 5.41, 5.42, & 5.43*). Therefore, wallowing activity at the waterholes has an indirect relationship to rainfall, but a significant

relationship with the amount of surface water available in the waterholes for wallowing activity to take place.

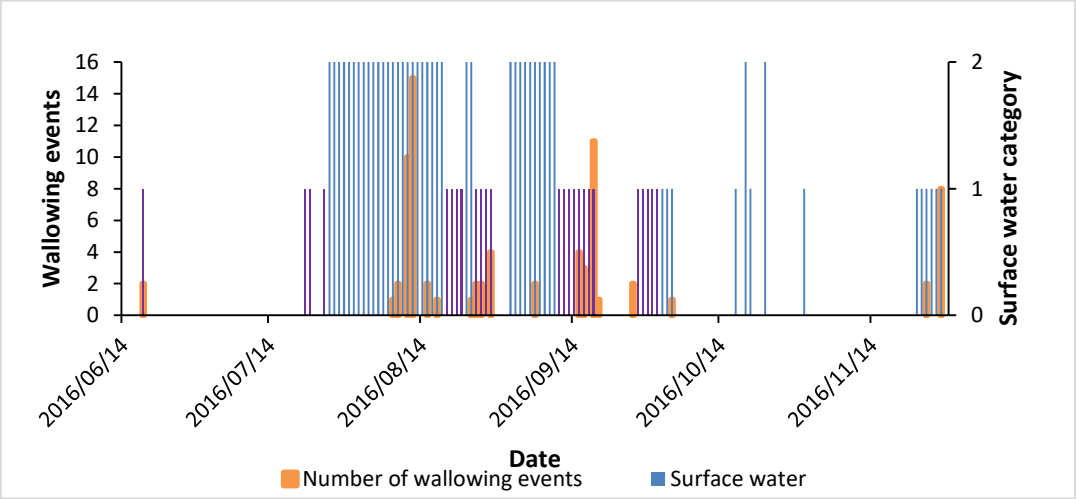


Figure 5. 41: Total number of wallowing events in relation to surface water available at site A waterhole over the study period. Different surface water categories are represented by 0=Dry, 1=Muddy (purple), 2=Water (blue).

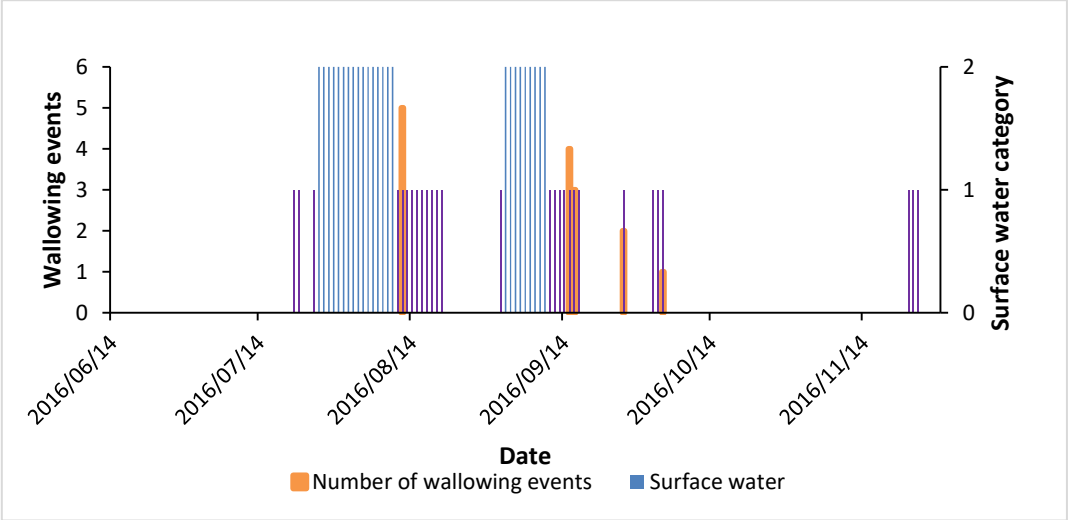


Figure 5. 42: Total number of wallowing events in relation to surface water available at site B waterhole over the study period. Different surface water categories are represented by 0=Dry, 1=Muddy (purple), 2=Water (blue).

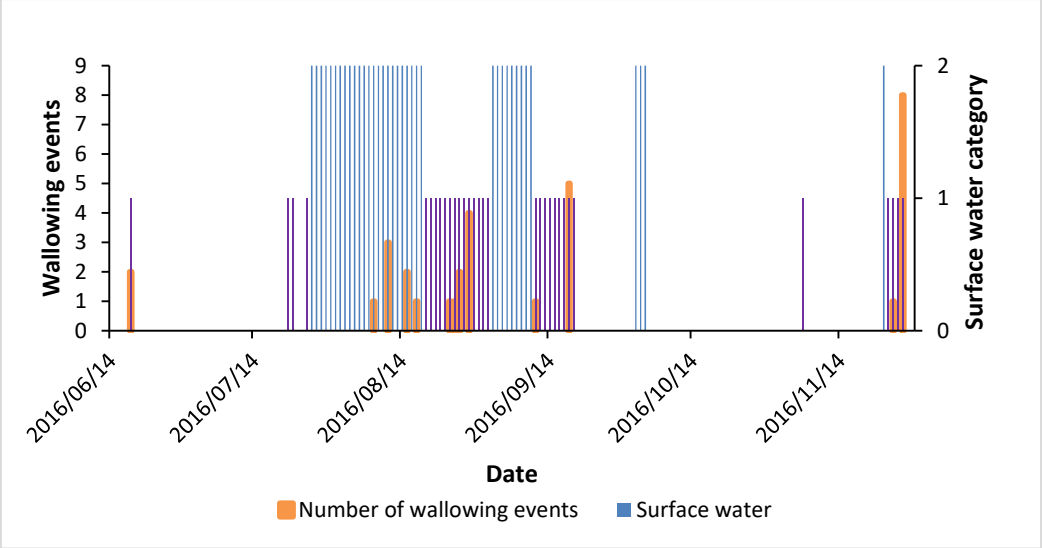


Figure 5. 43: Total number of wallowing events in relation to surface water available at site C waterhole over the study period. Different surface water categories are represent by 0=Dry, 1=Muddy (purple), 2=Water (blue).

The type of surface water (dry, muddy, or water) influences the amount of wallowing events that take place, as more wallowing events occur when the waterholes had a muddy consistency (*Figure 5.41, 5.42, 5.43; Table 5.19*). Elephant, warthog, and white rhino show a preference in wallowing activity when the waterholes had a muddy consistency (*Table 5.19*).

Table 5. 19: Total number of wallowing events at waterholes in relation to different surface water categories (dry, muddy, and water). Asterisk (*) has been marked on the largest number wallowing events per species.

Site A	**Warthog**	**Elephant**
Water	8	3
Muddy	*10	*8
Dry	0	0
Site B	**Warthog**	**White rhino**
Water	0	0
Muddy	*13	*2
Dry	0	0
Site C	**Warthog**	**White rhino**
Water	1	6
Muddy	*17	*8
Dry	0	0

5.18 Summary

Primate and ungulate species such as warthog and Burchell's zebra occurred at the waterholes diurnally (08:00–17:00). Peak visitation times were in the afternoon/midday. Species that predominantly visited the waterholes during nocturnal hours were carnivores (i.e. brown hyena) and nocturnal species such as porcupine, common duiker, bat-eared fox, bushbuck, bush pig, and scrub hare. All megaherbivores such as giraffe, hippopotamus, black rhino, white rhino, and elephants were observed during nocturnal and diurnal hours. However, elephant, black rhino, and hippopotamus had peak visitation times during nocturnal hours at the waterholes.

Local weather variables (temperature and rainfall) had no significant relationship with the number of faunal sightings at the waterholes. However, when temperatures peaked (T_{max}) there was a decrease in the number of fauna sighted at the waterholes. In addition, T_{min} had a significant relationship with the number of faunal sightings. As temperature decreased, there was a decrease in the number of faunal sightings. A shift in temporal visitation patterns occurred in association with variations in daylight hours, hourly shifts can be observed in response to sunrise and sunset times. However, springbok, impala, Burchell's zebra, and warthog still have peak visitation when daily temperatures peak. When conducting a lag displacement (cross correlation) between rainfall and the number of species sighted, it revealed a 2-week lag. Two weeks after rainfall events, there is an increase in faunal species utilising the waterholes, however, this lag is not statistically significant. However, there is a significant relationship between the number of fauna sighted at the waterholes and available surface water. Thus, faunal occurrence at the waterholes has an indirect relationship to rainfall, but a significant relationship with the amount of surface water available in the waterholes.

Warthog wallowing activity occurs throughout the day (09:00-16:00). However, peak wallowing activity occurs in the afternoon when temperature are highest. Elephant wallowing activity only occurred at midday (12:00-13:00). White rhino have wallowing activity throughout the day. Shifts in wallowing activity occurred for warthog and white rhino. Elephants were only observed wallowing in August, so shifts in wallowing activity in the different months could not be established. There is no significant relationship between the number of wallowing events and rainfall, T_{avg}, and T_{min}. However, there is a significant relationship between T_{max} and the number of wallowing events. Therefore, as temperatures increase so does the number of wallowing events. Furthermore, there was a clear lag in wallowing activity 2-weeks after rainfall events, which was highly significant. Thus, available surface water had a greater relationship with wallowing behaviour than temperature and rainfall. The greatest wallowing activity took place in the waterholes when they were a muddy consistency.

Chapter 6

Discussion



6. Discussion

6.1 Introduction

The aim of this research was to assess the patterns of faunal occurrence at naturally-forming waterholes in Shamwari Private Game Reserve by means of camera traps. Analysis of camera trap images was used to determine faunal visitation patterns and wallowing behaviour. This research explores the influence of local daily weather conditions (temperature and rainfall) on faunal visitation patterns and wallowing behaviour, both daily and monthly. As the two main weather variables that influence faunal visitation patterns in any given environment are temperature and rainfall (Skinner & Chimimba, 2005). Understanding faunal occurrence at naturally-forming waterholes becomes important in facilitation of management decisions to achieve a 'desired ecosystem state' (Venter *et al*., 2008), in particular, with predicted climate changes in local rainfall and temperature, which will affect survival of species, and their performance (van Wilgen, 2015).

There has been extensive research in quantifying the relationship between species richness and climatic variables (Hawkins *et al*., 2003). However, climatic variables affecting species behaviour in Shamwari Private Game Reserve have not been explored. Thus, analysis of the relationship between local weather variables and faunal activity at naturally-forming waterholes is important to fill the gaps in literature. It is important to note that this study is only based on three naturally-forming waterholes and a larger scale research project is necessary to gain a holistic understanding of how faunal behaviour is influenced by local weather conditions in Shamwari. This discussion interprets research findings of the investigation and makes comparisons with previous research. The final section outlines the limitations experienced throughout this investigation, which includes methodological, data, and statistical limitations and how these limitations were addressed.

6.2 Faunal Sightings

The abundance and diversity of species observed at the naturally-forming waterholes was influenced by local weather conditions, however, many other different factors could have influenced the species observed at each site. These include; surface water availability, waterhole morphology, soil properties, vegetation, tree cover (shade), water-dependency of species, predation, human presence, species avoidance, intra- and inter-species competition, moon phases, seasonality, the hour of day (Young, 1970; Valeix *et al*., 2007b, 2008a; Kamanda *et al*., 2008; Fuller *et al*., 2014; Trent, 2016). However, further research is necessary to determine how each of these environmental

differences influence fauna and wallowing behaviour, as localised environments lead to localised faunal occurrence and utilisation behaviour at water sources (Gray *et al*., 2012; Trent, 2016).

Differences in vegetation surrounding the waterholes may have influenced the species that populated each site, due to differences in vegetation structure and composition, food quality, and availability (Owen-Smith, 2002; Saetnan & Skarpe, 2006; Gaillard *et al*., 2008; Trent, 2016). In addition, species have different food preferences (feeding guilds – grazers, browsers, mixed feeders, and carnivores) which influences which species populate each site (Ayeni, 1975; Western, 1975; Owen-Smith, 2002, 2003; Searle & Shipley, 2008). Physiological adaptations, the ability of species to prevent water loss, and diet influences the water dependency of species (Owen-Smith, 2002; Searle & Shipley, 2008; Cain *et al*., 2012), which plays a role in the species observed at the waterholes. The water intake of some species comes from animal tissue, succulent leaves, and fruits to meet daily water requirements (Western, 1975; Derry, 2004; Halidu *et al*., 2013, Fourie, 2014). For example, browsers can access their water requirements from the vegetation they consume, whereas, grazers need to drink more regularly (Western, 1975; Smit, 2011; Trent, 2016).

While site C has more bare soil and a variety of different trees and shrubs surrounding the waterhole, sites A and B have a variety of grass species in the piosphere. Grasses surrounding sites A and B, therefore hold more grazing opportunities for herbivore species, which may be why more grazers were sighted at these sites (*Figure 3.5, 3.6, 3.7, 5.7, 5.8 & 5.9; Table 5.4*). The piosphere is a grazing hotspot (Jarman, 1972; Parker *et al*., 2009; Cromsigt & Beest, 2014), thus could be attracting more grazing species to the grazing lawns around waterholes. In addition, trampling occurs around the fringes of waterholes, therefore, compacted soil attracts more animals (predominantly for feeding on shorter grass swards) of the waterhole piospheres (Wieren & Bakker, 2008; Parker *et al*., 2009; Engvall, 2013; Maraschin, 2016). Herbivore species were sighted more frequently at the waterholes compared to carnivores, in particular sites A and B (*Table 5.4*). As prey species congregate around water sources in open areas, where prey can detect predators more easily and prey is less likely to be ambushed by predators (Gaillard *et al*., 2008; Smit, 2011; Fourie, 2014; Stankowich & Reimers, 2015).

A variety of different trees and shrubs in the piosphere of sites B and C influence the number of browsers sighted at these waterholes (*Figure 5.7, 5.8, 5.9*). Site C had the largest number of browsers sighted, due to the large amount of herbaceous vegetation surrounding the waterhole (*Figure 3.7, 5.9*). Site C also attracted a far more diverse species composition compared to the other sites (*Table 5.4*), owing to vegetation surrounding the waterhole that allows for both browsers and grazers to utilise the piosphere. Kudu were sighted most frequently at site C, as there was a high

level of herbaceous vegetation present in the piosphere (*Figure 3.7; Table 5.4*), whereas, site A had a lack of herbaceous vegetation to support kudu foraging (*Figure 3.5*). Kudu avoid open areas (Owen-Smith, 2002; Fourie, 2014), which could explain their low number of sightings at site A. However, this is only based on this small study area and may differ in other areas of the reserve. Giraffe, on the other hand, were sighted more frequently at sites A and B, due to the openness of these sites (*Figure 3.5, 3.6*), as giraffes prefer to browse in open environments (Engvall, 2013).

White rhino were not observed at site A (*Table 5.4*). White rhino avoid open areas with little shade (Pienaar, 1994), which could explain why white rhino were absent at this site (*Table 5.4*). However, contradicting evidence suggests that white rhino prefer open woodlands, with scattered trees offer shade (Fourie, 2014). Bat-eared foxes were only observed in June at site C: this could be because of localised environmental conditions and seasonality (*Figure 5.6; Table 5.4*). Heavily grazed or bare soil areas have more insects present (Saetnan & Skarpe, 2006), as bat-eared foxes are insectivores, which may have attracted them to site C and explained their absence from sites A and B. In addition, in June, which is part of the dry season, there was only bare soil in the piosphere at site C. Thus, more insects may have been present to offer easier hunting grounds for these bat-eared foxes (Saetnan & Skarpe, 2006; Stuart & Stuart, 2015), as they were taking advantage of the localised food source. Bat-eared foxes have a large home range as they are specialised feeders (Davies *et al*., 2012), which explains their low number of sightings at the waterholes in this investigation. Furthermore, the rare sightings were attributed to their overall low numbers in Shamwari.

Hippopotamuses were observed at all the waterholes in this investigation (*Table 5.4*), which could be a consequence of the piospheres which provided sufficient grazing to permit their occurrence at these sites, as they favour short grass swards (Owen-Smith, 2002, 2008; Lewison, 2007; Waldram *et al*., 2007; Wieren & Bakker, 2008; Fourie, 2014; Stuart & Stuart, 2015; Trent, 2016). The largest number of hippopotamus sightings occurred at site A due to its closeness to the Bushman`s River (*Figure 3.5; Table 5.4*), as hippopotamuses are water-dependent species and are located submerged in permanent water during the day, which allows them to avoid heat stress (Smuts & Whyte, 1981; Estes, 1991; Clutton-Brock, 2001; Waldram *et al*., 2007; Stuart & Stuart, 2015). The largest number of hippopotamus sightings occurred in July and August (*Figure 5.4, 5.5, 5.6*), when the greatest surface water was present in the waterholes (*Figure 5.28, 5.29, 5.30*).

Waterbuck were observed at sites A and C, but not at site B (*Table 5.4*). This is because sites A and C are closer to the Bushman`s River compared to site B. Waterbuck are water-dependent species and prefer permanent water sources (i.e. rivers or large dams) rather than temporary ones like naturally-forming waterholes (Smit *et al*., 2007; Stuart & Stuart, 2015). Water-dependent species will be in

close proximity to permanent water sources (e.g. Bushman's River), in particular when natural waterholes are dry, as they need to drink more regularly during dry periods (Jarman, 1972; Haim *et al*., 1990; Mtahiko *et al*., 2006; Chamaillé-Jammes *et al*., 2007a; Valeix *et al*., 2009b; Smit, 2011; Halidu *et al*., 2013).

During this study, gemsbok were only present at site C (*Table 5.4*). Gemsbok mostly congregate at site C, as there may be less competition for resources compared with the other waterholes as gemsbok have adapted to semi-arid environments (Estes, 1991; Stuart & Stuart, 2015; Maraschin, 2016). Gemsbok were observed individually, which probably was a territorial male, as males are known to be solitary animals (Estes, 1991). Warthogs were the most observed herbivore species present at sites A and C (*Table 5.4*). The large number of sightings is due to the same warthogs revisiting the waterholes, as they are territorial and have a small home range of 0.6–3 km^2 (Bracke, 2011; Vanshoenwinkel *et al*., 2011; Trent, 2016). Other species (honey badger, bat-eared fox, bush pig, and lion) were observed infrequently at the waterholes, which reflects their overall low numbers at Shamwari (*Table 5.4*). For example the bush pig, which was sighted at site C and not at sites A and B (*Figure 3.7; Table 5.4*), as their habitat preference is dense bush and sites A and B were situated in open areas (Estes, 1991; Fourie, 2014; Stuart & Stuart, 2015).

Localised environmental conditions show how different factors (i.e. vegetation and seasonality) are an important consideration in faunal occurrence at these waterholes (Auer, 1997; Owen-Smith, 2002, 2008; Gosling, 2003; Maraschin, 2016). A number of factors could affect which species populated specific waterholes and influence the abundance and diversity of species at each waterhole (Koehncke, 2010; Trent, 2016). Due to the range of factors that could influence faunal behaviour, this is why each site was analysed separately. Habitat suitability for species primarily focuses on food (foraging efficiency), water, shelter, and security; therefore these three factors cannot be view independently (Owen-Smith, 2003; Searle & Shipley, 2008).

6.3 Faunal Activity

Faunal species observed at the waterholes show distinct temporal water-use behaviour of the different species. Ungulates visited the waterholes predominantly during the day (08:00–17:00) (*Tables 5.5, 5.6, 5.7*). Species that predominantly visited the waterholes during nocturnal hours were carnivores (brown hyena and lion) and nocturnal species such as porcupine, common duiker, bat-eared fox, hippopotamus, black rhino, bushbuck, bush pig, and scrub hare (*Table 5.5, 5.6, 5.7*). Nocturnal activity by these species was also observed by Jarman & Jarman (1973), Haim *et al*., (1990), and Stuart & Stuart (2015).

Black-backed jackals utilised the waterholes throughout the day (*Table 5.5, 5.6, 5.7*) even though they are known as a nocturnal species (Stuart & Stuart, 2015). The observations of black-backed Jackal in Shamwari were not consistent with the black-backed jackals in Kalahari Gemsbok National Park (South Africa) and Etosha National Park (Namibia), where they are most frequently sighted in the morning and evening (Du Preez & Grobler, 1977; Maraschin, 2016). However, Estes (1991) and Trent (2016) observed that black-backed jackals did appear at water sources during the day. At site A, black-backed jackals were observed at the waterhole throughout the day from 14-17 June (*Table 5.5*), due to the presence of a springbok carcass (*Figure 6.1*). Jackals are scavengers and visited the waterholes during the day to take advantage of the carcass (*Figure 6.1*), without competition from larger carnivores or scavengers (e.g. lions and brown hyenas) (Estes, 1991; Schuette *et al*., 2013; Fourie, 2014; Stuart & Stuart, 2015; Trent, 2016).



Figure 6. 1: Observation of black-backed jackal scavenging on springbok carcass at site A waterhole. Red circle is the location of the springbok carcass.

Honey badgers were only observed at the waterhole in the early morning (01:00-5:00), having strictly nocturnal visitation patterns at the waterhole (*Table 5.5, 5.7*). Bat-eared fox and lion visited at midnight (23:00–24:00) (*Table 5.6, 5.7*). Lion visitation patterns were similar to lions in Kruger National Park (South Africa), whose peak visitation times were at midnight (Trent, 2016). There was a lioness observed between 10:00–11:00 on 20 August (*Table 5.7*), which was known to have given birth to cubs (this information was received from the knowledge of the game rangers). Lionesses with small cubs are known to be more active during diurnal hours even though lions are more active at night (Estes, 1991). Brown hyenas had peak visitation times between 21:00–02:00 (*Table 5.8, 5.9, 5.10*). Peak activity of brown hyena in the Kalahari is also usually between midnight and dawn (Estes, 1991; Mills & Mills, 2010). Only individual brown hyenas were observed at the waterholes, as they are solitary animals (Estes, 1991).

Peak sightings of ungulates and primates (chacma baboon and vervet monkey) at the waterholes were strictly diurnal (*Table 5.8, 5.9; 5.10*). These peak visitation times shown by ungulates and primates species are identical to artificial waterholes in Kalahari Gemsbok National Park and Kruger National Park (Hayward & Hayward, 2012; Trent, 2016; Maraschin, 2016). Ungulates and primates drink at midday and avoid nocturnal hours due to predation (Ayeni, 1975; Hill *et al*., 2003; Owen-Smith, 2003; Valeix *et al*., 2007b; Valeix *et al*., 2008a, Hoffman, 2011; Hayward & Hayward, 2012; Crosmary *et al*., 2012, Stankowich & Reimers, 2015; Maraschin, 2016; Trent, 2016). Springbok, Burchell's zebra, and warthog are mutually exclusive to predators, as they do not visit the waterholes at the same time (*Figure 5.18, 5.20, 5.22*). In addition, the diurnal visitation times follow light availability, which enables prey to detect and escape predators (Weir & Davidson, 1965; Ayeni, 1975; Du Preez & Grobler, 1977; Hill *et al*., 2003; Davies *et al*., 2012; Stankowich & Reimers, 2015).

Since ungulate species have diurnal visitation times, it increases the number of individuals that congregate at the waterholes during the day. In addition, the number of individuals is influenced by the distribution and the abundance of resources that are present in the environment. One example were springbok, as they increased in numbers when there was sufficient amounts of rainfall (*Figure 5.4, 5.5, 5.6, 5.28, 5.29, 5.30*), providing suitable grass for grazing in the piosphere (Parris, 1976; Estes, 1991; Davies *et al*., 2012; Maraschin, 2016). Thus, an increased number of individuals was sighted at the waterholes (*Figure 5.4, 5.5, 5.6*), consistent with research in Kalahari Gemsbok National Park (Bergstrom & Skarpe, 1999; Maraschin, 2016). Species will increase time spent at waterholes as part of larger groups due to a reduced need for individual vigilante behaviour and reducing predation with an increase in collective vigilance (Jarman & Jarman, 1973; Bruger & Gochfeld, 1992; Valeix, 2007b; Périquet *et al*., 2010; Davies *et al*., 2012; Kurauwane *et al*., 2013; Beauchamp, 2015; Blumstein *et al*., 2015; Stankowich & Reimers, 2015), but this was not explored in this investigation.

Few predators were observed at the waterholes (*Table 5.4*), which could be due to their overall low numbers in Shamwari, or they may be situated around permanent water sources and not around naturally-forming waterholes. However, predation is known to be most frequent near water sources, as prey species congregate at waterholes for drinking when surface water is available (Davidson, 2010; De Boer *et al.*, 2010). Piospheres around waterholes are also grazing hotspots, which attract more prey ungulate species (Jarman, 1972; Waldram *et al*., 2007; Parker *et al*., 2009; Cromsigt & Beest, 2014). Naturally-forming waterholes, however, are often not permanent water sources, which in turn affect predator-prey relationships. Therefore, less predation could occur at these waterholes,

as temporary water sources and therefore prey are dispersed throughout the landscape after rainfall events (Weir, 1969; Jarman, 1972; Davidson *et al*., 2013).

Peak visitation times of Burchell's zebra at the waterholes was at midday (*Figure 5.13, 5.16; Table 5.8, 5.9; 5.10*), as they are the most vulnerable to predators and are favoured as prey by lions (Ayeni, 1975; Valeix *et al*., 2007b; Valeix *et al*., 2009a; Valeix, 2009c; Crosmary, 2012; Davidson *et al*., 2013; Engvall, 2013). However, contrasting information was observed in Kruger National Park where Burchell's zebra peak sightings occurred during or after sunrise (Owen-Smith & Goodall, 2014; Trent, 2016). The difference in peak visitation times could be due to the contrasting temperatures in each region, whereby visits to artificial waterholes in Kruger National Park took place when temperatures were cooler (Owen-Smith & Goodall, 2014). Similarities exist between Kruger National Park and Shamwari in September as peak visitation times were at sunrise (*Figure 5.13*). These temporal relationships between sunrise and sunset times and faunal activity are similar in many different areas of southern Africa, such as in Kruger National Park (Trent, 2016), Kalahari Gemsbok National Park (Maraschin, 2016), and Hwange National Park (Zimbabwe) (Valeix, 2011). Species utilisation at water sources is therefore controlled by predator avoidance, and other factors such as the amount of heat the species are exposed to and water loss (Ayeni, 1975; Cain *et al*., 2006; Epaphras *et al*., 2008; Simpson *et al*., 2011; Stankowich & Reimers, 2015).

Another species whose activity was influence by sunrise and sunset times in Shamwari is warthog. Peak visitation times of warthogs occurred at midday (*Table 5.8, 5.9; 5.10*), even though warthogs are vulnerable to hyperthermia (Somers, 1997; Engvall, 2013). Warthogs are strictly diurnal to avoid predation, even when temperatures increase (Somers, 1997; Bracke, 2011; Davidson *et al*., 2013). Warthog diurnal visitation times was also consistent with research conducted by Estes (1991) and Trent (2016), as they observed activity correlating with sunrise and sunset, when there was light present. Warthogs were present at the waterhole during diurnal hours when there was light available; however, before sunrise and after sunset, no warthogs were observed (*Figure 5.16; Table 5.5, 5.6, 5.7*). During nocturnal hours, warthogs use burrows for shelter from predators (Estes, 1991, Somers, 1997; Valeix *et al*., 2009c, White & Cameron, 2009; Nouvellet *et al*., 2011; Haynes, 2012; Engvall, 2013).

Peak visitation times of waterbuck were in the afternoon and late afternoon (*Table 5.8, 5.10*). This information differed from Valeix *et al*. (2007a) and Hayward & Hayward (2012) who observed waterbuck visiting waterholes in the morning. However, Fourie (2014) observed that waterbuck were more active during the morning and late afternoon. Impala peak visitation times occurred in the morning, midday (August), and late afternoon at the waterholes (*Table 5.8, 5.9; 5.10*), which is

similar to visitation times in Serengeti National Park (Tanzania) and Hwange National Park (Jarman & Jarman, 1973; Valeix *et al*., 2007b; Hayward & Hayward, 2012). However, visitation patterns of impala in Shamwari were dispersed throughout the day, including nocturnal hours (*Figure 5.11*). In the Kruger National Park, impala visitation times were predominantly diurnal (Fourie, 2014). The differing impala visitation pattern could be a consequence of the overall low numbers of top predators in Shamwari. This may suggest adaptive behaviour at Shamwari, which has also been observed by Berger *et al*. (2003) and Ydenberg & Prins (2012) in the Kruger National Park.

Gemsbok are known to visit artificial waterholes during nocturnal hours in Kalahari Gemsbok National Park, conserving water during the day by drinking during cooler periods (Maraschin, 2016). However, in Shamwari, gemsbok peak visitation times were predominantly during diurnal hours (09:00–15:00), but they were also sighted during nocturnal hours (*Table 5.10*). Gemsbok can withstand temperatures of 45°C (Mills & Mills, 2013; Maraschin, 2016), however, in Shamwari temperatures did not reach these peaks, enabling gemsbok to utilise the waterholes during diurnal hours and at midday (*Figure 5.1; Table 5.4*).

Bushbuck have peak visitation times at the waterholes during nocturnal hours (20:00–23:00) (*Table 5.10*) as they are less visible in the open by predators (*Table 5.10*) (Jarman & Jarman, 1973; Estes, 1991). During the day, they return to the safety of the thicket and avoid open areas (Estes, 1991; Stuart & Stuart, 2015). The common duiker is another ungulate whose peak visitation time is during nocturnal hours (*Table 5.8, 5.9, 5.10*). It was observed by Estes (1991) and Jarman & Jarman (1973) that common duikers have peak visitation times during night in areas where they are heavily hunted by predators. Alternative observations suggest that since common duiker are small antelopes they are not the main prey source for lions, but they may be favoured by other carnivore species (Davidson *et al*., 2013). Since common duiker are not a main prey source to predators, this may explain why they are not mutually exclusive to predators at the waterholes (*Figure 5.18, 5.20, 5.22*). Porcupines were another species whose visitation times overlapped with carnivores (*Figure 5.17, 5.18, 5.21, 5.22*), possibly because their quills are a morphological antipredator defence (Fourie, 2014; Stankowich & Reimers, 2015). Their visitation times were similar to those in Kruger National Park, however, they were also observed in the early morning and late afternoon in Kruger National Park (Estes, 1991; Stuart & Stuart, 2015).

In Shamwari, it was observed that carnivore and herbivore species visitation times are mutually exclusive (*Figure 5.17, 5.18, 5.19, 5.20, 5.21, 5.22*). These mutually exclusive visitation times were also observed by Ayeni, 1975 and Hayward & Hayward, 2012. However, in Shamwari, kudu and giraffe did not only visit the waterholes during the day at the waterholes, but exhibited nocturnal

visitation patterns as well (*Figure 5.12; Table 5.8, 5.9, 5.10*). This contradictory evidence could be because of a small population of top predators in Shamwari compared to Kruger National Park. However, in Addo Elephant National Park (South Africa) it was found that predators influenced kudu temporal visitation times during nocturnal hours (Tambling *et al*., 2015). Kudu visitation times were consistent with research conducted by Weir & Davison, 1965; Du Preez & Grobler, 1977; Valeix *et al*., 2007b; Hayward & Hayward, 2012, who observed kudu drinking in the morning and afternoon. Giraffe peak visitation times were in the morning and afternoon, and Hayward & Hayward (2012) observed that giraffe are predominantly daytime drinkers. However, they also visited during nocturnal hours (*Table 5.8, 5.9; 5.10*), which was similar to research by Weir & Davidson (1965). Other research (Du Preez & Grobler, 1977) in Etosha National Park observed that giraffe did not have specific drinking times, as giraffes are not influenced by surface water availability, as they gain their water requirements from the vegetation they consume (Owen-Smith, 2008).

Elephant peak visitation times were predominantly during the evening, but they were also observed at the waterholes in the morning (*Table 5.8, 5.10*). Similarly, in Etosha National Park and Hwange National Park, elephants are known to visit waterholes during nocturnal hours (Ayeni, 1975; Weir, 1969; Berger & Cunningham, 1998; Loarie *et al*., 2009). However, in Kruger National Park, Pilanesburg National Park (South Africa), Madikwe Game Reserve (South Africa), Mashatu Game Reserve (Botswana), and Tembe Elephant Park (South Africa) elephants peak visitation at waterholes was at midday (Hayward & Hayward, 2012), which is inconsistent with findings at Shamwari. Elephants are megaherbivores, which enables them to visit the waterholes during nocturnal hours (*Figure 5.20, 5.21, 5.22*), as they are typically not the target of predation (Ayeni, 1975; Ydenberg & Prins, 2012; Cromsigt & Beest, 2014; Stankowich & Reimers, 2015). Therefore, elephants are able to visit the waterholes during cooler periods and avoid the hottest times of the day (Weir & Davison, 1965; Kinahan *et al*., 2007; Valeix *et al*., 2007a, 2009a; Loarie *et al*., 2009; Shrader *et al*., 2010; Trent, 2016). Only elephant calves are at risk of predation by lions (Ayeni, 1975; Skinner & Chimimba, 2005; Valeix *et al*., 2007a), however, calves were still observed in herds that visited the waterholes during nocturnal hours.

Black rhino carried out strictly nocturnal visitation times at the waterholes and were absent during diurnal hours (*Table 5.9, 5.10*). Black rhino in the Masai Mara Game Reserve (Kenya) and the Kaokoveld (Namibia) had similar visitation times, as they are known to drink and stay in close proximity to waterholes during nocturnal hours (Shortridge, 1934; Mukinya, 1997). Black rhino are less active during the day and least active at midday (Shortridge, 1934; Estes, 1991), which is consistent with findings in this investigation. White rhino had peak visitation times predominantly in

the late afternoon and during nocturnal hours, which was when temperatures were coolest (*Table 5.9, 5.10*). Both white and black rhino came to the waterholes during nocturnal hours as they are not vulnerable to predators due to their body size (Berger & Cunningham, 1998; Owen-Smith, 2002; Berger *et al*., 2003; Stankowich & Reimers, 2015). They are also present with their calves during nocturnal hours.

6.4 Relationship between Faunal Activity and Local Weather Conditions

6.4.1 Temperature and Faunal Activity

Fauna have to confront many challenges in semi-arid environments, including temperature changes. A thermoneutral zone for each animal species' physiology encompasses a range of conditions in which animal activity can take place without their body temperature varying beyond a tolerable range, which varies for each species (Owen-Smith, 2002). Environmental conditions such as high ambient temperature or high solar radiation may lead to exacerbation of thermal load for different species (Owen-Smith, 2002). Therefore, temperature influences the occurrence of species at the waterholes, and thus, affects faunal visitation times (Owen-Smith, 2002; Gosling, 2003; Woodroffe, 2003; Hannah *et al*., 2007; Chaine & Clobert, 2012; van Wilgen *et al*., 2015). However, in Shamwari there is no significant relationship between the number of faunal sightings and T_{avg} at the waterholes (*Figure 5.23, Table 5.11*). However, when T_{max} and T_{min} peaked, there was a decrease in the number of faunal sightings at the waterholes, which was a significant relationship (*Figure 5.23*). Fauna seek shelter during cold and windy conditions to avoid thermal drain (Young, 1970; Jarman & Jarman, 1973; Owen-Smith, 2002; Jones, 2012), thus, decreasing foraging activity and drinking in the open at these waterholes. When temperatures increase, herbivores decrease time utilising water sources, which is consistent with research by Valiex *et al*. (2007). During peak temperatures at midday or in summer, foraging activity is restricted and there are typically extended periods of faunal inactivity (Jarman & Jarman, 1973; Owen-Smith, 2002). Periods of inactivity at the waterholes were seen in impala and kudu (*Figure 5.11, 5.12, 5.15*). Elephants did show periods of inactivity, however peak visitation occurred during nocturnal hours, and thus inactivity during diurnal hours was inconclusive (*Figure 5.15*). It was observed in Hwange National Park and Kruger National Park that there was a decrease in herbivore occurrence at waterholes during the hottest periods of the day (Valeix *et al*., 2007b; Shrestha *et al*., 2014; Trent, 2016). Therefore, temperature extremes reduce density of faunal species observed. However, in August, when temperatures peaked, and after the dry season in October, kudu had peak sightings at midday (*Figure 5.12*), possibly because they need to tolerate

high temperatures; this is to increase their foraging time at the expense of insulation for the cold during nocturnal hours (Owen-Smith, 2008; Haim *et al*., 1990).

Body size plays an important factor regarding the ability of a species to withstand temperatures (Lindstedt & Boyce, 1985; Speakman, 1996; Hayward & Hayward, 2012). Giraffe, white rhino, black rhino, and elephant have peak visitation times during cooler periods of the day because they are all megaherbivores and unable to regulate their body temperatures effectively. These species are dependent on shade during peak temperatures of midday, while wallowing species are dependent on suitable natural waterholes to undergo wallowing as means of thermoregulation (e.g. elephants and white rhino) (Stoneridge, 1934; Owen-Smith, 1974, 1988; Pienaar, 1994; Skead, 2007; Mueller *et al*., 2013). Thus, megaherbivores benefit from avoiding peak solar radiation, which was consistent with observations by Jarman & Jarman (1973). White rhino were sighted at the waterholes in the afternoon in June and July when temperatures were cooler. However, their peak visitation times were in the late afternoon, morning, and evening (*Figure 5.14 & Table 5.9, 5.10*). White rhino visit during these cooler daytime periods in August, September, and October (*Figure 5.14*), avoiding peak temperatures, which was also observed by Ayeni (1975), Lindstedt & Boyce (1985), and Berger & Cunningham (1998).

Carnivores predominantly visit the waterholes during nocturnal hours when temperatures are cooler. Many carnivore species are nocturnal and sleep during the day (Ayeni, 1975; Hayward & Hayward, 2012; Maraschin, 2016), which affects prey visitation times at the waterholes (*Table 5.8, 5.9, 5.10*). These observations were consistent with research undertaken in Kalahari Gemsbok National Park (Maraschin, 2016). Carnivores avoid open areas during times with highest temperatures as they are unable to withstand these temperature extremes (Valeix *et al*., 2007b; Epaphras *et al*., 2008; Simpson *et al*., 2011, Hayward & Hayward, 2012; Maraschin, 2016; Trent, 2016).

A shift in temporal visitation patterns is associated with temperature. This temporal shift is a behavioural adaptation in which species undergo to avoid thermal stress, exposure to heat, and water loss (Hill *et al*., 2003; Cain *et al*., 2006; Shrestha *et al*., 2014). However, springbok, Burchell's zebra and warthog still visited the waterholes during the hottest period of the day to avoid predation (*Figure 5.10, 5.13, 5.16*). These animals are able to adjust their body temperature through their hypothalamus, which is the part of the brain that monitors and adjusts body temperature (Clutton-Brock, 2001). However, according to Hayward & Hayward (2012), species prefer utilising waterholes at midday when temperatures peak, to reach their water requirements.

Furthermore, when there is a spike in temperature, species sighted at the waterholes shifted their visitation times to earlier or later in the day, so that they do not undergo heat stress (Jarman & Jarman, 1973; Cain *et al*., 2006; Shrestha *et al*., 2014). Therefore, ungulate species are more active during sunrise, sunset, and during nocturnal hours (Shresta *et al*., 2012). Springbok, kudu, Burchell`s zebra, white rhino, and warthog all showed a shift in visitation times when temperature increased (*Figure 5.10, 5.12, 5.13, 5.14, 5.15, 5.16*). However, Burchell's zebra only revealed a shift in visitation in November, when T_{avg} was at its highest (*Figure 5.13*). The temporal visitation times shifted monthly as T_{avg} increased, although the shift is slight. This slight shift was predominantly an hour earlier or later in the day, depending on the species and the T_{avg} in the different months (*Figure 5.10, 5.12, 5.13, 5.14, 5.15, 5.16*). The hourly difference is a response to the shifts in sunrise and sunset (variation in daylight hours) (Maloney *et al*., 2005; Nouvellet *et al*., 2011; Shrestha *et al*., 2014; Tambling *et al*., 2015; Trent, 2016). The hourly shift to earlier or later visitation times was consistent with observations in Kruger National Park, for Burchell's zebra, kudu, and warthog, but only when T_{avg} was greater than 20°C (Trent, 2016).

In November, however, springbok were observed at midday (*Figure 5.10*). Morphological, behavioural, and physiological adaptations enable springbok and impala to withstand high temperatures (Cain *et al*., 2006). The sandy and white colourations of these species prevent heat stress as the can help reflect sunlight (Abere & Oguzor, 2011; Boutin & Lane, 2014; Trent, 2016). Thus, it aids with thermoregulation, and therefore allows these temporal visitation patterns (*Table 5.8, 5.9, 5.10*). Impala function optimally at temperatures between 21–31°C without being inactive (Jarman & Jarman, 1973; Klein & Fairall, 1986), which could explain why an increased number of impala were sighted at the waterholes in October, when T_{avg} increased (*Figure 5.24*). However, T_{avg} did not exceed 28°C, as the Eastern Cape has lower temperatures than Kruger National Park and Kalahari Gemsbok National Park, where it is known that impala undergo heat stress with temperatures >35°C (Maloiy & Hopcraft, 1971; Maraschin, 2016; Trent, 2016). Temperature differences in these bioregions could contribute to differences in visitation times at the waterholes. However, impala only had peak visitation at the waterholes at midday in August. There was a shift in their visitation times to earlier in the morning or later in the afternoon in June and October (*Figure 5.10*). Previous research shows that impala avoid open areas when temperatures peak, and are located in the shade, which could explain why peak visitation patterns for impala are not at midday when T_{avg} increased (Jarman & Jarman, 1973). It could also explain why impala occurrence patterns at the waterholes shifted monthly, as the temperatures increased earlier in the day (*Figure 5.11*).

6.4.2 Rainfall and Faunal Activity

Various studies have analysed the temporal faunal distribution of species in relation to rainfall, as there is a close relationship between faunal movements and abundance with rainfall (Bergstrom & Skarpe, 1999; Owen-Smith, 2002; Ogutu *et al*. 2008) as the presence of surface water influences the abundance and distribution of species present in any given habitat (Williams & Wells, 1986; Redfern *et al*., 2005; Chamaillé-Jammes *et al*., 2007a; Halidu *et al*., 2013). However, in Shamwari a weak negative correlation exists between rainfall and the number of faunal sightings at the waterholes (*Figure 5.25*), which is consistent with research conducted in Kruger National Park (Trent, 2016). At the waterholes in Shamwari, Burchell's zebra, elephant, white rhino, impala, and warthog sightings have a very weak correlation with rainfall (*Figure 5.26; Table 5.12*). Springbok and kudu, on the other hand, show a moderate positive relationship with rainfall, but it is not statistically significant (*Figure 5.26; Table 5.12*). In Kruger National Park, the number of springbok at the waterholes shows a strong correlation to rainfall (Parris, 1984; Stapelberg *et al*., 2008). In Shamwari, there is no direct relationship with rainfall and the number of faunal sightings, however a 2-week lag in the number of faunal sightings at the waterholes after rainfall events is apparent (*Figure 5.25, 5.27*).

A large number of individuals were sighted at the waterholes on the day of rainfall events, and there is an increased number of faunal sightings 2 days after rainfall events (*Table 5.13*). This differed from Kruger National Park and Kalahari Gemsbok National Park, as more species were sighted the day before and on the day of rainfall events (Maraschin, 2016; Trent, 2016). However, research in Kruger National Park and Kalahari Gemsbok National Park focused on artificial waterholes, which have an inverse relationship between faunal visitation and rainfall events compared to naturally-forming waterholes. This is a consequence of surface water made available by rainfall, which influences which water sources species drink form (Ayeni, 1975; Maraschin, 2016; Trent, 2016). The naturally-forming waterholes are rain-fed and are dependent on seasonal rainfall patterns in the region, and only have surface water after consecutive days or large volumes of rainfall (Weir, 1969; Jarman, 1972; Chamaillé-Jammes *et al*., 2007a; Waldram *et al*., 2007; Makhabu *et al*., 2002, 2007; Alex, 2011; Viljoen, 2015; Stommel *et al*., 2016). Artificial waterholes have a higher abundance of faunal sightings before rainfall events, as there is no other surface water available, so species congregate around and are reliant on these artificial waterholes or other permanent water sources (Thrash *et al*., 1995; Dudley, 1997; Noble *et al*., 1998; James *et al*., 1999; Owen-Smith, 2002; Dolan, 2006; Epaphras *et al*., 2008; Valeix *et al*., 2008a, 2009a; Valeix, 2011; Blumstein, 2012; Davidson *et al*., 2013 Maraschin, 2016; Stommel *et al*., 2016). For example, elephants in the Kruger National Park decreased visits to artificial waterholes after an increase in rainfall events (Trent, 2016). However, in Ruaha National Park (Tanzania) there was an increase in elephants sighted at both artificial and

natural waterholes when there was surface water available (Barnes, 1983; Brikett *et al*., 2012; Trent, 2016). Thus, species become less reliant on artificial water sources or permanent water sources after rainfall events, as there is temporary surface water available throughout the protected area which the fauna can utilise (Epaphras *et al*., 2008; Rudee, 2011; Valeix, 2011; Maraschin, 2016; Trent, 2016). This can explain the decrease in the number of fauna present at the naturally-forming waterholes when they were dry in Shamwari, as no water was available for species to utilise (*Figure 5.28, 5.29, 5.30*).

Furthermore, both water-dependent and less water-dependent species are influenced by the available surface water (Trent, 2012, 2016; Stommel *et al*., 2016). Results demonstrate that water-dependent elephant, hippopotamus, white rhino, blesbok, Burchell's zebra, warthog, and red hartebeest utilised the waterholes more frequently when there was surface water available (*Figure 5.4, 5.5, 5.6, 5.28, 5.29, 5.30*). Thus, water-dependent species will congregate around areas where surface water is available, which is consistent with the literature (Ayeni, 1975; Goudie & Thomas, 1985; Franz *et al*., 2010; Trent, 2016).

The diversity of species and individual species abundance changed in the different months of the study period (June to November). In June and July when the waterholes were dry (*Figure 5.28, 5.29, 5.30*), species at the waterholes were less diverse (*Figure 5.4, 5.5, 5.6*). At the end of July and in August, there was surface water available (*Figure 5.28, 5.29, 5.30*) and there was greater diversity in species at the waterholes (*Figure 5.4, 5.5, 5.6*). For example, in June at site A, eight different species were sighted, whereas in August thirteen different species were sighted (*Figure 5.5, 5.6, 5.7*). Thus, available surface water influenced species diversity, consistent with previous observations (Williams & Wells, 1986; Cronje *et al*., 2005; Epaphras *et al*., 2008; Stapelberg *et al*., 2008; Bellard *et al*., 2012; Shresta *et al*., 2012; Gandiwa, 2013; Fuller *et al*., 2014; Stommel *et al*., 2016).

In addition, rainfall is a limiting constraint and contributes to vegetation growth and hence foraging availability and quality for fauna (Western, 1975; Owen-Smith, 2002; Ogutu *et al*. 2008). An increase in faunal sightings occurred 2-weeks after rainfall events, when new grass was made available for grazing (*Figure 6.2*). This is consistent with previous research (Bothma, 1972; Goudie & Thomas, 1985; Bergstrom & Skarpe, 1999; Olff *et al*., 2002; Owen-Smith, 2002, 2008; Redfern *et al*., 2003; Gaillard *et al.,* 2008; Prins & Fritz, 2008). Herbivores favour habitats where water intake and nutrients could be maximised (Park & Sohn; 2009).



Figure 6. 2: Grass growth after rainfall events at naturally-forming waterhole. Left: No grass present before rainfall events. Right: grass growth present after rainfall events.

Grazers were most frequently sighted at waterholes in August (*Figure 5.2, 5.7, 5.8, 5.9*), possibly due to the rains in July which promoted grass growth (re-growth) in the piosphere (Jarman, 1972; Owen-Smith, 2002; Chamaillé-Jammes *et al*., 2007a; Gaillard *et al*., 2008; Wieren & Bakker, 2008; Davies *et al*., 2012; Maraschin, 2016). In June, July, and October the piospheres had low grazing lawns due to low rainfall, thus fewer grazers were present at the waterholes during these months (*Figure 5.2, 5.7, 5.8, 5.9*). At site B, November had a large number of grazers at the waterhole (*Figure 5.8*), even though grazing lawns were not sufficient.

Browsers were least common at the waterholes in August, when there was available surface water (*Figure 5.7, 5.8, 5.9, 5.28, 5.29, 5.30*). In the months when the waterholes had dried up (June, October, and November), there were increased browsers (*Figure 5.7, 5.8, 5.9, 5.28, 5.29, 5.30*). Browsers increase in the number of sightings when there is no surface water as they have the ability to graze further away from water sources (Redfern *et al*., 2003). This was also observed in Kruger National Park (Trent, 2016). Kudu are primarily present in the months when there was very little or no available surface water (July, September, October, and November) (*Figure 5.4, 5.5, 5.6, 5.28, 5.29, 5.30*). In Kruger National Park, however, the kudu population was positively affected by rainfall and hence food production (Owen-Smith, 2002, 2008). However, at Shamwari, kudu forage evenly throughout the habitat throughout the seasons, as the evergreen spekboom (*Portulacaria afra*) is able to support the kudu`s water requirements even through the dry season (*Figure 5.4, 5.5, 5.6, 5.12*). Spekboom is also successful even under harsh conditions, in particular droughts (Ting & Hanscon, 1977). Thus, their visitation patterns at naturally-forming waterholes are not affected during periods with no available surface water (Owen-Smith, 2008).

White rhino increased at the waterholes after rainfall events (*Figure 5.26*), as they are water-dependent species, and require water daily for drinking and wallowing (Owen-Smith, 1974; Pienaar,

1994; Davies *et al*., 2012; Stuart & Stuart, 2015). White rhino were most frequently sighted in August when there was available surface water in the waterholes (*Figure 5.26, 5.28, 5.29, 5.30*). Similar observations of white rhino occurred in Kruger National Park (Owen-Smith, 1974; Estes, 1991; Pienaar, 1994; Clutton-Brock, 2001). White rhino are seldom found far from water sources, and will follow available surface water (Stoneridge, 1934). Furthermore, white rhino are known to travel greater distances in the dry than wet season, excluding excursions to adequate water sources (Owen-Smith, 2008; Mueller *et al*., 2013). There were fewer white rhino in June and November when there was less rainfall, as the waterholes were dry (*Figure 5.26*). In dry periods, white rhino are found in taller grasslands due to the depletion of favourable grass types, leading to a decrease in areas of once previously suitable grazing lawns (Owen-Smith, 2002; Waldram *et al*., 2007). This can be one of the explanations why white rhino were not frequently sighted in June and November at the waterholes (*Figure 5.4, 5.5, 5.6*).

Black rhino were most frequently sighted in June when the waterholes were dry (*Figure 5.5, 5.6, 5.29, 5.30*). Black rhino are able to forage evenly throughout the dry season on evergreen spekboom (*Portulacaria afra*) which is able to support their water requirements, even through the dry season. Black rhino are dependent on woody vegetation and succulents in the dry season (Estes, 1991; Dudley, 1997; Owen-Smith, 2008). However, black rhino may not have occurred at the waterholes when there was surface water available, as Shortridge (1934) observed that black rhino travelled farther distances in Malilangwe Wildlife Reserve (Zimbabwe) when there is surface water dispersed throughout the landscape. Thus, black rhino may have been dispersed throughout Shamwari, utilising surface water from elsewhere in the landscape.

Elephants are known to migrate to different areas during the year as a result of seasonal changes in vegetation, in particular for adequate grass, which is their favourite food for forage and water (Thrash *et al*., 1993; Loarie *et al*., 2009; Haynes, 2011; Birkett *et al*., 2012). August had the highest elephant sightings throughout the investigation (*Figure 5.4, 5.5, 5.6*). During June, July, October and November there were very few elephants at the waterholes as there was insufficient surface water available. Elephants stay in close proximity to permanent water sources in the dry season (Laws, 1970; Western, 1975; Barnes, 1983; Leggett *et al*., 2003, 2004; Leggett, 2006a, 2006b; Chamaillé-Jammes *et al*., 2007a; Loarie *et al*., 2009; Valeix *et al*., 2009a; Franz *et al*., 2010), which could account for the low numbers at Shamwari waterholes when they were dry. Thus, elephants had a strong presence at the waterholes when surface water was available, for either drinking or wallowing (*Figure 5.28, 5.29, 5.30*).

Giraffe were observed drinking at the waterholes when there was water available (*Figure 5.4, 5.5, 5.6, 5.28, 5.29, 5.30*). Even though they are a less water-dependent species, they are known to take advantage of available water to drink (Owen-Smith, 2008). Baboons were sighted at the waterholes when there was water available (*Figure 5.5*), as they are also found in areas where there is available surface water and food (Hoffman, 2011).

Carnivores were uncommonly sighted at the waterholes. One factor could been the time period in which data were collected (*Figure 5.7, 5.8, 5.9*), during winter months and below average rainfall. Predators are known to stay near perennial water sources during dry months, to ambush their prey (Owen-Smith, 2002; Simpson *et al*., 2011; Davidson *et al*., 2013). In addition, carnivores did not show a preference in temporal visitation patterns and surface water availability at the waterholes (*Figure 5.7, 5.8, 5.9*). However, they were observed utilising the waterholes when water was available (*Figure 6.3*). However, brown hyena were sighted most frequently during June and July, during the dry period (*Figure 5.4, 5.5, 5.6, 5.7, 5.8, 5.9*). Brown hyena in Kalahari Gemsbok National Park had contrasting visitation patterns, as brown hyena at artificial waterholes was not seasonally influenced (Maraschin, 2016).



Figure 6. 3: Carnivore species utilising the waterholes when there was surface water available. Left: Brown Hyena. Right: Black-backed jackal.

Bushbuck were sighted most frequently in September and November, when there was very little or no surface water available (*Figure 5.6, 5.30*). Bushbuck are known to favour shrubs in the wet season (Okiria, 1980), which site C`s vegetation around the waterhole provides. Impala, in Shamwari, showed no seasonal visitation patterns at the waterholes (*Figure 5.12*), which is consistent with previous work (Young, 1972; Jarman & Jarman, 1973; Shresta *et al*., 2012; Kurauwane *et al*., 2013). Impala are mixed feeders (Estes, 1991; Owen-Smith, 2008; Kurauwane *et al*., 2013) and browse on spekboom evenly in Shamwari. Gemsbok are less water-dependent and are adapted to low rainfall

conditions (Stuart & Stuart, 2015). However, in Shamwari, gemsbok sightings increased in August after large quantities of rainfall (*Figure 5.4, 5.5, 5.6*), as they are known to congregated around areas after rainfall events as it stimulates grass growth (Estes, 1991; Stuart & Stuart, 2015).

6.5 Wallowing Activity

It was evident that elephants, white rhino, and warthog utilised the naturally-forming waterholes for wallowing activity and not just drinking. Wallowing is a behavioural adaptation that elephants, white rhino, and warthogs engage in, predominantly in response to local weather changes, to thermoregulate (Skinner & Chimimba, 2005; Bracke, 2011; Megaze *et al*., 2013; Mueller *et al*., 2013). Warthogs had a large number of wallowing events (n=48) at the waterholes, compared to elephants (n=11) and white rhino (n=15) (*Figure 5.34*). This large number of warthog wallowing events is likely a consequence of revisits by the same warthogs as they have a small home range and are territorial (Bracke, 2011; Vanshoenwinkel *et al*., 2011; Trent, 2016). Warthog's large abundance in Shamwari may also be attributed to their large numbers at the waterholes, compared to elephants and white rhino (*Table 5.4*).

6.6 Temperature and Wallowing Activity

At the waterholes there was no significant relationship between T_{avg} and T_{min} and the number of wallowing events. However, there is a positive significant relationship between T_{max} and the number of wallowing events (*Figure 5.36; Table 5.15*). When temperature reaches its peak (T_{max}), there is an increase in the number of wallowing events (*Figure 5.36; Table 5.15*). However, even when temperatures increase (hot conditions), surface water becomes the limiting constraint, as it also required before wallowing can take place (Hawkins *et al*., 2003; Valiex *et al*., 2009a).

6.6.1 Warthog Wallowing Activity and Temperature

Wallowing activity by warthogs occurred between 09:00–16:00, which was strictly diurnal (*Figure 5.31*). Peak wallowing activity was in the afternoon, generally when temperatures are at their peak (*Figure 5.31*). Afternoon wallowing is consistent with observations in Hluhluwe-iMfolozi National Park (Somers, 1997) and Kruger National Park (Trent, 2016). However, Bracke (2011) observed other pig-like animals' wallowing activities in the morning and afternoon. Warthogs can spend up to 3 hours wallowing in the morning and 0.5 hours in the afternoon (Estes, 1991; Pinto, 2013; Bracke, 2011; Vanshoenwinkel *et al*., 2011). When temperatures increased, there was an increase in warthog wallowing events (*Figure 5.37; Table 5.16*) because warthogs are sensitive to heat and

cannot regulate their body temperature effectively without wallowing (Estes, 1991; Skinner & Chimimba, 2005; Bracke, 2011; Dunkin *et al*., 2013; Megaze *et al*., 2013).

Temporal shifts in wallowing activity were evident for warthogs. Shifts to earlier and later wallowing times at the waterholes occurred from August to November, as T_{avg} increased (*Figure 5.35, 5.36*). It is known that when there is an increase in temperature, the visiting times of species will shift to earlier or later in the day so that species do not undergo heat stress (Cain *et al*., 2006; Valeix *et al*., 2007a; Haynes, 2012; Engvall, 2013). Thus, seasonality influences the amount and timing of wallowing behaviour (Hall *et al*., 1999; Bracke, 2011).

6.6.2 Elephant Wallowing Activity and Temperature

Wallowing activity by elephants only occurred at midday (12:00-13:00) when temperatures were at their peak (*Figure 5.31*). Peak wallowing activity by elephants also only occurred in August, when temperatures peaked (*Figure 5.37*). Since elephants were only observed wallowing in August, shifts in wallowing activity could not be established (*Figure 5.35*). Elephants are known to wallow as a means of thermoregulation to cool their body temperature and they use mud to protect their skin from direct solar radiation (Weir, 1969; Ng *et al*., 2001; Bracke, 2011; Vanshoenwinkel *et al*., 2011; Haynes, 2012; Engvall, 2013; Mueller *et al*., 2013; Stuart & Stuart, 2015). However, there is a weak positive relationship of T_{avg} and T_{max} and the number of wallowing events by elephants at Shamwari (*Table 5.16*). Observations by Mueller *et al*. (2013) are inconsistent with these findings, as they state that there is an increase in elephant wallowing events when there is an increase in temperature. However, elephants are likely wallowing in other waterholes in Shamwari. Elephants also use their trunks to spray themselves with water, dust, mud, or mud-like substances to cool themselves down (Flint & Bond, 1968; Weir, 1969; Butler, 1995; Haynes, 2012; Engvall, 2013). This behaviour was observed regularly but was not examined in detail in this study.

6.6.3 White Rhino Wallowing Activity and Temperature

Peak wallowing activity of white rhino occurs predominantly in the morning (08:00–09:00), afternoon (13:00–15:00), and late afternoon (16:00–17:00) (*Figure 5.31*). Other literature reveals that when temperatures peak, white rhino are usually wallow at midday (Owen-Smith, 1988). However, in this investigation very little wallowing activity occurred at this time (*Figure 5.31*). When temperatures increase, species usually decrease their time at water sources, in particular megaherbivores (Ayeni, 1975; Valeix *et al*., 2007b). This could explain why white rhino peak wallowing activity occurred in the morning and late afternoon and not at midday (*Figure 5.31*). Thus, white rhino rest at midday, when temperatures are at their peak (Mueller *et al*., 2013). Owen-Smith (1994) observed white rhino seek shade from trees at midday.

There was a weak positive relationship between T_{avg} and T_{max} and the number of wallowing events by white rhino, and a weak negative relationship between T_{min} and the number of wallowing events, but these were all not statistically significant (*Table 5.16*). However, an increase in wallowing events was observed in August when temperatures peaked (T_{max}) (*Figure 5.37*). Research in Kruger National Park is consistent with these findings (Pienaar, 1994; Trent, 2016), where an increase in white rhino wallowing events was observed when temperature peaked (T_{max}).

6.7 Rainfall and Wallowing Activity

In Shamwari, rainfall and wallowing activity have no statistical relationship at the naturally-forming waterholes (*Figure 5.38, 5.39*). A weak negative relationship between rainfall and the number of wallowing events was found for elephant, white rhino, and warthog, but these were not statistically significant (*Figure 5.29, Table 5.16*). At Tembe Elephant Park, the number of elephant wallowing events increased during the wet season when there was an increase in surface water availability (Bigwood, 2011).

In Shamwari, it is evident that a 2-week lag exists between wallowing activities after rainfall events, in particular after large volumes of rainfall, which was highly significant (*Figure 5.38, 5.39, & 5.40*). The time lag exists as there was adequate surface water present in the waterholes to allow for wallowing to take place (*Figure 5.41, 5.42, 5.43*). An increased number of wallowing events took place after more than two days of rainfall compared to the day of rainfall or one/two days after rainfall (*Table 5.17*). Thus, natural surface water has a greater influence on wallowing activity than rainfall at naturally-forming waterholes, as the waterholes are only utilised when surface water was available. This is consistent with previous findings (Jarman, 1972; Auer, 1997; Vanshoenwinkel *et al*., 2011; Hayward & Hayward, 2012; Trent, 2016). Elephants, white rhino, and warthogs all engage in wallowing, but can only do so when there is surface water or mud in water sources (Trent, 2012, 2016; Stuart & Stuart, 2015). Seasonality also affects the frequency and duration of wallowing, and there is a direct correlation between temperature and surface water availability (Hall *et al*., 1999; Bracke, 2011).

Elephants and white rhino are known to wallow at least once a day when there is surface water available (Vanschoenwinkel *et al*., 2011). Wallowing frequency is directly linked to spatial and temporal surface water distribution and availability (Knight, 1995). Wallowing frequency of white rhino increases when there is surface water available in waterholes (Owen-Smith, 1974). However, this was not found in Shamwari where the spatial distribution of surface water played an essential factor in wallowing behaviour after large rainfall events. Thus, less wallowing activity took place at

the waterholes until other smaller depression dried up (temporary pools) and surface water was only available in these deeper naturally-forming waterholes or permanent water sources (e.g. Bushman's River) (*Figure 5.38; Table 5.18, 5.19*).

In the dry months of the study period (June, July, October, and November) (*Figure 5.35*), the waterholes were predominantly dry so no wallowing or very little wallowing took place (*Figure 5.34, 5.35*). In the dry season, wallowing species will travel throughout the landscape to find an adequate water source (Jarman, 1972; Bracke, 2011; Stommel *et al*., 2016). However, warthogs wallowed all year-round as they were observed wallowing in June, even when temperatures were cooler (*Figure 5.34*). The greatest wallowing of elephants and white rhino took place in August when the waterholes had surface water and mud (*Figure 5.2, 5.34, 5.35*). Warthog peak wallowing took place in September (*Figure 5.34, 5.35*), as they were able to wallow when there was less surface water and smaller quantities of mud was available, whereas elephants and white rhino need deeper water.

6.8 Mutual Exclusivity of Wallowing Mammals

Mutual exclusivity of species at waterholes is a significant factor to consider with wallowing species, in particular elephants and white rhino with regards to their large body size. Elephants were observed at all the waterholes as they have a large home range and are mixed feeders (*Table 5.4*) (Prins & Fritz, 2008; Bracke, 2011; Vanshoenwinkel *et al*., 2011). Elephants are the most persistent users of waterholes compared to rhino and warthogs, according to Jarman (1972) and Bigwood (2011). However, observations in Shamwari show that warthogs were the most persistent users of the waterholes (*Figure 5.34*), as they stay in close proximity to water sources and will remain at waterholes even when they have dried up (Bracke, 2011).

Elephants and white rhino wallowing activity were mutually exclusive, therefore they will not utilise the waterholes at the same time (*Figure 5.33*). Elephants and rhino avoided using each other's waterholes due to the differing habitat preferences and topographical factors (Jarman, 1972). However, each waterhole is not mutually exclusive to these individual mammal wallowing species (elephants, white rhino, and warthog) and they used the same waterhole, but not at the same time (*Figure 5.33*). The competition between elephant, white rhino and warthog is not well understood. It was observed by Speakman (1996) and Berge & Cunningham (1998) that body size and inter-species dominance are related. Elephants and rhino are known to displace smaller herbivores from waterholes for resource exploitation and territory (Barnes, 1983; Owen-Smith, 1996, 2002; Valeix *et al*., 2007a, 2009a). In this investigation when elephants were present at the waterholes, it was observed that there is a decline in other species, thereby giving the appearance that elephants are

dominant in the Shamwari landscape. However, this is not well understood and other factors such as waterhole size influence faunal displacement (Owen-Smith, 2002; Prins & Frits, 2008).

Warthogs were observed at the waterholes at the same time as elephants and white rhino, but they did not wallow in the waterholes at the same time (*Figure 5.33, 6.4*). Warthogs will move off from the waterholes when elephants approach and would return to the waterhole after they leave (Ayeni, 1975; Berger & Cunningham, 1998; Valeix *et al*., 2007a). Warthog displacement by elephants and white rhino was observed in Shamwari, as elephants and white rhino are known to show aggression to other species when present at water sources (Du Preez & Grobler, 1977). Therefore, warthogs utilised the waterholes when elephants and rhinos were absent. An increased number of warthogs were present at the waterhole in September, when there was a decrease in white rhino and no elephants observed (*Figure 5.34*). Warthogs were able to wallow without competition from the larger species (Saetnan & Skarpe, 2006).



Figure 6. 4: White rhino and warthog present at the waterholes at the same time.

Inter-species competition between elephants and white rhino means that they are not at the waterholes at the same time (*Figure 5.33*). Young elephants in the Pilanesburg National Park are known to kill white rhino (Berger & Cunningham, 1998; Garaï, 2013). To avoid competition, shifting temporal niches in relation to competitors becomes a behavioural adaptation (Jarman & Jarman, 1973; Davies *et al*., 2012). Peak visitation times of elephants was during nocturnal hours, whereas white rhino peak visitation times occurred in the late afternoon and during diurnal hours (*Table 5.8, 5.9, 5.10*).

An increase in temperature and a greater need to wallow for thermoregulation may result in an increase inter-species competition at waterholes, where suitable wallowing can take place (Jones,

2012). Evaporation, infiltration, and depletion of water in waterholes is becoming a challenge and making surface water and food scarcer, in particular during the dry season (Owen-Smith, 2002, 2008; Valeix *et al*., 2007a, 2009a; Smit & Ferreira, 2010; van Wilgen, 2015; Stommel *et al*., 2016). An increase in intra-species competition could increase due to climate variability, in particular fragmented protected areas (Owen-Smith, 2002, 2008; Blumstein, 2012; Garaï, 2013). When surface water decreases, competition between species increases (Owen-Smith, 1988; Voeten & Prins, 1999, Skarpe *et al*., 2004; Valeix *et al*., 2007a). During the study period, white rhino were observed fighting at the dry site B waterhole (*Figure 6.5*); this could have been a dispute about territory (Owen-Smith, 1971) or resource competition, when the habitat was poor. When there was adequate grass growth, a number of white rhino were observed at site C waterhole together (*Figure 6.5*). This could be a consequence of low competition (less pressure for grazing) between individuals when there is abundance of resources, predominantly during the growing season/wet season (Lindstedt & Boyce, 1985; Jones, 2012).



Figure 6. 5: Left: White rhino fighting at site B waterhole. Right: Several white rhino visiting site C waterhole at the same time.

With projected climate change, an increase in temperature, and rainfall variability could result in increased competition for waterhole resources (Voeten & Prins, 1999; Owen-Smith, 2008; Blumstein, 2012). Another factor is species being confined to smaller fragmented habitats, which will likely increase competitive interactions and inter-species aggression (Kalikawa, 1990; Berger & Cunningham, 1998; Shroyer *et al*., 2001; Chaine & Clobert, 2012; Garaï, 2013). However, further research is necessary to understand how climate change will influence inter-species behaviour at water sources.

6.9 Limitations

During the course of this research, a number of limitations were encountered, predominantly during the field data collection phase. Addressing these limitations experienced will aid future researchers on how to avoid these problems in future research.

6.9.1 Technical Limitations

Climate data were obtained from the South African Weather Service (SAWS) from the Addo Elephant National Park weather station (station = 0055447A7). This station was chosen as it is the closest reliable weather station to Shamwari (23 km) and is in the same climatic zone as Shamwari (*Figure 3.1*). However, the distance of this weather station to Shamwari may mean there could be temperature and precipitation differences in this two areas and the topography of the waterholes may likely influence the temperature data, thus influencing the faunal behaviour. However, this weather station was the only reliable available weather data for this investigation. It was important to have temperature and rainfall records that are appropriate, as temperature and rainfall variability of the area of studies varies temporally, spatially, and in terms of intensity (Ayeni, 1977; Hayward & Hayward, 2012). The data received had two days (daily data) of temperature (short-term data) missing. SAWS only provides daily data, therefore, hourly data were not used for this project for a more in-depth investigation.

During the study period there were technical limitations with Bushnell trophy camera traps. This includes obstruction by glare during sunsets at the waterholes (*Figure 6.6*). The glare changed in the different months in which the camera traps were out in the field.



Figure 6. 6: Glare at sunset as a limitation of camera trap positon.

Another technical limitation was condensation in the morning when the camera traps were activated. Condensation caused blurring of images, making it more difficult to identify species (*Figure 6.7*).



Figure 6. 7: Condensation causing a white blur, making it difficult to identify species in the images.

Another limitation, was the resolution of the images with no spotlight (flood light), to identify species at the waterholes at night. Larger species shapes could be identified in the background (e.g. elephant), however smaller species were difficult to locate and identify (*Figure 6.8*), thus affecting the results of the faunal behaviour during nocturnal hours.



Figure 6. 8: Images activated at night, without a spotlight (flood light) making it impossible to identify the species at the waterholes, in particular if it was a small species.

One of the biggest limitations experienced in the field was the presence of elephants in Shamwari. Elephants are highly inquisitive animals and inspected the camera traps in the field, which resulted in number of outcomes. First, elephants moved branches into the view of the camera. When Shamwari experienced strong winds the branch would move, activating the camera trap, taking unnecessary number of images (*Figure 6.9*), and creating 'empty-data' images. Second, at night with this branch present it caused a white blur in the images as a result of the flash. Therefore, species which activated the camera trap would not be identified and some could be identified, causing a loss of data (*Figure 6.9*).



Figure 6. 9: Right: Elephant shifting vegetation. Left: Vegetation causing a white blur and obstructing the image making it difficult to identify the species present at the waterhole or whether it was the wind moving the branch.

Lastly, elephants ended up pulling the camera trap at site A. Once the camera trap was pulled out it was taken approximately 100 m away from the waterhole. Thus, no data was captured during this time, causing a loss of data which explains the discrepancy found in *Table 4.2* and *Table 6.1* (*Figure 6.10*). Once the issues were discovered the problem was quickly resolved and the camera trap was put back in it proper location. Branches that could possibly fall in front of the camera traps and activate the motion sensor were sawn off, thus eliminating vegetation hindrance and data loss or disruption.



Figure 6. 10: Right: Elephants resulted in camera traps being pulled up. Left: Resulting shift in camera trap position.

6.9.2 Data Limitations

Missing data occurred in August 2016 and September 2016 at site A. Sites B and C experienced no missing data (*Table 6.1*). No malfunctions of the camera traps were experienced during the study

period, and all missing data was caused by elephants and vegetation hindrance. All images captured were trigger by the motion sensor, some days may not have experienced any faunal occurrence (over the 24-hour period), and this explains why there were no images taken on certain days.

Table 6. 1: Missing camera trap data over the study period.

	Site A	Site B	Site C
No. of days of missing data	28	None	None
Total number of days of data captured	141	169	169
No. of camera trap images archived	1236	1897	1156

Tourist visitation occurred at sites B and C, even though the chosen sites are relatively isolated and away from tourist hotspots. The tourist visitation either on foot or in vehicles was a limitation, as it is known to influence whether species would utilise the waterholes or not (*Figure 6.11*) (Weir & Davidson, 1965; Kamanda *et al*., 2008, Valeix *et al*., 2008b; Stankowich & Reimers, 2015). Site B had 16 images with vehicles which activated the camera trap and 3 images with tourists on foot (nature walking). Site C had 11 images with vehicles that activated the camera trap. Faunal behaviour was disrupted due to noise levels of vehicles and tourists (Kamanda *et al*., 2008; Stankowich & Reimers, 2015). Fauna will respond in different ways to human presence depending on the openness of the environment and distance to shelter, also whether human presence is on foot or in a vehicle (Stankowich & Reimers, 2015).



Figure 6. 11: Right: Tourist on a walking experience in Shamwari at waterhole. Left: Tourist vehicle at waterhole.

6.9.3 Statistical Limitations

Missing days at site A could have influenced the statistical analysis, as important observations may have been missed. Underestimation and overestimation of faunal counts when analysing data may be a limitation. To reduce the effects of overestimation, individual recognition of larger species (e.g. elephant) should be undertaken, however Bowkett *et al*. (2007) stated that this is often not feasible as some individuals may not show distinguishing features. Other methods should be used to compare camera trap data to ensure optimal accuracy.

6.9.4 Addressing the Limitations

The limitations that were experienced in this research could be rectified. Missing T_{avg} data experienced by the South African National Weather Service (SAWS) was completely unavoidable, but T_{max} and T_{min} were provided, therefore, T_{avg} could be calculated. Missing temperature data could have been filled in by other online sources (this was not done for this research); however, inaccurate (incorrect) data are a possibility and could have resulted in anomalies in the data set. For future research in this field installation of Tiny Tag temperature loggers would be advantageous, however, with the presence of inquisitive elephants it would not be advisable.

To ensure that elephants would decrease their inquisitive nature towards the camera traps, mud was rubbed on the casing to remove the scent of humans and reduce the unfamiliar scent for animals. *Acacia karoo* branches were placed around the camera (ensuring they did not interfere with the motion sensor) so the thorns would act as a faunal deterrent. In future research using camera traps or webcam devices, other elephant deterrents should be tested, such as chilli-based methods for repelling elephant away from camera traps so the data collection process is not interfered with (Parker & Osborn, 2006; Garaï, 2013; Karidozo & Osborn, 2015).

The camera trap devices should be strategically placed to cover larger expanses of the research area in question, and ensuring they do not directly face the sun. The use of webcam devices instead of camera traps would be more advantageous for future research; however, webcams still have their disadvantages. This research was completed on a short temporal scale, it would be sensible to investigate faunal behaviour on a longer-temporal scale at the naturally-forming waterholes. Having a larger data set would be statistically advisable, to determine the seasonal differences and the inter-annual variability with local weather variables.

The volume of surface water in the naturally-forming waterholes should have been explored in this research project to determine if a relationship between the number of faunal sightings and volume of surface water existed. In this investigation it was been established that there is a relationship between the number of faunal sightings and surface water availability. A further study into the

volume of surface water and how it influences faunal occurrence patterns at naturally-forming waterholes will be useful. Volume of water in the waterholes was not explored in this study, as when it was apparent how useful this information would have been, it was too late to start the data collection process.

6.10 Implications of Data

The literature reveals the formation of naturally-forming waterholes to be highly localised to specific environmental conditions which include microscale weather conditions, species present in the environment, and other consequences by animal action within the landscape, forming zoogenous pools (Bracke, 2011). These localised environmental conditions at the waterholes and many other factors affect the visitation patterns of species. Due to time constraints, not all variables could be explored in this research. Three naturally-forming waterholes were observed in this study, which consisted of different geologies and vegetation structure which were not explored in detail and could affect faunal abundance, diversity, and visitation patterns (Gertenbach, 1983).

Waterhole morphology could also be a significant factor, which influences wallowing activity. It was observed that area and depth of waterholes was one key factor affecting faunal utilisation (Koehncke, 2010; Trent, 2016). Elephant wallowing activity only occurred at site A and no wallowing events took place at sites B and C (*Figure 5.31*). The morphology of site C waterhole – its deep depth and small width – could explain why no wallowing activity by elephants took place there (*Table 3.1*). Elephants' large body size (Koehncke, 2010; Gray *et al*., 2012), denied them the ability to wallow in this specific waterhole, because of its small width. It was observed that different body sized species are associated more with particular waterholes than others (Halidu *et al*., 2013). This could explain why elephants only wallowed at site A, as the waterhole had a shallow depth, which allowed for easy access. Other differences between the waterholes include their size, regularity of flooding (overflow), nature of sedimentary fill, particle size, soil type, geology, overall morphology, chemical composition, and the vegetation cover surrounding the waterholes (Gaillard *et al*., 2008; Alistoun, 2012; Trent, 2016). All of these are factors that influence faunal utilisation and wallowing behaviour at waterhole sites. Furthermore, it is important to note that these waterhole parameters are just a 'snapshot' in time and their morphology is constantly changing.

Faunal visitation patterns may not be a full representative throughout the Shamwari landscape as it is only based at three sites. This research was conducted on a short temporal scale – a longer time scale and spatial scale study is necessary to fully understand faunal visitation patterns and their relationship to local weather variables. To establish a bioregional (Eastern Cape) study of visitation

patterns at waterholes, a larger landscape needs to be investigated, as each bioregion is different, thus will need different management strategies.

Over the past century there has been a decrease in rainfall across southern Africa (Hoffman & Vogel, 2008; Derry & Dougill, 2008; Reddy *et al*., 2010; Hetem *et al*., 2014). In 2016, South Africa had below-average rainfall recorded (Botai *et al*., 2016). The Standardised Precipitation Index (SPI) (which is a drought indicator) from December 2015 to November 2016 revealed that prolonged drought existed, and Shamwari Private Game Reserve experienced moderately to severely dry conditions over a 12-month period (SAWS, 2016a). Over the study period from June to November 2016, Shamwari experienced somewhat to moderately dry conditions (National Drought Mitigation Centre, 2015b; SAWS, 2016a), and from September to November 2016 severely dry conditions were experienced (National Drought Mitigation Centre, 2015a; SAWS, 2016a). Due to the lack of rainfall during the study period, it led to the waterholes being predominantly dry, leading to faster evaporation and infiltration rates than years with normal rainfall, which in turn may have affected faunal utilisation. Further research is needed to investigate faunal occurrence at these waterholes on a longer temporal scale.

The impacts of increasing temperature and variability in rainfall patterns will impact on future faunal occurrence and utilisation at waterholes in Shamwari (van Wilgen, 2015). Understanding shifting visitation patterns in terms of surface water availability (rainfall variability) is important. Furthermore, understanding surface water availability will allow Shamwari to increase the number of artificial waterholes that mimic naturally-forming waterholes, if necessary. To cope with the variability of available surface water, increases in temperature, and possible changes in the quality and quantity of the Bushmans River. Human requirements from the Bushman's River could diminish permanent natural water availability in Shamwari or may cause the river to be less desirable to wildlife (Smit *et al*., 2007; Epaphras *et al*., 2008).

Management strategies need to be put in place to cope with the effects of climate change, predominantly increased temperatures and variability in surface water (van Wilgen *et al*., 2015). Understanding the behaviour of the species, both occurrence and utilisation, at naturally-forming waterholes will contribute to knowledge in management decisions, predominantly those species that are water-dependent and are more vulnerable to the effects of climate change (e.g. warthog) (Hetem *et al*., 2014; Maraschin, 2016). Management decisions are essential when providing suitable quantities of water at supplementary water sources and ensuring that these are distributed at appropriate distances and they do not compromise the functionality of the landscape. Furthermore, with the increased reliance on supplementary water sources, there will be an increased

zoogeomorphic effect and vegetation destruction in the piosphere at these water sources, which need to be explored (Owen-Smith, 2002, 2008).

Special attention at a bioregional or continental level to conservation planning and implementation has only been the focus in research in the past decade (Kerley *et al*., 2003). Similarly, different protected areas in different regions are vulnerable to climate change and some protected areas are more vulnerable compared to others (Gillson *et al*., 2013; van Wilgen *et al*., 2015). The Kruger National Park is one protected area within southern Africa that is vulnerable to climate change (Gillson *et al*., 2013; van Wilgen *et al*., 2015), and these vulnerable regions need special attention. Research at a bioregional level will contribute towards adaptive management solutions and policies (Gillson *et al*., 2013; van Wilgen *et al*., 2015). As understanding the resilience of species at a bioregional level are needed, so appropriate interventions can be established to determine what interventions are needed for each region, as each region differs (Gillson *et al*., 2013). However, the data that has been collected at each site is only based at these three sites in Shamwari Private Game Reserve. Thus, using these results is by means of extrapolation, if applied to faunal visitation in southern Africa. Nevertheless, these results are consistent with data in other bioregions of southern Africa and are applicable, which emphasis`s how research on a bioregional level is necessary.

6.11 Summary

Grazers were the most frequently sighted species at the naturally-forming waterholes and have large overall numbers compared to browsers and mixed feeders. Grazers are water-dependent and need to drink regularly to meet daily water requirements, however they could only utilise the waterholes when there was surface water available. Carnivores were not sighted frequently at the waterholes, but mainly when there was available surface water. Visitation patterns differed between diurnal and nocturnal species. Ungulate species such as warthog and Burchell's zebra occurred at the waterholes diurnally (08:00–17:00). Species that predominantly during nocturnal hours were carnivores and specialised nocturnal species. A shift in temporal visitation patterns occurred in association with temperature, so species are able to avoid thermal stress, exposure to heat, and water loss. Species will shift their visitation to earlier or later in the day to avoid peak temperature. Hourly shifts can be observed in response to sunrise and sunset (variations in daylight hours). However, springbok, impala, Burchell's zebra, and warthog still have peak visitation when daily temperatures were highest, to avoid predation.

Two weeks after rainfall events there is an increase in faunal species utilising the waterholes. The 2-week period was the average allotted time for adequate grass growth in the piosphere, where

herbivores could graze. With this rapid re-growth, grass can support high levels of herbivore activity. A significant relationship existed between the number of fauna sighted at the waterholes and available surface water, as waterholes are only utilised when there is surface water available. Therefore, surface water availability has a greater influence on faunal occurrence compared to rainfall and temperature.

Shifts in the timing of wallowing activity occurred for warthog and white rhino. Wallowing will take place earlier or later in the day to avoid peak temperatures. The main seasonal factor influencing wallowing activity was rainfall, as it affected how much surface water was available. There was a clear lag in wallowing activity 2-weeks after rainfall events, which was highly significant. Thus, available surface water had a greater relationship to wallowing behaviour than temperature and rainfall. The amount of surface water available in the waterholes also influenced the wallowing behaviour of these species.

Chapter 7

Conclusions



7. Conclusions

7.1 Introduction

Extensive research has been conducted on faunal occurrence and utilisation patterns at waterholes in conservation areas in southern Africa (Ayeni, 1975; Hayward & Hayward, 2012; Maraschin, 2016; Trent, 2016). However, artificial waterholes are the main focus of research, as they are constantly monitored and are easily accessible making it a prime research study area (Ayeni, 1975), and there has been little attention paid to naturally-forming waterholes. Furthermore, there are still many gaps regarding faunal water-source utilisation in different bioregions of southern Africa, in particular relation to wallowing at naturally-forming waterholes. Different regions in southern Africa have likely different responses to the effects of climate and local weather variability and climate change (Chamaillé-Jammes *et al*., 2007a; van Wilgen *et al*., 2015). Different protected areas in different bioregions are also more vulnerable than others to local weather variability and climate change (Chamaillé-Jammes *et al*., 2007a; Gillson *et al*., 2013; van Wilgen *et al*., 2015). Wallowing is essential for elephants, white rhino, and warthogs as they are sparsely haired water-dependent species. Wallowing activity by animals is associated with thermoregulation and it is a basic ethological need (Weir, 1965; Ng *et al*., 2001; Bracke, 2011; Vanshoenwinkel *et al*., 2011; Haynes, 2012; Engvall, 2013; Stuart & Stuart, 2015).

With projected climate change, it is important to understand faunal occurrence and wallowing behaviour at naturally-forming waterholes as changes in temperature and rainfall can lead to reduced available surface water in these waterholes. This study has provided species-specific occurrence and utilisation patterns at naturally-forming waterholes in Shamwari Private Game Reserve, Eastern Cape, through the analysis of short-term local weather variables, of temperature and rainfall, including surface water availability. Providing a better understanding into wallowing behaviour of elephants, white rhino, and warthog and how wallowing activity is influence by local weather variables.

7.2 Consolidation of Research Findings

Three study objectives were identified to achieve the research aim of this investigation. The research aimed to investigate how daily and monthly variations in local weather conditions affect the occurrence and wallowing behaviour of faunal species at naturally-forming waterholes in Shamwari Private Game Reserve, Eastern Cape, South Africa. Camera traps were used to reveal the faunal occurrence patterns and wallowing behaviour over a six-month period.

Objective 1. To establish the daily and monthly faunal occurrence at naturally-forming waterholes in Shamwari Private Game Reserve for a six-month period (June – November 2016).

Grazers were the most frequently sighted species at the naturally-forming waterholes. This is a consequence of their overall large numbers in Shamwari, compared to browsers and mixed feeders. In addition, they are water-dependent species and need to drink regularly to meet daily water-requirements, but this could only be done when there was surface water available. Carnivores were not sighted frequently at the waterholes, as Shamwari has a small top predator population, carnivores are less water-dependent. Black-backed jackal and brown hyena were observed utilising the waterholes, but only when there was available surface water. Honey badger, bat-eared fox, bush pig and lion were observed infrequently, which reflects their overall low numbers in Shamwari.

Visitation patterns differed between diurnal and nocturnal species. Ungulate species such as warthog and Burchell's zebra, occurred at the waterholes diurnally (08:00–17:00). Peak visitation times were in the afternoon/midday. Species that predominantly visited the waterholes during nocturnal hours were carnivores (brown hyena and lion) and nocturnal species such as porcupine, common duiker, bat-eared fox, bushbuck, bush pig, and scrub hare. All megaherbivores such as giraffe, hippopotamus, black rhino, white rhino, and elephants were observed during nocturnal hours, as they are not vulnerable to predation due to their large body size, but they were also observed diurnally. Elephant, black rhino, and hippopotamus had peak visitation times during nocturnal hours.

Monthly patterns did emerge in this study, even though it was short-term. Available surface water influenced the occurrence of species at the waterholes. Warthog, Burchell's zebra, elephant, hippopotamus and white rhino increased in abundance in the months when the waterholes had surface water available, as they are water-dependent species.

Objective 2. To identify any relationship between faunal occurrence patterns and local daily weather conditions (rainfall and temperature) over the same six-month period.

Local weather variables (temperature and rainfall) had no significant relationship with the number of faunal sightings at the waterholes. However, when temperatures peaked (T_{max}) there was a decrease in the number of fauna. In addition, as temperature decreased there was a decrease in the number of faunal sightings. A shift in temporal visitation patterns occurred in association with temperature, related to the need of species to avoid thermal stress, exposure to heat, and water loss. Species will shift their visitation to earlier or later in the day to avoid peak temperature. Hourly shifts can be

observed in response to sunrise and sunset (variations in daylight hours). However, springbok, impala, Burchell's zebra and warthog still have peak visitation when daily temperatures were at their peak, to avoid predation.

The dominant climatic factor is rainfall (Ogutu *et al*. 2008). However, there is no statistical relationship between the number of faunal species sighted at the waterholes and rainfall. When conducting a lag displacement (cross correlation) between rainfall and the number of species sighted, it revealed a 2-week lag. Two weeks after rainfall events there is an increase in faunal species utilising the waterholes, however this lag is not statistically significant. The 2-week period was the allotted time for adequate grass growth in the piosphere, where herbivores could graze. There is a significant relationship between the number of fauna sighted and available surface water, as waterholes are only utilised when there is surface water. Therefore, surface water availability has a greater influence of the number of fauna sighted at waterholes compared to rainfall. Thus, surface water made available by rainfall is the dominant variable which influences faunal occurrence and behaviour.

Objective 3. To establish the number of wallowing events both daily and monthly at naturally-forming waterholes for a six-month period.

Warthog wallowing activity occurs throughout the day (09:00-16:00). However, peak wallowing activity occurs in the afternoon when temperatures are highest. Elephant wallowing only occurred at midday (12:00-13:00). White rhino have wallowing activity throughout the day. Shifts in wallowing activity occurred for warthog and white rhino. Wallowing will take place earlier or later in the day to avoid peak temperatures. However, elephants were only observed wallowing in August, so shifts in wallowing activity in the different months could not be established. The main seasonal factor which influenced the monthly shifts in wallowing activity was rainfall, as it affected how much surface water was available in the waterholes.

Objective 4. To identify if there is a relationship between local weather conditions (rainfall and temperature) and wallowing behaviour over a six-month period or to determine if wallowing is an event driven process.

There is no significant relationship between the number of wallowing events and T_{avg} and T_{min}. However, there is a significant relationship between T_{max} and the number of wallowing events.

Therefore, as the temperatures peak (T_{max}) there is an increase in wallowing activity. Rainfall and the number of wallowing events for each species had no significant relationship. However, there was a clear lag in wallowing activity 2-weeks after rainfall events, which was highly significant. Thus, available surface water had a greater relationship with wallowing behaviour than temperature and rainfall. Elephants, white rhino, and warthogs utilised the waterholes to engage in wallowing only when there was available surface water or mud present in the waterholes. Therefore, wallowing activity is event-driven and only occurred when mud or water was present. The amount of surface water available in the waterholes influenced the wallowing behaviour of these species, as the greatest wallowing activity took place when waterholes had a muddy consistency.

7.3 Future of Fauna in South Africa

Research on the variability in local weather in protected areas still needs to be conducted at a bioregional level in southern Africa so that mitigation strategies can be adapted to aid in future management decisions, in particular for species that are water-dependent. Africa is one of the most vulnerable regions to climate change, which poses a serious threat for the survival of many species (Amouzou, 2010). Projected climate change will negatively influence South Africa`s biodiversity related to surface water availability, due to increased temperature, evaporation rates, and variability of rainfall, with the added pressure of shrinking surface water sources, which increases species reliance on supplementary water sources in protected areas (Smit & Ferreira, 2010; Maraschin, 2016).

An interconnected web of consequences in protected areas will arise as a response to climate change, where climate change may be too fast for species adaptation (Hannah *et al*., 2007; Hetem *et al*., 2014). Species will undergo a temporal niche shift with increased temperatures. Shifts in faunal utilisation patterns to earlier or later in the day will transpire to avoid thermal stress, thus affecting the vigilance behaviour of herbivore species at these waterholes (Swenson, 2003; Davies *et al*., 2012; Beauchamp, 2015; Stankowich & Reimers, 2015; van Wilgen *et al*., 2015). In turn, carnivore visitation will be affected and carnivores will shift visitation times to later in the evening, when temperatures are cooler. Shifts in seasonal visitation times will be altered by the variability of rainfall, which in turn affects food availability (as rain promotes grass growth) (Owen-Smith, 2002; Fischlin *et al*., 2007).

Wallowing species will be negatively affected by climate change, as thermoregulation influences the visitation times that these species drink or wallow at water sources (Hewitson & Crane, 2006; Kruger, 2006; Valeix *et al*., 2007a; Huey *et al*., 2012). It was observed by Huey *et al*. (2012) that behavioural thermoregulation (e.g. wallowing) acts as a buffer to any increase in temperatures.

Therefore, increased wallowing frequency will take place by elephants, white rhino, and warthogs to cope with the increased temperatures. Warthogs are highly vulnerable during periods of low rainfall, as warthogs are known to be the first species to decline during droughts, as they are vulnerable to changes in water and food availability (Walker *et al*., 1987; Mason, 1990; Owen-Smith, 2002). Thus, behavioural and physiological adaptations become a necessity to investigate, and to establish species-specific water requirements and how they are influenced by climate change (Bellard *et al*., 2012). Increased temperature and a greater need to wallow may result in increased intra- and inter-species competition at waterholes (Jones, 2012). Elephants and rhino may experience an increase in confrontation at water sources (Valeix *et al*., 2007a; Owen-Smith, 2008). For future species distribution and abundance to be predicted and protected, it becomes essential to implement adequate management strategies to conserve species that are sensitive to climate change, in particular wallowing species (Chown & Gaston, 2004; Gaston *et al*., 2006; Fuller *et al*., 2014; Maraschin, 2016).

7.4 Implications for Management

Limited research is available on the bioregional variability of rainfall in southern Africa. Research of this nature is essential, as it is important for management of protected areas to understand climate change. Therefore, management decisions can be put in place to ensure sustainability of wildlife in protected areas, and provision of supplementary water sources (Maraschin, 2016). It is critical to understand how local weather variables influence fauna, so that impacts are detected early, and adaptive management solutions can be put in place (van Wilgen, 2015).

Artificial waterholes are reported by Van Rooyen *et al*. (2008) to aid in conservation of species, to keep wildlife away from farming areas, sustain migratory species, and increase tourist potential of the protected area (Halidu *et al*., 2013). They are the main prevention mitigation strategy during drought events, against mass mortality of large herbivores and water-dependent species (Thrash *et al*., 1993; Valeix *et al*., 2009a). Artificial waterholes are implemented in many protected areas to help alleviate water shortages (Rosenstock *et al*., 1999; Epaphras *et al*., 2008; Franz *et al*., 2010). However, there are many disadvantages of artificial waterholes, as they alter the natural balance of an ecosystem (e.g. changing faunal natural behaviour), in particular spatial variability in herbivore populations (Knight, 1995; James *et al*., 1999; Nangula & Oba, 2004; Chamaillé-Jammes *et al*., 2007a; Farmer, 2010). If artificial waterholes are to be implemented as a drought mitigation strategy, it is important that the water availability replicates the natural water system of the region (Loarie *et al*., 2009). Naturally-forming waterholes vary on different spatial and temporal scales, which is an

important management consideration (Cronje *et al*., 2005; Chamaillé-Jammes *et al*., 2007b), otherwise over-provision of water sources could lead to a reduction in some species populations during drought periods, as has been seen in Klaserie Private Nature Reserve (South Africa). Here, there was a 90% reduction in population as a result of over-provision of water points and over-utilisation in some areas, leading to increased degradation during dry periods (Owen-Smith, 2002; Nangula & Oba, 2004; Chamaillé-Jammes *et al*., 2007a; Franz *et al*., 2010). This also occurred in the Kruger National Park leading to the closure of artificial waterholes and dams (Pienaar *et al*., 1997). Karroo National Park (South Africa) and Mokala National Parks (South Africa) are alternating between open and closed water sources, as it facilitates a more natural distribution and utilisation of fauna (Karoo National Park Management Plan, 2008; Mokala National Park Management Plan, 2008). Temporarily closing down supplementary water sources will be beneficial as it would be more variable water supply, which is similar to naturally-forming waterholes, and promoting vegetation growth in the piosphere (Smit & Grant, 2009).

Dispersed water sources through the landscape will reduce the impacts that megaherbivores have on isolated water sources, in particular the trampling/vegetation destruction of piospheres (Thrash, 2000; Harris *et al*., 2008). Thus, artificial waterholes should mimic naturally-forming waterholes (James *et al*., 1999; Loarie *et al*., 2009). It is essential to ensure fauna are provided with adequate water in the artificial waterholes, making research into species-specific drinking patterns and wallowing behaviour crucial. Artificial waterholes need to be constructed to ensure that waterholes are not only utilised for drinking, but also wallowing. Deepening of existing artificial and naturally-forming waterholes, for these waterholes to maximize water retention (reduce evaporation) during dry months, may be a management possibility (Gray *et al*., 2012; Stommel *et al*., 2016). Implications associated with this management decision are possible, as depth and area of waterholes influence faunal activities (Koehncke, 2010). In addition, monitoring can establish species-specific behaviour and distribution patterns on a bioregional level, however there is limited knowledge on faunal distribution in relation to climate change at this level (Erasmus *et al.,* 2002; Trent, 2012; Willis *et al*., 2013). Therefore, research and monitoring of wildlife in protected areas is a fundamental requirement to manage the environment adequately. This is achieved by examining what management initiatives and policies influence wildlife and how environmental change may affect fauna in the future (Carbone *et al*., 2002; McGoech *et al*., 2011).

7.5 Future Research

Future research in terms of the effects that local weather variables and climate change have on wildlife is necessary as there are still research gaps in the literature. Climate variability, in particular droughts, will affect an ecosystems in its entirety and can cause irreversible ecological changes (Vetter, 2009; Bobich *et al*., 2014). Many variables affect the visitation times of fauna at naturally-forming waterholes, both temporally and spatially. These factors need to be explored in detail. These factors include cloud cover, wind, vegetation growth, surrounding vegetation, tree cover (shade), water-dependency of faunal species, predation, tourist presence, species avoidance, inter- and intra-species competition, piosphere dynamics, morphology, soil type, and particle size. Future research is needed of the implications of the drying up of naturally-forming waterholes, due to the consequences of climate change (increased rainfall variability and temperatures). Research is also necessary on the influence that drying up of naturally-forming waterholes will have on wallowing species and their ability to adapt to these changes, and how these species thermoregulate. Further knowledge is needed to determine how animal movements between naturally-forming waterholes are affected with increased variability of rainfall, as research predominantly focuses on artificial waterholes.

Wallowing species have different habitat preferences of water sources. Rhino prefer a landscape that is made up of granites compared to basalts (Cromsigt & Beest, 2014), which could be reasons why rhino did not occur at site A. Elephants have an increased presence at water sources in areas that consist of basalts and a decreased presence in areas with granite (Smit et al., 2007). Different geologies of waterholes needs to be further explored to determine if the underlying geology influences spatial wallowing activity within the landscape. This will be beneficial when constructing artificial waterholes, to a species' environmental preference. Sediment transfer by wallowing species occurs at water sources, which has received very little attention (Cromsigt & Beest, 2014). These wallowing mammals are the main drivers of landscape development and animal sediment transfer, making it important to understand their role as zoogeomorphic agents, in particular when it comes to maintaining naturally-forming waterholes or digging zoogenous pools (Butler, 1995; *Fey et al.*, 2010; Engvall, 2013; Cromsigt & Beest, 2014). In addition, research is needed into species-specific geomorphic impacts on the landscape, as each species fills a different niche and exploits the environment in diverse ways; therefore it results in different environmental impacts at each site (Woodward *et al*., 2005). Animals have a collective geomorphic impact on the environment, making understanding the holistic consequences on the landscape highly important (Butler, 1995). However, the interlinkages between animals, climate, and geomorphology are not well understood and future research is needed, in particular with the added pressures of climate change.

Future research is also needed to determine if these naturally-forming waterholes formed as a result of salt-licks (*section 2.2.3*). Salt-licks have high concentrations of water-soluble sodium, which animals require for their daily nutritional requirements (Haynes, 2012). In addition, the soils have significant concentrations of calcium, magnesium, and potassium and are usually located on grassy plains (Weir, 1969; Parris, 1976). Research of this nature will be beneficial, to establish if the waterholes have a positive feedback with high water availability and low salinity or negative feedback with low water availability and a high soil salinity (Yair, 1995). In addition, to determine if salt accumulation is occurring at the waterholes, as they have a closed drainage system, and with added pressures of climate change.

7.6 Final Word

Extensive research is ongoing to understand protected areas and species behaviour, to ensure biodiversity is 'preserved'. Without assessing every aspect of the environment, management of protected areas delude themselves, in fully understanding the effects and sustainability of a bioregions ecosystem and the species within it. Thus, research of how anthropogenic and climatic variables influence or have altered the environment is necessary, with all the interconnected links that exists between these elements. Only then by studying the effects that animals have on the landscape and how the landscape influences animals will a holistic understanding be achieved. Only then may management decisions and polices be implemented to preserve biodiversity.

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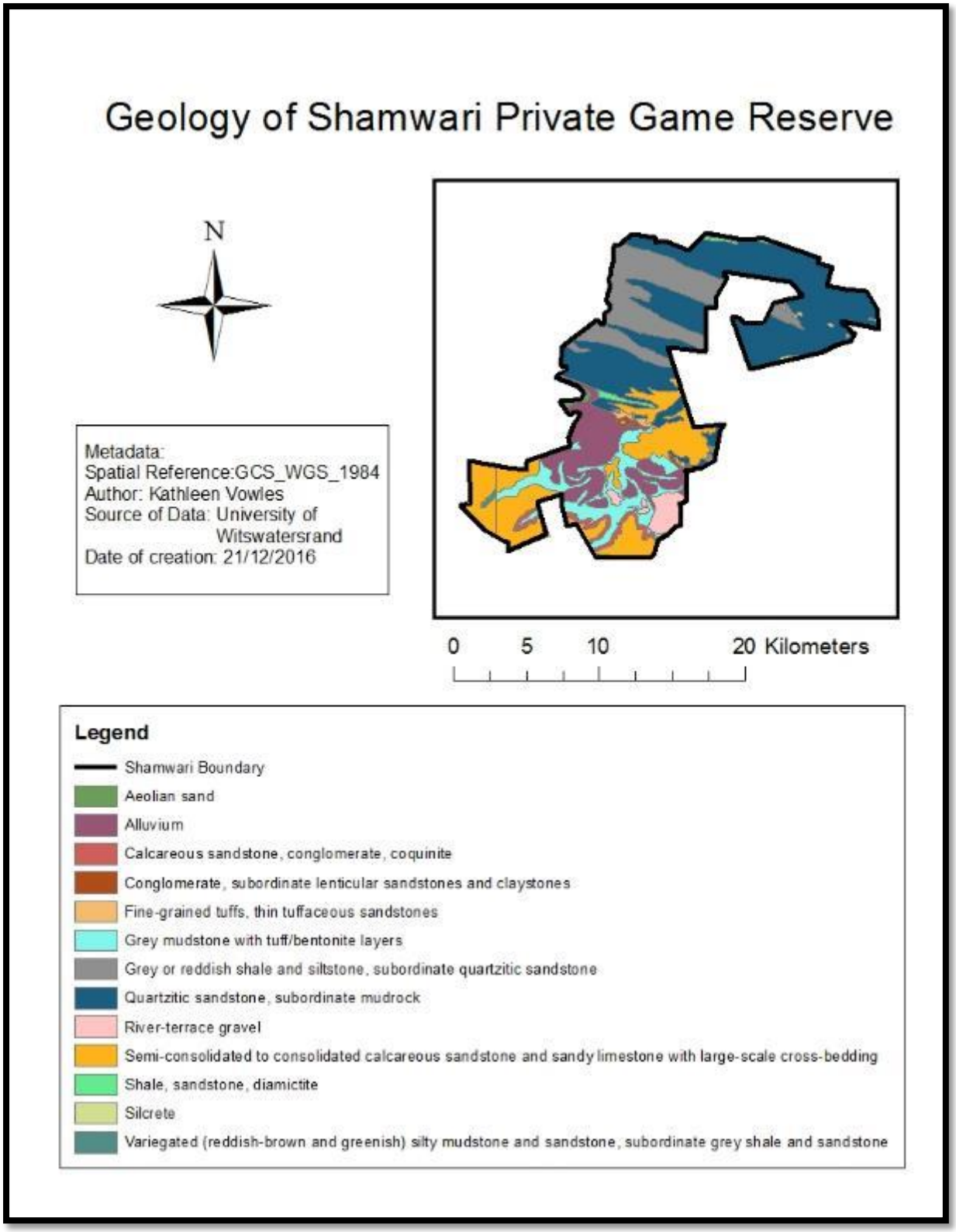
Appendix



Appendix 1: Geological map of Shamwari Private Game Reserve. Specific site locations were withheld due to the unfortunate reality of poaching in South Africa.

Joburg
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Johannesburg City Parks and Zoo (NPC)

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Johannesburg Zoo
Private Bag X13
Jan Smuts Avenue
11 April 2016

Dear: Kathleen Vowles

RE: Transportation and Deposition of sediment by wallowing animals (elephant and White Rhino)

This letter serves to confirm that your request to conduct research at the Zoo on the above mentioned title has been accepted by Johannesburg City Parks and Zoo Ethics Committee.

Please note that you will be expected to provide a calendar or time table indicating your Zoo Visitations. Johannesburg City Parks and Zoo retains the right to cancel your permit, if you do not comply with JCPZ rules.

Regards
Tshepang Makganye

Date: 11 April 2016

Acting Head of the Zoo
Chairperson: JCPZ Ethics Committee

Directors: Mr J Mabaso (Chairperson), Ms N Mogorosi, Mr JS Ngubane, Mr A Rajah, Mr M Makgonye, Mr V Leketi, Ms N Sandlana, Mr A September, Ms B Dollie, Mr B Nelana (Managing Director), Ms M Sedite (Chief Financial Officer), Ms A Shongwe (Company Secretary)

Reg No: 2000/028782/08

Appendix 2: Johannesburg Zoo permission form to conducted research within the zoo. Please note my research dissertation title has changed since the testing of camera trap casing in the elephant enclosure.

Appendix 3: Equation used in statistical analysis of data.

Equation 1: Arithmetic average (Lomax, 2007; Underhill & Bradfield, 2009).

$$A = \frac{1}{n}\sum_{i=1}^{n} \alpha i$$

Equation 2: The Pearson Correlation Coefficient (Manly, 2009; Underhill & Bradfield, 2009).

$$r = \left| \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i} - \bar{x})^2 \sum(y_i - \bar{y})^2} \right|$$

Equation 3: Regression analysis (best-fit line) (Lomax, 2007: Manly, 2009)

$$y = ax + b$$

Equation 3.1: (Manly, 2009; Underhill & Bradfield, Fitchett *et al*., 2014)

$$b = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}}$$

Equation 3.2: (Manly, 2009; Underhill & Bradfield, 2009; Fitchett *et al*., 2014)

$$a = \frac{\sum y - b\sum x}{n}$$

STRICTLY CONFIDENTIAL

ANIMAL ETHICS SCREENING COMMITTEE (AESC)

CLEARANCE CERTIFICATE NO. 2016/04/21/0

APPLICANT: Ms K Vowles

SCHOOL: Geography, Archaeology & Environmental Studies
DEPARTMENT:
LOCATION:

PROJECT TITLE: Quantity of sediment transported and deposited by elephants, rhino and warthogs from a natural waterhole after one wallowing event in Shamwari Private Game Reserve, Eastern Cape, South Africa

Number and Species

Sediment from 2 African elephants, 2 White Rhinoceros and 2 Warthogs

Approval was given for the use of animals for the project described above at an AESC meeting held on 2016/04/19. This approval remains valid until 2018/04/20.

The use of these animals is subject to AESC guidelines for the use and care of animals, is limited to the procedures described in the application form and is subject to any additional conditions listed below:

None

Signed: _____ Date: 22 April 2016
(Chairperson, AESC)

I am satisfied that the persons listed in this application are competent to perform the procedures therein, in terms of Section 23 (1) (c) of the Veterinary and Para-Veterinary Professions Act (19 of 1982)

Signed: _____ Date: 21 April 2106
(Registered Veterinarian)

cc: Supervisor: Professor J Knight
Director: CAS

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Appendix 4: Animal ethics research permission form. Please note since the start of research dissertation, my research title has changed due to limitations experienced in the field.