University of the Witwatersrand

School of Geography, Archaeology and Environmental Studies

MAMMAL UTILISATION OF ARTIFICIAL WATER SOURCES IN THE CENTRAL KRUGER NATIONAL PARK: CONTEMPORARY SEASONAL PATTERNS AND IMPLICATIONS FOR CLIMATE CHANGE SCENARIOS

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Declaration

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in the School of Geography, Archaeology and Environmental Studies at the University of the Witwatersrand. It has not been submitted for any degree or examination at any other University.

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23 August 2016

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Date

Abstract

Monitoring the status and abundance of mammals, as well as establishing threats to biodiversity in different areas, is an essential management requirement in protected areas. Monitoring mammal species can assist in determining species interactions, patterns of behaviour and is important for further research, policy and management strategies. Water provision has implications for the preservation of wildlife, and is thus a management concern. Numerous studies monitoring mammal water utilisation patterns have employed traditional data collection methods, which are restricted primarily to diurnal observation during specific time intervals. Given the projected future impacts of global climate change on regional water availability, it is essential to investigate current water usage by mammals in the Kruger National Park (KNP), so as to better ascertain likely future water requirements under climate change scenarios. The use of remote photography for scientific observation, investigation and monitoring has many potential benefits, and an innovative and relatively new method through which one can observe mammal water source visitation patterns, is through the use webcams. There has been comparatively little research on mammal water requirements and visitation patterns at water provisioning sites using remote photography as a data collection method. Further to this, there is a gap in our knowledge concerning how daily climate variables (*viz*. temperature and rainfall) and astronomical conditions control water source visitation patterns at the finer temporal scale.

This research primarily contributes to understanding contemporary water source visitation patterns and how this will influence future management decisions. At a broader scale, determining recent visitation patterns is critical in the context of projected future climatic changes and the associated water requirements for mammals of KNP. Webcam images were obtained for the period March 2012 - March 2014, captured at two artificial water sources in the central KNP. A clear divide is exhibited between herbivore and carnivore visitation patterns, with herbivores exhibiting exclusively diurnal patterns and carnivores' nocturnal patterns. Significant relationships with T_{avg} intervals demonstrate that the majority of herbivores are shifting their visitation periods earlier in the day per 5°C increase in mean daily temperature, while the majority of carnivores are shifting their visitation periods later in the night per 5°C increase in mean daily temperature, however there is variability of species responses across the two study sites. Under the highest T_{avg} interval (30°C - 35°C) impala, warthog, southern giraffe, African buffalo and plains zebra exhibit a shift to earlier visitation by 1 – 6 hours, forcing them to utilise the water sources outside of their preferred temporal range. The influence of the timing of rainfall events indicates that the mean number of individual species sightings is significantly larger on days before rainfall compared to days after rainfall. The study highlights that water-dependent herbivores utilise the artificial water sources in relative proportion to their abundance in the central KNP, while water-independent herbivores are avoiding these artificial water sources. The findings of this research could be used to supplement current water provisioning guidelines and plan for water provisioning efforts in future.

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List of Acronyms and Abbreviations

AWS – Automatic Weather Station

DWP – Drought Water-Points

ENSO – El Niño Southern Oscillation

FTP – File Transfer Protocol

GB – Gigabyte

GLTP – Great Limpopo Transfrontier Park

GPS – Global Positioning System

HOU – Houtboschrand

KB - Kilobyte

KFI – Kingfisherspruit

KNP – Kruger National Park

NP – National Park

NWA – N’wanetsi

SAEON – South African Environmental Network

SAM – Strategic Adaptive Management

SANParks – South African National Parks

SAT – Satara

SAWC – South African Wildlife College

SAWS – South African Weather Services

TPC’s - Thresholds of Potential Concern

TSB – Technical Services Boreholes

TSH – Tshokwane

WINSCP – Windows Secure Copy

mm – millimetres

T_{avg} – average temperature

T_{max} – maximum temperature

T_{min} – minimum temperature

List of Statistical Terms

r value: Pearson Correlation Coefficient - indicates the strength of a relationship. Values of r range between -1 and +1, with values of r close to -1 indicating a strong negative correlation, values of r close to +1 indicating a strong positive correlation, and values of r close to 0 indicating little or no correlation.

p value: The measure of statistical significance or confidence, determined by the strength of the correlation and the sample size.

n value: The total number of data values.

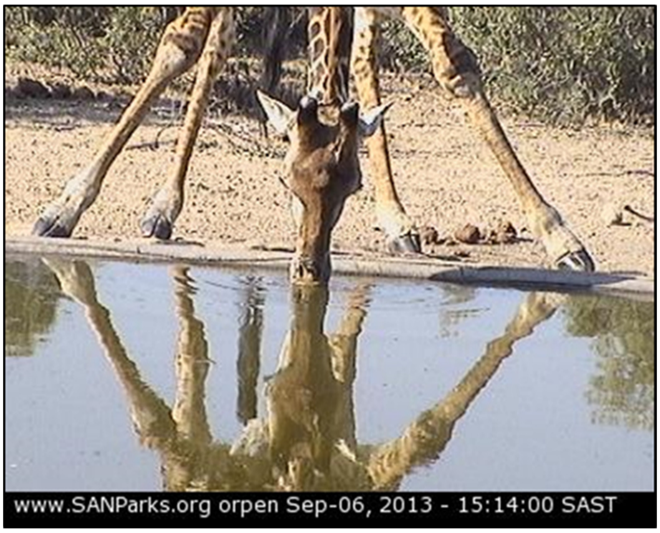
ANOVA – Analysis of variance

PCA – Principal Component Analysis

E: Electivity - ranges from -1 and +1, with negative values closer to -1 suggesting avoidance or inaccessibility; positive values closer to 1 suggest preference or active selection. A value of zero suggests random selection or neutrality.

CHAPTER ONE

Introduction



Chapter 1 - Introduction

1.1 Overview

The utilisation and management of artificial water sources in arid, semi-arid and seasonally-dry ecosystems is employed globally (Vaughan & Weis, 1999), with artificial water points providing permanent water to non-domestic animals in North and South America, Europe, Australasia and Africa. The supplementation of water, specifically in water-stressed environments, where mammals are exposed to high temperatures and challenged with seasonal shifts in the availability of this crucial resource, is especially important (Simpson *et al.*, 2011). In the arid and semi-arid regions of the western United States and Australia, water has been provisioned in areas where few natural sources of water occur thereby encouraging mammals to utilise these water-scarce areas, providing water-dependent mammals with water during the dry season, and offsetting the anthropogenic exploitation of natural water sources (James *et al.*, 1999; Rosenstock *et al.*, 1999; Marshal *et al.*, 2006).

This provision of water, in addition to fire regimes, culling programs and fencing, is a particularly important wildlife management tool in water-limited savanna ecosystems (Owen-Smith, 1996; Smit *et al.*, 2007a). Throughout Africa, particularly in water-stressed countries, a large number of protected areas have constructed water sources. Water is supplied in pans which are filled with water pumped by diesel engines, such as in Hwange National Park (Kamanda *et al.*, 2008). These artificial water sources provide the necessary water to sustain mammals, particularly in the dry season and in arid environments, and have become essential management tools in maintaining mammal populations in most African National Parks (Tefempa *et al.*, 2008).

In South Africa, many private game reserves and protected areas under South African National Parks (SANParks) management provide water to mammals: Addo Elephant National Park (Merte *et al.*, 2010), Kalahari Gemsbok National Park (Child *et al.*, 1971; Bothma, 2005), Klaserie Private Nature Reserve (Parker & Witkowski, 1999), Kruger

National Park (Smit *et al.*, 2007a), Manyeleti Game Reserve (Cronje *et al.*, 2005), Sabi Sand Reserve (Thomas *et al.*, 2008) and Tembe Elephant Park (Shannon *et al.*, 2009) amongst others.

As is typical of water provision globally and in Africa, supplementing water in (KNP) is particularly important where water is historically scarce and its availability temporally and spatially variable (Pienaar, 1970). However, the addition of artificial water sources into savanna ecosystems is a controversial issue (Owen-Smith, 1996; Smit *et al.*, 2007a; Smit & Grant, 2009); with the identification of multiple negative consequences due to the excessive supply of surface water being notably the impact on vegetation and rare antelope species from studies in KNP (Thrash *et al.*, 1991a,b; Thrash *et al.*, 1993a; Harrington *et al.*, 1999; Thrash, 1997) the Kgalagadi Transfrontier Park (Knight, 1995a), Kutse Game Reserve (Hitchcock, 1996) and Ruaha National Park (Epaphras *et al.*, 2008). Consequently, this evidence led to a recent review of water provision policies and the adjustment in the number of active artificial water sources in KNP (Cain *et al.*, 2012; Smit, 2013) and elsewhere, in Hwange National Park, the number of open artificial water points is alternated to control elephant population size (Chamaillé-Jammes *et al.*, 2007a). In contrast, it has been suggested that the number of artificial water sources be increased in the Serengeti and Waza National Parks to increase the water supply to animals and so lessen the impact on the vegetation and soil surrounding the natural sources of water in these environments (Tefempa *et al.*, 2008; Hagwet *et al.*, 2014).

Water is considered an essential resource (Pienaar, 1970), crucial to the survival of both terrestrial mammals and vegetation, and which forms the habitat for biota of aquatic ecosystems, including rivers, streams and pans (Pienaar *et al.*, 1997). The scarcity of this vital resource therefore threatens the existence and persistence of biodiversity. Water availability and supplementation thus have important implications for the preservation of biodiversity, and is a management concern in conservation areas. Despite conflicting perceptions regarding management, artificial water sources remain a necessity in conservation areas where natural permanent water is limited or absent (Smit & Ferreira, 2010).

The overarching management focus of KNP, as guided by the Objectives Hierarchy of SANParks, is to ensure the survival of animals and vegetation in a natural environment which accommodates fluctuations and variability in the system (SANParks, 2003). Water provision in KNP has a long history, dating back almost 80 years, but the management thereof has changed as knowledge has advanced. The most recent management strategy governing artificial water source provision in KNP follows an adaptive management and systems approach, defined as an evolving method of implementing interventions and gaining knowledge on how they influence ecosystems (Smit *et al.*, 2008). This approach seeks to imitate, as far as possible, the natural occurrence of surface water availability in the park (Smit *et al.*, 2008). Despite this, it is recognised in KNP and other conservation areas under SANParks custodianship that artificial water sources remain vital as protected areas are unnatural, closed systems that must protect biodiversity whilst sustaining tourism (Smit *et al.*, 2008; Venter & Smit, 2011).

Camera traps and other remote photography techniques have recently been used as novel survey tools, and have been recognised as a valuable and cost-effective technology for the study of animal abundance and density across spatial and temporal scales (Silver *et al.*, 2004; Heilbrun *et al.*, 2006; Chapman & Balme, 2010; Gerber *et al.*, 2010). However, there is a pressing need for research to comparatively evaluate the benefits of different animal monitoring techniques in conservation areas (Silveira *et al.*, 2003). The use of remote photography is an innovative method, with little published work, through which to monitor the drinking patterns of mammals, and to determine how water source use is influenced by weather, landscape and predation risk/conflict avoidance. Webcams or motion-sensor cameras overlooking artificial water sources provide an economical opportunity to undertake research with minimal disturbance to mammals. To date, there has been limited research investigating water requirements and usage habits of mammals using remote photography as a data collection method. Recent analyses of webcam imagery by Hayward & Hayward (2012) documented the timing of waterhole visitation by mammals at five southern African wildlife reserves highlighting seasonal patterns of use. However, there remains a gap in our knowledge concerning how daily climate variables (*viz.* temperature, rainfall and wind) and variability therein impact water sources usage patterns at fine temporal scales.

1.2 Background and Context

Water provision in KNP has a long history which has moved through different phases as management and knowledge have evolved. The early recognition by Warden James Stevenson-Hamilton that natural water sources were drying up in KNP led to the conception of the Water-for-Game project, which was initiated in 1933 to supply water to mammals during drought years (Stevenson-Hamilton, 1933). Implementation was done so without any specific design and it was not envisaged that providing extensive additional sources of water to mammals might have negative impacts on the ecosystem (Pienaar, 1970).

In addition to the perception that the natural sources of water in KNP were insufficient to support the mammal populations (Pienaar, 1970), the deteriorating flow and pollution of the perennial rivers in KNP in the mid 1940's provided further motivation for the provision of alternate sources of water (Pienaar *et al.*, 1997). This pollution resulted in poor water quality, whilst siltation of rivers occurred due to industry, agriculture and expanding rural populations bordering KNP (Pienaar *et al.*, 1997). In addition, artificial water sources were established due to increasing mammal density in KNP, which placed additional pressure on the remaining natural water sources. Overgrazing around permanent water sources became a feature of the landscape as mammals congregated around these sources during the dry seasons (Pienaar, 1970).

During the early 1960's, rigorous research undertaken in KNP provided information on mammal migration patterns and specific habitat needs of mammals, particularly for rare or threatened species. Counteracting the migration of mammal populations to water resources outside of the park became essential following the erection of fences, which started in the early 1960's (Pienaar, 1970). This increased knowledge and more focused objectives reshaped the principles of the Water-for-Game project, which aimed to i) encourage mammals to stay in the park during the dry season, ii) to expand the grazing extent of mammals, and iii) to increase the density of mammals in KNP (Pienaar, 1970). A revised approach detailed:

- Preserving and securing natural water sources;
- Supplementing water only in areas where natural sources of water occurred;
- Building dams only if they had the potential to supply water to mammals throughout a drought period and if they accommodated the needs of a range of different animals; and
- Constructing concrete basins to minimise water loss through evaporation (Pienaar, 1970).

In 1997, the water provision policy in KNP was further revised (Pienaar *et al.*, 1997) due to the recognition that the extensive provision of water to mammals was having various negative impacts on the environment and on specific species (Smit, 2013): *viz.* the impact on vegetation (Thrash, 1998a; Thrash *et al.*, 1993a) and soil (Thrash, 1997), surrounding artificial water sources due to overgrazing and a decline in roan antelope population numbers (Harrington *et al.*, 1999). The overall goal of the revised water distribution policy for KNP was to replicate a more natural pattern of water supply to mammals that would both support animals whilst still providing tourists with opportunities to view game congregating around water sources during the dry season (Pienaar *et al.*, 1997).

The current systems approach to managing water provision in KNP promotes a more natural distribution of water supply in order to imitate the natural variability of water availability in different months, seasons and years in different areas of the park (Smit *et al.*, 2008). In line with this, KNP management has redressed the widespread and uniform water provision efforts of the past since the late 1990's through active and selective water source and dam decommission and/or destruction (Smit, 2013).

The principles guiding the current provision of artificial water in KNP can be summarised as follows:

- Natural water sources are reliant on rainfall;
- Wet and dry periods due to the cyclical rainfall patterns influence surface water availability;
- KNP is no longer a completely natural system, with the movement of animals constrained within the park; and
- External influences impact on the quantity and quality of water in perennial rivers of KNP (Pienaar, 1970; Pienaar *et al.*, 1997).

The current water provision policy for KNP supports the continued closure of a number of artificial water sources in accordance with knowledge gained and the ‘learn-by-doing’ adaptive management approach (Smit, 2013). Three main guidelines are used by park management when considering the supplementation of water in KNP:

- Water should not be provided in areas where natural sources of water do not occur;
- Water should not be provided uniformly across the landscape, which would influence natural distribution patterns of mammals; and
- Water should be provided under extreme climatic conditions, where human-induced constraints affect the natural availability of water in the park (Pienaar *et al.*, 1997).

In line with these guidelines, water points and dams in KNP have been evaluated according to specific criteria to determine whether they should be closed to animals permanently, closed temporarily, to remain operational, or be used for other management purposes (Pienaar *et al.*, 1997). The latter includes boreholes that are no longer operational as drinking points, but are reserved for use by technical services for road works or other maintenance purposes (Zambatis, pers comm, 2015). The decision to close a number of dams in KNP is due to the negative impacts that dams have on the river system, not providing a suitable, natural habitat for aquatic biota, their visually unappealing presence in a natural environment (Pienaar *et al.*, 1997). Additionally, during drought, dams dry up and the concentration of water-dependent herbivores that have artificially built up around the dams move to natural water bodies with the consequent oversaturation of natural water sources such as rivers/pools.

The systematic closure of water points and dams has been a simultaneous process, with the areas in which these structures were placed being rehabilitated (Pienaar *et al.*, 1997). Approximately 230 of the 365 boreholes will eventually be permanently closed under the revised water provision policy and approximately 50 boreholes will be temporarily closed, used as standby water sources with possible re-opening under adaptive conditions. Water will not necessarily be supplemented uniformly across the landscape during water shortage situations; the current thinking being to provide water, as far as possible, in areas where it occurs naturally (Zambatis, pers comm, 2015). The process of curtailing the extensive artificial water supply in KNP and determining which water sources be permanently or only temporarily decommissioned is complicated as many different factors need to be considered (Smit, 2013). Popular tourist water points, which occur near roads and where there are no significant environmental impacts, will remain operational (Pienaar *et al.*, 1997). If a natural river pool exists in a location near to a water point, the natural river pool will be used as an alternative for both animal drinking purposes and tourist benefit, and the artificial water point will be closed (Zambatis, pers comm, 2015). A timeline summary of water provision in KNP is presented in *Table 1.1*.

Table 1.1 History of water provision in Kruger National Park, 1930 - 2015.

Year	Activity of the Water-for-Game project
1933	• Public effort to raise money in order to drill boreholes in waterless areas (Stevenson-Hamilton, 1933). • The drilling of boreholes commenced in September 1933, with the first borehole sunk at Pretoriuskop rest camp (Pienaar, 1985). • Four boreholes completed by the end of that year (Stevenson-Hamilton, 1933).
1935 - 1939	• Construction of the Kumane earth dam was completed in 1935 (Pienaar, 1985). • Boreholes at Gudzane, Bangu, Shivulani, Ngwenyene, Malopene North and the Malopene Gate were drilled (Pienaar, 1985). • In 1937 two earth dams were constructed on the Mooiplaas Vlei and Dzombo Spruit and construction of the Folly dam was completed (Pienaar, 1985). • In 1939 windmills were constructed at Stangene, Babalala, Nwarihlangari South, Nkulumbene North, Nwashitsumbe North, Dzombyane, Mashikiri, Masandje, Nkovakulu and Klopperfontein (Pienaar, 1985).
1940 - 1945	• By the end of 1940, six dams had been built, and thirteen boreholes and eight wells had been drilled (Pienaar, 1970). • Eileen Orpen dam and Mlambane dam were built in 1944 (Pienaar, 1970; Pienaar, 1985). • In 1945 two concrete dams were constructed in the Isweni River and Tsange (Pienaar, 1985).
1949 - 1951	• Funds were raised which enabled the Water-for-Game project to continue and for more boreholes to be drilled (Pienaar, 1970; Pienaar, 1985). • Fifty-one new boreholes were drilled in 1950; however, only 46 provided water. • An additional 8 boreholes were drilled in 1951 (Pienaar, 1970; Pienaar, 1985). • Construction of the Mlondozi dam was completed in 1951 (Pienaar, 1985).
1952	• Concrete weirs were erected on several seasonal rivers, forming the Gudzane, Mlondozi and N'Wanetsi dams (Pienaar, 1970), along with the construction of the Lindanda, Ngotsa, Nguweni, Bangu No.1, and Bangu No.2 concrete dams (Pienaar, 1985). • Two boreholes were sunk (Pienaar, 1985). • A total of 56 boreholes completed the borehole project at this stage (Pienaar, 1985).
1954	• In 1954 two earth dams were constructed at Naphe Spring and Matukwala (Pienaar, 1985).
1955	• Board of Trustees agreed that additional dams and boreholes were needed, particularly along the western boundary to encourage animals to stay in the park (Pienaar, 1970; Pienaar, 1985). • Biyamiti and Phugwane concrete dams constructed (Pienaar, 1985).
1956 - 1960	• Construction of Klopperfontein dam and Ngwenyeni dam completed in 1956 (Pienaar, 1985). • Earth dams constructed at Lipape, Mhlanganzwane, Bubube, Vutomi, Pswaeni and Mpanamana (Pienaar, 1985). • Construction of the Shisakashangodzo dam completed in 1958 (Pienaar, 1985). • In 1960, two concrete dams constructed on the Tswiriri and Nwanitsana spruits and two gauging-weirs were erected on the Biyamiti and N'Wanetsi rivers (Pienaar, 1985).

1961 - 1970	• Research supports the drafting of a more formal water provision plan (Pienaar, 1970). • Boreholes at Shiyanamane, Vlakgesicht, Nwatindlofu, Ngwanutsatsa and Kolwane were drilled to support animals during the severe drought period (Pienaar, 1985). • Construction completed on 14 earth and concrete dams (Pienaar, 1985). • Engelhard dam was built in 1970; the Olifants-Satara pipeline and 3 earth dams were built on the Mtshawu, Nyamundwa and Mareya spruits (Pienaar, 1985).
1971 - 1977	• The Water-for-Game project continued through the wet period of 1971 - 1977, with earth dams built on the Newu, Stolsnek, Mpondo, Mashengane, Nkulumbeni north, Kokodzi, Mashokwe, Manzemba, Dzombo, and Maswitakali spruits (Pienaar, 1985). • Large concrete dam constructed at Sirheni in 1971 (Pienaar, 1985). • In 1972 the Wik-en-Weeg dam was built (Pienaar, 1985). • In 1973 construction of the Pionier dam and Mingerhout weir was completed and the construction of the Black Heron weir commenced (Pienaar, 1985).
1981 - 1990	• Early 1980's the drilling of boreholes was completed (Pienaar, 1985). • The Mulalane Spruit was dammed in 1981 and the Silwervis dam was completed in 1982 (Pienaar, 1985). • Initiation of KNP Rivers Research Program in 1987 (Pienaar *et al*., 1997). • In 1988 the first solar-energy pumps were fitted at boreholes (Pienaar *et al*.,1997) • During the 1980s and beginning of the 1990s it was recognised that the extensive provision of water throughout KNP had a range of negative impacts on the environment (Smit, 2013).
1994	• Twelve artificial waterholes were closed and the Stangene earth dam was emptied (Pienaar *et al*., 1997; Grant *et al*., 2002).
1995	• In total, 365 boreholes had been drilled and 50 earth dams had been constructed between 1933 and 1995 (Gaylard *et al*., 2003).
1997	• Revision of KNP water provision policy (Pienaar *et al*., 1997; Smit, 2013). • Recommendation that 132 boreholes be closed and 151 boreholes remain operational; during phase one of the revised water-distribution policy (Pienaar *et al*., 1997).
2011	• Approximately 200 of the 365 boreholes constructed decommissioned since the revision of the water provision policy in 1997 (Venter & Smit, 2011).
2012	• Immediate closure approved for 6 concrete weirs, 7 concrete dams and 11 earthen dams (Zambatis, 2012). • Closures of water points, dams and weirs carried out simultaneously, and the process of closing down structures determined by availability of funds and a workforce to complete rehabilitation (Zambatis, pers comm, 2015).
2014	• Process of decommissioning waterholes continues
2015	• 34 re-commissioned water points and an additional number of water points to remain open, are currently operational or kept in reserve to supplement water during a drought, or to provide water for alternate management activities (Zambatis, pers comms, 2015). • By the end of 2015, 5 earthen dams to be closed and 8 earthen dams, 1 rock dam and 1 fountain to be closed with alternative access to natural water sources provided (Zambatis, 2012).

1.3 Problem Statement

Managers of conservation areas worldwide are confronted with many challenges. These have become increasingly multifaceted over recent decades and must consider the diverse nature of the abiotic and biotic environment under custodianship, the increasing requirements of tourists, population growth and the need for more land for development, and the threat of global climate change (Venter *et al.*, 2008). The adaptive management approach, as employed by SANParks, takes into account possible but unaccounted for changes in the social, political, economic, environmental and political landscape, and the transformation of knowledge and principles (van Wilgen & Biggs, 2011). Whilst socio-political changes are less easily forecast, understanding current water use requirements by mammals in KNP under contemporary climatic conditions is essential in projecting future impacts of global climate change on water availability.

Global climate change will impact different regions in different ways and certain regions, such as southern Africa, are especially susceptible to the impacts of a changing climate (Magadza, 1994). Research on climate change and its impacts in southern Africa indicate that "... South Africa is likely to experience substantial climate change in the next decades and that the effects of this change, especially on biodiversity, will be dramatic" (van Jaarsveld & Chown, 2001). Of the multiple consequences that are projected to occur due to extreme changes in climate in coming decades, availability and the quality of water are major concerns (Davis, 2010). Future climate change will have a direct impact on water supply as the climate system and the earth's hydrological cycle are closely linked (Davis, 2010), and the hydrological cycle is significantly influenced by even slight shifts in the climate system (Scholes & Biggs, 2004).

The lowveld region of north-eastern South Africa, where KNP is located, is an area that is already compromised due to limited water resources (Moon *et al.*, 1997). Climate change and extreme changes in temperature and precipitation are likely to cause additional water stress in this already water sensitive area. The lowveld is associated with variation from extreme drought periods to periods of heavy rainfall (Mason, 1996). Even minor changes in rainfall in this area due to climate change are expected to significantly affect the occurrence and severity of drought periods (Mason, 1996). The likely future temperature and rainfall projections for north-eastern South Africa include increases in maximum, mean and minimum temperatures, increases in the number of annual rain days, and an increase in the mean annual rainfall (Davis, 2010). The quantity of water available is determined by the amount of rainfall received and by evaporation rates (Scholes & Biggs, 2004). Although it is envisaged that rainfall is likely to increase, it is also expected that evaporation rates are likely to increase disproportionally due to increasing temperatures (Davis, 2010); reducing both surface water quantity and the duration of availability. In African savanna ecosystems, with their distinct wet and dry seasons, rainfall is an important driving force in the system (Mills *et al*., 1995), influencing species population numbers amongst other things (Ogutu & Owen-Smith, 2003). Increasing global temperatures are expected to enhance dry season drought conditions in savannas through increased evaporation, intensifying water-stress for animals and vegetation (Ogutu & Owen-Smith, 2003). Management in conservation areas need to consider that shutting down artificial water sources may influence not only the adjusted behaviour of mammals in their movement patterns and habitat ranges, but also the impact of changing regional rainfall patterns which will further significantly affect water quantity and availability, thus impacting on mammals and their water-use behaviours. (Ryan & Getz, 2005).

1.4 Research Rationale

It is becoming increasingly more important for conservation areas to incorporate information on climate change/variability into management strategies, and to understand the likely effects such change/variability may have on mammal behaviour and distribution patterns, health and population biology. It is also crucial that relatively cheap, reliable methods of monitoring mammals be identified (Silveira *et al*., 2003) and tested. This study therefore aims to demonstrate that webcam imagery can be used as a reliable data source from which to answer valid scientific questions related to drinking ecology and climate change. Any management decisions taken at present need to have considered future challenges and need to have been informed by knowledge gained from question-driven research (Venter *et al*., 2008). To this end, management and decision-makers could utilise information on water source reliance and mammal behaviours to supplement their current water provisioning guidelines and plan for water provisioning efforts in future, in view of the projected climate change impacts in conservation areas.

It has been projected that by 2050, 69% of South African mammals could be under threat of extinction due to mid-range climate change (Thomas et al., 2004), whilst 66% of mammal species in KNP may be at risk of extinction (Erasmus et al., 2002). Climate change will have multiple impacts on biodiversity, initiating shifting rainfall patterns, increasing extreme climatic events such as droughts and flooding and altering El Niño cycles (Hannah et al., 2002), which will consequently influence the distribution of water. In light of the predicted pressures on water availability due to global climate change, there are certainly going to be implications for mammal water-use behavior. Mammals will need to contend with both increasing temperature and changing rainfall patterns, and consequently increased evaporation, therefore resulting in changes in drinking water distribution and availability. The number of days which fall either side of species thermal tolerance ranges, are likely to increase (Parmesan et al., 2000).

Consequently, these predicted changes are likely to drive responses in mammal behaviour, over daily, monthly, seasonal and annual time scales, and thus their potential to tolerate changes in climatic conditions will be based on adjusting activity patterns in relation to extreme and variable temperature and rainfall conditions (Shrestha et al., 2014). Knowledge on mammal reliance on artificial water sources, and thus their water requirements, as well as other behaviours, is crucial to understanding how mammals are impacted by climate change (Fuller et al., 2014). Recent findings by van Wilgen et al. (2015) reported that the temperature increases within various SANParks already exceed the projected temperature increases for specific regions in southern Africa. Thus suggesting that mammals within these protected areas are currently being influenced by climate change (van Wilgen et al., 2015). An increase in mean minimum and maximum temperatures has also been reported for KNP. Additionally, across the majority of national parks there has been an increase in days with temperatures > 35°C, which will likely impact existing water sources (van Wilgen et al., 2015).

It has also been noted that rainfall is moving towards a more erratic seasonal pattern, particularly in KNP and Mapungubwe National Park, and consequently extended dry periods (van Wilgen et al., 2015). The intensification of shifting rainfall patterns due to climate change is likely to influence mammal populations particularly in semi-arid and arid national parks and game reserves (Hulme, 2005; Owen-Smith & Ogutu, 2012), as this is likely to affect both water availability and distribution. Variable annual rainfall patterns can greatly restrict the number of mammals that an environment can support, thus having an impact on mammal populations (Hulme, 2005). It is likely that mammals which depend on water for drinking as well as for thermoregulation purposes, may be more influenced by shifting rainfall patterns, as the availability of pools of water may be restricted during periods of low rainfall. Extended dry periods due to a reduced rainfall season, as well as increasing mean minimum and maximum temperatures (van Wilgen et al., 2015) has consequences for water-dependent species and their physiological water requirements. Therefore, the supplementation of water through artificial water sources is important to maintain mammal population numbers (Chamaillé-Jammes et al., 2007b).

1.5 Study Aims and Objectives

The primary aim of this research is to determine recent (March 2012 – March 2014) patterns of water source utilisation for mammal, and species-associations, under contemporary climatic conditions, using complete, high temporal resolution webcam imagery in the central KNP (*Figure 1.1*). Embedded within this is the aim to expand our knowledge of climate-related mammal drinking and water-use trends by utilising a unique wildlife monitoring methodology.

1.5.1 The Specific Aims are:

- To determine the extent to which different climatic and environmental conditions - in particular extreme climatic events – influence the temporal usage of artificial water sources by mammals in the central KNP.
- To compare three scales of mammal census data for the Satara area of KNP, using site (webcam imagery), area (local counts conducted by co-workers) and regional (aerial census data provided by SANParks) mammal abundance data.

1.6 Objectives

1.6.1 Water Source Visitation Patterns

- To track mammal visitation patterns at two artificial water sources, over a 24- and 25-month period using remote imagery, in the central KNP.
- To establish mammal water source visitation patterns (daily and monthly) and reliance under 'normal' rainfall and temperature conditions and more particularly under 'extreme' (any conditions that fall outside of the standard deviation for the data analysed) climate conditions.
- To establish mammal water source utilisation behaviour patterns (daily and monthly) under 'normal' rainfall and temperature conditions and more particularly under 'extreme' climate conditions.
- To establish whether various mammals utilise the artificial water sources in proportion to their abundance in the area or if specific mammals favour or avoid these artificial water sources.
- To determine the impact of various other environmental conditions (sunrise, sunset and moon phases) on water source visitation patterns and behaviours.
- To forecast water source visitation patterns based on specific climate projections for eastern South Africa.

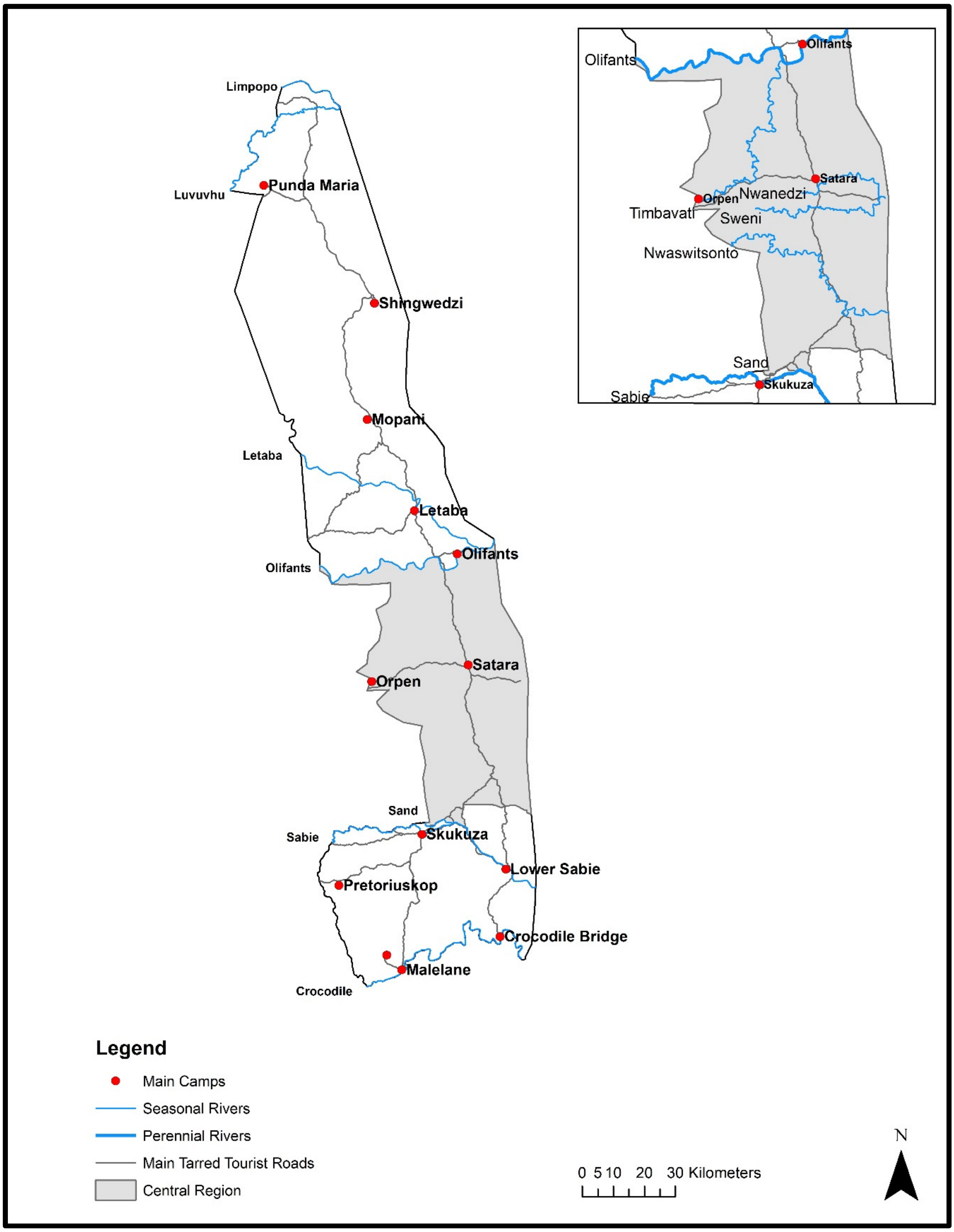


Figure 1.1: Map of the Kruger National Park, indicating the main rest camps, main tarred tourist roads and main perennial rivers. An inset map indicates the study region (the central part of the park), the two study sites (Orpen and Satara), the main tarred tourist roads and seasonal rivers.

CHAPTER TWO

Environmental Setting

Chapter 2 - Environmental Setting

2.1 Introduction

This research dissertation is a desk-top study focused on KNP, South Africa – specifically using imagery captured by webcams at the centrally-located Satara and Orpen artificial water sources to improve understanding of mammal water-use requirements under, in particular, extreme climatic conditions. KNP is known globally due to the large area under conservation and is considered heterogeneous due to various geological constituents, the alternating wet and dry periods, the abundant mega-fauna and the important regulatory function of fire in the system (Pickett *et al.*, 2003). This chapter provides an overview of the landscapes within central KNP, with a particular focus on water in the landscape and water provisioning, climate, and mammal distribution and abundance. There is an interaction between components in the different landscapes, with climate, geomorphology/topography, geology and soils and water in the landscape influencing vegetation composition, thus impacting on mammal distribution and abundance within these areas in central KNP (*Figure 2.1*).

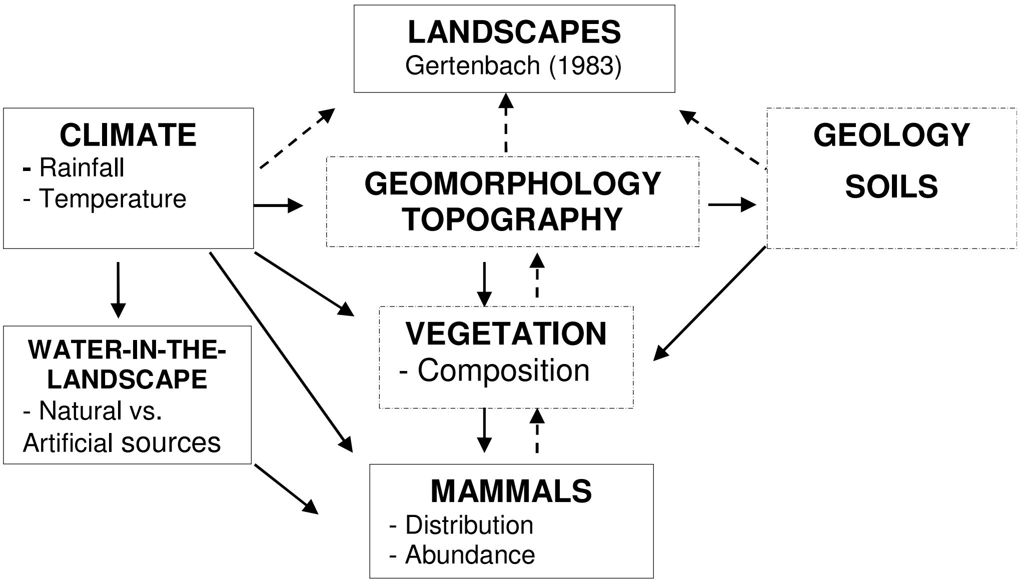


Figure 2.1: Schematic representation of the abiotic and biotic components within the different landscapes, which impact mammal distribution and abundance in central Kruger National Park. The dashed arrows link the components in the Gertenbach (1983) landscape classification system.

2.2 Regional Description of the Lowveld

The lowveld region of South Africa is bounded by the Drakensberg Escarpment to the west, the vast Mozambique coastal plain to the east (Venter *et al*., 2003), the Soutpansberg Mountain range in the north and the Kingdom of Swaziland in the South (Pollard *et al*., 2003). KNP occupies a large proportion of the semi-arid lowveld and straddles the Limpopo and Mpumalanga provinces. International borders with Mozambique and Zimbabwe provide the eastern and northern park boundaries, respectively. The north-western, south-western and southern boundaries of KNP abut densely populated settlements (Venter, 1990). The Gonarezhou National Park in Zimbabwe and the Limpopo National Park in Mozambique have been unified with KNP to form the Great Limpopo Transfrontier Park (GLTP) (Freitag-Ronaldson & Venter, 2008). Adjacent to the southern border of KNP there is large-scale intensive crop production including sugarcane, citrus and other sub-tropical fruits and vegetables, as well as cattle ranching (Grossman & Gandar, 1989).

2.3 SANParks / Kruger National Park Conservation and Management Mandate

In KNP, research and management are closely linked (Mabunda *et al*., 2003), with research playing an integral part in changing management objectives and instituting management policies and practices over the years. Throughout the history of KNP, the main aim of management has been to conserve the rich diversity of animals and vegetation and maintain the ecosystems, as far as possible, in their natural and unspoilt condition (Joubert, 1986). During the 1920’s and 1930’s, the management of wildlife was driven largely by two conflicting perspectives; those of the national park and those of scientists, which included veterinarians (Carruthers, 2008). The initial challenges that park warden Colonel Stevenson-Hamilton faced in managing the mammals of KNP were extensive drought periods, low numbers of mammals and damaging wildfires. These three particular management issues (*viz.* water provision, controlling mammal populations and burning) consequently shaped much of the management history in KNP prior to the 1990's (Joubert, 1986). Social and political transformation of the 1980’s, as well as adjustments in opinions on how ecosystems should be managed, led to a more hands-off, less 'excessive' approach in managing KNP (Mills *et al.*, 2003). The main management interventions have been culling of both carnivores and herbivores, which is no longer carried out; artificial water provision, which is currently being reduced; fencing the park, which has been removed between the park and private reserves; burning of vegetation every three years, which is now done in a more adaptive manner; and the construction of roads and firebreaks (Eckhardt *et al.*, 2000).

Past animal population regulation practices in KNP involved the reduction in numbers of predators from the early 1900's through to the 1960's, due to declining ungulate population numbers; herbivore population reductions during the 1960's and 1980's, due to the overutilization of habitat by high density species (Freitag-Ronaldson & Foxcroft, 2003), and the culling of approximately 16,000 elephants during the period between 1966 and 1994 to maintain the numbers at ~7,000 (Venter *et al.*, 2008). Water provision, through the establishment of ~365 artificial waterholes and ~70 dams, aimed to augment water during drought periods throughout the park (Pienaar, 1970). The management of both mammal populations and water provision in the park has subsequently changed under the new KNP management strategy.

During the period 1995 to 2000, KNP adopted a new adaptive management strategy, specifically Strategic Adaptive Management (SAM), which incorporates the notion of spatial and temporal heterogeneity in the landscape (Venter *et al.*, 2008). SAM involves the process of establishing a program in which to monitor the state of the environment using specified limits called Thresholds of Potential Concern (TPC's) (Mills *et al.*, 2003), which facilitate management decisions in achieving a 'desired ecosystem state' (Venter *et al.*, 2008). SAM is a progressive and adaptive management strategy, in which the contribution of scientific knowledge is fundamental (Biggs & Rogers, 2003). The underlying principal of the strategy is to 'learn-by-doing', using relevant *scientific* information and adapting management decisions accordingly (Roux & Foxcroft, 2011).

Under SAM, a hierarchy of objectives prioritise the management goals of KNP, and these objectives fall under the over-arching aim of the park (Biggs & Rogers, 2003).

Current management thinking on elephant population regulation practices, using SAM principals, is that by returning the temporal and spatial availability of resources (i.e. water distribution) to a more natural distribution across the landscape will promote a more natural population response to environmental factors (SANParks, 2012). Similarly, current management thinking on water provision in the park involves a systems approach under the broader SAM, in which the main management aim is to, as far as possible, simulate a natural pattern of water distribution throughout the park (Smit *et al*., 2008), leading to the wide-scale closure of both artificial water sources and artificial dams (Venter *et al*., 2008). There is a large contrast in water provision between KNP and the western private protected areas directly west of Orpen, with water point density significantly higher in the private protected areas compared to KNP (Child et al., 2013).

Management of KNP is facing enhanced challenges during the 21st century; predominantly social factors and global environmental concerns, including climate change and nitrogen-deposition originating from outside the park (Venter *et al*., 2008), as well as the concern of bush encroachment as a result of CO_2 fertilization (Bond & Midgley, 2012; Smit & Prins, 2015). A forward-looking management strategy such as SAM is therefore necessary when considering the potential future impacts that are likely to affect the conservation efforts of KNP.

2.4 Water in the Landscape and Water Provisioning

Due to topographic differences and the underlying geology in KNP, the density of streams is higher on the western granite than in the eastern basaltic plains (Venter & Bristow, 1986). The natural surface water sources of KNP are classified as either riparian (*viz.* rivers, streams, pools and wetlands) or savanna (*viz.* springs, pans and vleis), with specific riparian and savanna sources providing the only permanent sources of water (Gaylard *et al*., 2003). Ten main river systems cross the lowveld (Partridge *et al*., 2010), with seven major rivers entering and, together with their tributaries, draining KNP from west to east (Venter & Bristow, 1986). From north to south, these include the Limpopo, Luvuvhu, Shingwedzi, Letaba, Olifants, Sabie and Crocodile Rivers. With the exception of the Shingwedzi, the aforementioned rivers are classified as perennial (Eckhardt *et al*., 2000). Increasing pressure has been placed on these rivers due to water extraction external to the park, primarily for large- and small-scale crop farming, industry and forestry, which consequently diminish flow in the river systems (Moon *et al*., 1997). The riparian vegetation surrounding major rivers in KNP has been impacted by recent flood events, especially along the Sabie, Shingwedzi and Olifants Rivers (Viljoen, 2015).

There are also a number of ephemeral rivers throughout KNP - such as the Shingwedzi, which only flow during the wet season (Venter & Bristow, 1986); however, pools and pans which have developed in the riverbed caused by flooding may provide a permanent source of water throughout the dry season (Viljoen 2015). Natural ephemeral water sources in KNP are spatially and temporally variable and are largely dependent on preceding catchment-level rainfall. During years when rainfall exceeds the average, a number of pools hold water and even seasonal rivers continue to flow during the dry season, conversely, in years of below average rainfall, water availability may be restricted to only a small number of deep pools during the dry season (Gaylard *et al*., 2003).

Four main seasonally flowing rivers in the central region include the Nwaswitsonto, Sweni, Nwanedzi and Timbavati. Numerous dams and artificial water sources were constructed throughout the park, of which ~110 were established in central KNP (Gaylard *et al*., 2003). Many of these dams and artificial water sources are in various stages of closure under the revised water provision policy (Pienaar *et al*., 1997) (*Table 2.1; Table 2.2*); specific artificial water sources will be closed in the short- (by the end of 2015) to long-term (by the end of 2020).

Table 2.1: The closure schedule for five artificial dams in the Kingfisherspruit and Satara ranger sections in central Kruger National Park (Zambatis, 2012).

Section	Name	Type	Closure Schedule
Kingfisherspruit	Hartbees Fontein	Earthen dam	Closed, no alternative
KFI	Rabelais	Earthen dam	Closed, with alternative
KFI	Shimangwaneni	Earthen dam	Closure by 2020, with alternative
KFI	Shisakarangondzo	Concrete dam	Closed, no alternative
Satara	Marheya	Earthen dam	Closure by end of 2015, no alternative

Table 2.2: The closure schedule for twenty artificial water-points, six water-points earmarked as technical services boreholes and four drought water-points in the Kingfisherspruit and Satara ranger sections of central Kruger National Park (Zambatis, 2012).

Section	Name	Status	Closure Schedule
Kingfisherspruit	Eileen	Closed	To remain closed
KFI	Fairfield	Open	Closure by end of 2015, with alternative (TSB)
KFI	Kolwana	Closed	To remain closed
KFI	Leeubron	Open	Closure by end of 2015, with alternative (TSB)
KFI	Mahlabyanini	Closed	To remain closed
KFI	Mondzweni	Closed	To remain closed
KFI	N'wamatsatsa	Closed	To remain closed
KFI	N'watinhlarhu	Closed	To remain closed
KFI	Rabelais	Open	Closure by end of 2015, with alternative (TSB)
KFI	Red Gorton	Closed	To remain closed
KFI	Talamati	Closed	DWP
KFI	Timbavati	Closed	To remain closed
KFI	Tswaene	Closed	To remain closed
Satara	Girivana No2	Closed	DWP
SAT	Mapetane	Closed	No alternative
SAT	Marheya North	Closed	To remain closed
SAT	Mavumbye	Closed	No alternative (TSB)
SAT	MhisanaMond	Closed	DWP
SAT	Milaleni	Closed	To remain closed
SAT	Muzandzeni	Open	Closure by end of 2015, with alternative (TSB)
SAT	Nkambana	Closed	To remain closed
SAT	Nsemani	Closed	To remain closed
SAT	Ntomeni	Closed	To remain closed
SAT	N'wanetsi East	Closed	To remain closed
SAT	Rizandzeni	Closed	To remain closed
SAT	Rockvale	Open	Closure by end of 2015, with alternative (TSB)
SAT	Shibotwana	Open	DWP
SAT	Shishangani	Open	Closure by end of 2015, with alternative
SAT	Sweni	Open	Closure by end of 2015, with alternative

It is proposed that alternative water-points be provided in different areas with the construction of loop roads, or in some cases such existing roads being closed. Certain artificial water sources will remain open (*Table 2.3*), whilst others will be closed as water-points but may continue to be used as Technical Services Boreholes (TSB) or Drought Water-Points (DWP), and thus be maintained and used in the event of serious drought (*Table 2.3*) (Zambatis, 2012). The two study sites (Orpen and Satara) are located within the Kingfisherspruit and Satara ranger sections (*Figure 2.2*) which have both benefitted from a fair amount of artificial water provision in the past and have likely supported higher mammal densities than would occur naturally due to increased surface water availability.

Table 2.3: Ten artificial water-points and ten artificial dams to remain open or to become drought water-points in different ranger sections of central Kruger National Park (Zambatis, 2012).

Section	**Name**	**Type**	**Status**
Houtboschrand	Bangu	Borehole	Open (DWP)
HOU	Piet Grobler	Concrete dam	Open
Kingfisherspruit	Ngwenyeni	Concrete weir	Open
KFI	Ngwenyeni No1	Borehole	Open
N'wanetsi	Gudzani	Concrete dam	Open
NWA	Kumana	Borehole	Open (DWP)
NWA	Kumana	Earthen dam	Open
NWA	N'wanetsi	Concrete dam	Open
NWA	Wenela	Concrete weir	Open
Satara	Girivana No3	Borehole	Open
SAT	Ngotso South	Pipeline trough	Open
SAT	Nsemani	Earthen dam	Open
SAT	Shidzidzi	Pipeline trough	Open
SAT	Welverdiend	Borehole	Open (DWP)
SAT	Witpens	Pipeline trough	Open
Tshokwane	Manzimhlophe No1	Borehole	Open (DWP)
TSH	Mazithi	Earthen dam	Open
TSH	Orpen	Concrete dam	Open
TSH	Shiteveteve West	Borehole	Open
TSH	Silolweni	Earthen dam	Open

2.5 Climate of South Africa and Kruger National Park

2.5.1 Temperature

KNP has a temperature gradient from relatively cooler conditions in the south (temperate climate) to warmer conditions in the north (tropical and subtropical climate) (Mabunda *et* *al*., 2003; Venter *et al*., 2003). High temperatures are experienced in the summer months, which average over 30°C, with maximum temperatures frequently exceeding 40°C. Temperatures in KNP are usually warm due to its subtropical location and low altitude (Venter *et al*., 2003). The primary cause of high temperatures experienced in KNP is the high level of solar radiation, with consequent high evapotranspiration rates (Venter *et al*., 2003). On the 26 February 1992, a record maximum temperature of 48°C was recorded at Shingwedzi in northern KNP, whilst the maximum temperature recorded on this day in central KNP (for Satara) was 45.2°C (Zambatis & Biggs, 1995).

Autumn is warm and winters are mild and usually free of frost, due to the anticyclone which persists over the centre of South Africa during this time (Venter & Gertenbach, 1986). During the winter months (June - August), a high pressure system develops over South Africa which is conducive to warm days, clear skies and cold nights, with little rainfall over the interior and eastern part of the country (Davis, 2011). Cold conditions manifest from cold frontal systems which pass over South Africa in the winter months (Venter & Gertenbach, 1986). The average minimum winter temperature for central KNP is ~10°C, however, temperatures can reach near freezing.

2.5.2 Precipitation

As is typical to savannas, the climate alternates between annual wet and dry periods (Grossman & Gandar, 1989), consequently, rainfall has important influences on surface water availability, vegetation growth and associated food supply to herbivores in these environments (Ogutu & Owen-Smith, 2003). During the summer months, due to instability in the atmosphere, KNP receives most of its rainfall in the form of convective thunderstorms (Venter *et al*., 2003). However, the mean annual rainfall decreases from south to north and from east to west (Gertenbach, 1980), excluding the far northwest and southwest, where rainfall is controlled by topography (Venter *et al*., 2003). Rainfall distribution over the country is uneven, with the western side of the country broadly receiving less rainfall than the east (Davis, 2010).

The long-term (approximately 54 years) mean annual rainfall for Satara is 543.7mm (Zambatis, 2003). The majority (~80%) of rain falls between October to March (Owen-Smith & Ogutu, 2012). Conversely, the dry season extends from April to September (Owen-Smith & Ogutu, 2012), during which time seasonal water sources dry up and water-dependent mammals shift their drinking to artificial water sources and semi-permanent water sources (Thrash, 1998b). The summer months of December - February are the wettest on average, with the largest volumes of accumulated rainfall, whilst the winter months of June - August receive little, if any rain. The rainfall pattern in KNP is cyclical, moving between periods of above and below the long-term average, approximately every 8 to 14 years (Zambatis, 2003). This has implications for plant and mammal species, especially during severe drought periods (Venter, 1990). Drought, defined here as a prolonged period in which there is an absence of precipitation (Rouault & Richard, 2003), is a common occurrence in South Africa and KNP, and is characterised by a loss of vegetation and overgrazing (Moon *et al.*, 1997; Rouault & Richard, 2003). During late summer, tropical cyclones developing over the warm Indian Ocean, and moving in an easterly direction, occasionally make landfall on the Mozambique and South African coasts. The associated intense rainfall usually results in severe flooding in coastal and adjacent interior regions, including on occasions the KNP (Tyson & Preston-Whyte, 2000; Venter *et al.*, 2008; Davis, 2011; Malherbe *et al.*, 2012).

2.6 Mammal Distribution and Abundance

Different land management classification systems have been developed for KNP, based on vegetation and geology. Gertenbach (1983) divided KNP into 35 landscapes, which were classified by differences in geomorphology, climate, soil, and mammals and vegetation in specific areas; this classification is applicable to this study due to the particular focus on factors which influence mammal distribution and abundance in different landscapes in central KNP (*Figure 2.2*).

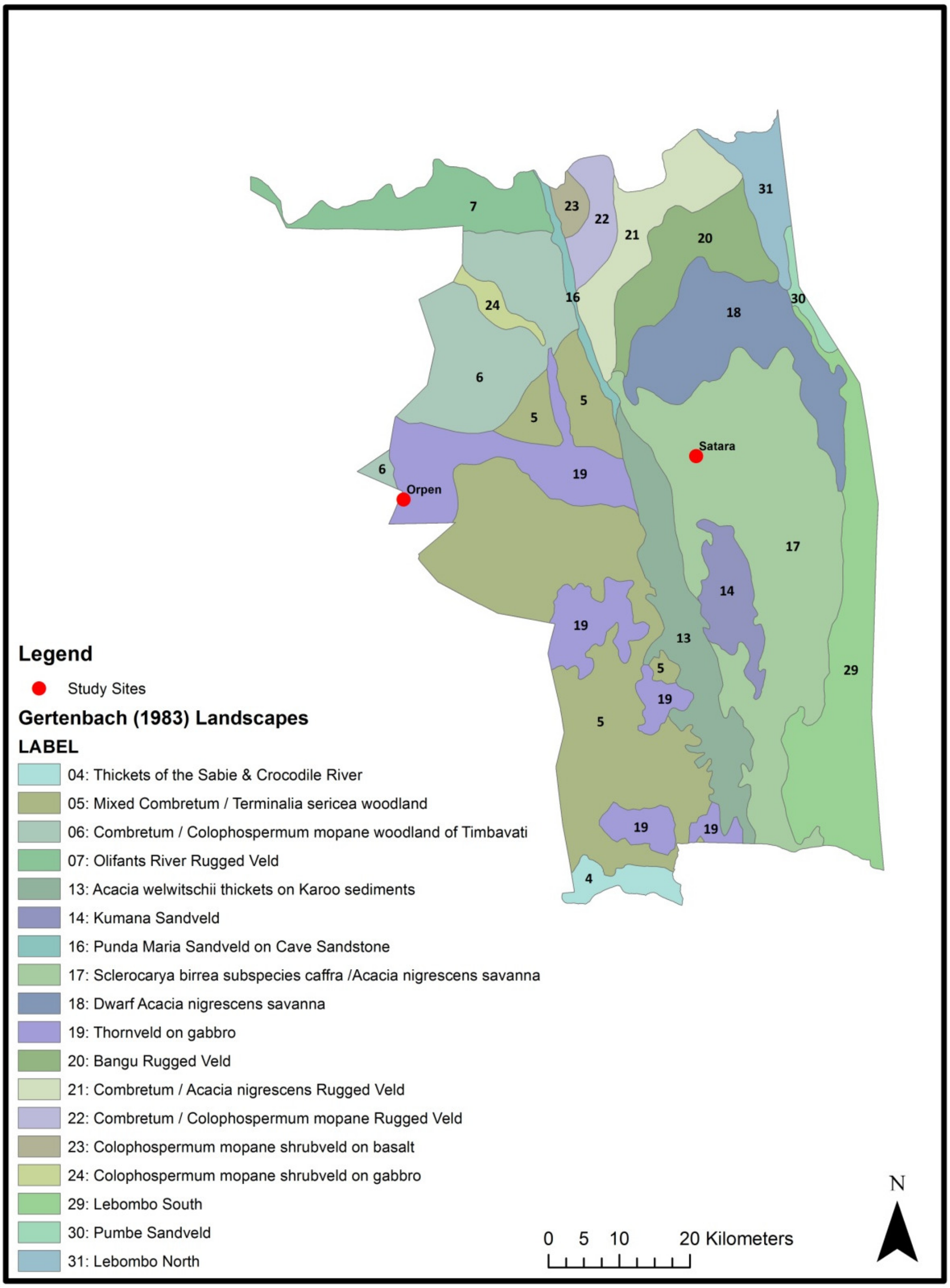


Figure 2.2: Map of the landscapes of central Kruger National Park, showing the location of study sites Satara and Orpen in landscapes 17 and 19, respectively (after Gertenbach, 1983).

KNP is situated within the lowveld geomorphic province, as classified by Partridge *et al*. (2010), and can be divided lengthwise into two distinct geological zones: granite rock to the west and basaltic rock to the east (Venter, 1990). Satara rest camp is situated on the basaltic geological zone, whilst Orpen rest camp is situated on fertile gabbro intrusions. The soils in KNP correspond with the geological zones, with sandy and light coloured soils found in the western zone (Orpen) and clayey dark coloured soils in the eastern zone (Satara) (Joubert, 1986). In KNP, particular soil types and climate gradients support specific vegetation communities (Venter & Gertenbach, 1986), therefore the large variety of soils and rocks in KNP, in part, supports the diverse plant component, which in turn are associated with particular mammal assemblages (Venter *et al*., 2003; Viljoen, 2015) (*Table 2.4*).

Apart from contributing the bulk of biodiversity within KNP, vegetation serves as an important food source and provides habitat for various mammals (Venter & Gertenbach, 1986). KNP is defined as part of the savanna biome within the southern African region (Scholes, 1997); savannas are characterised by tropical grassland landscapes (van Wilgen *et al*., 2000), having the unifying feature of woody trees and shrubs forming a variously continuous canopy over continuous grass coverage (Scholes & Archer, 1997; Schmidt *et al*., 2002). The central KNP is able to support large herds of herbivores due to the availability of nutrient-rich low grass forage and an exposed low level shrub layer (Venter, 1990). The Satara landscape is characterised as open parkland, with tall trees, a distinct shrub layer of woody plants and C4 grasses (Gertenbach, 1983). The different landscape vegetation zones of KNP make it diverse and compatible for many different species and these particular zones can be used functionally in conservation management and decision making (Gertenbach, 1983). The vegetation of the Satara landscape is classified as *S Birrea/Acacia nigrescens* Tree Savanna (Landscape 17) and the vegetation of Orpen as Thornveld on Gabbro (Landscape 19) (Gertenbach, 1983) (*Table 2.4; Figure 2.2*).

Table 2.4: Landscape classification of topography/geomorphology, geology, soils and vegetation for central Kruger National Park. Landscapes in which the Satara (17) and Orpen (19) study sites are situated are highlighted in grey (after Gertenbach, 1983).

No.	Topography / Geomorphology	Geology	Soils	Vegetation
4	Gently undulating landscape, with granite koppies. Intersected by numerous spruits.	Archaean granite and gneiss, intersected by dolerite intrusions	Relatively shallow, high clay and mineral content	Dense woody vegetation
5	Gently undulating landscape. Occurs close to watersheds, upper courses of spruits.	Granite and gneiss, numerous dolerite intrusions	Upland soils are sandy, lower-lying soils have high clay and sodium content	Dense bush savanna in the uplands, open tree savanna in the bottomlands
6	Gently undulating landscape. Drained by tributaries of the Timbavati.	Granite and gneiss, intersected by numerous dolerite intrusions	Upland soils are sandy, lower-lying soils have a high clay content	Open bush savanna in the uplands, well-defined field layer
7	Strongly undulating landscape, steep slopes.	Granite, parent material comprises metamorphic rock	Generally shallow and stony soils (Lithosols)	Xerophytic, field layer is sparse with dense woody vegetation
13	Gently undulating landscape, with slight slopes. Small pans and spruits.	Karoo sediments (Ecca-Shales)	Lithosols on sandstone outcrops, shallow and deep sandy soils, clayey soils and sodium rich brackish soils	Moderate tree savanna, with an open low shrub layer
14	Gently undulating landscape. Drained by tributaries of the Sweni.	Karoo sediments (Cave Sandstone, Red Beds and Ecca-Shales)	Lithosols on sandstone outcrops, shallow and deep sandy soils, clayey soils and sodium rich brackish soils	Moderate tree savanna, with an open low shrub layer
16	Prominent koppies and steep slopes. Drained by the Nkovakula spruit.	Cave Sandstone of the Clarens formation	Lithosols and deep, grey to yellow sandy soils in the lower-lying areas	Open tree and shrub savanna. Poorly developed field layer
17	Flat plains, well-defined drainage channels.	Sabie River Basalt, few dolerite intrusions	Black, brown or red clayey soils	Open tree savanna, dense shrub layer

No.	Topography / Geomorphology	Geology	Soils	Vegetation
18	Generally flat, high-lying plains. Pans and spruits.	Basalt, with numerous amygdales and Olivine	Dark, clayey soils	Open shrub savanna
19	Flat, to gently undulating landscape with prominent koppies.	Gabbro	Dark, clayey soils	Open savanna with a dense field layer
20	Undulating landscape. Drained by the Bangu and Ngotsa spruits.	Basalt, with limestone concretions	Shallow, dark brown to grey, stony soils	Open savanna, with poorly developed field layer
21	Undulating landscape. Drained by a number of small spruits.	Basalt, with limestone concretions	Shallow, dark brown to grey, stony soils	Open savanna, with poorly developed field layer
22	Flat plains with rocky outcrops.	Basalt, outcrops of tuff, breccia, limburgite and rhyolite	Generally shallow and dark soils	Open shrub savanna
23	Flat, to gently undulating landscape. Intersected by Olifants and Letaba rivers. Marshes/Vleis.	Letaba Basalt, numerous dolerite intrusions	Dark brown, reddish soils high clay content	Open tree and shrub savanna, well-developed field layer
24	Flat, to gently undulating landscape with prominent koppies.	Gabbro	Dark soils, high clay content	Open tree savanna, well-developed field layer
29	Mountainous, steep slopes with flat plateaus.	Rhyolite and granophyre of the Lebombo Group	Lithosols	Open tree savanna, well-developed field layer
30	Strongly undulating landscape, with extensive plateaus.	Rhyolite and granophyre of the Lebombo Group	Deep sandy soils and shallow Lithosols	Shrub savanna, well-developed field layer
31	Mountainous, steep slopes with flat plateaus.	Rhyolite and granophyre of the Lebombo Group	Shallow, rocky soils	Open tree savanna, naturally sparse field layer

The central region of KNP is known for the large herds of game that occupy the area (Burkepile *et al.*, 2013), with the greatest density of mammals in landscape 13 (see *Table 2.4*) due to the abundance of palatable grasses and an open shrub layer. Conversely, landscape 6 has a low density of grazers due to thick woody vegetation (Gertenbach, 1983). Landscape 17 (*Table 2.5*), in which the Satara rest camp is situated, supports open grassy plains favoured by large populations of wildebeest and zebra; these species move annually between the southern and northern extent of this landscape (Gertenbach, 1983), as do large numbers of impala, kudu, giraffe and buffalo (Gertenbach, 1983; Schütze, 2002). Landscape 19 (*Table 2.5*), in which the Orpen rest camp is situated, is favoured by browsers such as kudu and giraffe; grazers such as buffalo, warthog, waterbuck and wildebeest; and mixed feeders such as elephant and impala (Gertenbach, 1983; Burkepile *et al.*, 2013). Large numbers of wildebeest occur near Orpen, favouring the *Chloris virgata/Acacia nigrescens* shrubveld (Gertenbach, 1983). Similarly, large concentrations of wildebeest occur in the area to the north-east of Satara between the Sweni River and the Mlondozi dam (Schütze, 2002; Burkepile *et al.*, 2013).

A relatively large population of black rhinoceros occurs along the N'waswitsonto and Sweni rivers, whilst white rhinoceros occur within the Tshokwane, Satara and N'wanetsi sections (Schütze, 2002). The Gertenbach (1983) landscapes and the associated large mammals in central KNP region are presented in (*Table 2.5*). Typical carnivores that commonly occur within central KNP include spotted hyaena and cheetah, particularly in the Kingfisherspruit, N'wanetsi, Satara and Tshokwane sections (Schütze, 2002). Lion are common in the Satara and Tshokwane sections (Schütze, 2002) due to their prey preference of wildebeest, zebra and buffalo occurring in large numbers in this region (Mills & Funston, 2003). Although wild dog are rare, they are most commonly sighted between the Sabie River and Tshokwane/Kingfisherspruit sections and black-backed jackal occur in most parts of KNP, but are particularly common in the central region (Schütze, 2002).

Table 2.5: Landscape classification and associated mammals for central Kruger National Park. Landscapes in which the Satara (17) and Orpen (19) study sites are situated, are highlighted in grey (after Gertenbach, 1983).

No.	Associated Mammals
4	Largest impala population. Elephant, kudu, duiker, steenbok, bushbuck and giraffe are common. Lion, leopard, wild dog and spotted hyaena are important carnivores. Hippopotamus are abundant in rivers.
5	Ideal habitat for sable antelope. Kudu, giraffe, buffalo, and elephant are common. Zebra occur in small groups. Impala and warthogs occur near available water. Lion and leopard are present.
6	Ideal habitat for sable antelope, elephant, buffalo, kudu and impala close to spruits. Zebra occur in small groups.
7	Elephant, zebra in small groups and impala can be found along the river. Giraffe, kudu and waterbuck are abundant. Lion, leopard and hyaena are important carnivores.
13	Large number of impala, wildebeest and zebra. Giraffe, kudu, steenbok and duiker are present. Elephant breeding herds and buffalo move through this area. Waterbuck are found at the pans. Lion and hyaena are abundant.
14	Ideal habitat for elephant breeding herds. Kudu, giraffe, impala and white rhino are common. Warthog are abundant. Waterbuck occur near permanent water. Lion and leopard are present.
16	Elephant and buffalo are important species in this landscape. Kudu, impala, steenbok, grysbok, nyala and pairs of klipspringers are commonly found. Baboons are found along the rivers.
17	Wildebeest, zebra and lion are abundant. Buffalo, kudu, giraffe, waterbuck, steenbok and ostrich occur in large numbers. Solitary elephant bulls. Tsessebe and reedbuck are found in specific areas.
18	Largest population of kudu. Small numbers of sable antelope, zebra, impala, wildebeest, giraffe, waterbuck, warthog, lion, hyaena and cheetah. Herds of buffalo pass through this area.
19	Kudu, impala, giraffe, waterbuck, warthog, buffalo and elephant bulls. Zebra and wildebeest occur after fire.
20	Ideal habitat for wildebeest and zebra. Kudu and giraffe and lion and hyaena are abundant.
21	Impala, kudu, waterbuck and giraffe. Elephant bulls next to the river and buffalo bulls in the reeds. Baboons near the river. Lion, leopard and hyaena are present.
22	Buffalo and zebra are important species. Impala, waterbuck, kudu, giraffe and elephant bulls. Hippopotamus are abundant. Roan antelope, eland and tsessebe in northern parts of this landscape.
23	Roan and sable antelope, tsessebe and eland in average numbers. Buffalo and zebra are abundant. Elephant bulls, steenbok and Sharpe's grysbok are common. Waterbuck are found near permanent water. Ostrich and leopard can be seen.
24	Roan antelope, buffalo, zebra, eland, ostrich, white rhinoceros and solitary elephant bulls.
29	Common species are kudu, impala, giraffe and buffalo bulls. Klipspringers are abundant.
30	Buffalo, zebra, impala, giraffe and warthog occur in this area.
31	Kudu found in the Lebombo mountains. Small numbers of buffalo, impala, zebra, waterbuck and warthog. Sharpe's grysbok, duikers, bushbuck and giraffe are found in dense ravines. Breeding herds of elephants are found north and south of the Olifants river.

Initially herbivore aerial surveys were conducted annually in KNP, however, from 2010 the surveys have been conducted biennially, with the herbivore survey (excluding elephant and buffalo) being a sample count, using distance methodology to convert the counts to estimates. Most recently, aerial surveys of herbivores were undertaken in 2012 and 2014; with species estimates for central KNP being calculated by applying a formula to up-scale the actual observations from the census. Impala have the highest density of the species estimates for both the 2012 and 2014 aerial surveys in the central KNP (*Table 2.6*). African savanna elephant (hereafter referred to as African elephant) and African buffalo counts are undertaken in a separate survey where drainage lines are flown, and are direct total counts of the entire area, and are assumed to have captured all individuals, therefore no up-scaling is applied. The most recent surveys for the two former species were conducted in 2011 and 2012 (Botha, pers comm, 2015) (*Table 2.7*).

Table 2.6: Select species estimates for central Kruger National Park from the 2012 and 2014 SANParks aerial surveys (Botha, pers comm, 2014).

	2012	**2014**
Species	**Species Estimate**	
Impala	78992	42324
Plains zebra	10049	10473
Blue wildebeest	9165	7087
Waterbuck	3329	790
Southern giraffe	2410	2691
Warthog	624	1415
Greater kudu	N/A	2958

Table 2.7: African buffalo and African elephant counts for central Kruger National Park from the 2011 and 2012 aerial surveys (Botha, pers comm, 2014).

	2011		**2012**	
Species	**Calves**	**Total**	**Calves**	**Total**
Buffalo bulls		169		215
Buffalo herd		7331		6591
Elephant bulls		322		300
Elephant herd	139	3434	272	3843
Buffalo total		**7500**		**6806**
Elephant total		**3895**		**4415**

CHAPTER THREE

Literature Review

Chapter 3 - Literature Review

3.1 Introduction

It is indisputable that water is an essential resource for animals (Rosenstock *et al.*, 1999), especially in arid and semi-arid regions (Landsberg *et al.*, 1997; James *et al.*, 1999; Tefempa *et al.*, 2008; Simpson *et al.*, 2011). In such regions, the availability of water is variable throughout the year and is especially scarce during the dry season (Valeix *et al.*, 2009a). Consequently, large areas across Africa and Asia are not suitable perennial habitats for mammals that are dependent on water (Estes, 1991). The majority of large herbivores in arid and semi-arid areas need to drink water in order to fulfill their daily requirements, which are only supplemented by the vegetation that they feed on (Chamaillé-Jammes *et al.*, 2007b). Artificial water sources therefore provide an important alternate source of water during the harsh dry season, when both water and food become limiting (Ayeni, 1975). In particular, water needs to be provisioned to mammals in closed-in systems where natural perennial sources of water are scarce (Smit & Ferreira, 2010). Certain environmental factors (increased temperature, decreased precipitation, drought events and increased evaporation rates) decrease natural surface water available to mammals and thus increases the need for/reliance on supplemental water, which is particularly relevant in the context of projected climate change scenarios.

3.2 Global, Continental, Regional and National Perspectives on Water Source Use

Artificial water sources in arid and semi-arid environments are a widespread global management intervention on which mammals rely for survival (James *et al.*, 1999). Outside of Africa various conservation areas are situated in water-limited environments and as a consequence water is provided to sustain a range of species, such as coatis (Burger & Gochfeld, 1992); white-faced monkeys (Vaughan & Weis, 1999); white-tailed deer (Gallina *et al.*, 1997) wild boar and red deer (Vicente *et al.*, 2007); and hanuman langur populations (Waite *et al.*, 2007) through the use of artificial water sources (*Table 3.1*). Particularly, artificial water sources have become a feature in the natural landscape and are one of the main management interventions in most national parks and game reserves on the African continent (*Table 3.1*) (Ritter & Bednekoff, 1995; Tefempa *et al.*, 2008). In 1950, artificial water sources were established in Tsavo National Park (East) to enhance the game viewing opportunities for tourists, to satisfy the drinking requirements of mammals inside the park and to encourage mammals to expand their ranges into different areas of the park, so avoiding overgrazing around the river beds (Ayeni, 1975). Artificial water sources are especially important in Ruaha (Epaphras *et al.*, 2008) and Serengeti National Parks, Tanzania (Hagwet *et al.*, 2014) where the exploitation of upstream natural water sources for human requirements has reduced river flow and so diminished natural water availability (Epaphras *et al.*, 2008).

Table 3.1: Conservation areas globally, excluding South Africa, providing artificial water sources.

Country	**Conservation Area**	**Publication**
Costa Rica	Guanacaste Conservation Area	Vaughan and Weis, 1999
	Palo Verde National Wildlife Refuge	Burger and Gochfeld, 1992
Mexico	Rancho San Francisco	Gallina *et al.*, 1997
Southwestern United States	Cabeza Prieta National Wildlife Refuge	Broyles and Cutler, 1999
Brazil	Serra da Capivara National Park	Silveira *et al.*, 2009
Spain	South Central Spain	Vicente *et al.*, 2007
India	Gir National Park and Sanctuary	Mukherjee and Borad, 2004
	Kumbhalgarh Wildlife Sanctuary	Waite *et al.*, 2007
	Sariska Tiger Reserve	Ross and Srivastava, 1994
Australia	Arid and semi-arid rangelands	James *et al.*, 1999
Cameroon	Waza National Park	Tefempa *et al.*, 2008
Kenya	Nairobi National Park	Hillman and Hillman, 1977
	Tsavo National Park	Ayeni, 1975
Tanzania	Ruaha National Park	Epaphras *et al.*, 2008
	Serengeti National Park	Hagwet *et al.*, 2014
Malawi	Lengwe National Park	Kazembe, 2009
	Liwonde National Park	Dudley, 1997
	Majete Wildlife Reserve	Staub et., 2013
Zambia	Lusaka National Park	Nyirenda *et al.*, 2014
Zimbabwe	Hwange National Park	Chamaillé-Jammes *et al.*, 2007a
Namibia	Etosha National Park	du Preez and Grobler, 1977
	Khaudum National Park	Wanke and Wanke, 2007
Botswana	Central Kalahari Game Reserve	Kalikawa, 1990
	Chobe National Park	Kalwij *et al.*, 2010
	Kutse Game Reserve	Hitchcock, 1996
	Nxai Pan National Park	Ritter and Bednekoff, 1995

In southern Africa, numerous conservation areas are located in semi-arid regions where the perennial availability of natural water is limited (*Table 3.1*) (Wanke & Wanke, 2007). In Lusaka National Park, Zambia, wetlands in the southern region of the park provide adequate seasonal water, although, these wetlands are vulnerable to sand extraction outside of the park (Nyirenda *et al.*, 2014). Between 1930 and 1980 artificial water sources were constructed in Hwange National Park, Zimbabwe to distribute water-dependent mammals into different grazing areas in the dry season and to increase herbivore numbers (Chamaillé-Jammes *et al.*, 2007a; Kamanda *et al.*, 2008). In Chobe National Park, artificial water points were established to limit the overutilisation of riparian vegetation by elephants along the Chobe and Linyanti rivers (Owen-Smith, 1996). The Kgalagadi Transfrontier Park, which incorporates the Gemsbok National Park (Botswana) and the Kalahari Gemsbok National Park (South Africa), is devoid of natural water, except when rain is experienced, and artificial water sources sustain water-dependent herbivores here (Shroyer *et al.*, 2001). The loss of wildebeest and hartebeest populations from both the Central Kalahari Game Reserve and Kgalagadi Transfrontier Park was a consequence of fences blocking their seasonal migration outside of the protected area to fulfill their water requirements; this was resolved by the supplementation of water through artificial water sources in both conservation areas (Kalikawa, 1990; Shroyer *et al.*, 2001).

In South Africa, various national parks and private nature and game reserves provide supplementary water sources through artificial waterholes and troughs (*Table 3.2*), such as in Addo Elephant National Park where artificial water points are required as wildlife congregates in areas that are not in close proximity to natural water sources. However, a current management objective in Addo Elephant National Park, as with all national parks, is to try and maintain a more natural seasonal and spatial distribution of water. In the Tankwa Karoo National Park, in addition to the present eight water points, four new water points are planned by 2024 (Tankwa Karoo National Park Management Plan 2014-2024, 2014). In KNP the revised water provision policy involves closing numerous artificial water points and dams (Pienaar *et al.*, 1997). Similarly, in Mapungubwe National Park the water provision policy has been revised stating that select artificial water sources are to be removed (Mapungubwe National Park Management Plan 2013-2023, 2013) and in Marakele National Park only artificial water sources that are considered to be necessary ecologically in the environment are to be maintained (Marakele National Park Management Plan 2014-2024, 2014). In Mountain Zebra National Park, there are no perennial natural water sources and water is supplemented, although the number of artificial water points is negligible (Mountain Zebra National Park Management Plan, 2008). In the Kalahari Gemsbok National Park, artificial water sources were established in the 1930's due to the construction of fences around the park, which has led to an increase in wildebeest numbers (Kalahari National Park Management Plan, 2008). Artificial water sources have been added to South African game and nature reserves as a technique to increase the opportunities of mammal sightings for tourists such as in the Klaserie Private Nature Reserve (Parker & Witkowski, 1999), similarly in Karoo and Mokala National Parks, artificial water points are typically for tourist benefit and the current management objective is to alternate open and closed water points to facilitate a more natural distribution and utilisation pattern by mammals (Karoo National Park Management Plan, 2008; Mokala National Park Management Plan, 2008).

Table 3.2: National parks and game and nature reserves in South Africa providing artificial water sources.

Conservation Area	**Location**	**Publication**
Addo Elephant National Park	Eastern Cape	SANParks, 2008
Camdeboo National Park	Eastern Cape	SANParks, 2013
Kalahari Gemsbok National Park	Northern Cape	SANParks, 2008
Karoo National Park	Western Cape	Gaylard & Johnson, 2008
Klaserie Private Nature Reserve	Limpopo	Walker *et al.*, 1987
Kruger National Park	Limpopo, Mpumalanga	Freitag-Ronaldson & Venter, 2008
Manyeleti Game Reserve	Limpopo	Cronje *et al.*, 2005
Mapungubwe National Park	Limpopo	SANParks, 2013
Marakele National Park	Limpopo	Novellie & Spies, 2014
Mkuze Game Reserve	KwaZulu-Natal	Goodman, 1982
Mokala National Park	Northern Cape	Daemane & Spies, 2008
Pilanesberg National Park	North West	Hayward & Hayward, 2012
Sabi Sand Game Reserve	Mpumalanga	Thomas *et al.*, 2008
Tankwa Karoo National Park	Northern Cape, Western Cape	Strauss & Cowell, 2014
Tembe Elephant Park	KwaZulu-Natal	Shannon *et al.*, 2009

3.3 Water Dependency in Mammals

Mammals have different broad water requirements and can be divided into two categories, water-dependent or water-independent, based on how regularly they need to drink (Redfern *et al.*, 2005). Water-dependent species (waterbuck and zebra) generally need to drink every one to two days in the dry season (Young, 1970) with buffalo showing strong water-dependence by needing to drink or wallow every day (Estes, 1991) and conversely water-independent species such as giraffe, are able to go without water for up to three to four days (Tefempa *et al.*, 2008). Water-dependency is influenced by physiological adaptations and ability to prevent water loss, as well as diet. Despite this, there is limited information on how frequently, and how far, mammals travel to water (Cain *et al.*, 2012). It has been recognised that grazing herbivores are typically water-dependent, whilst browsers are typically water-independent (*Table 3.3*) (Western, 1975; Estes, 1991; Redfern *et al.*, 2003). The leaves of trees and shrubs hold water in the dry months and therefore browsers are less dependent on surface water as their water requirements are fulfilled by the vegetation that they consume (Owen-Smith, 1999). Impala are classified as a water-dependent species and are found in close proximity to water throughout the dry season; but as mixed feeders they are able to fulfill their water requirements by foraging on green vegetation (Estes, 1991) and consequently have periods of two to three days between drinking (Young, 1970). Wildebeest are recognised as being strongly water-dependent in most environments, in contrast, in the arid Kalahari they are able to survive without regular access to water and can acquire water by digging up the bulbs and roots of water-storing plants (Child *et al.*, 1971; Estes, 1991; Knight, 1995b).

Carnivores can generally acquire an adequate amount of moisture from consuming the body fluids and blood of their prey (Eloff, 1973; Ayeni, 1975). Spotted hyaenas are water-dependent (Cooper, 1989), however, in the recent study by Hayward & Hayward (2012), hyaenas were observed to have low water requirements, along with lion and kudu whilst hippopotamus, warthog and blue wildebeest have high water requirements.

Table 3.3: Select water-dependent and water-independent mammals from Africa, based on species sighted during the study period in central Kruger National Park.

Mammal	Scientific Name	Water requirement	Feeding Guild	Location	Author	Year
Lesser kudu	*Tragelaphus imberbis*	water-independent	Browser	Amboseli Ecosystem	Western	1975
Greater kudu	*Tragelaphus strepsiceros*			Kruger National Park	Owen-Smith	1990
				Five Study Locations*	Hayward & Hayward	2012
Masai giraffe	*Giraffa camelopardalis*	water-independent	Browser	Amboseli Ecosystem	Western	1975
African buffalo	*Syncerus caffer*	water-dependent	Grazer	Amboseli Ecosystem	Western	1975
Blue wildebeest	*Connochaetes taurinus*	water-independent	Grazer	Kgalagadi Transfrontier Park	Child *et al*.	1971
		water-dependent		Amboseli Ecosystem	Western	1975
				Kruger National Park	Smit *et al*.	2007a
				Five Study Locations*	Hayward & Hayward	2012
Common waterbuck	*Kobus ellipsiprymnus*	water-dependent	Grazer	Amboseli Ecosystem	Western	1975
Hippopotamus	*Hippopotamus amphibious*	water-dependent	Grazer	Amboseli Ecosystem	Western	1975
				Five Study Locations*	Hayward & Hayward	2012
Plains zebra	*Equus quagga/Equus burchelli*	water-dependent	Grazer	Amboseli Ecosystem	Western	1975
				Kruger National Park	Harrington *et al*.	1999
				Kruger National Park	Smit *et al*.	2007a
Warthog	*Phacochoerus africanus*	water-dependent	Grazer	Amboseli Ecosystem	Western	1975
				Five Study Locations*	Hayward & Hayward	2012
African savanna elephant	*Loxodonta africana*	water-dependent	Mixed Feeder	Amboseli Ecosystem	Western	1975
				Kruger National Park	Young	1970
				Waza National Park	Tefempa *et al*.	2008
Impala	*Aepyceros melampus*	water-dependent	Mixed Feeder	Kruger National Park	Young	1970
Leopard	*Panthera pardus*	water-independent	Carnivore	Kalahari Gemsbok National Park	Bothma & Le Riche	1984
Lion	*Panthera leo*	water-independent	Carnivore	Five Study Locations*	Hayward & Hayward	2012
Spotted hyaena	*Crocuta crocuta*	water-dependent	Carnivore	Chobe National Park	Cooper	1989
		water-independent		Five Study Locations*	Hayward & Hayward	2012

3.4 Mammal Visitation Patterns

Mammal utilisation of artificial water sources has been documented by various studies in relation to which species utilise them, when species utilise them and how water source usage by various species changes in relation to the time of the day, the season and the contemporary climatic conditions. Different mammals have been observed to display different types of behaviour when approaching or utilising artificial water sources (Kamanda *et al.*, 2008; Tefempa *et al.*, 2008).

3.4.1 Effects of Environmental Conditions (Temperature, Rainfall and the Moon Cycle)

3.4.1.1 Daily

Several studies have documented temporal drinking patterns of mammals in different regions, with species being classified roughly as either dawn, morning, midday, afternoon, dusk or nighttime drinkers (*Table 3.4*). Early studies by Weir & Davison (1965) in Hwange National Park, Ayeni (1975) in Tsavo National Park and du Preez & Grobler (1977) in Etosha National Park, were comprehensive in their investigations, using either 24-hour census methods (Weir & Davison, 1965; du Preez & Grobler, 1977) or recording mammal drinking patterns during particular hours (Ayeni, 1975). These studies significantly contributed to understanding mammal drinking patterns at artificial water sources, and specific mammal drinking behaviours.

The study by Ayeni (1975) focused on the effect of artificial water sources on the seasonal distribution of mammals, although specific temporal use at the hourly-scale was also noted. Species of smaller body size, such as warthog and zebra, were observed to utilise artificial water sources primarily during the day (Ayeni, 1975; du Preez & Grobler, 1977). However, larger species (rhinoceros, elephant and buffalo) were observed drinking during the night (Ayeni, 1975). Small mammals are able to endure hot periods during the day as they have mechanisms to control body heat, and in contrast, large mammals such as elephant, buffalo and rhinoceros, are not able to manage their body temperatures as efficiently, and therefore avoid expending energy and drinking from water sources at times when the temperature is high (Ayeni, 1975). During the hottest times of the day (midday) between 12:00 and 13:00, mammal water source use decreases (Ayeni, 1975; Tefempa *et al*., 2008; Hayward & Hayward, 2012), with decreased drinking activity observed when the ambient temperature was ≥ 35°C or ≤ 19°C in KNP (Young, 1970). During cooler periods of the day (early morning and at night) predators utilise water sources and consequently prey species drink during the day when other mammals are drinking in order to benefit from group vigilance (Ayeni, 1975).

More recent studies by Tefempa *et al*. (2008) and Hayward & Hayward (2012) have added to the body of literature on the temporal drinking patterns of mammals. The study by Hayward & Hayward (2012), uniquely using webcams, documented opposing peak drinking periods for large prey and predators, 11:00 for the former and 19:00 for the latter. Previous work by Weir & Davison (1965) and Valeix *et al*. (2007a) in Hwange National Park documented that elephant water source use peaked during dusk, in contrast, elephant water source use in KNP peaked during midday (Hayward & Hayward, 2012). Giraffe are predominantly daytime drinkers (Hayward & Hayward, 2012), conversely, Weir & Davison (1965) documented them drinking in the evening, whilst du Preez & Grobler (1977) report that giraffes do not have a specific drinking period but favour drinking in the evening. Jackal in Etosha National Park are predominantly nighttime drinkers (du Preez & Grobler, 1977) whilst those in Waza National Park prefer drinking during the day (Tefempa *et al*., 2008). Lions are known to sleep during the day and become more active in the late afternoon at which time they will seek drinking water (du Preez & Grobler, 1977), conversely in Hwange National Park lions were reported to drink throughout the day (Weir & Davison, 1965). For certain species it is not possible to generalise predominant drinking periods, such as giraffe, however, other species such as impala show a predominant drinking period after dusk and before the afternoon.

Table 3.4: Predominant drinking periods and drinking times of selected mammals in conservation areas in Africa, based on species sighted during the study period in central Kruger National Park.

Mammal	**Drinking time**	**Drinking period**	**Location (NP, GR)**	**Author**	**Year**
African buffalo	18:00 - 20:00	Dusk, Night	Hwange NP	Weir & Davison	1965
		Dusk, Night	Tsavo NP	Ayeni	1975
	10:30 - 12:30	Morning, Midday	Rwenzori NP	Grimsdell & Field	1976
	6:00 - 8:00/ 10:00 - 12:00	Dawn, Morning	Kruger NP	Ryan & Jordaan	2005
	6:00 / 18:00	Dawn, Dusk	Hwange NP	Valeix *et al.*	2009b
African savanna elephant	18:30 - 21:00	Dusk, Night	Hwange NP	Weir & Davison	1965
	19:00	Dusk	Hwange NP	Valeix *et al.*	2007a
	13:00	Midday	Five locations*	Hayward & Hayward	2012
Blue wildebeest	5:00 - 9:00	Dawn, Morning	Hwange NP	Weir & Davison	1965
	10:00 - 11:00/ 12:00 - 13:00	Morning, Midday	Etosha NP	du Preez & Grobler	1977
	6:00	Dawn	Hwange NP	Valeix *et al.*	2007a
	16:00	Afternoon	Five locations*	Hayward & Hayward	2012
Chacma baboon	15:00	Afternoon	Five locations*	Hayward & Hayward	2012
Common waterbuck	6:00	Dawn	Hwange NP	Valeix *et al.*	2007a
	10:00	Morning	Five locations*	Hayward & Hayward	2012
Greater kudu	14:00 - 17:00	Afternoon, Dusk	Hwange NP	Weir & Davison	1965
	9:00 - 10:00	Morning	Etosha NP	du Preez & Grobler	1977
	9:00	Morning	Hwange NP	Valeix *et al.*	2007a
	16:00	Afternoon	Five locations*	Hayward & Hayward	2012
Impala	10:00 - 14:00	Morning, Midday	Serengeti NP	Jarman & Jarman	1973
	8:00	Morning	Hwange NP	Valeix *et al.*	2007a
	11:00	Midday	Five locations*	Hayward & Hayward	2012
Jackal black-backed		Night	Etosha NP	du Preez & Grobler	1977
Lion	6:00 - 18:00	Dawn, Dusk	Hwange NP	Weir & Davison	1965
	17:00 - 23:00	Dusk, Night	Etosha NP	du Preez & Grobler	1977
Nyala	11:00	Midday	Five locations*	Hayward & Hayward	2012
Plains zebra	16:00 - 20:00	Afternoon, Night	Hwange NP	Weir & Davison	1965
	12:00 - 13:00	Midday	Etosha NP	du Preez & Grobler	1977
	12:00	Midday	Hwange NP	Valeix *et al.*	2007a
	9:00 - 15:00	Morning, Midday, Afternoon	Kruger NP	Cain *et al.*	2012
	16:00	Afternoon	Five locations*	Hayward & Hayward	2012

Mammal	Drinking time	Drinking period	Location (NP, GR)	Author	Year
Southern giraffe	18:00 - 22:00	Dusk, Night	Hwange NP	Weir & Davison	1965
		Morning, Dusk	Tsavo NP	Ayeni	1975
	18:00 - 19:00	Dusk	Etosha NP	du Preez & Grobler	1977
	16:00	Afternoon	Hwange NP	Valeix *et al.*	2007a
	8:00 - 12:00/ 14:00 - 18:00	Morning, Midday Afternoon, Dusk	Waza NP	Tefempa *et al.*	2008
	16:00	Afternoon	Five locations*	Hayward & Hayward	2012
Spotted hyaena	00:00 - 1:00	Night	Etosha NP	du Preez & Grobler	1977
	17:00 - 21:00	Dusk, Night	Ongava GR	Stratford & Stratford	2011
Vervet monkey	13:00 - 15:00	Midday, Afternoon	Masai-Amboseli GR	Struhsaker	1967
Warthog	5:00 - 10:00/ 14:00 - 17:00	Dawn, Morning Afternoon, Dusk	Hwange NP	Weir & Davison	1965
	14:00 - 15:00	Afternoon	Etosha NP	du Preez & Grobler	1977
	9:00	Morning	Hwange NP	Valeix *et al.*	2007a
	6:00 - 11:00/ 14:00 - 18:00	Dawn, Morning Afternoon, Dusk	Waza NP	Tefempa *et al.*	2008
	12:00	Midday	Five locations*	Hayward & Hayward	2012

* Kruger and Pilanesberg National Parks, Madikwe and Mashatsu Game Reserves and Tembe Elephant Park

Few studies have documented the influence of the moon cycle on mammal drinking patterns at water sources, and there is a gap in the literature of the effects of moonlight for different species (Prugh & Golden, 2014). However, Ayeni (1975) found that herbivores drink later than usual during moonlit, relative to cloudy or moonless, nights. Changes in moon phases dictate the amount of light available at night, likely affecting the behaviour of both prey and predatory species (Prugh & Golden, 2014). During full moon, the opportunity for herbivores to detect predators when drinking is improved; cloudy or moonless nights decrease the opportunity for prey species to detect predators (van Orsdol, 1984; Crosmary *et al.*, 2012). Predatory species are less active on moonlit nights as hunting success decreases (Prugh & Golden, 2014).

3.4.1.2 Seasonal

Herbivore proximity to water in areas where surface-water availability is variable over space and time is key to identifying both foraging and drinking patterns over spatial scales (Ogutu *et al.*, 2014). Daily weather conditions such as wind, temperature and rainfall affect which areas mammals congregate in, and additionally how much influence mammals will have on a particular area in terms of overgrazing, trampling and accumulation of dung (Owen-Smith, 1999) whilst the seasonal distribution of mammals is influenced by their requirements for food, rest and water, and they will move into different areas to fulfill these requirements (Afolayan & Ajayi, 1980; Thrash *et al.*, 1993b). Certain species are confined to specific areas due to their forage requirements; sable and roan antelope, tsessebe and eland inhabit the northern section of KNP, waterbuck are found along river courses, whereas kudu, zebra, buffalo and impala are widespread throughout KNP (Chirima *et al.*, 2012). The distribution of herbivore species is determined by wet and dry seasons which affect the availability of forage and water and how far a species will need to travel in order to access these resources (Smit & Grant, 2009). A relationship between forage quality and quantity and the availability of water has been noted to influence where certain species are located; when forage quantity decreases, the distribution of larger grazer species expands away from water and when forage quality decreases, the distribution of smaller grazer species expands away from water. The distribution of water-independent browser species is typically spread out away from water sources (Redfern *et al.*, 2003). The availability of forage also has an influence on the type of water source that water-dependent species drink from and consequently on the dispersal patterns of these species. When forage availability increases, water-dependent species aggregate around permanent water sources, however, when forage availability decreases, water-dependent species spread out and utilise ephemeral water sources (Redfern *et al.*, 2005).

The number of mammals frequenting artificial water sources increases during the dry season, conversely when water is widely available during the wet season, mammals spread out and utilise natural water sources as well as the artificial water sources (Thrash *et al.*, 1995; Valeix *et al.*, 2008). The distribution of impala in KNP is significantly associated with the availability of water, along with their forage requirements and contemporary weather conditions and consequently, impala remain in close proximity to sources of water (Young, 1972). The availability of water across the landscape thus has a strong influence on the daily concentration and seasonal distribution of mammals (Redfern *et al.*, 2005). Extensive provision of artificial water sources has changed the seasonal distribution of mammals, as water is no longer a constraining resource and therefore the movement patterns of mammals in search of water have changed (Smit & Grant, 2009). An important driver of changes in herbivore distribution during the dry season is the seasonal transformation of the quantity of available water sources (Redfern *et al.*, 2005; Chamaillé-Jammes *et al.*, 2008) therefore, artificial water sources are one of the few management tools in which to influence the distribution of mammals over an area (Cronje *et al.*, 2005). In the Manyeleti Game Reserve, natural and artificial water sources were monitored seasonally and it was documented that even with the construction of artificial water sources in the reserve, there was still a natural cycle of water availability, distributing mammals to different areas when various water sources dried-up or filled-up (Cronje *et al.*, 2005).

The movement of elephants in national parks and game reserves is constrained by fences, particularly during the wet season, and by the provision of water, dispersing elephants into other foraging areas during the dry season, and both of these management tools can influence elephant abundance and distribution patterns (Harris *et al.*, 2008; Loarie *et al.*, 2009; Shrader *et al.*, 2010). A pattern between studies in three contrasting environments, revealed that elephants prefer habitats in close proximity to water sources and will remain close to permanent water during the dry season (Harris *et al.*, 2008; Shrader *et al.*, 2010). The joint influence of fences and the widespread provision of water on elephant behaviour and their consequent impacts on vegetation and other mammals is more evident in dry periods (Shrader *et al.*, 2010). A study by Smit *et al.* (2007a) on mammals frequenting artificial and natural water sources in KNP, identified important characteristics and patterns of behaviour which proved useful for management (policies) and an important finding of the study was that the addition of artificial water sources in the park resulted in changes in the landscape and are therefore one of the factors that can facilitate the spread of large herbivores in semi-arid savanna nature reserves (Smit *et al.*, 2007).

3.4.2 Effects of Species Interactions

3.4.2.1 Competition

The aggregation of mammals at artificial water sources in the dry season facilitates competition and temporal partitioning for water at these sites (Valeix *et al.*, 2007a). Competition within and between species, and predation, are therefore influenced by the availability and distribution of water. The presence of elephants at water sources in Hwange National Park during the dry season did not inhibit other herbivores from drinking, rather, herbivores utilised the water sources for longer periods in the presence of elephants (Valeix *et al.*, 2009a). In Nxai Pan National Park, during the dry season, female springbok converged on the only permanent source of water available, which was an artificial water source, in which male springbok with larger horns and broader necks were observed to control territories in which they would be exposed to more female springbok. The provision of water has thus had an influence on the intra-specific competition for territories by male springbok and consequently affects yearly mating patterns. It is therefore likely that the provision of water at artificial waterholes would have the same consequences for other territorial and water-dependent species such as impala and white rhinoceros (Ritter & Bednekoff, 1995).

Many factors influence the decision as to whether mammals decide to drink and for how long. A detailed study in Hwange National Park revealed four factors that specifically influence the decision and need to drink (Valeix *et al.*, 2007b): 1) The availability of water increases the likelihood of drinking, particularly in dry periods, but decreases the time spent drinking due to competition; 2) Thermoregulation controls the time that mammals spend drinking, in relation to climatic conditions. At hotter times of the day mammals spend less time drinking in order to minimise exposure to direct sunlight, whilst during windy conditions mammals spend more time drinking as they are more easily able to regulate their body temperature; 3) The perceived risk of predation decreases the time spent at a water source; and 4) Interference competition also negatively influences the likelihood that mammals will drink. However, when more herbivores are present at a water source they spend a longer time drinking (Valeix *et al.*, 2007b).

Various studies have shown that mammals display different types of vigilance behaviours both when approaching artificial water sources and when drinking. Wildebeest and springbok drink as a herd and are particularly vigilant when approaching water sources (du Preez & Grobler, 1977). Warthog have been observed at times drinking together with large mammals in Etosha National Park (du Preez & Grobler, 1977) and were observed drinking with both elephants and buffalo in KNP (Trent, 2012), although Ayeni (1975) reported that small mammals usually move aside when large mammals come to drink at a water source. This could be because zebra, elephant and rhinoceros show aggression towards other species when drinking (du Preez & Grobler, 1977). Where water is particularly scarce, elephant herds may organise themselves to successively drink from an artificial water source, as observed in the Hwange National Park (Grab pers obs). Zebra, kudu (du Preez & Grobler, 1977) and buffalo herds (Ayeni, 1975) leave the water source as soon as they have fulfilled their need for water.

Further, the presence of tourists in close proximity to artificial water sources also has the potential to disrupt mammal drinking behaviour (Kamanda *et al.*, 2008). In both Hwange National Park and Waza National Park it was documented that mammals drinking at artificial water sources were disrupted by the presence of vehicles and tourists, and the associated noise levels, consequently leading to increased vigilance behaviour (Kamanda *et al.*, 2008; Tefempa *et al.*, 2008). Vigilance behaviour is defined as the time taken by mammals to examine the area around a water source before drinking. The results from the study by Kamanda *et al.* (2008) suggested that vigilance increased with an increased presence of tourists, conversely, vigilance behaviour decreased when fewer tourists were present. When mammals spend time being vigilant, their opportunity to feed and drink, and the time available for these necessary behaviours is minimized (van der Meer *et al.*, 2012). In the Ibex Reserve in Saudi Arabia, the drinking patterns of mountain gazelles and nubian ibex were significantly affected by the presence of tourists, with both species avoiding the water source for a short period even after the tourists had left. As both the mountain gazelle and nubian ibex are priority conservation species it was suggested that tourist visits to the water sources be limited (Wakefield & Attum, 2006).

3.4.2.2 Predation

Seasonal changes in the availability of surface water in semi-arid environments dictate the activity patterns of predators and so affects the spatial and temporal dynamics of prey species across the landscape. This has implications for predator-prey interactions and the utilisation of artificial water sources, especially those in areas without natural water, which ultimately influence the ecology of these interactions (Davidson *et al.*, 2013). Artificial water sources can facilitate predatory behaviour where predators conceal themselves in the vegetation surrounding these areas and ambush prey species (Burger & Gochfeld, 1992). In the dry season, mammals converge on permanent water sources which heightens vegetation and land degradation around these areas and increases the competition between species for constraining resources (Cain *et al.*, 2012). However, the increased concentration of prey species also draws predators to these sites (Davidson *et al.*, 2013). The presence of water sources influence the location of lion territories; lions located in close proximity to a water source have the advantage of preying on mammals approaching to drink (Valeix *et al.*, 2010).

In Ruaha National Park lions have been observed to use the areas around, and at, artificial and natural water sources to hunt (Epaphras *et al.*, 2008). Lion kills of elephant and giraffe in Hwange National Park, and of waterbuck in Klaserie Private Nature Reserve were observed to be in close proximity to a waterhole or water point (De Boer *et al.*, 2010; Davidson *et al.*, 2013). In contrast, small antelopes were typically killed at greater distances from water sources (Davidson *et al.*, 2013) likely because these are less regular water source visitors. The spatial dynamics of lion kills in Klaserie Private Nature Reserve are related to the water-dependency of the prey species, with water-dependent buffalo and wildebeest typically killed nearer to a water source than water-independent species (De Boer *et al.*, 2010). These relationships are expected given that the water-dependency of grazers restricts them to areas usually in close proximity to water sources (Valeix *et al.*, 2009b; Smit, 2011). Contrary to this, the location of water-independent browsers is not limited to areas close to water sources (Valeix *et al.*, 2009b).

The vigilance behaviour of herbivores differs between prey species at risk of predation, however, for most herbivores, when moving towards a water source, their level of vigilance is affected by the herd size of that species, and when drinking, vigilance depends largely on the collective group size of different species. Kudu, giraffe and zebra are particularly vigilant when moving towards a water source, and all three species retreat quickly after drinking. Giraffe are documented to spend a longer period drinking when in large mixed groups, whilst individuals in large herds of kudu spent less time drinking. Zebra favour water sources situated in open areas (Périquet *et al.*, 2010). Further research by Périquet *et al.* (2012) investigated the drinking behaviour of plains zebra and impala when predators (lions) were near, with zebra exhibiting intense vigilance whereas impala were unaffected. There are two levels of vigilance: routine vigilance where the head is lifted and there is an inspection of the surroundings while moving, and intense vigilance where there is an inspection of the surroundings and the individual has stopped movement (Périquet *et al.*, 2012). A larger group of mammals around an artificial water source will reduce the need for individual vigilance behaviour and decrease vulnerability to predation, as was observed when coati were drinking in the Palo Verde National Wildlife Refuge, Costa Rica (Burger & Gochfeld, 1992).

3.5 Benefits of Artificial Water Sources

There are few studies which have investigated the particular benefits that artificial water sources may have on mammal populations, however, it has been recognised that the advantages of artificial water sources have mainly been for humans (Burkett & Thompson, 1994). The addition of artificial water sources into national parks and game reserves can be beneficial to management in meeting touristic and conservation objectives and are often hubs of activity, especially in the dry season when many different species congregate around these sources. Artificial water sources are therefore popular sites in which mammals can be viewed and photographed by tourists (Ayeni, 1975), particularly attracting the larger and well recognised species (Shannon *et al.*, 2009). Due to the high numbers and the variety of species needing to drink, these features can be an economical way in which researchers can document water source visitation patterns and monitor the number of mammals that come and drink (Ayeni, 1975).

Management of conservation areas expect certain benefits for mammals by constructing artificial water sources, these benefits include increasing the habitat use areas for mammals and increasing the chance of survival of water-dependent mammals (Rosenstock *et al.*, 1999). By increasing the number of available water sources in a national park or game reserve, the distance between water sources is reduced, which will benefit water-dependent species that would usually need to travel long distances to find water. Additionally, there would be a decrease in competition for water and space between the same species and different species at natural water sources (Epaphras *et al.*, 2008). In general, there is improved water quality in artificial water sources due to the constant replacement of borehole water compared to long-standing water in natural pools.

3.6 Disadvantages of Artificial Water Sources

Artificial water sources have the potential to alter the natural balance of an area, therefore having an impact on biodiversity (James *et al.*, 1999). Such water sources result in the concentration of many different mammals into an area, with consequent overgrazing and trampling. In addition, the numbers and distribution of water-dependent species may increase and stimulate hunting and predation (James *et al.*, 1999). Several studies have highlighted that mammals drinking from artificial water sources face the challenges of increased predation and the transference of disease (Rosenstock *et al.*, 1999; Epaphras *et al.*, 2008). The supplementation of water can influence both mammals and vegetation in different ways in particular areas. The provision of water through artificial water sources can be damaging to mammals as it can lead to changes in their natural behaviour and consequently result in decreasing their chances of survival (Knight, 1995a). It is important that the availability of water is replicated naturally, as excessive water provision creates an unnatural pattern of landscape utilisation, especially for elephants, and this may lead to negative impacts on other mammals and vegetation (Loarie *et al.*, 2009).

In the Kgalagadi Transfrontier Park, water provision resulted in the unintended loss of wildebeest and eland, as these species changed their distribution due to the permanent availability of water, consequently encouraging the species to overutilise areas which they would usually only move to during specific periods of water availability (Knight, 1995a). The severe decline in numbers of the rare roan antelope in KNP, during the period between 1986 - 1993 was attributed to a number of possible reasons: supplementation of water in the northern basalt plains in the northeastern corner of KNP, which is known to be where roan antelope occur, resulted in an increase in both zebra and wildebeest seeking water during the drought period of 1982 - 1983 (Harrington *et al.*, 1999). These species distinctly favour a tall grass environment where there is little competition with various other grazer species (Smit & Grant, 2009) consequently the increase in numbers of zebra and wildebeest caused an increase in the grazing intensity in the roan antelope habitat and a decline in tall grass cover. This affected the resources available to the roan antelope as well as increased the vulnerability of roan antelope calves that need to be concealed in the long grass for protection from predation. In addition, the increase in numbers of zebra and wildebeest led to an increase in lion numbers in the area, and therefore an increase in predation of the roan antelope. All of these factors contributed to the decline of the roan antelope population, however, the underlying cause of the decline can be attributed to the provision of artificial water sources in their habitat (Harrington *et al.*, 1999). The closure of artificial water sources during 1995 in the eastern Vlakteplaas has led to a decline in zebra population numbers in the area (Dunham *et al.*, 2004), however, it will take a number of years for the low population numbers of roan antelope to recover, which could be additionally threatened by climate change impacts on habitat (Grant *et al.*, 2002).

The term 'piosphere' was described by Lange (1969) as the area where there is a relationship between a water point and mammals foraging around a water point, and the consequent impacts on the vegetation in close proximity to the water point. The 'piosphere' is therefore an important system to consider in rangeland management (Lange, 1969). The addition of artificial water sources into an environment can change grazing patterns, which is influenced by the quantity of mammals, the time spent grazing and the area in which grazing occurs (Graz *et al.*, 2012).

The impact of large herbivores on the herbaceous vegetation around artificial water sources in KNP was examined by Thrash (1998a), with two patterns of impact identified around the drinking troughs; 1) the sacrifice area, which is an area that did not have permanent herbaceous vegetation due to the concentration of large herbivores in this area in the dry season; and 2) the dry season zone, which is an area that extends to 10km from water and is relatively well utilised by mammals in the dry season. This zone emerges due to the provision of water in areas where water is not naturally available in the dry season (Thrash, 1998a). In contrast to previous work, in Chobe National Park, during a 12-year period of supplementing water, there was an increase in tree-composition around artificial water sources, despite a significant increase in the elephant population. This finding differs to what is usually expected when hypothesizing about the influence of artificial water sources on the surrounding vegetation. It was, however, added that the increase in tree-composition was due to a number of different causal factors, including fires and a succession of wet years (Kalwij *et al.*, 2010).

In KNP the seedlings of woody vegetation around artificial water source sites struggle to survive due to the pressure of trampling by concentrations of large herbivores around these sites. Large herbivores have an obvious impact on the woody plants and shrubs around artificial water sources, with an increase in quantity of shrubs extending outwards from water sources. The provision of water in KNP results in a multiple 'piosphere' effect, as the impact on vegetation is not limited to the area in close proximity to the artificial water sources but can extend up to a few thousand meters away from the artificial water sources (Brits *et al.*, 2002). The distance between water sources, the preceding rainfall season and mammal abundance has an impact on the vegetation and land surrounding water sources. It has been recommended that artificial water sources be grouped in specific areas and that these groups of water sources are dispersed throughout habitats to reduce the impacts of trampling by large herbivores on isolated water sources (Thrash, 2000). Over a period of time, the widespread provision of artificial water sources results in a decrease in herbaceous vegetation and suitable forage for grazers in the vicinity of these sources (Parker & Witkowski, 1999).

In KNP, around the Wik-en-Weeg dam, the impact on herbaceous vegetation was more significant than on the woody vegetation around the dam due to herbaceous vegetation being more sensitive to trampling by mammals (Thrash *et al.*, 1991a). Therefore, vegetation that is able to withstand the impacts of trampling around an artificial water source will have a greater chance of survival (Tolsma *et al.*, 1987). In support of previous work in KNP, it was also found that the occurrence of specific species was stable whilst other herbaceous and woody plant species increased or decreased as influenced by either rainfall or grazing or both in the Kalahari Gemsbok National Park (van Rooyen *et al.*, 1990).

3.7 Management of Artificial Water Sources

The provision of artificial water supplies has implications for the management of important conservation areas. Managers of national parks are able to manipulate where (location) and when (season) water is supplemented in artificial water sources, whereas natural sources of water are variable over space and time due to climatic factors (Cronje *et al.*, 2005). The requirement of management to not only meet the needs of mammals but also satisfy the needs of tourists is an additional motivation for providing artificial water sources (Smit & Ferreira, 2010). It is important that mammal drinking patterns across different temporal scales (daily, monthly, seasonally and yearly) be monitored, in order to establish the reliance of mammals on these sources during different climatic conditions and to provide this information to management (Hitchcock, 1996).

Management needs to consider the consequences of opening more artificial water sources or closing down artificial water sources, in order to restore a more natural pattern of surface-water availability. Closing down artificial water sources could have negative impacts on the land and vegetation around the open artificial water sources, and this degradation may be enhanced during dry periods (Franz *et al.*, 2010). It has been suggested that rotating and alternating surface-water availability by opening and temporarily closing down specific artificial water sources will prevent degradation and overutilisation of vegetation in specific areas (Smit & Grant, 2009; Franz *et al.*, 2010; Gaugris & van Rooyen, 2010). This system of alternating water sources in different areas, as well as keeping specific permanent water sources, is likely to be beneficial for numerous mammals, as well as promoting vegetation growth (Smit & Grant, 2009). It is recommended by Smit & Ferreira (2010) that if more supplementary water sources are added into KNP, that these sources should not be positioned in close proximity to drier rivers, as this would encourage elephants to move into these areas throughout different seasons. Certain species will be affected differently by the changes in the water distribution in KNP; species such as waterbuck that favour the riparian vegetation habitat, are likely to be impacted by an increase in other species utilising this habitat, due to the removal of artificial water sources (Redfern *et al.*, 2005). In response to changes in river systems due to climate change and human interference, rivers may become less desirable to species such as waterbuck, elephant and buffalo, and thus artificial water sources may possibly become essential for the survival of these species (Smit *et al.*, 2007a). The removal of artificial water sources in KNP will be determined by species utilisation of ephemeral water sources in the park. Removing artificial water sources will have an effect on herbivore distribution and population numbers as these sources have permitted these species to move into areas in which they would not usually utilise, therefore sustaining a larger population over a wider area (Redfern *et al.*, 2005). The definite consequences for mammals and their water requirements from removing artificial water sources will only be known when a drought is experienced, as under contemporary climatic conditions these consequences may not be evident (Smit & Grant, 2009). Surface-water availability fluctuates throughout different periods, which is an important management consideration, thus it is important that management undertake scientific studies in order to understand the necessity for artificial water sources during and between different seasons and that the impacts of water provision on mammals and vegetation are recognised (Chamaillé-Jammes *et al.*, 2007b).

3.8 Approaches to Studying Mammal Behaviour

Monitoring and observing species over long periods of time provides valuable information on the habitat preferences of specific mammals, the number of different species that occur in specific environments and data on population statistics (Ancrenaz *et al.*, 2012). A fundamental requirement of managing biodiversity in national parks is that of monitoring and observing mammals and examining how different management policies and environmental changes may affect behaviour and population numbers (Carbone *et al.*, 2002; McGeoch *et al.*, 2011). Two different approaches to observing and monitoring mammals have been recognised: 1) the lagrangrian approach, which requires that a specific animal or group of animals be followed and their movement across different areas are tracked (GPS tagging, tracking an animal on foot or from a car), and 2) the eulerian approach, in which a particular area is monitored and any animals moving into the area are recorded (Kays *et al.*, 2010). Remote photography techniques fall under the eulerian approach as cameras are set up in a specific area and images are captured of mammals within that area (Kays *et al.*, 2010).

3.8.1 Traditional Methods of Monitoring

A pattern between studies where similar traditional methods were used by Weir & Davison (1965) in Hwange National Park, Young (1970) in KNP, Ayeni (1975) in Tsavo National Park and du Preez & Grobler (1977) in Etosha National Park where observers counted mammals at water sources from a vehicle or from a hide and the time at which different species came to drink was noted in each study. Weir & Davison (1965) and du Preez & Grobler (1977) carried out their observation studies over a 24-hour period, specifically during the full moon so as to identify species drinking at night. Mammals were counted during the day by two observers from a hide (Ayeni, 1975) and additionally night time observations took place from a vehicle at a floodlit water source. The study by Young (1970) was carried out during the day and at night, and during moonless nights a search light was used to identify mammals at the water sources (Young, 1970).

In studies in which the main objective has been to observe the behaviour of mammals, water sources have proved to be unique and convenient sites in which to conduct this research. Monitoring the behaviour of mammals from a vehicle parked at a distance of approximately 100 meters from a water source or from a hide or tourist platform have been the standard methods used in many ecological studies observing a selection of different species (Child *et al.*, 1971; Hitchcock, 1996; Chamaillé-Jammes *et al.*, 2007a; Tefempa *et al.*, 2008; Valeix *et al.*, 2009a; Crosmary *et al.*, 2012) or observing a specific species, such as sable antelope (Kamanda *et al.*, 2008) and elephants (Merte *et al.*, 2010). A different method of identifying which particular mammals utilise water sources is to mark out quadrants around a water source and identify species based on the spoor and droppings left within the boundaries set out around the water source; this method was used in a study by Epaphras *et al.* (2008).

Additional methods of observing the behaviour of specific species is to follow them either on foot and track their movements in the sand, or from a vehicle using binoculars. The behaviour and various daily activities of warthog (Clough & Hassam, 1970), impala

(Young, 1972; Jarman & Jarman, 1973), lion (Eloff, 1973) and bushbuck (Okiria, 1980) were monitored by researchers in vehicles, and elephants were followed on foot to observe their daily activity patterns (Guy, 1976).

These traditional methods of monitoring mammal behaviour and recording mammal numbers have a temporal limitation as observation is mostly restricted to daytime hours and therefore studies are generally limited to a 12-hour observation period. However, during full moon there is an opportunity to observe mammals throughout the night (Crosmary *et al*., 2012). The continuous observation of mammals at a water source or following them in a vehicle or on foot requires the effort of at least two observers (Eloff, 1973) with sufficient experience and knowledge on specific species behaviour (Cilliers, 1989). Daily weather conditions can impact on data collection, as high temperatures can limit the ability of trackers on foot (Eloff, 1973) and during the wet season roads may be inaccessible in a vehicle (du Preez & Grobler, 1977). Additionally, the vegetation in particular areas can affect the ability to detect mammals and observe their behaviour, and in woodland areas visibility may be limited (Jarman & Jarman, 1973) whereas in areas where vegetation is less dense and there is short grass, mammals may be more easily identified (Clough & Hassam, 1970).

3.9 Mammal Census Methods

Important factors such as the study site, the time available, budget, the species being researched and the data that need to be acquired, should be considered when choosing the appropriate method to monitor mammal behaviour and population numbers (Gaidet-Drapier *et al*., 2006; Ancrenaz *et al*., 2012). Generally, ground-based census methods (foot counts, bicycle counts and water source counts) are less expensive methods when compared to an aerial census (Gaidet-Drapier *et al*., 2006). Comparisons between four different census methods (foot counts, bicycle counts, water source counts and aerial census) in Zimbabwe (Gaidet-Drapier *et al*., 2006), highlighted that bicycle and foot counts are inexpensive methods in small conservation areas whilst car counts were found to be the least useful census method, conversely water source counts were the most useful census method, being the least demanding in terms of physical requirements and effort and cost-effective (Gaidet-Drapier *et al.*, 2006).

Recent research by Valeix *et al.* (2008) in Hwange National Park used a similar methodological approach to the 4 studies undertaken in the late 1960's and early 1970's, carrying out a mammal census at water sources, over a 24-hour period during the late dry season. Despite work by Valeix *et al.* (2008), conducting a census at water sources has not been a widely used method for establishing population numbers of multiple species, and therefore this study is unique. There are many advantages to monitoring mammals at a water source, given that it provides the researcher with a large amount of data over a long period of time at a fine temporal scale. There is also the advantage of being able to identify small herbivores and birds at water sources and therefore data can be collected on the drinking patterns of these species (Valeix *et al.*, 2008). Due to changes in surface-water availability in different seasons, mammals will change their drinking patterns according to the distribution of water and therefore differences can be noted in drinking patterns between seasons and between years (Valeix *et al.*, 2008). Water source census is not a conventional method in which to record mammal numbers whilst aerial census is a traditional method of observing mammals and obtaining population numbers (Valeix *et al.*, 2008).

Aerial counts of mammals are a valuable method in which to obtain population numbers and are particularly useful in large national parks and game reserves which cover extensive areas of land, however, it has been recognised that there are numerous biases in aerial counts and therefore inaccurate data can be obtained (Jachmann, 2002). Aerial census biases are mainly linked to the ability of an observer to identify species as the environment that certain mammals inhabit and their behaviour influences the ability to record mammal numbers and consequently, aerial censuses may produce more reliable counts if done in a more open environment. Further to this, factors such as vegetation, specific mammal characteristics, the amount of mammals in a group, the effect of the aircraft on mammals, wet and dry seasons and weather conditions affect the process of an aerial census and the data that are obtained (Jachmann, 2002; Redfern *et al.*, 2002). It has been highlighted by Jachmann (2002) that the major disadvantage of aerial census is undercounting, compared to line transect foot counts which provide more accurate counts. It is therefore advised that the reliability of aerial census counts be considered when using the information to inform and assist in management decisions (Redfern *et al.*, 2002). It is suggested by Jachmann (2002) that aerial counts are suitable for larger grazer species, however, for smaller browsers and carnivores, other census techniques such as strip-line transects or water source counts would be more reliable (Jachmann, 2002).

3.10 Remote Photography

Traditional methods of observing mammal behaviour, such as direct observation, have largely been substituted by remote photography technologies (Cutler & Swann, 1999; Meek & Pittet, 2012) which are generally applicable in most environments (Silveira *et al.*, 2003) and can be used for many different ecological research disciplines (Cutler & Swann, 1999; Ancrenaz *et al.*, 2012). Remote photography is described as the process of taking pictures of mammals without the requirement of the physical presence of a researcher (Cutler & Swann, 1999). Remote photography techniques (camera-trapping and webcams) are non-invasive (do not involve the physical trapping, marking or collaring of mammals) strategies in which to monitor and observe mammals, along with other methods such as transect surveys (Silveira *et al.*, 2003; Ancrenaz *et al.*, 2012).

3.10.1 Camera-traps

Modern camera-trap and webcam technologies have numerous advantages when compared with traditional monitoring and surveying methods (*Table 3.5*) (Ancrenaz *et al.*, 2012). Images captured by remote photography technologies provide an objective source of data and therefore subjective and inter-observer biases associated with traditional methods of observation are counteracted using this modern technology (Cutler & Swann, 1999; Yasuda, 2004; Kays *et al.*, 2010; Rovero *et al.*, 2010).

Table 3.5: The advantages and disadvantages of remote photography techniques for mammal monitoring purposes.

Advantages	**Disadvantages**
• Photographs of rare, secretive and nocturnal species (Cutler & Swann, 1999; Rovero *et al*., 2010; Ancrenaz *et al*., 2012).	• Mammals may run away before the camera is able to capture an image (Lyra-Jorge *et al*., 2008).
• Useful for monitoring medium to large sized mammals (Lyra-Jorge *et al*., 2008; Ancrenaz *et al*., 2012).	• The size of birds and small mammals are often not picked up by cameras (Ancrenaz *et al*., 2012).
• Collect ecological data on species survival rates (Karanth & Nichols, 1998), species interactions (Kierulff *et al*., 2004), presence, abundance, distribution and behaviour (Silveira *et al*., 2003; Ancrenaz *et al*., 2012).	• The presence of cameras may disturb certain species and affect their typical behaviour patterns (Cutler & Swann, 1999; Lyra-Jorge *et al*., 2008; Ancrenaz *et al*., 2012; Rovero *et al*., 2013).
• Data on the daily activity patterns of mammals, as images are time stamped (Lyra-Jorge *et al*., 2008; Rovero *et al*., 2010).	• Inquisitive species may interfere with cameras by pushing them over, resulting in damage to the camera (Ancrenaz *et al*., 2012).
• Useful for capture-recapture purposes to identify individual mammals (Heilbrun *et al*., 2006) using pelage characteristics (Rovero *et al*., 2010).	• Recognising individual mammals is not often feasible (Bowkett *et al*., 2007). This can result in over counting and overestimation of abundance (Silveira *et al*., 2003; Lyra-Jorge *et al*., 2008).
• Cameras can be used in areas with different environmental and climatic conditions (Silveira *et al*., 2003).	• Cameras in unprotected areas may be interfered with or stolen by people Silver *et al*., 2004; Pettorelli *et al*., 2010).
• Less time consuming and labour intensive than traditional methods (Kays *et al*., 2010; Meek and Pittet, 2012).	• Methods of inferring information from images is problematic (Bowkett *et al*., 2007).
• Research can be undertaken over different temporal (seasons and across years) and spatial scales (Karanth & Nichols, 1998; Ancrenaz *et al*., 2012; Sollmann *et al*., 2013).	• Cameras may be triggered by obstructing vegetation or by changes in the ambient temperature (Lyra-Jorge *et al*., 2008; Brown & Gehrt, 2009).
• Images can be archived and used for future retrospective studies (Kelly & Holub, 2008; Rowcliffe & Carbone, 2008).	• Analysing a large amount of images is time consuming (Ancrenaz *et al*., 2012).
• Minimal disturbance to the surrounding environment, mammals and vegetation (Silveira *et al*., 2003; Rovero *et al*., 2010).	
• Cameras are a research investment and can be used again in different studies (Silveira *et al*., 2003; Lyra-Jorge *et al*., 2008; Rovero & Marshall, 2009).	

A pattern between studies comparing camera trap methods to line transect counting techniques highlighted that line transect techniques are particularly restricting as they are time-consuming, expensive, require the expertise of experienced researchers and are limited by environmental conditions (Silveira *et al*., 2003; Kielrulff *et al*., 2004; Rovero & Marshall, 2009). Furthermore, line transect counts facilitate the identification of large species during the day over small or nocturnal species (Silveira *et al*., 2003). Comparisons between camera traps and track plot counts have revealed that track plot counts are especially useful in determining species richness and abundance indices (Silveira *et al*., 2003), however, they require the expertise of at least two researchers and a vehicle, tracking over large spatial scales and long temporal periods (Silveira *et al*., 2003; Lyra-Jorge *et al*., 2008; Kays *et al*., 2010). Track plot counts are limited by contemporary weather conditions as rain and wind can remove records (Silveira *et al*., 2003; Lyra-Jorge *et al*., 2008). It is noted that both the camera trap method and track plot counts can overestimate abundance due to over counting (Silveira *et al*., 2003; Lyra-Jorge *et al*., 2008).

The use of remote photography in ecological studies has shaped a new methodology in which to observe and monitor mammals, and has made it possible for researchers to acquire valuable information on species that would usually be difficult to study using traditional methods (Brown & Gehrt, 2009). It has been noted that there are certain procedural limitations related to the data collected by remote photography technologies and how such data have been interpreted and applied in different studies (*Table 3.5*) (Kelly, 2008). There has, however, been a substantial increase in the number of published ecological studies using camera-traps to assist in the research process over the last 10 years (Rowcliffe & Carbone, 2008; Rovero *et al*., 2010).

3.10.1.2 Camera Traps Used for Ecological Studies

Camera traps have been used in numerous scientific research studies on various mammals in different locations around the world; over variable time scales and with different research aims and objectives (Cutler & Swann, 1999). Camera-trap 'photographic' capture-recapture methodology is an effective method in which to determine population size of tigers, including other individually recognisable species (Karanth, 1995), such as jaguars in Belize and Bolivia (Silver *et al.*, 2004); leopards (Chauhan *et al.*, 2005) and tigers in India (Karanth & Nichols, 1998); leopards in the N'wanetsi Concession in KNP (Maputla *et al.*, 2013), Phinda Private Game Reserve (Balme *et al.*, 2010) and Zululand Rhino Reserve (Chapman & Balme, 2010), South Africa; and Cheetahs in the Atherstone Collaborative Nature Reserve, South Africa (Marnewick *et al.*, 2008). If individuals are not individually recognisable, camera-traps can be used to determine the occurrence of a species in a specific environment (Jennelle *et al.*, 2002). Camera-traps were also used in Bandipur National Park, India, to analyse the population structure of Asian elephants (Varma *et al.*, 2006), in central Japan to study medium and large sized terrestrial mammals (Yasuda, 2004) and in the Khao Yai National Park, Thailand, camera-traps have been used in long-term studies throughout different seasons (Jenks *et al.*, 2011). Camera-traps have been valuable for studies in the Udzungwa Mountain National Park, Tanzania, to assess the influence of environmental and anthropogenic factors on the habitat use of two specific forest antelopes (Bowkett *et al.*, 2007).

In Pilanesberg National Park camera-traps have been a useful tool to estimate brown hyaena (Thorn *et al.*, 2009). It has been noted that the majority of published studies using camera traps in different regions of the world are particularly centered on one or two specific species (Kelly & Holub, 2008; Tobler *et al.*, 2008). Images not containing information on a focus species are often not used and are archived or discarded however, images captured by camera-traps can provide information on numerous species inhabiting a particular area and therefore these images should be archived for opportunities to use in future studies (Kelly & Holub, 2008).

3.11 Webcams and Mammal Observation

Webcams have been set up in various natural environments around the world as a tourist initiative, streaming live images or videos across different websites, where people all over the world can access these sites and remotely observe animals in different locations over a 24-hour basis (Kamphof, 2011). The World Land Trust have webcams that stream live images from tropical forests in Ecuador and Argentina (www.worldlandtrust.org/webcam). Africam.com is a popular website where people can access live video streaming of specific locations in different game reserves in South Africa (Kamphof, 2011). Similarly, webcams have also been set up at various water sources located in national parks and game reserves in South Africa, such as Madikwe Game Reserve, Pilanesberg National Park and Tembe Elephant Park (Hayward & Hayward, 2012). On the SANParks website, images and live video can be accessed, providing tourists with the opportunity to view mammals drinking at water sources in Addo Elephant National Park, Kgalagadi National Park (Nossob) and in KNP, where webcams have been set up at two artificial water sources near to the Satara and Orpen tourist camps (www.sanparks.co.za/webcams/). Webcams set up in remote environments that provide people with images of mammals that inhabit these areas are becoming progressively popular tools in which to provide opportunities for people to remotely observe mammals (Hayward & Hayward, 2012). However, there is concern that the use of webcams to live stream images and videos on various online platforms puts specific species at risk, as the location and activity patterns of these species can be observed by poachers (Northcut, 2012). The use of webcams to collect information for scientific research purposes has not been widely used to date, with few studies undertaken using webcams for wildlife monitoring.

Webcams have been used in avian studies, to observe eggs in nests and monitor the changes in nestling activity (Hudson & Bird, 2006) as well as to examine bird migration patterns (Verstraten *et al.*, 2010). A recent study by Hayward & Hayward (2012) is the first study to have assessed the value of webcams for scientific research purposes and to observe the drinking patterns of wildlife in different South African locations. The study successfully collected useful data on specific species drinking patterns at water sources, verifying the use of this technology for scientific studies (Hayward & Hayward, 2012).

Webcams provide a cost-effective method in which to observe wildlife behaviour (Hayward & Hayward, 2012), providing a permanent data record (Hudson & Bird, 2006). Webcams share many of the advantages of camera-traps, with the added advantages of capturing numerous images without the concern about the storage capacity of memory cards (Porter *et al.*, 2010). Remote photography technologies provide a unique and valuable method in which to observe and monitor mammal populations and establish the current and future threats to these populations, particularly taking into consideration projected future climate change scenarios, which is important for the survival and management of these species in conservation areas (Pettorelli *et al.*, 2010).

3.12 Climate Change in Southern Africa

Over the central interior of southern Africa there has been a trend towards intense warming (Hulme *et al.*, 2001), with an increase in the number of hot days and nights and a decrease in the number of extremely cold days and nights (New *et al.*, 2006). Rainfall over southern Africa is seasonally and annually variable, and is influenced by the amount of solar radiation, changing position of the Hadley cell and the dominant winds in summer and winter (Jury, 2013). The start of the rainfall season in southern Africa has shifted to a later period and it has been noted that the rainfall season in southern Africa continues over a shorter temporal scale (Shongwe *et al.*, 2009).

3.12.1 Temperature Trends and Projections

There has been an increase in days with warmer temperatures and a decrease in days with cooler temperatures, whilst there has also been a widespread increase in nights with warmer temperatures and a decrease in nights with cooler temperatures (Kruger & Shongwe, 2004). Particularly, there has been a significant increase in nights with warmer temperatures on the east coast, the eastern interior region and in the northern Cape interior (Kruger & Shongwe, 2004). The most intense warming has been noted within the month of April and in autumn (Kruger & Shongwe, 2004).

A pattern between studies analysing the trends of daily maximum and minimum temperature extremes for South Africa, revealed that over most of the Country there has been an increase in the daily minimum temperatures in the Limpopo Province and areas of northern Mpumalanga, excluding the central interior region (Kruger & Sekele, 2013; MacKellar *et al*., 2014), whilst across South Africa there has also been an increase in daily maximum temperatures (Kruger & Sekele, 2013), which have increased particularly in the months of June, July and August. Minimum and maximum temperature increases were noted to be significantly higher in the western region and northeastern interior region of South Africa (Kruger & Sekele, 2013) consequently, it has also been highlighted that a significant increase in heat waves has been experienced in the most northern areas of the western and northeastern interior regions (Kruger & Sekele, 2013). Temperature trends for the Limpopo Province, in which the majority of KNP is situated, for the period 1950 - 1999, revealed that there has been a general increase in the mean annual temperature of 0.12°C/decade (Tshiala *et al*., 2011). The substantial increase in temperature over this Province could have considerable impacts on the water resources and biodiversity in this region (Tshiala *et al*., 2011). Temperature trend analysis for Skukuza for the period 1960 - 2001 indicated that there has been a distinct increase in the minimum temperature from the beginning of the study period (Kruger *et al*., 2002).

In South Africa, a possible increase of 1°C to 3°C in temperature is projected over the next 5 decades as well as a possible decrease of 5 to 10% of contemporary rainfall (Madzwamuse, 2010). In support of the general warming trend over most of South Africa, with certain regions experiencing stronger increases and a higher rate of recurrence of warm extremes from the 1960's onwards (Kruger & Shongwe, 2004; Kruger & Sekele, 2013; MacKellar *et al*., 2014), future temperature projections for northeastern South Africa, including the Mpumalanga, Limpopo and Gauteng Provinces suggest an increase in the annual maximum daily temperature of 0.5°C, with a decrease of between 0.27°C and 1.26°C in April, May, June and July, an increase in the annual mean daily temperature of between 0°C and 0.89°C and an increase in the minimum daily temperature of between 0.6°C and 1.16°C for all months of the year (Davis, 2010).

3.12.2 Precipitation Trends and Projections

Climate change in South Africa is likely to increase the intensity and frequency of extreme events such as flooding and drought periods due to an increase in rainfall events over a shorter period, and there will be longer periods without rainfall (Petersen & Holness, 2012). It is projected that there will be a decrease in the mean summer precipitation rates, particularly in the arid and semi-arid regions of southern Africa (Shongwe *et al.*, 2009). Analyses of daily precipitation trends from 138 rainfall stations in South Africa, for the period 1910 - 2004, highlighted that in general there have been no major changes in the rainfall over South Africa (Kruger, 2006), despite this, it has been noted that there have been significant increases in annual rainfall in the southern Free State and in an area north of the Eastern Cape, whilst there has been a decrease in annual rainfall in Limpopo, Mpumalanga, eastern Free State and part of the Eastern Cape (Kruger, 2006). There has been a considerable decrease in rainfall and the number of rain days particularly in the central and northeastern region of South Africa (Kruger, 2006; Mackellar *et al.*, 2014). Across most of South Africa there has been an increase in the number of heavy rainfall events (Mason *et al.*, 1999). Monthly rainfall data from Skukuza for the period 1912 - 2001, Kruger *et al.* (2002) shows that the long-term average rainfall has been fairly consistent throughout this period in this area.

In the lowveld region there has been a decrease in the number of rain days in the months of January, February, March, April, May, September, October, November and December (Mackellar *et al.*, 2014), this is validated for most of South Africa where similarly there has been a significant decrease in rainfall in the months of December, January and February observed over the period from 1900 - 2000 (Hulme *et al.*, 2001). Similarly future climate projections for southern and tropical Africa using the period 1975 - 2005 (present) compared to the period 2070 - 2100 (future), revealed that for South Africa in the South Western Cape, there is projected to be a significant decrease in rainfall in the future climate scenario. The eastern half of South Africa is projected to become drier due to a decrease in annual rainfall, particularly in the northeast, although rainfall is projected to increase during summer (Engelbrecht *et al.*, 2009). This is in contradiction to the future rainfall projections for northeastern South Africa, using ten global circulations models, which suggest an increase in the total annual rainfall, fluctuating between 301mm to 758mm per annum (Davis, 2010). It is, however, projected that with increasing temperatures, evaporation rates are likely to increase and this will have an impact on available water sources (Davis, 2010). The region in South Africa that is projected to become wetter in the future climate scenario is the central interior (Engelbrecht *et al.*, 2009), this projection corresponds with the findings of Kruger (2006), which highlighted that annual precipitation has increased in parts of the central interior of South Africa, with a decrease in annual precipitation over parts of the eastern half of South Africa.

3.13 Impacts of Climate Change on the Conservation Sector

The majority of wildlife conservation areas in southern Africa and South Africa are situated in areas where water is a scarce resource; and with the projected climate change impacts, these areas are expected to become more arid (Magadza, 1994) due to changing rainfall patterns (Owen-Smith & Ogutu, 2012). The conservation sector and particularly the biodiversity within conservation areas in South Africa are likely to be affected significantly by climate change (van Jaarsveld & Chown, 2001; Davis, 2010). Species may respond to climate change by altering their habitat use (spatial), shifting their daily and seasonal utilisation of resources (temporal) or adapting to changes by adjusting their behaviour or physiological mechanisms (Bellard *et al.*, 2012). The movement of mammals is confined within conservation areas, which will limit their ability to modify their distribution patterns in response to changing climatic patterns (Thomas *et al.*, 2004; Owen-Smith & Ogutu, 2012). Species are likely to shift their distribution and range towards an easterly direction, however, range contractions are expected to occur along the eastern regions of South Africa (van Jaarsveld & Chown, 2001; Davis, 2010). The increasing rates of carbon dioxide released into the atmosphere is expected to have an impact on both the savanna and grassland biomes, due to the invasion of bush and woody species, which has implications for wildlife grazing (Petersen & Holness, 2012). The incidence of wildfires is likely to increase, along with an increase in alien invasive species and further fragmentation of natural habitats which all have implications for the survival of mammals in conservation areas in South Africa (Davis, 2010). An increase in rainfall and therefore an increase in flooding events, will lead to the build-up of sediment in rivers, which is likely to have an impact on the water quality of downstream sources (Petersen & Holness, 2012).

KNP forms part of the savanna biome, and it is predicted that, globally, vegetation in savanna biomes will be negatively impacted due to the variability of rainfall amongst other factors (Fischlin *et al.*, 2007). Increasing global temperatures are expected to enhance dry season drought conditions in savanna biomes due to an increase in evaporation which will therefore intensify the water loss of both mammals and vegetation (Ogutu & Owen-Smith, 2003). The survival of wildlife is affected by both climatic conditions, which influences physiology; and the quantity and quality of vegetation available (Thuiller *et al.*, 2006). The likely impacts of climate change on mammals inhabiting the savanna biomes are not well known (Fischlin *et al.*, 2007), however, the increase in occurrence and intensity of droughts and floods will have a major impact on species in savanna habitats (Owen-Smith & Ogutu, 2012). Drought threatens the survival of mammal populations in arid and semi-arid environments in the 21st century, and it is predicted that sedentary species such as grazers and mixed feeders will be most affected by the increasing occurrence of drought as they favour vegetation that is drought-intolerant (Duncan *et al.*, 2012). Hartebeest and waterbuck are species that will be significantly affected by increasing drought conditions under climate change scenarios, whereas the survival of buffalo and impala will not be significantly impacted (Duncan *et al.*, 2012). Changing regional rainfall patterns will significantly affect water quality, quantity and availability, thus impacting on mammals and their water-use behaviours in savanna regions. Many factors influence the vulnerability of mammals in conservation areas and a major limiting resource is surface water availability. With changing rainfall patterns and increasing temperatures due to climate change, management of conservation areas need to provide a sufficient number of water sources and ensure that there is suitable tree cover for mammals to rest under during extreme temperature conditions (Mawdsley & Surridge, 2012). It is suggested that the management objectives for artificial water provision in conservation areas should be directed towards distributing water points in specific areas in the landscape, so that they benefit both mobile and sedentary species (Duncan *et al.*, 2012). Future studies need to concentrate on the impacts of climate variability and climate extremes on specific habitats of wild mammals, to establish wildlife vulnerability and therefore identify conservation areas that are likely to be most affected by climate change (Dockerty *et al.*, 2003; Williams *et al.*, 2008) or strategic management policies can be put in place considering climate change projections (Duncan *et al.*, 2012).

3.14 Conclusion

Artificial water sources are needed globally to supplement water in different conservation environments around the world and in this literature review the purpose of artificial water sources in different areas has been highlighted. Different mammals have different water requirements and utilise artificial water sources over different temporal and spatial scales. The supplementation of water through the use of artificial water sources is a contentious subject, with many negative impacts on both mammals and vegetation and the wider environments in which they have been implemented. However, they are beneficial for certain species and for tourist initiatives and therefore assist in achieving management objectives. There are numerous methods in which to study and observe mammal drinking patterns, with various advantages and disadvantages connected to these various methods. The traditional and modern approaches of mammal observation methods have been reviewed with a particular focus on remote photography methods. It is necessary to establish reliable methods with which to monitor mammal populations and their behaviour, particularly in the context of future projected climate change scenarios for South Africa. Few studies have used webcam imagery to study and observe mammal drinking patterns and behaviour under contemporary climatic conditions and therefore the aim of this study is to add to this particular gap in the literature. Expanding knowledge on climate-related mammal behavioural trends is critical in shaping decisions about water provision, and what factors should be considered important when making future water provision decisions within the framework of projected future climate trends.

CHAPTER FOUR

Data and Methodology

Chapter 4 - Data and Methodology

4.1 Introduction

The primary aim of this desktop study is to improve knowledge pertaining to mammal waterhole visitation patterns, and their relationships with contemporary climate and astronomical conditions and time of day. Mammal visitation behaviour was explored between species, and according to temperature, rainfall, sunrise and sunset and moon phases. This was undertaken using high temporal resolution webcam imagery from two artificial water sources located in the central KNP, and corresponding climate and astronomical data, to determine the extent to which different climatic and astronomical factors control the temporal visitation patterns by species and species associations. It is also of interest to determine the extent to which proportional visitation of mammals at the water sources is representative of broader populations in the park, to assess whether any relationships have broader application. This facilitated predictions regarding the impact of regional climate change and associated extreme temperature and rainfall events on water consumption behaviour. This chapter provides an overview of the data collection process and outlines the details of the data that were acquired, followed by a discussion on the methodology that was used to determine the relationships between mammal visitation trends and climatic and astronomical variables. The description of the data analysis process follows the structure of the sections in the results chapter to facilitate ease of reading.

4.2 Data

4.2.1 Data Collection

Webcams have been established in several national parks in South Africa as a tourist initiative by SANParks, allowing images to be viewed in real-time by wildlife enthusiasts worldwide. These webcam images have the potential to further contribute valuable scientific data. Webcam imagery from KNP has provided valuable scientific data on water source visitation patterns and behaviour for a pilot project run during the 2012 dry-season which highlighted that specific species have clear daily visitation patterns (Trent, 2012). KNP has a network of artificial water sources which provide researchers with a valuable study site to explore alternate water sources. The acquisition of webcam imagery across seasons at artificial water sources presents a source of environmental change data. The formulation of testable research questions further validates this remote imagery as a source of valuable long-term ecological data. In this instance the research questions focus on waterhole visitation patterns under normal and extreme climatic conditions, and so require 'natural' assemblages of mammals in a relatively natural environment, where their water source visitation behaviour is under natural controls of weather, landscape and predation risk/conflict avoidance. As the researcher has to inspect each webcam image from the two sites at a 15-second resolution, the data collection process formed a large component of this study. As very few studies using webcam imagery to study mammal populations and behaviour exist, the data collection and analysis methods were developed from a range of studies with comparable aims within the ecology, animal behavioural, digital repeat photography, climate science and environmental science domains (Richardson *et al.*, 2007; Verstraeten *et al.*, 2010; Hayward & Hayward, 2012; Sonnentag *et al.*, 2012).

4.2.2 Webcam Imagery

Two webcams were selected for this study, which operate at Orpen and Satara artificial water sources respectively, and which capture images at 15-second intervals over the full 24-hour period daily (*Table 4.1*). The Orpen webcam, overlooking an artificial water source adjacent to the Orpen rest camp (*Figure 4.1a*), became operational in 2004. The Orpen artificial water source is supplied from borehole water, and is controlled by a ball-valve so that the water source remains full (Sowry, pers comm, 2015). The Satara webcam, located at a water source adjacent to Satara rest camp (*Figure 4.1b*), was established in 2005. Both the Satara and Orpen artificial water sources are illuminated at night by a spotlight to allow the webcams to continue capturing photographs of the mammals when dark. The webcams capturing images at these two webcams are featured on the SANParks website (www.sanparks.org/webcams/).

Table 4.1: Location and landscape details of the Orpen and Satara artificial water sources.

Study Site Details						
Site	**Description**	**Location**	**Closest Main Road**	**GPS Coordinate**	**Gertenbach Landscape No.**	**Gertenbach Landscape Area (km^2)**
Orpen	Concrete waterhole	Orpen rest camp	H7	24°28'32.94"S 31°23'24.91"E	19	685
Satara	Concrete water trough	Satara rest camp	H1-4	24°23'33.30"S 31°46'44.53"E	17	1411

The webcam images captured from 2004 to February 2012 were unavailable for this study as images are deleted after 30 days. Each webcam image is ~30 Kilobytes (KB) and therefore a large amount of storage space is required for the images to be archived on both a monthly and annual basis (*Table 4.2*). The webcam imagery used in this project were acquired from SANParks under an agreement with the SANParks E-Commerce Department to automatically forward ~10,000 daily images to the WITS FTP server for retrieval and analysis. The images were retrieved from the WITS FTP server using WINSCP (Windows Secure Copy), and subsequently saved to an external hard drive for long-term storage. The webcam images are all embedded with a date/time stamp facilitating accurate temporal analysis (*Figure 4.1 a, b*).

Table 4.2: Webcam image details for Orpen and Satara.

Webcam Imagery Details								
Site	**Monitoring Period**	**No. of Days Active**	**No. of Webcam Images**	**Storage Required (GB)**	**Avg No. of Monthly Images (15 sec)**	**Storage Required (GB)**	**Avg No. of Monthly Images (30 sec)**	**Storage Required (GB)**
Orpen	14 Mar 2012 - 31 Mar 2014	639	2,061,727	58.99	101653	2.91	58053	1.66
Satara	1 Apr 2012 - 31 Mar 2014	623	1,827,096	52.27	103114	2.95	38350	1.10

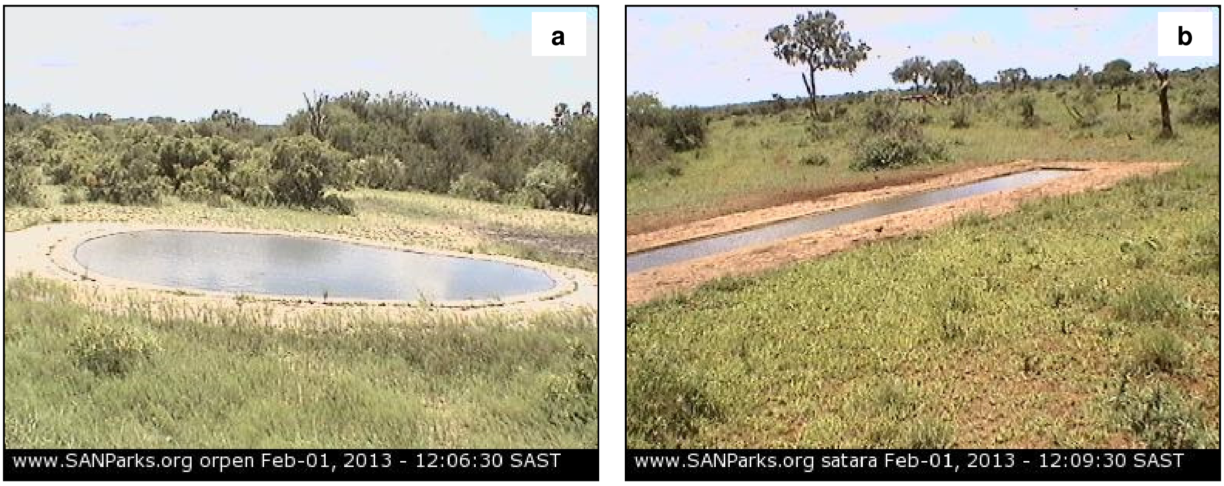


Figure 4.1: a) Webcam image of Orpen artificial waterhole and b) webcam image of Satara artificial water trough

The data analysis process was conducted using webcam imagery captured at the Orpen and Satara artificial water sources over a 25- and 24-month period respectively, and involved the identification of mammal species captured in the webcam images. The mammal species present were identified, the number of individuals counted and the date and time that they visited the water source recorded. Mammals were only counted if they were observed utilising the water sources, i.e. drinking or wallowing. The majority of mammal species were easily identifiable using the 'Field Guide to the Mammals of the Kruger National Park (Schütze, 2002). Double counting of an individual might have occurred as most of the mammals visiting the water sources do not have easily recognisable characteristics. In some cases, unusual features, such as an elephant with a broken tusk, could be used to identify individuals at different times of appearance.

Avian and reptile species were also observed visiting the Orpen and Satara water sources. However, their visitation patterns were not recorded during this study so as to maintain focus on mammal species only (*Table 4.3*). Small birds and reptiles were not easily identifiable due to the low resolution of the webcam images.

Table 4.3: Avian and reptile species that were observed at Orpen and Satara water sources, but which were excluded from the study.

Species Excluded from the Study	
Scientific Name	**Common Name**
Ardea melanocephala	Black-headed Heron
Alopochen aegyptiaca	Egyptian Goose
Ardea cinerea	Grey Heron
Numida meleagris	Helmeted Guineafowl
Leptoptilos crumeniferus	Marabou Stork
Ephippiorhynchus senegalensis	Saddle-billed Stork
Bucorvus leadbeateri	Southern Ground Hornbill
Bubo africanus	Spotted Eagle-Owl
Aquila rapax	Tawny Eagle
Pelusios subniger	Pan Hinged Terrapin

Mammal waterhole visitation was recorded at 15-second intervals in monthly *Microsoft Excel* spreadsheets, with each species listed and daily sightings recorded. Each day of the month and each mammal species were listed vertically in *Microsoft Excel* with the time in 15-second intervals listed horizontally. When a mammal was observed visiting the water source, the number of individuals were recorded at first appearance. A zero was used to indicate that the same number of individual/s were present at the water source to record time spent at the water source. However, if further mammals appeared, their presence was recorded and the zero would be replaced with the number of additional individuals. Each horizontal row, represented one day, for each species, with the sum of each row representing the total number of individuals of that species visiting the water source per day. The sum function does not count zeros and therefore only the total numbers of individuals were counted. The raw mammal visitation data (15-second intervals) for each mammal species, and for each month, were grouped into hourly and quarter hourly intervals. Seasonal, monthly and daily totals were calculated to facilitate correlation analyses with corresponding climate and astronomical variables (*Figure 4.2*).

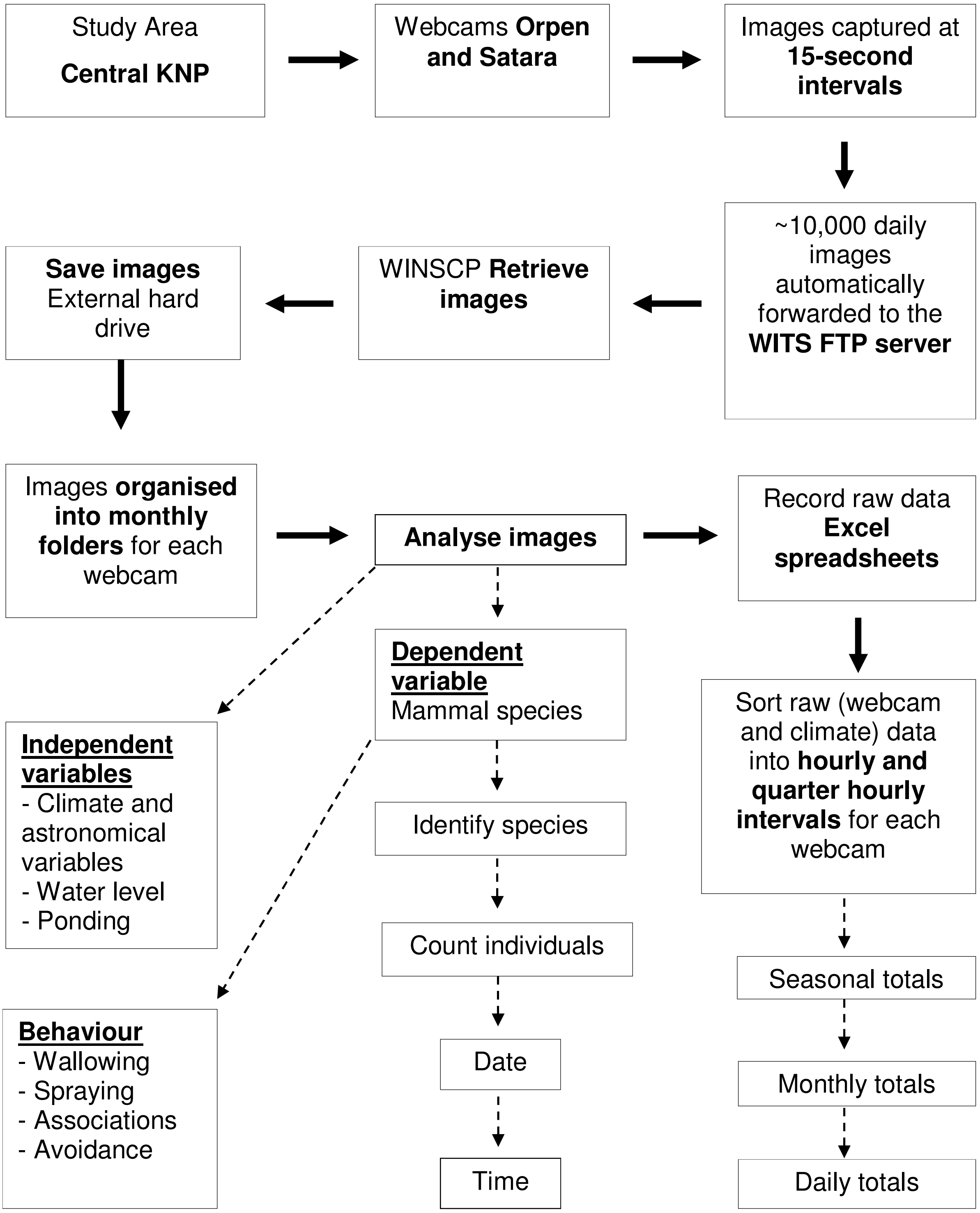


Figure 4.2: Schematic representation of the data collection and data analysis process.

4.2.3 Climate Data

Climate data are important to establish relationships between temporal variations in mammal visitation times and concurrent climatic fluctuations. Where possible, climate data were sourced from locations as close to the water sources as possible, so as to facilitate high resolution comparison (*Table 4.4*).

4.2.3.1 Temperature Data

Hourly temperature data for Orpen, for the period March 2012 to June 2012, were obtained from the South African Wildlife College (SAWC), situated 10km west of Orpen gate and from the SAEON weather station, situated in Welverdiend village, directly across the road from the SAWC. Hourly temperature data for Satara for the period April 2012 to March 2014 were obtained from SANParks. Weather parameters were recorded at Satara Automatic Weather Station (AWS), situated in the Satara rest camp (*Table 4.4*).

Table 4.4: Details of the weather stations used to obtain temperature and rainfall data.

Weather Station Details				
Weather Station	**Rainfall / Temperature**	**Resolution**	**Location**	**Distance (Kms) to Weather Stations**
Orpen				
Welverdiend	Temperature	Hourly	24°34'16.10"S, 31°20'41.15"E	~ 15
SAWC	Temperature	30 minute	24°32'26.63"S, 31°20'10.39"E	~25
Tiny-tag Temperature logger	Temperature	15 minute	24°27'39.04"S, 31°26'49.37"E	~ 7
Kingfisherspruit 0638748_2	Rainfall	Daily	24°28'1.2"S, 31°25'1.2"E	~3
Satara				
Satara AWS	Temperature	30 minute	24°23'51.7"S, 31°46'40.0"E	~2
Tiny-tag Temperature logger	Temperature	15 minute	24°21'40.12"S, 31°41'36.55"E	~ 19
Nwanedzi 0639868_1	Rainfall	Daily	24°28'1.2"S, 31°58'58.8"E	~ 25
Hoedspruit 0638081_1	Temperature	Hourly	24°21'S, 31°3'E	~ 100

Quarter-hourly temperature data for the period September 2012 to March 2014 were obtained from on-site, temporary tiny-tag loggers set up at the Kingfisherspruit section ranger's house, near to the Orpen artificial water source, and at an existing research site near to the Satara artificial water source (*Table 4.4*). These tiny-tag temperature loggers were set up to obtain temperature data as close to the study sites as possible. Temperature data were recorded with one reading taken in direct sunlight and another in natural shade; this allowed the actual air temperatures experienced by mammals to be measured. Direct sunlight temperature data were sorted into hourly intervals to correspond to hourly mammal waterhole visitation data.

Additional hourly temperature data for the period March 2012 to March 2014 were sourced from one South African Weather Service (SAWS) station (Hoedspruit), which is the weather station closest to the central KNP. The SAWS use robust climate recording gauges and the data undergo thorough management and checking procedures before disseminating data.

The Hoedspruit temperature data were used to substitute for gaps (46 days) in the temperature logger data and data received from other sources. Pearson's correlation coefficients (*Equation 1*) between the temperature logger data, hourly temperature data from the SAWC, Welverdiend and Satara AWS and the additional Hoedspruit data show statistically significant, strong correlations between all readings, permitting the use of the Hoedspruit data for substitution where necessary (*Table 4.5*). To enable the most accurate correspondence of visitation and temperature data, the closest records were used wherever possible.

Table 4.5: Pearson's correlation analysis of temperature data received from Hoedspruit and the Orpen and Satara temperature data loggers and between Hoedspruit and the Welverdiend and SAWC. Pearson's correlation analysis of the Satara temperature logger data and the Satara AWS temperature data.

Temperature Data Analysis					
	Orpen	**Satara**	**Welverdiend**	**SAWC**	**Satara AWS**
Time	**r-value**	**r-value**	**r-value**	**r-value**	**r-value**
1:00	0.89	0.91	0.77	0.70	0.98
2:00	0.89	0.91	0.77	0.69	0.98
3:00	0.88	0.92	0.79	0.65	0.98
4:00	0.88	0.91	0.84	0.70	0.98
5:00	0.88	0.91	0.83	0.72	0.98
6:00	0.90	0.92	0.80	0.69	0.97
7:00	0.92	0.93	0.84	0.66	0.96
8:00	0.94	0.89	0.88	0.86	0.92
9:00	0.87	0.86	0.91	0.83	0.91
10:00	0.86	0.84	0.90	0.89	0.93
11:00	0.84	0.85	0.94	0.88	0.93
12:00	0.85	0.86	0.95	0.90	0.93
13:00	0.86	0.89	0.97	0.92	0.94
14:00	0.87	0.90	0.97	0.93	0.95
15:00	0.88	0.90	0.97	0.94	0.96
16:00	0.90	0.92	0.97	0.93	0.96
17:00	0.93	0.93	0.94	0.96	0.95
18:00	0.93	0.92	0.86	0.66	0.97
19:00	0.89	0.90	0.79	0.51	0.97
20:00	0.87	0.90	0.72	0.52	0.97
21:00	0.86	0.91	0.63	0.50	0.97
22:00	0.87	0.91	0.57	0.50	0.97
23:00	0.87	0.91	0.66	0.53	0.97
0:00	0.88	0.90	0.64	0.62	0.98

4.2.3.2 Rainfall Data

Daily rainfall data for the period March 2012 to March 2014 were obtained from two SAWS stations, Kingfisherspruit (closest station to Orpen) and Nwanedzi (closest station to Satara) (*Table 4.4*). The SAWS performed interval data checking.

4.2.4 Astronomical Data

Mammal species partition their activity periods to specific times over the 24-hour cycle, with some species exhibiting strictly diurnal, nocturnal, crepuscular or cathemeral behaviour (Bennie *et al.*, 2014). Temporal partitioning of activity patterns may be controlled by various astronomical variables relating to the amount of light available, as influenced by sunrise and sunset times and moon phases (Bennie *et al.*, 2014). There is a gap of knowledge on the influence that astronomical variables might have on African mammal species behaviour, thus making it important to investigate the influence of moon phases and shifting sunrise and sunset times on the visitation patterns of mammal species in KNP.

4.2.4.1 Moon Phase Data

The nocturnal visitation patterns of mammals were monitored according to the moon phases to establish whether the variation in illumination associated with full and new moon might have a particular influence on waterhole visitation trends. Moon phase data for the period March 2012 to March 2014 (*Table 4.6*) were acquired from the Johannesburg planetarium website (www.planetarium.co.za).

This data included the date and time of the four main lunar phases, new moon, first quarter, full moon and last quarter. New moon was defined as the time when the moon is < 5% illuminated, relative to full moon which was defined as the time when the moon is > 95% illuminated, whilst the first and last quarter were defined as the period when the moon is 50% illuminated (Cozzi *et al.*, 2012), thus indicating the various scales of illumination.

Table 4.6: Moon phase dates for South Africa for the period March 2012 - March 2014.

Moon Phase Dates for South Africa			
New Moon	**First Quarter**	**Full Moon**	**Last Quarter**
-	-	-	15-Mar-12
22-Mar-12	30-Mar-12	6-Apr-12	13-Apr-12
21-Apr-12	29-Apr-12	6-May-12	12-May-12
21-May-12	28-May-12	4-Jun-12	11-Jun-12
19-Jun-12	27-Jun-12	3-Jul-12	11-Jul-12
19-Jul-12	26-Jul-12	2-Aug-12	9-Aug-12
17-Aug-12	24-Aug-12	31-Aug-12	8-Sep-12
16-Sep-12	22-Sep-12	30-Sep-12	8-Oct-12
15-Oct-12	22-Oct-12	29-Oct-12	7-Nov-12
14-Nov-12	20-Nov-12	28-Nov-12	6-Dec-12
13-Dec-12	20-Dec-12	28-Dec-12	5-Jan-13
11-Jan-13	19-Jan-13	27-Jan-13	3-Feb-13
10-Feb-13	17-Feb-13	25-Feb-13	4-Mar-13
11-Mar-13	19-Mar-13	27-Mar-13	3-Apr-13
10-Apr-13	18-Apr-13	25-Apr-13	2-May-13
10-May-13	18-May-13	25-May-13	31-May-13
8-Jun-13	16-Jun-13	23-Jun-13	30-Jun-13
8-Jul-13	16-Jul-13	22-Jul-13	29-Jul-13
6-Aug-13	14-Aug-13	21-Aug-13	28-Aug-13
5-Sep-13	12-Sep-13	19-Sep-13	27-Sep-13
5-Oct-13	12-Oct-13	19-Oct-13	27-Oct-13
3-Nov-13	10-Nov-13	17-Nov-13	25-Nov-13
3-Dec-13	9-Dec-13	17-Dec-13	25-Dec-13
1-Jan-14	8-Jan-14	16-Jan-14	24-Jan-14
30-Jan-14	6-Feb-14	15-Feb-14	22-Feb-14
1-Mar-14	8-Mar-14	16-Mar-14	24-Mar-14
30-Mar-14			

4.2.4.2 Sunrise and Sunset Data

Daily sunrise and sunset times for Skukuza, southern KNP region, for the period March 2012 to March 2014, for both study sites, were retrieved from www.timebie.com/sun/skukuzaza.php (*Table 4.7*). Skukuza is ~137km south-east of Orpen rest camp and ~93km south-west of Satara rest camp, and was the closest location from which daily sunrise and sunset times could be obtained. Day length varied from the maximum of ~14 hours in December and minimum day length was ~11 hours in June (*Table 4.7*).

Table 4.7: Average monthly sunrise and sunset times for Skukuza, for the period March 2012 - March 2014.

Average Monthly Sunrise and Sunset Times for Skukuza			
Month	**Sunrise**	**Sunset**	**Day Length (Hrs)**
March-12	5:55	18:08	12:13
April-12	6:08	17:38	11:30
May-12	6:22	17:17	10:54
June-12	6:35	17:12	10:36
July-12	6:36	17:21	10:44
August-12	6:20	17:35	11:15
September-12	5:50	17:47	11:56
October-12	5:19	18:00	12:40
November-12	4:59	18:18	13:19
December-12	4:59	18:39	13:39
January-13	5:17	18:47	13:30
February-13	5:38	18:36	12:57
March-13	5:54	18:10	12:15
April-13	6:08	17:39	11:31
May-13	6:22	17:17	10:55
June-13	6:35	17:12	10:36
July-13	6:37	17:21	10:44
August-13	6:20	17:35	11:14
September-13	5:51	17:46	11:55
October-13	5:20	17:59	12:38
November-13	4:59	18:17	13:18
December-13	4:59	18:38	13:39
January-14	5:17	18:47	13:30
February-14	5:38	18:36	12:57
March-14	5:54	18:10	12:15

4.2.5 Survey Data

Census data are valuable for comparison as they provide a regional comparison to the very local, site-specific nature of the webcam counts. Aerial surveys are undertaken on an annual basis in KNP to obtain mammal estimates. As of 2010, the surveys have been conducted biennially, with the herbivore survey (excluding elephant and buffalo), being a sample count, using distance methodology to convert the counts to estimates (Botha, pers comm, 2014). Large herbivores in the aerial surveys include giraffe, impala, kudu, warthog, waterbuck, white rhinoceros, wildebeest and zebra. Elephant and buffalo are counted in an independent helicopter survey, flown along drainage lines deriving direct total counts of the entire area, which are assumed to capture all individuals and therefore no up-scaling is applied (Botha, pers comm, 2014). Mammal estimate data from the 2012 and 2014 aerial surveys were provided by SANParks for a selection of the general herbivore species, and reflects the abundance of species in the central KNP at a regional scale. Elephant and buffalo aerial survey data were provided for 2011 and 2012.

Additionally, the central region was divided (Judith Botha, SANParks) into two subsets for Orpen and Satara, using the dominant geological/biological boundary of the granite-basalt division. These dominant geological units play a major role in the distribution of vegetation (Venter *et al.*, 2003). The central region was subdivided according to the two dominant geologies, and the transect lines from the 2012 aerial survey were clipped to the relevant geological subsets. Distance analyses were then run for both of the subsets to determine mammal estimates east and west of the geological boundary.

Finer resolution herbivore abundance data for the Satara region were made available by Prof. Deron Burkepile, following timed counts carried out on the Satara experimental burn plots (within 2km of the Satara webcam) during recent years. These represent herbivore abundance data at the local scale, and an intermediate spatial resolution between the regional census data and the site-specific webcam data.

4.3 Methodology

4.3.1 Data Analysis

The raw mammal visitation data were used to determine specific visitation patterns and trends and whether these patterns and trends are controlled by climate (temperature and rainfall) and astronomical (moon phases, sunrise and sunset) variables. Mammal behaviour, notes on the surrounding environment and weather observations (wind, rainfall and mist) were recorded in a log-book. The majority of the statistical analyses were performed in *Microsoft Excel*, with the more specialised tests run using the statistical coding platform R, running scripts developed by Dr Jennifer Fitchett.

4.3.1.1 Optimal Resolution

Mammal visitation counts were recorded from photographs captured every 15-seconds and totaled for each hourly and quarter-hourly interval, thus maintaining high resolution of these data across the different temporal intervals for the study period. An analysis of the literature, however, would suggest that many webcams do not capture the data at such high temporal resolution. The optimal resolution for webcam analyses is therefore explored to understand comparability of webcam studies and to consequently test the validity of lower temporal resolution studies. Optimal resolution was visually explored using a rarefaction curve, determining thresholds for improved and constant species representation (Raup, 1975; Crist & Veech, 2006). This analysis was performed for four individual months, spanning each season. At the 15-second interval, the complete dataset was used, however, for the lower resolution intervals the total 15-second interval dataset was dropped, with data deleted to contain only 30-second, 1-minute, 5-minute, 15-minute, 30-minute, 1-hour, 6-hour, 12-hr and 24-hour readings. Each temporal resolution was plotted against the number of mammals counted, and the optimal resolution was obtained when the graph showed a plateau.

4.3.1.2 Classification of Peak Mammal Visitation Periods

During the pilot study in 2012, and during the process of analysing mammal visitation times from the webcam imagery, it was recognised that specific mammals exhibit clear temporal visitation patterns. The hourly interval data were used to explore these specific patterns and the 24-hour day was divided into eight specific periods, which relate to the major visitation periods of the mammal species observed, in order to categorise predominant mammal visitation periods (Cozzi *et al.*, 2012). Mammal species were categorised according to their feeding guilds, which are associated with their water-dependence (Ayeni, 1975; Western, 1975). For each mammal species, the total number of sightings for each hour was calculated for the period March 2012/April 2012 - March 2014 and these numbers were then grouped into their associated time category, with the percentage distribution subsequently calculated to establish their peak visitation times.

Cluster analysis facilitates the statistical identification of grouping together similar objects or separating disparate objects (Legendre & Legendre, 1998). Cluster analysis and Principal Component Analysis (PCA) have been used in other mammal behavioural studies to segregate groups of common behaviour (Chamaillé-Jammes *et al.*, 2007a; Gandiwa, 2013). Thus, to objectively test mammal visitation patterns and trends, unconstrained cluster analysis was performed using the Euclidean method, with the distance between species calculated using Ward's D method by calculating the hourly percentages for each mammal species (Legendre & Legendre, 1998; Manly, 2009). The number of significant groups was determined using a silhouette plot. Unconstrained cluster analysis was performed on a range of species to allow true associations across the guilds and other known implicit groupings to be made. The cluster analysis output was presented as a dendrogram, measured by the Ward's D distance (Legendre & Legendre, 1998).

It is suggested that cluster analysis and PCA should be used as a combined statistical method (Townend, 2002). Thus, to further statistically explore the dominant mammal visitation patterns and trends and determine which species visit the waterholes concurrently, PCA was used (Manly, 2009), with time as the vector and mammal species as the points. Species scores were obtained from the PCA output and used to statistically determine overlapping visitation times. Clusters in points on the PCA biplot were compared to the author's observed patterns and to the cluster analysis output.

4.3.1.3 Seasonal Visitation Patterns

To determine the seasonal visitation patterns for each mammal species, mammal sightings were averaged for the wet and dry seasons. To compare mammal visitation inter-seasonally, correlation tests were performed on the average number of sightings per season and the T_{avg} per season, and it was thus established whether mammal visitation patterns can be analysed across annual and inter-annual time periods. The total sightings per month per waterhole were grouped according to season, and the percentage of mammal sightings per season was used to identify seasonal visitation trends across the study period.

4.3.1.4 Temporal Visitation Shift between Wet and Dry Seasons

A two sample test, assuming unequal variances (t-test) was used to determine whether species timing of water source visitation patterns shifted according to the four wet and dry periods. Pooled species hourly visitation totals per month were separated according to the wet and dry periods. A two-tailed t-test was used to determine whether the timing of visitation shifted between and within the wet and dry periods, thus exploring whether there was no significant difference between the two dry seasons/wet seasons and whether there was a difference between the 2012 wet and dry periods and 2013 wet and dry periods. If the t-statistic > t critical value, then the null hypothesis was rejected.

4.3.1.5 Mean Duration of Visitation

The time spent visiting the water sources is calculated per species visiting the water source collectively, from the time the first individual arrived to the time that the last individual left the water source. Mean monthly time spent visiting the water sources was calculated per month per species. Additionally, to determine seasonal differences in time spent visiting the water sources, time spent visiting the water sources was calculated per month for all mammals, with standard deviation indicating that certain species mean visitation times have large variations (Valeix *et al*., 2007b). To calculate the time spent visiting the water sources per mammal species per day, the count function in *Microsoft Excel* was used. The count function counts the number of cells that contain numbers, assigning a value of 1 to every cell that contains numbers, therefore zeros were used to indicate presence of mammals at the water sources or the number of images containing mammal species.

4.3.1.6 Similarities and Differences (Orpen and Satara)

Pearson's correlation was used to test the statistical significance of the relationships between mammal visitation times at Orpen and Satara. The p-values were extracted from the Pearson correlation table, and were tested at the 95% and 99% significance level (Underhill & Bradfield, 2009). A correlation coefficient (r) that is close to 1 or -1 indicates a strong correlation, while a correlation coefficient close to 0 indicates a poor correlation. Additionally, a positive correlation coefficient indicates a direct relationship, with an increase in T_{avg} (independent variable), mammal visitation times (dependent variable) shift later, and vice versa. A negative correlation indicates an opposite relationship, with sunrise and sunset times shifting earlier (independent variable), mammal visitation times (dependent variable) shift later, and vice versa (Towend, 2002; Manly, 2009; Underhill & Bradfield, 2009).

Pearson correlation coefficient was calculated using *Microsoft Excel*, using the equation:

$$|r| = \left|\frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum y_i - \bar{y})^2}}\right| \qquad \text{(Equation 1)}$$

(Underhill & Bradfield, 2009)

4.3.2 Relationship between Mammal Visitation, Climate and Astronomical Variables

Climatic and astronomical variables are known to influence mammal behaviour and activity patterns due to variations in both thermal conditions and light availability (Tefempa *et al.*, 2008; Bennie *et al.*, 2014). The climate patterns for the study period were explored to determine inter-seasonal variation by calculating mean monthly temperature and rainfall. Statistical outliers were calculated and rejected from the sample set. The lower and upper quartiles are values which fall at quarter points (25% and 75%) in the dataset (Dytham, 2011).

The lower quartile was calculated using the equation (m represents the mode):

$$l = \frac{m+1}{2} \qquad \text{(Equation 2)}$$

And the upper quartile was calculated using the equation (n represents the highest number):

$$u = n - l + 1 \qquad \text{(Equation 3)}$$

(Underhill & Bradfield, 2009)

Using the lower and upper quartile equations, outliers in the dataset were calculated. Outliers are values which are different to the majority of other values in a dataset, which either reflect errors in data collection or represent anomalies that likely occurred (Underhill & Bradfield, 2009). Outliers are therefore represented as values that fall above the upper bracket:

$$x_m + 6(x_u - x_{m)}$$ (Equation 4)

(Underhill & Bradfield, 2009)

Or values that fall below the lower bracket:

$$x_m - 6(x_u - x_{l)}$$ (Equation 5)

(Underhill & Bradfield, 2009)

The mean hourly water source visitation trends for the period March 2012/ April 2012 - March 2014 were calculated for both water source sites using the total mammal sightings. This was plotted against the hourly T_{avg} for the study period to visually explore the relationship between peak visitation times and coinciding temperature. The lag time was calculated as the difference between the time that the peak sightings occurred and the time of peak temperature.

The relationship between hourly mammal visitation patterns and T_{avg} were explored as low temperatures during the night may influence nocturnal visitation patterns whilst high temperatures during the day may influence diurnal visitation patterns (Bennie *et al.*, 2014). Five temperature intervals were chosen according to daily T_{avg}: >10°C $T_{avg\,<}$15°C, >15°C T_{avg} <20°C, >20°C Tavg $_{<}$25°C, >25°C $T_{avg\,<}$30°C and > 30°C $T_{avg\,<}$ 35°C, which were used to determine whether mammal visitation shifts earlier or later during different temperature conditions, which is important in the context of future projected climate change scenarios.

The hourly visitation times were averaged for all mammal species and plotted against the respective T_{avg} intervals. For Satara, the peak visitation times were split between herbivores and carnivores, as double peaks in visitation were observed. Once the shifts in visitation patterns in relation to T_{avg} intervals were determined, it was then important to establish the rate of change of visitation patterns, as influenced by T_{avg} intervals. Regression analysis is used when there are dependent and independent values in a dataset for which a relationship needs to be determined (Towend, 2002). Linear regression analysis was calculated to explore the rate of change over time between peak visitation times and the different temperature intervals, using the equation for the line of best fit through the data points (Towend, 2002):

$$y = ax + b$$

(Equation 6)
(Lomax & Hahs-Vaughn, 2012; Manly, 2009)

Once the best-fit line has been determined, the values of *a* (slope) and *b* (y intercept) can be calculated, using the equation:

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

(Equation 7)
(Manly, 2009; Underhill & Bradfield, 2009)

The coefficient of x then needs to be calculated which indicates the rate of change of the dependent variable (mammal visitation patterns) as influenced by the independent variable (T_{avg}), using the equation:

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

(Equation 8)
(Manly, 2009; Underhill & Bradfield, 2009)

Linear regression analysis results for the change over time between peak visitation times and different temperature intervals are given as the shifting of visitation times in minutes per 5°C T_{avg} interval (min/°C). At a finer temporal scale it is important to determine the relationship between time of day, peak appearance and T_{avg}, T_{max} and T_{min} so as to establish whether specific mammals shift their peak visitation times in relation to daily temperatures (time of peak appearance and the number of mammals at their peak appearance). This was calculated over 15 minute intervals for each day for the period March 2012/ April 2012 - March 2014, with peak time and peak appearance correlated (*Equation 1*) with daily T_{avg}, T_{max} T_{min} for that day.

The relationship between monthly visitation patterns per mammal species and T_{avg} were calculated using the hourly visitation patterns for each mammal species for each month across the study period, correlated (*Equation 1*) with hourly T_{avg} to determine species behavioral responses to T_{avg}. T_{avg} varies across seasons, and thus monthly and seasonal patterns can be established.

Mammal visitation patterns to water sources are influenced by rainfall, as rainfall affects both water availability and distribution in semi-arid regions, therefore the number of mammals recorded visiting artificial water sources during rainfall events are likely to reflect daily and seasonal patterns of reliance on these water sources (Valeix *et al*., 2008). To establish whether the average number of total mammal species changes on days of rainfall, before rainfall and after rainfall, and whether there is a relationship between the amount of rainfall received and total mammal sightings, the total mammal sightings were organised to correspond with 1 and 2 days before rainfall, days of rainfall, and 1 and 2 days after rainfall. Pearson's correlation (*Equation 1*) was used to test the relationship between the total rainfall for each of these categories and total mammal sightings on a given day.

Pearson’s correlation (*Equation 1*) was used to calculate species specific relationships with the timing of rainfall events, using the daily number of individuals per mammal sightings per artificial water source. This was used to determine whether individual species mean sightings were positively or negatively correlated with the timing of rainfall events. A single factor, one-tailed z-test was used to determine whether the mean number of sightings on the day of rainfall are significantly larger than the mean sightings 1 day after rainfall and 2 days after rainfall.

Mammals partition their behaviour and patterns of activity in response to the amount of light available, as influenced by shifts in sunrise and sunset times and moon phases (Bennie *et al*., 2014). Water source visitation patterns are likely influenced by these astronomical variables such as sunlight and moonlight, as well as physiological adaptations, predator-prey relations and climatic variables (Bennie *et al.*, 2014). There is a gap in the literature concerning the temporal partitioning of water source visitation patterns as influenced by astronomical variables, particularly in KNP. Sunrise and sunset times are likely to have influence on the visitation patterns of species which show peaks in visitation during the periods of dawn and dusk. Thus, the daily peak visitation times of mammals that specifically visit water sources during these time periods were correlated (*Equation 1*) with daily sunrise and sunset times to establish whether their peak visitation times shift according to seasonal changes in sunrise and sunset times.

Moon phases influence the activity patterns of nocturnal and diurnal species, with the amount of illumination influencing dominant and sub-dominant predator interactions and predator-prey relations, and the distribution of species and their utilisation of different habitats (Cozzi *et al.*, 2012; Prugh *et al.*, 2014). The majority of carnivores exhibited nocturnal visitation patterns and conversely the majority of herbivores exhibited diurnal visitation patterns, thus the influence of moon phases was investigated for mammals that showed peaks in nocturnal visitation patterns. For the nocturnal species, the dates of peak visitation at the water sources in each month of the study period were explored for overlaps with the dates of each of the four dominant moon phases, with illumination ranging from < 5%, 50% and > 95%. A one-way ANOVA test was run, using the mean visitation patterns on each of the days of specific moon phase for all nocturnal species.

4.3.3 Three Scales of Survey Data

Regional, local and geological survey data were compared to the webcam survey data to establish whether relationships between mammal visitation patterns and contemporary climatic and astronomical variables can be considered representative for the broader KNP region, or whether they are specific to artificial water sources. This also facilitated the exploration of seasonal patterns of greater or lesser species representation at the water source.

4.3.3.1 Proportional Comparison of Three Scales of Mammal Survey Data

Orpen webcam survey data for the subset of mammals observed in the census, were compared to the regional (central KNP) percentage distribution of mammals. Similarly, Satara webcam survey data for the subset of mammals observed in the census, were compared to the regional (central KNP) and local (Satara area) percentage distribution of mammals. Exploring the percentage distributions of overlapping species determined whether these mammal species visit the water sources in relative proportion to their regional and local abundance. Where they are not consistent, active selection or avoidance of the water source by species is indicated.

4.3.3.2 Correlation between Three Scales of Survey Data

To determine the extent to which inferences made at the webcam scale can be extended to the broader regional mammal populations, survey data (aerial, local and geological/biological) were correlated to the webcam survey dataset (*Equation 1*). This was performed with the annually totaled webcam data and monthly totaled webcam data for the species common to all of the datasets. Monthly correlations facilitate the exploration of seasonal patterns showing greater representation of the census data, and in turn, patterns of seasonal preferential use or avoidance by mammals at water sources.

4.3.3.3 Comparison of Observed Proportional Visitation with Expected Proportional Visitation

To determine whether the overall observed proportional visitation (webcam data) and the expected proportional visitation (local, landscape and regional estimate data) for the pooled mammal species were significantly similar, a chi-squared test of independence was run. The null hypothesis was that there is no relationship.

4.3.3.4 Quantification of Preferential or Avoidance Behaviour

To quantify whether specific species are selecting for / exhibiting preferential use or avoidance behaviours at the two artificial water sources, the index of electivity was calculated with the proportions between individual species water source visitation estimates and their regional and landscape estimates, using Ivlev's index of electivity. Ivlev's index of electivity has been used to measure the level of selection or avoidance of a particular prey species by a specific predator (Strauss, 1979). The index of electivity can therefore be used to quantify whether specific species are visiting the artificial water sources in proportion to their abundance within the landscape (granite / basalt) or region (central KNP), and thus determine avoidance or preferential behaviour. The index of electivity was calculated using the equation:

$$E = \frac{r_i - p_i}{r_i + p_i} \tag{Equation 9}$$

(Strauss, 1979)

Ivlev's electivity index (E), a measure of electivity, ranges from -1 and +1, with E values close to -1 indicating avoidance or inaccessibility, E values close to +1 indicating preference or active selection, and an E value close to 0 indicating random selection or neutrality (Strauss, 1979; Manly, 1993; Laliberte & Ripple, 2004). Positive values ≥ 0.50 represent preferential use while negative values < -0.50 represent avoidance behaviour.

The r_i value corresponds with the proportional abundance of mammals visiting the Orpen and Satara artificial water sources (site specific) and the proportional abundance of mammals within the Orpen and Satara landscapes (local estimate). The p_i value corresponds with the proportional abundance of mammals within central KNP (regional estimate).

CHAPTER FIVE

Results

Chapter 5 - Results

5.1 Introduction

With the increasing need to monitor mammal populations and specifically assess their behavioral patterns and physiological responses to changing environmental conditions, webcam imagery is used to investigate temporal and climate-related water source visitation trends. Embedded within this is the need to test the optimal temporal resolution of webcam imagery in order to establish the accuracy and utility of the data captured at different temporal intervals, and therefore obtain useable scientific data on mammal behaviour. Within a broader context, the relationship between webcam imagery and aerial survey data is tested, to determine whether valid inferences can be made about populations using the former technique.

5.2 Optimal Resolution

Very few studies have used webcam imagery to monitor mammal behaviour, with Hayward & Hayward (2012) presenting the only comparable research to date. However, only a single image per hour was used in that study. It is important to verify at what temporal scale the utility of remote-sensed imagery for detecting different species may be jeopardised, thus making it necessary to determine that the temporal resolution of images yields representative data. Additionally, it is important to establish whether high temporal resolution data captured every 15-seconds (almost continuous monitoring) is the most representative resolution and has an advantage over previous studies which used a coarser temporal resolution. Furthermore, establishing whether high resolution data are necessary will provide information about the storage facilities required if these images are to be archived for retrospective studies.

Webcam imagery obtained for this study was captured at 15-second intervals, with ~5760 daily images received from SANParks. All data analyses were performed at this resolution. Four months were selected for the optimal temporal resolution analysis (March

2014, July 2013, September 2013 and December 2013), which reflect each season as well as being those months with the highest number of images (> 50%). Rarefaction curves were produced by sub-sampling data at lower resolutions from within the complete data set, exploring variations in total numbers of species covered (Raup, 1975). Overall an equal number of images depicting mammals were captured at 15- and 30-second intervals, suggesting that a 30-second interval is an acceptable resolution and no further information would be gained from increasing the resolution to 15-seconds.

The optimal temporal resolution differs between species. For example, the presence of African wild cat, honey badger, mongoose, serval, greater kudu, southern giraffe and warthog was recorded where the image capture rate was < 1 minute, likely because most of these species spend on average < 1 minute at the water sources, while African civet, chacma baboon and lion would not be included if the resolution is > 5 minutes, and likewise for African elephant, black-backed jackal and common duiker if the resolution is > 15 minutes. Therefore, finer-scale resolutions of < 1, < 5 and < 15 minutes are required to sufficiently capture such species' visitation patterns. In contrast, impala, blue wildebeest, African buffalo, plains zebra, small-spotted genet and spotted hyaena (hereafter referred to as hyaena) remained up to 1 hour, and thus require a lower monitoring resolution. Thus, water source visitation patterns monitored at various resolutions would yield different results for different species, depending on the frequency of their visits to the water sources, the time spent at the water sources, and additionally their seasonal patterns of visitation. In order to obtain a representative pattern of visitation across all species, a low resolution is recommended for future studies.

There is a clear seasonal divide, with spring and summer (September and December 2013) indicating a higher resolution compared to autumn and winter (March 2014 and July 2013) for all species (*Figure 5.1*). This suggests that a 30-second resolution would be sufficient in autumn and winter when a higher number of mammals visit water sources. However, during spring and summer when a lower number of mammals visit the artificial water sources, a finer temporal resolution would be required.

For March 2014 and July 2013, at the 30-minute to 6-hour time intervals the graph flattens out showing that this resolution is insufficient to study mammal visitation patterns at the water sources. To obtain representative data, imagery for these specific months would need to be captured and analysed at < 5 minute intervals. This is important due to storage constraints, and many organisations might prefer to store only one or two images per day, which would compromise future research efforts. To test relationships between water source visitation patterns and environmental variables, different resolutions are required to facilitate comparisons. For instance, sunrise and sunset data (15-minute intervals) and temperature data (1-hour intervals) requiring high resolution webcam imagery, while rainfall data (daily) require lower resolution webcam imagery.

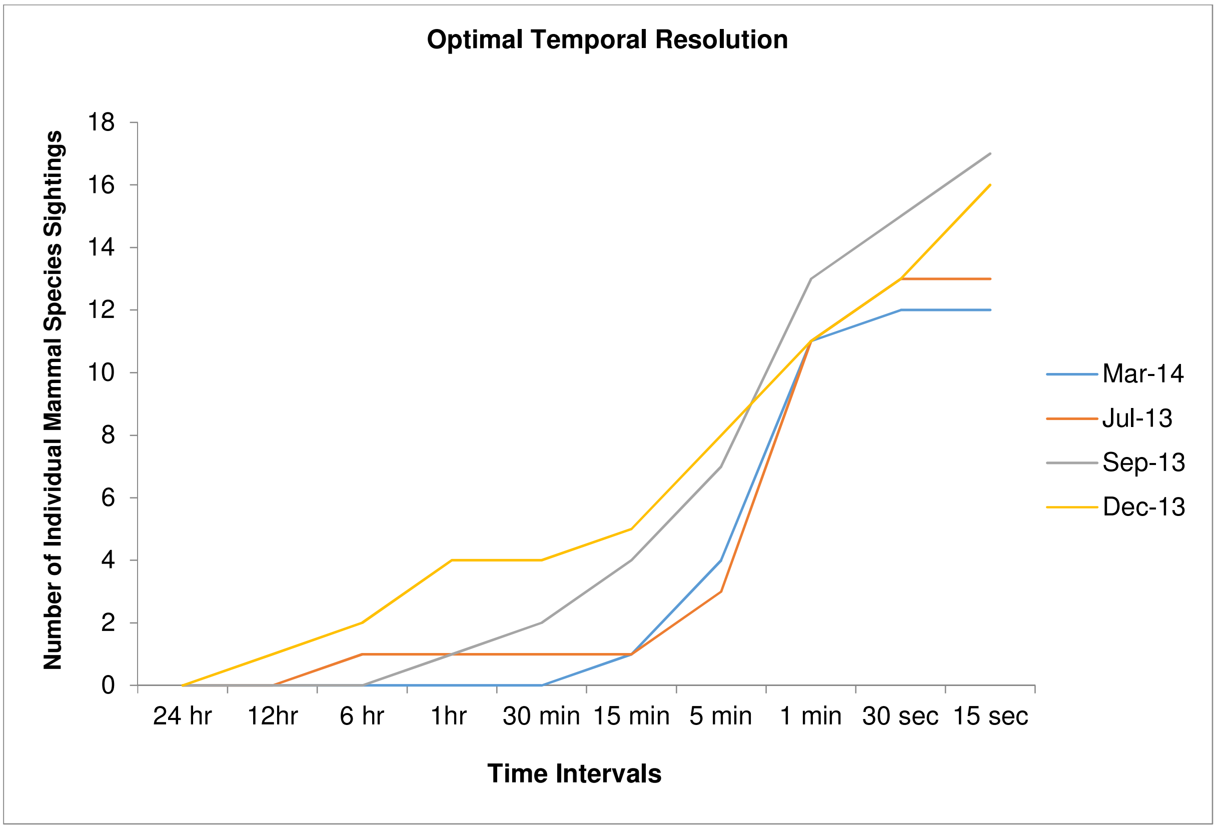


Figure 5.1: Rarefaction curves demonstrating optimal temporal resolution of webcam imagery for capturing mammal sightings at water sources

5.2 Distribution of Mammal Sightings

Webcam imagery of mammal visits to the water sources at Orpen and Satara were analysed per 24-hour period. These data were used to determine the predominant daily and seasonal visitation patterns, as well as the duration of time spent at water sources. Visitation patterns were established over 25- and 24-months at Orpen and Satara, respectively. Hourly temperature and daily rainfall data were used to establish possible climatic influences on visitation patterns. Further, the possible influence of day length variations (sunrise and sunset times) and moon phases were tested. Aerial census data for the central KNP region, obtained from SANParks, and local survey data for the Satara and N'wanetsi areas, obtained from Prof. Deron Burkepile, were used to establish whether mammal visitation at the artificial water sources reflected the relative abundance of species in central KNP, or whether there is possible avoidance behaviour.

A total of 46,866 mammal visitations, from 28 species, were recorded at the Orpen and Satara artificial water sources over the study period. Mammals were categorised according to their feeding guild; carnivores are predominantly nocturnal drinkers and are water-independent (an exception being the spotted hyaena), whilst herbivores and primates are predominantly water-dependent diurnal drinkers (Ayeni, 1975; Western, 1975) (*Table 5.1*). Three species of mongoose, *Mungos mungo* (banded mongoose), *Helogale parvula* (dwarf mongoose) and *Ichneumia albicauda* (white-tailed mongoose) visited the water sources. However, their visits were too infrequent to establish specific patterns, and are hereafter grouped together as mongoose. Some species, such as African wild dog (*Lycaon* pictus), caracal (*Caracal caracal*), common waterbuck (*Kobus ellipsiprymnus*) and nyala (*Tragelaphus angasii*) were only sighted on rare occasions (< 1 image capture per 6 months). These species were excluded from the analyses.

Table 5.1: Mammal sightings (> 1 image capture per 6 months) at Orpen and Satara water sources (O = Orpen, S = Satara and B = both), categorised according to their feeding guild.

Feeding Guild		**Scientific Name**	**Common Name**	**Water-Dependent**	**Water Source**
CARNIVORE		*Civettictis civetta*	African civet	x	B
		Felis silvestris	African wild cat	x	B
		Canis mesomelas	Black-backed jackal	x	B
		Mellivora capensis	Honey badger	x	B
		Panthera pardus	Leopard	x	O
		Panthera leo	Lion	x	B
		Leptailurus serval	Serval	x	B
		Genetta genetta	Small-spotted genet	x	B
		Crocuta crocuta	Spotted hyaena	✓	B
HERBIVORE	Browser	*Sylvicapra grimmia*	Common duiker	x	B
		Tragelaphus strepsiceros	Greater kudu	x	B
		Giraffa camelopardalis	Southern giraffe	x	B
	Grazer	*Syncerus caffer*	African buffalo	✓	B
		Connochaetes taurinus	Blue wildebeest	✓	B
		Hippopotamus amphibious	Hippopotamus	✓	O
		Equus quagga	Plains zebra	✓	B
		Phacochoerus africanus	Warthog	✓	B
	Mixed Feeder	*Loxodonta africana*	African savanna elephant	✓	B
		Aepyceros melampus	Impala	✓	B
PRIMATE		*Papio hamadryas*	Chacma baboon	✓	B
		Cercopithecus pygerythrus	Vervet monkey	x	O

5.2.1 Mammal Sightings at the Orpen Artificial Water Source

A total of 30,176 mammal sightings (average of 40 sightings per day), comprising 28 species, were recorded at Orpen artificial waterhole from March 2012 to March 2014 (*Table 5.1*). Impala (48.71% of total sightings; 587.84 average sightings per month), warthog (11.79%; 142.24) and blue wildebeest (11.22%; 135.36) were the most commonly and frequently sighted mammals, whilst hippopotamus (0.09%; 1.04), serval (0.02%; 0.24) and African wild cat (0.01%; 0.12) were the three least commonly and frequently sighted species relative to the occurrence of other mammals in this study (*Figure 5.2*).

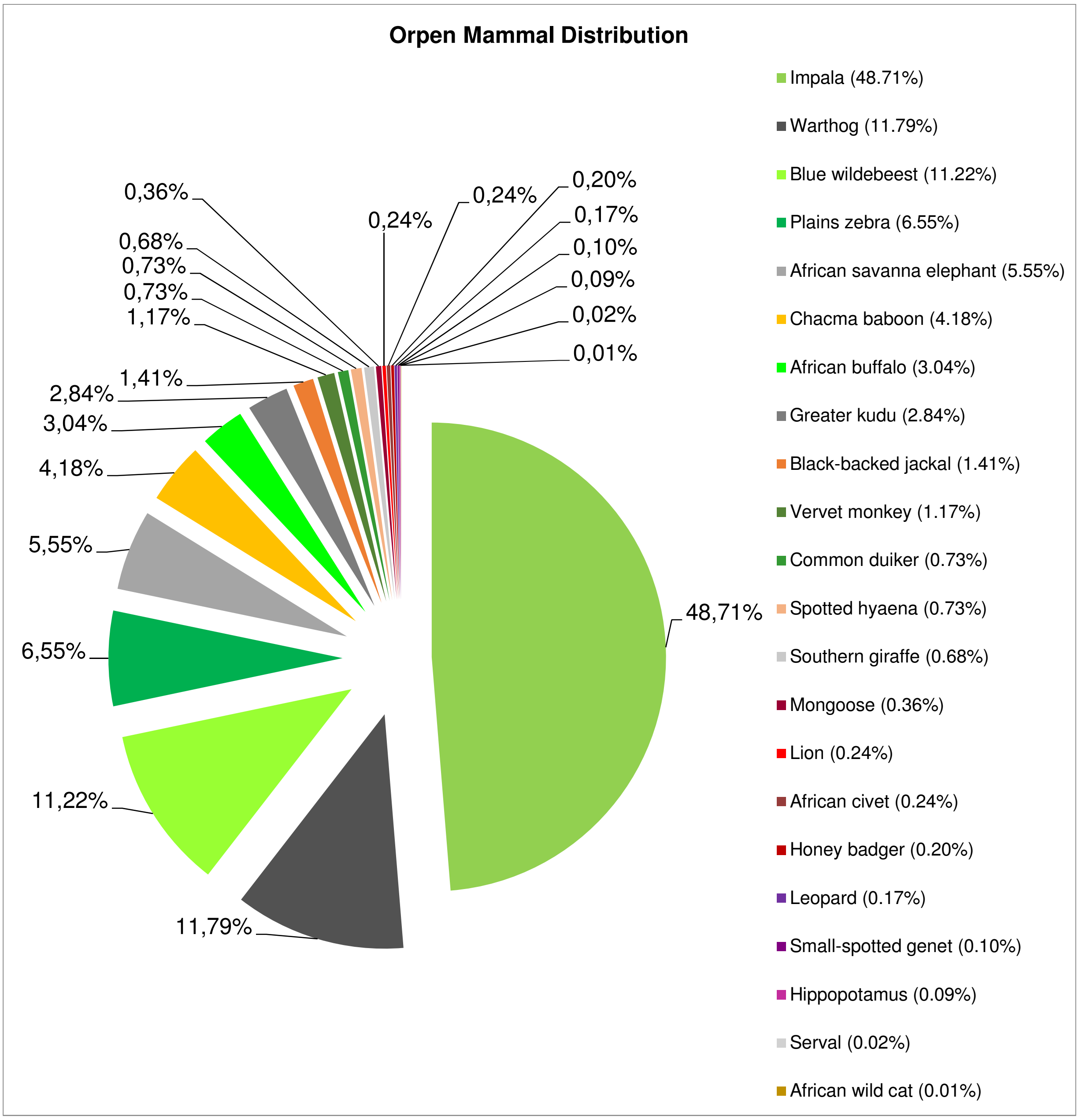


Figure 5.2: Percentage composition of the commonly sighted mammals at Orpen waterhole.

Herbivores were the most commonly sighted species guild at Orpen, comprising 91.19% of the total mammal sightings. Mixed feeders account for 59.50% of the total number of herbivores sighted, with impala making up the majority of total sightings for mixed feeders (89.77%) and for herbivores in general (48.71%). Hourly, monthly and total count data for the study period per species is presented in *Appendix A.1 & A.3* (Orpen) and *A.2 & A.3* (Satara).

Table 5.2: Total sightings per mammal species and the percentage of species per feeding guild at Orpen waterhole for the period March 2012 to March 2014.

Feeding Guild		**Mammal**	**Total Sightings**	**% of Feeding Guild**	**Water-dependent**
HERBIVORES	Mixed Feeders	Impala	14696	89.77%	✓
		African savanna elephant	1674	10.23%	✓
	Grazers	Warthog	3556	36.07%	✓
		Blue wildebeest	3384	34.33%	✓
		Plains zebra	1976	20.04%	✓
		African buffalo	916	9.29%	✓
		Hippopotamus	26	0.26%	✓
	Browsers	Greater kudu	857	66.74%	x
		Common duiker	221	17.21%	x
		Southern giraffe	206	16.04%	x
		Total Mixed Feeders	**16370**	**59.50%**	
		Total Grazers	**9858**	**35.83%**	
		Total Browsers	**1284**	**4.67%**	
PRIMATES		Chacma baboon	1261	78.13%	✓
		Vervet monkey	353	21.87%	x
CARNIVORES		Black-backed jackal	424	40.61%	x
		Spotted hyaena	219	20.98%	✓
		Mongoose	108	10.34%	x
		Lion	73	6.99%	x
		African civet	72	6.90%	x
		Honey badger	59	5.65%	x
		Leopard	51	4.89%	x
		Small-spotted genet	29	2.78%	x
		Serval	6	0.57%	x
		African wild cat	3	0.29%	x
		Total Herbivores	**27512**	**91.19%**	
		Total Primates	**1614**	**5.35%**	
		Total Carnivores	**1044**	**3.46%**	
		Total Mammal Sightings at Orpen	**30170**		

Warthog were the most commonly sighted grazer, comprising 36.07%, whilst hippopotamus were both the least commonly sighted grazer and herbivore (0.26%). Southern giraffe were the least sighted browser (16.04%). Primates comprise 5.35% of the total sightings, with carnivores accounting for only 3.46% of total mammal sightings (*Table 5.2*). Black-backed jackals were the most commonly sighted carnivore at Orpen (1.41% of total mammal sightings respectively). Spotted hyaena, recognised as the only water-dependent carnivore in this study, were the second most commonly sighted carnivore at Orpen (0.73% of total mammal sightings) (*Figure 5.2; Table 5.2*).

5.2.2 Mammal Sightings at the Satara Artificial Water Source

A total of 16,690 mammal sightings (average of 23 sightings per day), comprising 20 species, were recorded at Satara artificial water trough for the period April 2012 to March 2014. Impala (34.87% of total sightings; 242.46 average sightings per month), blue wildebeest (27.23%; 189.33) and plains zebra (18.17%; 126.33) were the most commonly and frequently sighted mammals at Satara water trough, whilst mongoose (0.18%; 1.25), honey badger (0.05%; 0.33) and serval (0.01%; 0.08) were the three least commonly sighted species (*Figure 5.3*).

As is the case for Orpen, black-backed jackal (4.10%) were the most commonly sighted carnivore and spotted hyaena (3.04%) the second most frequently sighted carnivore at Satara. Herbivores were also the most frequently sighted species guild at Satara and comprise 88.46% of the total mammal sightings. Amongst herbivores, grazers (55.93%) and mixed feeders (41.82%) accounted for the majority of total sightings, with browsers (2.25%) the least commonly sighted herbivores. Carnivores comprise 9.15% of the total sightings, whilst primates (chacma baboons) were the least commonly sighted species and account for 2.39% of total sightings (*Figure 5.3; Table 5.3*). Serval were recorded within the least commonly sighted species group at both Orpen and Satara (0.02% and 0.01%, respectively).

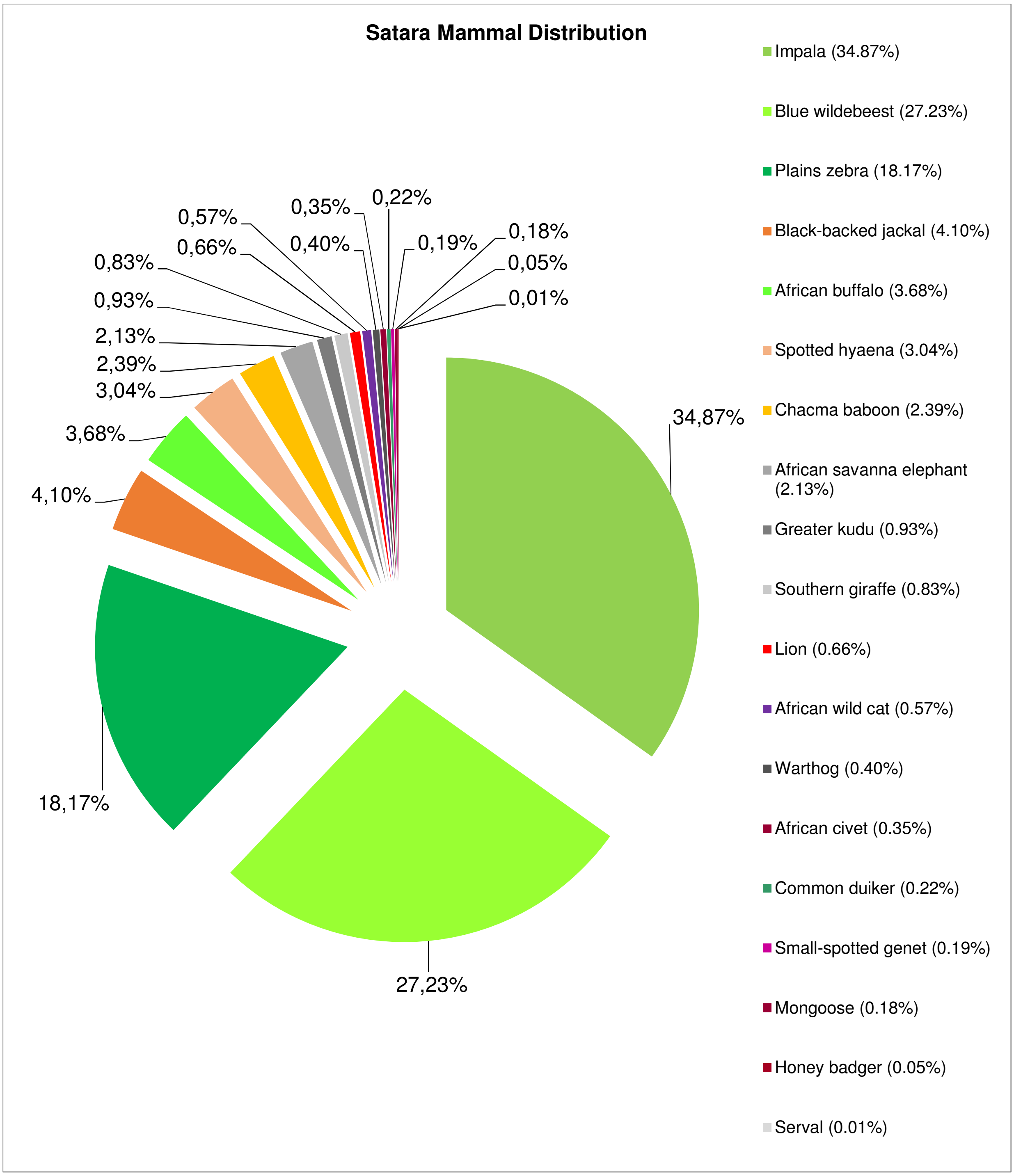


Figure 5.3: Percentage composition of the commonly sighted mammals at Satara water trough.

Table 5.3: Total sightings per mammal species and percentage of species per feeding guild at Satara water trough for the period April 2012 to March 2014.

Feeding Guild		**Mammal**	**Total Sightings**	**% of Feeding Guild**	**Water-dependent**
HERBIVORES	Grazers	Blue wildebeest	4544	55.03%	✓
		Plains zebra	3032	36.72%	✓
		African buffalo	615	7.45%	✓
		Warthog	67	0.81%	✓
	Mixed Feeders	Impala	5819	94.25%	✓
		African savanna elephant	355	5.75%	✓
	Browsers	Greater kudu	156	46.99%	x
		Southern Giraffe	139	41.87%	x
		Common duiker	37	11.14%	x
		Total Grazers	**8258**	**55.93%**	
		Total Mixed Feeders	**6174**	**41.82%**	
		Total Browsers	**332**	**2.25%**	
CARNIVORES		Black-backed jackal	684	44.79%	x
		Spotted hyaena	507	33.20%	✓
		Lion	110	7.20%	x
		African wild cat	95	6.22%	x
		African civet	59	3.86%	x
		Small-spotted genet	32	2.10%	x
		Mongoose	30	1.96%	x
		Honey badger	8	0.52%	x
		Serval	2	0.13%	x
PRIMATES		Chacma baboon	399	100.00%	✓
		Total Herbivores	**14764**	**88.46%**	
		Total Carnivores	**1527**	**9.15%**	
		Total Primates	**399**	**2.39%**	
		Total Mammal Sightings at Satara	**16690**		

5.3 Temporal Water Source Visitation Patterns

5.3.1 Daily Visitation Patterns

To explore daily water source visitation patterns, each 24-hour period was grouped into eight equal time intervals: dawn from 5:00am to 7:59am; morning from 8:00am to 10:59am; midday from 11:00am to 13:59pm; afternoon from 14:00pm to 16:59pm; dusk from 17:00pm to 19:59pm; early night from 20:00pm to 22:59pm; midnight from 23:00pm to 1:59am; and early morning from 2:00am to 4:59am. Dawn and dusk are the broad periods spanning sunrise and sunset respectively, and take seasonality into account, with the timing of sunrise ranging from 4:56 - 6:39, and sunset falling between 17:11 - 18:49, with a period of twilight on either side. At Orpen, the majority of species were sighted during midday (36.92%) and morning (32.47%) (*Figure 5.4*), whilst at Satara sightings were more evenly distributed from dawn to dusk, but again were predominant during the morning (28.98%) and midday (20.20%). This is consistent with other research, which showed this as the period during which the most numerically abundant herbivores drink (Valeix *et al.*, 2007a) (*Figure 5.4*). At Satara, an overall higher percentage of carnivores (9.15%) were recorded drinking from this water trough, which accounts for a higher percentage of nocturnal (dusk, early night, midnight and early morning) waterhole visitation (24.22%) compared to Orpen (12.38%) (*Table 5.3; Figure 5.4*).

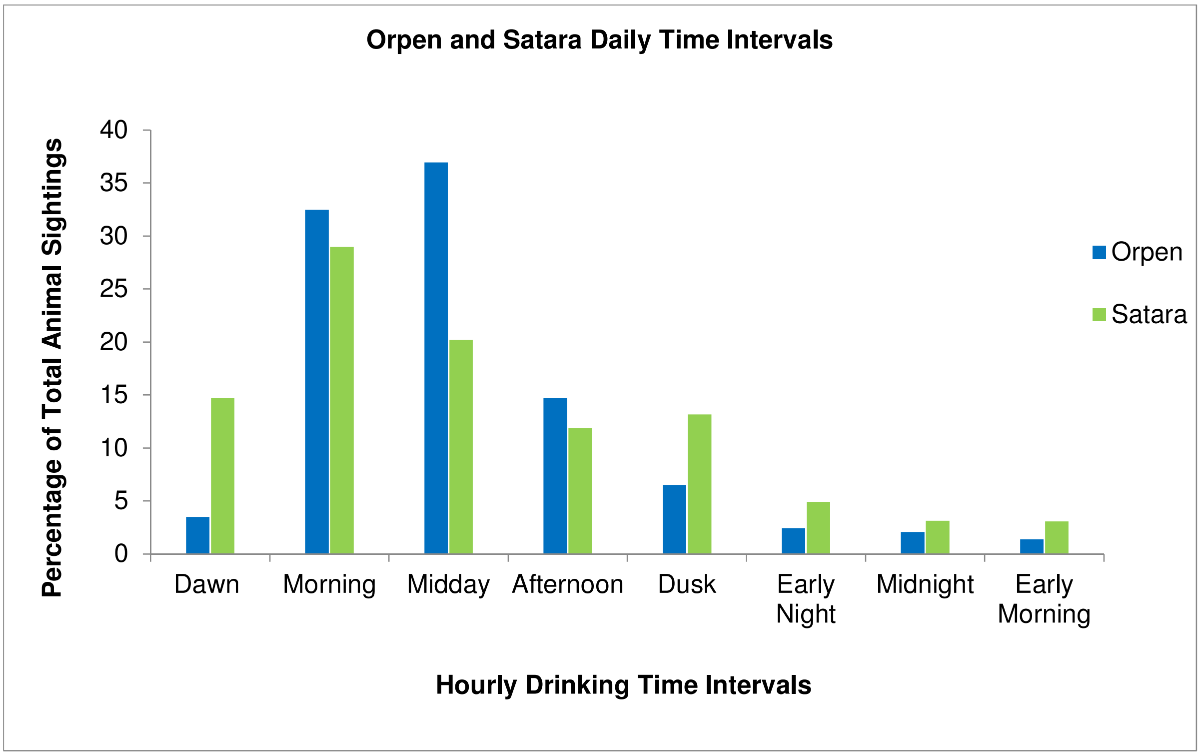


Figure 5.4: Hourly visitation for all species at the Orpen and Satara water sources for the period March 2012 to March 2014.

5.3.2 Daily Mammal Visitation Patterns at Orpen

Daily mammal visitation patterns to the waterhole were averaged over the 25-month period to determine the peak visitation intervals (based on the eight time blocks defined previously) for each species. Peak visitation or appearance was classified as that period during which the most visitations by a particular species occurred. Herbivores and primates account for the majority of species drinking from the waterhole diurnally, with peak appearance occurring in the morning for medium-sized water-dependent species, (viz. blue wildebeest (41.25% of visitations) and plains zebra (44.08%) and during midday for smaller water-dependent species, such as impala (44.17%) and warthog (34.59%) (*Table 5.4*). The majority of carnivores visited the waterhole nocturnally, although peak appearance for leopard (25.49% of visitations) and serval (33.33%) occurred at dusk (*Table 5.4*). The mega-herbivores, African elephant (25.33% of visitations) and African buffalo (22.93%), also visited the waterhole predominantly at dusk. Common duiker was the only small-sized herbivore to predominantly drink (27.60%) nocturnally (*Table 5.4*).

Chacma baboon, greater kudu, southern giraffe, vervet monkey and warthog all exhibit strictly diurnal waterhole visitation patterns, with no sightings of these species after 20:00. In contrast, African civet, hippopotamus, honey badger, serval and small-spotted genet exhibit strictly nocturnal waterhole visitation patterns, with no sightings of these species between 8:00 and 17:00. Hippopotamus are the only herbivores to show this distinct nocturnal visitation pattern. Waterhole visitation intervals for most species clustered together within specific diurnal or nocturnal periods, with the periods of 2nd and 3rd highest percentage visitation usually flanking the period of peak visitation. African wild cat, leopard and hippopotamus, which exhibit more widely dispersed visitation across the 24-hour period, were exceptions.

Table 5.4: Percentage of sightings of each mammal species in each time category for the period March 2012 to March 2014 at Orpen waterhole. Peak visitation times are highlighted dark green (peak interval), olive green (2nd peak interval) and light green (3rd peak interval).

Predominant Visitation Period		**Mammal**	**Dawn (5:00 - 7:59)**	**Morning (8:00 - 10:59)**	**Midday (11:00 - 13:59)**	**Afternoon (14:00 - 16:59)**	**Dusk (17:00 - 19:59)**	**Early Night (20:00 - 22:59)**	**Midnight (23:00 - 1:59)**	**Early Morning (2:00 - 4:59)**
Diurnal	Morning	Blue wildebeest (n= 3384)	7.98%	41.25%	34.13%	11.64%	3.13%	0.80%	0.56%	0.50%
		Plains zebra (n= 1976)	2.18%	44.08%	37.25%	12.75%	2.58%	0.66%	0.15%	0.35%
	Midday	Chacma baboon (n= 1261)	0.16%	30.29%	43.22%	19.59%	6.74%	0.00%	0.00%	0.00%
		Impala (n= 14696)	2.25%	36.73%	44.17%	13.31%	3.40%	0.01%	0.09%	0.04%
		Greater kudu (n= 857)	0.12%	23.10%	40.02%	32.56%	4.20%	0.00%	0.00%	0.00%
		Mongoose (n= 108)	11.11%	13.89%	30.56%	12.04%	16.67%	3.70%	8.33%	3.70%
		Vervet monkey (n= 353)	0.57%	26.91%	43.06%	25.78%	3.68%	0.00%	0.00%	0.00%
		Warthog (n= 3556)	3.99%	29.98%	34.59%	21.77%	9.67%	0.00%	0.00%	0.00%
	Afternoon	African wild cat (n= 3)	0.00%	0.00%	0.00%	66.67%	0.00%	33.33%	0.00%	0.00%
		Southern giraffe (n= 206)	3.40%	10.68%	37.38%	37.86%	10.68%	0.00%	0.00%	0.00%
Nocturnal	Dusk	African buffalo (n= 916)	5.57%	20.96%	15.83%	10.59%	22.93%	10.81%	8.84%	4.48%
		Common duiker (n= 221)	7.24%	13.12%	3.17%	3.17%	27.60%	20.81%	13.12%	11.76%
		African savanna elephant (n= 1674)	2.63%	6.87%	12.49%	14.22%	25.33%	19.53%	13.14%	5.79%
		Leopard (n= 51)	19.61%	0.00%	0.00%	0.00%	25.49%	11.76%	19.61%	23.53%
		Serval (n= 6)	0.00%	0.00%	0.00%	0.00%	33.33%	16.67%	16.67%	33.33%
	Early Night	African civet (n= 72)	5.56%	0.00%	0.00%	0.00%	5.56%	40.28%	25.00%	23.61%
		Honey badger (n= 59)	18.64%	0.00%	0.00%	0.00%	3.39%	28.81%	22.03%	27.12%
		Lion (n= 73)	12.33%	2.74%	0.00%	0.00%	6.85%	45.21%	17.81%	15.07%
	Midnight	Black-backed jackal (n= 424)	13.92%	3.54%	4.25%	3.07%	12.03%	17.92%	24.29%	20.99%
		Hippopotamus (n= 26)	15.38%	0.00%	0.00%	0.00%	0.00%	34.62%	42.31%	7.69%
		Spotted hyaena (n= 219)	16.89%	0.46%	0.00%	0.00%	5.48%	17.81%	32.42%	26.94%
	Early Morning	Small-spotted genet (n= 29)	13.79%	0.00%	0.00%	0.00%	3.45%	17.24%	24.14%	41.38%

Cluster analysis was performed per predefined period of percentage visitation patterns for each species to segregate patterns in the predominant temporal visitation periods for each species (*Figure 5.5*) and to provide an objective means of comparison to the patterns seen in *Table 5.4*. When comparing observations of peak visitation times in *Table 5.4* to the cluster analysis output, the observational accuracy can be determined. The left cluster (group 1) comprising wildebeest, impala, zebra, giraffe, warthog, kudu, baboon and vervet monkey grouped together species which drink diurnally and segregated predominantly morning drinkers (sub-group 1a) from midday and afternoon drinkers (collectively sub-group 1b) (*Figure 5.5*).

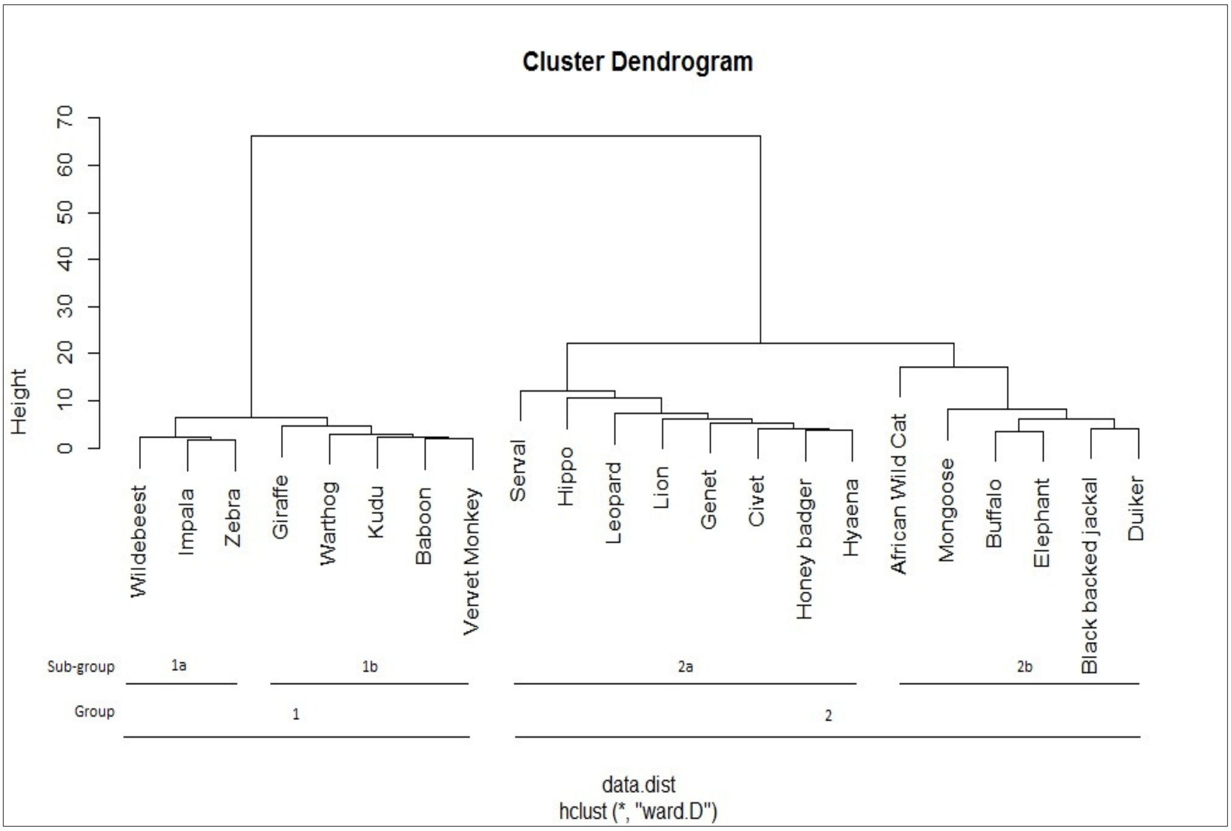


Figure 5.5: Cluster dendrogram showing the dominant temporal visitation times of mammals at Orpen waterhole.

The right cluster (group 2) comprising serval, hippopotamus, leopard, lion, genet, civet, honey badger, hyaena, African wild cat, mongoose, buffalo, elephant, black-backed jackal and duiker broadly grouped as species that utilise the waterhole nocturnally. Sub-group 2a comprises the bulk of those species listed in *Table 5.2* as carnivores, which predominantly visit the waterhole nocturnally, during the early night and midnight. Species in sub-group 2b visit the waterhole diurnally and nocturnally, with buffalo, elephant and duiker exhibiting peak visitation times during dusk, black-backed jackal during midnight, and mongoose and African wild cat during the day. However, all of these species show dispersed patterns of visitation throughout the day and night. These patterns largely agree with the periods of peak visitation shown in *Table 5.4*. The height differential in the cluster dendrogram simply indicates that there is more variation in the right cluster than in the left cluster.

The same percentage peak appearance dataset for each species was used to perform Principal Component Analysis (PCA) to further explore groups of species having similar patterns in their periods of peak visitation. Principal component one (PC1) separated species according to the broad time of visitation, dividing nocturnal (left) and diurnal (right) drinkers (*Figure 5.6*), and demonstrating a high level of congruency with the cluster analysis output (*Figure 5.5*). No clear pattern was detected for the arrangement of species on Principal component two (PC2, *Figure 5.6*), suggesting that the species are responding to non-time related drivers, such as local climate conditions (temperature and rainfall), astronomical factors (e.g. moon phases) or behavioural controls (competition/avoidance), which likely influence the temporal visitation patterns of specific species. These possible drivers are explored later in Section 5.4. African wild cat and hippopotamus appear as outliers on the PCA biplot. This is likely due to the infrequent use of the waterhole by African wild cat, whilst hippopotamus only visit the waterhole when grazing; not so much to drink, but rather to wallow.

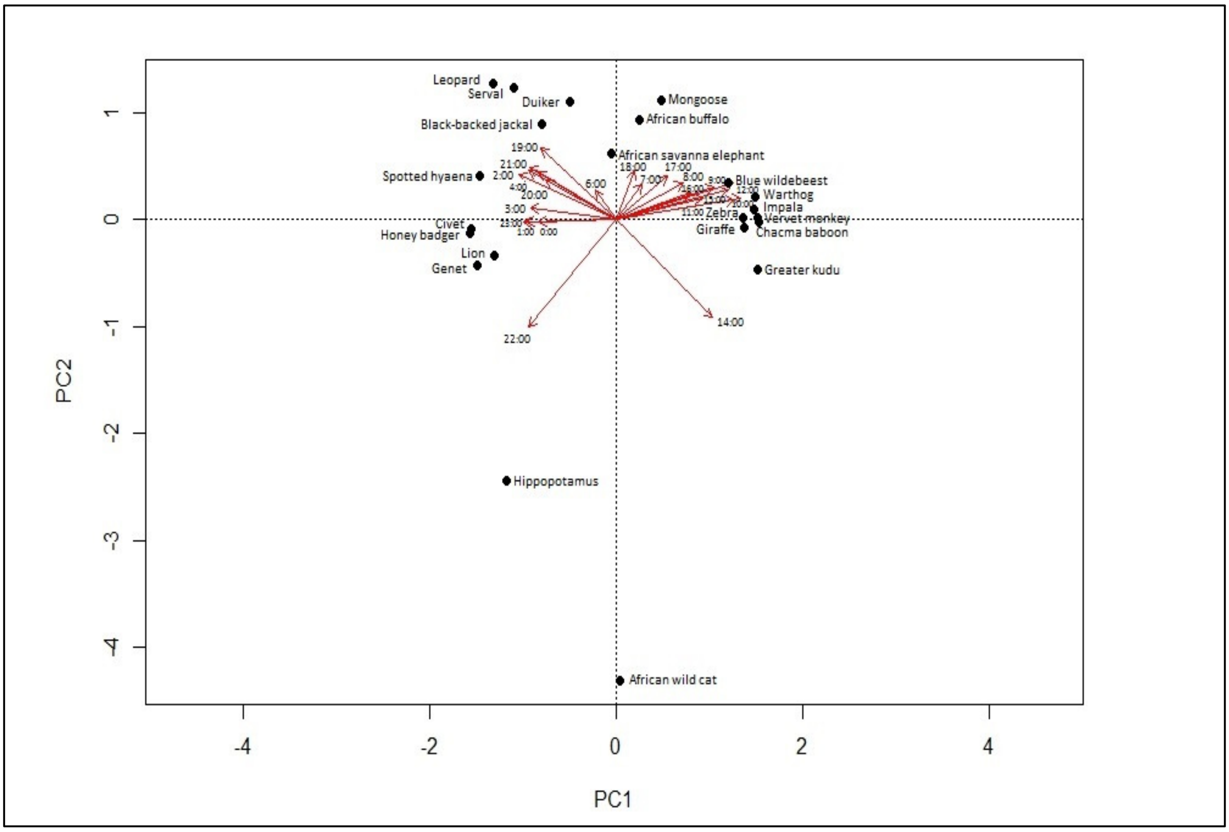


Figure 5.6: Principal component analysis biplot showing the dominant visitation times of mammals and species associations at Orpen waterhole.

The ordination output scores for PC1 for mammals that visit the waterhole diurnally, show two groups of species associations between plains zebra (1.37) and southern giraffe (1.38); and impala, warthog, vervet monkey, greater kudu and chacma baboon, which show the closest species associations (> 1.5 respectively). African wild cat (0.05), African buffalo (0.25) and mongoose (0.49) exhibit the least similar species association scores (> 0.20 difference), which highlights the behaviour of these species, having little inter-species associations. Similarly, hippopotamus (-1.18), serval (-1.10), black-backed jackal (-0.80) and common duiker (-0.49) have largely different species scores when compared to other mammals utilising the waterhole.

Early night waterhole visitors, such as honey badger and African civet, show the closest nocturnal species overlap, both with scores of -1.56. Small-spotted genet and spotted hyaena (-1.49 and -1.46 respectively), and lion and leopard (-1.32 and -1.30 respectively) have similar PC1 scores. However, these species were never observed at the waterhole together, indicating temporal partitioning between smaller (small-spotted genet and spotted hyaena) and larger (lion and leopard) carnivores. African elephant had a PC1 score (-0.05) which is dissimilar to any other herbivore species, such as common duiker (-0.49) and African buffalo (0.25), but was closest to African wild cat (0.05). However, African elephant were sometimes observed at the waterhole with other herbivores, which supports earlier research finding that elephants do not prevent other herbivores from utilising the same waterhole (Valeix *et al.*, 2009a). As expected, there are large differences between the PC1 scores of carnivores (<-1) and herbivores (>1), with the exception of the African buffalo, African elephant and African wild cat, which do not conform to this statement.

5.3.3 Daily Mammal Visitation Patterns at Satara

At Satara water trough, herbivores and primates similarly account for the majority of diurnal drinkers, with smaller- and larger-sized mammals often utilising the water trough during the same period. African elephant are the only herbivore to predominantly drink during the afternoon and at dusk (22.82% and 22.54% of visitations, respectively), whilst common duiker was the only herbivore to drink predominantly during the early morning (48.65%) (*Table 5.5*). Cluster analysis for Satara grouped baboon, kudu, giraffe, warthog, elephant, wildebeest, impala and zebra, segregating the diurnal drinkers (left cluster, group 1) from serval, honey badger, mongoose, civet, genet, lion, buffalo, duiker, African wild cat, black-backed jackal and hyaena as nocturnal (right cluster - group 2) drinkers (*Figure 5.7*). Diurnal drinkers were grouped into their predominant visitation periods: chacma baboon at dawn; greater kudu, southern giraffe and warthog at midday. These mammals exhibit strictly diurnal visitation patterns (sub-group 1a) whilst African elephant visit the water trough during the afternoon/dusk and blue wildebeest, impala and plains zebra during the morning, yet were also recorded at the water trough during nocturnal hours (sub-group 1b).

Table 5.5: Percentage of sightings of each mammal species in each time category for the period March 2012 to March 2014 at Satara water trough. Peak visitation times are highlighted dark green (peak interval), olive green (2nd peak interval) and light green (3rd peak interval).

Predominant Visitation Period		**Mammal**	**Dawn (5:00 - 7:59)**	**Morning (8:00 - 10:59)**	**Midday (11:00 - 13:59)**	**Afternoon (14:00 - 16:59)**	**Dusk (17:00 - 19:59)**	**Early Night (20:00 - 22:59)**	**Midnight (23:00 - 1:59)**	**Early Morning (2:00 - 4:59)**
Diurnal	Dawn	African buffalo (n= 615)	30.41%	10.57%	0.81%	0.65%	21.14%	19.51%	5.69%	11.22%
	Morning	Chacma baboon (n= 399)	8.02%	79.20%	7.27%	5.51%	0.00%	0.00%	0.00%	0.00%
		Impala (n= 5819)	9.11%	32.53%	29.94%	14.59%	12.60%	0.65%	0.29%	0.29%
		Blue wildebeest (n= 4544)	25.31%	27.40%	15.40%	10.28%	15.85%	2.66%	1.67%	1.43%
		Plains zebra (n= 3032)	12.04%	40.17%	22.59%	14.64%	8.08%	1.12%	0.53%	0.82%
	Midday	Southern giraffe (n= 139)	2.16%	6.47%	41.73%	37.41%	12.23%	0.00%	0.00%	0.00%
		Greater kudu (n= 156)	1.92%	21.15%	42.95%	26.28%	7.69%	0.00%	0.00%	0.00%
		Warthog (n= 67)	10.45%	20.90%	25.37%	23.88%	19.40%	0.00%	0.00%	0.00%
Nocturnal	Afternoon / Dusk	African savanna elephant (n= 355)	3.94%	8.45%	18.31%	22.82%	22.54%	12.96%	7.61%	3.38%
	Early night	African wildcat (n= 95)	17.89%	0.00%	0.00%	0.00%	10.53%	25.26%	23.16%	23.16%
		Black-backed jackal (n= 684)	11.26%	0.44%	0.15%	0.15%	22.51%	29.39%	20.32%	15.79%
		Mongoose (n= 30)	6.67%	20.00%	0.00%	10.00%	0.00%	30.00%	16.67%	16.67%
		Spotted hyaena (n= 507)	11.05%	0.59%	0.59%	0.20%	14.20%	33.14%	19.92%	20.32%
	Midnight	Honey badger (n= 8)	12.50%	12.50%	0.00%	0.00%	12.50%	25.00%	37.50%	0.00%
		Lion (n= 110)	5.45%	0.00%	0.00%	0.00%	0.00%	20.91%	43.64%	30.00%
		Serval (n= 2)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	50.00%
		Small-spotted genet (n= 32)	3.13%	0.00%	0.00%	0.00%	0.00%	21.88%	37.50%	37.50%
	Early morning	African civet (n= 59)	5.08%	0.00%	0.00%	0.00%	5.08%	27.12%	25.42%	37.29%
		Common duiker (n= 37)	10.81%	0.00%	0.00%	0.00%	2.70%	24.32%	13.51%	48.65%

Grouping for the nocturnal drinkers appears to largely reflect their peak visitation periods, with honey badger and mongoose predominantly drinking from the water trough during the early night period (sub-group 2a); African civet, small-spotted genet and lion exhibiting strict nocturnal visitation periods (sub-group 2b), and African buffalo, common duiker, African wild cat, black-backed jackal and spotted hyaena utilising the water trough nocturnally and at dawn (sub-group 2c). Similarly, the right cluster shows greater variability compared to the left cluster, segregating the species with a range of different peak visitation times. Mongoose, honey badger and serval, which are clustered in sub-group 2a, represent the least commonly sighted species at the Satara water trough. The mammals which have distinct nocturnal visitation patterns are carnivores, with the exception of common duiker. Peak visitation intervals for the majority of mammals are clustered within specific diurnal and nocturnal periods, with the exception of African buffalo, African wild cat and mongoose, which have widely dispersed visitation patterns.

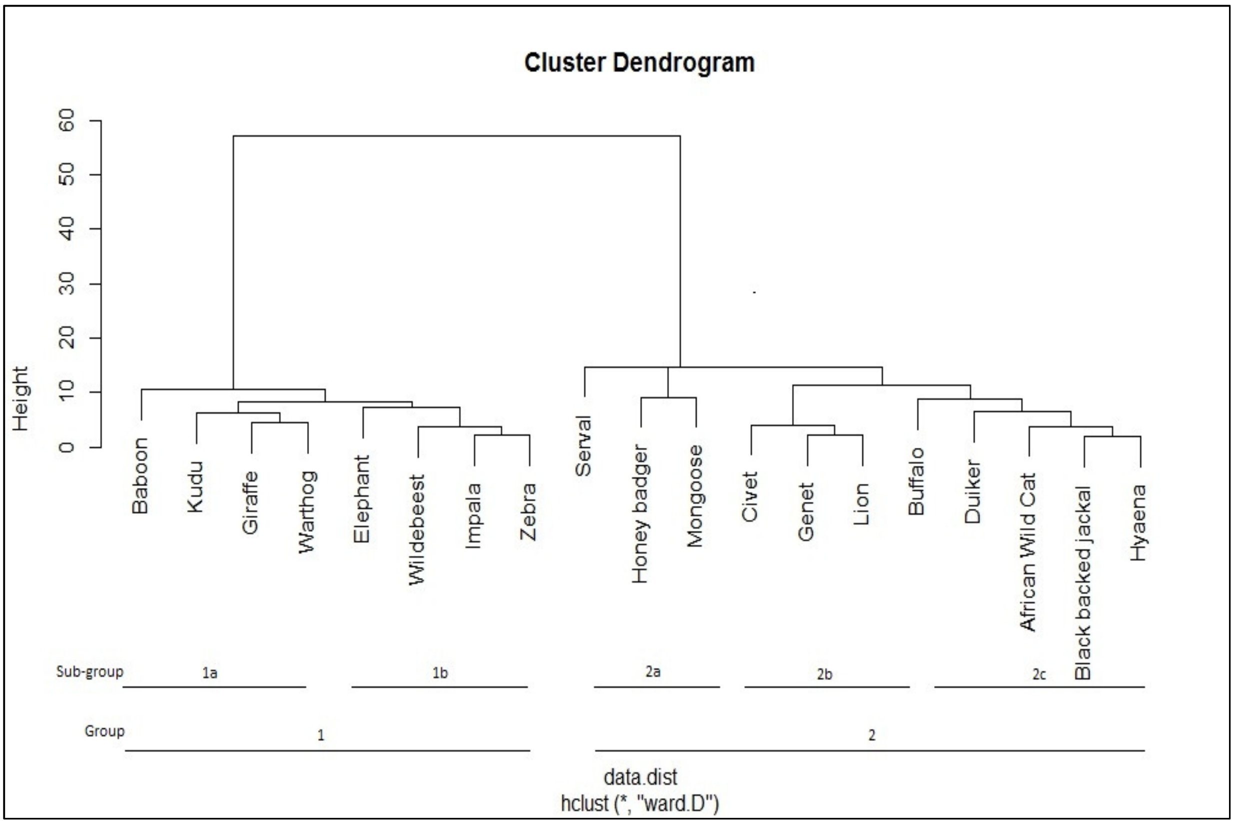


Figure 5.7: Cluster dendrogram showing the dominant visitation times of mammals at Satara water trough.

The PCA for Satara displayed similar patterns to that for Orpen, with PC1 segregating nocturnal (left) from diurnal (right) drinkers. Likewise, PC2 shows no clear pattern for mammals grouped together, and therefore could suggest that mammals are responding to other drivers. Serval are an outlier on PC2, indicating that PC2 is likely influencing the time that serval visit the water trough differently compared to other carnivores (*Figure 5.8*).

The PC1 species scores at Satara show that southern giraffe, warthog and greater kudu (1.68, 1.68 and 1.71 respectively) have the closest species associations, agreeing with patterns observed at the water trough, where these species predominantly visit during midday. Impala (1.58), plains zebra (1.48) and chacma baboon (1.44) show relatively close species scores (< 0.15 difference), indicating that water trough visitation for these species may overlap. African elephant indicate the least similar scores compared to other species (0.68), showing strong species avoidance behaviour at this water trough, which could likely be explained by elephant bulls predominantly utilising this water trough. African buffalo and African elephant generally visit water sources in large herds, and although these species would not need to temporally partition their water source visits (Valeix *et al.*, 2007a), there are large differences between their species scores (-0.11 and 0.68 respectively), likely explained by the small size of Satara water trough, which is not able to accommodate numerous large species drinking from the water trough at the same time, whilst Orpen waterhole is a much larger waterhole, where inter-specific competition could be avoided by shifting their drinking positions at the waterhole and thus PC1 scores between these two species show a smaller difference (0.25 and -0.05 respectively).

Small-spotted genet (-1.52), lion (-1.51) and African civet (-1.48) show similar species scores (< 0.15 difference), indicating that there could be temporal overlap of these species at the water trough and similarly, common duiker and African wild cat (-1.35 for both) could encounter each other at the water trough, however, these species were never observed at the water trough at the same time. Medium- and small-sized carnivores, spotted hyaena (-1.08) and black-backed jackal (-1.04), show similar species scores (0.02

difference), with predominant visits to the water trough during the early night and midnight, whilst, serval (-0.80), mongoose (-0.69) and honey badger (-0.48) have the least similar PC1 scores compared to other nocturnal species.

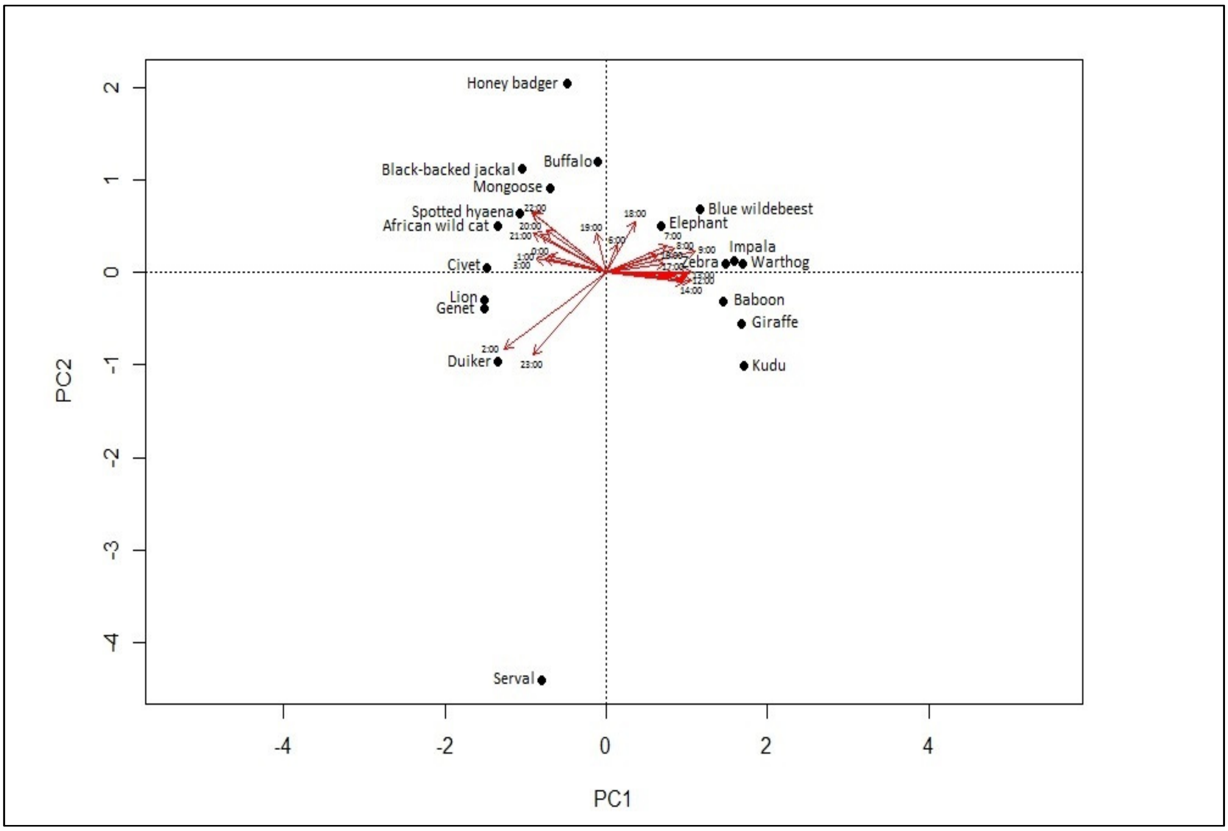


Figure 5.8: Principal component analysis biplot showing the dominant visitation times of mammals and species associations at Satara water trough.

5.3.4 Comparisons of Water Source Visitation between and within Seasons

For all mammals at Orpen and Satara, there are significant, strong, correlations between water source visits and season (*Table 5.6*), showing that visitation patterns are similar within the same seasons, thus, justifying the pooling of data into these seasons. Therefore, water source visitation patterns were analysed at monthly and seasonal intervals, across annual and inter-annual periods for autumn, winter, spring and summer, to explore how visitation is spread across these four seasons.

Table 5.6: Seasonal comparisons for each season in 2012 and 2013, of average mammal sightings. Strong (≥ 0.50) significant correlations are indicated by an asterisk and very strong (≥ 0.90) significant correlations are indicated by a double asterisk.

Seasonal Comparisons for Pooled Mammal Sightings		
	Season	**Avg Sightings**
Orpen	Autumn	**0.94
	Winter	**0.96
	Spring	*0.73
	Summer	**0.93
	Wet	**0.94
	Dry	**0.99
Satara	Autumn	*0.82
	Winter	*0.82
	Spring	*0.70
	Summer	*0.81
	Wet	*0.87
	Dry	*0.83

5.3.5 Seasonal Visitation Patterns for All Species Combined (Orpen)

Mammal visitation showed the strongest seasonal preferences during winter 2012 (60.62%), whilst the weakest seasonal preferences are shown for spring 2012 (5.18%) (*Table 5.7*). In contrast, mammal visitation showed the strongest seasonal preferences during spring (35.99%) and winter 2013 (31.23%), with the weakest seasonal preferences during autumn 2013. Visitation patterns were relatively similar during the dry (54.16%) and wet (45.84%) seasons of 2013 (*Table 5.7*).

Table 5.7: Percentage of total monthly and seasonal sightings at Orpen waterhole for the period March 2012 to March 2014. Highest and lowest percentages highlighted in dark grey and light grey.

Orpen					
	Month/s	**Total Sightings**	**% Per Month**	**% Per Season**	**Rainfall (mm)**
Autumn	Mar-12	569	1.93	17.53	60.4
	Apr-12	471	1.60		
	May-12	1466	4.98		
Winter	Jun-12	2053	6.97	60.62	0.0
	Jul-12	3253	11.05		
	Aug-12	3362	11.42		
Spring	Sep-12	232	0.79	5.18	238.2
	Oct-12	237	0.80		
	Nov-12	272	0.92		
Summer	Dec-12	804	2.73	16.67	497.7
	Jan-13	1016	3.45		
	Feb-13	564	1.92		
Autumn	Mar-13	598	2.03	9.60	106.3
	Apr-13	473	1.61		
	May-13	383	1.30		
Winter	Jun-13	1383	4.70	31.23	21.7
	Jul-13	1475	5.01		
	Aug-13	1871	6.35		
Spring	Sep-13	2690	9.14	35.99	126.1
	Oct-13	1730	5.88		
	Nov-13	1030	3.50		
Summer	Dec-13	1973	6.70	23.18	256.4
	Jan-14	599	2.03		
	Feb-14	938	3.19		
	Mar-14	734	2.43		
Wet Season	Oct - Mar 2012	3491	24.36		697.5
Dry Season	Apr - Sep 2012	10837	75.64		67.6
Wet Season	Oct - Mar 2013	7004	45.84		545.2
Dry Season	Apr - Sep 2013	8275	54.16		124.0

5.3.5.1 Species-Specific Seasonal Visitation Patterns (Orpen)

Mammal sightings were averaged for the two dry seasons and two wet seasons of the study period. The majority of carnivores and herbivores visited the waterhole predominantly (>70%) during the dry season (*Table 5.8*). However, some species (lion, blue wildebeest, African elephant and chacma baboon) showed no seasonal preference (seasonal values differ by < 20%). African civet, black-backed jackal, leopard, small-spotted genet, common duiker, greater kudu, African buffalo, hippopotamus, warthog and vervet monkey show strong seasonal preference (seasonal values differ by > 50%), with the highest percentage use of visitation recorded during the dry season.

Table 5.8: Percentage seasonal waterhole utilisation at Orpen for specific species (April 2012 to March 2014). Highest percentages highlighted in grey. Species showing no seasonal preference are marked with an asterisk (*) (seasonal values differ by < 20%), species showing strong seasonal preference are marked with a double asterisk (**) (seasonal values differ by > 50%).

Mammal	**Total Sightings**	**Dry Season % (Apr 2012 - Sep 2012) (Apr 2013 - Sep 2013)**	**Wet Season % (Oct 2012 - Mar 2013) (Oct 2013 - Mar 2014)**
African civet**	(n = 72)	93.06	6.94
Black-backed jackal**	(n = 415)	86.51	13.49
Honey badger	(n = 59)	71.19	28.81
Leopard**	(n = 50)	84.00	16.00
Lion*	(n = 72)	41.67	58.33
Small-spotted genet**	(n = 28)	78.57	21.43
Spotted hyaena	(n = 215)	74.42	25.58
Common duiker**	(n = 221)	97.74	2.26
Greater kudu**	(n = 839)	79.38	20.62
Southern giraffe	(n = 195)	74.87	25.13
African buffalo**	(n = 903)	79.18	20.82
Blue wildebeest*	(n = 3241)	40.70	59.30
Hippopotamus**	(n = 26)	84.62	15.38
Plains zebra	(n = 1970)	64.52	35.48
Warthog**	(n= 3476)	82.25	17.75
African savanna elephant*	(n = 1633)	56.52	43.48
Impala	(n = 14536)	63.99	36.01
Chacma baboon*	(n = 1183)	47.80	52.20
Vervet monkey**	(n = 353)	93.20	6.80

5.3.5.2 Temporal Visitation Shift between Wet and Dry Seasons (Orpen)

To explore whether mammal species are shifting their daily timing of water source utilisation periods according to season (wet and dry), individual mammal species hourly visitation totals per month were separated according to the wet and dry seasons. Hypotheses for a comparison of means test is that there is no difference between the two dry seasons and no difference between the two wet seasons, whilst there is a difference between the 2012 dry season and 2012 wet season and a difference between the 2013 dry season and 2013 wet season.

Pooled species hourly visitation patterns per wet and dry season show a peak in visitation at 10:00 during both the 2012 dry and wet seasons (*Figure 5.9*), however, a comparison of means test indicates that there is a significant difference ($t = 2.50$, $p < 0.05$) between the pooled species hourly visitation patterns between the 2012 dry and wet seasons. Peaks in visitation are shown at 11:00 during the 2013 dry season and at 8:00 during the 2012 wet season (*Figure 5.9*), indicating an earlier shift in the daily timing of waterhole visitations during the 2013 wet season, however, a comparison of means test reveals no difference ($t = 0.48$, $p > 0.05$) between the hourly visitation patterns for the 2013 dry and wet seasons

Pooled species seasonal visitation patterns across the 24-hour day show no difference between the hourly visitation patterns of the 2012 and 2013 dry seasons ($t = 0.71$, $p > 0.05$) and no significant difference between the 2012 and 2013 wet seasons ($t = -2.18$, $p < 0.05$). Thus, mammals exhibit temporal shifts in the timing of their visitation to the waterhole according to season, with season reflecting changes in climatic variables (temperature and rainfall), as well as light availability (sunrise and sunset times).

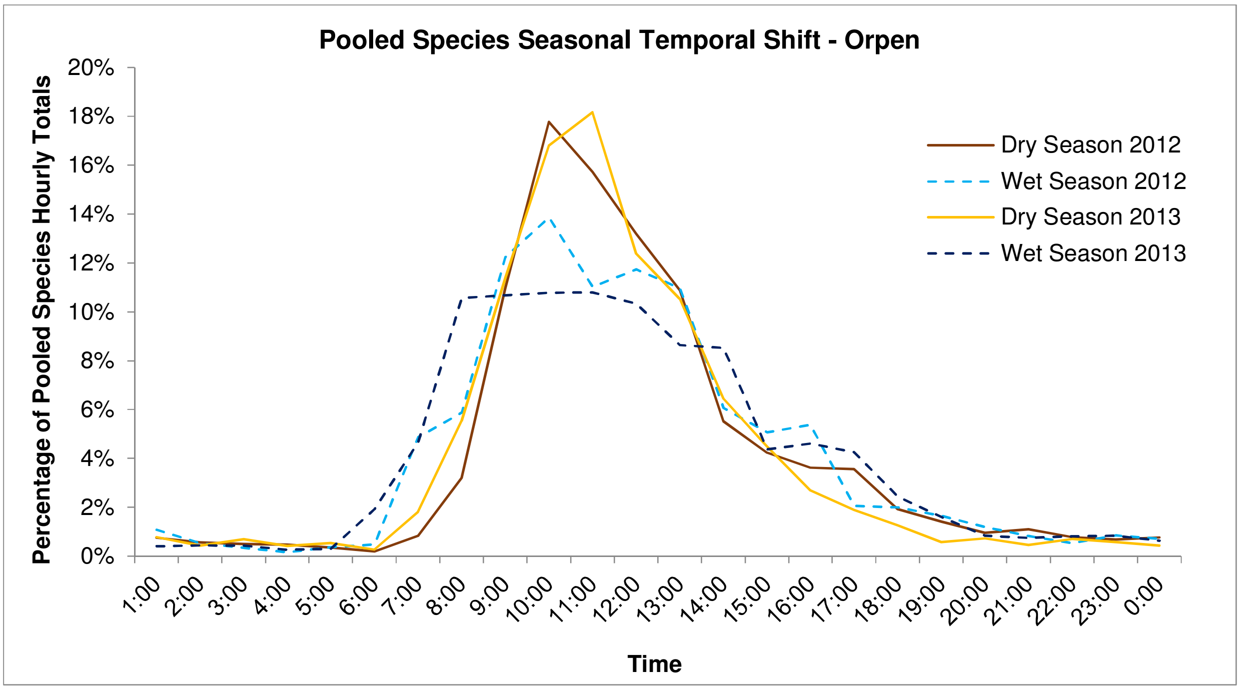


Figure 5.9: Pooled species temporal shifts in visitation, at Orpen waterhole, within and between the wet and dry seasons.

5.3.6 Seasonal Visitation Patterns for All Species Combined (Satara)

Mammal visitation showed the strongest seasonal preferences during winter 2012 (39.13%) and the weakest seasonal preferences during spring 2012 (8.62%) (*Table 5.9*), reflecting the broader dry (63.15%) and wet (36.85%) season distribution of visitation. In contrast, mammal visitation showed the strongest seasonal preferences during summer 2013 (42.58%) with a relatively even distribution of water trough visits during autumn, winter and spring 2013 (20.01%, 19.16% and 18.25% respectively). Similar rainfall conditions for Satara, where 30.7mm of rainfall was received during the dry season of 2012, resulted in a high percentage of visits to the water trough during winter, whilst the low percentage of visits in spring and summer are a consequence of a high volume of rainfall (478.6mm) in the 2012 wet season.

Table 5.9: Percentage of total monthly and seasonal sightings at Satara water trough for the period April 2012 to March 2014. Highest and lowest percentages highlighted in dark grey.

Satara					
	Month/s	**Total Sightings**	**% Per Month**	**% Per Season**	**Rainfall (mm)**
	Mar-12	-	-		
Autumn	Apr-12	1197	7.34	26.75	47.5
	May-12	1180	7.24		
	Jun-12	921	5.65		
Winter	Jul-12	1287	7.89	39.13	0.0
	Aug-12	1269	7.78		
	Sep-12	246	1.51		
Spring	Oct-12	103	0.63	8.62	145.8
	Nov-12	417	2.56		
	Dec-12	533	3.27		
Summer	Jan-13	748	4.59	25.49	353.8
	Feb-13	984	6.03		
	Mar-13	775	4.75		
Autumn	Apr-13	373	2.29	20.01	87.8
	May-13	337	2.07		
	Jun-13	702	4.30		
Winter	Jul-13	463	2.84	19.16	10.8
	Aug-13	257	1.58		
	Sep-13	425	2.61		
Spring	Oct-13	345	2.12	18.25	111.9
	Nov-13	585	3.59		
	Dec-13	1681	10.31		
Summer	Jan-14	850	5.21	42.58	338.4
	Feb-14	630	3.86		
	Mar-14	382	2.29		
Wet Season	Oct - Mar 2012	3560	36.85		478.6
Dry Season	Apr - Sep 2012	6100	63.15		30.7
Wet Season	Oct - Mar 2013	4473	63.63		553.3
Dry Season	Apr - Sep 2013	2557	36.37		104.7

5.3.6.1 Species-Specific Seasonal Visitation Patterns (Satara)

At Satara water trough, African civet (88.14%), common duiker (83.78%), greater kudu (87.82%), southern giraffe (79.14%) and warthog (88.06%) predominantly (> 50%

difference between seasons) drink during the dry season, whilst lion (75.45%) and African elephant (75.77%) predominantly (> 50% difference between seasons) drink during the wet season at the given water trough (*Table 5.10*). The former species therefore exhibit strong seasonal preference. Highly water-dependent species such as blue wildebeest and impala, exhibit relatively similar dry and wet season water trough visitation patterns, or no seasonal preference (< 20% difference between seasons) (*Table 5.10*), highlighting that these species rely on the Satara water trough throughout the wet and dry seasons. African wild cat show strong seasonal patterns only at Satara water trough, as their seasonal preferences could not be established at Orpen due to their infrequent visitation patterns at this waterhole. African elephant, lion and plains zebra show strong seasonal preferences only at Orpen waterhole, whilst baboon, impala and blue wildebeest show no seasonal preference at both water sources.

Table 5.10: Percentage seasonal water trough utilisation at Satara for specific species (April 2012 - March 2014). Highest percentages highlighted in grey. Species showing no seasonal preference are marked with an asterisk (*) (seasonal values differ by < 20%), species showing strong seasonal preference are marked with a double asterisk (**) (seasonal values differ by > 50%).

Mammal	**Total Sightings**	**Dry Season %** **(Apr 2012 - Sep 2012)** **(Apr 2013 - Sep 2013)**	**Wet Season %** **(Oct 2012 - Mar 2013)** **(Oct 2013 - Mar 2014)**
African civet**	(n = 59)	88.14	11.86
African wildcat*	(n = 95)	49.47	50.53
Black-backed jackal	(n = 684)	62.43	37.57
Lion**	(n = 110)	24.55	75.45
Small-spotted genet	(n = 32)	31.25	68.75
Spotted hyaena	(n = 507)	71.01	28.99
Common duiker**	(n = 37)	83.78	16.22
Greater kudu**	(n = 156)	87.82	12.18
Southern giraffe**	(n = 139)	79.14	20.86
African buffalo	(n = 615)	70.08	29.92
Blue wildebeest*	(n = 4544)	42.25	57.75
Plains zebra	(n = 3032)	68.54	31.46
Warthog**	(n = 67)	88.06	11.94
African savanna elephant**	(n = 355)	24.23	75.77
Impala*	(n = 5819)	46.11	53.89
Chacma baboon*	(n = 399)	46.37	53.63

5.3.6.2 Temporal Visitation Shift between Wet and Dry Seasons (Satara)

Pooled species hourly visitation patterns for the 2012 and 2013 wet season show peaks in visitation at 7:00 (*Figure 5.10*), and a comparison of means test indicates no difference (t = -0.94, p > 0.05) between the mean visitation patterns between these two seasons. Peak visitation during the 2012 dry season is shown at 9:00, while during the 2013 dry season peak visitation is at 8:00 (*Figure 5.10*). A comparison of means test revealed that there is a significant difference (t = 2.58, p < 0.05) between the mean visitation patterns during the two dry seasons.

There is no difference (t = 1.77, p > 0.05) between the mean visitation patterns of the 2012 dry and wet seasons, and there is no significant difference (t = -2.19, p < 0.05) between the 2013 dry and wet seasons. This suggests that mammals at the Satara water trough are not shifting their daily timing of visitations between seasons, however, they are showing similar patterns within seasons.

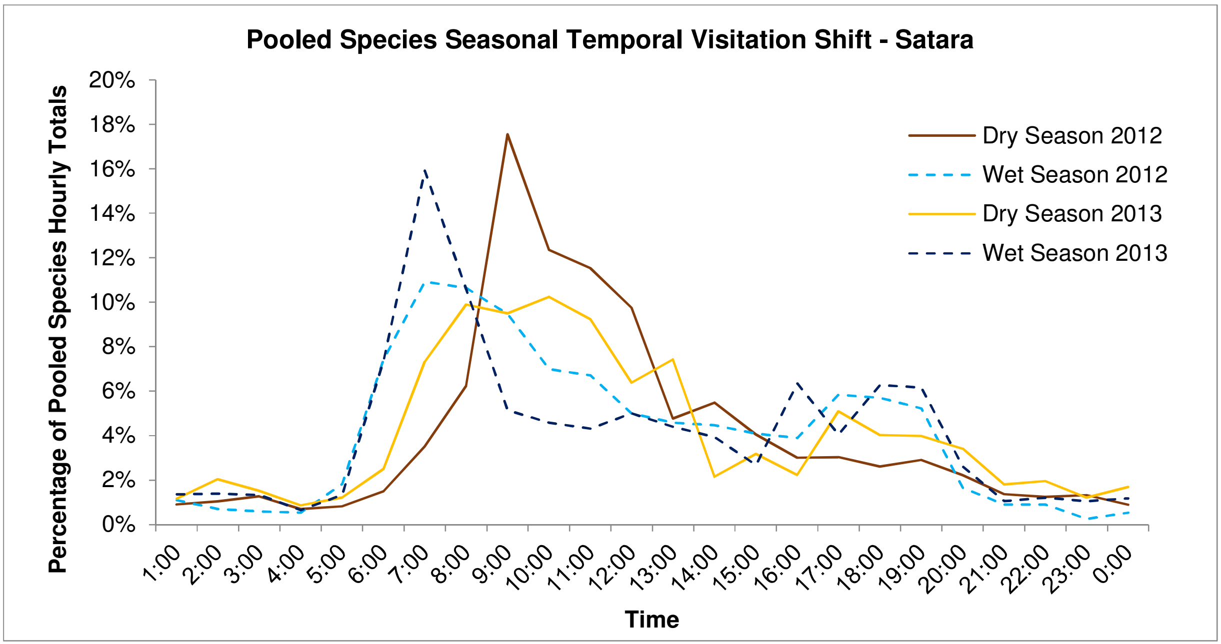


Figure 5.10: Pooled species temporal shifts in visitation, at Satara water trough, within and between the wet and dry seasons.

5.3.7 Duration of Water Source Visitation

As the identification of individuals was not possible in this study, the time spent at the waterhole was calculated per species group/herd/family unit, from the time the first individual in a group started drinking to the time that the last individual left the water source.

5.3.7.1 Duration of Mean Water Source Visitation per Species (Orpen)

Mean monthly time spent at Orpen waterhole ranged from 7 minutes, 6 seconds in September 2013 to 43.6 seconds in October 2012. Seasonal patterns and fluctuations are shown for pooled species duration of waterhole visits, with pronounced peaks in the mean time spent at Orpen waterhole occurring in the winter months of June, July and August 2012 and in September and October 2013, likely a consequence of rainfall received during and prior to these periods. It is also important to explore whether a particular species or feeding guild is responsible for driving these seasonal patterns of time spent at the waterhole.

The average time spent at the waterhole was calculated per month. The monthly distribution of the time spent at the waterhole shows a seasonal pattern exhibited by herbivores (in particular mixed feeders) and black-backed jackals (*Table 5.11*), suggesting that these species may change their time spent at the waterhole depending on season/climate, thus highlighting the importance of exploring the seasonal patterns in time spent at the waterhole, and how these patterns differ between and within feeding guild species classifications.

The mean time spent at the waterhole was < 1 minute for all carnivores for the period March 2012 - March 2014 (*Figure 5.9*), ranging from ~53 seconds for black-backed jackal to < 15 seconds for honey badger (*Table 5.11*). In contrast, the mean time spent at the waterhole by herbivores collectively was > 1 min (*Figure 5.12; Table 5.11*).

Table 5.11: Monthly mean time spent at Orpen waterhole per mammal species, for the period March 2012 to March 2014.

Orpen												< 1 min		< 5 min		< 10 min		< 15 min		> 15 min	
	African Civet	African wild cat	Small-spotted genet	Honey badger	Black-backed jackal	Leopard	Lion	Mongoose	Serval	Spotted hyaena	Common duiker	Greater kudu	Southern giraffe	African buffalo	Blue wildebeest	Plains zebra	Warthog	African elephant	Impala	Chacma	Vervet monkey
Mar-12	-	-	18s	-	2m6s	15s	15s	-	30s	15s	-	1m19s	2m36s	2m48s	3m12s	15s	4m6s	11m36s	11m36s	6m	-
Apr-12	15s	-	15s	-	24s	-	-	15s	-	15s	-	33s	48s	4m24s	1m30s	42s	2m48s	2m18s	4m12s	1m54s	15s
May-12	15s	-	24s	15s	1m18s	15s	15s	18s	-	19s	15s	1m39s	24s	6m6s	2m54s	1m54s	5m54s	13m6s	13m6s	1m24s	1m18s
Jun-12	34s	-	18s	15s	1m42s	15s	15s	-	-	21s	1m43s	48s	1m36s	14m	1m54s	2m18s	9m36s	3m30s	39m54s	1m12s	1m48s
Jul-12	30s	-	15s	15s	1m30s	15s	-	-	-	41s	2m25s	2m5s	30s	9m	3m6s	4m54s	12m54s	11m12s	27m42s	4m	4m18s
Aug-12	15s	-	-	15s	2m54s	54s	-	-	-	1m24s	2m43s	2m21s	2m48s	11m18s	2m30s	7m48s	15m30s	9m36	31m54s	2m54s	1m12s
Sep-12	-	-	-	-	15s	-	-	-	-	15s	24s	46s	54s	15s	18s	42s	1m36s	4m24s	3m24s	30s	-
Oct-12	-	-	-	15s	18s	-	-	-	-	44s	-	15s	-	42s	1m	-	1m12s	48s	3m18s	48s	24s
Nov-12	-	-	-	15s	15s	15s	-	-	-	15s	-	15s	-	1m24s	36s	1m36s	1m	3m54s	5m	1m6s	-
Dec-12	-	-	-	-	-	-	-	-	15s	15s	-	28s	-	9m24s	3m42s	5m30s	48s	5m36s	18m	2m18s	15s
Jan-13	-	-	-	-	15s	15s	49s	-	-	15s	-	15s	-	1m6s	5m54s	3m36s	2m	2m18s	14m30s	6m12s	15s
Feb-13	-	-	-	-	-	-	-	-	-	24s	-	15s	-	15s	3m12s	2m48s	1m30s	15s	5m6s	1m	-
Mar-13	-	-	-	15s	30s	-	15s	26s	-	15s	-	15s	15s	42s	5m30s	4m42s	2m42s	7m48s	1m18s	3m54s	-
Apr-13	-	-	-	-	18s	15s	-	15s	44s	51s	-	15s	24s	3m6s	1m42s	1m54s	1m24s	6m12s	3m6s	2m24s	15s
May-13	15s	-	15s	-	15s	25s	-	15s	-	15s	-	15s	1m12s	2m54s	1m	1m12s	3m6s	11m12s	1m24s	2m18s	18s
Jun-13	42s	-	-	15s	54s	20s	-	17s	15s	15s	15s	1m10s	54s	5m24s	2m48s	17m30s	11m18s	1m12s	11m24s	3m36s	24s
Jul-13	15s	-	-	-	15s	17s	15s	-	-	24s	17s	1m20s	1m30s	8m12s	1m48s	5m30s	16m18s	13m12s	14m54s	2m54s	18s
Aug-13	-	15s	15s	18s	1m30s	15s	38s	-	-	1m8s	15s	5m10s	4m30s	1m6s	3m6s	24s	19m42s	14m6s	21m36s	3m6s	15s
Sep-13	15s	-	-	24s	130s	55s	1m6s	15s	-	2m22s	37s	4m13s	5m12s	10m48s	4m	3m18s	31m	17m36s	44m42s	15s	15s
Oct-13	15s	-	-	15s	2m12s	-	-	21s	30s	26s	15s	2m41s	5m36s	9m12s	4m42s	1m54s	25m	32m48s	21m12s	1m18s	15s
Nov-13	-	-	24s	-	18s	-	15s	27s	-	15s	-	53s	54s	15s	1m6s	30s	3m12s	14m24s	14m6s	42s	-
Dec-13	-	-	15s	15s	42s	15s	46s	15s	-	15s	-	22s	-	48s	9m12s	3m	2m48s	10m54s	25m6s	2m6s	-
Jan-14	15s	-	-	15s	-	-	15s	-	-	22s	-	15s	-	-	1m6s	2m	1m24s	2m42s	8m48s	1m6s	-
Feb-14	-	-	15s	15s	-	15s	37s	-	-	-	-	-	-	24s	1m54s	4m30s	1m	2m18s	11m54s	2m30s	-
Mar-14	-	-	-	-	-	-	18.6s	15s	-	-	-	15s	-	-	36s	2m	36s	7m	9m12s	1m30s	15s

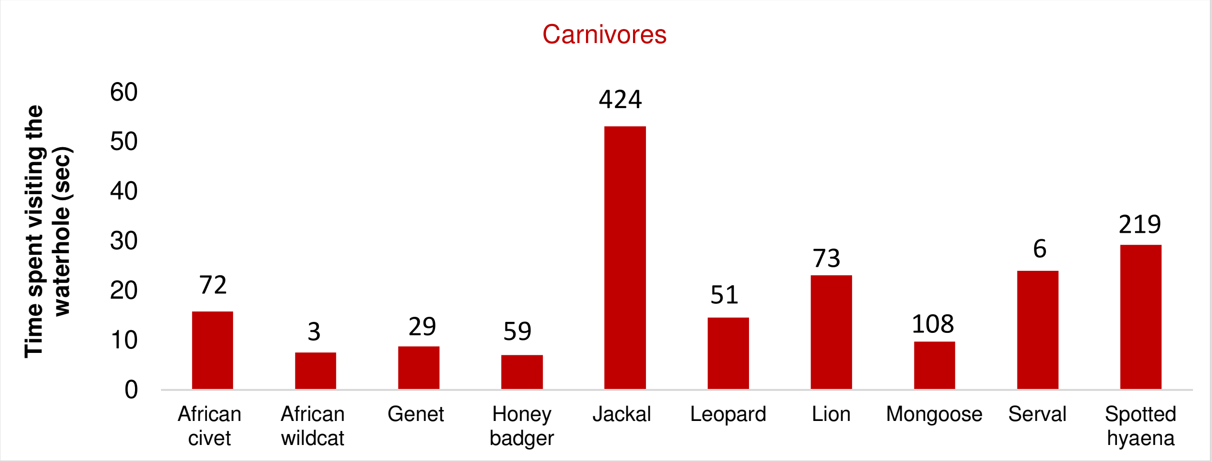


Figure 5.11: Mean time carnivores spent at Orpen waterhole for the period March 2012 to March 2014. The number of sightings (n) is indicated for each species.

Mixed feeders (elephant and impala) spend the longest mean time at the waterhole (8 minutes, 18 seconds and 14 minutes, 42 seconds, respectively), while browsers (common duiker, greater kudu and southern giraffe) and primates (chacma baboon and vervet monkey) spend, on average, < 3 minutes at the waterhole (*Figure 5.12*).

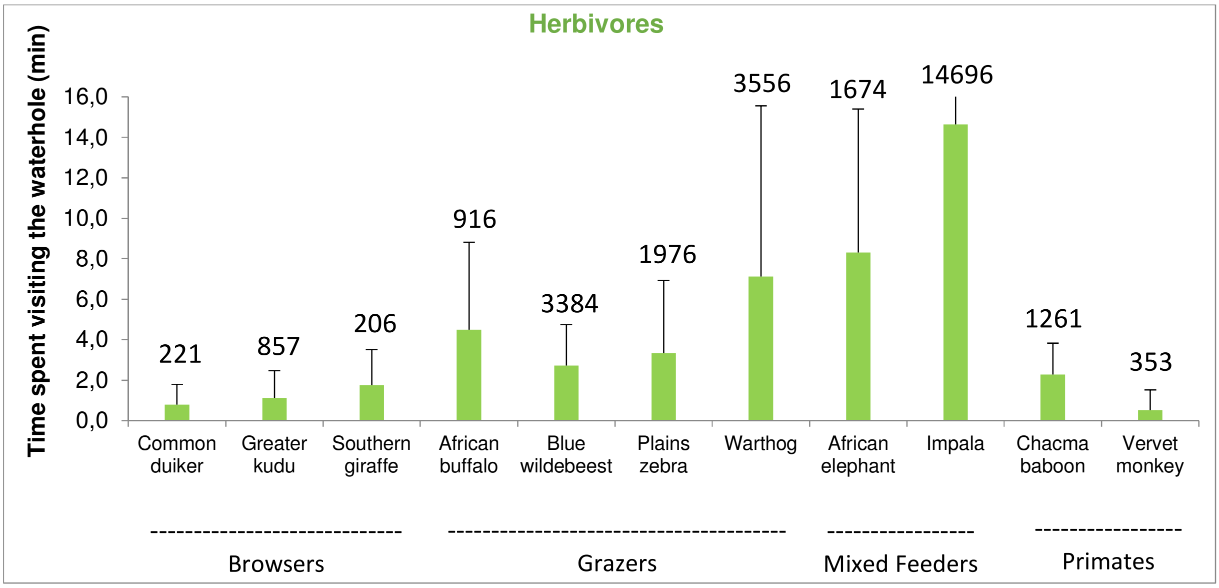


Figure 5.12: Mean time herbivores spent at Orpen waterhole for the period March 2012 to March 2014. The number of sightings (n) is indicated for each species.

5.3.7.2 Duration of Water Source Visitation per Feeding Guild (Seasonal Patterns)

Herbivores show the longest mean time spent at the waterhole during winter 2012 (7 minutes, 36 seconds) and the shortest mean time spent at the waterhole during spring 2012 (1 minute, 18 seconds) and during 2013 the mean time spent at the waterhole was longest during spring (8 minutes, 6 seconds) and winter (5 minutes, 54 seconds). The mean monthly time spent at Orpen waterhole by herbivores ranged from 11 minutes, 6 seconds in September 2013 and 53.9 seconds in October 2012 (*Figure 5.13*).

Herbivores are showing broad seasonal fluctuations in time spent at the waterhole (*Figure 5.13*). Specifically, grazers and mixed feeders seem to be driving the pooled species seasonal fluctuations at Orpen, showing similar seasonal patterns in longest and shortest mean time spent at the waterhole, with the least time spent during spring 2012 and autumn 2013 (*Figure 5.14b,c*). Browsers spent least time at the waterhole during both summer seasons (12.0 seconds and 18.0 seconds, respectively) of the study period (*Figure 5.14a*).

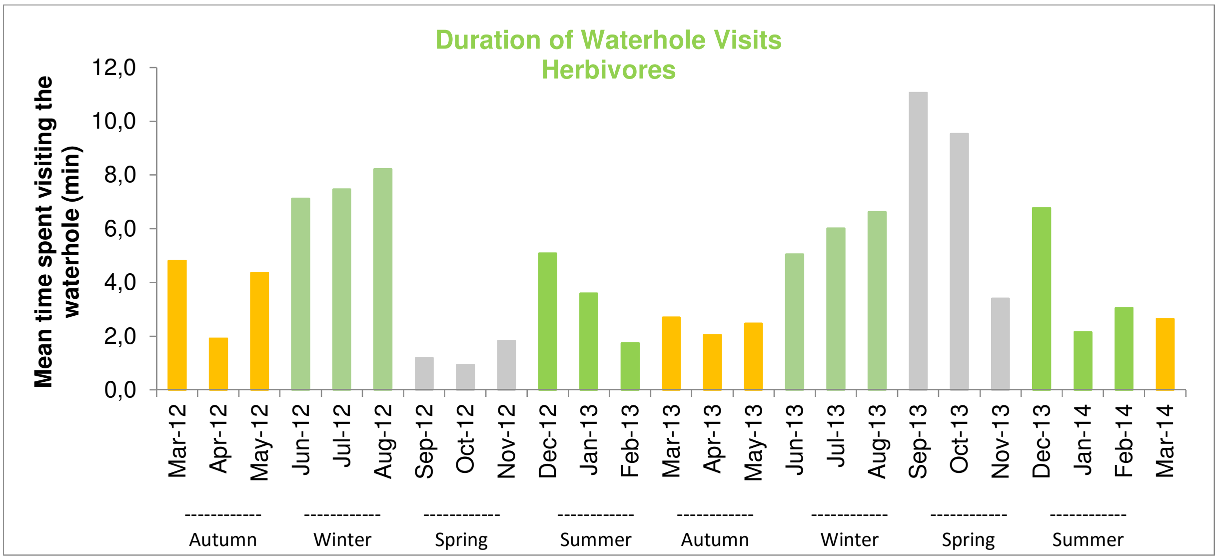


Figure 5.13: Mean monthly time that herbivores spent at Orpen for the period March 2012 to March 2014.

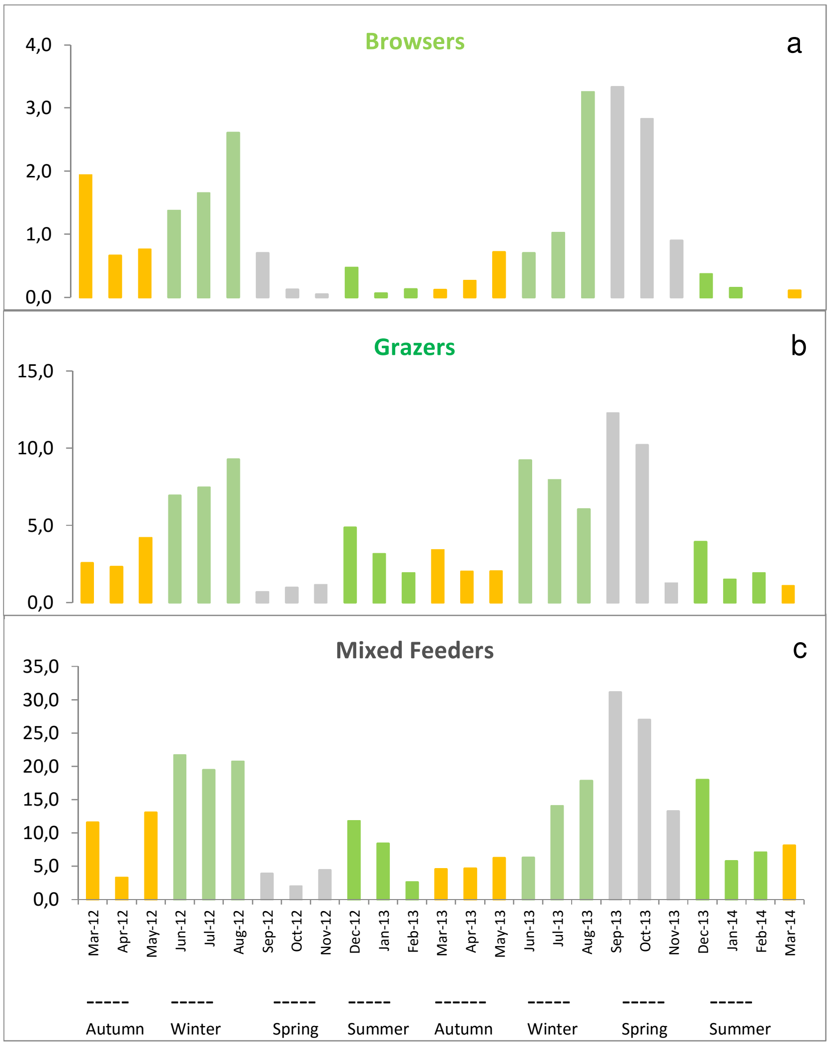


Figure 5.14: Mean monthly time a) browsers, b) grazers and c) mixed feeders spent at Orpen waterhole for the period March 2012 to March 2014.

Carnivores exhibit erratic seasonal patterns in time spent at the waterhole, however, showing pronounced peaks during winter 2012 and spring 2013 (*Figure 5.15*). Mean time spent at the waterhole ranged from 38.0 seconds during winter 2012 to 10.8 seconds during spring 2012, while the mean time spent at the waterhole during spring and summer 2013 was 36.5 and 11.1 seconds respectively.

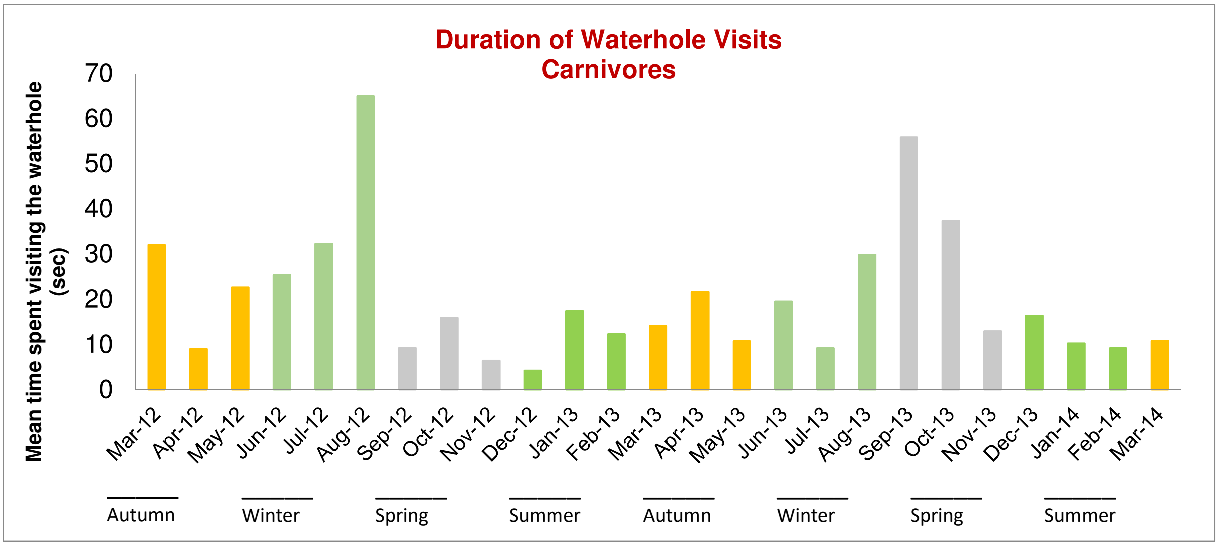


Figure 5.15: Monthly mean time carnivores spent at Orpen waterhole for the period March 2012 to March 2014.

5.3.7.3 Duration of Mean Water Source Visitation per Species (Satara)

Mean monthly time spent at Satara water trough ranged from 4 minutes, 18 seconds in February 2013 to 36.4 seconds in August 2013. Pronounced peaks in water trough visitation patterns also occurred in April 2012 and November 2012 (4.2 minutes for both months). The pooled species mean time spent at Satara water trough does not show a distinct seasonal pattern, however inter-annually, time spent at the water trough is higher in 2012 than 2013. The mean duration spent at Satara water trough for most carnivores was < 1 minute, with the exception of spotted hyaena and black-backed jackal, which respectively spent 70.1 and 66.6 seconds at the water trough, while honey badger spent the least time (< 15 seconds) (*Table 5.12; Figure 5.16*). Spotted hyaena drank from Satara water trough and were frequently observed sitting in the trough. Additionally, they used the water trough for caching purposes, to store meat so that other predators could not detect the meat, which helps explain the > 1-minute duration spent at this water trough. The duration of water trough visits at Satara does not have a distinct feeding guild separation pattern as that observed at Orpen.

Table 5.12: Monthly mean time spent at Satara water trough per mammal species for the period April 2012 to March 2014.

Satara									< 1 min		< 5 min		< 10 min		< 15 min		> 15 min	
	African civet	African wild cat	Genet	Honey badger	Jackal	Lion	Mongoose	Serval	Spotted hyaena	Duiker	Greater kudu	Giraffe	African buffalo	Blue wildebeest	Plains zebra	Warthog	African elephant	Impala	Chacma baboon
Apr-12	-	-	-	-	54s	-	-	-	1m12s	-	1m12s	4m36s	5m30s	7m54s	7m18s	15s	1m12s	15m24s	36s
May-12	-	-	15s	-	2m6s	15s	-	15s	3m30s	-	1m	1m18s	5m54s	5m36s	6m6s	15s	1m24s	13m54s	15s
Jun-12	-	-	-	-	1m24s	18s	-	-	54s	15s	15s	15s	1m24s	2m36s	9m24s	-	4m36s	4m6s	18s
Jul-12	-	-	-	-	1m42s	-	-	-	3m	18s	15s	15s	3m54s	2m24s	8m42s	-	4m48s	9m18s	15s
Aug-12	15s	1m18s	-	-	2m18s	-	-	-	3m6s	15s	30s	18s	1m24s	2m18s	10m18s	-	1m42s	6m18s	18s
Sep-12	-	15s	-	-	-	-	-	-	1m6s	-	-	-	1m24s	1m30s	4m24s	-	9m36s	1m18s	-
Oct-12	15s	30s	-	-	18s	-	-	-	1m6s	-	-	36s	1m36s	18s	15s	-	9m30s	24s	15s
Nov-12	-	-	-	-	18s	24s	-	-	1m42s	-	-	-	4m4s	4m18s	5m42s	-	17m18s	2m6s	1m12s
Dec-12		-	-	-	15s		-	-	1m42s	-	-	-	2m	2m48s	1m42s	-	1m54s	7m36s	30s
Jan-13	-	-	-	-	18s	15s	-	-	1m18s	-	-	54s	1m	5m48s	3m36s	-	7m54s	12m36s	24s
Feb-13	-	36s	-	-	36s	-	18s	-	42s	-	-	-	54s	9m18s	15m30s	-	1m30s	12m36s	36s
Mar-13	-	15s	15s	-	48s	-	36s	-	42s	-	-	24s	-	8m24s	2m42s	-	1m30s	11m54s	-
Apr-13	-	15s	-	-	15s	15s	15s	-	24s	-	-	36s	18s	2m48s	42s	-	1m30s	2m18s	1m24s
May-13	15s	-	-	-	15s	-	15s	18s	24s	-	-	24s	54s	2m30s	1m42s	-	36s	1m12s	24s
Jun-13	30s	18s	15s	-	1m12s	-	-	-	48s	-	15s	24s	18s	7m30s	4m	15s	30s	2m24s	42s
Jul-13	36s	48s	15s	-	1m24s	-	-	-	1m12s	-	15s	-	30s	2m	6m6s	42s	42s	1m42s	18s
Aug-13	24s	54s		-	42s	-	-	-	24s	30s	24s	15s	42s	18s	1m30s	30s	18s	1m42s	-
Sep-13	24s	2m36s	-	15s	1m42s	15s	-	-	1m54s	42s	24s	15s	1m30s	15s	1m42s	48s	24s	2m6s	36s
Oct-13	-	3m24s	15s	-	1m12s	24s	-	-	42s	48s	-	18s	24s	1m18s	42s	15s	4m42s	1m30s	1m
Nov-13	-	2m24s	15s	-	2m12s	1m36s	-	-	54s	18s	42s	-	24s	2m24s	36s	-	4m54s	5m54s	18s
Dec-13	-	36s	36s	-	3m18s	54s	-	-	30s	-	-	15s	2m12s	12m48s	10m18s	15s	2m42s	14m48s	18s
Jan-14	15s	30s	15s	-	1m18s	2m30s	-	-	18s	-	-	-	-	5m30s	5m18s	15s	1m18s	3m42	54s
Feb-14	-	24s	-	-	24s	15s	-	-	18s	-	-	18s	15s	3m24s	3m24s	15s	5m6s	4m24s	24s
Mar-14	-	-	-	-	1m6s	54s	-	-	15s	-	-	18s	-	1m18s	48s	-	1m	2m42s	-

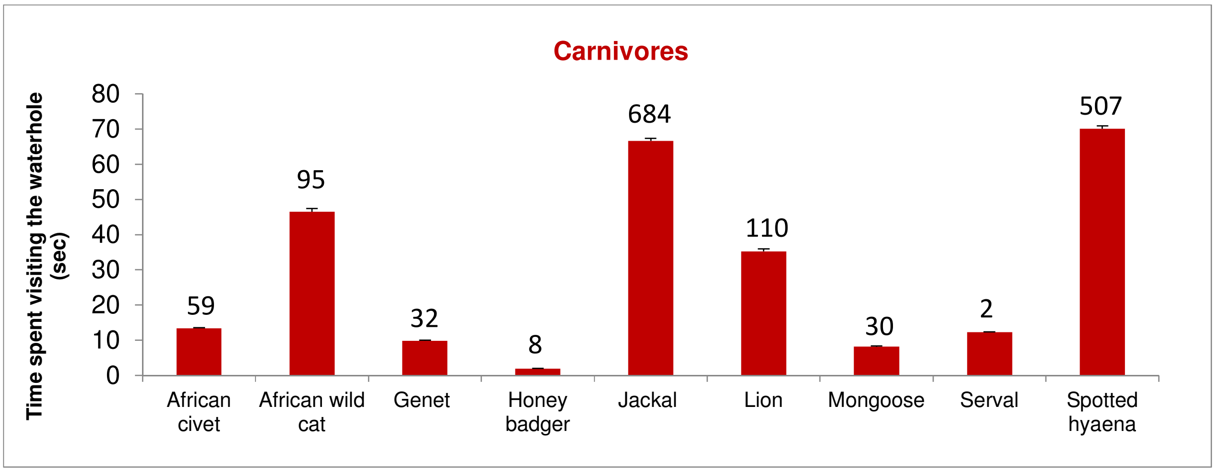


Figure 5.16: Mean time carnivores spent at Satara water trough for the period April 2012 to March 2014. The number of sightings (n) is indicated for each species.

Impala spent the longest time at the Satara water trough, with a mean visitation of 5 minutes, 54 seconds, whilst warthog spent the least time at the water trough (< 15 seconds) (*Table 5.12; Figure 5.17*). Compared to the mixed feeders and grazers, browsers and chacma baboon spent the least time at the water trough (< 40 seconds).

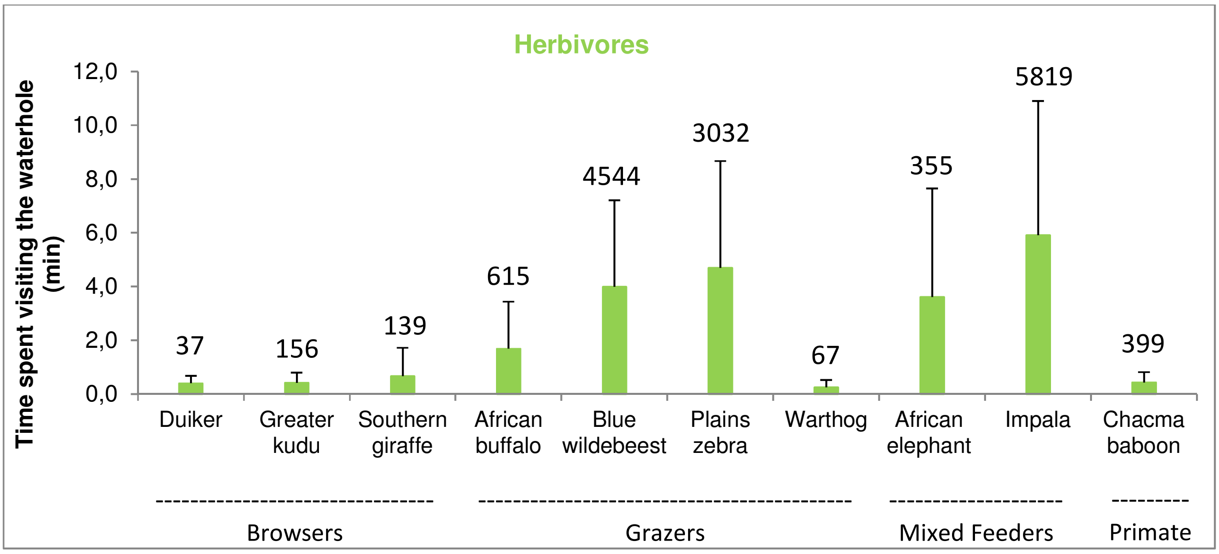


Figure 5.17: Mean time herbivores spent at Satara water trough for the period April 2012 to March 2014. The number of sightings (n) is indicated for each species.

5.3.7.4 Duration of Water Source Visitation per Feeding Guild (Seasonal Patterns)

Herbivores at Satara show a different seasonal pattern of time spent at the water trough, compared to Orpen, with pronounced peaks during spring and summer (*Figure 5.18*) and not during the winter months as shown for Orpen. The longest time spent at the water trough for herbivores was during summer 2012 (4 minutes, 42 seconds) whilst the least time spent at the water trough was during winter and spring 2013 (1 minute, 18 seconds at both waterholes). Browsers, grazers and mixed feeders (*Figure 5.19a,b,c*) all spent the longest time at the water trough during autumn 2012 (2.0 minutes, 8.0 minutes and 4 minutes, 48 seconds, respectively), however the pooled herbivore seasonal duration at water troughs show that the longest time spent is during summer 2012 (54.0 seconds) (*Figure 5.18*). There is an erratic pattern between the different feeding guilds of the least time spent at the water trough, fluctuating from winter 2012 (12.0 seconds) and summer 2013 (12.0 seconds) for browsers, spring 2013 (1.0 minute) for grazers and winter 2013 (1minute, 12 seconds) for mixed feeders (*Figure 5.19a,b,c*). These fluctuations highlight that mixed feeders are the driving force of the seasonal patterns for the longest mean time spent at the Satara water trough, whilst grazers and mixed feeders are the driving force of the seasonal patterns for the shortest time at the trough.

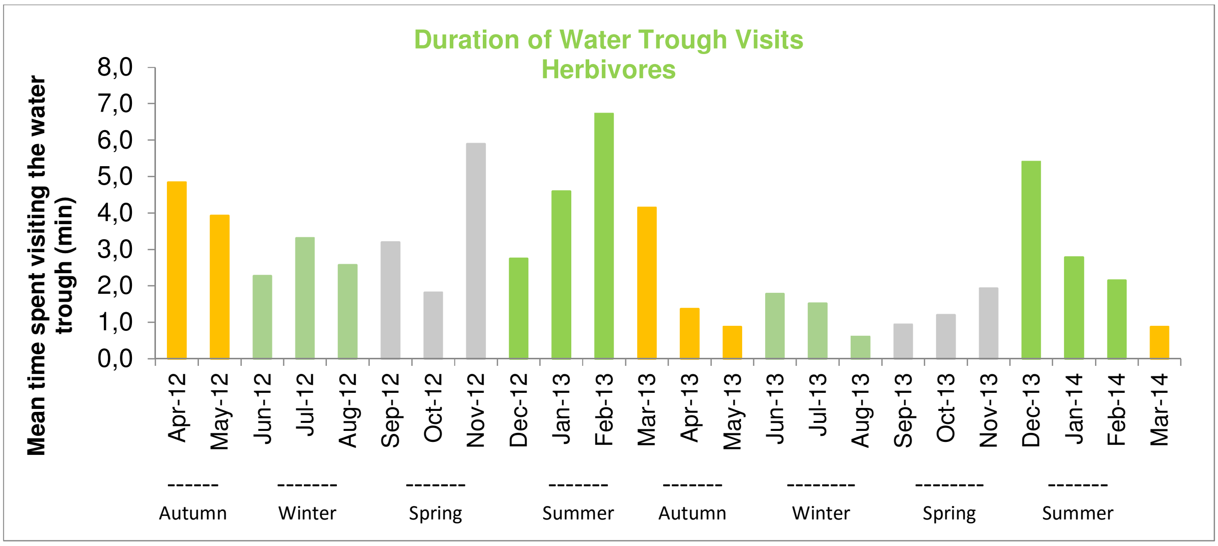


Figure 5.18: Mean monthly time that herbivores spent at Satara for the period April 2012 to March 2014.

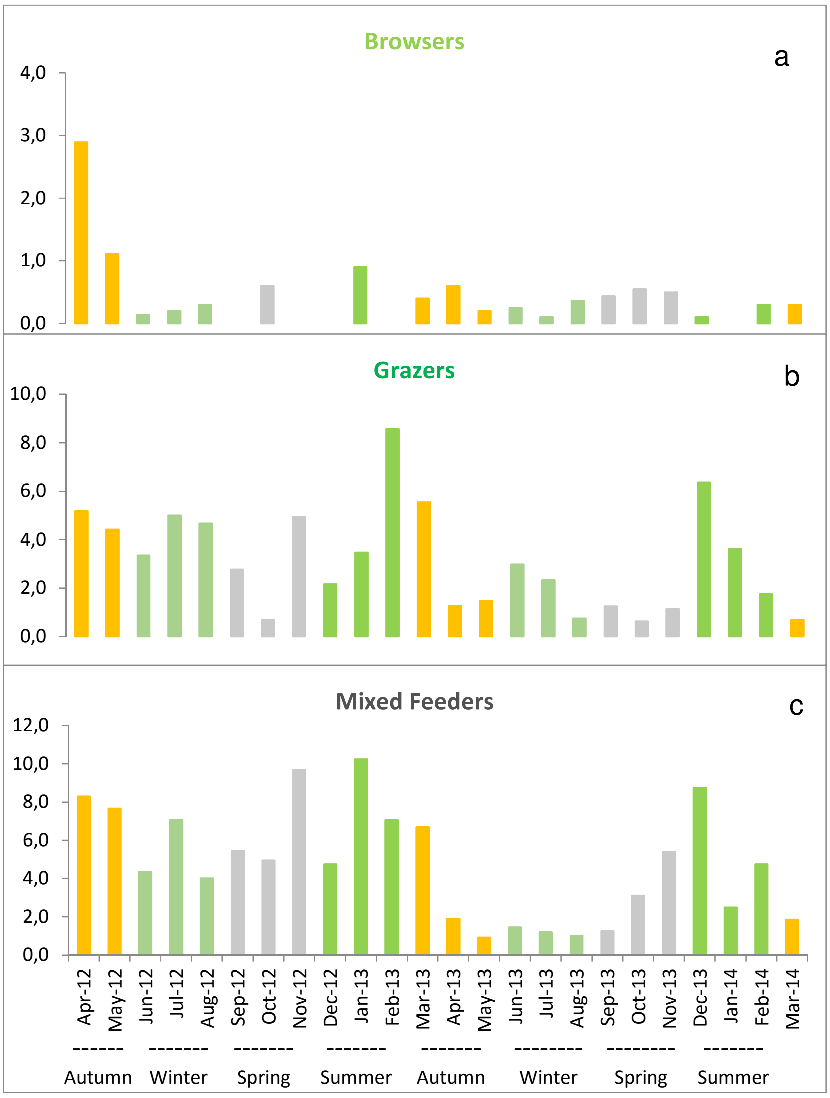


Figure 5.19: Mean monthly time a) browsers, b) grazers and c) mixed feeders spent at Satara water trough for the period April 2012 to March 2014.

Carnivores at Satara also show an erratic seasonal pattern of time spent at the water trough, however, the longest mean time spent at the water trough was during winter 2012 (1 minute, 12 seconds), with the longest mean time spent during August 2012 (1 minute, 42 seconds). The shortest average time spent at the water trough is in during autumn 2013 (8.0 seconds) (*Figure 5.20*). Carnivores are thus showing a different seasonal pattern of time spent at the water trough when compared to the pooled species distribution and herbivores.

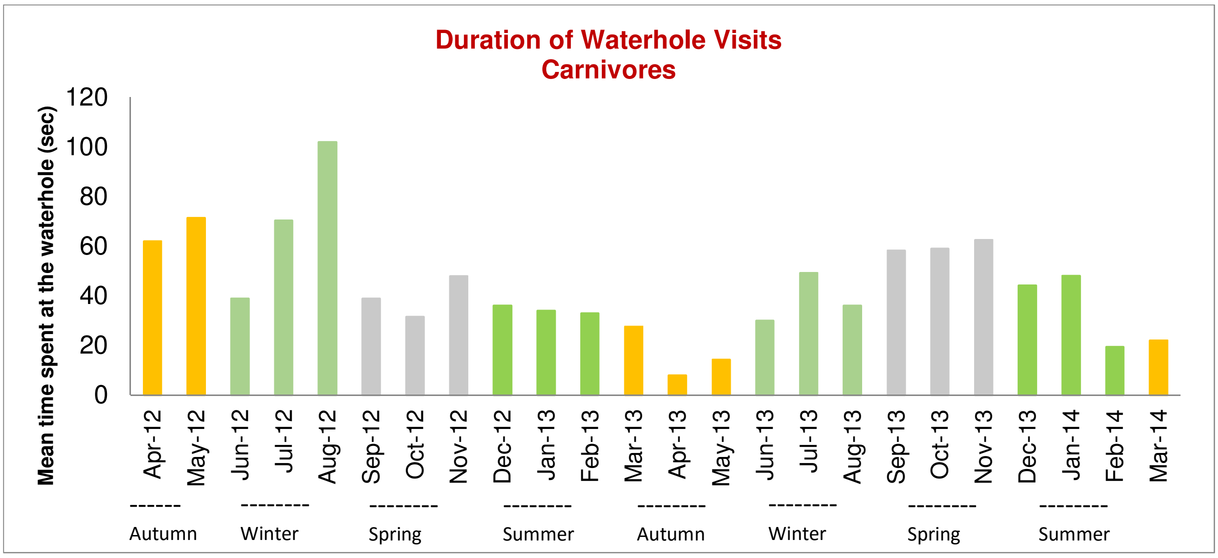


Figure 5.20: Mean monthly time that herbivores spent at Satara for the period April 2012 to March 2014.

5.3.9 Similarities and Differences of Visitation Patterns at Orpen and Satara

Seasonally, mammal visitation patterns at Orpen and Satara are similar, with the majority of mammal (> 70%) visitations occurring during the dry season when there is little or no rainfall and thus fewer natural water sources available to drink from. Blue wildebeest predominantly drink during the wet season at both Orpen (59.30%) and Satara (57.75%), but only marginally more so than during the dry season; a pattern which is likely due to the species being highly water-dependent and therefore having to drink throughout the year. Mammals that displayed the greatest difference in seasonal visitation patterns at Satara and Orpen were small-spotted genet (78.57% difference between dry and wet season visitation), African elephant (56.52%) and impala (63.99%), which all record an increase in visitation during the dry season at Orpen, and conversely small-spotted genet (68.75% difference between dry and wet season visitation), African elephant (75.77%) and impala (53.89%) indicate an increase in visitation during the wet season at Satara.

The timing of peak visitation shows strong relationships between Orpen and Satara for many species, with highly significant strong relationships, as well as the same or similar

(1 hour difference) peak visitation times for African civet (r = 0.84, p < 0.0001) (20:00 and 20:00, respectively), greater kudu (r = 0.74, p > 0.0005) (11:00 and 12:00, respectively), impala (r = 0.89, p <0.0001) (10:00 and 9:00, respectively), plains zebra (r = 0.88, p < 0.0001) (10:00 and 9:00, respectively) and small-spotted genet (r = 0.78, p > 0.0005) (2:00 and 2:00, respectively) (*Table 5.13*). Weak, insignificant correlations as well as different (> 5 hours' difference) peak visitation times between the two sites are observed for African wild cat (r = -0.08, p > 0.20) (14:00 and 0:00, respectively), common duiker (r = 0.12, p > 0.20) (18:00 and 3:00, respectively), mongoose (r = -0.02, p >0.20) (13:00 and 22:00, respectively) and serval (r = 0.15, p > 0.20) (19:00 and 2:00, respectively) (*Table 5.13*).

Table 5.13: Pearson's correlation table and significance of the relationship between mammal visitation times at Orpen and Satara water sources. Strong relationships (≥ 0.50) are indicated by an asterisk and very strong relationships (≥ 0.90) indicated by a double asterisk. Highly significant relationships are highlighted in grey. Significant relationships are tested at the 95% and 99% level.

Mammal	**r-value**	**p-value**	**Significance**	**Peak Visitation Time (Orpen)**	**Peak Visitation Time (Satara)**
African buffalo	0.15	p > 0.20	Not significant	9:00	7:00
African civet	*0.84	p < 0.0001	Highly significant	20:00	2:00 / 20:00
African elephant	*0.59	p > 0.0005	Highly significant	18:00	12:00 / 16:00
African wild cat	-0.08	p > 0.20	Not significant	14:00	0:00
Black-backed jackal	*0.70	p > 0.0005	Highly significant	2:00 / 0:00	19:00
Blue wildebeest	*0.59	p > 0.0005	Highly significant	10:00	7:00
Chacma baboon	*0.34	p > 0.01	Significant	10:00 / 13:00	8:00
Common duiker	0.12	p > 0.20	Not significant	18:00	3:00
Greater kudu	*0.74	p > 0.0005	Highly significant	11:00	12:00
Honey badger	*0.44	p > 0.01	Significant	5:00	1:00 / 22:00
Impala	*0.89	p < 0.0001	Highly significant	10:00	9:00
Lion	*0.44	p > 0.01	Significant	21:00	1:00
Mongoose	-0.02	p > 0.20	Not significant	13:00	22:00
Plains zebra	*0.88	p < 0.0001	Highly significant	10:00	9:00
Serval	0.15	p > 0.20	Not significant	19:00	2:00 / 23:00
Small-spotted genet	*0.78	p > 0.0005	Highly significant	2:00	2:00
Southern giraffe	**0.93	p < 0.0001	Highly significant	13:00	15:00
Spotted hyaena	*0.68	p > 0.0005	Highly significant	0:00	20:00
Warthog	*0.75	p > 0.0005	Highly significant	10:00	13:00

5.3.10 Summary

Herbivores were the most frequently sighted species at both Orpen and Satara water sources, highlighting their well-known water needs. Different species have distinct peak visitation patterns, with herbivores typically diurnal and conversely carnivores being typically nocturnal in their visitation of the water sources. This can largely be attributed to their differences in diet and physiological adaptations and thus their water requirements. Additionally, the influence of predator-prey interactions, herbivores restrict their water source visits to hours of daylight to avoid carnivores. Seasonal visitation patterns vary between species, with highly water-dependent species, with the exception of African buffalo and African elephant at Satara, not showing distinct seasonal visitation patterns, therefore relying on the artificial water sources throughout the wet and dry seasons.

5.4 Relationship between Mammal Visitation, Climate and Astronomical Variables

5.4.1 Introduction

Temperature and rainfall are two important climatic factors that have an influence on mammal behaviour (Skinner & Chimimba, 2005), particularly in semi-arid environments where the availability and distribution of water influences mammal habitat and abundance during the dry season (Chamaillé-Jammes *et al.*, 2007b). Temperature and rainfall conditions, in particular, have an influence on mammal water requirements and their selection and use of water sources during different temporal context (Tefempa *et al.*, 2008). However, this has not been tested in KNP for these specific mammal species. The analysis of relationships between mammal water source visitation patterns and climatic and astronomical factors would serve to fill a knowledge gap on climate-related mammal water source requirements/behaviour.

5.4.1.1 Seasonal Climate and Astronomical Variables for the Study Period

At both study sites sunrise ranged from 4:56 - 6:01 during the wet season and 5:53 - 6:39 during the dry season, with sunset ranging from 17:55 - 18:23 during the wet season and 17:20 - 17:53 during the dry season. Outliers were calculated for temperature, indicating that any value which is higher than the maximum outlier value is considered a maximum extreme, whilst any value which is lower than the minimum outlier value is considered a minimum extreme. Annual rainfall over the study period for Orpen was 356.9mm in 2012 and 811.7mm in 2013. The highest and lowest wet season rainfall for a particular day, ranged from 184.0mm - 0.2mm, respectively, whilst the highest and lowest dry season rainfall for a particular day, ranged from 44.2mm - 0.2mm, respectively. A maximum hourly temperature of 42.9°C was recorded during the 2012 wet season, whilst the lowest hourly minimum temperature (0.7°C) was recorded during the 2013 dry season (*Figure 5.21; Table 5.14*).

Annual rainfall over the study period for Satara was 272.5mm in 2012 and 689.1mm in 2013. The highest and lowest wet season rainfall for a particular day ranged from 153.0mm - 0.1mm, respectively, whilst the highest and lowest dry season rainfall for a particular day ranged from 44.0mm - 2.0mm, respectively) (*Figure 5.22; Table 5.14*). The highest hourly maximum temperature (42.6°C) was recorded during the 2012 wet season, whilst the lowest hourly minimum temperature (3.4°C) was recorded during the 2012 dry season.

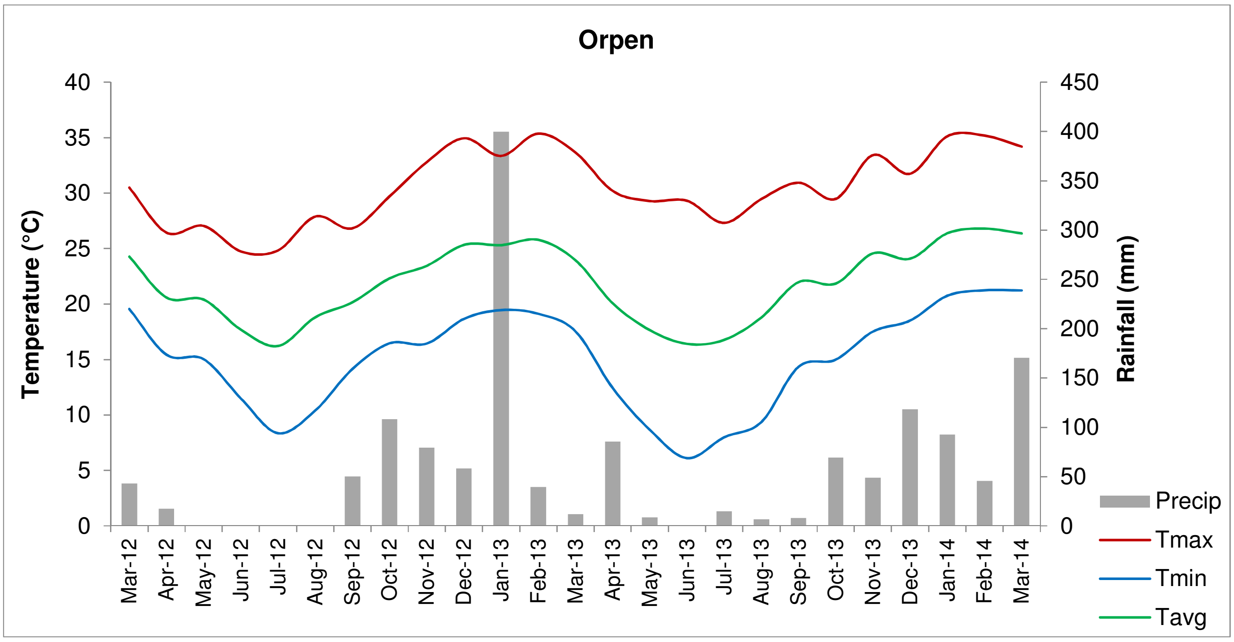


Figure 5.21: Seasonal variation of monthly climate variables at Orpen for the period March 2012 to March 2014.

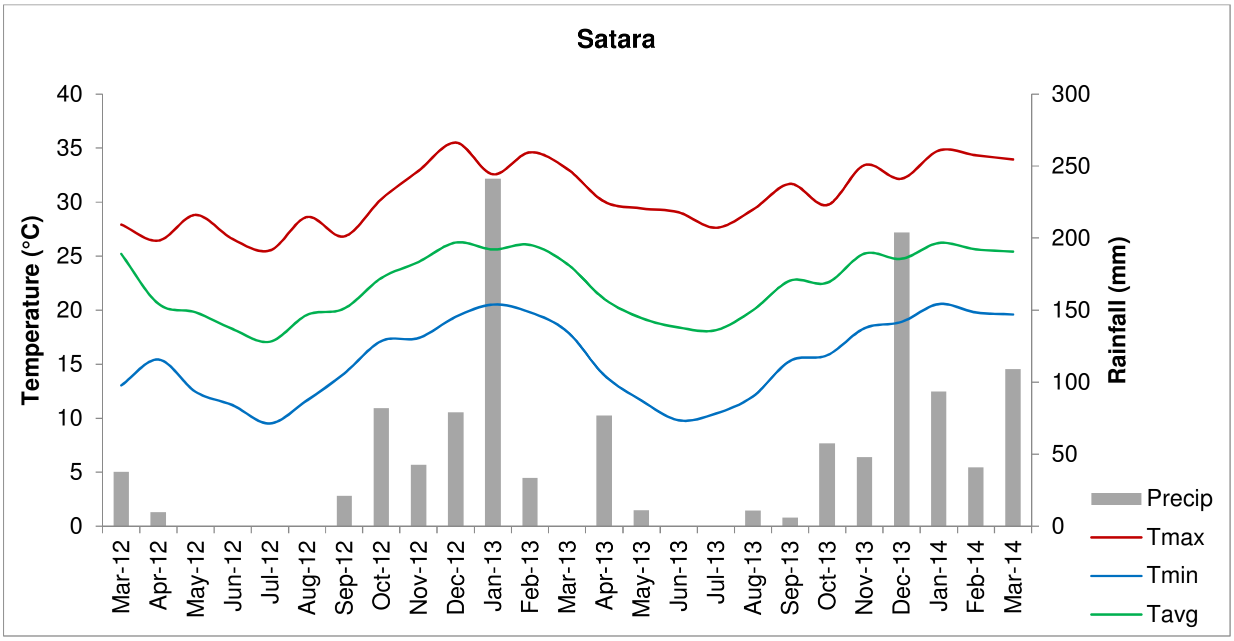


Figure 5.22: Seasonal variation of monthly climate variables at Satara, for the period March 2012 to March 2014.

Table 5.14: Seasonal temperature and rainfall summary statistics for the period March 2012 to March 2014 (Orpen) and April 2012 to March 2014 (Satara).

Seasonal Climate Summary Statistics				
	Dry Season April - September		**Wet Season October - March**	
	Temperature (°C)	**Rainfall (mm)**	**Temperature (°C)**	**Rainfall (mm)**
Orpen				
2012				
Seasonal Average	19.0	8.5	24.3	16.2
Seasonal Maximum	37.4	16.8	42.9	184.0
Seasonal Minimum	1.2	0.5	8.2	0.9
Seasonal Range	36.2	16.3	34.7	183.1
Variance	5.8	6.2	5.9	30.4
Maximum Outlier	> 34.6		> 41.0	
Minimum Outlier	< 3.4		< 7.5	
2013				
Seasonal Average	18.6	12.4	25.0	9.1
Seasonal Maximum	41.6	44.2	42.4	47.6
Seasonal Minimum	0.7	0.2	7.1	0.2
Seasonal Range	40.9	44.0	35.3	47.4
Variance	7.6	16.5	5.8	11.4
Maximum Outlier	> 40.9		> 41.3	
Minimum Outlier	< -4.0		< 8.5	
Satara				
2012				
Seasonal Average	19.1	7.7	24.9	17.7
Seasonal Maximum	37.4	11.5	42.6	53.2
Seasonal Minimum	3.4	4.0	10.3	0.4
Seasonal Range	34.0	7.5	32.3	52.8
Variance	6.1	3.5	5.7	16.7
Maximum Outlier	> 36.5		> 40.9	
Minimum Outlier	< 1.6		< 8.8	
2013				
Seasonal Average	19.9	15.0	25.0	19.1
Seasonal Maximum	41.1	44.0	42.3	153.0
Seasonal Minimum	5.1	2.0	9.4	0.1
Seasonal Range	36.0	42.0	32.9	152.9
Variance	6.8	16.1	5.7	28.3
Maximum Outlier	> 40.4		> 41.3	
Minimum Outlier	< -0.8		< 8.5	

5.4.2 Patterns in Mean Hourly Mammal Water Source Visitation and T_{max}, T_{min} and T_{avg}

Average hourly water source visitation for pooled species for March 2012 to March 2014, exhibit similar patterns, at both water sources. Pronounced peaks of activity occur diurnally, at 10:00 and 11:00 at Orpen (*Figure 5.23*) and at 9:00 at Satara (*Figure 5.24*). Visitation declines prior to the hottest T_{avg} period of the day (from 10:00 onwards) at both water sources, with a continual decrease in visits at Orpen. In contrast, at Satara there is a slight increase in late afternoon visitations (14:00 to 19:00 hours).

Peak sightings occur at 10:00 when the mean temperature is 25°C at Orpen, whilst the mean daily peak temperature (29°C) occurs at 14:00; therefore there is a four-hour lead time between peak sightings and peak temperature. At Satara, peak sightings occur at 9:00 when the mean temperature is 24°C. Mean daily peak temperature (30°C) occurs at 14:00, reflecting a five-hour lead time. Satara shows higher nocturnal visitation compared to Orpen, reflecting the higher percentage (9.15% vs. 3.46%, respectively) of nocturnal species utilising the Satara water trough.

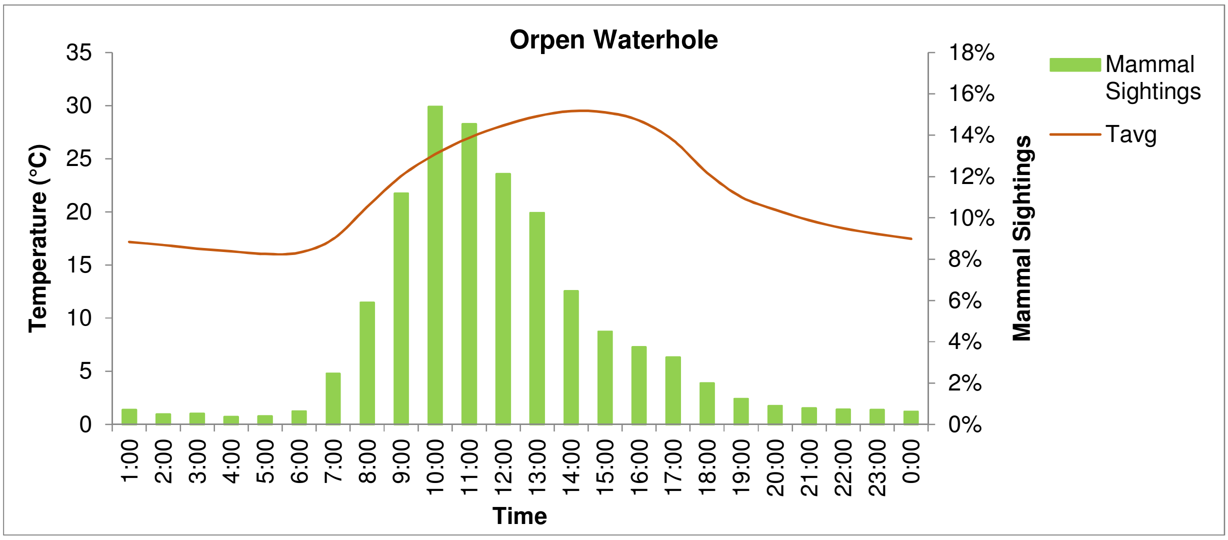


Figure 5.23: Hourly visitation patterns for all species and hourly T_{avg} for the period March 2012 to March 2014 at the Orpen waterhole.

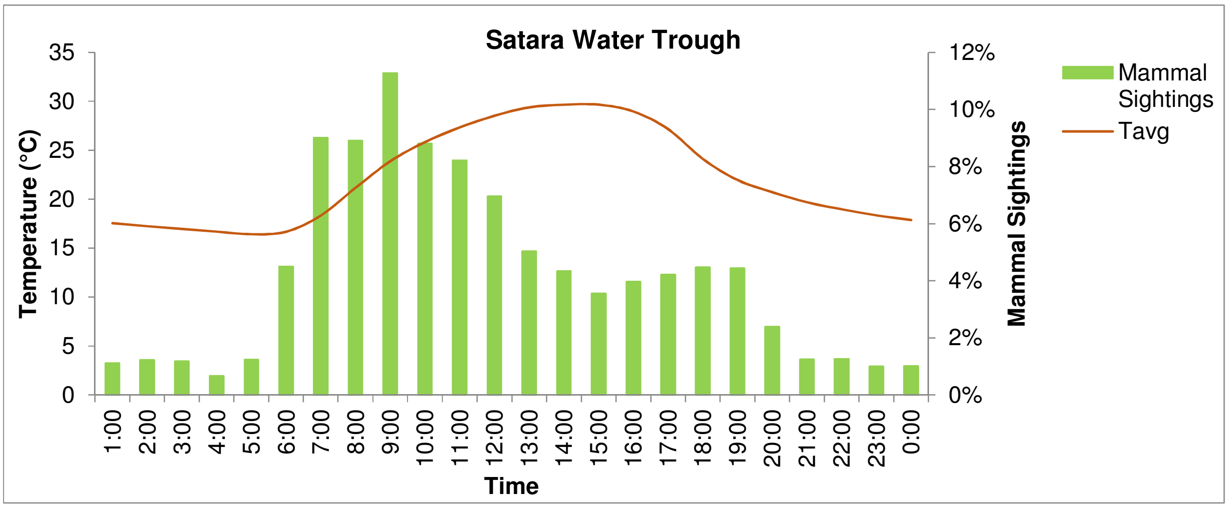


Figure 5.24: Hourly visitation patterns for all species and hourly T_{avg} for the period April 2012 to March 2014 at Satara water trough.

5.4.3 Relationship between Hourly Mammal Visitation Patterns and Temperature Intervals

Mammal visitation behaviour at the water sources seems to be influenced by ambient temperature conditions, and therefore it is important to determine optimal water source visitation periods controlled by specific temperature intervals. Five temperature intervals were chosen according to daily T_{avg}: ≥10°C T_{avg} <15°C, ≥15°C T_{avg} <20°C, ≥20°C T_{avg} <25°C, ≥25°C T_{avg} <30°C, and ≥30°C T_{avg} <35°C. Mammal visitation behaviour in response to T_{avg} intervals was analysed according to feeding guild classifications, herbivores (including primates) and carnivores. The visitation behaviour of carnivores was specifically analysed for the period 17:00 - 0:00.

5.4.3.1 Hourly Mammal Visitation Patterns and Temperature Intervals (Orpen)

Average herbivore visitation trends for the whole period of study at Orpen shift according to daily average temperature intervals (*Figure 5.25*). The peak time/s at which herbivore sightings occur during days with temperatures between 10°C - 15°C are the latest at

11:00 (25% of mammal sightings) and 13:00 (16% of mammal sightings in this interval), indicating a bimodal distribution. There is a shift to earlier peak visitation for days with temperatures between 15°C - 20°C, 20°C - 25°C and between 25°C - 30°C, all at 10:00 (18%, 16% and 14% mammal sightings, respectively) with each of these representing a unimodal distribution. The earliest peak arrivals occur on days with average temperatures between 30°C - 35°C, with two peak visitation times at 8:00 (18% of mammal sightings) and 12:00 (15% of mammal sightings), representing a multimodal distribution. The shift from unimodal to multimodal distributions suggests more variability in visitations between adjacent time units. Therefore, a broad trend towards earlier visitation under warmer temperatures is apparent; except for midday drinking, which may be necessary under extremely hot conditions. Regression analysis quantified these shifts as earlier visitation during the day at a rate of 36 minutes per 5°C increase in mean daily temperature ($r = 0.87$, $p < 0.0001$). However, as the peak visitation time remains at 10:00 for three of the intervals, it would appear that this is the optimal waterhole visitation time period and that only when T_{avg} is <15°C ('cold') or T_{avg} is >30°C ('hot'), do visitation times shift earlier or later.

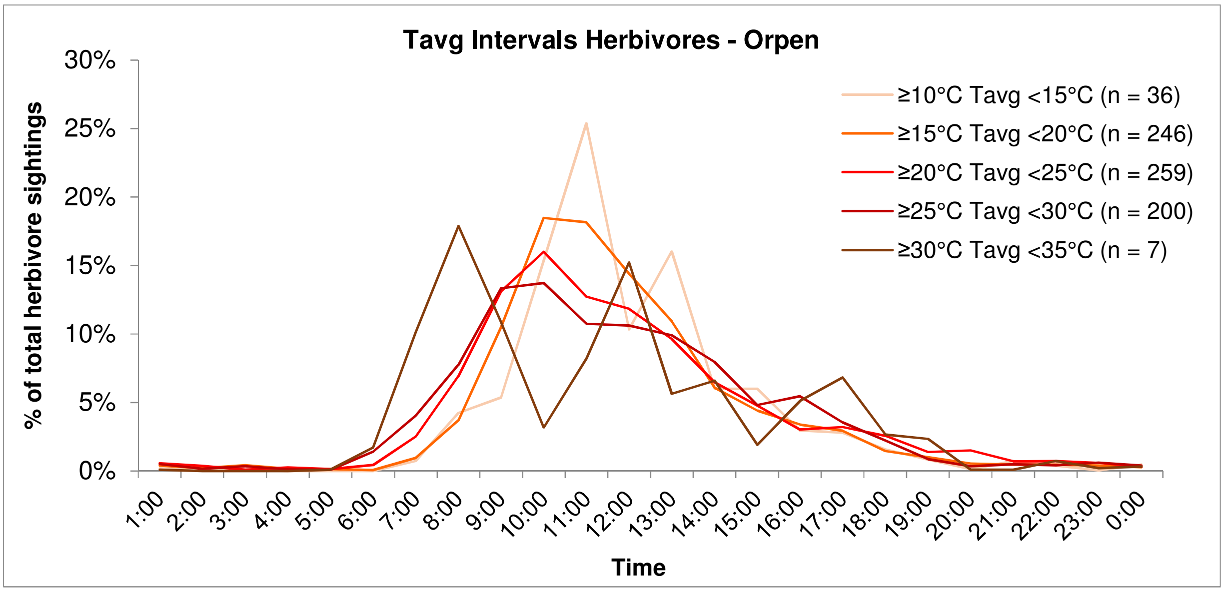


Figure 5.25: Herbivore visitation patterns and temperature intervals based on daily T_{avg} at Orpen, partitioned as a percentage of total daily sightings.

The earliest peak arrivals for carnivores is at 20:00, which occurs on days with average temperatures between 10°C - 15°C (9% of mammal sightings), also with a peak at 0:00 (9% of mammal sightings) and 30°C - 35°C (25% of mammal sightings) (*Figure 5.26*). There is a shift to later peak visitation for days with temperatures between 15°C - 20°C at 21:00 and 23:00 (10% and 8% of mammal sightings), also representing a bimodal distribution and for days with temperatures between 25°C - 30°C (13% of mammal sightings) at 21:00. The latest peak arrival occurs on days with average temperatures between 20°C - 25°C (9% of mammal sightings). Carnivore visitation patterns on all of the days with temperatures between 10°C - 30°C represent multimodal distributions, suggesting greater variability between adjacent time units. Visitation patterns on days with temperatures > 30°C represents a unimodal distribution (*Figure 5.26*). These patterns demonstrate that either side of the optimal bracket (10°C - 20°C), carnivores are shifting their drinking times later into the night by 120 minutes ($r = 0.96$, $p < 0.0001$) per 5°C increase for mean daily temperatures between 10°C - 20°C, and are shifting their drinking times earlier in the night by a 120 minutes ($r = 0.96$, $p < 0.0001$) per 5°C increase in mean daily temperature between 20°C - 30°C.

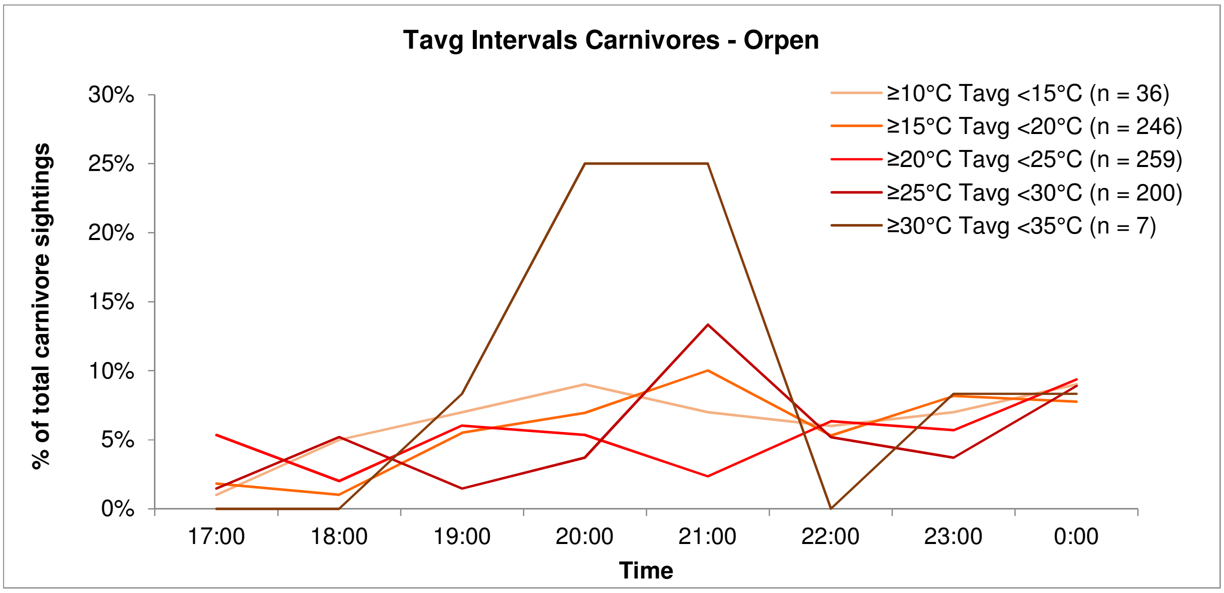


Figure 5.26: Carnivore visitation patterns and temperature intervals based on daily T_{avg} at Orpen, partitioned as a percentage of total daily sightings.

5.4.3.2 Hourly Mammal Visitation Patterns and Temperature Intervals (Satara)

The peak time at which herbivore sightings occur during days with temperatures between 10°C - 15°C is at 17:00 (18% of mammal sightings) (*Figure 5.27*). There is a large shift to earlier peak visitation on days with temperatures between 15°C - 20°C and 20°C - 25°C, both at 09:00 (17% and 16% of mammal sightings, respectively). The earliest shift occurs on days with temperatures between 25°C - 30°C, at 07:00 (14% of mammal sightings). On days with temperatures between 30°C - 35°C, the peak time when herbivores are sighted is at 8:00 (18% of mammal sightings). On days with temperatures between 10°C - 15°C and 30°C - 35°C, herbivore visitation patterns represent multimodal distributions, indicating greater variability between the adjacent time units (*Figure 5.27*). These patterns demonstrate a rate of change of 120 minutes earlier in the day for each 5°C increase in mean daily temperature ($r = 0.79$, $p < 0.05$). However, as the peak visitation time remains at 09:00 for two of the intervals, it would appear that this is the optimal water trough visitation time and that only when T_{avg} is < 15°C or T_{avg} is > 25°C, do visitation times shift earlier and/or later.

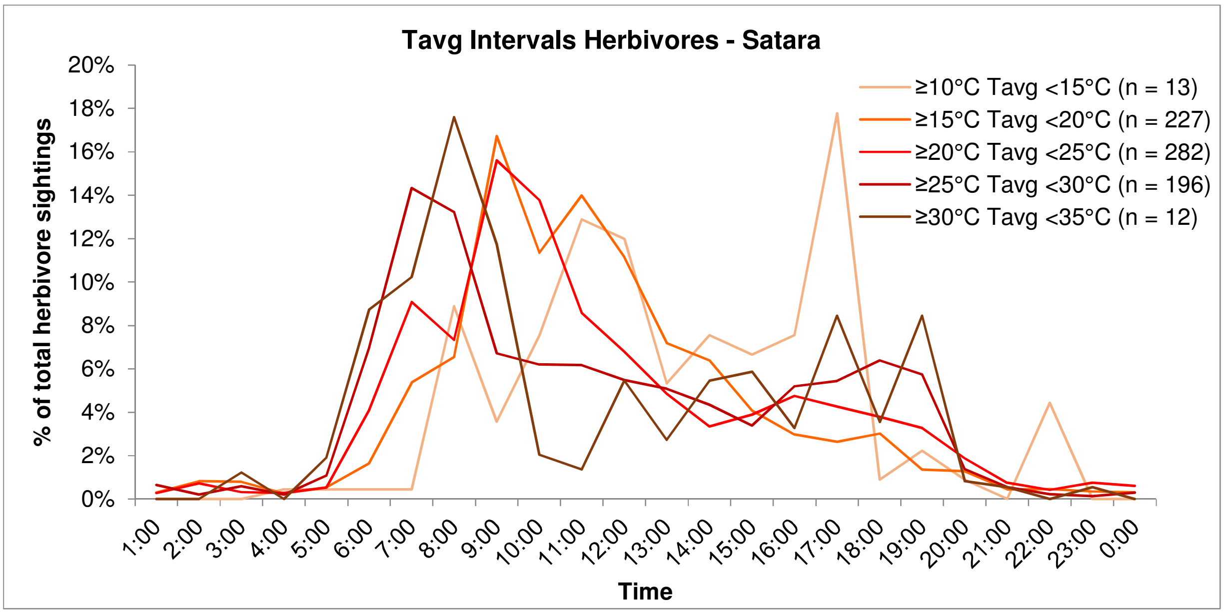


Figure 5.27: Herbivore visitation patterns and temperature intervals based on daily T_{avg} at Satara, partitioned as a percentage of total daily sightings.

The peak time/s of carnivore visitations on days with mean temperatures between 10°C - 15°C and 15°C - 20°C are the earliest at 19:00 (23% and 14% of mammal sightings) (*Figure 5.28*). On days when the temperature is between 20°C - 25°C, 25°C - 30°C and 30°C - 35°C, there is a shift to later visitation, at 20:00 (12%, 12% and 25% of mammal sightings respectively), with these visitation patterns representing bimodal distributions. Regression analysis quantified that carnivore visitation patterns are shifting later into the night by 18 minutes per 5°C increase in mean daily temperature ($r = 0.87$, $p < 0.01$) and under the highest T_{avg} interval the highest percentage (25%) of mammal sightings occur at 20:00. Notably, all peak visitations occur during the early night, and no peak visitations occur during late night.

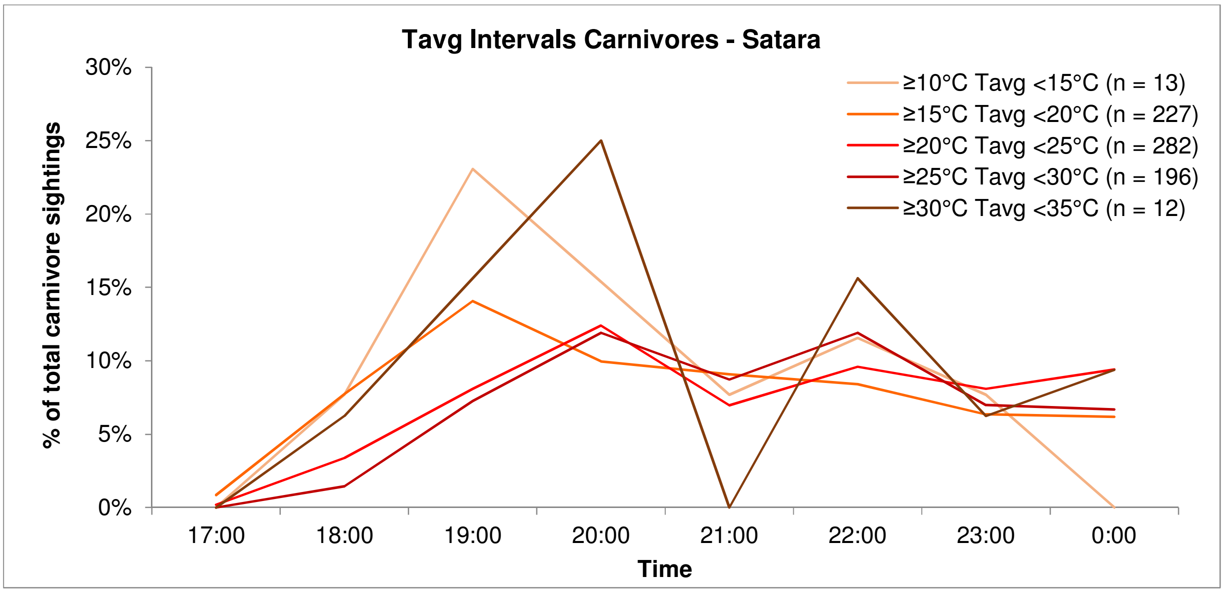


Figure 5.28: Carnivore visitation patterns and temperature intervals based on T_{avg} at Satara, partitioned as a percentage of total daily sightings.

5.4.3.3 Species-Specific Hourly Visitation Patterns and Temperature Intervals (Orpen)

Species-specific responses to changes in temperature may differ according to feeding guild, body size, physiological adaptations and predator-prey interactions. A shift in visitation times is demonstrated for blue wildebeest, warthog and southern giraffe when $T_{avg} \geq 20°C$. Impala exhibit the most extreme response to changing T_{avg} as they shift their visitation times when $T_{avg} \geq 15°C$, whilst plains zebra only shift their visitation times when $T_{avg} \geq 30°C$. African buffalo visit the waterhole during the morning when $T_{avg} \geq 30°C$, whilst African elephant show a clear pattern of avoidance of drinking from the waterhole during midday and the afternoon when T_{avg} is likely the highest, and thus visit the waterhole at dusk when $T_{avg} \geq 30°C$. African buffalo and African elephant, are species which display diurnal, crepuscular and nocturnal waterhole visitation patterns (*Table 5.15; Figure 5.29f,g*), and both of these species were observed using the waterhole for thermoregulation purposes, wallowing and spraying themselves to cool down.

The nocturnal species all have small sample sizes, and thus there are likely to be anomalies. Therefore no conclusions can be stated about any particular shifts in visitation patterns with T_{avg} intervals (*Table 5.15; Figure 5.29h,i,j*). However, these species predominantly display nocturnal visitation patterns and are not influenced by sunlight and consequent high temperatures, they are therefore less influenced by diurnal heat.

Table 5.15: Peak visitation times for each species during the five T_{avg} intervals for Orpen.

Orpen - Peak visitation times at T_{avg} intervals					
	$\geq 10°C\ T_{avg} < 15°C$	$\geq 15°C\ T_{avg} < 20°C$	$\geq 20°C\ T_{avg} < 25°C$	$\geq 25°C\ T_{avg} < 30°C$	$\geq 30°C\ T_{avg} < 35°C$
Wildebeest	11:00 (147)	11:00 (823)	10:00 (1036)	9:00 (1264)	7:00 (114)
Zebra	10:00 (154)	10:00 (826)	10:00 (471)	10:00 (476)	8:00 (49)
Impala	11:00 (968)	10:00 (5403)	10:00 (3419)	10:00 (4311)	8:00 (595)
Warthog	11:00 (377)	11:00 (1838)	10:00 (893)	10:00 (411)	10:00 (37)
Giraffe	13:00 (9)	13:00 (109)	11:00 (62)	12:00 (23)	7:00 (3)
Buffalo	9:00 (122)	18:00 (449)	20:00 (212)	1:00 (109)	8:00 (24)
Elephant	15:00 (87)	11:00 (581)	19:00 (611)	18:00 (346)	19:00 (49)
Civet	20:00 (11)	20:00 (48)	4:00 (10)	1:00 (3)	(0)
Lion	(0)	5:00 (21)	22:00 (22)	21:00 (28)	21:00 (2)
Hyaena	1:00 (26)	5:00 (99)	2:00 (63)	3:00 (29)	21:00 (2)

Regression analysis quantified the shifts for each species' visitation patterns in relation to T_{avg} categories, indicating that all herbivore visitation patterns are shifting significantly earlier during the day, with the exception of African elephant which are shifting their visitation patterns later into the night by 90 minutes per 5°C increase in mean daily temperature ($r = 0.69$, $p < 0.0001$) (*Table 5.16*). For herbivores, African buffalo and African elephant show the greatest temporal shifts in their visitation patterns per 5°C increase in mean daily temperature (*Table 5.16; Figure 5.29f,g*).

Table 5.16: Regression analysis of specific species peak visitation shifts per minute and per 5°C intervals.

Orpen - Regression Analysis					
	Earlier/Later	**Per minute**	**Per 5°C Interval**	**r- value**	**p-value**
Wildebeest	Earlier in the day	12.0	60	0.94	$p < 0.0001$
Zebra	Earlier in the day	4.8	24	0.71	$p < 0.0001$
Impala	Earlier in the day	7.2	36	0.87	$p < 0.0001$
Warthog	Earlier in the day	3.6	18	0.87	$p < 0.0001$
Giraffe	Earlier in the day	15.6	78	0.83	$p < 0.0001$
Buffalo	Earlier in the day	22.8	114	0.38	$p < 0.05$
Elephant	Later in the night	18.0	90	0.69	$p < 0.0001$
Civet	Earlier	87.6	440	0.93	$p < 0.0001$
Lion	Later in the night	56.4	282	0.74	$p < 0.0001$
Hyaena	Later in the night	45.6	228	0.72	$p < 0.0001$

Under the hottest temperature conditions $T_{avg} \geq 30°C$, certain species are utilising the waterhole outside of their previously defined peak visitation range whilst other species are staying within their peak predefined range. Blue wildebeest are shifting their visitation time an hour earlier, from morning to dawn under the hottest T_{avg} conditions. Impala and warthog are shifting their peak visitation period from midday to morning and southern giraffe are shifting their peak visitation period from afternoon to dawn under the hottest T_{avg} conditions. Additionally, African buffalo are shifting their visitation patterns from dusk to morning under the hottest T_{avg} conditions. The majority of herbivores showing this response to the hottest T_{avg} interval are grazers, with the exception of giraffe which are browsers. Spotted hyaena are the only carnivores exhibiting a shift in their visitation patterns under the hottest T_{avg} conditions, shifting their peak time from midnight to early night (21:00).

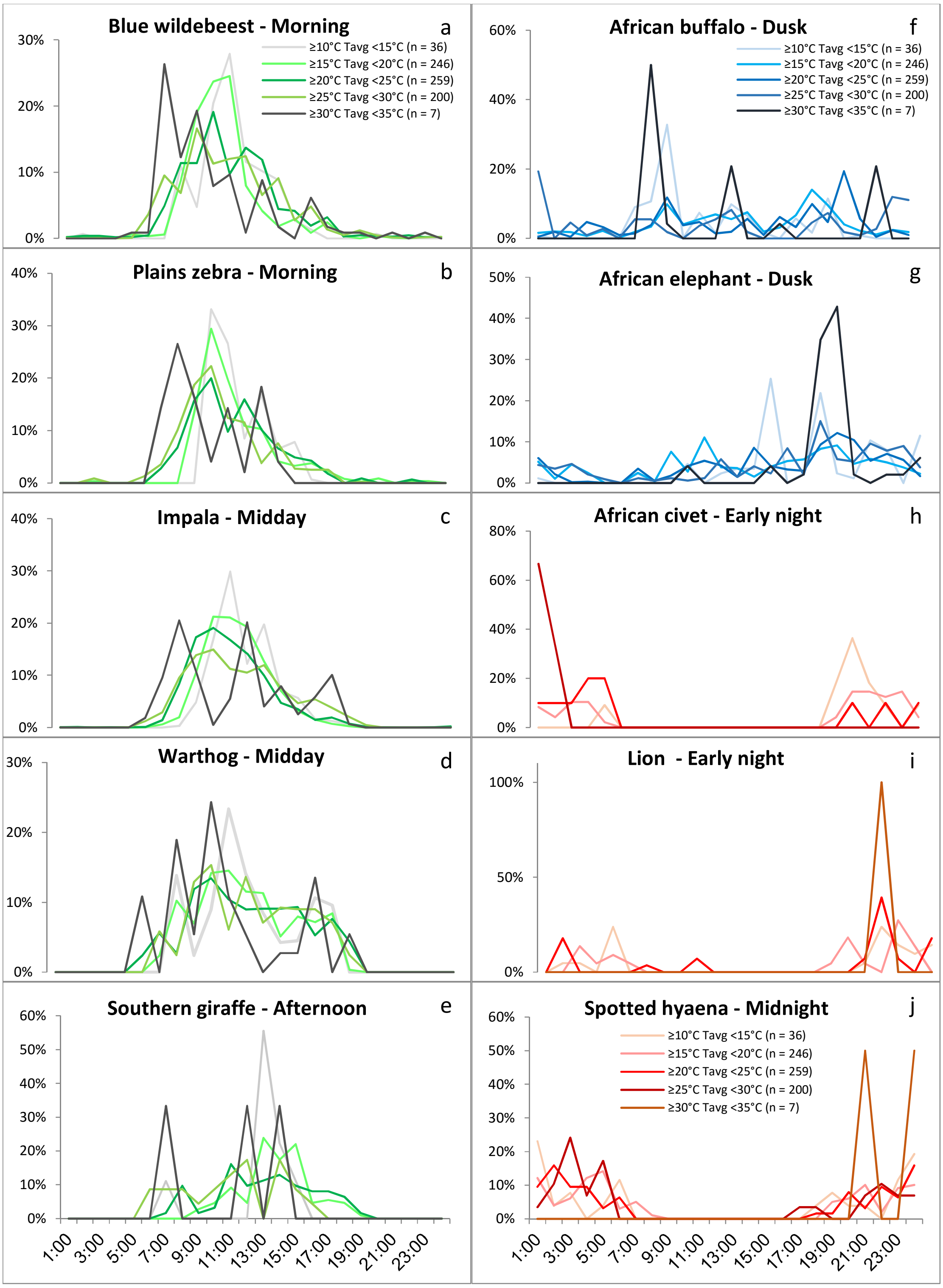


Figure 5.29: Hourly waterhole visitation patterns for each species for each T_{avg} interval for Orpen. Species with clear time preferences selected and categorised according to peak appearance. Herbivores indicated in green, carnivores in red and large herbivores in blue.

5.4.3.4 Species-Specific Hourly Visitation Patterns and Temperature Intervals (Satara)

At Satara, an earlier shift in visitation times is demonstrated for plains zebra and greater kudu when $T_{avg} \geq 20°C$. Impala show the most extreme shift in their visitation patterns when T_{avg} is $\geq 15°C$ showing that with increased T_{avg} these species are drinking from the water trough earlier in the day (*Table 5.17*). Blue wildebeest exhibit two large temporal shifts in response to changing T_{avg} intervals, shifting their visitation times from late at night (22:00) during $T_{avg} \geq 10°C$ to midday during $T_{avg} \geq 15°C$, and additionally shifting their visitation earlier during the day when $T_{avg} \geq 20°C$ (*Figure 5.30d; Table 5.17*). Chacma baboon and African buffalo only shift their visitation patterns in response to $T_{avg} \geq 25°C$ and $\geq 30°C$, respectively (*Table 5.17*).

African elephant, spotted hyaena and lion, which have predominantly dusk and nocturnal visitation habits, do not exhibit a clear pattern with T_{avg} intervals. African elephant show avoidance behaviour during times of the day when T_{avg} was likely the highest (*Figure 5.30g*). Thus suggesting that they avoid open areas during hot conditions as they are not able to withstand high temperatures, but are able to protect themselves against predation (Ayeni, 1975). Consequently demonstrating their peak nocturnal visitation patterns.

Variable species' responses are thus noted to T_{avg} intervals, with water dependent herbivores (particularly grazers, with the exception of southern giraffe at Orpen and greater kudu at Satara) displaying shifts in their behaviour to avoid heat. Carnivores are not displaying a clear response to T_{avg} intervals, however, their visitation patterns are multimodal in distribution, indicating variability between the adjacent time units.

Table 5.17: Peak visitation times for each species during the five T_{avg} intervals for Satara.

Satara - Peak visitation time at T_{avg} intervals					
	≥ 10°C T_{avg} < 15°C	≥ 15°C T_{avg} < 20°C	≥ 20°C T_{avg} < 25°C	≥ 25°C T_{avg} < 30°C	≥ 30°C T_{avg} < 35°C
Buffalo	20:00 (4)	7:00 (263)	19:00 (180)	20:00 (140)	7:00 (28)
Impala	17:00 (114)	9:00 (1430)	9:00 (1464)	8:00 (2349)	8:00 (462)
Baboon	(0)	9:00 (112)	9:00 (99)	8:00 (166)	8:00 (22)
Wildebeest	22:00 (15)	11:00 (1156)	7:00 (1452)	7:00 (1763)	7:00 (158)
Zebra	12:00 (84)	9:00 (1321)	10:00 (826)	7:00 (773)	6:00 (28)
Kudu	(0)	14:00 (64)	12:00 (62)	12:00 (19)	12:00 (10)
Elephant	22:00 (4)	17:00 (61)	18:00 (97)	12:00 (175)	19:00 (18)
Hyaena	4:00 (8)	19:00 (238)	20:00 (171)	20:00 (79)	5:00 (11)
Lion	(0)	1:00 (7)	1:00 (43)	2:00 (53)	22:00 (7)
Civet	(0)	20:00 (30)	1:00 (22)	2:00 (7)	(0)

Regression analysis quantified that blue wildebeest and impala exhibit the greatest temporal shifts. These species drink earlier during the day by 204 minutes ($r = 0.83$, $p < 0.0001$) and 114 minutes ($r = 0.78$, $p < 0.0001$) per 5°C increase in mean daily temperature (*Table 5.18*).

Table 5.18: Regression analysis of specific species peak visitation shifts per minute and per 5°C intervals.

Satara - Regression analysis of specific species peak visitation shifts at T_{avg} intervals					
	Earlier/Later	**Per minute**	**Per 5°C Interval**	**r- value**	**p-value**
Buffalo	Earlier	15.6	78	0.29	$p > 0.05$
Impala	Earlier	22.8	114	0.78	$p < 0.0001$
Baboon	Earlier	4.8	24	0.89	$p < 0.0001$
Wildebeest	Earlier	40.8	204	0.83	$p < 0.0001$
Zebra	Earlier	16.8	84	0.93	$p < 0.0001$
Kudu	Earlier	7.2	36	0.77	$p < 0.0001$
Elephant	Earlier	13.2	66	0.48	$p < 0.05$
Hyaena	Later	3.6	18	0.05	$p > 0.05$
Lion	Later	76.8	384	0.80	$p < 0.0001$
African civet	Earlier	108.0	540	0.84	$p < 0.0001$

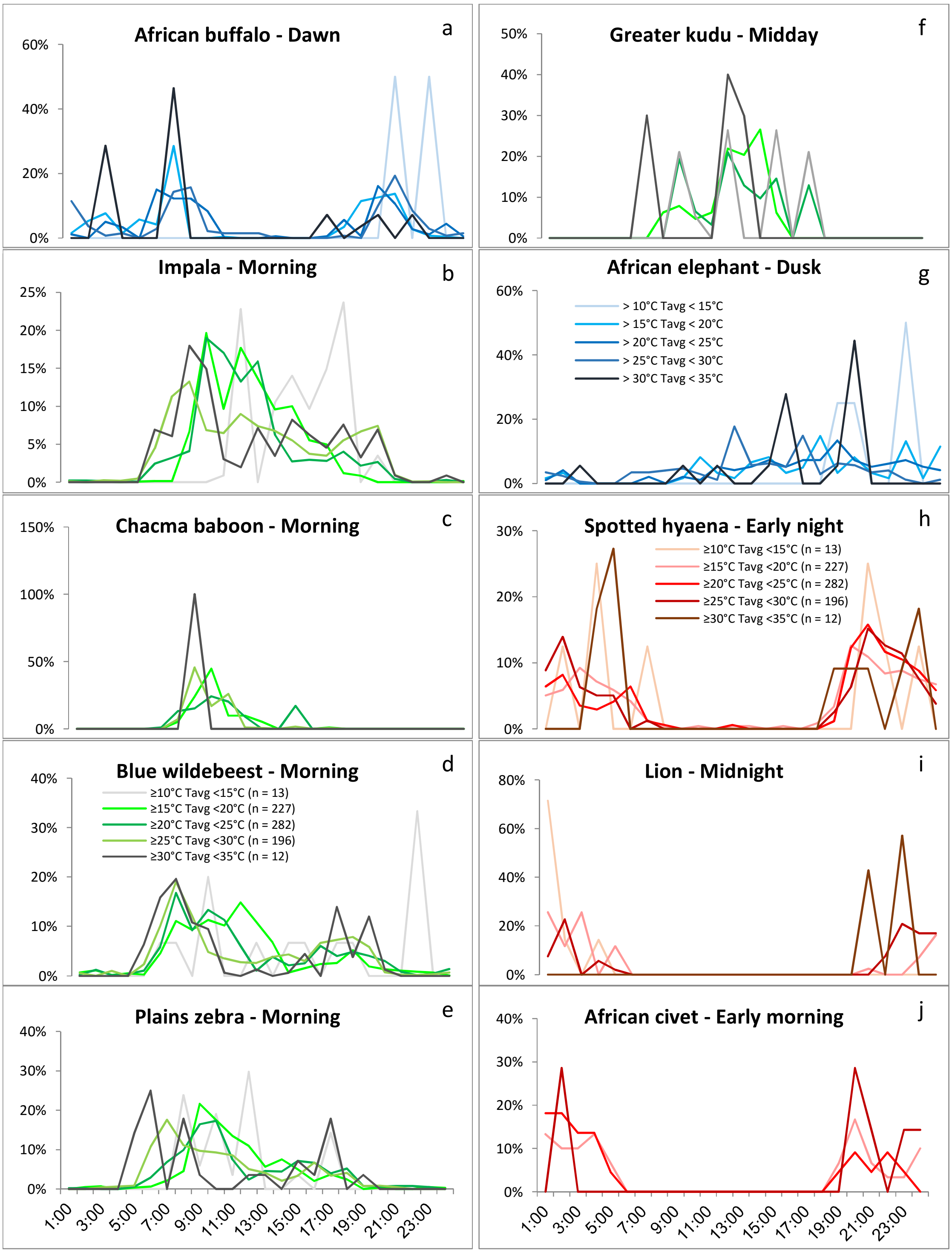


Figure 5.30: Hourly waterhole visitation patterns for each species for each T_{avg} interval for Satara. Species with clear time preferences selected and categorised according to peak appearance. Herbivores indicated in green, carnivores in red and large herbivores in blue.

Most of the species at Satara are drinking from the water trough within their range under the hottest T_{avg} interval, however, blue wildebeest and plains zebra show a shift from their peak predefined visitation period, from morning to dawn. Southern giraffe show a shift to later in the day, from midday to dusk.

5.4.4 Relationship between Peak Visitation and Temperature

5.4.4.1 Peak Visitation and Temperature

Various factors influence mammal visitation at water sources, and consequently the probability of visitation will be determined by the proximity to other available water sources, surrounding vegetation, water-dependence, ambient temperature, rainfall, species avoidance, competition and associations as well as the hour of day (Young, 1970). It is therefore important, at a finer scale, to examine relationships between the peak visitation by various mammals and all temperatures, rather than for broad temperature classes/intervals, to determine how mammals are responding to temperature as a driver of behaviour.

This section examines the relationship between the number of individuals per mammal species at their peak visitation time with daily T_{max}, T_{min} and T_{avg}, to determine whether: 1) fewer mammals visit the water sources on hotter days or 2) more mammals visit the water sources on hot days due to their water requirements. Negative r-values indicate that fewer individuals per species are drinking from the water sources on hot days whilst positive r-values indicate that more individuals per species are drinking from the water sources on hot days. The majority of mammals demonstrate weak, negative relationships between the number of individuals at peak visitation and T_{max}, T_{min} and T_{avg} (*Table 5.19*).

The most significant correlations are shown for T_{min} whilst the least significant correlations are shown for T_{max} (*Table 5.19*). There is, however, no clear pattern indicating whether a specific feeding guild is responding to a particular temperature variable. There is one significant, negative relationship between the number of individuals at peak visitation and

T_{min} at Satara, for African civet (r = -0.20). However, at Orpen significant, negative relationships between the number of individuals at peak visitation and T_{max}, T_{min} and T_{avg} are found for African civet, common duiker, and warthog (*Table 5.19*). Black-backed jackal and vervet monkey both exhibit significant negative relationships with T_{min} and T_{avg}.

Table 5.19: Pearson's correlation between number of individuals at peak visitation and daily T_{max}, T_{min} and T_{avg}. Significant positive relationships tested at the 95% level, highlighted in light green and significant negative relationships tested at the 95% level, highlighted in light red.

	Orpen			**Satara**		
	No. of Individuals at Peak Visitation			**No. of Individuals at Peak Visitation**		
Mammal	**T_{max}**	**T_{min}**	**T_{avg}**	**T_{max}**	**T_{min}**	**T_{avg}**
African wild cat	-	-	-	0.10	0.00	0.08
African civet	-0.22	-0.25	-0.28	-0.06	-0.20	-0.14
Black-backed jackal	-0.14	-0.29	-0.23	-0.01	-0.06	-0.03
Honey badger	-0.05	-0.12	-0.11	-	-	-
Leopard	-0.05	-0.12	-0.10	-	-	-
Lion	0.05	0.04	0.05	0.15	0.11	0.17
Mongoose	0.02	-0.01	-0.01	-0.01	0.01	-0.01
Small-spotted genet	-0.04	-0.04	-0.05	0.09	0.06	0.09
Spotted hyaena	-0.08	-0.22	-0.16	-0.07	-0.14	-0.11
Common duiker	-0.27	-0.32	-0.33	0.01	-0.13	-0.04
Greater kudu	0.00	-0.24	-0.11	0.02	-0.10	-0.04
Southern giraffe	-0.07	-0.15	-0.12	0.01	-0.06	-0.03
African buffalo	-0.13	-0.17	-0.17	-0.03	-0.07	-0.05
Blue wildebeest	0.13	0.03	0.11	0.14	0.05	0.10
Plains zebra	0.01	-0.20	-0.11	-0.06	-0.14	-0.11
Warthog	-0.24	-0.39	-0.36	0.06	-0.08	0.00
African savanna elephant	-0.02	-0.06	-0.04	0.13	0.17	0.17
Impala	0.09	-0.21	-0.04	0.16	0.00	0.12
Chacma baboon	0.04	0.00	0.03	0.10	0.04	0.09
Vervet monkey	-0.13	-0.20	-0.21	-	-	-

The weak significant relationships between the number of individuals of each species visitation during peak visitation and temperature are likely driven by various mechanisms, such as herd size, predator/prey relationships, species associations and habitat. There is only one significant relationship between the number of individuals at peak visitation across all species and temperature at Satara, compared to Orpen, where there are more significant relationships between the number of individuals at peak visitation and temperature, particularly with T_{min}.

5.4.5 Relationship between Monthly Visitation Patterns per Mammal Species and Monthly T_{avg}

Temperature and rainfall vary seasonally, typically influencing mammal visitation patterns to water sources. It is therefore important to statistically test whether visitation patterns are climate-related for specific mammal species and whether these patterns differ between and within seasons, linking together changes in temperature, rainfall and the length of day.

Similar monthly water source visitation patterns are identified for Orpen and Satara in relation to monthly T_{avg} (*Table 5.20; Table 5.21*). The direction of the relationship between hourly visitation patterns and hourly T_{avg} has a distinct split between herbivores and carnivores. Broadly, positive relationships exist between hourly visitation numbers and hourly T_{avg} per month for the majority of herbivores, whilst negative relationships exist for all carnivores. This split between the two feeding guilds suggests that these visitation patterns are largely influenced by these species' physiological water-dependency. Furthermore, the correlations between hourly average temperature and hourly visitation patterns, vary by month, with higher visitation rates during winter likely related to reduced water availability during the season (Valeix *et al.*, 2009a) and with low temperatures not being a major controlling variable.

The results presented in *Table 5.20* indicate that carnivores have a negative association between their hourly visitation patterns and hourly T_{avg} per month, indicating that their hourly visitations per month decrease with higher hourly T_{avg}. Conversely, herbivores typically exhibit a positive association between their hourly visitation patterns and hourly

T_{avg} per month, indicating that that their hourly visitations per month increase with higher T_{avg}.

The strongest relationships with T_{avg} and hourly visitation are recorded for all species for the months of March to August, which are in the dry season, when mammals are largely reliant on artificial water sources as well as during spring, (particularly exhibited by carnivores). Orpen has stronger relationships than Satara, likely explained by the proximity of the latter water trough to two seasonal rivers, which mammals may preferentially visit if water is available. At Satara carnivores show a higher number of significant relationships compared to carnivores at Orpen (*Table 5.20; Table 5.21*), and at Satara, herbivores have fewer significant relationships than at Orpen.

At Orpen, impala and warthog have the strongest, significant relationships between visitation patterns and $T_{avg,}$ for most of the months, thus indicating a consistent diurnal visitation pattern, largely independent of rainfall and species-associations (*Table 5.20*). At both Orpen and Satara, greater kudu and southern giraffe have more significant relationships with monthly T_{avg} during the dry season, indicating that their visitation patterns increase with higher T_{avg}, and low rainfall may additionally drive these patterns during such months. Vervet monkey and baboon show erratic relationships with T_{avg} across all months. Mega-herbivores, African buffalo and African elephant show the least number of very strong relationships with T_{avg}. At both Orpen and Satara, spotted hyaena have strong relationships between visitation patterns and T_{avg} across the majority of months analysed, as they visit the waterhole for a variety of different reasons (cooling off and caching meat), other than to access drinking water. Black-backed jackal and African civet exhibit erratic significant relationships with seasonal T_{avg}. These relationships between hourly T_{avg} and hourly visitation patterns per month, exhibit patterns which are likely influenced by underlying physiology and behaviour, as well as conditions that typify each season, thus reflecting responses which are driven by different climate variables, and consequently the availability and distribution of water.

Table 5.20: Pearson's correlation between hourly T_{avg} and average hourly number of individuals per species per month. Weak correlations indicated in light pink/green colour, strong correlations indicated in the medium pink/green colour, very strong correlations indicated by the darkest pink/green colour. Significant correlations indicated by an asterisk (*).

Orpen	**African civet**	**Black-backed jackal**	**Honey badger**	**Leopard**	**Lion**	**Small-spotted genet**	**Spotted hyaena**	**Common duiker**	**Greater kudu**	**Southern giraffe**	**African buffalo**	**Blue wildebeest**	**Plains zebra**	**Warthog**	**African elephant**	**Impala**	**Chacma baboon**	**Vervet monkey**
Mar-12	-	-0.43	-	-0.20	-0.01	-0.21	-0.12	-	0.49	0.31	0.04	0.30	0.22	0.71*	0.40	0.49	0.35	-
Apr-12	-0.35	-0.25	-	-0.31	-	-0.34	-0.34	-	0.51*	0.10	-0.22	0.58*	0.41	0.80*	0.15	0.54*	0.25	0.13
May-12	-0.55*	-0.13	0.00	-0.16	-0.12	-0.29	-0.42	-0.12	0.76*	0.34	-0.02	0.42	0.59*	0.81*	0.17	0.68*	0.15	0.67*
Jun-12	-0.41	-0.50*	-0.24	-0.30	-0.22	-0.48	-0.52*	-0.05	0.55*	0.64*	0.45	0.26	0.47	0.77*	0.25	0.59*	0.48	0.50*
Jul-12	-0.28	-0.49	-0.39	-0.16	-	-0.37	-0.40	-0.42*	0.61*	0.31	0.28	0.35	0.37	0.65*	-0.01	0.52*	0.50*	0.66*
Aug-12	-0.30	-0.65*	-0.34	-0.37	-	-	-0.75*	-0.16	0.66*	0.59*	0.40	0.39	0.45	0.65*	0.24	0.54*	0.30	0.46
Sep-12	-	-0.07	-	-	-	-	-0.21	0.09	0.56*	0.54*	0.20	0.55*	0.25	0.36	0.19	0.55*	0.45	0.33
Oct-12	-	-0.26	-0.35	-0.20	-	-	-0.38	-0.24	0.34	-	0.06	0.30	-	0.57*	-0.35	0.39	0.29	0.34
Nov-12	-	-0.26	-0.25	-0.12	-	-	-0.06	-	0.32	-	0.19	0.39	0.51*	0.49	0.31	0.59*	0.26	-
Dec-12	-	-	-0.17	-	-	-	-0.37	-	0.29	-	-0.27	0.30	0.41	0.35	0.02	0.62*	0.41	0.52*
Jan-13	-	-0.03	-	-0.17	-0.19	-	-0.38	-	0.46	0.15	-0.13	0.44	0.15	0.71*	0.19	0.62*	0.52*	0.21
Feb-13	-	-	-	-	-	-0.22	-0.34	-	0.32	-	-0.30	0.54*	0.49	0.69*	-0.17	0.79*	0.41	-
Mar-13	-	-0.26	-0.42	-	-0.21	-	-0.27	-	0.31	0.31	-0.25	0.39	0.54*	0.64*	-0.23	0.46	0.45	0.31
Apr-13	-	-0.40	-0.19	-0.18	-	-	-0.47	-	0.41	0.12	-0.30	0.55*	0.57*	0.78*	0.10	0.56*	0.51*	0.18
May-13	-0.28	-0.29	-	-0.19	-	-0.15	-0.25	-	0.40	0.59*	-0.07	0.41	0.50*	0.79*	-0.26	0.60*	0.62*	0.53*
Jun-13	-0.22	-0.35	-0.29	-0.36	-	-0.19	-0.41	-0.21	0.67*	0.56*	0.29	0.47	0.59*	0.69*	-0.29	0.69*	0.51*	0.51*
Jul-13	-0.22	-0.40	-0.15	-0.36	-0.16	-0.08	-0.33	0.10	0.53	0.59*	0.55*	0.56*	0.52*	0.59*	0.37	0.67*	0.58*	0.48
Aug-13	-	-0.68*	-0.27	-0.03	-0.26	-0.19	-0.44	-0.27	0.56*	0.54*	-0.03	0.40	0.27	0.36	0.38	0.56*	0.43	0.21
Sep-13	-0.40	-0.31	-0.56*	-0.30	-0.19	-	-0.53*	-0.28	0.78*	0.57*	0.36	0.26	0.49	0.25	-0.40	0.38	0.04	0.34
Oct-13	-0.32	-0.47	-0.29	-	-	-	-0.30	-0.30	0.61*	0.64*	0.03	0.03	0.39	0.12	0.35	0.24	0.38	0.14
Nov-13	-	-0.41	-	-	-0.20	-0.14	-0.26	-	0.59*	0.25	-0.16	0.17	0.09	0.77*	0.09	0.53*	0.42	0.14
Dec-13	-	-0.38	-0.26	-0.31	-0.34	-0.19	-0.46	-	0.50*	-	0.00	0.28	0.44	0.73*	0.08	0.54*	0.74*	-
Jan-14	-0.20	-	-0.32	-	0.12	-	-0.40	-	0.32	-	-	0.32	0.29	0.47*	-0.31	0.71*	0.52*	0.38
Feb-14	-	-0.24	-0.10	-0.10	-0.29	-0.21	-	-	-	-	0.07	0.61*	0.44	0.81*	-0.25	0.79*	0.61*	0.29
Mar-14	-	-	-	-	-0.13	-0.22	-	-	0.23	-	-	0.21	0.52*	0.64*	0.03	0.66*	0.62*	0.35

Table 5.21: Pearson's correlation between hourly T_{avg} and average hourly number of individuals per species per month. Weak correlations indicated in light pink/green colour, strong correlations indicated in the medium pink/green colour, very strong correlations indicated by the darkest pink/green colour. Significant correlations indicated by an asterisk (*).

Satara	African civet	African wild cat	Black-backed jackal	Lion	Small-spotted genet	Spotted hyaena	Common duiker	Greater kudu	Southern giraffe	African buffalo	Blue wildebeest	Plains zebra	Warthog	African elephant	Impala	Chacma baboon
Apr-12	-	-	-0.24	-	-	-0.33	-	0.60*	0.68*	-0.27	0.15	0.39	0.25	0.48	0.48	0.28
May-12	-	-	-0.36	-0.30	-0.15	-0.48	-	0.37	0.64*	-0.26	0.18	0.38	0.40	0.16	0.48	0.21
Jun-12	-	-0.20	-0.07	-0.22	-	-0.19	-0.24	0.29	0.33	-0.31	0.23	0.51*	0.33	-0.07	0.67*	-0.18
Jul-12	-	-0.23	-0.34	-0.23	-	-0.56*	-0.37	0.39	0.29	-0.32	0.38	0.37	-	0.48	0.63*	-0.07
Aug-12	0.00	-0.37	-0.51*	-	-	-0.60*	-0.30	0.32	0.32	-0.26	0.15	0.41	-	0.52*	0.36	-0.15
Sep-12	-	-0.20	-0.19	-	-	-0.30	-	-	-	-0.01	0.17	0.31	-	0.19	0.50*	-0.07
Oct-12	-0.24	-0.30	-0.23	-	-	-0.30	-	-	0.20	-0.25	-0.01	0.17	-	0.35	0.21	-0.15
Nov-12	-	-	-0.36	-0.19	-	-0.51*	-	-	-	-0.23	-0.11	0.07	-	0.41	0.42	0.03
Dec-12	-	-0.26	-0.40	-	-	-0.49	-	-	-	-0.28	-0.08	0.06	-	0.20	0.49	-0.06
Jan-13	-	-	-0.52*	-0.21	-	-0.22	-	-	0.22	-0.08	-0.18	0.26	-	0.50*	0.32	-0.01
Feb-13	-	-0.25	-0.34	-	-	-0.49	-	-	-	0.04	0.46	0.17	-	-0.04	0.68*	0.19
Mar-13	-	-0.03	-0.68*	-	-0.23	-0.52*	-	-	0.35	-	0.17	0.18	-	0.39	0.58*	0.11
Apr-13	-	-0.30	-0.23	-0.20	-0.23	-0.51*	-	-	0.40	-0.21	0.47	0.58*	-	0.13	0.60*	0.32
May-13	-0.32	-	-0.42	-	-	-0.33	-	0.34	0.24	-0.09	0.13	0.58*	-	0.32	0.50*	0.17
Jun-13	-0.54*	-0.27	-0.61*	-	-0.32	-0.42	-	0.13	0.52*	-0.26	0.16	0.47	0.26	-0.01	0.63*	0.23
Jul-13	-0.50*	-0.53*	-0.47	-	-0.26	-0.57*	-	0.31	-	-0.17	0.31	0.25	0.68*	-0.15	0.40	0.10
Aug-13	-0.41	-0.40	-0.22	-	-	-0.16	-0.42	0.43	0.01	-0.17	0.02	0.24	0.70*	-0.20	0.38	-0.01
Sep-13	-0.30	-0.59*	-0.37	-0.26	-0.16	-0.27	-0.41	0.42	0.31	-0.09	-0.27	0.15	0.06	-0.04	0.34	-0.05
Oct-13	-0.28	-0.23	-0.04	-0.26	-0.46	-0.33	-0.20	-	0.24	-0.16	-0.22	0.37	-0.05	0.04	0.57*	0.02
Nov-13	-0.26	-0.15	-0.70*	-0.36	-0.31	-0.34	-0.24	0.36	-	-0.34	0.50*	0.23	-	0.48	0.75*	-0.01
Dec-13	-0.24	-0.43	-0.67*	-0.33	-0.51*	-0.47	-	-	0.30	-0.16	0.18	0.35	-0.21	0.41	0.13	-0.11
Jan-14	-0.22	-0.31	-0.63*	-0.43	-0.30	-0.48	-	-	-	-	0.02	0.09	0.37	0.02	0.03	0.20
Feb-14	-	-0.35	-0.10	-0.26	-	-0.32	-	-	0.14	-0.23	0.30	0.42	0.23	0.06	0.42	0.25
Mar-14	-	-	-0.54*	-0.25	-	-0.30	-	-	0.43	-0.23	0.29	0.25	-	-0.09	0.10	0.19

5.4.6 Relationship between the Timing of Rainfall Events and Total Daily (Pooled) Mammal Sightings

During the wet season, herbivore populations disperse into different habitats as water availability increases due to an increase in rainfall (Valeix *et al.*, 2010). It is therefore important to establish what the response of mammals is to the timing of rainfall events: 1) during rainfall, 2) after rainfall, and 3) during periods not linked to a rainfall event (days before rainfall). From the webcam images it was observed that large pools of water formed after a rainfall event, providing temporary sources of water to mammals. In addition, it is important to establish species-specific responses to the presence and absence of rainfall, and thus the volume of rainfall which determines the formation of temporary pools of water. These responses would determine whether specific species exhibit preferential or avoidance behaviour. The results of the regression and correlation analyses between the number of individuals for all mammal species (pooled species) and daily rainfall indicate that mammal sightings are highest before and on days of rainfall, whilst average mammal sightings are lowest 1 and 2 days after rainfall (*Table 5.22*). For both Orpen and Satara, a comparison of means test between days before and on rainfall and days after rainfall indicates that the mean of pooled species visitation on days before and on the day of rainfall is significantly larger than the mean of pooled species visitation on days after rainfall ($z = 5.74$; $p < 0.0001$) and ($z = 5.36$; $p < 0.0001$, respectively).

Pearson's correlation of daily rainfall and daily total number of individual mammal species 2 days before a rainfall event at Orpen and 1 day before a rainfall event at Satara, show weak, negative relationships, as mammals are more reliant on the water sources during these dry periods. Pearson's correlation of daily rainfall and daily total mammal sightings show stronger relationships for 1 day after ($r = -0.10$ at Orpen; $r = -0.18$ at Satara) and 2 days after ($r = -0.20$ at Orpen; $r = -0.14$ at Satara) rainfall events, with negative relationships indicating that fewer mammals visit the water sources on days with higher rainfall amounts. These relationships can be attributed to pools of water, which occur when daily rainfall is > 15mm, (observed from the webcam images), and thus mammals are able to drink from these temporary sources of water which occur naturally. Mammals are thus less reliant on the artificial water sources during these periods. The pools of water which formed were largely dependent on the volume of rainfall received during previous events and temporary pools were generally observed to dry within two days of a rainfall event. The relationships between rainfall and mammal numbers are weak for days before rainfall and on the day of rainfall (*Table 5.22*), however, days after rainfall show higher correlation values, with stronger negative relationships shown between the total number of individual mammal species sightings and 2 days after rainfall at Orpen, and similarly, this relationship is also noted for 1 day after rainfall at Satara.

The highest average mammal sightings are recorded 2 days before rainfall, with a decrease in average sightings during and after rainfall events, thus, explaining a possible preference for drinking from natural water sources or temporary pools of water, which become available after rainfall events. The weak correlations between the total number of individual mammal species and rainfall events could be explained by the high number of permanent water sources in this environment, therefore mammal water requirements and their relative water source visitation patterns are less constrained by this climatic variable, compared to temperature. The significant negative correlation between pooled daily number of individual mammal sightings and days after rainfall, suggests that it is important to investigate species-specific responses to the timing of rainfall events and the presence and absence of rainfall.

Table 5.22: Average total number of individual mammal species sightings and relationships between days before and after rainfall and on rainfall days for all mammal species at Orpen and Satara. Pearson's correlation between sightings and rainfall for each timing category, negative relationships are highlighted in light orange and positive relationships are highlighted in light green. Significant negative relationships are highlighted in dark orange. Significance tested at the 95% level.

Orpen					
	2 days before	1 day before	Day of rainfall	1 day after	2 days after
Avg Sightings	38	34	22	11	17
Sightings and rainfall (r)	-0.04	0.03	-0.01	-0.10	-0.20
Satara					
	2 days before	1 day before	Day of rainfall	1 day after	2 days after
Avg Sightings	32	27	26	10	8
Sightings and rainfall (r)	0.02	-0.08	-0.11	-0.18	-0.14

5.4.6.1 Species-specific Relationships with the Timing of Rainfall Events (Orpen)

To capture whether specific species/feeding guilds exhibit specific rainfall-related behaviours and whether one particular species is driving the pooled species relationships with the timing of rainfall events, Pearson's correlation was calculated for individual species per artificial water source. The daily number of individuals per mammal sightings that were recorded at the water sources on the days of specific timing categories of rainfall events were calculated *Table 5.23*. A comparison of means test (z-test: single factor) was also run to establish whether the mean on the day of rainfall is significantly larger than the means 1 day after rainfall and 2 days after rainfall, so as to determine whether specific-species responses to rainfall is significantly different (*Table 5.24*). The presence of rainfall on a given day is unlikely to affect species visitation patterns, whilst 1 day after and 2 days after rainfall is likely to affect species visitation patterns due to water availability in temporary pools which species can drink from (presence of rainfall).

A significant, negative relationship is found for 2 days after a rainfall event with the daily total number of individual sightings of blue wildebeest ($r = -0.17$). However, the mean on the day of rainfall is significantly larger than the mean 1 day after rainfall ($z = 2.73$, $p < 0.05$) and the mean 2 days after is not smaller than the mean on the day of rainfall ($z = 0.62$, $p > 0.05$). The same relationship is shown for 1 day and 2 days after rainfall with the daily total number of individual sightings of warthog ($r = -0.17$ and $r = -0.18$, respectively) ($z = 2.34$, $p < 0.05$ and $z = 0.83$, $p > 0.05$, respectively) (*Table 5.23; Table 5.24*). All daily total number of individual species sightings with the timing of rainfall events show weak relationships, however, the number of sightings for specific species recorded on the day of rainfall are noted to decrease 1 day after and 2 days after the rainfall event.

Table 5.23: Pearson's correlation of daily total species sightings and the timing of rainfall events at Orpen. Significant, negative relationships are highlighted in light orange and tested at the 95% significance interval. Species which show a large difference in the number of sightings on the day of rainfall, compared to 1 day after and 2 days after rainfall, are marked with an asterisk.

Orpen										
Daily total individual species sightings and the timing of rainfall events (March 2012 - March 2014)										
	2 days before	(n)	1 day before	(n)	Day of rainfall	(n)	1 day after	(n)	2 days after	(n)
African civet	-0.06	(5)	0.03	(4)	-0.07	(3)	-0.07	(2)	-0.05	(2)
Black-backed jackal*	-0.03	(35)	-0.10	(26)	0.10	(20)	-0.08	(8)	-0.11	(8)
Honey badger	-0.08	(4)	0.07	(8)	0.07	(7)	-0.12	(6)	0.00	(7)
Leopard	0.01	(2)	-0.06	(5)	-0.02	(5)	-0.05	(1)	-0.07	(2)
Lion	0.00	(7)	-0.02	(10)	-0.06	(12)	-0.02	(13)	-0.04	(9)
Mongoose	-0.03	(16)	0.04	(7)	-0.06	(2)	-0.06	(10)	0.02	(12)
Small-spotted genet	0.03	(2)	0.00	(5)	-	-	0.03	(2)	-	-
Spotted hyaena	0.10	(30)	-0.13	(19)	-0.11	(15)	-0.13	(14)	-0.04	(20)
Common duiker	-0.04	(3)	-0.02	(3)	-0.05	(3)	-	-	-	-
Greater kudu	-0.04	(56)	0.01	(74)	-0.04	(53)	-0.07	(37)	-0.04	(57)
Southern giraffe	-0.03	(10)	-0.08	(13)	-0.02	(10)	-0.08	(12)	-0.06	(17)
African buffalo*	-0.01	(76)	-0.05	(40)	-0.06	(37)	-0.06	(28)	-0.07	(28)
Blue wildebeest*	-0.06	(814)	0.02	(710)	-0.02	(486)	-0.11	(176)	-0.17	(405)
Plains zebra*	-0.05	(203)	-0.04	(238)	0.00	(231)	-0.12	(80)	-0.13	(127)
Warthog*	-0.07	(288)	-0.02	(254)	-0.05	(204)	-0.17	(116)	-0.18	(168)
African elephant*	-0.08	(78)	-0.08	(127)	-0.07	(232)	-0.09	(94)	-0.09	(93)
Impala*	-0.02	(2601)	0.04	(2329)	0.03	(1241)	-0.03	(551)	-0.11	(633)
Chacma baboon*	-0.05	(278)	-0.01	(199)	-0.07	(171)	-0.12	(68)	-0.05	(108)
Vervet monkey	0.07	(7)	-0.05	(11)	0.08	(11)	-0.04	(7)	-0.03	(14)

Black-backed jackal, plains zebra, African elephant, impala, chacma baboon and leopard all exhibit a decrease in the number of individual sightings 1 day after and 2 days after a rainfall event; the former species, with the exception of leopard and chacma baboon, all show that their mean sightings on the day of rainfall are significantly larger than the mean sightings 1 and 2 days after rainfall. These species are therefore driving the pooled species responses to the timing of rainfall events, specifically decreasing their visitations after rainfall events.

Table 5.24: Comparison of means test between the day of rainfall and 1 and 2 days after a rainfall event for each species at Orpen. Significant relationships are highlighted in grey and tested at the 95% significance interval.

Orpen - Comparison of means test				
	1 Day After		**2 Days After**	
	z-value	**p-value**	**z-value**	**p-value**
African civet	0.45	$p > 0.05$	0.45	$p > 0.05$
Black-backed jackal*	1.82	$p < 0.05$	1.82	$p < 0.05$
Honey badger	0.24	$p > 0.05$	0.00	-
Leopard	1.61	$p > 0.05$	1.10	$p > 0.05$
Lion	-0.10	$p > 0.05$	0.36	$p > 0.05$
Mongoose	-1.08	$p > 0.05$	-0.90	$p > 0.05$
Small-spotted genet	-	-	-	-
Spotted hyaena	0.17	$p > 0.05$	-0.72	$p > 0.05$
Common duiker	-	-	-	-
Greater kudu	0.80	$p > 0.05$	-0.19	$p > 0.05$
Southern giraffe	-0.29	$p > 0.05$	-0.56	$p > 0.05$
African buffalo*	0.54	$p > 0.05$	0.53	$p > 0.05$
Blue wildebeest*	2.73	$p < 0.05$	0.62	$p > 0.05$
Plains zebra*	2.60	$p < 0.05$	1.74	$p < 0.05$
Warthog*	2.34	$p < 0.05$	0.83	$p > 0.05$
African elephant*	2.25	$p < 0.05$	2.32	$p < 0.05$
Impala*	1.77	$p < 0.05$	1.84	$p < 0.05$
Chacma baboon*	1.97	$p < 0.05$	1.09	$p > 0.05$
Vervet monkey	0.63	$p > 0.05$	-0.26	$p > 0.05$

African buffalo show a decrease in sightings 1 day after a rainfall event, however, the mean sightings 1 day after a rainfall event are not smaller than the mean sightings on the day of rainfall ($z = 0.54$, $p > 0.05$) (*Table 5.24*). Greater kudu and vervet monkey all show a decrease in the number of individual sightings 1 day after a rainfall event, however, 2 days after the rainfall event their numbers show an increase. Lion show an increase in the number of individual sightings 1 day after a rainfall event, whilst mongoose and southern giraffe sightings increase 1 day and 2 days after a rainfall event.

5.4.6.2 Species-specific Relationships with the Timing of Rainfall Events (Satara)

Plains zebra and chacma baboon exhibit a positive significant relationship with the day of rainfall. Black-backed jackal exhibit positive relationships with days of rainfall and 1 day after rainfall events (*Table 5.25*), indicating that the number of individual sightings of these species increase with an increase in the presence of rainfall.

Table 5.25: Pearson's correlation of daily total species sightings and the timing of rainfall events at Satara. Significant, negative relationships are highlighted in light orange and significant positive relationships highlighted in light green and tested at the 95% significance interval. Species which show a large difference in the number of sightings on the day of rainfall compared to 1 day after and 2 days after rainfall are marked with an asterisk.

Satara										
Daily total individual species sightings and the timing of rainfall events (April 2012 - March 2014)										
	2 days before	**(n)**	**1 day before**	**(n)**	**Day of rainfall**	**(n)**	**1 day after**	**(n)**	**2 days after**	**(n)**
African wild cat	-0.13	(8)	-0.07	(8)	-0.08	(3)	-0.01	(2)	-0.07	(1)
Black-backed jackal*	0.15	(55)	0.17	(56)	0.20	(51)	0.38	(44)	0.17	(44)
Lion	-0.15	(36)	-0.01	(32)	-0.04	(9)	-0.10	(11)	-0.07	(4)
Small-spotted genet	-0.06	(4)	-0.12	(5)	-	-	-0.06	(1)	-0.07	(2)
Spotted hyaena*	-0.06	(40)	0.12	(35)	-0.04	(36)	-0.20	(26)	-0.12	(18)
Southern giraffe	-0.16	(6)	0.06	(4)	0.05	(4)	-0.09	(3)	-0.05	(5)
African buffalo	-0.03	(72)	-0.05	(60)	-0.12	(25)	-0.07	(43)	-0.07	(20)
Blue wildebeest*	0.09	(642)	-0.12	(454)	-0.05	(510)	-0.19	(161)	-0.11	(200)
Plains zebra*	0.03	(237)	0.00	(158)	0.26	(207)	-0.18	(133)	-0.13	(103)
Warthog	-0.13	(6)	-0.08	(3)	-0.09	(2)	-	-	-	-
African elephant*	-0.16	(81)	-0.10	(74)	-0.16	(56)	-0.23	(37)	-0.17	(29)
Impala*	0.02	(883)	-0.07	(865)	-0.17	(808)	-0.14	(201)	-0.09	(81)
Chacma baboon	-0.12	(60)	0.08	(32)	0.35	(16)	-0.07	(5)	-0.08	(39)

The mean sightings for plains zebra on the day of rainfall compared with the mean sightings 2 days after rainfall reflect a different pattern of significantly larger means on the day of rainfall, which is consistent with the daily sightings that were recorded. Spotted hyaena and African elephant exhibit a negative significant relationship with 1 day after a rainfall event, indicating that these species sightings decrease with an increase in rainfall

(*Table 5.25; Table 5.26*). The majority of species at Satara water trough exhibit this pattern of a decrease in sightings after a rainfall event. Lion and African buffalo show an increase 1 day after a rainfall event but these sightings decrease 2 days after the rainfall event. Warthog were not sighted 1 day to 2 days after a rainfall event. Blue wildebeest, impala, African elephant, black-backed jackal and spotted hyaena all show a decrease in the number of individual sightings 1 to 2 days after a rainfall event, with a comparison of means test supporting these findings for blue wildebeest and impala, with the mean sightings on the day of rainfall being significantly larger than the mean sightings 1 (z = 2.88 and z = 2.26, $p < 0.05$, respectively) and 2 days (z = 2.42 and z = 2.81, $p < 0.05$, respectively) after rainfall (*Table 5.26*).

Table 5.26: Comparison of means test between the day of rainfall and 1 to 2 days after a rainfall event for each species at Satara. Significant relationships are highlighted in grey and tested at the 95% significance interval.

Satara - Comparison of means test				
	1 Day After		**2 Days After**	
	z-value	**p-value**	**z-value**	**p-value**
African wild cat	0.46	p > 0.05	1.09	p < 0.05
Black-backed jackal*	0.54	p > 0.05	0.52	p > 0.05
Lion	-0.26	p > 0.05	0.77	p > 0.05
Small-spotted genet	-	-	-	-
Spotted hyaena*	1.25	p > 0.05	2.31	p < 0.05
Southern giraffe	0.23	p > 0.05	-0.17	p > 0.05
African buffalo	-0.77	p > 0.05	0.30	p > 0.05
Blue wildebeest*	2.88	p < 0.05	2.42	p < 0.05
Plains zebra*	1.48	p > 0.05	2.20	p < 0.05
Warthog	-	-	-	-
African elephant*	1.07	p > 0.05	1.38	p > 0.05
Impala*	2.26	p < 0.05	2.81	p < 0.05
Chacma baboon	1.40	p > 0.05	-1.14	p > 0.05

5.4.7 Relationship between Daily Sunrise and Sunset

Seasonal shifts in the timing of sunrise and sunset influence both the hours of light and temperature. Daily sunrise and sunset times were correlated with daily peak visitation times per mammal species, and separated into groups reflecting a predominant dawn or dusk visitation peak, to examine whether: 1) mammal visitation times shift earlier with earlier sunrise/sunset times; 2) mammal visitation times shift earlier with later sunrise/sunset times; 3) mammal visitation times shift later with later sunrise/sunset times; and 4) mammal visitation times shift later with later sunrise/sunset times. These were correlated over 15-minute intervals to capture the fine-scale seasonal temporal shifts in sunrise and sunset.

5.4.7.1 Species-specific Relationships with Daily Sunrise and Sunset (Orpen)

Mammals that predominantly visit Orpen waterhole during dawn show weak relationships between their daily peak visitation times and daily sunrise. Peak visitation time by Southern giraffe (r = 0.26) has a significant positive relationship with the timing of sunrise, reflecting the earlier waterhole visitation with earlier sunrise, and later visitation with later sunrise (*Table 5.27*). Conversely, leopard (r = -0.21) and small-spotted genet (r = -0.21) show significant, negative relationships (*Table 5.27*), indicating that these species visit the waterhole later with advancing sunrise and earlier with delayed sunrise. This has implications for predator/prey interactions as both large and small-sized carnivores and herbivores show this similar pattern.

Insignificant, weak negative relationships with sunrise are shown for African buffalo (r = -0.06), blue wildebeest (r = -0.04), impala (r = -0.05), lion (r = -0.10) and spotted hyaena (r = -0.12). Conversely, plains zebra (r = 0.04), warthog (r = 0.01), honey badger (r = 0.12) and mongoose (r= 0.13) have insignificant weak positive relationships with sunrise.

Mammals that predominantly visit the Orpen waterhole during dusk have weak (< 0.50) negative, or positive relationships between the peak visitation and daily sunset. Weak positive relationships are found for African buffalo (r = 0.07), African elephant (r = 0.05), blue wildebeest (r = 0.06), chacma baboon (r = 0.13), greater kudu (r = 0.04), impala (r = 0.12), warthog (r = 0.06) and lion (r = 0.12) (*Table 5.27*), indicating that these species visit the waterhole earlier with earlier sunset and later with later sunset.

The weak negative relationships seen for common duiker (r = -0.12) and black-backed jackal (-0.03) indicate that these species visit the waterhole earlier with later sunset and later with earlier sunrise. Interestingly, African buffalo, blue wildebeest, impala, leopard and lion show contrasting relationships between peak visitation and sunrise (negative relationships) and sunset (positive relationships). Southern giraffe and mongoose show positive relationships with sunrise and negative relationships with sunset.

African civet (r = -0.25) and mongoose (r = -0.17), which visit the waterhole during dusk, show significant negative relationships with sunset (r = -0.25), whilst small-spotted genet, which visit the waterhole during dawn, show a significant negative relationship with sunrise (r = -0.21) (*Table 5.27*), suggesting that these small carnivores shift their visitation times towards a period of more light, and to possibly avoid overlap with larger carnivores.

No species at Orpen have negative relationships with both sunrise and sunset, which might have been expected for the nocturnal species. Most of the relationships are weak (< 0.50), indicating that seasonal shifts in sunrise and sunset times have little influence on waterhole visitation patterns. Artificial lights at both water sources may influence species-interactions.

Table 5.27: Pearson's correlation of peak visitation times and sunrise and sunset per mammal species at Orpen waterhole. Significant relationships are indicated by an asterisk, tested at the 95% significance level. Positive relationships are highlighted in light green and negative relationships are highlighted in light red.

Orpen		
Peak Time and Sunrise (Dawn)		
Feeding Guild	**Mammal**	**r-value**
Herbivores	African buffalo	-0.06
	Blue wildebeest	-0.04
	Impala	-0.05
	Plains zebra	0.04
	Southern giraffe	*0.26
	Warthog	0.01
Carnivores	Honey badger	0.12
	Leopard	*-0.21
	Lion	-0.10
	Mongoose	0.13
	Small-spotted genet	*-0.21
	Spotted hyaena	-0.12
Peak Time and Sunset (Dusk)		
Herbivores	African buffalo	0.07
	African savanna elephant	0.05
	Blue wildebeest	0.06
	Chacma baboon	0.13
	Common duiker	-0.12
	Greater kudu	0.04
	Impala	0.12
	Southern giraffe	*-0.35
	Warthog	0.06
Carnivores	African civet	*-0.25
	Black-backed jackal	-0.03
	Leopard	*0.18
	Lion	0.12
	Mongoose	*-0.17

5.4.7.2 Species-Specific Relationships with Daily Sunrise and Sunset (Satara)

Lion are the only large carnivore species to have significant relationships between their daily peak visitation times and daily sunrise (r = -0.45) and sunset (r = 0.39) (*Table 5.28*), indicating that they visit the Satara water trough earlier as the sun rises later, and later as the sun rises earlier, and in contrast visit the water trough earlier as the sun sets earlier and later as the sun sets later.

African buffalo show an inverse pattern between their daily peak visitation times and sunrise and sunset, when compared with Orpen, demonstrating a positive relationship with sunrise (r = 0.16) and a significant, negative relationship with sunset (r = -0.20) (*Table 5.28*). African elephant predominantly visit the water trough during dusk, and show a shift in visitation times with sunset, utilising the water trough earlier with later sunset and later with earlier sunset (r = -0.20). Warthog, a small-sized herbivore which are vulnerable to predation, show a significant, positive relationship with sunrise (r = 0.26), shifting their peak visitation times earlier with earlier sunrise and later with later sunrise. Plains zebra were the only species to exhibit negative relationships for both sunrise and sunset (r = -0.03 and r = -0.02, respectively), however, these relationships are weak. Common duiker exhibit a significant negative relationship with sunrise and a significant positive relationship with sunset (r = -0.31 and r = 0.32, respectively).

At Satara, mammals that predominantly visit the water trough during dawn and dusk show weak, negative or positive relationships between their peak period of visitation and daily sunrise and sunset, as was also shown for Orpen waterhole. The majority of carnivores at Satara show a negative relationship with sunset, with the exception of African civet (r = 0.02), and conversely show a positive relationship with sunset, with the exception of African civet (r = -0.09) and black-backed jackal (r = -0.06) (*Table 5.28*). In contrast, herbivores, such as African buffalo, blue wildebeest, warthog and greater kudu show an opposite pattern, with positive relationships found for sunrise and negative relationships found for sunset, indicating that they are shifting their dawn visitation periods earlier with earlier sunrise and later with later sunrise, and conversely, adjusting their dusk visitation times earlier with later sunset and later with earlier sunset.

Table 5.28: Pearson's correlation of peak visitation times and sunrise and sunset per mammal species at Satara. Significant relationships are indicated by an asterisk, tested at the 95% significance level. Positive relationships are highlighted in light green and negative relationships are highlighted in light red.

Satara		
Peak Time and Sunrise (Dawn)		
Feeding Guild	**Mammal**	**r-value**
Herbivores	African buffalo	0.16
	Blue wildebeest	0.07
	Chacma baboon	*0.18
	Common duiker	*-0.31
	Greater kudu	*0.19
	Impala	-0.12
	Plains zebra	-0.03
	Southern giraffe	0.01
	Warthog	*0.26
Carnivores	African civet	0.02
	African wild cat	*-0.21
	Lion	*-0.45
	Mongoose	-0.01
	Small-spotted genet	-0.06
	Spotted hyaena	-0.03
Peak Time and Sunset (Dusk)		
Herbivores	African buffalo	*-0.20
	African savanna elephant	*-0.20
	Blue wildebeest	-0.07
	Chacma baboon	-0.04
	Common duiker	*0.32
	Greater kudu	-0.10
	Impala	0.07
	Plains zebra	-0.02
	Warthog	-0.11
Carnivores	African civet	-0.09
	African wild cat	0.14
	Black-backed jackal	-0.06
	Lion	*0.39
	Mongoose	*0.18
	Spotted hyaena	0.03

5.4.8 Relationship between Moon Phase Dates and Peak Visitation Times

Moon phases affect the amount of light available, with the least amount of light available 2 days before, 2 days after and on new moon dates. The most amount of light is available during the 2 days before, 2 days after and on full moon dates. Few studies have highlighted the influence of moon phase on mammal behaviour, particularly water source visitation patterns, therefore it is important to determine whether: 1) peak mammal visitation times are influenced by new moon, first quarter, last quarter and full moon periods. This is tested with species that visit the water sources nocturnally, which includes the majority of carnivores, which are likely to be more active on nights with increased light availability. The date of peak appearance for each species for each month of the study period was recorded, which were cross-checked with the dates on which the four moon phases occurred. Each mammal species daily visitation patterns, which fell on either the day of new moon, first quarter, full moon or last quarter, within the time period from 17:00 - 0:00, (the period when moonlight is only source of light available), were analysed using an Analysis of Variance (ANOVA) test. ANOVA was used to determine whether there is any difference between the mean sightings during the four different moon phases.

Moon phases overlap more with mammal visitation patterns at Orpen (*Table 5.29*) than at Satara (*Table 5.30*), however, there is no consistent pattern between dates of peak visitation and the moon phase, and therefore no single moon phase is driving an increase in nocturnal visitation. African buffalo and African elephant show the most overlap with moon phase dates at both Orpen and Satara (*Table 5.29; Table 5.30*), with peak visitations of African buffalo occurring on full moon dates, likely because there is more light available and their ability to detect predators would improve (van Orsdol, 1984; Crosmary *et al*., 2012). African civet and Serval at Orpen, and African wild cat, common duiker, honey badger, serval and small-spotted genet at Satara, show no overlap between peak appearance dates and moon phase dates, likely due to their infrequent visitation patterns at these water sources (*Table 5.30*).

Table 5.29: Date of peak waterhole visitation per species and the correspondence with moon phase dates at Orpen waterhole for the period March 2012 to March 2014.

Orpen

	African civet	African wild cat	Black-backed jackal	Honey badger	Leopard	Lion	Serval	Small-spotted genet	Spotted hyaena	African buffalo	African elephant	Common duiker
Mar-12	-	-	30 ░	-	15 ▓	23	20	26	*	23	30 ░	-
Apr-12	*	-	5	-	*	-	-	*	20	18	10	-
May-12	*	-	28 ░	21 ▤	*	19	-	14	29	6 █	18	24
Jun-12	23	-	9	29	*	22	-	23	16	22	11 ▓	24
Jul-12	6	-	29	1	*	-	-	2	7	24	13	*
Aug-12	*	-	11	3	27	-	-	-	30	7	5	29
Sep-12	-	-	3	-	-	-	-	-	5	6	20	4
Oct-12	-	-	19	19	28	-	-	-	10	29 █	*	10
Nov-12	-	-	*	20 ░	16	-	-	-	*	3	28 █	-
Dec-12	-	-	-	18	-	-	29	-	*	14	*	-
Jan-13	-	-	10	-	8	27 █	-	-	6	2	6	-
Feb-13	-	-	-	-	-	-	-	19	12	*	17 ░	-
Mar-13	-	-	14	29	-	31	-	-	*	21	*	-
Apr-13	-	-	14	5	*	*	*	-	14	14	19	-
May-13	*	-	1	-	8	-	-	2 ▓	9	2 ▓	15	-
Jun-13	14	-	*	*	*	-	12	22	5	30 ▓	4	*
Jul-13	*	-	*	1	*	3	-	30	13	16	10	*
Aug-13	-	23	27	23	*	23	-	29	21 █	12	31	*
Sep-13	*	-	*	*	*	1	-	-	*	20	*	27 ▓
Oct-13	*	-	*	30	-	-	8	-	*	12 ░	21	12 ░
Nov-13	-	3 ▤	*	-	-	30	-	-	*	25 ▓	19	-
Dec-13	-	-	26	*	*	6	-	16	*	2	1	-
Jan-14	25	-	-	*	-	17	-	-	21	-	15	-
Feb-14	-	-	23	22 ▓	18	20	-	24	-	*	23	-
Mar-14	-	-	-	-	-	1 ▤	-	3	-	-	1 ▤	-

-	no appearance
*	appeared once on more than one day
▤	New moon
░	First quarter
█	Full Moon
▓	Last quarter

Table 5.30: Date of peak waterhole visitation per species and the correspondence with moon phase dates at Satara water trough for the period April 2012 to March 2014.

Satara

	African civet	African wild cat	Black-backed jackal	Honey badger	Lion	Small-spotted genet	Spotted hyaena	Serval	African buffalo	African elephant	Common duiker
Apr-12	-	-	18	-	-	-	23	-	16	6	-
May-12	-	-	26	-	24	29	7	27	14	*	-
Jun-12	-	15	27	-	18	-	15	-	16	*	30
Jul-12	-	15	21	-	7	-	14	-	7	25	-
Aug-12	*	11	1	-	-	-	4	-	2	11	*
Sep-12	-	18	3	-	-	-	9	-	1	6	-
Oct-12	10	*	9	-	-	-	10	-	12	*	-
Nov-12	-	-	5	-	5	-	18	-	20	*	-
Dec-12	-	21	15	-	-	-	28	-	28	26	-
Jan-13	-	-	10	-	11	-	10	-	28	8	-
Feb-13	-	5	*	-	-	-	5	-	12	11	-
Mar-13	-	31	5	-	-	22	21	-	-	5	-
Apr-13	-	*	2	-	2	16	*	-	2	29	-
May-13	*	-	*	-	-	-	*	29	25	*	-
Jun-13	*	*	26	-	-	*	29	-	7	*	-
Jul-13	*	25	*	-	-	*	10	-	6	*	-
Aug-13	*	*	*	-	-	-	*	-	14	31	*
Sep-13	*	24	20	20	8	*	25	-	20	*	*
Oct-13	*	*	*	-	12	*	7	-	13	11	*
Nov-13	3	*	14	-	8	*	27	-	7	27	*
Dec-13	19	20	29	21	4	*	*	-	26	8	-
Jan-14	10	12	27	-	21	-	*	-	-	21	-
Feb-14	-	*	*	-	10	-	25	-	20	12	-
Mar-14	-	-	8	*	2	-	2	-	21	5	-

-	no appearance
*	appeared once on more than one day
▧	New moon
░	First quarter
■	Full Moon
▓	Last quarter

ANOVA of the visitation patterns on each of the days of specific moon phase, revealed no significant relationships between the mean sightings for all nocturnal species. The erratic overlap between the date of the four moon phases and the date of peak visitation of nocturnal species, as well as no significant results between the mean sightings between the four moon phases, suggests that environmental variables and surrounding habitat are likely to influence the amount of light available, such as cloudy nights, as opposed to clear nights or substantial tree canopy cover.

5.4.9 Summary

Average monthly water source visitation patterns show strong positive relationships with monthly T_{avg} for water-dependent species and positive relationships for herbivore visitation patterns and $T_{avg,}$ indicating that temperature is a likely mechanism controlling herbivore visitation patterns. In contrast, negative relationships are recorded for carnivore visitation patterns and T_{avg}, indicating that their water source visitation patterns are not controlled by temperature but rather by their need to drink water. Daily temperature and peak appearance all showed weak relationships, however, stronger relationships are shown with temperature intervals, indicating that a large shift in temperature is required to influence mammal water source visitation patterns. Daily mammal visitation patterns had weak, negative relationships with daily rainfall, however, stronger, negative relationships were exhibited for 1 and 2 days after rainfall, thus tentatively indicating that mammals prefer to drink from temporary ponds following rainfall events, and are less reliant on artificial water sources during such periods. Poor relationships are recorded with sunrise, sunset and moon phases.

All of the relationships with climate and astronomical factors are relatively weak, and the patterns of relationships, especially between carnivores and herbivores suggest predator-prey relationships are a far more dominant influence. Different mammal species respond to different climatic, astronomical and environmental variables, with certain variables having a greater control over specific species than others. Temperature seems to have the greatest influence on mammal visitation times, and thus changes in this climatic variable due to projected climate change scenarios are likely to have the greatest influence on mammal water source visitation patterns in future (*Table 5.31*).

Table 5.31: Summary of the strongest relationship or significant relationships between the various response and driver metrics, for each of these species at Orpen and Satara.

Summary Table of Significant Relationships between 1 Response Variable and 1 Driver Variable

	Orpen			**Satara**		
	Response variable	**Driver Variable**	**r-value**	**Response variable**	**Driver Variable**	**r-value**
African civet	↓No. of indiv/peak	↑Daily T_{avg}	-0.28	↓No. of indiv/peak	↑Daily T_{min}	-0.20
African wild cat	*No significant relationship*			←/→ visitation time	→/← Sunrise	-0.21
Black-backed jackal	↓No. of indiv/peak	↑Daily T_{min}	-0.29	↑No. of indiv	↑1 Day After Rain	0.38
Honey badger	*No significant relationship*			*No significant relationship*		
Leopard	←/→ visitation time	→/← Sunrise	-0.21	-	-	-
Lion	*No significant relationship*			←/→ visitation time	→/← Sunrise	-0.45
Mongoose	←/→ visitation time	→/← Sunset	-0.17	←/→ visitation time	←/→ Sunset	0.18
Small-spotted genet	←/→ visitation time	→/← Sunrise	-0.21	*No significant relationship*		
Spotted hyaena	↓No. of indiv/peak	↑Daily T_{min}	-0.22	↓No. of indiv	↑1Day After Rain	-0.20
Common duiker	↓No. of indiv/peak	↑Daily T_{avg}	-0.33	←/→ visitation time	←/→ Sunset	0.32
Greater kudu	↓No. of indiv/peak	↑Daily T_{min}	-0.24	*No significant relationship*		
Southern giraffe	←/→ visitation time	→/← Sunset	-0.35	*No significant relationship*		
African buffalo	*No significant relationship*			←/→ visitation time	→/← Sunset	-0.20
Blue wildebeest	↓No. of indiv	↑2 Days After Rain	-0.17	*No significant relationship*		
Plains zebra	↓No. of indiv/peak	↑Daily T_{min}	-0.20	↑No. of indiv	↑On Day of Rain	0.26
Warthog	↓No. of indiv/peak	↑Daily T_{min}	-0.39	←/→ visitation time	←/→ Sunrise	0.26
African elephant	*No significant relationship*			↓No. of indiv	↑1 Day After Rain	-0.23
Impala	↓No. of indiv/peak	↑Daily T_{min}	-0.21	←/→ visitation time	→/← Sunset	-0.20
Chacma baboon	*No significant relationship*			↑No. of indiv	↑On Day of Rain	0.35
Vervet monkey	↓No. of indiv/peak	↑Daily T_{avg}	-0.21	-	-	-

↑ - Increasing number of individuals/temperature
↓ - Decreasing number of individuals/temperature
→ - Later visitation time
← - Earlier visitation time

5.5 Relationship between Water Source Visitation and Mammal Densities

5.5.1 Correlation between Observed and Estimated Proportional Representation

Pearson's correlation between the proportional representation in the herbivore community that was observed at the water sources (webcam) with the three estimates of proportional representation (aerial estimates, local estimates and landscape estimates), is used to determine whether monthly patterns are representative across the different scales of survey data. Waterhole observations (i.e. site specific) were correlated with regional (aerial census) and local estimates (experimental burn plot surveys), as well as regional estimates partitioned according to the dominant geology (landscape) underlying the camps at which the water sources are situated. Orpen, situated on the western boundary of KNP, is underlain by gabbro and Satara, situated in the eastern side of KNP, is underlain with basalt. Webcam data were collected across the wet and dry seasons, the experimental burn plot survey data were collected during the wet season, whilst the aerial survey was undertaken during the dry season, thus correlations between the webcam data and three estimates of proportional representation are only analysed for the periods where there is overlap between the different scales of data.

Relationships between the proportional representation of herbivores observed at the Orpen waterhole and the proportional representation of herbivores in the regional and landscape estimates were very strong in the winter months of June, July and August 2012 and 2013 and in September 2012 and 2013 (*Table 5.32*). The Orpen proportional representation of regional and landscape estimates exhibit a greater number of very strong relationships during 2013 than in 2012. Relationships between the proportional representation of herbivores observed at the Satara water trough and the proportional representation of herbivores in the regional and landscape estimates show stronger significant relationships during the dry season in 2012, compared to the dry season in 2013, whilst very strong relationships are shown for September 2013 and in contrast, weak relationships are shown for September 2012. Observed visitation by herbivores to the Satara water trough show stronger significant relationships with local estimates during the 2013 wet season compared to the 2012 wet season.

Table 5.32: Pearson's correlation table of the monthly proportional representation in the herbivore community that was observed at the water sources with the three estimates of proportional representation (aerial, local and landscape). Strong, significant relationships are indicated by an asterisk and very strong (≥ 0.90), significant relationships are indicated by a double asterisk. Periods of overlap (when the surveys were undertaken) between the webcam data and aerial survey/local survey or landscape, are highlighted in grey.

	Orpen			**Satara**		
	Aerial Survey	**Local Survey**	**Landscape (Granite)**	**Aerial Survey**	**Local Survey**	**Landscape (Basalt)**
Mar-12	*0.66	-	0.63	-	-	-
Apr-12	0.54	-	*0.85	*0.80	**0.90	*0.86
May-12	*0.78	-	*0.88	*0.88	**0.94	**0.92
Jun-12	**0.92	-	**0.99	0.36	*0.76	0.35
Jul-12	**0.93	-	**0.99	*0.86	**0.97	*0.87
Aug-12	**0.91	-	**0.99	*0.72	**0.95	*0.72
Sep-12	**0.92	-	**0.97	0.44	*0.75	0.46
Oct-12	*0.88	-	*0.87	0.32	0.16	0.51
Nov-12	**0.95	-	**0.95	0.31	0.44	0.30
Dec-12	**0.98	-	**0.95	**0.95	*0.84	**0.97
Jan-13	*0.89	-	*0.83	**0.90	*0.82	**0.93
Feb-13	*0.69	-	0.59	*0.62	*0.84	0.67
Mar-13	0.10	-	0.06	*0.61	*0.64	0.66
Apr-13	*0.87	-	*0.88	0.45	0.52	0.48
May-13	0.30	-	0.51	0.31	0.48	0.35
Jun-13	**0.94	-	**0.96	0.45	0.57	0.49
Jul-13	**0.96	-	**0.99	0.41	*0.77	0.45
Aug-13	**0.96	-	**0.98	**0.93	**0.94	**0.94
Sep-13	**0.98	-	**0.99	**0.91	*0.89	**0.95
Oct-13	**0.95	-	**0.95	*0.88	*0.88	**0.92
Nov-13	**0.97	-	**0.98	**0.95	*0.82	**0.96
Dec-13	**0.91	-	*0.87	*0.77	*0.80	*0.82
Jan-14	**0.99	-	**0.98	0.43	*0.65	0.48
Feb-14	**0.97	-	**0.95	*0.80	*0.87	*0.85
Mar-14	**0.98	-	**0.99	**0.92	*0.87	**0.96

5.2 Comparison of Observed Proportional Visitation with Expected Proportional Visitation

To determine whether the overall observed proportional visitation (webcam data) and the expected proportional visitation (local, landscape and regional estimate data) for pooled mammal species are significantly similar, (i.e. indicating that mammals are utilising the water sources in proportion to their abundance within the local, landscape and central regions), a chi-squared test of independence was run. At both Orpen and Satara the waterhole visitation patterns are showing significantly similar relationships with the proportional distribution of mammal species in the granite/basalts-only landscapes and the central region (*Table 5.33*).

Table 5.33: Chi-squared test for independence between the different proportions of mammal communities surveyed in the three scales of estimate data. Significant relationships indicated with an asterisk.

Chi-Squared Test for Independence		
	χ^2	**p-value**
Orpen		
Webcam vs. Granite	*14.27	$p < 0.05$
Regional vs. Webcam	*15.30	$p < 0.05$
Regional vs. Granite	7.34	$p > 0.05$
Satara		
Webcam vs. Basalt	*15.67	$p < 0.05$
Local vs. Webcam	*16.09	$p < 0.05$
Local vs. Basalt	9.89	$p > 0.05$
Regional vs. Webcam	*25.18	$p < 0.05$
Regional vs. Local	*23.74	$p < 0.05$
Regional vs. Basalt	4.59	$p > 0.05$

5.2.1 Proportional Comparison of Two Scales of Mammal Estimate Data (Orpen)

Mammal estimate data for central KNP, provided by SANParks from the 2012 and 2014 aerial surveys, represent the regional estimates of proportional population densities, whilst webcam imagery reflects site-specific observations within this region. The regional estimates and landscape estimates were compared to the site-specific observations to:

1) establish whether mammal species are utilising Orpen waterhole in proportion to their abundance in the central region, or 2) investigate whether certain species are preferentially utilising or avoiding this waterhole. The species included in this comparison are determined by the available aerial census data and the available landscape estimates. The proportional visitation by certain species at the Orpen waterhole differs from their regional and landscape (granite) presence (*Figure 5.31*).

Impala were estimated at 78.86% of the estimated mammal community within the landscape and at 63.64% of the surveyed mammal community for the central region; however, this species comprised 53.90% of waterhole visitations (*Figure 5.31a,b,c*). Therefore impala are showing a lower proportion waterhole visitation patterns comparable to their population numbers within the granite landscape and in the central KNP. Blue wildebeest preferentially visit artificial waterholes relative to natural water sources to satisfy their water requirements (Smit *et al.*, 2007a), and are showing higher proportions between the waterhole visitation at Orpen (12.41%) and their regional (8.53%) and landscape (1.50%) estimates (*Figure 5.31a,b,c*).

Warthog show the largest range between their waterhole visitation at Orpen (13.04%) and their distribution in the central region (1.07%), however, their low regional estimate may be attributed to the fact that they hide in burrows and may not have been seen during the aerial survey. African buffalo were estimated at 7.14% of the estimated mammal community within the central region, however, this species comprised 3.36% of waterhole visitations (*Figure 5.24*). African elephant represent 6.14% of the waterhole visitations, with their proportional distribution ranging from 4.63% the central region and 2.47% in the landscape (*Figure 5.31a,b,c*). Southern giraffe show lower proportions between their waterhole visitation at Orpen (0.76%) and their landscape (2.76%) and regional estimates (2.68%), whilst greater kudu show relative proportional representation between their landscape distribution (3.48%%) and their waterhole visitation (3.14%), however, they only comprise 1.55% of the surveyed mammal community for the central region (*Figure 5.31a,b,c*).

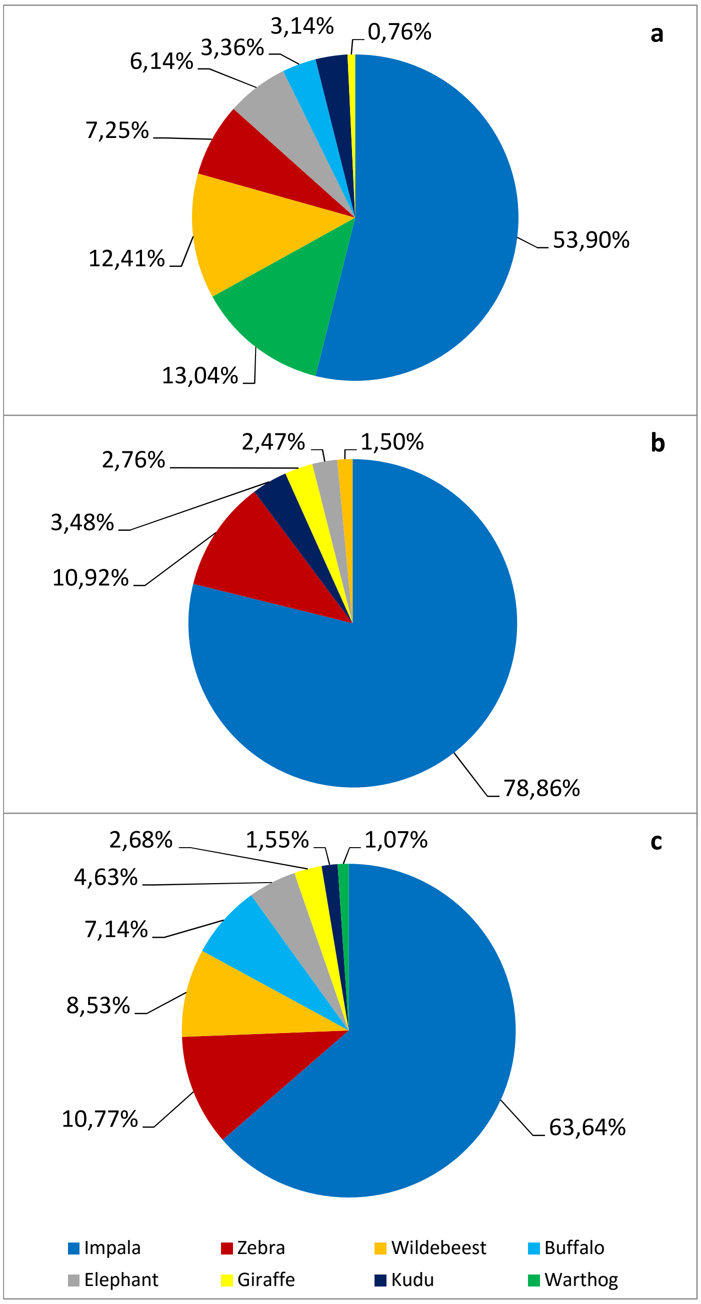


Figure 5.31: Percentage contribution of select herbivore species to a) 2012 - 2014 cumulative Orpen waterhole visitation, b) 2012 - 2014 granite-only landscape estimates and c) 2012 - 2014 regional estimates.

Impala, plains zebra and southern giraffe all exhibit the same proportional distribution across the three scales of mammal estimate data, with their highest proportions in the landscape, while blue wildebeest and African elephant exhibit the same proportional representation, with their waterhole visitations comprising the highest percentage.

5.2.2 Quantification of Preferential or Avoidance Behaviour (Orpen)

To quantify whether specific species are selecting for / exhibiting preferential use or avoidance behaviours at artificial water sources, the index of electivity was calculated with the proportions between individual species waterhole visitation and their regional and landscape estimates, using Ivlev's index of electivity (1961). Ivlev's electivity index (E) ranges from -1 and 1, with negative values closer to -1 suggesting avoidance or inaccessibility; in contrast, positive values closer to 1 suggest preference or active selection while a value of zero suggests random selection or neutrality (Strauss, 1979; Manly, 1993; Laliberte & Ripple, 2004). Positive values ≥ 0.50 represent preferential use while negative values <-0.50 represent avoidance behaviour.

Warthog were the only species to exhibit strong preferential visitation behaviour (E = 0.85) at Orpen waterhole (*Table 5.34*), when the proportion of their regional estimates is compared to the proportion of total number of visitations observed at the waterhole, which is evident in their range of proportional distribution in the central region and their observed visitation at the waterhole. Impala display a weak, negative electivity value with their regional estimate (E = -0.08), however, they show a strong, positive electivity value (E = 0.50) with their landscape estimate, indicating that may show a preference to utilising the Orpen waterhole (*Table 5.34*).

African elephant show weak, positive electivity values for both their regional and landscape estimates (E = 0.15 and E = 0.04, respectively) when compared to their waterhole visitation, while plains zebra show a weak, negative electivity value for their regional estimate (E = -0.19) and a strong, negative electivity value with their landscape estimate (E = -0.51) (*Table 5.34*), suggesting avoidance of the Orpen waterhole. Southern giraffe exhibit an inverse relationship between their regional and landscape estimates, when compared to their proportional distribution of waterhole visitations, thus indicating avoidance (E = -0.56) behaviour of the waterhole within their larger regional proportional distribution. However, their proportional distribution within the granite landscape shows strong preferential (E = 0.82) use of the Orpen waterhole (*Table 5.34*).

Table 5.34: Ivlev's index of electivity scores for each surveyed mammal species at Orpen. Positive values highlighted in light green and negative values highlighted in light red. Positive values ≥0.50 represent preferential use whilst negative values <-0.50 represent avoidance behaviour, indicated with an asterisk.

Orpen		
Ivlev's (1961) index of electivity		
	Electivity (E)	
Mammal	**Regional**	**Landscape (Granite)**
Warthog	*0.85	-
Greater kudu	0.34	-0.10
Blue wildebeest	0.19	-0.11
African elephant	0.14	0.04
Impala	-0.08	*0.50
Plains zebra	-0.20	*-0.51
African buffalo	-0.36	-
Southern giraffe	*-0.56	*0.82

5.2.3 Proportional Comparison of Three Scales of Mammal Estimate Data (Satara)

For Satara, herbivore abundance data for the Satara Experimental Burn Plots was made available by Prof. Deron Burkepile; representing a 3rd (regional, basalts-only landscape and *local*) estimate of proportional species representation for comparison with the site observations. Impala were estimated at 63.64% and 63.33% within their surveyed mammal community for basalt-only landscape and central region, whilst their local and water trough visitations represent smaller proportions (43.36% and 39.51%, respectively) (*Figure 5.32a,b,c,d*), thus likely indicating that this species may be utilising other water sources in the area to satisfy their water requirements.

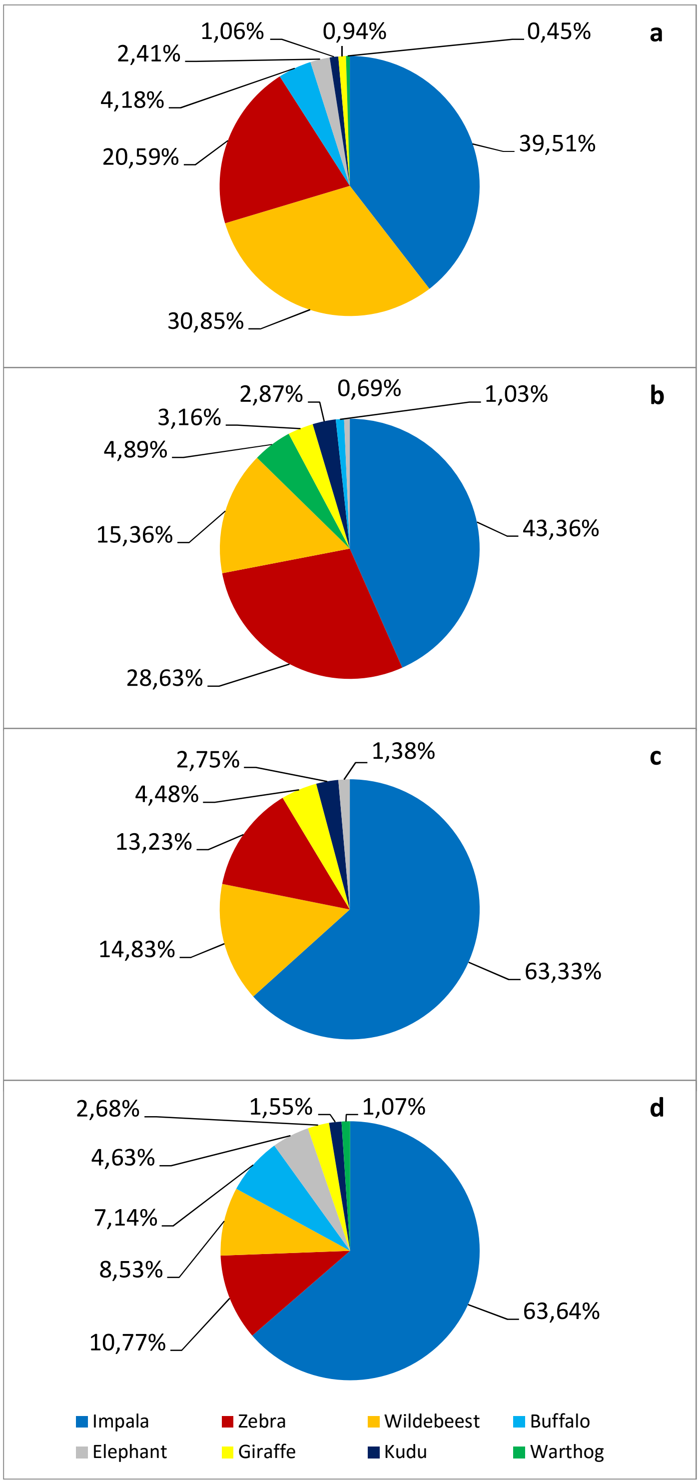


Figure 5.32: Percentage contribution of select herbivore species to a) 2012 - 2013 cumulative Satara water trough visitation, b) 2006 - 2011 local estimates, c) 2012 - 2014 basalt-only landscape estimates and d) 2012 - 2014 regional estimates.

Blue wildebeest at Satara were estimated at 8.53% within their surveyed mammal community for the central region, however, they comprised 30.85% of the water trough visitations. Plains zebra comprise 28.63% of their local mammal community, with their waterhole visitations comprising 20.59%, however, their proportional distributions within the basalt-only landscape and central region represent 13.23% and 10.77% of the surveyed mammal community (*Figure 5.32a,b,c,d*).

African buffalo and African elephant comprise 7.14% and 4.63% of the surveyed mammal community in the central region respectively, however, they comprise the lowest proportions within the local surveyed mammal community, with African elephant also comprising the lowest proportion (1.38%) of the surveyed mammal community within the basalt-only landscape (*Figure 5.32a,b,c,d*). Southern giraffe and greater kudu, both water-independent species, comprise 2.68% and 1.55% of the surveyed mammal community in the central region and thus comprise 0.94% and 1.06% respectively, of water trough visitations.

5.2.4 Quantification of Preferential or Avoidance Behaviour (Satara)

Blue wildebeest exhibit preferential (E = 0.57) use of the Satara water trough, when comparing their proportional distribution within the central region to their water trough visitation patterns, whilst African buffalo and African elephant both exhibit preferential (E = 0.60 and E = 0.55, respectively) use of the Satara water trough when comparing their local proportional distribution to their water trough visitation patterns (*Table 5.35*).A converse pattern is observed with southern giraffe at Satara, compared to Orpen, as their proportional distribution within the basalt-only landscape shows that they avoid (E = -0.65) using the Satara water trough (*Table 5.35*).

Table 5.35: Ivlev's index of electivity scores for each surveyed mammal species at Satara. Positive values highlighted in light green and negative values highlighted in light red. Positive values ≥ 0.50 represent preferential use whilst negative values <-0.50 represent avoidance behaviour, indicated with an asterisk.

Satara			
Ivlev's (1961) index of electivity			
	Electivity (E)		
Mammal	**Regional**	**Landscape (Basalt)**	**Local**
Blue wildebeest	*0.57	0.35	0.34
Plains zebra	0.31	0.22	-0.16
Greater kudu	-0.19	-0.44	-0.46
Impala	-0.23	-0.23	-0.05
African buffalo	-0.26	-	*0.60
African savanna elephant	-0.32	0.27	*0.55
Warthog	-0.40	-	*-0.83
Southern giraffe	-0.48	*-0.65	-0.54

CHAPTER SIX

Discussion

Chapter 6 - Discussion

6.1 Introduction

The broad aim of this study is to assess mammal visitation patterns at artificial water sources in central KNP using webcam imagery as an ecological data source. The study further explores the influence of various climatic and astronomical variables on visitation patterns. There has been little previous work on assessing mammal drinking behaviour using remote photography; however, it is an emerging ecological data collection tool (Hayward & Hayward, 2012). At a fine temporal scale, it is important to determine the various environmental drivers influencing mammal visitation patterns and species-specific reliance on artificial water sources, so as to inform management guidelines on current and future water provisioning strategies. The analysis of this webcam imagery will contribute to understanding recent climate-related mammal visitation and water-use trends at two artificial water sources in a semi-arid savanna, and provide an indication of likely shifts in visitation patterns in response to future projected climate change scenarios in southern Africa. This discussion interprets the most significant findings of this study, and provides a critical comparison with previous studies dealing with mammalian water-use behaviour. Following this, the broader implications of the study are discussed, with a focus on mammal reliance on artificial water sources, likely behavioural adjustments to future projected climates, and the importance of future/continued/ongoing water-provisioning efforts in conservation areas. Finally, the various methodological limitations associated with remote imagery technology and the data limitations encountered during this study are discussed.

6.2 Analysis of Webcam Imagery

Webcam imagery has not been a widely used method to study mammal behavior in ecological studies. It was therefore important to establish whether the temporal resolution at which the images are captured (4 frames per minute) would adequately reflect water source visitation patterns for all species at hourly, daily and seasonal scales. This was done both to ensure that this study returned a composite of water-use behaviour, but more importantly to inform future studies utilising this progressive method as to the optimal resolution requirements. Regarding the latter, there was a clear distinction between species that required either lower or higher resolution monitoring. Impala, blue wildebeest and plains zebra, identified as some of the most water-dependent species in this study require low temporal resolution monitoring (up to 1 hour), likely because of these species abundance and frequent visitation patterns. Conversely, the least frequently sighted species (serval) require high temporal resolution monitoring (< 1 minute).

Additionally, there was also a notable seasonal effect. During spring and summer (wet season) when surface water is widely available to mammals, their use of and dependence on artificial water sources decreases. Thus a higher temporal resolution is required to monitor visitation patterns during these periods. However, when the quantity of surface water and moisture content in vegetation decreases due to less rainfall, the need for mammals to drink and rely on few available water sources increases, and consequently visitation patterns multiply. Thus, a lower resolution is required to sufficiently monitor mammal behaviour during the dry season.

6.3 Mammal Distribution at Orpen and Satara Artificial Water Sources

The distribution of mammal visitation varied between water sources, with these frequency distributions likely reflecting underlying factors attributable to species associations and predator-prey interactions. Additionally, factors directly linked to the physical structures of the water sources, the surrounding environment and the natural abundance of species, could account for the differences observed at the water sources. Despite waterbuck being classified as a water-dependent species, they were rarely sighted at the artificial water sources. This is likely due to their preference for natural water sources, such as rivers and large dams, and associated concentration in riverine habitat (Smit *et al.*, 2007a). Similarly, water-independent nyala concentrate along rivers (Grant *et al.*, 2002). Such factors likely account for these species infrequently (one sighting each during the 25-

month study period) visiting the studied artificial water sources. African wild dog were sighted only on two occasions, and only at Orpen. These infrequent visitations likely reflect their overall low numbers in the park, despite being known to drink regularly and favour water during hot periods (Estes, 1991). Additionally, wild dogs are territorial (Mills & Gorman, 1997) and avoid areas where there are high densities of spotted hyaena and lion due to kleptoparasitism and predation (Mills & Gorman, 1997; Ndaimani *et al.*, 2016). Thus maintaining a strict territory in the Orpen area where a lower percentage of the two latter carnivore species were observed. Although censused in the central region of KNP white and black rhinoceros were never observed utilising either the Orpen or Satara water sources, which is consistent with the findings of Hayward & Hayward (2012).

Hippopotamus, leopard and vervet monkey were only sighted at the Orpen waterhole, with hippopotamus likely utilising this, and not the Satara trough, as the depth of the former allows them to fully submerge themselves. Hippopotamus only exhibited nocturnal visitation patterns, and were never seen during the morning, midday and afternoon. This behavior is likely linked to their nocturnal foraging bouts, in which they can travel a distance of 10km, returning before dawn (Estes, 1991). Thus, species composition was more diverse at the Orpen waterhole than the Satara water trough, possibly owing to the structure of the water sources and those species needs they are able to accommodate (i.e. only drinking or also wallowing). Although Orpen waterhole supports a more diverse range of species, the landscape in which the waterhole is situated does not necessarily maintain a higher density of mammals compared to Satara. The lower number of herbivores recorded visiting the Satara water trough could be explained by the higher predator numbers, as shown in this study around Satara, which may be contributing to higher herbivore numbers at Orpen as opposed to Satara. Carnivores were more commonly sighted at Satara (9.15%) than at Orpen (3.46%).

Throughout the study period, impala and blue wildebeest were the most commonly sighted species at Orpen and Satara. A distinct difference between Orpen and Satara was exhibited by warthog, which were one of the most commonly sighted mammals at

Orpen (11.79% of total visitations; ẋ = 142 sightings per month), yet were not commonly sighted at Satara (0.40%; ẋ = 3). Additionally, warthog were the most commonly sighted grazer at Orpen (36.07% of grazer sightings), but the least commonly sighted grazer at Satara (0.81%). The higher number of sightings of warthog at Orpen could be as a result of the same resident warthogs that keep returning to the same waterhole. Collectively, the most commonly sighted feeding guilds at both Orpen and Satara were mixed feeders (59.50% and 41.82%, respectively) and grazers (35.83% and 55.93%, respectively), broadly depicting relative abundance of species (Redfern *et al.*, 2005; Hayward & Hayward, 2012). There are fewer browsers than grazers in the KNP system and therefore you would expect to see more grazers than browsers at the water sources. At both water sources, strict browsers comprised the least commonly sighted herbivore (4.67% and 2.25%, respectively). Browsers are typically less water-dependent than grazers, as they are able to access leaves which have a high moisture content (Western, 1975), while grazers need to access water regularly (Western, 1975; Smit, 2011).

Southern giraffe were the least sighted browsers at Orpen (16.04% of browser sightings), indicating their low water requirements and/or their low abundance in the granite landscape (n = 1319). Additionally, giraffe have a splay-legged drinking position, bending and angling their front legs to obtain an appropriate distance and height to the water source, consequently they are particularly vulnerable in this position, and therefore drink for only a few seconds before standing up (Dagg, 2014). Southern giraffe comprised 41.87% of browser sightings at Satara, likely due to their higher abundance within the basalt landscape (n = 3147). Primates comprised a higher percentage at Orpen (5.35%) than Satara (2.39%). This is likely because chacma baboon were the only primate to utilise the Satara water trough. Vervet monkeys were additionally recorded for Orpen.

The unequal distribution of utilisation validates the difference in water requirements between the different feeding guilds. Additionally, this difference is also because there is a much higher abundance of herbivores than carnivores within the KNP system; a general pattern within most conservation areas, where the abundance of top carnivores is low (Sinclair et al., 2013).

Black-backed jackal were the most commonly sighted carnivore at both Orpen and Satara (40.61% and 44.79% of carnivore visitations, respectively), likely reflecting that they are common within the Orpen and Satara areas. Additionally, the black-backed jackal may have been attracted to the water sources due these sites being illuminated at night, where they might catch insects which are drawn towards the light. Spotted hyaena were the second most commonly sighted carnivore (20.98% and 33.20%, respectively). The frequent visitation patterns exhibited by spotted hyaena at Satara water trough ($\dot{x} = 0.69$ sightings per day) than at Orpen ($\dot{x} = 0.29$ per day) reflect their water-dependence and thus their reliance on this water source for drinking and other activities such as caching, compared to the infrequent visitation patterns exhibited by lion at Orpen and Satara ($\dot{x} = 0.10$ and $\dot{x} = 0.15$ sightings per day, respectively). Spotted hyaena require regular access to water, and will journey out of their territories to find water when it is only sparsely available during the dry season (Cooper, 1989; Skinner & Chimimba, 2005). Spotted hyaena were observed sitting or standing in the Satara water trough during spring, summer and autumn. This behaviour was erratic in relation to the time of day, however, it was associated with hotter periods when hourly $T_{avg} > 24.26°C$. In addition, spotted hyaena also utilised the water trough for caching meat, which was observed on four different days during autumn and winter. Similar behaviour has been observed in the Serengeti National Park, where spotted hyaena cache chunks of meat under water (either a small water source or lake) as a way to store food and hide it from other predators (Kruuk, 1972). This behaviour was only observed at Satara, possibly because the small size and shallow depth of the water trough made it possible for the meat to be retrieved easily. Few lions (< 200 of likely the same individuals returning to the waterhole in their range) were sighted utilising the water sources throughout the study period, despite their large numbers in the central region of KNP where prey species are abundant. This is likely because lion are water-independent; however, if water is available they are known to drink frequently (Skinner & Chimimba, 2005). Serval were the least frequently sighted carnivore species at both Orpen (0.02%; ẋ = 0.24 sightings per month) and Satara (0.01%; ẋ = 0.08).

During this study it became evident that some species *viz.* Chacma baboon, African buffalo, African elephant, spotted hyaena and warthog utilise the artificial water sources for activities other than drinking. Chacma baboons were observed swimming in the Satara water trough, typically during the early morning from 7:00 to 9:00am. This activity took place between mean hourly temperatures of 20 - 28°C, with no seasonal preference. Activities in baboons are constrained by higher ambient temperatures, which may result in thermal stress (Hill, 2006). The temperature range and time of day that they were observed swimming may be in response to higher morning temperatures, therefore supporting their need to cool down and avoid thermal stress. At both Orpen and Satara, bull African elephants were observed spraying themselves with water (*Figure 6.1b*), from September to January, after midday and more particularly during the afternoon, when the mean hourly temperature was between 28 - 37°C. This behaviour by bull African elephants during hot periods suggests a thermoregulatory function. Warthog and African buffalo were observed wallowing in Orpen waterhole as well as in the large puddles that formed after rain and in mud once the puddles dried up (*Figure 6.1c,d,e,f*). Warthog were seen wallowing in spring, summer and autumn (51 of 748 days in the study period), generally after midday, when the mean hourly temperature was between 23 - 41°C and when T_{avg} was 33.28°C. Warthog are known to be sensitive to temperature extremes, and are unable to regulate their body temperature effectively, thus relying on their burrows for shelter on cold or rainy days and wallowing on hot days, which assists them with cooling (Estes, 1991; Bracke, 2011). Further to this, warthogs are particularly vulnerable during periods of low rainfall, as they maintain territories and thus rely on specific water sources (Owen-Smith & Mills, 2006). Consequently, they are usually one of the first species to experience major population declines with shifting climatic conditions and subsequent changes to the availability of food and water (Walker *et al.*, 1987; Mason, 1990).

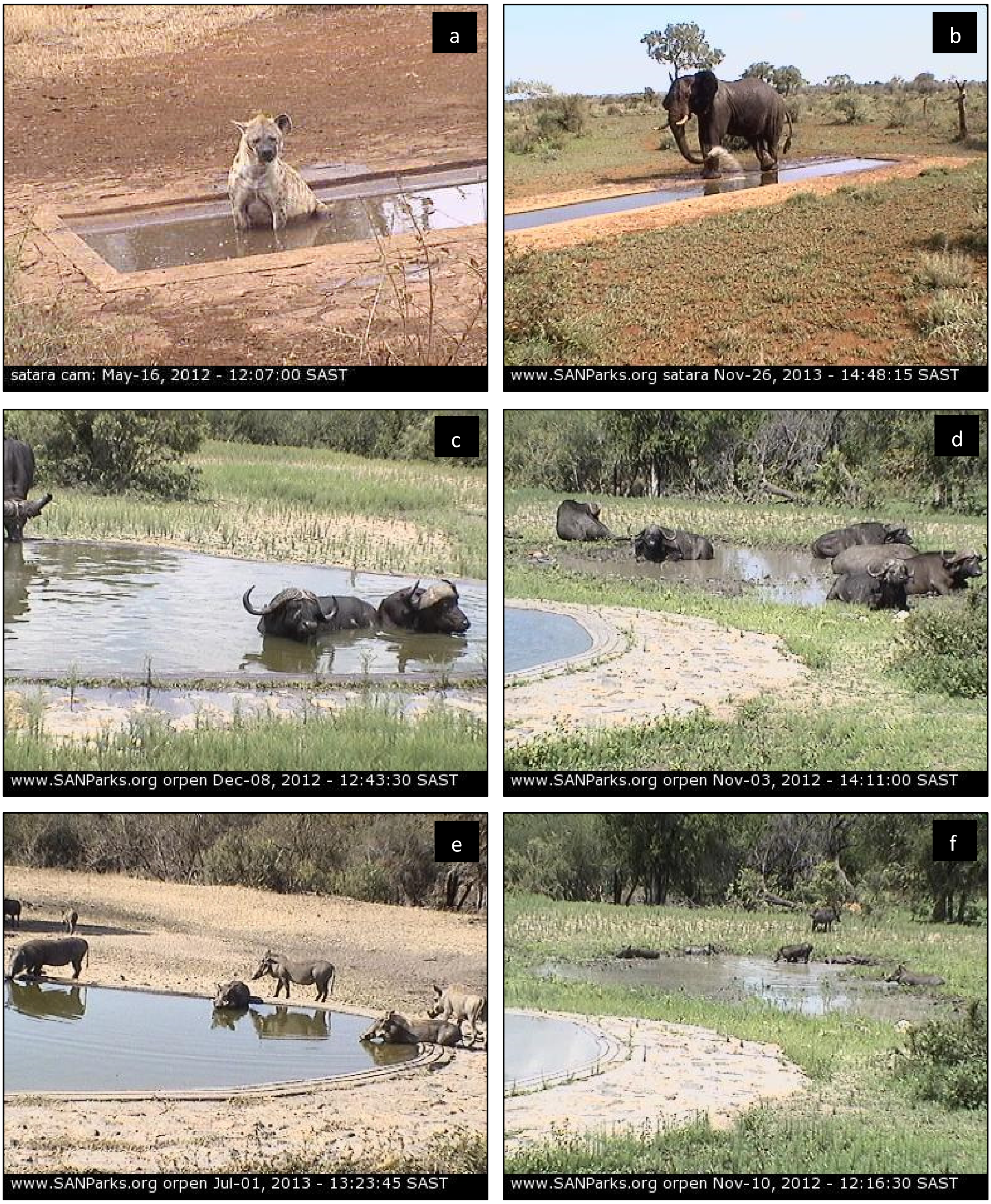


Figure 6.1: Spotted hyaena sitting in the Satara water trough, b) African elephant spraying itself with water from the Satara water trough, c) African buffalo wallowing in the Orpen waterhole, d) African buffalo wallowing in the puddle next to the Orpen waterhole, e) Warthogs wallowing in the Orpen waterhole and f) Warthogs wallowing in the puddle next to the Orpen waterhole.

African buffalo were also seen wallowing during spring, summer and autumn, in the morning and after midday, when the mean hourly temperature was between 28 - ≤ 41°C, inclusive and when T_{avg} was 31.04°C. This behaviour supports the suggestion that wallowing can be linked to higher ambient temperatures and is a behavioural trait used for thermoregulation (Skinner & Chimimba, 2005; Megaze *et al.*, 2013), assisting with heat loss while immersed in water as well as further heat loss when out of the water (Dunkin *et al.*, 2013).

6.4 Temporal Visitation Patterns

Herbivores exhibited predominant diurnal water source visitation patterns (8:00 - 17:00) while carnivores exhibited nocturnal visitation patterns (20:00 - 4:00), thus showing distinct temporal partitioning with regards to their water-use behavior. It has been noted in previous mammal behavioural studies that herbivores and carnivores drink at different times (e.g. Ayeni, 1975; Hayward & Hayward, 2012), with the cluster analyses validating the classification of dominant diurnal and nocturnal visitation patterns. However, there are a few exceptions to this pattern, with herbivores such as African buffalo, African elephant, common duiker and hippopotamus, and carnivores such as black-backed jackal and spotted hyaena exhibiting both diurnal and nocturnal visitations. Although African buffalo and African elephant are less vulnerable to predation, they may choose to drink during the day, under hotter temperature conditions. This is possibly to avoid the perceived threat of predation, particularly when there are calves present (Davidson *et al.*, 2013; Tambling *et al.*, 2015). Hippopotamus possibly exhibit nocturnal utilization as they graze during the night (Estes, 1991). Black-backed jackal are likely exhibiting diurnal visitation patterns to avoid overlap with large predators such as lion, as is also seen with wild dog and cheetah (Hayward & Slotow, 2005).

Whilst predator-prey interactions are more likely to explain whether prey species decide to visit the artificial water sources (Valeix *et al.*, 2007b), additional drivers such as climatic, astronomical and environmental factors influence the physiological and behavioural responses of species and their requirements for water. These factors consequently influence their visitation patterns at water sources.

6.4.1 Species Avoidance

Many species at Orpen and Satara exhibited similar temporal visitation patterns, suggesting that these patterns are common throughout the landscape, which was similarly found in Hwange National Park (Valeix, 2011). Mammals utilise a behavioural mechanism of adjusting the timing and duration of daily activities to control the extent of their heat exposure and water loss (Cain *et al.*, 2006). Herbivore species have different water requirements and have varying levels of water-dependency due to various physiological, morphological and behavioural adaptations that enable some species to survive in high-temperature, low-water environments (Cain *et al.*, 2006).

The concentration of mammal species within a particular landscape influences their use of specific water sources (Young, 1970). Thus, species' visitation patterns to water sources are likely determined by various factors (forage availability, presence of predators and water-dependency) within a landscape and not exclusively by the availability of a permanent water source. Mammals display different predominant activity periods throughout the diel cycle (Kronfeld-Schor & Dayan, 2003).

It is noted in this study that the daily temporal visitation patterns exhibited by mammal species differed according to feeding guild and body size, which broadly reflects their water-dependence as well as their risk of predation. Herbivores and small carnivores can temporally partition their visitation patterns to avoid overlap with predators by visiting the water sources during specific time periods (Valeix *et al.*, 2009c; Crosmary, 2012). Prey species abundance within specific habitats are both controlled by the presence of predators and by resource availability, and consequently, the permanent availability of water in artificial water sources has a further influence on predator-prey interactions as herbivores are likely to congregate in areas with perennial water sources (Valeix *et al.*, 2009b). Daily visitation patterns for all species demonstrate that the Orpen waterhole has more daytime sightings (dawn, morning, midday and afternoon) (87.62%) than Satara (75.78%). Conversely, Satara has proportionally more nocturnal sightings (dusk, early night, midnight and early morning) (24.22% vs. 12.38%), likely explained by Satara having more carnivore visitations.

Certain small- (impala) and medium-sized (blue wildebeest, greater kudu and plains zebra) herbivores are able to endure hotter temperatures than large herbivores such as African elephant and African buffalo (Ayeni, 1975), validating pronounced peaks in visitation during midday. Additionally, these species are restricting their visitation times to during the day, likely to reduce the risk of predation after dark (Weir & Davidson, 1965; du Preez & Grobler, 1977).

At both water sources, greater kudu, southern giraffe, vervet monkey, warthog and chacma baboons exhibited strict diurnal water source visitation patterns, with none of these species visitation patterns occurring before 5:45 or after 18:30. Strictly diurnal species may need to shift their water utilisation patterns to cooler nocturnal periods due to increasing daily temperatures (Huey *et al.*, 2012). However, this behavioural shift could lead to an overlap with predators (Hetem *et al.*, 2014). It would be expected that warthog, which are susceptible to thermal stress (Bracke, 2011), would be active during cooler periods (at night) and avoid the hottest periods of the day (midday and afternoon). However, warthog visitation peaked during midday and therefore their strict diurnal pattern is determined by the threat of predation and less because their heat/water balance/thermal limitations demand it. Chacma baboons generally utilised the water sources after sunrise and before sunset (6:00 - 17:30), with a strict cessation of visitation shown at Satara at 15:30, as they find a roost before sunset (Estes, 1991). Conversely, vervet monkeys favour riverine vegetation (Estes, 1991; Skinner & Chimimba, 2005) and maintain small territories (McDougall *et al.*, 2010), thus accounting for their infrequent daily visitation patterns at Orpen artificial waterhole (ẋ = 0.47 sightings) compared to chacma baboons (ẋ = 2 sightings).

Despite southern giraffe being water-independent, and thus able to endure drought periods, they can drink on a daily basis (Dagg, 2014). However, during this study their average sightings were < 1 per day (ẋ = 0.28 sightings per day at Orpen; ẋ = 0.19 at Satara), despite available water. It was recorded during this study that southern giraffe only drink during the day (5:45 - 18:30), however, Dagg (2014) recorded giraffe drinking during both day and night. Their peak visitation was during midday and the afternoon at both water sources, with other studies showing that they rest in the shade during the hottest periods of the day (Skinner & Chimimba, 2005).

Mega-herbivores (e.g. African elephant and African buffalo) are less vulnerable than small- and medium-sized herbivores to predation. These species visit water sources in large herds (≥ 20 individuals) and, given their large size, they are better able to protect themselves against predators than plains zebra and blue wildebeest (De Boer, 1990). Thus temporal partitioning of water source visitation is expected for the latter two species. During this study both plains zebra and blue wildebeest were rarely observed at the water sources after sunset (< 3% of total sightings), with drinking taking place primarily during the morning (8:00 – 10:59).

Peak visitation by African elephants at Orpen was during dusk (25.33%) and early night (19.53%), supporting studies in Hwange (Weir & Davidson, 1965; Valeix *et al*., 2007a) and Tsavo National Parks (Ayeni, 1975). It would be expected that their large body size allows them to visit the water sources during periods of overlap with large predators (de Boer, 1990). In contrast, at Satara, African elephant visitation peaked during the hottest part of the day (afternoon, dusk and midday; 22.82%, 22.54% and 18.31%, respectively); a midday peak in KNP, Pilanesberg National Park, Madikwe Game Reserve, Tembe Elephant Park and Mashatu Game Reserve, was also reported by Hayward & Hayward

(2012). African buffalo exhibited peak visitation times during dusk at Orpen (22.93%), however, at Satara their peak visitation period was during dawn (30.41%). This is in agreement with a study in Addo Elephant National Park, which observed that the presence of predators constrained the nocturnal activity patterns of African buffalo and greater kudu (Tambling *et al.*, 2015). Larger mammals such as African elephant and African buffalo temporally partition their visits to the water sources to cooler periods during the day (Ayeni, 1975), explaining the peak visitation time during dusk and morning.

During the study period, only one kill was observed at the water sources. An African buffalo was killed at the Satara water trough during dawn in the early dry season (2012), likely due to a trade-off, drinking during a risky period due to a decrease in the distribution and availability of water (*Figure 6.2a,b*). In a study in Hwange National Park, it was noted that the seasonal availability of water influences lion kills (Davidson *et al.*, 2013). Consequently, during dry years, species may be compelled to shift their temporal drinking patterns and thus risk the threat of predation due to their drinking water requirements (Valeix *et al.*, 2009b).

Figure 6.2: a, b) One male lion and two female lions taking down an African buffalo at the Satara water trough.

There is a gap of knowledge on the water needs of carnivores (Edwards *et al.*, 2015), as well as the influence of climate and astronomical conditions on their water reliance behaviour and visitation patterns. In KNP, where there is a diverse carnivore population, competition for resources such as water is likely to occur between dominant and sub-dominant species (Edwards *et al.*, 2015). However, at both water sources this clear divide between visitation patterns of large and small-sized carnivores is not evident. The majority of carnivore species visited the water sources nocturnally, from 20:00 (early night) to 4:59 (early morning) before dawn; this pattern was similarly observed in southwest Namibia (Edwards *et al.*, 2015). Specific carnivore visitation patterns which feel outside of the dominant visitation pattern were similar to the patterns observed in the study by Edwards *et al.* (2015) for 1) leopard, exhibiting predominant visitation patterns during dusk (25.49%), 2) black-backed jackal, exhibiting visitation patterns throughout the day and night, as they are considered nocturnal but are also diurnally active (Estes, 1991), and 3) honey badger, visiting the Satara water trough during dawn and in the morning. The study by Edwards *et al.* (2015) reported that small and large carnivores exhibited distinct temporal partitioning to avoid overlap at water sources. Overlap between species is likely caused by ecological drivers, such as temperature, and by interactions between predators which play a role in the predominant visitation patterns displayed by these species.

Honey badger (at Orpen) were never sighted from 8:00 - 16:59 and lion (at Satara) were never sighted from 8:00 - 19:59, therefore indicating that these mammals are strictly nocturnal drinkers at these water sources; at the alternative water source both species were sighted during the morning (8:00 – 10:59). African civet (at both water sources) and leopard (at Orpen) were only sighted from 17:00 - 7:59. At Orpen, serval were sighted at dusk, while at Satara, they were strictly nocturnal, only seen during midnight and the early morning. Small predators have been observed to shift their activity patterns to midnight to avoid large predators (Hayward & Slotow, 2009). Black-backed jackal (at Orpen) and serval and small-spotted genet (at Satara) all exhibit peak visitation times during midnight, although, lion also exhibit the same peak visitation period. However, none of these species were seen at the water sources at the same time. This could indicate that large predators such as leopard and lion temporally partition their visits to limit overlap at the waterhole, additionally the activity patterns of these large predators have been observed to decrease during midnight, which is usually the time when least light is available, shifting activity to dawn and dusk (Hayward & Slotow, 2009). However, this pattern was not observed with visitation patterns at both water sources, as both leopard and lion exhibited peak visitation times during midnight. Consequently, the diel phase which is most risky for prey species to drink at water sources is between early night and early morning (20:00 - 4:59), due to lion and spotted hyaena likely being present at the water sources during this period at both Orpen and Satara. This trend was also observed by Tambling *et al.* (2015), who indicate that during nocturnal periods, medium-sized herbivores are under greater threat of predation. A risk period for herbivores which includes daylight was reported by Valeix *et al.* (2009c) between 17:00 and 8:00. Furthermore, leopard exhibit peak visitation times during dusk (17:00 - 19:59) and early morning (2:00 - 4:59), thus extending the predation risk period for prey species at Orpen waterhole.

6.4.2 Species Overlaps

Herbivores, specifically grazers, were generally observed to have inter-species overlaps, likely using group vigilance to their advantage to avoid predation (Ayeni, 1975). Plains zebra and blue wildebeest had the most noticeable species overlap based on observation, which is consistent with Hayward & Hayward (2012). Their observed overlap may reflect the advantage that plains zebra offer to other species given their sharp sense of sight and smell (Skinner & Chimimba, 2005). It is notable that blue wildebeest were generally observed to arrive at the water sources before a herd of plains zebra, similarly observed by Young (1970). Plains zebra and blue wildebeest were generally observed visiting the water sources during the same time periods (*Table 6.1*) (i.e. during midday at Orpen and during the morning at Satara) (see also Valeix *et al.*, 2009c). Additionally, these two species are particularly vulnerable prey species and thus form inter-specific interactions by synchronizing their visitation times at water sources to increase their ability to detect predators (de Boer, 1990), specifically choosing to utilise water sources in areas that are more open (Smit, 2011).

Table 6.1: List of species social organisation, species overlaps, species not overlapping and other behaviour observed at Orpen and Satara water sources.

Mammal Behaviour				
	Social Organisation	**Species Overlap**	**Species Not Overlapping**	**Other**
African civet	Solitary/pairs	None	Black-backed jackal	-
African wildcat	Solitary	None	None	-
Black-backed jackal	Solitary/pairs/packs (4 - 5 individuals)	None	Hyaena, civet	Kleptoparasitism
Honey badger	Solitary/pairs	None	None	-
Leopard	Solitary	None	None	-
Lion	Males (solitary), lionesses and cubs drank together	None	None	-
Small-spotted genet	Solitary	None	None	-
Spotted hyaena	Solitary / pairs / clan (4 -5 individuals)	None	Buffalo, jackal	Cache meat
Common duiker	Solitary / pairs	None	None	-
Greater kudu	Family herd of about 5 individuals	Impala	None	Cautious approach
Southern giraffe	Bulls (solitary), tower of < 5 individuals	Zebra, buffalo	Warthog	Cautious approach
African buffalo	Small herds (< 10 individuals) or large herds (> 20 individuals)	Giraffe, impala, warthog	Elephant, spotted hyaena	Wallowing
Blue wildebeest	Large herds (> 20 individuals)	Zebra, impala, warthog	Buffalo, elephant	Synchronize times with zebra
Plains zebra	Small (< 5 individuals) to large herds (≥ 15 individuals)	Wildebeest, impala, warthog, giraffe, baboon	Buffalo, elephant	Cautious approach
Warthog	Sounder of 3 - 7 individuals	Impala, wildebeest, zebra, buffalo, elephant	Giraffe	Wallowing
African elephant	Bulls (solitary or group of < 4 individuals), females and calves in large family groups	Warthog	Buffalo	Bulls spray themselves with water
Impala	Large herds (> 25 individuals)	Wildebeest, zebra, baboons, buffalo, warthog, kudu, vervet monkey	Elephant	-
Chacma baboon	Troops of 5 - 20 individuals	Impala, zebra	Warthog	Grooming. Swimming
Vervet monkey	Solitary or in small troops (< 10 individuals)	Impala	None	-

Chacma baboons were observed at the water sources with both impala and plains zebra, showing similar (> 1.5) PCA scores, and are similarly sighted foraging with most browsing and grazing ungulate species (Skinner & Chimimba, 2005). Chacma baboons also show a similar (> 1.5) PCA score to warthogs. However, it was observed on one occasion that a troop of chacma baboons moved away from the water source when warthogs approached to drink (*Table 6.1*).

Most carnivores, excluding spotted hyaena and black-backed jackal, were not observed to have any species overlaps (*Table 6.1*). Spotted hyaena and black-backed jackal were seen at the Satara water trough together, with two black-backed jackal displaying kleptoparasitism (*Figure 6.3a,b*), a behaviour in which one species steals food from another. This has been noted previously in lion, spotted and brown hyaena and black-backed jackal (Cloudsley-Thompson, 1996). Black-backed jackals are known as scavengers and have been observed snatching pieces of meat from lion and hyaena (Estes, 1991; Schuette *et al.*, 2013).

Figure 6.3: a) Black-backed jackal waiting for a spotted hyaena to retrieve a piece of meat/bone out of the water trough, b) Black-backed jackal eating the piece of meat stolen from the spotted hyaena.

6.4.3 Seasonal Patterns of Visitation

The increase in rainfall in summer 2012/2013 likely ensured that there was more water in the landscape for the following dry season, therefore reflecting the relatively even distribution of mammals visiting the water source in autumn and winter 2013. However, the 2013 dry season rainfall received at both Orpen and Satara was below the average rainfall for the period 2007 – 2014. High levels of water source utilization in summer could be explained by the drying up of temporary pools of water which persisted throughout the dry season, but dried up as temperatures increase in spring and summer, therefore compelling mammals to drink from artificial water sources. A strong seasonal preference is expected in winter, particularly for herbivores, which congregate around water sources during the dry season, as the moisture content of vegetation decreases, and water availability is reduced. However, they maintain an extensive distribution in the wet season (Valeix *et al*., 2010), therefore reflecting the broader dry (75.64%) and wet (24.36%) season visitation patterns in 2012.

Seasonal visitation patterns by species was linked to the seasonal variation of water availability. African civet, common duiker, greater kudu and warthog exhibited strong dry season visitation preferences (> 50% difference in visitations across the wet and dry periods). Conversely, there was not a large difference (< 20%) in visitation during the wet and dry periods for blue wildebeest and chacma baboon at both water sources. This is likely explained by blue wildebeest and chacma baboon (largely water-dependent species), relying on water sources during both the wet and dry seasons. Blue wildebeest are highly water-dependent, thus drinking daily and foraging in close proximity to water (Berry, 1980), validating the indistinct seasonal drinking pattern observed here. At Orpen and Satara, warthog exhibited a strong seasonal preference for the dry season (82.25% and 88.06%, respectively) while plains zebra exhibited a higher percentage of use during the dry season, however, not showing as strong a preference (64.52% and 68.54%, respectively). The seasonal preferences exhibited by warthog and plains zebra in this study are in contrast to findings of Hayward & Hayward (2012) which show that these two species exhibit no seasonal preference.

The pattern of distinct increases in visitation during the dry season for African buffalo and warthog was similarly observed in Tsavo National Park (Ayeni, 1975). For warthogs, increased visitation during the dry season is also in support of previous work by Somers (1997), which showed that this species drinking frequency per hour increased during the dry season. The strong seasonal preference exhibited by warthog might be explained by their sedentary nature (Mason, 1990) which forces this species to rely on this artificial water source when the distribution/availability of water in the landscape decreases.

Impala showed an increase in visitation during the dry season at Orpen, however, they exhibited no seasonal preference at Satara. These findings are not consistent with recent research which reported that impala visitation peaked during summer (Hayward & Hayward, 2012). At Orpen, impala drank frequently, averaging 25.67 and 25.16 individuals per day during the 2012 and 2013 dry seasons validating that impala are particularly during the dry season (Jarman & Jarman, 1973), however, they can go several days without needing to drink if they can obtain sufficient moisture from green vegetation (Estes, 1991). The frequent sightings of impala reflects their abundance within the landscape.

Blue wildebeest showed no distinct seasonal preference at either water source, highlighting strong dependency on water throughout the wet and dry periods. This would support previous work, which showed daily drinking and foraging in close proximity to water (Berry, 1980). At both Orpen and Satara, blue wildebeest exhibited daily visitation patterns which are relatively consistent throughout the 2012 and 2013 wet periods (4.99 and 5.57 sightings at Orpen; 6.53 and 7.88 at Satara, respectively). Additionally, their daily visitation patterns were consistent during the 2012 and 2013 dry periods (4.10 and 3.10 sightings at Orpen; 5.84 and 4.66 sightings at Satara, respectively), and therefore further validates their dependence on water irrespective of season.

Vervet monkey (only sighted at Orpen) visitation peaked during the dry season (93.20%); indicating that this species is reliant on artificial water sources during the dry season and are less reliant on these sources during the wet season (Struhsaker, 1967). Dry season peaks in visitation were also recorded for greater kudu at both Orpen and Satara (79.38% and 87.82%, respectively), although in arid regions kudu have adapted to survive with little or no drinking (Skinner & Chimimba, 2005).

African elephant showed no seasonal preference at Orpen waterhole (56.52% in the dry season and 43.48% in the wet season), and can go without drinking for two to three days in the dry season (Skinner and Chimimba, 2005). However, they do require fresh water and shade to rest in during the heat of the day, particularly during periods of high temperatures (Skinner & Chimimba, 2005; Kinahan *et al.*, 2007). Conversely, African elephant at the Satara water trough, show a strong wet seasonal preference (75.77%). Both of these patterns are in contrast to seasonal drinking behaviours observed in Tsavo National Park (Ayeni, 1975) and in a recent study by Hayward & Hayward (2012) which was carried out at five different study sites throughout South Africa, where the numbers of African elephants at a water source increased during the dry season. Hippopotamus exhibited a strong dry season preference during both the 2012 and 2013 dry periods (76.92% and 92.31%, respectively) in their use of artificial water sources at the Orpen waterhole, as natural water levels are lowered due to less rainfall.

6.4.4 Time Spent at Artificial Water Sources

The duration that mammals spend visiting water sources is influenced by season, thermoregulation, species associations and herd size (Valeix *et al.*, 2007b). Additionally, the role of size, feeding guild and abundance of each species also influence the time spent drinking as these factors are known to shape species responses to the threat of predation (Valeix *et al.*, 2009b). Time spent drinking from water sources is, however, largely influenced by thermoregulation, as with an increase in temperature, the time spent at the water source decreases. This is particularly evident for larger sized herbivores such as African buffalo, African elephant, southern giraffe and plains zebra (Ayeni, 1975; Valeix *et al.*, 2007b). However, during warm conditions when certain mammals (i.e. African buffalo) wallow in the water sources, the time spent at the water sources increases.

Mixed-feeding impala (at both Orpen and Satara) and African elephant (at Orpen) spent more time (mean of 14 minutes, 42 seconds and 5 minutes, 54 seconds, time from when the first individual in a group starts to drink until the time the last individual in the group stops drinking, respectively) and (8 minutes, 18 seconds) drinking than other herbivores. This may in part be explained by the fact that mixed feeders and grazers are known to be water-dependent (Western, 1975; Estes, 1991) and therefore require a higher volume of water and consequently spend more time visiting water sources. However, the longer time spent at the water sources by impala and African elephant could additionally be explained by both the abundance of impala in central KNP, and their large herd sizes, which facilitate visitation at water sources and the large body size of African elephant. Furthermore, the duration of time that herbivores spend at water sources is influenced by the number of different herbivore species at the water source at the same time, likely explained by an increased level of vigilance with a higher number of species (Valeix *et al.*, 2007b). This behaviour was displayed by impala, which were noted having a high number of species-associations. On an individual basis, African elephant bulls were observed to spend a long time at the water sources, on one occasion a bull spent ~120 minutes at Satara water trough. It has been noted that an individual can consume ~200 liters during a single drinking episode (Skinner & Chimimba, 2005).

The least amount of time (< 3 minutes) spent at both water sources for herbivores was exhibited by browsers (common duiker, greater kudu and southern giraffe). Southern giraffe and greater kudu were particularly cautious when approaching both of the water sources. Greater kudu would consistently be on the lookout, with one or two individuals standing and observing the surroundings; if alarmed while drinking, they would retreat into the bush (Estes, 1991), thus explaining the short time (< 2 minutes) spent at the water sources. At both Orpen and Satara, carnivores spent < 1 minute utilising these water sources, with the exception of black-backed jackal and spotted hyaena which spent on average 1 minute 6 seconds and 1 minute, 12 seconds, respectively at Satara.

6.5 Differences between Species Visitation at Orpen and Satara

Variation in timing trends and overall levels of water source utilisation for individual species at Orpen and Satara may, in part, be explained by differences of the two sites including vegetation, proximity to roads, proximity to rest camps, proximity to other water sources, predator-prey interactions, topography and abundance. Therefore it is not possible to generalise results for the broader landscape due to the divergent patterns observed between the two study sites, suggesting that local conditions/context are important. Additionally, these differences could be explained by the design of the water source: the size, structure, depth, perimeter and ability to get into the water, which could facilitate species avoidance or associations. Orpen artificial waterhole is a large, round cement shape, whilst Satara is a narrow, long, rectangular cement 'trough'. Species such as blue wildebeest, plains zebra, greater kudu and warthog, which exhibit similar temporal visitation periods at both water sources, showing strict diurnal patterns, are more specific in their drinking requirements, possibly attributed to predation risk.

Orpen waterhole had 44.69% more total visitations than Satara, suggesting that there is a lot of variability between the two sites. This difference is most likely linked to the availability of alternative water sources, however, it could also be linked to the size of the water sources, and thus the 'accommodation' space available. Distance estimates of herbivores per landscape, indicate that the basalts support a greater number of greater kudu, southern giraffe, blue wildebeest, plains zebra and impala. However, there are a greater number of African elephant in the Orpen landscape. Therefore, the higher percentage of visitations at Orpen is not due to greater mammal abundance, but this difference could be explained by the available water sources in the two different management regions. The closest river to the Orpen waterhole is the Timbavati (< 2km), followed by the Sweni river (~18.34km); the Satara water trough is in close proximity to both the Nwanedzi (~2.06km) and Sweni (~8.98km) rivers (*Table 6.2*), as well as benefitting from additional supplementary boreholes. The relative lack of natural surface water in the immediate vicinity of the Orpen waterhole likely explains heavy utilisation here. These rivers which are in close proximity to the study sites are seasonal, with the closest perennial river (Olifants) located ~45.51km from Orpen and ~46.31km from Satara (*Table 6.2*). Browsers such as greater kudu and southern giraffe, and mixed feeders such as African elephant and impala, favour rivers over artificial water sources. Conversely, grazers, such as African buffalo, blue wildebeest and plains zebra, favour artificial water sources over rivers (Smit *et al*., 2007a). The preferences of blue wildebeest and plains zebra for artificial water sources is supported by their high levels of utilization at both Orpen and Satara, with impala also exhibiting a preference for the artificial water sources, which is in the contrast to the findings by Smit *et al.* (2007a).

Larger African elephant herds ($\dot{x}$ = 13 individuals, maximum = 30 individuals) were observed visiting Orpen waterhole, where many individuals are able to congregate at one time, drinking from the waterhole simultaneously, whilst lone bulls or smaller herds ($\dot{x}$ = 3 individuals, maximum = 15 individuals) were observed at Satara water trough. This difference is likely due to both the shape and size of the two water sources (i.e. ‘accommodation space’), the proximity of these water sources to rivers and further to this the greater African elephant density in the Orpen landscape. Additionally, solitary elephant bulls are known to be found in the Satara landscape (Gertenbach, 1983). Mixed herds of African elephants, which generally consist of adults and juveniles, need to travel over shorter distances to find water and drink more regularly than bull African elephants (Smit *et al*., 2007b). Furthermore, mixed herds have been found near rivers, where they are able to forage the vegetation in close proximity to the rivers and drink water (Smit *et al*., 2007b).

Table 6.2: The approximate distances of Orpen and Satara to the main seasonal and perennial rivers in the central region. Closest distance to a river is highlighted in grey.

Distance to Rivers					
Orpen			**Satara**		
River	**Seasonality**	**Distance (~km)**	**River**	**Seasonality**	**Distance (~km)**
Nwanedzi	Seasonal	33.21	Nwanedzi	Seasonal	2.06
Nwaswitsonto	Seasonal	19.01	Nwaswitsonto	Seasonal	24.42
Olifants	Perennial	45.51	Olifants	Perennial	46.31
Sabie	Perennial	63.71	Sabie	Perennial	63.46
Sweni	Seasonal	18.34	Sweni	Seasonal	8.98
Timbavati	Seasonal	2.00	Timbavati	Seasonal	19.22

6.6 Unmeasured variables

Various additional drivers of mammal behaviour at artificial water sources may have influenced their use by species, and the temporal patterns of visitation (*Table 6.3*). Due to time constraints, not all variables could be assessed for their impact on drinking behaviour and water source use. For example, the presence of adults and juveniles was not determined for each species, which has been shown to be an influential driver of both the decision to drink as well as the time spent drinking (Valeix *et al*., 2007b).

The presence of tourists affects species behaviour at water sources and ultimately whether a species decides to utilise a water source (Kamanda *et al*., 2008). The influence of this variable on visitation patterns could not be determined during this study, however, this impact is minimal given the heavy use of the Orpen waterhole, despite being very close to a very busy road / camp. The risk of hunting has also been found to affect herbivore visitation patterns at water sources (Crosmary *et al*., 2012), although this factor is not applicable in KNP.

Table 6.3: Multiple drivers influencing water source visitation patterns. Variables which were considered for this study, but for which no analyses were conducted, are indicated with an asterisk.

Additional drivers of mammal behaviour at artificial water sources	
Environmental	
Surrounding vegetation – forage*	Valeix *et al.* (2008)
Tree cover - shade	Young (1970)
Availability of water after rainfall	Young (1970)
Water quality	Smit *et al.*, 2007b
Cloud cover	Valeix *et al.*, 2008
Wind patterns*	Valeix *et al.*, 2008
Behavioural	
Physiology	Young, 1970
Predator-prey interactions*	Fuller *et al.*, 2014
Interference competition	Valeix *et al.*, 2007b
Juveniles	Valeix *et al.*, 2007b
Herd size	Valeix *et al.*, 2007b
Thermoregulation	Valeix *et al.*, 2007b
Water source specific	
Size and shape	Adams & Thibault, 2006
Location specific	
Proximity to rest camps	
Proximity to roads	
Proximity to other water sources - artificial water sources, dams and rivers*	Young, 1970
Tourist presence	Kamanda *et al.*, 2008
Hunting	Crosmary *et al.*, 2012

6.7 Environmental and Astronomical Influences on Mammal Visitation Patterns (Measured Variables)

Environmental and astronomical conditions which control temperature, light and water availability, influence the predominant activity periods and visitation patterns of mammals at water sources (Young, 1970; Maloney, 2005; Tefempa *et al.*, 2008). Rainfall constrains mammal behaviour in savanna environments (Owen-Smith, 2000), however, the temporal partitioning of various daily mammal activities is largely influenced by light availability and temperature, as controlled by sunrise and sunset and the angle of the sun (Nouvellet *et* *al.*, 2012; Owen-Smith & Goodall, 2014). Additionally, mammal behaviour is influenced on a seasonal basis according to variation in both climatic variables and forage availability (Owen-Smith & Goodall, 2014).

6.7.1 Temperature

Temperature is a likely key driver of the diel and seasonal patterns seen in herbivore visitation, whilst rainfall, and thus the availability and distribution of natural surface water, is likely a driver of the type of water source which mammals drink from; broadly depicting a temporal control of temperature and a spatial control of rainfall. Mammal visitation declined during the hottest hourly T_{avg} at both Orpen and Satara. This pattern is in agreement with research in Hwange National Park, where there was a decline in herbivore presence in open areas during the hottest periods of the day (Valeix *et al.*, 2007b), and in Waza National Park, where there was a decrease in water source visitation between 12:00 and 13:00 when temperatures were highest (Tefempa *et al.*, 2008). Furthermore, in KNP, it has been observed that ungulates are less likely to travel to water sources when the temperature is > 35°C (Young, 1970). Similarly, they are less likely to drink when the temperature is < 19°C (Young, 1970).

The trend for all species investigated to have earlier visitation on days with the highest T_{avg}, may reflect contemporary behavioural adjustments to the extreme temperatures which are likely exacerbated under future projected climate change scenarios. The shift in timing of daily visitations, reflects changes in temperature, rainfall, sunrise and sunset, with extreme temperature conditions likely to further influence the timing of daily activities, with an increased risk of thermal stress (Shrestha *et al.*, 2014). At Orpen and Satara, pooled herbivore peak visitation periods shift earlier during the day with increasing T_{avg}; the earliest peaks occur on days with temperatures between 30°C - 35°C at Orpen and between 25°C - 30°C at Satara. Such results indicate a broad trend towards earlier diurnal visitation patterns during higher T_{avg} intervals. The optimal periods of water source visitation are 10:00 at Orpen and 9:00 at Satara. Species utilise water sources during these time intervals to reduce thermal stress and avoid heat loads during the hottest period of the day.

Orpen demonstrates clear diurnal visitation peaks in relation to T_{avg}, whilst at Satara T_{avg} appears to also affect nocturnal visitation patterns. There are a higher percentage of carnivores visiting Satara water trough (9.15%) compared to Orpen (3.46%), likely contributing to the weaker relationship between T_{avg} and mammal visitation here. This suggests that predator/prey relationships have a greater influence on herbivore visitation patterns at Satara relative to the Orpen water source. Peak visitation periods for pooled carnivores are shifting later into the night at both water sources as T_{avg} increases.

Behavioural responses to temperature differ between species (body size and feeding guild). It is therefore expected that smaller species (impala and warthog) would show more pronounced changes in drinking behaviour between seasons and between average and extreme days. Herbivores, in particular, may be reacting to the fine scale change in temperature occurring at an hourly interval, which allows them to adjust their activity patterns throughout the day, according to the ambient temperature (Shrestha *et al.*, 2014; Tambling *et al*, 2015). Thus, to determine the influence of temperature on mammal visitation patterns at water sources, data need to be analysed at a fine resolution.

Blue wildebeest, warthog and southern giraffe at Orpen, and plains zebra, greater kudu and blue wildebeest at Satara, exhibit a shift to earlier visitation when T_{avg} is >20°C, likely because temperatures will also be higher at earlier hours on such days, which possibly triggers instinctual behavioural responses toward feeding, resting and drinking. It is interesting to note that both water-dependent and water-independent herbivores are exhibiting the same response to T_{avg}. This supports the fact that during summer, mammals are adjusting their diurnal activity patterns to avoid heat stress (Shrestha *et al.*, 2014).

African elephant require shade during the heat of the day, particularly during periods of high temperatures (Skinner & Chimimba, 2005; Kinahan *et al.*, 2007). This behaviour explains why they shift their peak visitation times later into the evening on the highest T_{avg} days. However, a recent study by Tambling *et al.* (2015) noted that African elephant foraging activity in Addo Elephant National Park increased during the day when maximum ambient temperatures were highest. African buffalo utilise both Orpen and Satara water provisioning sites earlier during the morning on the highest T_{avg} days, a trend similarly found with the foraging behaviour of African buffalo in KNP (Owen-Smith & Goodall, 2014). These patterns support larger mammals (such as African elephant and African buffalo) not being able to withstand high temperatures and therefore avoid utilising water sources during such periods. African buffalo and African elephant show weak relationships with T_{avg} and no clear seasonal patterns of visitation, indicating that their large body size is likely facilitating their dispersed monthly drinking patterns and their ability to shift drinking times in favour of changing environmental conditions with little regard of large predators. Conversely, smaller mammals shift their water source visitation periods in response to the threat of predation (Ayeni, 1975). Medium-sized herbivores lose water by sweating and panting, which they use as a mechanism for evaporative cooling (Maloiy & Hopcraft, 1971). Impala function optimally and are most active at temperatures between 21°C - 31°C (Klein & Fairall, 1986). Impala experience thermal stress at temperatures between 35°C - 50°C (Maloiy & Hopcraft, 1971) and are consequently vulnerable to temperature extremes (Klein & Fairall, 1986). This vulnerability supports the extreme shifting of their peak visitation periods one hour earlier when $T_{avg} > 15$°C. Under the highest T_{avg} interval, impala, along with warthog, southern giraffe and African buffalo at Orpen, and plains zebra at Satara, show a shift to earlier visitation by between 1 - 6 hours, thus forcing them to utilise the water sources outside of their preferred temporal range.

Blue wildebeest demonstrate weak correlations between their peak appearance and temperature variables (T_{max}, T_{min} and T_{avg}), and therefore a lack of relationships with their peak appearance and temperature variables (T_{max}, T_{min} and T_{avg}), confirming their strong water-dependency irrespective of the time of day or temperature. The strictly diurnal visitation patterns of blue wildebeest may suggest that their behaviour is largely driven by predator avoidance, as they are a preferred prey species for lions due to their body size (Hayward & Kerley, 2005). However, at both Orpen and Satara, blue wildebeest are observed drinking 1 hour earlier outside of their preferred range, from morning (8:00 – 10:59) to dawn (5:00 – 7:59) under the highest T_{avg} interval, which has the consequence of overlapping with predators such as leopard (at Orpen), lion and spotted hyaena (at Orpen and Satara). Blue wildebeest have been noted to adjust both their daily and seasonal patterns of behaviour, particularly the amount of time spent feeding, under higher temperature conditions (Maloney *et al.*, 2005).

The increase in temperature due to the hotter and more arid environments predicted for some areas under climate change will add further stress to mammal species living in these environments as they will need to cope with higher temperatures, and changing rainfall patterns, likely increasing their need for water (Fuller *et al.*, 2014). Thus, the temporal partitioning of daily activities by mammal species will be influenced by increasing temperatures and environmental changes, likely forcing mammals to trade-off drinking from water sources during the day when temperatures are high, so as to avoid predation at night (Fuller *et al.*, 2014). However, specific trade-offs as evident in the behaviour patterns revealed by the webcam analysis, suggest that nocturnal visits to water sources may increase following very hot days. The adjustments that mammals will need to make to their behaviour patterns and physiology due to environmental change, will have consequences for their survival (Kronfeld-Schor, 2015).

6.7.2 Rainfall

The presence and absence of rainfall has an influence on temporal visitation patterns at water sources, over monthly, seasonal and inter-annual scales. The absence of rainfall, due to drought, which may occur over an extended period, is likely to have a significant impact on mammal visitation patterns, with some species possibly deviating from predominantly nocturnal visitation to also utilising the artificial water sources diurnally.

At both water sources, pooled mammal species sightings increase on days before and on the day of rainfall, likely because of increased time since the previous rainfall event, with significantly higher means on days before rainfall compared to days after rainfall. Herbivores, specifically water-dependent species, rely on drinking water during the dry season when the vegetation that they consume is unable to fulfill their water requirements (Valeix, 2011). During the wet season, or during periods of rainfall, the formation of pools of water increases both the distribution and availability of water to mammals, thus explaining the decrease in visitation after rainfall events. Herbivores are therefore particularly influenced by the timing of rainfall events, as the presence and absence of this climatic variable affects their ability to access this resource on a seasonal basis. This feeding guild would be then expected to drive such a response to the presence and absence of rainfall. However, of the herbivores, grazers and mixed feeders show that the mean number of sightings on the day of rainfall, are significantly higher compared to 1 or 2 days after rainfall.

The majority of carnivores show no clear relationship with the timing of rainfall events, indicating that these species utilise water sources only if it is available, therefore their visitation patterns are not influenced by the presence or absence of rainfall. An exception is black-backed jackal, which exhibit a decrease in the number of sightings 1 or 2 days after rainfall, which is possibly linked to their diet, which includes insects (Hall-Martin & Botha, 1980), which would be most abundant immediately after rain or during the wet season.

Certain species such as hippopotamus, which were observed to predominantly utilise Orpen waterhole during the dry season, may need to utilise this waterhole when rainfall is below average in the wet season months, as this species is particularly vulnerable to shifting rainfall patterns (Lewison, 2007). Hippopotamus are reliant on pools of water in which they can submerge themselves during the day, and during drought conditions the availability of suitable pools decreases, which promotes overcrowding and intra-species competition (Smuts & Whyte, 1981). Thus further increasing this species dependence on artificial water sources.

6.7.3 Sunrise and Sunset

A recent study in KNP found that pronounced peaks in the activity patterns of sable antelope, African buffalo and plains zebra occurred during or after sunrise and close to sunset, likely coinciding with the cooler diurnal periods (Owen-Smith & Goodall, 2014). Exclusively diurnal mammals (most of the herbivores in this study) are likely to partition their visitation patterns in relation to changing sunrise and sunset times and the availability of light, whilst exclusively nocturnal mammals are likely to adjust their visitation patterns before sunrise and after sunset (Hill *et al*., 2003). Herbivores are more influenced by the seasonal variation in day length than carnivores as their activity patterns are restricted by light availability (Hill *et al*., 2003).

Black-backed jackal utilised both Orpen and Satara predominantly during the night, and displayed a weak, negative correlation with sunset (r = -0.03 and r = -0.06, respectively), thus visiting the water sources earlier as sunset shifted later and vice versa, essentially avoiding visitation during dusk. However, elsewhere the predominant activity periods of this species overlapped with sunrise and sunset (Walton & Joly, 2003).

At Orpen, southern giraffe and leopard show significant relationships with both sunrise (r = 0.26 and r = -0.21, respectively) and sunset (r = -0.35 and r = 0.18, respectively). For southern giraffe, as sunrise shifts earlier, visitation shifts earlier, and when sunrise shifts later, their peak visitation times shift later. Conversely, as sunset shifts earlier, their visitation times shift later, and as sunset shifts later, visitation times shift earlier. Leopard displayed inverse relationships. These patterns indicate that during seasons with longer periods of daylight (spring and summer), southern giraffe shift an entire period of activity earlier. Leopard shift their activity period (delimited by later dawn visitation patterns and later dusk visitation patterns) later.

At Satara, African buffalo have a positive relationship with sunrise (r = 0.16) and a negative relationship with sunset (r = -0.20). These relationships demonstrate that this species are avoiding the water sources when temperature and light availability are likely to increase with sunrise. This is likely explained by African buffalo being physiologically unable to tolerate high temperatures, but because they are less vulnerable to predation with visitation to water sources in large herds, shifting their dusk visitation times (earlier with later sunset and later with earlier sunset) is less important. African elephant show a similar pattern with sunset (r = -0.20), likely also due to their large body size allowing them to defend against predators.

At Orpen, warthog were the only species that exhibited positive relationships with sunrise (r = 0.01) and sunset (r = 0.06). This species is capitalizing on the longer period of daylight, utilising the waterhole earlier in the morning and later in the evening, therefore their period of activity is wider when there is more light available. Warthogs are strictly diurnal, and female warthogs and their young typically move into their burrows before dark, where they are sheltered from both the risk of predation and climatic conditions (Estes, 1991). At Satara, warthog exhibit a positive relationship with sunrise (r = 0.26), therefore making use of longer daylight hours, when more light is available, and are likely avoiding overlap with predators. This behaviour confirms that warthog are responding to changes in light availability and temperature as a consequence of changes in time, which is thus a variable which prey species can manipulate to avoid encountering predators at water sources and the threat of predation (Valeix *et al.*, 2009c).

Lion exhibit a negative relationship with sunrise at both Orpen and Satara (r = -0.10 and r = -0.45, respectively). However, more interestingly, they exhibit a positive relationship with sunset at both water sources (r = 0.12 and r = 0.39, respectively) (significant at Satara), utilising the water sources earlier with earlier sunset and later with later sunset. This pattern of shifting peak visitation times could be explained by their activity periods; lion being active during dawn and dusk, and may shift their water source visitation patterns with sunset in an attempt to encounter crepuscular prey species at the water source. No species at Orpen had negative relationships with both sunrise and sunset. However, at Satara, plains zebra exhibit a weak negative relationship with both of these variables (r = -0.03 and r = -0.02, respectively). This pattern might have been expected for a nocturnal species, as this would have reflected shorter periods of activity with increasing hours of daylight, and therefore less hours of darkness.

6.8 Broader Implications of Results

The Orpen and Satara artificial water sources are positioned in different regions within central KNP, underlain by different geologies which are characterised by specific vegetation (Gertenbach, 1983). The results from these two water sources are site specific, representing only two landscape units in KNP, and it is therefore not possible to determine whether the species composition and abundances observed in this study, are representative of broader mammal behaviour patterns in KNP. A comparison of local with regional mammal abundance is necessary to establish representivity within the larger landscape units of the study sites. Further to this, the broad aim of this study was to contribute to the understanding of mammal temporal visitation patterns at artificial water sources, and more specifically towards exploring these patterns as affected by various climatic and astronomical components. In the context of future climate change scenarios and the resultant decreasing natural water supplies, the water provisioning policy for KNP may need to be further revised, as artificial water sources are likely to become essential to meet mammalian water requirements.

6.8.1 Preference and Avoidance of Artificial Water Sources

Aerial census for KNP is an important ecological monitoring methodology, which provides management with mammal population estimates (Buckland *et al.*, 2015). However, there are biases associated with this methodology, notably a visibility bias, resulting in undercounting (Redfern *et al.*, 2002). A methodological limitation of the webcam survey, as an example of a local fixed point method, is over counting (however, webcams in this study were used to determine the relative proportions of different species), amongst others. These biases have implications for using either estimate for research and management purposes. It is therefore important to compare the data obtained from the webcams with other techniques. For the winter months of June, July and August the relative abundances calculated from the webcam data were statistically similar to those from the regional census.

The dominant underlying geologies of the regions in which Orpen and Satara are situated were used to explore whether there are differences in preferential or avoidance behaviour of the artificial water sources at the two study sites. Blue wildebeest at both Orpen and Satara show a higher proportional distribution locally than at larger scales (*Figure 5.31a,b; Figure 5.32a,c*), indicating preferential use of the water sources. This supports their abundance in close proximity to artificial water sources, as reported previously by Smit *et al.* (2007a).

Warthog and African elephant at Orpen exhibited notable preferential use of this waterhole, yet warthog at Satara exhibit strong avoidance of this water trough (*Table 5.34; Table 5.35*). African elephant have a weak association with rivers on granite, validating their preferential use of the Orpen artificial waterhole, yet have a strong association with rivers on basalts (Smit *et al.*, 2007a), possibly accounting for their relative avoidance of the Satara water trough. African buffalo, despite being known as water-dependent, exhibited avoidance behaviour for both Orpen and Satara water sources, likely because these mammals prefer larger bodies of water and positively associate with rivers on both basalt and granite (Smit *et al.*, 2007a).

Impala exhibited a higher percentage abundance in their landscape estimates at Orpen and Satara (*Figure 5.31a,b; Figure 5.32a,c*) compared to their use of the water sources; this being due to their strong association with rivers and the fact that they do not apparently occur in close proximity to artificial water sources (Smit *et al.*, 2007a). Despite their avoidance of these artificial water sources, they do rely on these structures for drinking, particularly during the dry season. Furthermore, the higher number of impala observed at the Orpen waterhole compared to Satara may be due to the species utilising other water sources at Satara, which is in agreement with the study by Smit *et al.* (2007a). The study found that impala have a strong association with rivers on basalts (Satara) and that large impala herds are not found in close proximity to artificial water sources on the basalts (Smit *et al.*, 2007a). A clear pattern is shown between water-dependent and water-independent species, with the exception of African buffalo at Orpen and warthog at Satara; the water-dependent species (impala, blue wildebeest, plains zebra and African elephant) are visiting these water sources in relative proportion to their abundance in the central region, whilst the water-independent (browsers) are exhibiting avoidance behaviour. Browsers, southern giraffe and greater kudu, both show indistinct proportional use of Orpen and Satara, compared with their landscape estimates, which corresponds with the Smit *et al.* (2007a) study, which documented that browsers show weak associations with artificial water sources and are consequently more commonly associated with rivers, as well as demonstrating that these species are not as reliant on these water sources as the water-dependent species.

6.8.2 Climate Change and Mammal Visitation Patterns

South Africa is likely to experience warming of between 1 and 3°C over the next 5 decades (Madzwamuse, 2010; Davis, 2010). Such a projected increase in temperature has implications for mammal water source visitation patterns, intra- and inter-species competition and predator-prey interactions, as herbivores are drinking from the water sources earlier on 'hot' days whilst carnivores are shifting their visitation patterns during the night in response to increasing temperature, thus indicating a narrowing/widening gap between the visitation periods between certain predators and prey and larger and smaller mammals. These changes in temporal visitation patterns are likely to influence the vigilance behaviour of individuals and groups of mammals. Considering the projected increases in mean maximum and minimum temperatures (van Wilgen *et al.*, 2015), mammals in KNP will likely be subjected to an increase in days which the temperature will be > 30°C. Specifically, water-dependent grazers and mixed feeders are responding to temperature cues and therefore their water/heat balance will force them to shift their visitation periods. Under extreme temperature conditions there might be pressure to drink very early during the day or late at night to avoid high diurnal temperatures. At Orpen blue wildebeest and plains zebra currently exhibit strong species-associations, visiting the waterhole at the same time during the morning. However, this species association will likely break down under extreme temperature conditions, as blue wildebeest are projected to shift their morning drinking period earlier, to dusk. This breakdown in association will likely have consequences as there will be less collective vigilance for predators. However, a new species association is likely to form as southern giraffe are expected to shift their visitation period to dawn, thus facilitating the association between this species and blue wildebeest. At Satara the species association between blue wildebeest and plains zebra will not be affected under extreme temperature conditions, as both of these species will shift their predominant visitation period from morning to dawn. These shifts to earlier visitation patterns for these herbivores may facilitate the overlap of activity periods between these preferred prey species and their predators.

Most of the predators show an erratic response to temperature intervals, therefore predicting their behaviour under extreme temperature conditions is less accurate, however, carnivores may shift their visitation patterns later into the night in response to warmer evening temperatures. Spotted hyaena exhibited both diurnal and nocturnal visitation patterns, and were also observed to sit in the water sources. Under extreme temperature conditions this carnivore may move towards a more diurnal visitation pattern, as their heat balance may demand it.

A new species association under extreme temperature conditions will also form between impala and plains zebra, as well as African buffalo, which will all drink within the same time period. There may be reduced competition between the mega-herbivores African buffalo and African elephant under extreme temperature conditions, as African buffalo are likely to shift their predominant visitation period to dawn whilst African elephant are likely to shift their predominant visitation periods to dusk. Impala and blue wildebeest are the most sensitive species to increasing temperature, as they respond at the lowest temperature interval. African buffalo and African elephant exhibit the most extreme response to increasing temperature, as their shifts to earlier and later visitation patterns are the largest per 5°C increase in temperature. These species temporal visitation patterns will therefore be particularly influenced under climate change conditions, with a notable change in their behaviour.

The increase in variation in rainfall patterns in KNP (van Wilgen *et al.*, 2015) will mean that mammals will experience longer dry periods, thus particularly influencing mixed feeders and grazers such as impala, African elephant, blue wildebeest and plains zebra, species which have been noted to respond to rainfall cues. Certain herbivores are choosing to drink during the day to avoid predators, however, other herbivores are drinking during the day because their heat/water balance demands it. Warthog and chacma baboon are likely responding to predator avoidance, as these species maintain a strict diurnal visitation pattern, which is less influenced by temperature and rainfall conditions. Whilst mixed cues (temperature, rainfall and predator avoidance) are exhibited by impala, blue wildebeest and plains zebra, with these species exhibiting shifts in their visitation patterns as influenced by a combination of these factors.

6.9 Methodological Limitations

The method used in this study to monitor mammal behavior at water sources, has not been widely employed to date. During the process of data collection and analysis, various limitations were encountered pertaining to the study sites, webcam, webcam and climate data and statistical analyses. Addressing these limitations should inform future research efforts using webcams to monitor mammal behaviour patterns.

6.9.1 Study Site Limitations

The data captured by the fixed webcams at Orpen and Satara are limited due to the continuous re-sampling of the two water source sites, therefore there is little context to the surrounding landscape. Artificial water sources supplement water in water scarce environments and are therefore likely to support higher numbers of mammals due to the permanent availability of water. Additionally, they are also likely to facilitate inter- and intra-species competition and interaction due to mammals congregating within these areas (Valeix *et al.*, 2007a). There are many advantages of artificial water sources given that they provide a permanent supply of water to mammals, they are inexpensive to construct and require little maintenance. Artificial water sources provide a useful study site to conduct research on mammal behaviour, attracting a range of species (Valeix *et al.*, 2008). Thus facilitating research on both large and small, diurnal and nocturnal mammals.

Both study sites are located in close proximity to tourist roads as well as to the Orpen and Satara rest camps. It is likely that the presence of both tourists and cars may influence mammal behaviour and consequently whether mammals decide to come and drink from these artificial water sources (Weir & Davidson, 1965; Kamanda *et al.*, 2008; Valeix *et al.*, 2008). Future studies could investigate whether this does affect specific species visitation patterns, by comparing mammal distribution at an artificial water source close to a rest camp/road with that of a water source situated in a remote area.

6.9.2 Webcam Image Limitations

The method by which webcam images are captured differ according to the position of the webcam and the mode of the camera, both with disadvantages and advantages. The static camera mode allows for a consistent view of the entire waterhole/trough, however, it means that the captured images have a wide field of view. The panning camera mode captures images of the water source from different angles throughout the day, panning from one side of the waterhole/trough to the other, capturing a narrow field of view. The disadvantage of the latter mode is that mammals visiting the water source may not be captured if the camera is not focused on the animal(s) at a specific time. The wide or narrow field of view of the cameras is adjusted by SANParks, thereby providing online viewers of the webcams a different perspective of the water source. Given the high temporal resolution at which images are captured, the different views are only likely to influence the data received during the wet season when mammal visitations decrease and for species which visit the water sources infrequently.

As expected, a considerable amount of time is required for image and data processing as reported by Ancrenaz *et al*. (2012). This is because a large number of images need to be individually viewed and interpreted due to the high temporal resolution required for data analysis. There are numerous 'data-empty’ images as the webcams capture images every 15-seconds, irrespective of whether or not mammals are visiting the artificial water sources. Consequently, large data storage systems are required to store the 'empty' images. The long-term storage of the images is therefore a potential concern, due to the sheer volume of images generated on a daily basis. However, the number of images received every month and the actual number of images which depicted mammals, was largely different, thus storage of the webcam images over a long-term period could be improved by discarding 'empty' images. It would be advantageous to develop a mammal recognition program which could archive only those images containing mammals. The pixel resolution of the webcam images is low, and it was therefore difficult to identify small mammals and avian species visiting the water sources, particularly in the early morning and late afternoon when shadows developed over the water sources. A higher pixel resolution would improve the opportunity of identifying smaller species by enhancing the detail captured in the webcam images, as shown in a study by Verstraeten *et al.* (2010) which assessed the migratory patterns of birds using webcam technology. Therefore, the analysis of avian and small mammal species at the two water sources was excluded in this study. The reflection of the sun on the water at the Orpen artificial waterhole, and the resultant glare on the images between 6:00 - 8:00am during winter, confounded this.

As expected, the recognition of individual mammals is not often feasible, as reported by (Bowkett *et al.*, 2007). In the absence of tagging or marking individuals, it was not possible to identify whether the same individuals visited the water sources more than once a day; nor was it possible to record the exact time that each individual spent visiting the water sources. Addressing this short-fall would facilitate studies that specifically focused on the behavioural patterns of individuals. There is the possibility that resident animals (e.g. a local warthog clan staying close to Orpen waterhole) repeatedly utilise the waterhole, which is then not representative of the larger warthog population in the landscape. Prolonged webcam failure due to technical problems affected the continuity of the dataset. Large gaps in the data occurred due to power failures, resulting in missing imagery. Adverse weather conditions, especially rainfall affected the functioning of the webcam, specifically at Satara. Data received during the 2012 pilot project for the period March 2012 - August 2012 was manually forwarded by Steven Macintyre (SANParks) to the WITS FTP site, and various technological limitations were encountered with this process, thus resulting in large data gaps. To reduce the number of missing images, the automatic pull of webcam images on a daily basis was set up at the beginning of the Masters study.

6.9.3 Climate Data Limitations

Hourly temperature data were obtained from different sources, as during the pilot study in 2012, temperature loggers did not exist in close proximity to the study sites. Temperature data recorded at different sites are likely to have slight differences, due to different instruments used and differences in location. Gaps in the Hoedspruit hourly temperature data are likely due to technological issues. There were no gaps in the rainfall data obtained from SAWS for the Kingfisherspruit and Nwanedzi rainfall stations.

6.9.4 Statistical Limitations

Gaps in the webcam and climate datasets (*Table 6.3*) were considered when performing statistical analyses, with missing images and temperature and rainfall values having implications for the accuracy and consistency of results, as also for the strength of the findings. A large percentage of missing webcam imagery for certain months may bias results, and therefore skew the data. Missing webcam data was not interpolated. Small-sample sizes may result in anomalies and were therefore not interpreted. The proximity to other water sources, surrounding vegetation, presence of predators and local weather conditions, are all external factors which may play a part in shaping visitation trends at different water source locations. In this study, it was not possible to test all of the potential drivers of mammal water source visitation patterns. A further influence of these patterns could be attributed to the location of artificial water sources in close proximity to rest camps (i.e. Satara and Orpen), which could have a deterrent influence on the more timid species.

6.9.5 Recommendations to Overcome Outlined Limitations

Camera-traps could be placed at strategic points covering large areas (of specific landscapes within KNP), which could address the concern of limited contextual data due to the continuous re-sampling of one particular area. To capture data that represents a range of species, the cameras need to maintain a wide field of view of both of the water sources. The development of an image processing system which could filter and store images which contain mammals (Porter *et al*., 2010), would address the amount of time needed to interpret each individual image. Additionally, less storage space would be required to store images.

Table 6.4: Missing webcam imagery and temperature data for Orpen (March 2012 - March 2014) and Satara (April 2012 - March 2014).

	Webcam Imagery						**Temperature Data**		
	Orpen			**Satara**			**Orpen Logger**	**Satara Logger**	**Hoedspruit SAWS**
Month	% Images Missing	No. of missing days	No. of consecutive gaps	% Images Missing	No. of missing days	No. of consecutive gaps	No. of missing days	No. of missing days	No. of missing days
Mar-12	63.8	16	13	-	-	-	-	-	0
Apr-12	48.7	9	7	51.1	11	7	-	-	0
May-12	24.7	5	2	31.8	5	2	-	-	0
Jun-12	28.8	8	8	62.1	13	13	-	-	0
Jul-12	26.2	1	1	46.6	4	3	-	-	0
Aug-12	14.2	0	0	40.4	0	0	-	-	0
Sep-12	53.7	13	10	82.7	14	10	-	-	0
Oct-12	24.5	9	8	65.5	9	8	9	9	0
Nov-12	60.4	11	6	53.6	7	7	0	0	0
Dec-12	13.3	2	2	78.6	13	13	0	0	0
Jan-13	19.8	2	1	53.1	8	8	0	0	0
Feb-13	56.2	6	3	44.2	1	1	0	0	0
Mar-13	65.9	8	5	42.1	4	3	0	0	0
Apr-13	49.3	3	2	33.5	0	0	0	0	0
May-13	55.8	8	8	42.8	0	0	0	0	0
Jun-13	56.5	6	3	50.8	1	1	0	0	0
Jul-13	46.7	4	1	43.5	4	1	0	0	0
Aug-13	38.0	1	1	68.1	9	4	0	0	0
Sep-13	33.4	0	0	44.1	1	1	17	17	0
Oct-13	41.7	2	2	38.4	1	1	20	20	8
Nov-13	36.1	0	0	32.9	0	0	0	0	0
Dec-13	14.2	0	0	36.6	2	2	0	0	0
Jan-14	27.3	2	2	29.6	0	0	0	0	0
Feb-14	30.3	3	3	32.9	0	0	0	0	0
Mar-14	33.4	3	2	32.6	0	0	0	0	0

CHAPTER SEVEN

Conclusion

Chapter 7 - Conclusion

7.1 Introduction

Monitoring mammal behaviour at artificial water sources utilising webcam imagery is a relatively innovative research methodology in the field of wildlife ecology (Valeix *et al.*, 2008; Hayward & Hayward, 2012). Over the last 40-years, numerous studies have documented mammal visitation patterns and behaviour at water sources, over different periods, using various research methods (Ayeni, 1975; du Preez, 1977; Epaphras *et al.*, 2008; Tefempa *et al.*, 2008; Hayward & Hayward, 2012). The use of webcams for scientific observation and monitoring over long time periods has many potential benefits and can assist in answering ecologically relevant questions; in this instance investigating mammal behaviour over temporal and spatial scales in relation to environmental variables. Orpen and Satara are both situated in the central KNP which has benefitted from significant supplemental water provision in the past; thus the central region is likely supporting higher than normal mammal densities. However, there will be a significant reduction in surface water in the next five years due to the revised current water provision policy. Consequently, it is anticipated that these densities in central KNP will likely decrease, or rather redistribute, thereafter. This is based on the assumption of likely increased future water stress in the region, as supported by future projected climate change scenarios for north-eastern South Africa. It is essential to therefore investigate current water usage by mammals in KNP under contemporary climate conditions, and use this knowledge of water-use behaviours and reliance to inform changes in provision policies under climate change.

Within this framework, the primary aim of this study was to contribute to understanding the water-use patterns of mammals and how these are impacted by environmental and especially climate variables. Webcam imagery from March 2012 – March 2014 has provided information on species-specific water source visitation patterns under various climatic and astronomical conditions, and across seasonal changes. The fine temporal scale (15-seconds) of the imagery, which is unique to this study, has allowed for a more complete representation of mammal water source utilisation patterns than presented in previous studies. Further to this, the likely responses of species under extreme temperature reduced rainfall conditions, and the consequences of these responses for species interactions, competition and behaviour are demonstrated.

7.2 Consolidation of Research Findings

Six study objectives were formulated to achieve the broad aim of the study. A consolidation of the most significant findings under each objective is presented here.

1. *To track mammal visitation patterns at two artificial water sources, over a 24- (Satara) and 25-month (Orpen) period using remote imagery, in the central KNP.*

Webcam data were analysed to determine the fine scale temporal visitation patterns of mammals at the Orpen and Satara artificial water sources. Species, number of individuals, and the times they were observed at the water sources, were recorded every 15-seconds between March 2012 – March 2014. In order to determine the peak visitation periods for each species at the water sources, their visitation patterns were grouped into eight categories, from dawn to early morning.

Orpen waterhole had 44.69% more mammal visitations than Satara, likely due to the higher number of predators around Satara, which may be contributing to higher herbivore numbers at Orpen opposed to Satara. Notably, hippopotamus were only observed at Orpen waterhole, along with leopard and vervet monkey. Carnivores have a higher percentage representation at Satara (9.15% of all mammal visits) relative to Orpen (3.46%). Herbivores, in particular mixed feeders and grazers, were the most commonly observed species at both water sources, validating their need to drink on a regular basis. Identifying specific species within these two feeding guilds informs management of their reliance on these water sources. Carnivores and primates were the least sighted species at both water sources, indicating their water-independence and validating literature (e.g. Skinner & Chimimba, 2005).

Predominant daily visitation times were documented for each observed species, with cluster analysis grouping species which exhibit similar diel visitation patterns. This approach highlighted a notable divide between diurnal (herbivores and primates) and nocturnal (carnivores) species visitation patterns. These results were expected, with previous studies (e.g. Ayeni, 1975; Hayward & Hayward, 2012) identifying similar patterns of visitation, and the predominantly diurnal pattern displayed by herbivores, likely being in response to the threat of predation during the night. Exceptions to this pattern displayed by herbivores are noted for African buffalo, African elephant, hippopotamus and common duiker.

African civet, common duiker, greater kudu and warthog exhibited strong dry season preference in their use of both of the water sources. However, the strongly water-dependent blue wildebeest exhibited no seasonal preference, thus relying on artificial water sources equally during the wet and dry seasons. Most of the grazers and some mixed feeders, also water-dependent species, rely heavily on artificial water sources during the dry season and will experience greater vulnerability to the drought conditions which are projected to become more frequent and severe under climate change scenarios (Duncan *et al.*, 2012).

2. *To establish mammal water source visitation patterns (daily and monthly) and reliance under 'normal' rainfall and temperature conditions and more particularly under 'extreme' (any conditions that fall outside of the standard deviation for the data analysed) climate conditions.*

At both water sources, broadly pooled species relationships with hourly T_{avg} across the study period indicate that mammal visitations typically decrease during the afternoon when the hottest temperatures are experienced. However, significant positive relationships with monthly T_{avg} were exhibited for the majority of herbivores, demonstrating that the number of visitations increased with an increase in monthly T_{avg}, with these species drinking more during the hotter months. Conversely, the majority of carnivores exhibited a significant negative relationship with monthly T_{avg}, demonstrating a decrease in visitations during spring and summer. These patterns validate the distinct differences in water needs displayed by the two main feeding guilds. Correlation and regression analyses of mammal visitation patterns with hourly T_{avg} highlighted that herbivores are shifting their visitation periods earlier in the day by 36 minutes (at Orpen) and by 120 minutes (at Satara) per 5°C increase in mean daily temperature. In contrast, carnivores are shifting their visitation periods later into the night by 120 minutes (at Orpen) and by 18 minutes (at Satara) per 5°C increase in mean daily temperature. The large difference in species behaviour at Orpen and Satara in response to temperature suggests that there is a lot of variability of drinking patterns between the two sites. These differences may also reflect the plasticity of species behaviour as controlled by different variables between sites. However, at both water sources, impala (highly water-dependent) are the most sensitive species to increasing mean daily temperature, as they initiate a shift in their visitation periods at $T_{avg} \geq 15°C$.

Mean species sightings are significantly higher on days before rainfall compared to days after rainfall, suggesting that reliance on these artificial water sources is higher when there is less natural water available in pools and rivers. However, there was no clear divide between species responses to the presence and absence of rainfall, with no species or guild driving the pooled species response. These results suggest that water may need to be supplemented on a seasonal basis to sustain the water needs of particularly water-dependent species.

3. *To establish mammal water source utilisation behaviour patterns (daily and monthly) under ‘normal’ rainfall and temperature conditions and more particularly under ‘extreme’ climate conditions.*

Throughout the study period, species behaviour at the artificial water sources was documented. Herbivores, in particular grazers and mixed feeders, were identified having more species associations compared to browsers, carnivores and primates. Additionally, grazers and mixed feeders congregated at the water sources in large herds, and in contrast, individuals within the latter feeding guilds were mostly solitary. At Orpen waterhole, hippopotamus, African buffalo and warthog were observed wallowing in the waterhole, and this behaviour can be linked to periods of higher T_{avg} (20°C - 40°C). These behaviours indicate that the artificial water sources are not only being used to meet the water requirements of mammals, but also as a thermoregulatory mechanism to tolerate extreme temperatures. This would likewise explain African elephant spraying themselves with water, and spotted hyaena sitting in the water, as observed at the Satara water trough.

4. *To establish whether various mammal species utilise the artificial water sources in proportion to their abundance in the area, or if specific species favour or avoid these artificial water sources.*

Observed herbivore visitation at Orpen waterhole shows stronger relationships with regional estimates than those at Satara. This suggests that at least in the Orpen area, herbivores are using the artificial water source in relative proportion to their landscape and regional abundance. However, the fewer strong correlations and overall weaker correlations for Satara suggest that species here may be drinking from other nearby water sources (*Table 5.32*). The relatively similar proportional visitation of the majority of grazers and mixed feeders at the artificial water sources, in relation to their regional, local and landscape densities, demonstrates that these water-dependent species are not displaying preferential or avoidance behavior in their use of the water sources. Conversely, water-independent browsers exhibited avoidance behaviour as their regional, local and landscape percentage abundances are greater than their relative presence at the water sources.

5. *To determine the impact of various other environmental conditions (sunrise, sunset and moon phases) on water source visitation patterns and behaviours.*

For most species, weak relationships exist between peak daily visitation times and sunrise and sunset. It was expected that the peak daily visitation times for herbivores might show positive relationships with both sunrise and sunset, allowing species to capitalize on the longer period of daylight. However, only exclusively diurnal warthog displayed this expected relationship, and adjust its water visitation periods according to the seasonal variation in day length. Conversely, a negative relationship with both sunrise and sunset might have been expected for carnivores, however, at neither water sources, did carnivores exhibit such a pattern. It was further expected that nocturnal species would be less frequently sighted at water sources on full moon nights, as hunting success has been found to decrease during such periods. However, again no significant relationships with the maximum number of sightings of nocturnal mammals were shown with any particular moon phase.

7.3 Touristic Appeal of Webcams

Artificial water sources benefit mammals as well as having touristic appeal, with a large number of tourists viewing mammals utilising the water sources online and whilst they are in the park. This study has been able to contribute useful information about mammal behaviour at artificial water sources, therefore adding value to the project and SANParks webcam tourist initiative (*Table 7.1*). The viewing opportunities that occur outside of permitted camp opening hours are limited to official park activities (night drives) or online viewing. Tourists in KNP are permitted to be driving around outside of camps during the following times:

- Nov, Dec and Jan: 4:30 – 18:30
- Oct, Feb and Mar: 5:30 – 18:00
- Aug, Sep and Apr: 6:00 – 18:00
- May, Jun and Jul: 6:00 – 17:30

Table 7.1: Tourist information detailing the most opportunistic sighting periods (time and month) per species at each artificial water source. Species that most consistently visit at particular times are highlighted.

Orpen				**Satara**			
Visitation Period	**Species**	**Time**	**Month**	**Visitation Period**	**Species**	**Time**	**Month**
Morning	Blue wildebeest	8:00 - 10:59	December	Dawn	African buffalo	5:00 - 7:59	July
	Plains zebra	8:00 - 10:59	August	Morning	Chacma baboon	8:00 - 10:59	October
Midday	Chacma baboon	11:00 - 12:59	July		Impala	8:00 - 10:59	December
	Impala	11:00 - 12:59	August		Blue wildebeest	8:00 - 10:59	December
	Greater kudu	11:00 - 12:59	August		Plains zebra	8:00 - 10:59	June
	Mongoose	11:00 - 12:59	March	Midday	Southern giraffe	11:00 - 12:59	April
	Vervet monkey	11:00 - 12:59	July		Greater kudu	11:00 - 12:59	August
	Warthog	11:00 - 12:59	August		Warthog	11:00 - 12:59	September
Afternoon	African wild cat	13:00 - 16:59	November	Afternoon	African elephant	13:00 - 16:59	November
	Southern giraffe	13:00 - 16:59	August	Early Night	African wildcat	20:00 - 22:59	August
Dusk	African buffalo	17:00 - 19:59	July		Black-backed jackal	20:00 - 22:59	July
	Common duiker	17:00 - 19:59	August		Mongoose	20:00 - 22:59	March
	African elephant	17:00 - 19:59	August		Spotted hyaena	20:00 - 22:59	May
	Leopard	17:00 - 19:59	August	Midnight	Honey badger	23:00 - 1:59	September
	Serval	17:00 - 19:59	April		Lion	23:00 - 1:59	December
Early Night	African civet	20:00 - 22:59	June		Serval	23:00 - 1:59	May
	Honey badger	20:00 - 22:59	August		Small-spotted genet	23:00 - 1:59	December
	Lion	20:00 - 22:59	December	Early Morning	African civet	2:00 - 4:59	July
Midnight	Black-backed jackal	23:00 - 1:59	August		Common duiker	2:00 - 4:59	August
	Hippopotamus	23:00 - 1:59	June				
	Spotted hyaena	23:00 - 1:59	August				
Early Morning	Small-spotted genet	2:00 - 4:59	June				

The periods of tourist activity thus mirror seasonal changes in sunrise and sunset. Official night drives give tourists the advantage of extended viewing hours, however, these drives return to the camps around 10/10:30pm. Therefore, any peak activity occurring later than those hours will only be for the benefit of online viewers. The SANParks webcam initiative thus provides online viewers with the opportunity to view species which they would not normally encounter in the park during the specified gate hours.

Additionally, a community of online webcam viewers has developed, with regular visitors posting highlights on a daily basis. With what is now essentially a continuous monitoring system where online viewers from different countries, not only view, but capture and comment on the highlights from the webcam imagery at these water sources. The online viewers are therefore able to monitor the webcams at a fine temporal scale, over the 24-hour period which would provide representative data, across species and seasons. The webcam forum provides a platform through which online viewers could contribute to the long term monitoring of mammal visitation patterns at the water sources. Providing data which could be utilised in future studies, and establishing a long-term data record. The suggestion is to create what is essentially an open source monitoring system, by adding a tick box form to any image that is posted on the forum. This will allow any online viewer the opportunity to tick the species and number of individuals/species sighted as observed on the webcam or webcam image. This forum would then form part of a citizen science project, which would engage the general public in science. Citizen science is a growing research tool, particularly within the field of ecology, with ‘citizen scientists’ contributing to projects involving climate change and population monitoring (Silvertown, 2009).

7.4 Implications for Water Provision in Wildlife Areas

A priority for management of national parks, and particularly smaller reserves, is to monitor habitats, the resource usage of mammals, and determine potential threats biodiversity will face due to anticipated future climate change (McGeoch *et al*., 2011). SANParks management follows a learn-by-doing approach, relying on contemporary research to inform decisions, as well as taking into account future projected climatic and environmental changes (Mabunda *et al.*, 2003).

The management implications noted within the context of this study are linked to the SANParks and KNP management mission, which is guided by both the over-arching biodiversity objectives as well as tourism requirements (SANParks, 2005). The broad management objective is to maintain mammal populations in as natural environment as possible, and underlying this are lower-tier ecosystem and biodiversity objectives (SANParks, 2005). The findings of this study contribute towards objectives within the context of 'water-in-the-landscape', and more specifically artificial water provisioning, providing knowledge on species-interactions at artificial water sources, concerning species associations, competition and predator-prey relationships, as well as informing management on different species reliance on supplemental water. Further to this, the study contributes towards the atmospheric effects objective, providing information concerning the contemporary control of rainfall and temperature on mammal behaviour. Additionally, shifting mammal visitation patterns in response to different temperature thresholds provides a forward looking representation of how mammal visitation patterns may be influenced by future climate change. The concept diagram (*Figure 7.1*) represents a summary of the most common responses of species to changes in temperature, rainfall, sunrise and sunset. Impala are the most sensitive species within this study, initiating a change in visitation patterns at the lowest temperature. At $T_{avg} \geq 15°C$ a shift towards earlier visitation as well as a higher number of individuals are observed. The broad contribution of this study therefore provides a foundation for future research to be expanded on, or a point of reference for similar research projects going forward. This study thus serves as a baseline off which changes in this environment, or other environments could be measured and compared.

The daily, monthly and seasonal reliance of particular species on artificial water sources informs discussions and policies concerning the supplementation of water in future, and whether they should be terminated, continued or changed on a seasonal basis in relation to prevailing climatic conditions. In the context of future climate change and the resultant decreasing natural water supplies, water provisioning policies may need to be further revised given that artificial water sources may become more essential. Artificial water source provision, however, should not be based exclusively on the needs of water-dependent mammals, with this research highlighting that various other factors, such as thermoregulation, caching and the abundance and distribution of species within specific regions (influenced by forage availability), need to be taken into account (Smit *et al.*, 2007a).

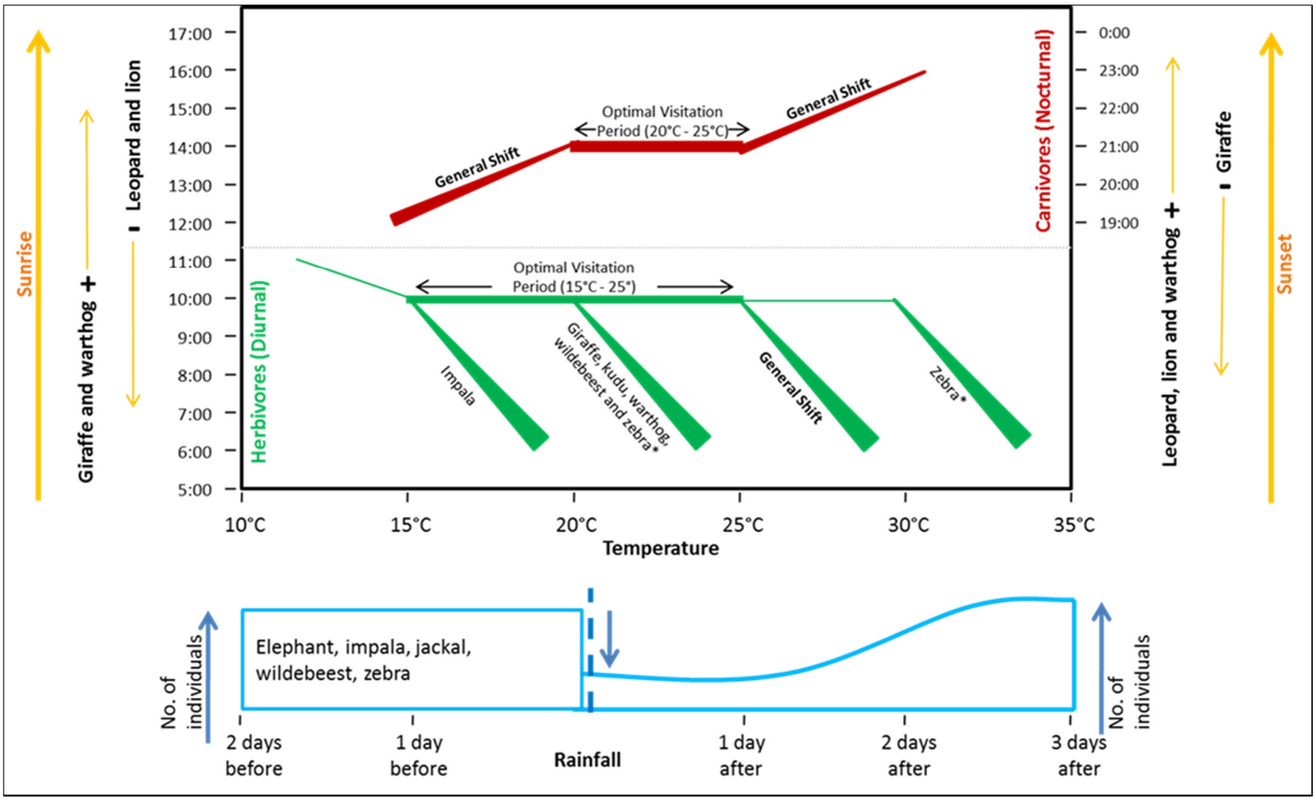


Figure 7.1: Concept diagram of the significant relationships, at both Orpen and Satara, between mammal behaviour responses to climatic (hourly Tavg and rainfall) and astronomical (sunrise and sunset) drivers.

Red shapes indicate carnivore responses. Green shapes indicate herbivore responses. Zebra* exhibited different responses to T_{avg} at Orpen and Satara, shifting their visitation period earlier at $T_{avg} \geq 20°C$ at Satara and only at $T_{avg} \geq 30°C$ at Orpen. Positive and negative relationships are shown with a plus or minus sign. The direction of the blue lines indicate either an increase or decrease in the number of individuals utilising the water sources in response to the absence or presence of rainfall. Solid thick green and red lines represent the optimal visitation period/temperature range. Tapered green and red shapes represent the shift (earlier or later) in time due to an increase in T_{avg}.

7.4.1 Management Recommendations

The projected changes of mammal drinking patterns under increasing temperature and reduced rainfall conditions will impact the management of artificial water sources in KNP. The current water provisioning policy is closing down artificial water sources which are not located in areas where natural water sources exist. The decision of which artificial water sources management should close down, should also take into account not only the location but the structure of the water source itself. A more holistic approach to water provisioning including, particular species behaviour, location, structure and volume of water should be considered so as to benefit a wider range of species needs.

With the observation that species not only use the water sources for drinking purposes but for additional purposes such as thermoregulation and caching, it is recommended that the long, narrow, water trough structure is less suited to a wider range of species needs. However, under extreme conditions it has been noted that aquatic mammals such as hippopotamus will utilise the artificial water sources as they are the only deep pools of water available.

The location of artificial water sources and the abundance of predators and herbivores within the different KNP landscapes should be taken into account when analysing the temporal utilisation of water sources and the level of dependence on water, considering the observation that a higher number of mammals utilised Orpen waterhole, compared to Satara. The difference in species responses to temperature across the two study sites highlights the variability of behaviour of the same species in different landscapes, reflecting their plasticity in terms of behaviour.

The structure and surface of artificial water sources can be dangerous for certain mammals. On two isolated occasions, a giraffe slipped into Orpen waterhole and struggled to lift itself out, possibly due to algae on the surface, making it slippery. One giraffe managed to retrieve itself, while the other died as a consequence of slipping. The structure (design) of artificial water sources thus needs better consideration of lining methods and side slopes.

It was witnessed that large herds of African buffalo and African elephant drained the Satara water trough. The smaller water troughs provide less water and are less likely to sustain the drinking needs of sizeable herds of large mammals. Thus in landscapes where these species are known to occur in large herds, artificial water sources should be sized to provide an adequate volume of standing water.

7.5 Recommendations for Future Research

The new water provision policy aims to supplement water in accordance with the natural distribution and availability of water which exists in KNP (Venter & Smit, 2011). Within this context, longer term studies could be carried out, utilising fine resolution remote imagery collection. Future studies that collect data over a longer period could compare multiple years, comprising drought conditions, flooding and average rainfall, as well as hotter than average years to determine whether the temporal patterns of visitation differ between extreme periods (Valeix, 2011).

There is also the potential for a comparison project, which could identify the difference in water visitation patterns at natural water sources compared to artificial water sources, which are situated in close proximity to tourist roads and camps. Camera traps could be utilised to capture imagery at more remote locations, without too much interference on the surrounding environment. To establish whether mammal drinking patterns are representative throughout KNP, there is the opportunity to monitor artificial water sources which are situated in different landscapes within the KNP environment. The landscapes in KNP comprise of various geologies, vegetation, climate and mammals and therefore require different management strategies (Gertenbach, 1983). Mammal drinking patterns could also be studied in different national parks which are situated in distinct biomes across the South African landscape. Comparisons could then be drawn between mammal drinking patterns in diverse climatic environments such as KNP, Kgalagadi Gemsbok National Park and Addo Elephant National Park. There is also the potential for future studies to explore individual mammal behaviour patterns at artificial water sources, which would be aided by tagging and GPS tracking mammals, thus allowing their daily water requirements and movements to water sources, to be tracked.

7.6 Epilogue

During the study period hippopotamus visitation at Orpen waterhole peaked during the dry season (84.62%) at midnight (23:00 - 1:59), although was fairly limited/rarely observed. Continued monitoring of the webcam imagery beyond the time frame of this project has revealed an adjustment in hippopotamus visitation times, daily and seasonally since, almost certainly due to the severe drought currently being experienced in KNP. Hippopotamus primarily graze nocturnally (Smuts & Whyte, 1981). However due to the drought they are shifting towards diurnal grazing patterns, as they need to travel further to find suitable forage. Additionally, during drought, fewer suitable pools of water for wallowing are available, and the in last remaining pools, large concentrations of hippopotamus can be found, which increases species-interactions and competition (Smuts & Whyte, 1981). Consequently, these pools become congested with these large herbivores and additionally become clogged with excrement (Smuts & Whyte, 1981). Under current drought conditions, two hippopotamus have become resident in the Orpen waterhole and have clogged it up (*Figure 7.2a,b*). This effectively makes the artificial water source, which is critical in the provision of supplemental water during times of limited natural availability, unavailable to other species within the mammal community, which might have been able to find other water sources if the park were ‘open’ to the larger landscape. The behavioural change of hippopotamus in response to the current drought in KNP, is an example of the resultant reliance on these artificial water sources during extreme climatic conditions. The shifting visitation patterns of this species has considerable ecological consequences, impacting on other species that utilise Orpen waterhole, and further to this will affect species interactions and competition.

Figure 7.2: a) Hippopotamus utilising Orpen waterhole during the day, likely due to the severe drought and b) Orpen waterhole clogged with hippopotamus excrement, and a warthog attempting to drink.

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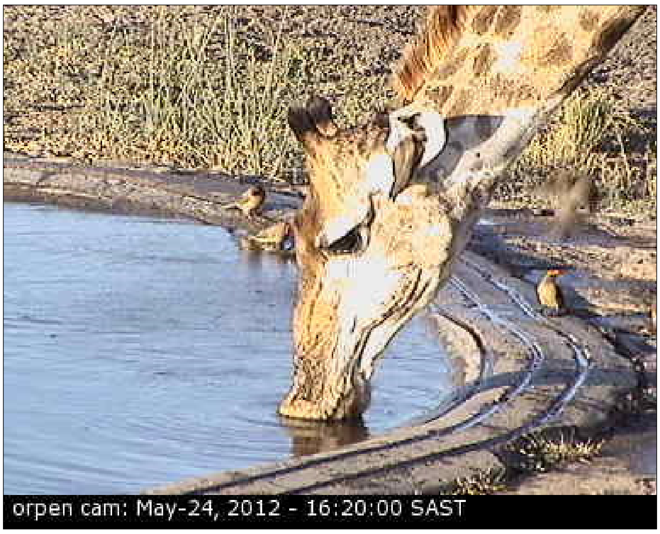

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Appendix

A.1 Orpen - Pooled species monthly totals, and pooled species hourly totals

Month	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	8:00:00	9:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00	0:00:00	Monthly Total
Mar-12	4	2	1	0	1	0	8	33	71	87	41	73	54	6	46	7	70	48	4	6	2	2	3	0	569
Apr-12	4	5	2	8	9	0	3	11	13	42	64	69	75	21	51	43	18	7	4	9	6	0	1	6	471
May-12	9	8	7	14	7	2	19	43	132	164	182	224	154	108	97	97	61	31	39	13	24	8	18	5	1466
Jun-12	16	12	10	5	6	11	9	32	136	349	306	307	329	106	106	61	76	40	25	31	23	19	15	23	2053
Jul-12	23	16	21	10	7	2	7	101	383	772	619	409	308	129	83	61	96	39	33	22	33	33	22	24	3253
Aug-12	29	20	15	15	10	6	52	153	514	561	505	378	295	215	108	126	116	84	47	26	31	15	18	23	3362
Sep-12	1	0	0	0	0	0	0	7	9	38	27	43	19	20	14	4	19	8	6	3	2	10	0	2	232
Oct-12	0	4	3	0	3	1	14	13	39	35	18	1	28	15	12	17	14	1	0	2	4	3	4	6	237
Nov-12	2	0	0	1	0	2	7	4	5	55	35	69	29	29	5	9	3	1	2	0	8	1	3	2	272
Dec-12	23	3	1	1	4	4	61	45	120	102	111	59	101	44	12	9	5	19	28	25	3	8	3	13	804
Jan-13	2	2	2	1	2	4	52	106	172	121	104	116	66	77	83	38	13	15	23	8	3	3	2	1	1016
Feb-13	0	2	1	2	1	2	3	15	62	35	66	83	94	29	47	84	21	9	1	3	1	2	1	0	564
Mar-13	11	8	5	1	3	4	33	22	29	136	51	82	65	18	18	31	16	25	4	4	10	2	17	3	598
Apr-13	5	6	10	4	2	6	3	10	25	17	86	36	104	52	26	16	25	8	7	8	3	4	5	5	473
May-13	18	5	5	7	7	3	2	4	20	21	53	59	41	24	43	13	7	8	4	9	9	14	3	4	383
Jun-13	6	7	3	5	5	2	2	65	59	170	322	145	196	175	78	49	43	14	7	9	3	2	11	5	1383
Jul-13	3	2	5	2	7	3	5	30	127	211	257	270	201	73	115	44	35	41	15	7	1	9	6	6	1475
Aug-13	11	6	13	2	17	3	46	117	153	388	393	299	134	112	53	49	12	19	0	5	8	19	5	7	1871
Sep-13	22	10	21	15	7	5	92	232	556	583	392	215	195	98	57	52	34	15	15	23	14	10	18	9	2690
Oct-13	6	8	11	13	7	26	76	357	279	182	187	107	76	89	60	24	52	37	49	21	10	13	32	8	1730
Nov-13	5	0	2	1	8	12	53	164	115	105	51	78	42	98	36	98	64	36	16	7	10	12	6	11	1030
Dec-13	4	9	9	3	3	71	146	106	287	232	239	207	189	143	65	74	58	23	42	17	14	9	14	9	1973
Jan-14	11	1	5	0	3	25	33	19	28	61	73	82	63	66	60	35	5	0	0	0	2	17	4	6	599
Feb-14	0	6	1	1	1	0	12	32	23	82	138	90	158	143	44	73	60	39	1	11	15	5	2	1	938
Mar-14	3	8	3	1	0	1	6	62	16	93	68	160	77	58	41	19	59	37	5	3	2	1	1	10	734
Hourly Total	218	150	156	112	120	195	744	1783	3373	4642	4388	3661	3093	1948	1360	1133	982	604	377	272	241	221	214	189	**30176**

A.2 Satara - Pooled species monthly totals, and pooled species hourly totals

Month	1:00:00	2:00:00	3:00:00	4:00:00	5:00:00	6:00:00	7:00:00	8:00:00	9:00:00	10:00:00	11:00:00	12:00:00	13:00:00	14:00:00	15:00:00	16:00:00	17:00:00	18:00:00	19:00:00	20:00:00	21:00:00	22:00:00	23:00:00	0:00:00	Monthly Total
Apr-12	6	20	20	6	10	17	62	101	235	111	105	152	58	72	31	49	27	18	33	26	12	10	3	13	1197
May-12	16	19	20	5	8	8	39	81	172	144	180	79	25	31	63	41	25	33	53	37	27	22	36	16	1180
Jun-12	11	4	5	1	0	2	12	43	116	154	148	91	60	75	62	23	18	28	18	11	7	12	14	6	921
Jul-12	4	10	16	16	20	7	56	63	227	155	126	156	60	96	54	35	50	38	20	31	18	12	9	8	1287
Aug-12	17	11	16	14	11	43	44	72	259	174	141	94	75	51	28	28	30	37	37	23	19	17	18	10	1269
Sep-12	1	0	0	0	1	14	1	20	61	16	3	23	13	9	9	7	35	5	16	7	0	3	1	1	246
Oct-12	1	5	3	0	2	11	14	0	5	3	3	1	1	1	0	8	1	13	11	14	0	2	0	4	103
Nov-12	5	6	2	7	17	62	47	34	29	2	11	10	16	9	8	19	23	62	17	5	16	5	3	2	417
Dec-12	18	0	5	4	23	36	48	71	49	18	46	26	6	20	37	12	28	26	50	3	1	4	1	1	533
Jan-13	5	3	1	0	14	109	75	103	43	24	26	41	30	42	14	38	63	34	57	15	6	4	1	0	748
Feb-13	3	6	0	7	7	44	91	75	98	84	113	43	64	59	49	55	55	54	44	18	3	7	2	3	984
Mar-13	7	5	10	1	2	3	114	96	113	118	40	57	46	28	38	7	38	14	7	4	6	10	2	9	775
Apr-13	2	6	2	0	4	2	25	30	15	20	63	49	56	18	19	11	6	5	4	9	4	5	2	16	373
May-13	2	9	2	2	3	3	43	15	55	17	35	15	28	12	1	12	33	18	18	3	4	4	2	1	337
Jun-13	9	6	13	2	3	6	56	74	54	120	74	19	81	3	33	1	35	29	13	25	16	16	8	6	702
Jul-13	11	14	5	8	10	9	20	44	60	48	44	45	8	7	6	20	25	25	9	13	7	10	8	7	463
Aug-13	1	8	4	4	3	0	19	31	32	39	15	24	4	1	15	7	5	5	13	14	2	2	3	6	257
Sep-13	5	9	13	6	8	44	24	59	27	18	5	11	13	14	7	6	26	21	45	23	13	13	8	7	425
Oct-13	3	16	4	2	5	20	14	33	34	25	13	17	9	3	8	28	26	13	15	20	10	10	13	4	345
Nov-13	17	5	16	7	9	26	26	56	24	9	48	46	19	43	35	42	43	32	20	30	12	5	8	7	585
Dec-13	19	10	25	15	40	191	266	156	33	67	44	35	110	68	63	79	56	133	178	32	9	21	11	20	1681
Jan-14	7	12	9	4	4	84	233	91	41	37	21	20	6	18	12	52	47	48	32	25	10	9	10	18	850
Feb-14	10	3	3	0	2	2	68	106	80	50	40	83	39	12	0	75	9	6	27	5	3	4	1	2	630
Mar-14	5	16	3	1	0	7	105	32	18	17	27	23	14	32	2	8	0	49	4	5	3	5	4	2	382
Hourly Total	185	203	197	112	206	750	1502	1486	1880	1470	1371	1160	841	724	594	663	704	746	741	398	208	212	168	169	**16690**

A.3 Orpen - Species monthly totals

Mammal	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Species Total
African wild cat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	3
Chacma baboon	79	46	29	35	64	65	8	16	17	44	95	17	50	29	50	82	93	50	14	46	26	101	52	88	65	1261
Black-backed jackal	9	8	38	60	54	95	4	6	2	0	2	0	10	7	6	20	10	27	30	17	6	12	0	1	0	424
African buffalo	13	36	50	138	154	141	6	7	6	79	15	3	7	19	27	30	36	15	63	59	4	6	0	2	0	916
Caracal	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
African civet	0	3	9	19	11	6	0	0	0	0	0	0	0	0	4	10	2	0	3	4	0	0	1	0	0	72
Common duiker	0	0	7	42	65	77	9	1	0	0	0	0	0	0	0	2	6	2	6	4	0	0	0	0	0	221
African savanna elephant	41	13	127	29	137	120	27	5	31	55	21	1	48	35	44	4	120	149	118	231	76	112	33	27	70	1674
Small-spotted genet	1	3	4	8	3	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	2	1	0	1	1	29
Southern giraffe	11	7	5	14	5	21	3	0	0	0	1	0	1	1	13	7	7	33	30	40	7	0	0	0	0	206
Hippopotamus	0	0	0	9	0	1	0	0	0	2	1	0	0	0	2	3	4	2	1	0	0	1	0	0	0	26
Honey badger	0	0	4	8	4	7	0	4	1	1	0	0	5	1	0	2	2	5	9	1	0	2	2	1	0	59
Spotted hyaena	4	5	10	16	17	34	4	10	2	3	4	4	2	14	7	7	10	14	22	10	4	6	10	0	0	219
Impala	160	114	480	968	1528	1509	98	99	117	363	481	214	65	168	51	620	742	1137	1887	849	680	1047	380	503	436	14696
Greater kudu	18	24	54	32	88	122	18	9	4	8	4	4	2	6	5	42	48	121	106	86	30	16	5	0	5	857
Leopard	1	2	5	3	2	10	0	1	3	0	1	0	0	2	4	4	4	2	4	0	0	2	0	1	0	51
Lion	1	0	8	5	0	0	0	0	0	0	2	0	2	0	0	0	2	6	9	0	4	18	2	12	2	73
Mongoose	0	6	12	2	0	0	0	0	0	1	0	0	20	5	4	17	0	1	2	3	19	2	0	1	13	108
Nyala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Serval	1	0	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	6
Vervet Monkey	0	3	33	63	134	43	1	5	0	3	4	0	1	6	17	13	8	3	5	3	2	0	2	2	2	353
Warthog	80	118	288	368	559	607	27	29	25	34	58	33	57	69	69	185	170	185	214	152	82	56	24	34	33	3556
Waterbuck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
African wild dog	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Blue wildebeest	143	64	229	95	192	166	5	45	29	111	272	217	234	79	43	158	100	105	83	172	74	514	55	154	45	3384
Plains zebra	6	19	72	139	236	338	21	0	35	99	55	70	94	30	36	175	109	12	84	52	12	76	33	111	62	1976
Monthly Total	569	471	1466	2053	3253	3362	232	237	272	804	1016	564	598	473	383	1383	1475	1871	2690	1730	1030	1973	599	938	734	**30176**

A.4 Satara - Species Monthly Totals

Mammal	**Apr-12**	**May-12**	**Jun-12**	**Jul-12**	**Aug-12**	**Sep-12**	**Oct-12**	**Nov-12**	**Dec-12**	**Jan-13**	**Feb-13**	**Mar-13**	**Apr-13**	**May-13**	**Jun-13**	**Jul-13**	**Aug-13**	**Sep-13**	**Oct-13**	**Nov-13**	**Dec-13**	**Jan-14**	**Feb-14**	**Mar-14**	**Species Total**
African wild cat	0	0	1	1	10	1	4	0	1	0	3	1	2	0	3	8	10	11	14	7	6	7	5	0	**95**
Chacma baboon	15	6	12	6	11	1	4	16	7	9	19	4	34	24	29	14	1	32	56	20	7	47	21	4	**399**
Black-backed jackal	23	72	48	70	86	6	6	10	5	8	17	21	1	10	34	35	14	28	26	35	54	41	9	25	**684**
African buffalo	55	85	19	92	54	32	23	50	32	14	15	0	4	13	4	12	19	42	14	13	21	0	1	1	**615**
African civet	0	0	0	0	3	0	3	0	0	0	0	0	0	5	12	13	9	10	1	1	1	1	0	0	**59**
Common duiker	0	0	3	6	3	0	0	0	0	0	0	0	0	0	0	0	8	11	4	2	0	0	0	0	**37**
African savanna elephant	5	6	12	20	12	10	10	61	14	60	9	11	8	2	6	2	1	2	14	28	13	8	25	16	**355**
Small-spotted genet	0	1	0	0	0	0	0	0	0	0	0	1	1	0	3	3	0	2	3	4	11	3	0	0	**32**
Southern giraffe	57	22	2	3	2	0	3	0	0	4	0	4	7	6	5	0	2	4	4	0	2	0	6	6	**139**
Honey Badger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0	2	**8**
Spotted hyaena	26	69	28	50	71	9	13	17	10	9	15	17	12	12	17	28	8	30	12	19	15	7	6	7	**507**
Impala	437	434	194	517	415	51	14	66	304	384	318	300	100	65	185	84	89	112	96	291	721	205	257	180	**5819**
Greater kudu	34	25	4	11	21	0	0	0	0	0	0	0	0	1	4	4	17	16	0	19	0	0	0	0	**156**
Lion	0	8	6	1	0	0	0	4	0	4	0	0	7	0	0	0	0	5	9	13	22	12	5	14	**110**
Mongoose	0	0	0	0	0	0	0	0	0	0	2	13	3	3	1	0	0	0	0	1	1	0	0	6	**30**
Serval	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**2**
Warthog	6	4	1	0	0	0	0	0	0	0	0	0	0	0	1	15	15	17	1	0	3	3	1	0	**67**
Blue wildebeest	326	236	152	148	152	54	18	127	127	204	346	367	176	156	328	120	21	51	58	112	620	362	196	87	**4544**
Plains zebra	213	211	439	362	429	82	5	66	33	52	240	36	18	39	70	125	43	47	33	20	183	154	98	34	**3032**
Monthly Total	1197	1180	921	1287	1269	246	103	417	533	748	984	775	373	337	702	463	257	425	345	585	1681	850	630	382	**16690**