

https://dspace.org/

Faunal distribution in relation to rainfall patterns in the Kalahari Gemsbok National Park

Maraschin, Nicoletta Maria Rita

2016

http://hdl.handle.net/10539/21743

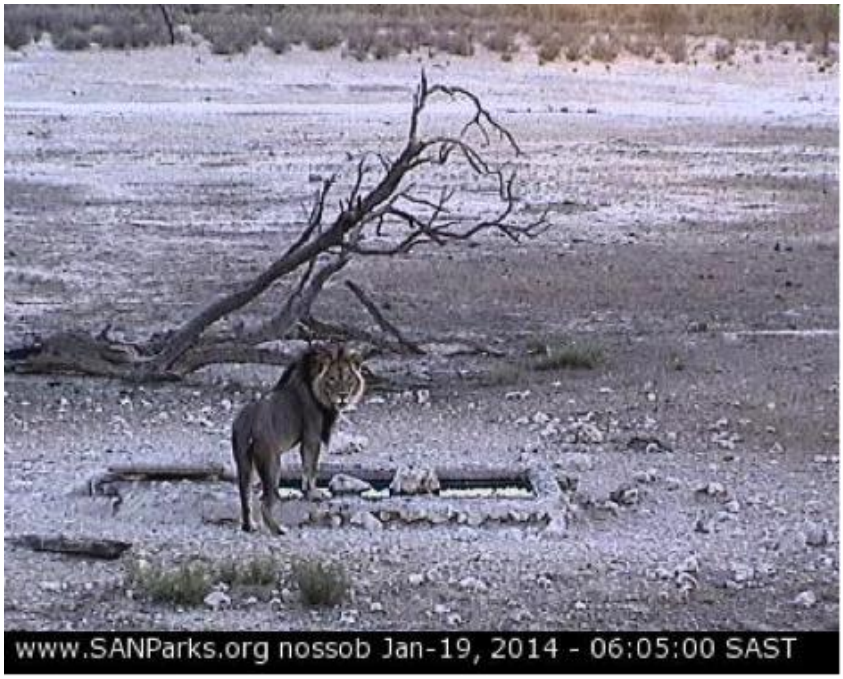
Maraschin, Nicoletta Maria Rita (2016) Faunal distribution in relation to rainfall patterns in the Kalahari Gemsbok National Park, University of Witwatersrand, Johannesburg, <http://wiredspace.wits.ac.za/handle/10539/21743>

Downloaded from a DSpace repository. https://dspace.org/

University of the Witwatersrand

School of Geography, Archaeology and Environmental Sciences

FAUNAL DISTRIBUTION IN RELATION TO RAINFALL PATTERNS IN THE KALAHARI GEMSBOK NATIONAL PARK: 2004-2013



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

Nicoletta Maria Rita Maraschin

Johannesburg, March 2016

Declaration

I hereby declare that this dissertation is my own, original work, except where otherwise acknowledged. It is being submitted for the degree MSc to the University of the Witwatersrand, Johannesburg. I have not submitted it previously, for the purpose of obtaining any degree, qualification at this, or any other, university.



Nicoletta Maraschin

04/08/2016

Date

Abstract

This project investigates the influence that rainfall and temperature patterns have on mammal drinking patterns at an artificial waterhole in KGNP at Nossob. On a regional scale, this project investigates long-term rainfall and temperature trends over three/four decades, and in some instances the past 100 years, respectively for KGNP using climate records from weather stations located within the park and adjacent areas. This project makes use of KGNP census data to observe spatio-temporal distributions of large mammals in relation to rainfall (and to a lesser extent temperature) variability. Investigations assess whether relationships exist between faunal movement and distribution and rainfall volume and frequency. On a local scale, this project makes use of webcam images measured at 15-second intervals to establish mammalian drinking patterns and waterhole use over a short time scale (October 2012 – December 2014).

The climate data for Twee Rivieren, Mata-Mata, Nossob and Upington reveal statistically significant increases in T_{max} (av. 0.04°C) over the study period, whilst in summary, mean regional temperatures have increased by almost 1.6°C over the past 40 years. Rainfall patterns have revealed a north to south gradient in KGNP, where the northern and central parts of the park are becoming drier and the southern parts are becoming wetter. This demonstrates rainfall variability throughout KGNP over the period 2004 - 2013. This study established a positive relationship between faunal distributions and rainfall patterns within the park, showing that certain species are highly reliant on rainfall as a source of drinking water. It has been established that herbivore species are more reliant on the water trough during the dry season, when surface water is not available. However, there is an even spread of carnivore species water trough usage during the wet and dry season throughout the year. It has been established that during rainfall events exceeding *ca*. 30mm, faunal species prefer to utilise the natural surface water rather than the artificial waterhole at Nossob. Water trough usage under different temperature thresholds has revealed that groups of species (carnivores and herbivores) drinking patterns shift to either earlier or later in the day when temperatures increase, in order to avoid heat stress. Changing rainfall patterns could drastically cause water shortages, which will negatively affect the amount of available drinking water for mammals within KGNP.

This study is important in contributing to an improved management of KGNP through providing a quantitative description of the relationship of mammal visitation at water troughs to the ambient climate. This is particularly valuable as climate change projections for the region suggest progressive drying. Water troughs will become an important source of moisture.

Acknowledgements

Firstly, I would like to thank my supervisor, Professor Stefan W. Grab and my co-supervisor, Dr Dave I. Thompson. The assistance that Prof Grab and Dr Thompson provided was paramount to the completion of this dissertation. Their continued support through editing, proofreading and advising were invaluable. Thank you for your help, I am truly grateful.

Furthermore, thanks must go to Dr Jennifer Fitchett for guiding me through the complex statistical procedures included in the results chapter. Dr Fitchett spent a tremendous amount of time providing guidance whilst I was compiling the results section. Without this invaluable guidance, this chapter would not have been possible.

I would like to thank James Pugin for the invaluable assistance in all the cartographic procedures throughout this dissertation. Further, thank you for your help in proofreading and the constant support and motivation provided. I would like to acknowledge the support of my family. Thanks to my mother, Lili, for her constant support and advice throughout this dissertation. Thank you to Amy Trent for her constant support and encouragement throughout this dissertation.

Thanks to SANParks for allowing this research to take place within Kalahari Gemsbok National Park (KGNP) and for providing me with the webcam images from the Nossob water trough. Thank you to Sherona Hooson for setting up the Wits FTP-server and for storing all of the webcam images. Thanks to Dr Marna Herbst from South African National Parks (SANParks) for providing me with aerial census data and reports for KGNP, along with the GIS databases.

Thanks to South African Weather Services (SAWS) for providing me with climatic data. Special thanks to Karin Oxley at SAWS for assisting and providing me with historical records from the SAWS data archive. Thank you to all others at SAWS that assisted me with obtaining data: Charlotte McBribe, Elsa DeJager, Phumudzo Tharaga and Lucky Dlamini.

Lastly, thank you to everyone who provided online support towards the effectiveness of this dissertation: Guy Castley, David Thomas and Annette Laursen.

Table of Contents

University of the Witwatersrand ..... **i**

Declaration ..... **ii**

Abstract ..... **iii**

Acknowledgements ..... **iv**

Table of Contents ..... **v**

List of Figures ..... **ix**

List of Tables ..... **xii**

1 Introduction **2**

1.1 Rationale: Contribution to Existing knowledge **5**

1.2 Background **7**

1.3 Aim and Objectives **8**

1.3.1 Aim 8

1.4 Objectives of Research **8**

2 Environmental Setting **11**

2.1 Introduction **11**

2.2 Background of Study Site **11**

2.3 Study Location **13**

2.4 Vegetation Units Within KGNP **13**

2.4.1 Zone 1: Riverbeds and Riverine Environments 13

2.4.2 Zone 2: Pans 14

2.4.3 Zone 3 High Dunes 15

2.4.4 Zone 4 Low Dunes 15

2.4.5 Zone 5: Plains 16

2.5 Climate of the Kalahari and KGNP **19**

2.6 Fauna of KGNP **20**

2.7 Description of Study Subjects **21**

3 Literature Review **24**

3.1 Introduction **24**

3.2 Climate Change **26**

3.2.1 Introduction 26
3.2.2 Extreme Climatic Conditions: Semi-Arid Environments 26
3.2.3 Climate Change in Southern Africa 27
3.2.4 Climate Change and Fauna 29
3.2.5 Climate Change and its Impacts on Fauna in South Africa 30
3.3 Drought in National Parks 31
3.3.1 Drought in the Kalahari 32
3.4 Mammal Drinking Behaviour/Patterns 33
3.4.1 Introduction: Distribution and Water Availability 33
3.4.2 Faunal Distribution in Relation to Rainfall Patterns 34
3.4.3 Mammal Drinking Patterns at Artificial Water Troughs 35
3.4.4 Negative Impacts of Artificial Water Troughs 36
3.4.5 Water Dependency of Ungulate Species 38
3.4.6 Thermoregulation by Ungulate Species 40
3.5 Monitoring Methods 41
3.5.1 Webcam Monitoring 42
3.5.2 Aerial Census Monitoring 45
3.6 Conclusion 46
4 Methodology 48
4.1 Data 48
4.1.1 Data Collection 48
4.2 Data Analysis 58
4.2.1 Long-Term Climate 58
4.3 Conclusion 69
5 Results 71
5.1 Long-term Annual Rainfall Patterns 71
5.1.1 Recent Trends (1975 - 2014) 77
5.1.2 Number of Rainfall Days per Year 79
5.2 Long-term Annual Temperature Patterns 80
5.2.1 Recent Temperature Trends 1975 - 2014 83
5.2.2 Number of Days within Acceptable Temperature Thresholds 85
5.3 Long-term Seasonal Patterns 85
5.3.1 Long-Term Seasonal Rainfall Patterns 85
5.3.2 Long-Term Seasonal Temperature Patterns 88
5.4 Summary 93
5.5 Recent Spatio-Temporal Rainfall Patterns: 2003 - 2014 94

5.5.1 Introduction 94
5.5.2 Rainfall Patterns: 2003 - 2014 94
5.6 Webcam Monitoring at Nossob Water Trough 98
5.6.1 Introduction 98
5.6.2 Total Species Over the Entire Period (October 2012 - February 2014) 98
5.6.3 Wet and Dry Season Faunal Distribution 99
5.7 Peak Utilisation During Morning, Afternoon and Evening 101
5.7.1 Morning Peak 101
5.7.2 Afternoon Peak 102
5.7.3 Evening Peak 102
5.8 Statistical Cluster Analysis 104
5.9 Principal Component Analysis (PCA) 106
5.10 Summary 109
5.11 Census Results: Introduction 109
5.12 Temperature and Rainfall Controls on Water Trough Usage 112
5.12.1 Introduction 112
5.12.2 Wet/Dry Water Trough Usage 112
5.12.3 Seasonal Water Trough Usage (2013 - 2014) 113
5.12.4 Relationship Between Visitation and T_{avg} 116
5.12.5 Temperature and Water Trough Usage 118
5.12.6 Temperature and Monthly Water Trough Usage 120
5.12.7 Rainfall and Water Trough Usage 121
5.13 Summary 127
6 Discussion 129
6.1 Introduction 129
6.2 Analysis of results 129
6.2.1 Regional Climatic Trends 129
6.2.2 Faunal Observations 142
6.2.3 Relationship between Fauna and Climate 153
6.3 Implications of Results 159
6.4 Limitations 163
6.4.1 Technical Limitations 163
6.4.2 Data Limitations 166
6.4.3 Statistical Limitations 169
6.4.4 Addressing the Limitations 169
7 Conclusion 172

7.1 Background....172
7.2 Achievement of Study Objectives....173
7.3 Implications for Management....178
7.4 Future Work....179
8 References....182
9 Appendix....201

List of Figures

Figure 1.1: Map of the Kalahari Gemsbok National Park (KGNP), within the greater KTP, demonstrating the localities of weather stations and the Mier/ San Heritage Land. 4
Figure 2.1: Map demonstrating the water troughs and ecological zones, consisting of rivers, pans, duneveld and plains, with the aerial census strata (A, B and C) demarcated. 18
Figure 4.1: Webcam image of the Nossob artificial water trough located at Nossob rest camp in KGNP. 51
Figure 4.2: Schematic flow chart of the webcam imagery data collection and subsequent analyses. 53
Figure 4.3: Survey flight lines (Transects) across KGNP - SANParks area. Map reconstructed from Castley, 2013. 57
Figure 5.1: Long-term rainfall trends for Twee Rivieren: 1940 - 2014. 72
Figure 5.2: Long-term rainfall trend for Mata-Mata: 1961 - 2014. 73
Figure 5.3: Long-term rainfall trends for Nossob: 1975 – 2014. 74
Figure 5.4: Long-term rainfall trends for Upington: 1883 - 2014. 75
Figure 5.5: Recent rainfall trends for Twee Rivieren, Mata Mata, Nossob and Upington (1975-2014). 79
Figure 5.6: Temperature averages, T_{max} and T_{min} trends for Twee Rivieren: 1961 - 2014. 81
Figure 5.7: Temperature averages, T_{max} and T_{min} trends for Mata-Mata: 1975 - 2014. 82
Figure 5.8: Temperature averages, T_{max} and T_{min} trends for Nossob: 1975-2014. 82
Figure 5.9: Temperature averages, T_{max} and T_{min} trends for Upington: 1940-2014. 83
Figure 5.10: Recent temperature T_{max} trends for Twee Rivieren: 1975 - 2014.84
Figure 5.11: Recent temperature T_{min} trends for Twee Rivieren: 1975 – 2014.84
Figure 5.12: Monthly average rainfall (mm), T_{max} and T_{min} for Twee Rivieren: 1940 - 2014. 86
Figure 5.13: Monthly average rainfall (mm), T_{max} and T_{min} for Mata-Mata: 1940 - 2014. 87

Figure 5.14: Monthly average rainfall (mm), T_{max} and T_{min} for Nossob: 1940 - 2014.....87
Figure 5.15: Monthly average rainfall (mm), T_{max} and T_{min} for Upington: 1940 - 2014.....88
Figure 5.16: Short-term annual rainfall (mm) averages: 2003 - 2013 (A - F). 95
Figure 5.17: Annual precipitation (mm) for the period 2003 - 2014 for 16 weather stations in KGNP. 97
Figure 5.18: Box-and-Whisker Plot demonstrating inter-annual rainfall variability for 16 weather stations in KGNP over the period 2003 - 2013. The mid-line represents the median with the box representing quartiles and the whiskers represent the minimum and maximum. The outliers are represented by a red dot.....97
Figure 5.19: Species water trough usage during the wet and dry seasons (October 2012 - August 2014). 101
Figure 5.20: Cluster analyses of animals grouped according to the distribution of visiting times. 105
Figure 5.21: PCA analysis demonstrating the time vectors which drive individual species water trough usage. 108
Figure 5.22: Number of fauna utilising the water trough over the study period (January 2013 - December 2014). 115
Figure 5.23: Carnivore temperature thresholds and percentage faunal water trough usage. 117
Figure 5.24: Herbivore temperature thresholds and percentage faunal water trough usage. 118
Figure 5.25: Faunal water trough usage during and after rainfall events. 123
Figure 5.26: Percentage specific species water trough usage during and after specific rainfall quantities. 125
Figure 5.27: Average faunal sightings observed up to 5 days after specific rainfall events natural surface water dissipates (October 2012 - December 2014). 127
Figure 6.1: Inter-annual rainfall variability (mm) across KGNP for the period 2004-2013 (A-J). 137
Figure 6.2: Average rainfall variability (mm) across KGNP for the period 2004-2013.....138

Figure 6.3: Map indicating decreasing, stable and increasing rainfall trends over the period 2003 - 2004 in KGNP. 139
Figure 6.4: Blue wildebeest utilising the natural surface water in the Nossob riverbed after heavy rainfall in March 2014. 143
Figure 6.5: Observation of successful predation by jackal on sand grouse at Nossob (Annette Laursen, 2015). 145
Figure 6.6: Jackal hunting at the Cubitjie Quap water trough at dawn (06:27) (Maraschin, 2015). 145
Figure 6.7: Successful Jackal hunting at the Cubitjie Quap water trough at dawn (Annette Laursen, 2015). 146
Figure 6.8: Gemsbok pair visiting at the water trough during the nocturnal hours. 147
Figure 6.9: A herd of blue wildebeest (n = 12) at the water trough. 148
Figure 6.10: A herd of springbok (n = 22) at the water trough. 149
Figure 6.11: Average rainfall for April (A) and September (B) across KGNP over the period 2003 - 2014. 155
Figure 6.12: Springbok and blue wildebeest grazing on vegetation to obtain moisture and food. 157
Figure 6.13: Webcam image being obstructed by sun glare during January 2014. 164
Figure 6.14: Image demonstrating a full view of the water trough. 165
Figure 6.15: Image demonstrating the webcam zoom/pan to the right. 165
Figure 6.16: Image demonstrating the webcam zoom/pan to the left. 165

List of Tables

Table 2.1: Vegetation classifications (shrubs, trees, grass and fruit) located within each of the 5 zones within KGNP (Van Rooyen, 2008). 17

Table 2.2: Table 2.2: Faunal species observed at the water trough (October 2012 - December 2014) and in the aerial census (2008 - 2012) during the study period, demonstrating distribution and average quantity. 22

Table 4.1: South African Weather Services weather stations located in and adjacent to KGNP. Weather stations in bold indicate long-term records.50

Table 4.2: Details of Nossob water trough located within KGNP 51

Table 4.3: Webcam details of total images captured at Nossob from October 2012 - December 2014. 52

Table 4.4: Avian and Mammalian species that were observed on rare occasions at the Nossob water trough from October 2012 - December 2014, but excluded from analysis. 54

Table 4.5: Months of the year, which classify each season 66

Table 5.1: Weather stations within KGNP (Nossob and Upington) that contain missing annual data. 72

Table 5.2: Annual average T_{max}, T_{min} and rainfall (mm). Statistically significant correlations ($p < 0.05$) are indicated with an asterisk; particularly strong correlations ($p < 0.01$) with a double asterisk. 76

Table 5.3: Rainfall (mm) cyclic patterns for Twee Rivieren, Mata-Mata, Nossob and Upington over the entire period.....77

Table 5.4 Recent climatic trends (T_{max}, T_{min} and rainfall) for Twee Rivieren, Mata-Mata, Nossob and Upington: 1975 - 2014. Statistically significant correlations ($p < 0.05$) are indicated with an asterisk; particularly strong correlations ($p < 0.01$) with a double asterisk. 78

Table 5.5: Number of rain days per year, total number of consecutive rain and non-rainfall days per year for the stations Twee Rivieren, Mata-Mata and Nossob. 80

Table 5.6: Number of T_{avg} days <10°C and >30°C per year for the stations Twee Rivieren, Mata-Mata and Nossob with full data sets. The year with the maximum number of days is in brackets under each station. 85

Table 5.7: Monthly rainfall (mm), T_{min} and T_{max} averages for four weather stations

located in or near KGNP in the Northern Cape, South Africa. Statistically significant correlations ($p < 0.05$) and particularly strong correlations ($p < 0.01$) are highlighted in light and dark grey respectively. 89
Table 5.8: Monthly mean T_{max} thresholds >40°C, T_{min} thresholds <0°C and rainfall thresholds >100mm (1883 - 2014).....93
Table 5.9: Annual average short-term rainfall (mm) time trends: 2003 - 2013. Statistically significant correlations ($p < 0.05$) are highlighted.....98
Table 5.10: Total faunal species over the study period (October 2012 - December 2014) per hour. The hour with the most animals per species is marked with an asterisk. 100
Table 5.11: Total number of animals (%) during the morning, afternoon and evening. Percentage peaks are highlighted: dark orange (peak hour), lighter organge (second highest peak hour) and the light orange (third highest peak hour). 103
Table 5.12: Relationship of census and rainfall data: 2004 - 2013. Statistically significant correlations ($p < 0.05$) are highlighted in light green and particularly strong correlations ($p < 0.01$) are highlighted in dark green.111
Table 5.13: Wet (November to April) and dry (May to October) season water trough usage. Variations >50% for each species are highlighted. 113
Table 5.14: Seasonal and monthly percentage faunal water trough usage (2013 - 2014). 114
Table 5.15: Correlation of peak hour water trough usage and temperature (T_{max}, T_{min} and T_{avg}). Statistically significant correlations (5% level) are highlighted, negative in green and positive in orange. 119
Table 5.16: Correlation of total faunal water trough usage and temperature (T_{max}, T_{min} and T_{avg}). 119
Table 5.17: Correlation of monthly water trough usage and temperature (T_{avg}). Statistically significant negative correlations are highlighted in green and positive in orange (95% level) with particularly strong correlations (99% level) highlighted in dark orange. 121
Table 5.18: Correlation of all rainfall days occurring over the study period and water trough usage for all species combined. Statistically significant correlations ($p < 0.05$) are marked with an asterisk. 122
Table 5.19: Correlation one day after the rainfall event and water trough usage.

Statistically significant correlations ($p < 0.05$) are marked with an asterisk. 124
Table 6.1: Stations within the northern, central and southern sectors of KGNP. Sectors divided by particular latitudes. 132
Table 6.2: Classification of wet and dry seasons, and peak water trough usage during the study period. 150
Table 6.3: Missing rainfall and temperature data for each weather station. Weather stations with long-term data are bold.....166
Table 6.4: Missing webcam images on a monthly time scale. 168
Table 6.5: Missing days per month for the webcam image data. 168
Table 6.6: Online climatic sources that were used to fill gaps in Twee Rivieren and Mata-Mata climatic data records. 170

List of Acronyms, Abbreviations and Statistical Terms

AERU: Arid Ecosystems Research Unit
ARC: Agricultural Research Cultural
DEA: Department of Environmental Affairs
ENSO: El Niño Southern Oscillation
FTP: file transfer protocol
GCM: Global Climate Models
GPS: Global Positioning System
IOD: Indian Ocean Dipole
IPCC: Intergovernmental Panel on Climate Change
IUCN: International Union for Conservation of Nature
Kb: kilobytes
KGNP: Kalahari Gemsbok National Park
KTP: Kgalagadi Transfrontier Park
M.a.s.l: Meters above sea level
No.: Number
PCA: principal component analysis
RNP: Ruaha National Park
SAEON: South African Environmental Observation Network
SANParks: South African National Parks
SAWS: South African Weather Services
Spp: Species
TAWIRI: Tanzania Wildlife Research Institute
WinSCP: Windows Secure Copy
Wits: University of the Witwatersrand
WWF: World Wildlife Fund

Av.: average

°C/yr: degrees Celsius change in temperature per year

mm/year: millimetre change in rainfall per year

T_{min}: minimum Temperature

T_{max}: maximum Temperature

T_{avg}: average Temperature

Km: kilometres

Mm: millimetres

M: meters

Statistical Terms

n value: The total number of data entries.

p value: A measure of the statistical significance of the outcome of a correlation or regression analysis. Smaller numbers indicate greater statistical significance.

r: Pearson Correlation Coefficient – a number between -1 and +1 providing a measure of the strength of the correlation between two factors. Values tending to 0 indicating a poor correlation, while values close to -1 indicate a strong negative correlation, and values close to +1 indicate a strong positive correlation.

σ: Standard Deviation - A measure that quantifies the amount of variation or dispersion of a set of data values.

Chapter 1

Introduction



1 Introduction

Protected areas are the intended sanctuary for those species occupying them and are seen as the backbone of conservation (Kiffner *et al.,* 2012). Such areas are important as they often provide the only remaining natural or semi-natural habitat within the larger landscape, and may harbour species that do not occur elsewhere (Pettorelli *et al.,* 2012). Africa contains a large proportion of the world's remaining biodiversity, and climate change is expected to severely impact these areas (Pettorelli *et al.,* 2012). However, it is also acknowledged that protected areas may be comprised by management efforts that are misguided or poorly implemented (Ogutu *et al.,* 2012). It is therefore important to monitor protected areas and to identify the impacts of climate change, and the ability of species to adapt to these changes (Hannah *et al.,* 2007).

Globally conservation methodology exists on how to record fauna, albeit for recording their behaviour, population or social interactions. The available studies interpret faunal behaviour using different methods of data collection, which include, amongst others, GPS collars in Tarangire National Park (Tanzania), which allows for monitoring both animal behaviour and interactions with the environment (Galanti *et al.,* 2000), and direct observation from a hide or motor vehicle, which involves counting fauna at water troughs in Tsavo National Park, Kenya (Ayeni, 1975). However, these techniques have several limitations: the use of GPS collars is costly (Caughley, 2006), whilst direct observation is time consuming (Georgiadis *et al.*, 2003).

The use of an aircraft with a few observers recording fauna, is a more efficient tool for monitoring faunal distributions as they cover a wide area in a short amount of time, which is more effective in a national park/protective area (Caro, 1999). The analysis of fauna locally requires an in field observer or a technique that offers a viable proxy for this observer such as webcams or photographic/video recording technique. Whilst studies have examined faunal behaviour using conventional methods such as direct observation (Ayeni, 1975), there is limited research on the

use of webcam images to monitor mammal activity and drinking behaviour and how these relate to local environmental and climatic conditions (Hayward and Hayward, 2012; Trent, 2012; Maraschin, 2013). Maraschin (2013) analysed faunal water trough usage relation to climatic patterns with the use of webcams within the Kalahari Gemsbok National Park (KGNP), which is located within the larger Kgalagadi Transfrontier Park (KTP).

The Kgalagadi Transfrontier Park (KTP) comprises two national parks joined across the international Botswana-South Africa border. KGNP, under the management of South African National Parks (SANParks), forms the South African component of the KTP (*Figure 1.1*). This region is predominantly semi-arid with an extreme degree of inter-annual rainfall variability and high temperatures (Mphale *et al.,* 2014). Therefore, KGNP is reliant on permanent water troughs to supply water to faunal species year round (Child *et al.*, 1971). Much of this will be exacerbated by climate change, as rainfall variability will increase as well as the number and size of extreme dry spells in KGNP (van Wilgen *et al.*, 2015).

Rainfall is the dominant climatic factor influencing herbivore population dynamics in African environments (Ogutu *et al.,* 2008). However, there is a knowledge gap in studies analysing how climate variables, specifically rainfall, control the species assemblages and distributions of African savanna ungulates within a semi-arid environment such as KGNP (Jeltsch, 1997; Ogutu *et al.,* 2008).

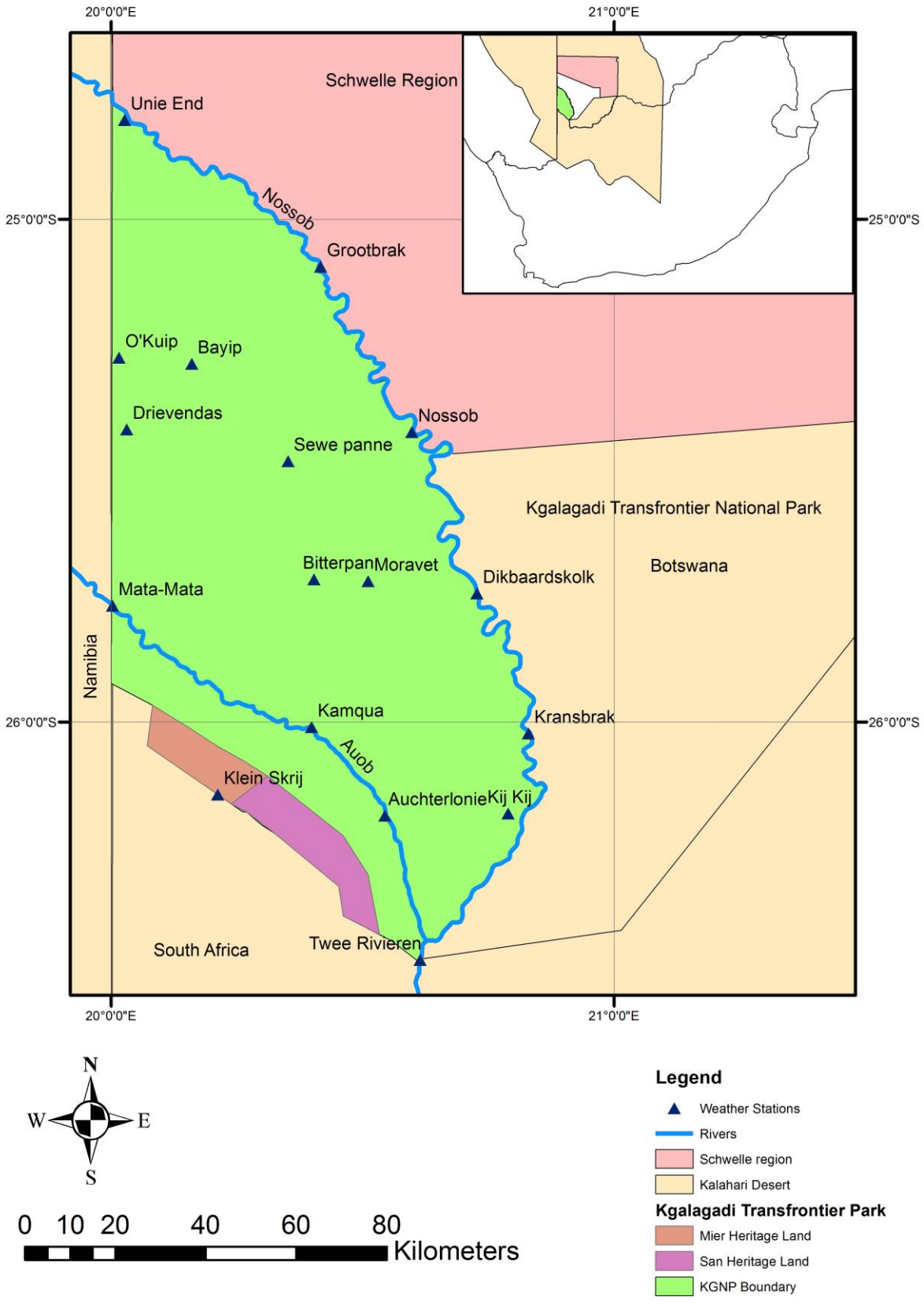


Figure 1.1: Map of the Kalahari Gemsbok National Park (KGNP), within greater KTP, which is within the Kalahari Desert and the Schwelle region, demonstrating the localities of weather stations and the Mier/ San Heritage Land.

1.1 Rationale: Contribution to Existing knowledge

The Kalahari is classified as semi-arid and has a notable lack of permanent and seasonal water sources, which is characteristic of semi-arid environments (Thomas and Shaw, 1991). These species traditionally migrated between the Kgalagadi and the Schwelle regions of northern Botswana (Okavango) (Mbaiwa and Mbaiwa, 2006). The Khukhe Fence, erected in 1958, extends from the Namibian border to form the northern boundary of the Central Kalahari Game Reserve. This fence severely limits the movements and migration of wildlife in the Schwelle region (northern Kgalagadi) to wet areas (Okavango Delta) during the dry seasons (*Figure, 2.1*) Mbaiwa and Mbaiwa, 2006). The construction of the KTP fence further limits the effects of wildlife movements out of the Transfrontier Park. Consequently, the construction of artificial water troughs for conservation purposes became an important initiative to reduce the mortality of water-dependent species in KTP, and elsewhere in Africa (Child *et al.,* 1971). Understanding the water requirements of water-dependent species, such as wildebeest, so that these species can be protected during dry years through the provision of supplementary water is therefore critical (Ayeni, 1975).

Hayward and Hayward (2012) have reported that limited research exists on the water requirements of wild-ranging animals. Among the papers that have been published, very few exist on faunal distributions in KGNP and the use of water troughs by faunal species. A knowledge gap exists on the use of water troughs by faunal species, with only a few studies being published (Ayeni, 1975; Hayward and Hayward, 2012). Child *et al.* (1971) is one of the very few studies that have been published on the use of mineralised water by Kalahari wildlife. Furthermore, Hayward and Hayward (2012) is the only study that used webcams to monitor faunal water trough usage in Africa.

Furthermore, earlier studies have made use of traditional monitoring methods, such as mark-recapture methods and labour intensive direct observation methods to establish animal behaviour and drinking patterns (Western, 1975; Ayeni, 1977; Valeix *et al.,* 2007). However, the primary limitations of these studies are that they

are time consuming, extremely costly and fauna and their behaviour may be negatively impacted by human interference (Wawerla *et al.,* 2009; Verstraeten *et al.,* 2010). Therefore, this study will contribute valuable knowledge towards the understanding of faunal regional distributions across KGNP landscape and the understanding of the influence on certain climatic factors (temperature and rainfall) on faunal water trough usage.

Recent technological advances can address these limitations. For example, the use of webcams can be used to gather a significant amount of data over any specific time period without much human involvement (Wawerla *et al.,* 2009; Porter *et al.,* 2010; Verstraeten *et al.,* 2010). An additional advantage is that these webcams allow data collection to be obtained without being intrusive or disruptive to the fauna being monitored (Locke *et al.,* 2005; Porter *et al.,* 2010). Further, webcam data can be a valuable remote source of information on specific faunal water requirements/drinking behaviours and is particularly important in a semi-arid environment where rainfall is variable and water is scarce (Hayward and Hayward, 2012) as it can illustrate species water dependency.

The study piloted by Hayward and Hayward (2012) used webcam imagery to document the time African fauna spend at a water trough. However, their research did not link drinking behaviour with temperature fluctuations and only focused on seasonal rainfall associated with the water trough. Further, the study analysed only a limited subset of available daily imagery, and so many faunal visits may have been missed. It is important to understand how specific temperature thresholds influence faunal drinking patterns, revealing temperature tolerances and associated water requirements (Peck *et al.,* 2009). To fill this knowledge gap, Trent (2012) and Maraschin (2013) initiated pilot projects using imagery from webcams situated in the Kruger National Park (KNP) and KGNP, respectively. These webcams capture images at 15 second intervals at the Satara and Orpen water troughs in KNP and at the Nossob water trough in KGNP.

The 2013 pilot study by Maraschin forms the foundation for this current Masters dissertation; having provided insight into the use of webcam imagery as a tool for remote sensing and a basic understanding of mammal water requirements in KGNP,

at least during a single summer. The current Masters project intends to document seasonal use of the supplemental water source by analysing webcam imagery from a 2-year period (October 2012 to December 2014), as well as understanding species-specific drinking behaviour in relation to rainfall and temperature patterns.

Water availability in KGNP has been affected by temperature increases and changes in precipitation (quantity and seasonality) (Lohmann *et al.*, 2012). In addition, increasing current evaporation rates linked to climate change in KNP, make it essential that supplementary water is provisioned to wildlife, especially in a semi-arid area such as KGNP (Redfern *et al.,* 2005). Research looking at faunal census data in relation to rainfall records, as a means of monitoring shifting faunal patterns in relation to climate, is limited, especially for the semi-arid KGNP (Erasmus *et al.,* 2002; Hetem *et al.,* 2014). However, such a comparison would elucidate the relationship and shifting patterns of fauna in relation to changing rainfall patterns (Rango *et al.,* 2005), and inform decisions and policies regarding faunal water requirements and the provision and future management of artificial water troughs within KGNP under a further changing climate.

1.2 Background

National Parks are important protected areas that are essential for the conservation of fauna, and require effective management. The uses of monitoring systems are important as they determine the threats to biodiversity and wildlife populations (Caro, 1999). Monitoring techniques can help to establish the specific faunal behavioural and distribution patterns within a protected area (Trent, 2012). Webcam live outdoor cameras are located in areas such as national parks for touristic and public faunal viewing through Internet networks, such as the SANParks website (Jacobs *et al.,* 2009; SANParks, 2015). For effective monitoring purposes, conservation foundations make use of webcams, which were initially installed for touristic purposes, to monitor water trough usage in African savannas and rivers frequented by wildlife (Kamphof, 2011; Hayward and Hayward, 2012).

Webcam imagery has been analysed for faunal behavioural data at the Nossob water trough in KGNP. A pilot study conducted in 2013 (Maraschin, 2013) analysed

webcam imagery from the Nossob water trough and correlated. Faunal water trough usage patterns with short-term weather data (October 2012 - July 2013). Results showed that certain weather events, such as high rainfall episodes and higher than average maximum temperatures, affected water trough usage and species' drinking behaviour. Usage decreased with/during/after high rainfall events as natural surface water was preferentially consumed, and the duration of drinking bouts increased during periods with maximum temperatures.

1.3 Aim and Objectives

1.3.1 Aim

This study, through a time-trend analysis of historical climatic data, investigates patterns of change in rainfall and temperature in KGNP in recent decades. By analysing historic rainfall and temperature trends throughout KGNP, this project adds to overall knowledge on rainfall variability and trends in the focused region of KGNP. The proposed project aims to validate decadal faunal census data which, when interpreted with concurrent climate data, contains valuable information on species distributions within KGNP and species-specific water requirements in relation to environmental conditions and certain climatic controls. Aerial distribution records have been obtained from SANParks for KGNP bi-annually (2004 - 2013) to establish large mammal distribution in KGNP. Additionally, the research uses webcam data from the Nossob water trough in KGNP to reveal drinking behaviours (i.e. time of visitation at the water source) over the period October 2012 - December 2014 and how these drinking patterns are impacted by daily and seasonal ambient environmental conditions.

1.4 Objectives of Research

- To establish historic patterns in rainfall and temperature (changes in rainfall event size over time, changes in mean annual precipitation and number of rain days over time, changes mean annual T_{min} and T_{max} and frequency of extreme events for KGNP over the period 1900 - 2014.
- To establish recent patterns in rainfall (volume per rainfall event, mean annual precipitation and frequency and number of rain days) for the period 2003 -

2014.

- To establish a spatio-temporal relationship between faunal distribution and patterns of rainfall within KGNP from 2004 - 2013.
- To establish faunal drinking patterns (average daily / seasonal time of visitation, average daily / seasonal duration of drinking and species-specific water requirements) at an artificial water point.
- To determine the influence of spatio-temporal rainfall patterns within KGNP on faunal drinking behaviour over a two-year period (October 2012 until December 2014).

Chapter 2

Environmental Setting



2 Environmental Setting

2.1 Introduction

This study focuses on mammal distribution and drinking behaviour in relation to rainfall from 2004 to 2013 focuses on faunal census and rainfall data from KGNP; the south African portion of the greater KTP. An analysis of the past 60 years or more of rainfall and temperature data from 16 SAWS weather stations in and adjacent to the park were conducted to investigate climatic patterns in KGNP, South Africa. Locally, this study makes use of a webcam overlooking the Nossob artificial waterhole in KGNP, with the captured imagery, documenting mammal drinking behaviours. This chapter explains the environmental setting of the study site, which includes a background to KTP and KGNP, and a brief explanation of the 5 major environmental zones found within KGNP. A description of the faunal species utilizing the Nossob water trough and fauna within the aerial census is discussed in *Table 2.2*. The regional climate and drivers of potential climate change is discussed.

2.2 Background of Study Site

The Kalahari is the largest sandveld area in the world, located in the western portion of the southern African subcontinent (Stapelberg *et al.,* 2008). The semi-arid Kalahari extends over 900 000 km^2 across much of Botswana and parts of Namibia and South Africa (Mills and Mills, 2013; Thondhlana *et al.*, 2011). The southern Kalahari region is defined as the area to the south of the Bakalahari Schwelle, a ridge that runs from Gobabis (Namibia) in the north-west to Lobatse in the south-east of Botswana (Haacke, 1984; Mills and Mills, 2013). The Schwelle separates the northern drainage basin - the Okwa and Hanahai river systems from the southern drainage basin - the Nossob, Auob, Molopo and Kuruman rivers. The southern Kalahari slopes south-westerly from the Schwelle (*Figure 1.1*) (Werger, 1978).

The KTP is located within the Kalahari and averages 900 m.a.s.l., with the lowest point located at Twee Rivieren in the southwest (Madzwamuse *et al.,* 2007). The Nossob, which means *dark clay*, and the Auob, which means *bitter water*, both have their sources in the mountains near Windhoek, Namibia. They both have a south-

easterly flow with the confluence in KGNP, which is the South African side of the KTP, 6km north of Twee Rivieren (van Wyk and Le Riche, 1984). These rivers are predominantly dry and only flow for short periods after high rainfall events (Parris, 1976). In recent times the Auob River flowed in 1934, 1963, 1974, while the Nossob River only flowed in 1934, 1964 and 1974 (SANParks, 2008).

In 1897, the government began surveying the land currently comprising KGNP and subdividing it into farms for white settlers. However, the Cape government decided to give the farms to coloured farmers instead (van Wyk and Le Riche, 1984; Thondhlana *et al.,* 2011). The South African government drilled boreholes along the Auob River bed during the outbreak of World War 1 in 1914 (Mills and Mills, 2013). Wildlife had deteriorated during the 1920s due to biltong hunters invading the area. Accordingly, during 1931 the area between the Nossob and Auob rivers was proclaimed as the Kalahari Gemsbok National Park (Mills and Mills, 2013). During this time, the borehole structures were abandoned (Van Wyk and Le Riche, 1984).

The old boreholes in the riverbed were re-commissioned in the early 1930s in order to encourage wildlife to stay in the park instead of leaving the unfenced boundaries where they were hunted and killed (Jeltsch *et al.,* 1997). Water that has leached into the sand forms large underground lakes. This groundwater is then extracted from the Nossob and Auob rivers and other areas in the park to provide water for the fauna (SANParks, 2008). After World War 2, fences were erected along the Park's western and southern boundaries. The eastern boundary remained unfenced leaving this border open for wildlife migration from east to west (Mbaiwa and Mbaiwa, 2006).

The South African and Botswana conservation agencies have had a co-operative agreement since the two parks, *viz*. the Kalahari Gemsbok National Park (South Africa) and the Gemsbok National Park (Botswana) respectively, were proclaimed. The Department of Wildlife and National Parks in Botswana, South African National Parks (SANParks) and the Peace Parks Foundation placed the groundwork for the establishment of the KTP. Botswana Department of Wildlife and National Parks and SANParks signed the agreement in 1999 and the governments endorsed the Management Plan. The Kgalagadi Transfrontier agreement acknowledges that management objectives will be implemented through the Wildlife Department in

Botswana and SANParks in South Africa (van Wyk and Le riche, 1984; Ramutsindela, 2007; Thondhlana *et al.*, 2011).

2.3 Study Location

This is a desktop study focused on KGNP, which is situated in the Northern Cape Province, South Africa, from approximately 22°10'E, 20°0'W, 24°6'N and 26°28'S. *Figure 1.1* demonstrates the location of the larger Kgalagadi Transfrontier Park, within the Kalahari Desert, which straddles the South Africa-Botswana border and is bounded by the South Africa-Namibia international border to the west. This map also contains the landmarks located within KGNP. *Figure 1.1* demonstrates the location of KGNP within the broader KGNP as well as the weather stations within the park. The park broadly comprises rivers, pans, dunes and plains (Van Rooyen *et al.,* 2008).

2.4 Vegetation Units Within KGNP

KGNP has been divided into 5 environmental zones, according to vegetation units (Van Rooyen *et al.,* 2008), and these will be used for the purpose of this project. The zones were demarcated in accordance with dominant flora as well as geographical features (Van Rooyen *et al.,* 2008; *Table 2.1, Figure 2.1*).

2.4.1 Zone 1: Riverbeds and Riverine Environments

The two main riverbeds located in KGNP are the Nossob and Auob Rivers. The Auob River is the boundary of Stratum C, whilst Stratum B is bordered by the Auob and Nossob rivers, and Stratum A consists of the northern Nossob River. Artificial water sources (*Table 2.1; Figure 2.1*) have been provided for faunal species due to the lack of permanent surface water in KGNP (Hayward and Hayward, 2012). The Nossob River, which forms the north-eastern boundary of KGNP, (Van Rooyen *et al.*, 2008).

The riverbeds comprise clays, which are rich in nutrients and compact, thus with poor water storage capacity (Werger, 1978). Temporary pools or streams in riverbeds form as a result of local runoff after heavy rainfall events (Makhabu *et al.,*

2002). The soils in these riverbeds contain fewer minerals than the pan floors, which create natural salt-licks (Parris, 1976). The vegetation occurring in the riverbeds consists of dwarf-shrub or grass communities and is similar to that found in pans, and is determined by both soil type and rainfall (*Table 2.1, Figure 2.1;* Parris, 1976; Werger, 1978).

The rivers have a much higher faunal density than that of the duneveld (Parris, 1976). The Nossob River is important during the wet season (September to January) for blue wildebeest, springbok, red hartebeest and gemsbok, however, there is considerable movement away from the river to the duneveld areas at the start of the dry season, in January every year (Bothma and Mills, 1977). As a result of the high density of herbivores in the riverbeds, there is correspondingly high density of carnivores (Parris, 1976). The vegetation that grows in the riverbeds is generally more nutritious than the vegetation growing in the duneveld (Kreulen, 1985).

2.4.2 Zone 2: Pans

The distinct difference between pans and rivers is that the former have an open drainage whilst pans have endorheic [1] drainage (Parris, 1976). Pans occur throughout KGNP and are found abundantly in the Sewe panne area and along the southern boundary bordering the Mier Settlement. Chamaille-Jammes *et al.* (2007a) report that pans provide natural surface-water, but do dry up during the dry season. There are two main pan types in KGNP, *viz.* calc pans (grass pans) and salt pans (Leistner, 1967; Van Rooyen *et al.,* 2008). Calc pans occur more frequently, which are infilled with claylike sediment on the pan floor (Makhabu *et al.,* 2002). Saltpans are less common and the pan floors are characterized by high sodium chloride content (Leistner, 1959; Bothma and de Graaff, 1973; Parris and Child, 1973; Parris, 1976; Scholes *et al.,* 2002). The vegetation of the bare pan surface (salt pans) consists of shrubs with grass species (*Table 2.1; Figure 2.1;* Bothma and De Graaff,

[1] Closed hydrological drainage systems, which drain into inland terminal locations where the water evaporates or leaches into the ground and has no access to discharge into the ocean (Hillyard, *et al.,* 2015).

1973; Van Rooyen *et al.,* 2008).

This vegetation is of high importance to the fauna in KGNP (Leistner, 1959) because of its richness in minerals, which is lacking in other vegetation zones within the park (Parris, 1976). In particular, grasses and the dwarf shrubs growing associated with the pans form an important dietary component of certain ungulate species, springbok and blue wildebeest (Parris, 1976; Kreulen, 1985). Further, ungulates, such as the less water-dependant gemsbok and red hartebeest, in KGNP rely heavily on the salt licks, found within pans because they contain a high source of nutrient minerals (Kreulen, 1985; Van Rooyen and Van Rooyen, 1998; Mills and Mills, 2013).

2.4.3 Zone 3 High Dunes

This zone consists of parallel high duneveld (*V. haematoxylon*), irregular high duneveld (*V. haematoxylon*) and parallel high duneveld (*V. erioloba-Senegalia mellifera*). The parallel (linear) high dunes are grass-covered and occur in the south in the vicinity of Twee Rivieren, located in the southern parts of strata A and C (*Table 2.1; Figure 2.1;* Bothma and de Graaff, 1973; Van Rooyen *et al.,* 2008; Mills and Mills, 2013). The irregular high duneveld occurs south of the Auob River and between the Nossob and Auob rivers in the south. This zone is mainly located within stratum C, and a small section in the south of stratum B (*Table 2.1; Figure 2.1*; Van Rooyen *et al.,* 2008). The parallel high duneveld consists of *V. erioloba* and *S. mellifera* open tree savanna. The soils are deep, reddish sand and these dunes occur along the strip northern side of the Auob River and on both sides of the Nossob River from Samevloeiing in the south to Langklaas in the north, forming the boundaries of stratum B. This landscape also occurs in the northern region of the park, south of Grootkolk (Van Rooyen *et al.,* 2008; *Table 2.1; Figure 2.1*).

2.4.4 Zone 4 Low Dunes

This zone consists of low duneveld (*V. erioloba-S. kalahariensis*), irregular low duneveld (*V. haematoxylon-S. ciliate*) and low undulating duneveld (*V. haematoxylon-C. glauca*). The low duneveld (along rivers) is characterised by open tree savanna and occurs in the interior duneveld in the north vicinity of Dankbaar, Gharagab and Bayip as well as the west of the Nossob River near Grootbrak,

located within strata A and B (*Table 2.1; Figure 2.1*; Leistner, 1967; Van Rooyen *et al.,* 2008). Irregular low duneveld consists mainly of *V. haematoxylon* and *S. ciliate* vegetation and is the largest landscape unit within KGNP. It includes the grass-covered irregular dunes in the south-western section, east of Mata-Mata and north of the Auob River, as well as from the south to the far north in the eastern interior duneveld, located in strata A and B (*Table 2.1; Figure 2.1*; Van Rooyen *et al.,* 2008; Mills and Mills, 2013). Undulating low duneveld consists of shrubby grassland and occurs throughout the interior duneveld from Kij Gamies in the south to Unions End in the north, located within strata A and B (*Table 2.1; Figure 2.1*; Van Rooyen *et al.,* 2008).

2.4.5 Zone 5: Plains

The area between the Nossob and the Auob Rivers contains a number of widespread, flat plains, often separated by narrow dune belts. Two types of plains exist within KGNP, which are undulating shrubland plains and grassy plains. Flat grassy plains are found in the central interior duneveld and contain scattered shrubs of *V. haematoxylon* (*Table 2.1; Figure 2.1*; Leistner, 1959; Thomas and Leason, 2005; Van Rooyen *et al.,* 2008).

Table 2.1: Vegetation classifications (shrubs, trees, grass and fruit) located within each of the 5 zones within KGNP (Van Rooyen, 2008).

Zone		Shrub																			Trees			Grass																										Fruit	
		Asparagus nelsii	*Deverra denudate*	*Eriocephalus aspalathoides*	*Eriocephalus pubescens*	*Galenia Africana*	*Gnidia Polycephala*	*Hypertelis salsoloides*	*Lagerra decurrens*	*Lebeckia linearifolia*	*Lycium cinereum*	*Rhigozum trichotomum*	*Rosenia humilis*	*Salsola namaqualandic*	*Salsola etoshensis*	*Senegalia mellifera*	*Vachellia haematoxylon*	*Zygophyllum simplex*	*Zygophyllum tenue*	*Aristida meridionalis*	*Boscia albitrunca*	*Vachellia eriobola*	*Vachellia luederitzii*	*Aristida meridionalis*	*Brachiaria glomerata*	*Centropodia glauca*	*Chloris virgate*	*Grewia flava*	*Eragrostis annulata*	*Eragrostis Ratifer*	*Enneapogon desvauxii*	*Eragrostis bicolor*	*Eragrostis echinochloidea*	*Eragrostis lehmanniana*	*Eragrostis pallens*	*Eragrostis porosa*	*Eragrostis trichophora*	*Eragrostis truncate*	*Panicum coloratum*	*Schmidtia kalaharensis*	*Sporobols rangei*	*Sporobolus coromandelianus*	*Sporobolus rangei*	*Stipagrostis amabilis*	*Stipagrostis ciliata*	*Stipagrostis obtusa*	*Stipagrostis uniplumis*	*Tragus racemose*	*Vachellia luederitzii*	*Acanthosicyos naudinianus*	*Citrullus lanatus*
Zone 1: Riverbeds	Nossb River and Auob River		✓		✓	✓			✓	✓		✓					✓					✓				✓		✓	✓	✓	✓						✓	✓												
Zone 2: Pans	Bare pan surface (salt pan) and grassy pans (*viz.* calc. pans)			✓	✓			✓			✓	✓		✓	✓		✓	✓	✓		✓	✓							✓		✓			✓		✓		✓	✓	✓	✓		✓		✓	✓			
Zone 3: High Dunes	*Vachellia haematoxylon* Parallel high duneveld	✓					✓			✓							✓					✓											✓			✓		✓					✓			✓		✓		
	Vachellia haematoxylon Irregular high duneveld											✓				✓	✓				✓				✓	✓									✓		✓					✓	✓		✓				
	Vachellia eriobola-Senegalia mellifera Parallel high duneveld	✓														✓	✓				✓	✓				✓		✓					✓					✓					✓			✓				
Zone 4: Low Dunes	*Vachellia eriobola-Schmidtia kalharensis* Low duneveld											✓				✓					✓	✓	✓			✓	✓						✓						✓					✓	✓		✓			✓	
	Vachellia haematoxylon-Stipagraostis ciliate Irregular low duneveld											✓				✓	✓				✓		✓		✓	✓							✓						✓					✓	✓	✓	✓			✓	✓
	Vachellia eriobola-Schmidtia kalharensi s Low undulating duneveld																			✓	✓	✓		✓		✓		✓					✓						✓								✓				
Zone 5: Plains	Undulating shrubland																✓						✓	✓	✓							✓						✓					✓			✓				
	Grass																✓			✓				✓	✓	✓							✓	✓										✓			✓				

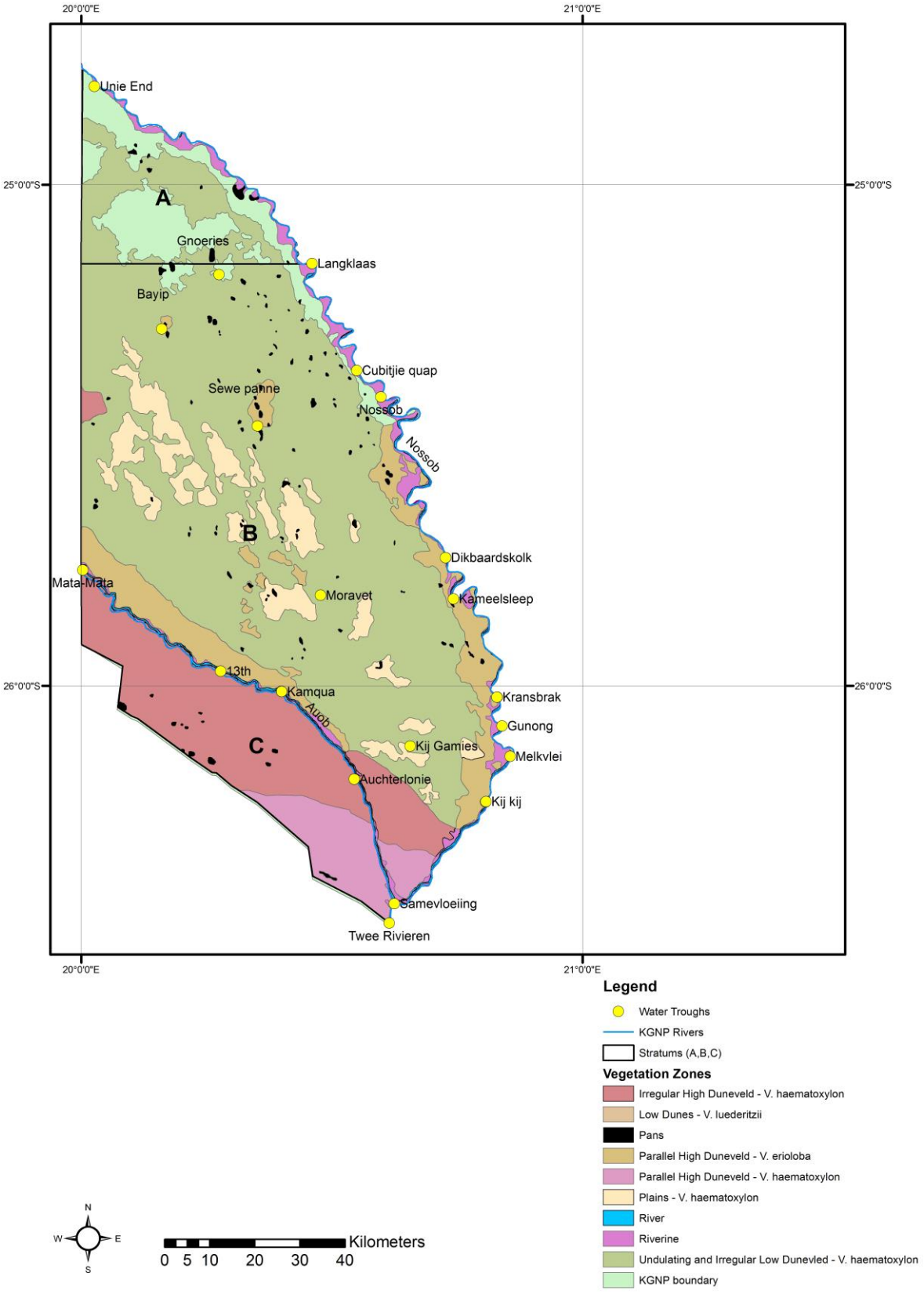


Figure 2.1: Map demonstrating the water troughs and ecological zones, consisting of rivers, pans, duneveld and plains, with the aerial census strata (A, B and C) demarcated.

2.5 Climate of the Kalahari and KGNP

The southern Kalahari is a semi-arid region. Most of the moisture in the southern Kalahari comes from anti-cyclones moving in from the Indian Ocean. However, the Drakensberg mountain range forms a rain shadow over the area, which creates a barrier to all but the deeper air currents. Sometimes rainfall is supplemented by moist air that moves down from the inter-tropical convergence zone, more specifically, from North-west Angola (Mills and Mills, 2013). Most rainfall occurs during the late summer months of November to March. The southern Kalahari receives a low annual average rainfall of 226mm (Tyson and Preston-Whyte, 2000). In KGNP - located within the southern Kalahari - the average annual rainfall generally ranges from 209mm at Mata-Mata (south-west) to 220mm at Twee Rivieren (south) and 230mm at Nossob in the North (Van Rooyen *et al.,* 1991). This demonstrates that KGNP is characterised by inter-annual rainfall variability to a certain extent. Rainfall data had been recorded since 1940 at Twee Rivieren, with annual totals ranging from, 90mm in 1984, 284mm in 1988, 77mm in 1998 and 317mm in 2000 (Thomas and Leason, 2005).

This can be confirmed by the numerous thunderstorms that occur within this region. Above average rainfall in KGNP is linked to river flow. This is evident in flooding that occurred during the years 1974 - 1976 in KGNP due to La Niña events that caused above average rainfall (660mm at Nossob) (Woodward and Lomas, 2004; Jury and Mpeta, 2005; Washington and Preston, 2006; Mills and Mills, 2013; Mackellar *et al.,* 2014).

Often, KGNP is cloudless which causes extremes in temperatures. Fluctuations in temperature are both seasonal and diurnal, with the days being hot and the nights cool - a common phenomenon in African semi-arid regions (Van Rooyen *et al.,* 2008; Mills and Mills, 2013). A combination of low humidity and high day-time temperatures creates high rates of evaporation and consequently very little/no surface water (Mills and Mills, 2013). The dry season is associated with depressed vapour pressure and cooler temperatures and occurs May through to October, when the minimum temperature can reach -10.3°C (Scholes *et al.,* 2002; Van Rooyen *et al.,* 2008;

Abere and Oguzor, 2011). The wet season occurs during summer (December through to April), when maximum temperatures can exceed 45°C (van Rooyen *et al.,* 2008).

KGNP region experiences extreme climatic events such as droughts, which are caused by highly erratic rainfall (Mphale *et al.,* 2014). According to Nash and Endfield, 2002) central southern Africa experienced drought periods during 1820 - 27, 1831 - 35, 1844 - 51, 1857 - 65, 1877 - 86 and 1994 - 99. El Niño Southern Oscillation (ENSO) is the main climatic phenomenon which, causing drought (Nicholson *et al.,* 2001). This phenomenon begins when the easterly winds in the Pacific, which normally blow from east to west, weaken. The major rain zone is shifted eastward towards the central Pacific, which causes a persistent dry period in Southern Africa, Indonesia, the Philippines and northern Australia. The coastal upwelling along the west coast of South America becomes significantly less and the nutrient-rich cold waters from the deep ocean are no longer found at the sea surface. The atmospheric and ocean behaviours support each other to create a full-scale El Niño event (Kovats *et al.,* 1999; Nash and Endfield, 2008). ENSO events strongly influence inter-annual climate variability in many countries in Africa, including parts of southern Africa. These regions may experience phenomenon such as regional and sea surface warming, changes in storm tracks and changes in precipitation patterns (Nash and Endfield, 2008). Abnormally warm temperatures in the Atlantic and Indian Ocean surrounding Africa cause drought conditions over Botswana and certain regions of southern Africa, including the Kalahari Desert (Nicholson *et al.,* 2001). Droughts are also linked with anti-cyclonic conditions, which have features of subsidence of air, compression and adiabatic warming of the local atmosphere. (Tyson and Preston-Whyte, 2000).

2.6 Fauna of KGNP

KGNP supports a wide variety of herbivores, including red hartebeest (*Alcelaphus buselaphus*), blue wildebeest (*Connochaetes taurinus*), springbok (*Antidorcas marsupialis*), gemsbok (*Oryx gazella*), common eland (*Tragelaphus oryx*) and steenbok (*Raphicerus campestris*) (*Table 2.2*; Campbell, 1981; Thouless, 1998). As the rainfall is low, most of the fauna have easily adapted physically to arid ecological

conditions, with the exception of the blue wildebeest (Silberbauer, 1981). There are a variety of predators including lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*), brown and spotted hyena (*Hyaena brunnea* and *Crocuta crocuta*) and black-backed jackal (*Canis mesomelas*) (hereafter, referred to as jackal) (*Table 2.2*) (Mills and Retief, 1984). Other species present include wild dog, caracal, African wildcat, honey badger, bat-eared and cape fox and slender and yellow mongooses (Campbell, 1981). These are rarely seen in the webcam images, so not used for the purpose of this project. Based on the poor resolution webcam imagery, many avian species could not be identified. In order for faunal species to survive in KGNP, it requires a balance between water intake and loss, where water loss is a continuous process through mechanisms such as breathing, cooling, faeces and urine (Bothma, 2005).

2.7 Description of Study Subjects

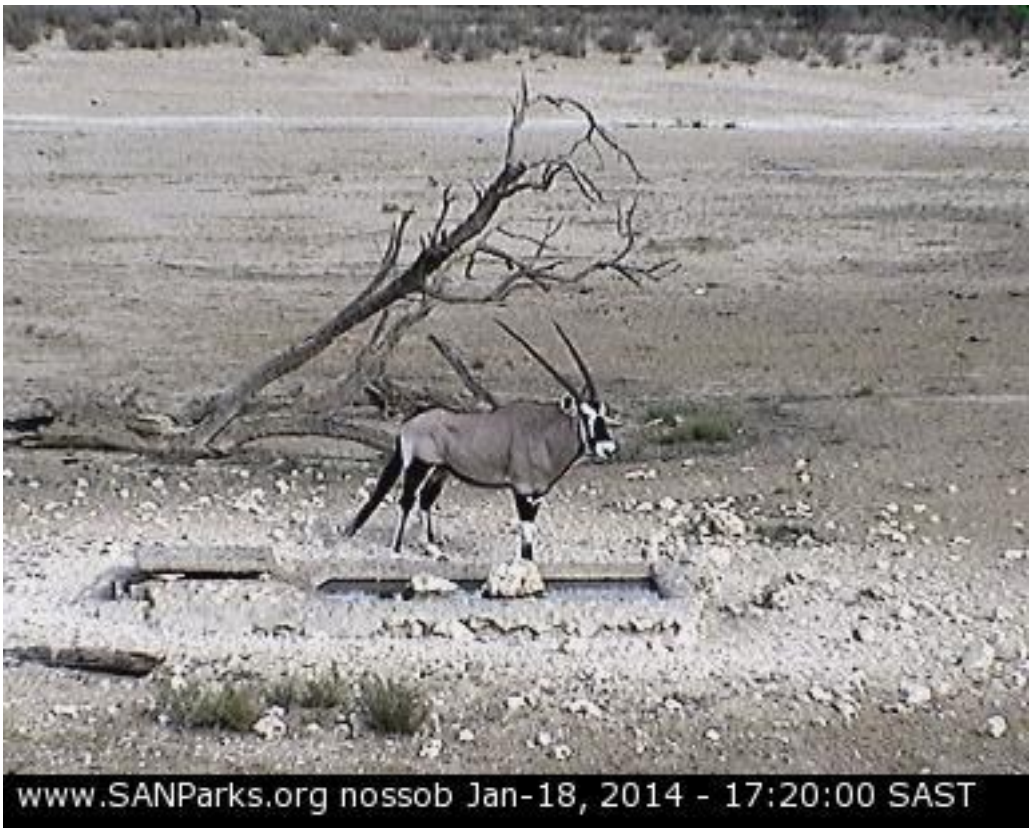
The study focussed on the distribution of large mammalian fauna within KGNP, as inferred from SANParks aerial census data, as well as drinking behaviour locally through imagery of fauna utilising the Nossob artificial water trough (*Table 2.2*). The South African Weather Services (SAWS) provided temperature and rainfall data to construct historic (100 years) and current climate patterns /trends (10 years) for KGNP. Ultimately, the he study focuses on understanding/explaining the effects of rainfall and temperature patterns and extremes on the distribution (seasonal, annual) and drinking behaviour (daily, seasonal) of select fauna in KGNP.

Table 2.2: Faunal species observed at the water trough (October 2012 - December 2014) and in the aerial census (2008 - 2012) during the study period, demonstrating distribution and average quantity.

	Common Name	Scientific Name	Water-dependent	Distribution April in KGNP (2008-2012)	Average fauna	Distribution September in KGNP (2008-2012)	Average fauna
Herbivores	Red Hartebeest	*Alcelaphus buselaphus*	✓	Predominantly located in north near Nossob with few individuals located in vicinity of Auob.	1992	Located in north of park around Gharagab.	1901
	Springbok	*Antidorcas marsupialis*	✓	Along Rivers, not present between Gunong and Dikbaardskolk.	5706	Concentrated on rivers, but preference to the Auob. Few individuals found near pans.	3691
	Blue wildebeest	*Connochaetes taurinus*	✓	Along Rivers, large numbers around Nossob.	1461	Northern section of Nossob river as well as Auob Limited numbers on south of Nossob.	5253
	Gemsbok	*Oryx gazella*	✗	Widespread.	13414	Widespread.	10384
	Steenbok	*Raphicerus campestris*	✗	-	3794	-	2501
	Common Eland	*Taurotragus oryx*	✗	-	23	-	8310
Carnivores	Cheetah	*Acinonyx jubatus*	✗	-	18	-	5
	Black-backed jackal	*Canis mesomelas*	✗	-	20	-	6
	Spotted hyena	*Crocuta crocuta*	✗	-	1	-	-
	Brown hyena	*Hyaena brunnea*	✗	-	-	-	3
	Lion	*Panthera leo*	✗	-	17	-	3
	Leopard	*Panthera pardus*	✗	-	-	-	-

Chapter 3

Literature Review



3 Literature Review

3.1 Introduction

Determining faunal water requirements in national parks, specifically arid and semi-arid regions where fauna are exposed to high temperatures and low rainfall, is especially important to understand how species distributions change according to climatic influences (Derry and Dougill, 2008). The rate of warming over the last 50 years is now double what it was over the preceding 100 years (Kruger and Sekele, 2013). Therefore, semi-arid and arid regions are expected to undergo major changes due to climate warming (Lioubimtseva, 2004; Chamaille-Jammes *et al.,* 2007b). These areas are undergoing increasing rates of desertification and this phenomenon is rapidly increasing, adversely causing increased and longer lasting drought periods (Le Houérou, 1996; Kahil *et al.,* 2015). The term ecological drought was defined by Hounam *et al.* (1975) in Le Houérou (1996:137) as '*A deficit of rainfall in respect to the long term mean, affecting a large area for one or several seasons or years, that drastically reduces primary production in natural ecosystems*'. Drought is a common phenomenon in semi-arid regions of Africa, such as the Kalahari (Mphale *et al.,* 2014). A reconstruction of historical rainfall patterns needs to be analysed so that an understanding can be gained on prolonged drought periods due to changing rainfall patterns.

Analyses of historical climate records give an understanding of long-term climate trends and how they are changing temporally. Such past climates have been reconstructed for rainfall and temperature variations for various locations globally, as well as locally in the Kalahari (Nash and Endfield, 2002; Nicholson, 2014). Fauna in semi-arid environments are exposed to high temperatures where annual evapotranspiration is at least twice as high as the annual rainfall (Abere and Oguzor, 2011). The African continent is one of the most vulnerable regions in the world to climate change, the negative effects of which pose a serious threat to the survival of many species (Amouzou, 2010). The rate of climate change presently is too fast for adaptation to take place, especially in mammal species where adaptation typically takes decades (Hetem *et al.,* 2014).

By studying faunal movement patterns valuable information can be determined regarding the distribution of species in both space and time, and the factors that influence their movement in different environments (Birkett *et al.,* 2012). Research conducted in African savanna environments investigated elephant movements, concluding that these are affected by seasonal changes in rainfall (Birkett *et al.,* 2012). Similarly, a study in the Mara-Serengeti ecosystem of Kenya and Tanzania documented that rainfall is the prime climatic factor underpinning the dynamics of African savanna ungulates (Ogutu *et al.,* 2008).

Rainfall limits the carrying capacity of herbivore species and migratory species will re-locate to areas with better access to resources during periods of low rainfall (Georgiadis *et al.,* 2003). In response to the lack of permanent water in semi-arid environments, borehole artificial water troughs were constructed in semi-arid environments such as the Kalahari to sustain the diversity of mammalian species (Van Rooyen *et al.,* 1994; Wanke and Wanke, 2007; Hayward and Hayward, 2012). Artificial water troughs have become a controversial topic for ecologists and conservationists working in semi-arid environments (Kasiringua, 2010). Artificial water troughs are positive with respect to their permanent water provision during times of drought or during prolonged dry seasons; however, negative factors associated with these water troughs, such as piospheres which includes trampling, local overgrazing and soil erosion caused by herbivore species that frequent them (Nangula and Oba, 2004; Derry and Dougill, 2008; Aldemo, 2011). Various techniques have been used to monitor mammal behaviour as well as mammal water consumption at natural and artificial water troughs (Ayeni, 1977; Kays *et al.,* 2011a; Rowcliffe *et al.,* 2011). These include aerial census, traditional ground observation techniques (manual faunal counting and radio-telemetry), motion sensitive camera traps and webcam live monitoring (Ayeni, 1977; Kays *et al.,* 2011a; Rowcliffe *et al.,* 2011).

Motion sensitive camera traps are used globally as a monitoring technique to record information such as the location, movement and behaviour of a broad range of species (Kays *et al.,* 2011a). An advantage of camera trapping is that it is not intrusive and results can be acquired within a short period of time (Marnewick *et al.,* 2008). A further tool utilised for monitoring mammal species is live monitoring via

webcams, which gives a single location data record, so that faunal behaviour can be observed at a specific time and tracked temporally (Kamphof, 2011). Webcam live monitoring has advantages over camera trap monitoring as it records images in real time, whereas camera traps only capture images on faunal motion detection and smaller species motion may not be detected. Webcam live images usually record at 15 - 30 second intervals, which makes monitoring more accurate as all species will be captured (Kamphof, 2011; Hayward and Hayward, 2012). Monitoring mammal behaviour at water troughs can contribute to the understanding of species-specific water requirements and how these species are affected by changing environmental and climatic conditions spatially and temporally (Ayeni, 1977; Hayward and Hayward, 2012). This research will make use of faunal census data to understand mammal distribution patterns and locally, webcam imagery at an artificial water trough to better understand mammal, more specifically herbivore drinking behaviour.

3.2 Climate Change

3.2.1 Introduction

Climate change is a widely known phenomenon that poses significant threats to biodiversity and species-specific vulnerabilities (Ackerly *et al.,* 2010; Winsemius *et al.,* 2014). Rainfall variability is a central characteristic in semi-arid regions, with most in constant threat of receiving minimal annual precipitation (Hetem *et al.,* 2014). Consequently, changes in rainfall variability and increases in evaporation rates contribute to decreased water availability for semi-arid biodiversity and fauna (Humphries *et al.*, 2004). Semi-arid biomes occupy more than 30% of the Earth's surface making them the most extensive land biome types (Lioubimtseva, 2004). Minor changes in temperature or precipitation regimes and changes in frequency and intensities of extreme climatic events, such as drought, could significantly alter the semi-arid environments and its water and vegetative products, as well as the composition, distribution and abundance of species (Archer and Predick, 2008).

3.2.2 Extreme Climatic Conditions: Semi-Arid Environments

Dryland areas can be defined as regions where rainfall does not meet the evaporative demand and occupy 45% of the land surface, and include grasslands,

shrublands, savannas, woodlands and hot/cold semi-arid environments (Bregas, 1998). Semi-arid environments are considered to be an environmental extreme where fauna and flora show specialized adaptations to aridity and temperature extremes (Noble and Gitay, 1996; Ackerly *et al.*, 2010). Climate change is likely to exacerbate extreme events in semi-arid regions as they will become hotter and not become significantly wetter (van Wilgen *et al.,* 2015). For most semi-arid regions, the temperature is projected to increase between 0.5°C and 2.0°C (Greco *et al.,* 1994; Desanker and Magadza, 2001; Eriksen *et al.,* 2008; Hoffman and Vogel, 2008; Hughes *et al.,* 2011). Many faunal and floral species are already at their tolerance limits due to extreme conditions and may not be able to persist should mean temperatures continue to increase (Skiles and Hanson, 1994; Thuiler, 2007).

Future projection model outputs show that there likely will be changes in extreme events such as increases in extreme high temperatures, decreases in extreme low temperatures, and increases in intense precipitation events over certain parts of Africa (Easterling *et al.* 2000). Regions that are expected to become drier will experience less frequent but more intense precipitation events with longer dry periods between these (D'Odorico *et al.,* 2012; Maliva and Missimer, 2012). According to Maliva and Missimer (2012), water sources in semi-arid regions are already under stress and the semi-arid regions in southern Africa are likely to suffer from increasing water depletion as both river flows and ground water recharge decline (Greco *et al.,* 1994; Moalafhi *et al.,* 2012; Mphale *et al.,* 2014).

3.2.3 Climate Change in Southern Africa

Southern Africa is broadly a semi-arid region, which experiences considerable inter- and intra- annual climate variability in rainfall and temperature patterns which often cause negative impacts on the ecological environment (Winsemius *et al.,* 2014). Studies on rainfall trends suggest that annual rainfall over most parts of southern Africa began to decrease as early as 1900 and continues to decrease with a predicted further decrease of 5% by 2050 in Botswana (Unganai, 1996; Therrell *et al.,* 2006; Moalafhi *et al.*, 2012; Mphale *et al.,* 2014). Hoffman and Vogel (2008) predict that annual rainfall is likely to decrease and rainfall variability (periods of extended dry spells and patterns of rainfall including the number of rainy days) is

expected to cause increased drought events in the southern African region, few case studies have validated this (New *et al.,* 2006; van Wilgen *et al.,* 2015)

Summer rainfall in Zimbabwe decreased by 10% during the period of 1900 - 1993, which results in an increase in drought periods (Unganai, 1996). To substantiate this, Adedoyin and Mphale (2002) analysed an annual rainfall time series over a 30 - year (1971 - 2000) period in Botswana and it was found that the annual rainfall has decreased at a significant rate of -2.02 to -2.18mm per year. Therefore, climate change is already affecting Botswana through decreases in rainfall and the number of rainy days, which is resulting in drier conditions and greater rainfall variability (Batisani and Yarnal, 2010). Future Global Climate Models (GCM) show that the southern parts of Africa, especially semi-arid environments, are projected to have reduced precipitation by 2050 and consequently soil moisture will be reduced (IPCC, 2007; Willis *et al.,* 2009). Locally, research on floral biodiversity in South African protected areas suggests that more than a third of plant species in the Augrabies Falls National Park and Melkbosrand might become locally extinct due to climate change (Rutherford *et al.,* 1999). Focusing on the southern Kalahari region in northern South Africa, biota, including faunal species, is under much threat from climate change (Wichmann *et al.,* 2003).

The changes in precipitation (decrease in mean annual rainfall and increase in inter-annual variability) have a direct impact on this region, as it may increase the risk of extinction of particular species (Tews *et al.,* 2004). The Botswana Kalahari Transect lies in the southern Africa plateau between the latitudes 12° - 28°S and longitudes 15° - 27°E (Ringrose *et al.,* 2003; Mphale *et al.,* 2014). Mphale *et al.* (2014) report that the Inter-Governmental Panel on Climate Change (IPCC) fourth assessment report has projected a 4% decrease in mean annual precipitation and >20% winter precipitation in the Botswana Kalahari Transect. This change in precipitation, as well as the increasing CO_2 levels, is likely to be advantageous to alien invasive species and threaten indigenous vegetation species in the region (Meadows, 2006).

Kruger and Sekele (2013) have reported on an increase in days and nights with high temperatures and decreases in days and nights with low temperatures in southern Africa. Temperature increases in southern Africa are at the highest in the arid north-

western KGNP, with a mean maximum temperature increase of 0.039°C. This equates to an average annual maximum temperature of 1.95°C since 1960 (van Wilgen *et al.,* 2015).

3.2.4 Climate Change and Fauna

Major climate events in the past have been the main cause for large-scale species extinction and movements (Erasmus *et al.,* 2002). It is becoming increasingly important to understand and predict the consequences that climate variability has on biodiversity (McNeely, 1995). It has become obvious that the impacts of climate change are widely detectable in many taxa, including shifts in phenology, distribution and demography (Ackerly *et al.,* 2010; Vittoz *et al.,* 2013). Thomas *et al.* (2004) documented changes affecting faunal species, and these include species extending their geographic range, declines in species abundance and migratory bird species arriving earlier than usual in spring after overwintering in the tropics. It has been stated that biological impacts will be greater where the degree and rate of climate change is greatest (Scheffer *et al.,* 2001).

Recent climatic changes have already caused shifts in species distributions and in general, species have been found to move their ranges poleward in latitude and upward in elevation at rates that are consistent with current temperature increases (Lawler *et al.,* 2009). However, Ogutu and Owen-smith (2003) claim that populations of species in protected areas are at a high risk from climate shifts and extreme climatic variability due to the construction of fences or other barriers; consequently these species cannot move between areas, for example, during the dry season. Therefore, such species may face local extinctions (Ogutu and Owen-smith, 2003; Maggini *et al.,* 2011). Studies have revealed that climate change presents major challenges to organisms and their vulnerability needs to be evaluated so that management strategies can be developed (Lee and Jetz, 2008). Vulnerability of a species to environmental change depends on the species' exposure and sensitivity to environmental change, its resilience to climate changes, and it's potential to adapt to these changes (Huey *et al.,* 2012). In order for biodiversity to be conserved, an understanding of such climatic changes is necessary (Rodrigues *et al.,* 2000).

Research conducted in Maasai Mara National Park, Kenya, shows that reduced rainfall and rising temperatures during the period of 1989 - 2003 diminished vegetation production and the availability of surface water, which affected herbivore species, and in turn carnivores (Ogutu *et al.,* 2008). Locally in South Africa, it is important to understand faunal species vulnerability to climate change and changing environments, especially in semi-arid regions.

3.2.5 Climate Change and its Impacts on Fauna in South Africa

Limited knowledge exists on the links between climate variability and faunal distributions in South Africa. Impacts of climate change will result in 80% of faunal species undergoing some, usually marked, alteration to their geographical ranges (Van Jaarsveld and Chown, 2001; Erasmus *et al.,* 2002; Willis *et al.,* 2013). These range shifts and migrations are estimated to take place in an easterly direction towards the eastern highlands; this is because the western parts of the country are predicted to experience increased aridity, with less aridification towards the east (van Jaarsveld and Chown, 2001). According to Hetem *et al.* (2014), the chance of extinction of mammals within South Africa is estimated to be as high as 69% by 2050.

Long-term monitoring in the KNP has shown that 7 of the present 11 ungulate species declined between the period 1977 and 1996 (Hetem *et al.,* 2014). It is estimated that this flagship conservation area in South Africa may lose up to 66% of animal species in future years due to climate change (Meadows, 2006). Tews *et al.* (2004) stated that climate change may have large and multiple effects in the semi-arid and arid savannas of the Kalahari. The annual amount and variation in precipitation is important for both plant and animal species and to the semi-arid ecosystem as an entity (Tews *et al.,* 2004). This is because such environments receive very little annual rainfall, which makes it difficult for the survival of most species (Van Rooyen *et al.,* 2008). Rainfall variability is becoming less in KGNP, with longer periods of dry spells, providing faunal species less natural water within the park (Chamaille-Jammes *et al.*, 2007b; van Wilgen *et al.,* 2015). Climate change effects faunal species directly by heightening their existing stresses through degradation of habitats through vegetation clearing, altered fire regimes and highly

modified water resources (Abbott and Le Maitre, 2010; DEA, 2013). Indirect impacts on species diversity include rising global average temperatures and changes in rainfall patterns and extreme weather events (Ackerly *et al.*, 2010; DEA, 2013). The Kalahari Gemsbok National Park (KGNP) comprises the South African component of the KTP, and this semi-arid ecosystem is highly vulnerable to climate change (Wichmann *et al.,* 2003). For instance, research on the Tawny Eagle (*Aquila rapax*) shows that decreased mean annual precipitation caused a decrease in population persistence of these raptors (Wichmann *et al.,* 2003).

Peterson *et al.* (2014) modelled the potential distribution of lion as a result of changing climate in Africa. These models project negative impacts in KTP and KGNP, where the suitability of these environments are expected to decline substantially. Increasing droughts will reduce prey availability for lion populations, especially those reliant on migratory prey species, which will result in an increase in cub and older adult mortality (Peterson *et al.,* 2014). Similarly, the continuously changing climate (rising temperatures, droughts, rainfall variability), will cause alterations in the ranges of species and these movements are likely to lead to changes in community structure and possibly in the way the community functions (van Jaarsveld and Chown, 2001). An understanding of future climate trends is important so that wildlife species can be conserved and biodiversity can be protected (Tews *et al.,* 2004; Ackerly *et al.*, 2010).

3.3 Drought in National Parks

Droughts are occurring worldwide in various national parks, affecting ecosystem processes as well as plant and faunal abundances and distributions (Bobich *et al.,* 2014). Droughts are sometimes short-term and may be followed by recovery during subsequent years of higher rainfall; however, often droughts are longer lasting and have devastating effects, which may trigger substantial and irreversible ecological changes (Vetter, 2009). A study in Ethiopia revealed high vulnerability to recurring periods of drought, given the low availability of surface water, which is detrimental to faunal species within conservation areas (Gebrehiwot *et al.,* 2011).

Research on the severity and worsening of droughts in Hwange National Park in Zimbabwe (1928 - 2005) revealed that both forage and surface-water availability are decreasing, negatively affecting large herbivores (Chamaille-Jammes *et al.,* 2007b). Surface water during the dry season is provided mainly through pumping of ground water. However, increasing water provision will be needed to compensate for the decreasing rainfall. As the drought worsens, some water troughs are likely to become seasonally dry, resulting in large herbivore concentrations around the remaining water troughs, with negative effects on the vegetation (Chamaille-Jammes *et al.,* 2007b). Similarly, droughts are affecting ecosystems in South African national parks.

A study in the Kruger National Park, South Africa, revealed that the decline in Tsessebe resulted from rainfall-induced changes in food availability during the dry season (Dunham *et al.,* 2004). Forage during the dry season is a key source, not only for Tsessebe but also for other African antelopes that graze selectively and the increasing droughts will affect grass growth negatively (Redfern, *et al.,* 2005). Recurring extreme climatic events, such as the increasing drought conditions in in semi-arid regions, will result in reduced perennial vegetation cover, increased bare ground, soil erosion and reduced rainfall (IPPC Synthesis report, 2007; Vetter, 2009).

3.3.1 Drought in the Kalahari

Due to the unreliability of rainfall and only a few permanent surface water resources, many mammal species (water-dependant species) are vulnerable, especially through the dry season (Juarez *et al.,* 2013). Increased desertification has been observed in KTP, where Landsat imagery portrays increases in the exposed soil surface from 1898 - 1994 (Palmer and van Rooyen, 1998). This desertification is irreversible and affects faunal populations negatively through the lack of vegetation cover and surface water availability (Schlesinger *et al.,* 1990; Peterson, *et al.,* 2012).

Mass-mortalities of large herbivores have occurred in the Kalahari due to drought and these die-offs resulted from below average rainfall during the drought years of 1963, 1970, 1979 and 1983 (Van Wyk and Le Riche, 1984; Knight, 1995).

Additionally, over the last century in the Kalahari, human-induced pressures, such as agriculture and infrastructural development, have increased (Verlinden *et al.*, 1998; Mbaiwa and Mbaiwa, 2006). This has restricted the natural range of ungulate species to predominantly within national parks, as well as limiting access for certain species, such as blue wildebeest, to natural perennial drinking water (Williamson and Williamson *et al.*, 1988). Some of the blue wildebeest die-offs in the central Kalahari of Botswana (1961, 1963 – 1964) (300000 deaths), 1979 (262000 deaths) and 1982 - 83 (52000 - 80000 deaths; Gadd, 2011) have been linked to the erection of veterinary control fences, which blocked migration patterns towards the Okavango region (Knight, 1995; Mbaiwa and Mbaiwa, 2006).

In the southern Kalahari, mainly in KGNP, mass mortalities also occurred during the drought that took place between 1977 and 1987. The faunal die-offs during May 1985 included ostrich and large ungulates such as blue wildebeest, eland, red hartebeest and gemsbok, and continued until the rains arrived in November 1985 (Knight, 1995). Blue wildebeest in particular, are less well adapted than other species to the very dry periods and they need to migrate to better pastures and surface water during such times (Campbell, 1981). Consequently, the large number of blue wildebeest deaths during the dry season can be related to their high dependency on water (Knight, 1995).

Artificial water troughs were constructed in the 1930s in the larger KTP (Van Rooyen *et al.,* 1994), making borehole water available for wildlife utilization. A total of 89 artificial water troughs were constructed in KGNP. To date, 88 of these water troughs are currently in operation (Knight, 1995; SANParks, 2008).

3.4 Mammal Drinking Behaviour/Patterns

3.4.1 Introduction: Distribution and Water Availability

Surface water resources are important components in semi-arid savanna landscapes as they supply water to large populations of wildlife (Strauch, 2013). The distribution of surface-water therefore has an influence on herbivore distribution patterns (Smit and Grant, 2009). Previously, Epaphras *et al.* (2008) reported that the distribution of

wildlife is related to water availability and during the dry season, wild ungulates consume more water to meet their bodily requirements. Consequently, their daily and seasonal migrations are dependent on the spatial and temporal distribution of surface water (Epaphras *et al.,* 2008). In Tsavo National Park, Kenya, research indicated that elephant populations might be related to temporal and spatial variations in primary production. Elephant populations were distributed in the south-east regions of the park (after the long rains) and in the west (after the short rains) during the dry season and were distributed more widely throughout the park during the rainy season (Phillipson, 1975). Irregular water availability in these semi-arid environments affects the possibilities of drinking and the amount and quality of food available for large herbivores (Bergstrom and Skarpe, 1999).

Research conducted on wild large herbivores in Gonarezhou National Park, Zimbabwe, concluded that grass cover and vegetation has a strong influence on wild herbivore densities and distributions (Gandiwa, 2013). Boone *et al.* (2006) modelled migratory pathways of blue wildebeest within the Serengeti ecosystem, linking migration here to access to green forage or rainfall which will cause green forage, or compensatory vegetation production and higher water quality. It has been established that in semi-arid savanna environments of southern Africa, many herbivore species migrate over long distances in response to water and food availability (Crowe, 1995). These herbivores in southern Africa are opportunistic in their migration for better water availability and grazing pastures (Bergstrom and Skarpe, 1999). However, as a result of permanent water troughs along the riverbeds in KGNP, wildebeest have become a sedentary species and do not need to migrate (Mills and Retief, 1984).

3.4.2 Faunal Distribution in Relation to Rainfall Patterns

It has been stated that climate change may significantly reduce habitat suitability and may threaten species with limited dispersal ability because this changes the vegetation distribution (Hulme, 2005). Therefore, an understanding of species-specific distributions in relation to rainfall patterns and food availability is pertinent to the current and future conservation of biodiversity (Jeltsch *et al.*, 1997; IPCC, 2007; Hetem *et al.,* 2014).

Semi-arid environments are known for having limited and variable rainfall that supplies resources in pulses (Chesson *et al.,* 2004). Therefore, in order for fauna to survive in these dry conditions, they have to adapt accordingly (Phillipson, 1975). Research in the Maasai Mara National Reserve concluded that rainfall is the prime climatic factor supporting the dynamics and movements of African savanna ungulates (Ogutu *et al.,* 2008). Additionally, the relationship between rainfall and soil nutrients may also play a role in the distribution of animals; this is because rainfall results in large plant biomass production and soil nutrients promote high concentrations of nutrients in the plant tissues (Olff *et al.,* 2002).

Studies in the southern Kalahari and KGNP documented a strong link between rainfall events on ungulate relocations to riverbeds in both the short- and long-term due to the richness of vegetation creating good food source along these riverbeds (Mills and Retief, 1984; Park and Sohn, 2009). Research in the broader Kalahari showed that the total number of animals and average group size of springbok, blue wildebeest and ostrich were all positively correlated with wet-season rainfall (Bergstrom and Skarpe, 1999). Blue wildebeest were the most water-dependent of these species; with the number of observed animals correlating significantly with rainfall (Bergstrom and Skarpe, 1999). Similarly, the survival of blue wildebeests under variable weather conditions depends on migratory behaviour to maximize nutrient availability (Sitati *et al.,* 2014).

3.4.3 Mammal Drinking Patterns at Artificial Water Troughs

The provision of water to wildlife is crucial during the dry season in many semi-arid areas. Artificial water troughs help to alleviate the effects of water shortages in rivers and pans (Epaphras, *et al.,* 2008; Franz *et al.,* 2010). Artificial water provided to wildlife in conservation areas helps to conserve faunal species, sustain migratory herds throughout the long dry periods, keep wildlife away from farming areas and to enhance the tourist potential of an area (van Rooyen *et al.,* 1994). Water can also be provision specifically to prevent mass mortality of large herbivores during extreme drought events (Thrash *et al.,* 1993). Water provision can change the way herbivores utilise the landscape, even when there is natural water available (Smit *et al.,* 2007).

Water-dependent species in a range of different habitats, such as the bighorn sheep in the south-western United States (Dolan, 2006) and herbivore populations in Australia (Noble *et al.,* 1998), show a positive correlation with their proximity to free water and water sources, and are distributed in close proximity to these water sources. Therefore, these species have become reliant on artificial water troughs to sustain their water requirements (Noble *et al.,* 1998; James *et al.,* 1999; Dolan, 2006). Indigenous faunal species that rely on drinking water are able to persist in areas that were previously seasonally or permanently not habitable; this has resulted in larger and more extensive populations of these species than would have occurred previously (Epaphras *et al.,* 2008; Kamanda *et al.,* 2008).

Supplemental water provision through the construction of artificial water troughs was implemented in Botswana National Parks by the Department of Wildlife and National Parks in the early 1990s (Kasiringua, 2010). This was done to reduce the concentration of big game - especially elephants which have been documented to cause habitat destruction at water sources (Mordi *et al.,* 1989), at permanent water sources. In another example, Khutse Game Reserve in Botswana constructed an artificial water trough on a saltpan in the 1980s in order to increase the availability of water during the dry season (Hitchcock, 1996).

3.4.4 Negative Impacts of Artificial Water Troughs

Providing supplemental water to wildlife is positive during the dry season, however, the effectiveness of this practice has been much debated (Mills and Retief, 1984; Krausman *et al.*, 2006). Surface water is often a central point for most herbivore species where high levels of herbivore impact, with decreasing distance from the water source, may occur. The construction of artificial water sources may therefore impact herbaceous composition through selective grazing of preferred species, trampling, dung and urine deposition (Thrash *et al.,* 1993; Franz *et al.,* 2010; Mukaru and Mapaure, 2012).

Multiple studies have shown that on-going heavy grazing and trampling around water points create radial patterns of degradation known as piospheres (Brits *et al.,* 2002).

The disturbance impact is highest at the core of a resource area and attenuates radially with increased distance from the patch centre. Consequently, these areas become heavily grazed/browsed and may become depleted as a food resource, especially during the dry season, forcing the animals to feed away from the water in search of better forage (Kasiringua, 2010). Elephants are highly dependent on surface water and woody vegetation, and thus congregate around perennial water sources in the dry season (Franz *et al.,* 2010). They consume large amounts of woody vegetation, which may lead to the destruction of woody plants around water sources (Franz *et al.,* 2010). In addition, it has been found that heavy grazing diminishes the cover of perennial grass species around water holes, favouring annual grass species (Thrash *et al.,* 1993). Another factor that has been considered as negative is the increased predation rates of herbivore species at these water troughs (Dolan, 2006; Crosmary *et al.,* 2012).

Research in Tanzania revealed that human activities outside of conservation areas have modified the natural availability of surface water within protected areas, such as the Ruaha National Park (RNP) (Epaphras *et al.,* 2008). Since the 1990s, this has led to the formerly perennial Great Ruaha River ceasing to flow during the dry season (Mtahiko *et al.,* 2006; Epaphras *et al.,* 2008). RNP presently has 20 natural perennial water troughs along the river where herbivores largely utilise the water sources during the dry season. This has had adverse effects on habitat over-utilization and degradation causing soil erosion, overgrazing, and tree destruction and trampling around the water troughs (Epaphras *et al.,* 2008). Another adverse effect of artificial water points in this area is that it attracts herders and their livestock (Mukaru and Mapaure, 2012), further exacerbating the piospheres effect (Bergstrom and Skarpe, 1999; de Leeuw, 2001; Kasiringua, 2010; Mukaru and Mapaure, 2012).

Studies in KNP revealed that the trampling effect due to increased herbivore numbers around water troughs has a negative impact on the survival of seedlings of woody plants. This is because water remains on top of the basaltic clay soil layers around the water trough longer and favours the faster growth of herbaceous plants, compared to woody plants, and these are not easily digested by wildlife (Brits *et al.,* 2002; Farmer, 2010). This is the same for the Kalahari (Jeltsch *et al.*, 1997), where the effect of grazing around artificial water troughs has resulted in the progressive

increase of unpalatable shrubs and stunted trees at the expense of palatable herbaceous vegetation. Child *et al.* (1971) was one of the first to study the effects of artificial water troughs on surrounding vegetation, showing veld-grass deterioration in association with artificial water troughs in KGNP, particularly along the Nossob River and Auob Rivers.

3.4.5 Water Dependency of Ungulate Species

Wildlife species have varying requirements in terms of water and their use of artificial water troughs. Species also utilise water troughs differently during the year according to the season and the available surface water (Knight, 1995). It has been observed that during the dry season in Tsavo, fauna accumulated around the water supplies, and then dispersed during the rains (Ayeni, 1977). Fauna are either water-independent or water-dependent, with dependence being influenced by the frequency of water consumption as well as access to surface water (Trent, 2012).

Highly water-dependent species utilise artificial water sources more regularly than water-independent species (Knight, 1995). Water-dependent species are not able to exist without access to available water sources and are based around the permanent water sources during the dry seasons (Ayeni, 1975). Grazer species are typically water-dependent and therefore, tend to need more access to natural and artificial watering points than browsers do (Derry, 2004; Derry and Dougill, 2008). The highly water-dependent species in southern Africa are blue wildebeest, red hartebeest and plains zebra, which are herbivores and classified as grazers (Knight, 1995).

Amongst the ungulates in KGNP, blue wildebeest are considered the most water-dependent. This species consumes water every second/third day at water troughs and are poorly adapted to dry conditions because of their physiology (Nagy and Knight, 1994; Auer, 1997; Schmidt-Nielsen, 1997). Blue wildebeest are disadvantaged because they have a flat wide mouth and only graze on short grasses and need to continue moving to ensure an adequate uptake of good quality food (Knight, 1995; Schmidt-Nielsen, 1997). During the rainy season, when plant moisture and water availability is high, blue wildebeest make use of the over-abundance of water by drinking frequently and resourcefully (Auer, 1997; Rudee, 2011).

Research showed that there was a negative correlation between numbers of blue wildebeest and distance to pans. These grazer populations occur in big groups and are not able to find enough grazing in the vicinity of pans (Bergstrom and Skarpe, 1999). The study by Kasiringua (2010) supports these conclusions, as blue wildebeest in this study, were located in close proximity to the water trough (200m). Sitati *et al.,* (2014) have attributed huge declines of blue wildebeest populations in various national parks (Maasai Mara ecosystem by 81%, Botswana by 90% and the Kruger National Park by 87%) to extreme drought conditions. Therefore, these species rely more heavily on perennial water sources in years of poor rainfall than water-independent species such as gemsbok (Knight, 1995).

The water-independent species in southern Africa are eland, south African giraffe, southern ostrich, gemsbok and greater kudu, which are classified as browsers because of the greater water storage within their food than compared to grass, which is usually dry in semi-arid regions (Western, 1975; Estes, 1991; Derry, 2004). Research in the Kalahari showed that steenbok and gemsbok distributions were negatively correlated with rainfall, and they are able to travel long distances due to the widespread, sporadic availability of suitable foods and thus are water-independent species (Bergstrom and Skarpe, 1999; Abere and Oguzor, 2011). A study in the Middle East (van Heezik *et al.,* 2003) on the Arabian Oryx has similarly shown that these animals are one of few arid-zone ungulates that can remain independent of water sources during the dry, summer months. This is because these species fulfil their water needs from forage and spend the hot part of the day lying completely inactive under shade trees (van Heezik *et al.,* 2003). An example of fauna fulfilling their water needs from forage is gemsbok the Kalahari, as this species supplements its water with the consumption of the Tsama melons (Derry, 2004).

De Leeuw *et al.* (2001) defined tolerance to aridity as the ability of animals to endure long periods under hot climatic conditions, without consuming water. Species are considered arid tolerant (water-independent) when showing physical adaptations to conserve water or when able to inhabit an area without watering points and surviving without drinking over a long period (de Leeuw *et al.,* 2001).

3.4.6 Thermoregulation by Ungulate Species

Faunal species display physiological plasticity to cope with daily and seasonal variations in ambient temperature within their environments (Shresta *et al.,* 2012). Semi-arid ungulates are constantly confronted by concerns of high solar radiation, high ambient temperatures, insufficient surface water, unpredictable food resources and challenges that prevent thermoregulation and water balance (Feldhamer *et al.,* 1999). The hotter and drier habitats predicted under climate change will have direct negative effects on faunal species through greater heat gain from the environment as well as increasing water requirements to dissipate heat through evaporation (Fuller *et al.,* 2014).

Research on antelope sensitivity to heat stress in an African semi-arid environment concluded that the activity of eland, impala and blue wildebeest was limited during spring but increased during summer due to increased food availability (Shresta *et al.,* 2012). Therefore, these ungulate species were more active during dawn, dusk and nocturnal hours due to the lower heat stress levels in summer. As a result, the spring season has high heat stress, a shortage of food sources and low water availability, which could be critical for the survival of these large African ungulates in semi-arid environments (Shresta *et al.,* 2012).

Species capable of existing with very little water generally possess certain physical characteristics; some have a light, sandy colouration, which aids thermoregulation in preventing against heat stress (Abere and Oguzor, 2011). This is evident in KGNP, where gemsbok exhibits characteristics to survive in a climate with low rainfall and high temperatures. These species allow their body temperature to fluctuate in response to environmental stress and when exposed to temperatures above 45°C, they do not sweat, instead they allow their body temperatures to ruse more than 40°C saving a significant amount of water. As their body temperature becomes higher than the outside temperature, heat will flow from the gemsbok into the environment during the nocturnal cooler air (Mills and Mills, 2013). It is essential to understand the physiological capacity of organisms temporally and spatially. This can then be related to their response and adaptation to climate change so that future species distribution and population dynamics can be predicted and protected. This is

essential in KGNP in order to implement successful management and conservation strategies to conserve species that are sensitive to climate change (i.e. decreasing rainfall and increasing temperatures) (Chown and Gaston, 2004; Gaston *et al.*, 2006; Fuller *et al.,* 2014).

3.5 Monitoring Methods

Several monitoring techniques exist to estimate the population size and distribution patterns of faunal species within National Parks (Funston *et al.,* 2010). Kays *et al.,* (2011a) outlined two basic ways to recording animal movement/distribution. The first, the Lagrangian approach, monitors a specific individual, for example, with the use of a GPS-tag, and records all the locations where it occurs (Kays *et al.,* 2011a). The second, the Eulerian approach, monitors a specific site/location and the animal species present (Smouse *et al.*, 2010; Kays *et al.,* 2011a; Kays *et al.,* 2011b). The Eulerian approach is sometimes preferred, as it is less invasive and does not require the capture of the animal. This approach makes use of a motion-sensitive camera (camera trap), which simply records a photograph of the animal passing it, as well as real-time webcam imagery (Kays *et al.,* 2011a; Hayward and Hayward, 2012). Radio-telemetry was the first technique used to find and track free-ranging animals, it was popular, as it required low cost, lightweight transmitters (Lord *et al.,* 1962). The disadvantage, apart from having to capture the animal, of this method is that because radio-telemetry data are manually recorded, it is limited in the intensity and scale of application (Kays *et al.,* 2011a).

Several studies on estimating population density and demographics on puma populations (Van Sickle and Lindzay, 1991) and African carnivores (Gusset and Burgener, 2005) have made use of indirect techniques, which make use of faunal footprints to estimate population density. These techniques often tend to be time consuming and expensive, and are not always accurate (Funston *et al.,* 2010). A wide range of methods has been used to monitor herbivore populations, such as observational direct counts (foot counts, water trough, aerial and drive), or indirect signs, such as tracks and dung (Wilson *et al.,* 1996; Cromsigt *et al.,* 2009). A study in Hluhluwe-iMfolozi Park on herbivore populations revealed that monitoring programs that make use of direct observational counts are not the optimal method to

monitor herbivore diversity and this is very labour intensive (Cromsigt *et al.,* 2009).

Camera traps have been used to monitor animal behaviour and movement patterns locally. Camera traps are rapidly becoming an important tool in conservation and ecological studies of terrestrial wildlife and have been used to estimate the abundance of individually marked species (Rowcliffe *et al.,* 2011). Animals are constantly moving, but because they are quiet and shy, camera traps are advantageous over many traditional techniques, such as radio-telemetry (Kays *et al.,* 2011b). Camera traps are an appropriate technique because they are non-invasive and do not affect most animal behaviour, they require low labour and can function for a long period of time with no intervention, they not only record the presence of species, but also record the behavioural patterns of animals which adds value to scientific research (Rowcliffe and Carbone, 2008; Kays *et al.,* 2011b).

Research conducted by Maputla *et al,* (2013) estimated leopard population abundance in the N'wanetsi concession in Kruger National Park with the use of camera traps. Results suggest that there are 15 - 35 individuals in a 150km^2 area of the N'wanetsi concession. Even though camera traps have been successful in many studies monitoring terrestrial animals, flaws do exist in this approach, and smaller mammal species may not be detected (Pollock *et al.,* 2002). An Eulerian approach, which is advantageous over camera trapping, is webcam live monitoring. Webcams can be used as a surveying method and a census tool for monitoring faunal water trough utilisation. There is limited research on the use of webcams as a census tool to monitor fauna drinking behaviour and water requirement, especially in a semi-arid region where water is scarce (Hayward and Hayward, 2012; Trent, 2012; Maraschin, 2013).

3.5.1 Webcam Monitoring

Environmental monitoring has become advanced through the development of technology, such as webcams (Liang *et al.,* 2005; Bradley *et al.,* 2010). Webcams provide unique perspectives at a local level and are typically side looking or oblique and can be developed at low cost and easily acquire high frequency imagery (Bradley *et al.,* 2010). As well as being low-cost cameras, webcams can be adapted

to robust weather conditions, and have the ability of being controlled remotely and do not need to be supervised in order for them to be operational (Verstraeten *et al.,* 2010). Webcams are unobtrusive and do not interfere with the behavioural patterns of species and species interactions. According to Verstraeten *et al.,* (2010), webcams have allowed for high frequency monitoring over long time spans, which have allowed them to capture events that are rare and would have otherwise gone unobserved.

Wildlife-based ecotourism is rapidly becoming more popular, especially where large mammals are featured in their natural habitat (Nevin and Gilbert, 2005). Wildlife viewing used to be considered as a non-consumptive human activity with little impact on animals, however, recent research has revealed that this is not the case, and that wildlife viewing has negative effects on animals as it is intrusive and disruptive and may cause bias in research results (Wawerla *et al.,* 2009). Traditional techniques such as mark and recapture and aerial counts are common ways of monitoring faunal species, but these are labour intensive and extremely costly (Handcock *et al.,* 2009). Webcams and camera systems have an additional advantage over these techniques, as they are less disruptive to animals being monitored (Roberts *et al.,* 2006). Webcam photography provides data that are more reliable than data provided through direct observation because photographs can be viewed by multiple researchers and stored for future analysis (Cutler and Swann, 1999; Bradley and Clarke, 2011).

The webcam system for monitoring has many advantages over traditional monitoring methods; however, a few challenges are still encountered with this approach (Locke *et al.,* 2005). Yasuda and Kawakami (2002) recognised that power supply is a major complication for field applications, as these systems are often located in remote regions without a power source. A high capacity battery was suggested to overcome this problem (Yasuda and Kawakami, 2002), or deep-cycle marine batteries that are continuously recharged via solar panels, which makes them self-sufficient (Locke *et al.,* 2005). Equipment is sometimes prone to mechanical and battery failures and all camera systems require regular maintenance and some technical expertise (Cutler and Swann, 1999). As well as technical and mechanical errors with webcams, a few challenges exist in the environment, for example the problem with sun glare, which

obstructs the webcam visibility. Adverse weather conditions, such as heavy rainfall events, cause problems with webcam functionality (Bradley and Clarke, 2011). Research with the use of webcam monitoring is still lacking globally, so in order to understand this monitoring technique more thoroughly, a considerable amount of research effort using this technique is required (Hayward and Hayward, 2012). It is hoped that this current study will provide information regarding further limitations of webcam imagery as a research data source.

The use of a webcam system aids biologists in the collection of vast quantities of video data research on the behaviour of certain faunal species and it also helps reduce the amount of manual labour to collect and process manual data (Wawerla *et al.*, 2009). Locke *et al.,* (2005) described a web-based, digital camera system for monitoring wildlife in environments that are inaccessible. The webcam was established near a permanent watering hole on Elephant Mountain where 486 digital photographs of west Texas wildlife were captured over the period between February 2002 and December 2003. This system was advantageous as it allowed for unobtrusive monitoring of wildlife at a remote site that was not easily accessible (Locke *et al.,* 2005).

Research on the use of webcams in South Africa is very limited and there are few researchers who have conducted studies with the use of webcams for monitoring wildlife. Webcams that capture images at 30 - second intervals were placed at water troughs in South Africa and faunal behaviour/drinking patterns monitored (Hayward and Hayward, 2012). A comparison was made between the Kruger National Park and Pilanesberg Park on faunal water trough utilisation and relative abundance per species located in the parks. The results showed that faunal preferential drinking time occurred during midday when the temperatures peaked (Hayward and Hayward, 2012). A further study in the Kruger National Park utilised daily webcam images to monitor wildlife at two water troughs (Satara and Orpen) (Trent, 2012).

Maraschin (2013) documented species water trough utilisation in the Kgalagadi Transfrontier Park at one artificial water trough (Nossob). The use of water troughs by species, as well as their behaviour, was monitored in both studies and patterns of water trough usage were correlated with relevant weather data. The results show

that certain species are highly dependent on water troughs and certain climatic conditions influence water trough usage (Trent, 2012; Maraschin, 2013).

3.5.2 Aerial Census Monitoring

Aerial census techniques are useful for estimating large populations across a region and understanding faunal distributions within that region (Castley, 2013). Aerial census makes use of light aircrafts or helicopters to count large mammals (Sutherland, 2006). This is the most effective survey method for the collection of wildlife census data (Sutherland, 2006) at relatively large spatial scales. The most common method involves flying strip transects at low altitude and having dedicated observers count or estimate the number of individuals within a specific area (Davis, 1982; Paine and Kiser, 2012). Accuracy is increased by allowing the observer unlimited downward vision from the aircraft (Krebs, 1999).

The advantages of aerial census techniques are that these cover a wide area in a short period of time and are easily repeatable (Davis, 1982). The disadvantages of aerial census techniques are that highly skilled observers are required because quick judgments need to be made (Paine and Kiser, 2012) and fatigue may be a problem (Sutherland, 2006). These problems of accuracy are solved with the use of vertical aerial photography, which is frequently used to make accurate wildlife counts. Vertical aerial photography can be used to capture large groups of animals if they cannot be counted rapidly enough (Sutherland, 2006) and time is saved whilst larger sample units can be captured (Rowat *et al.,* 2009). Aerial photography allows the observer to make accurate counts as images can be evaluated more than once (Paine and Kiser, 2012). Wildlife is mobile and by using aerial photography, it eliminates the movement problem and reduces the chances of fauna being counted more than once, or not at all (Komp, 1983).

In Australia, census data were used to evaluate the importance of permanent water sources in a semi-arid environment. Transects with water sources contained more individuals per count, especially during the summer seasons, than transects without available water. It was observed that the presence of water could alter the numbers of species in a habitat at any particular time of the year in Australia (Williams and

Wells, 1986). A study that has made use of aerial census faunal counts in the Serengeti showed that species did not decline, but populations remained stable in that region over the dry season 2013 (TAWIRI, 2013). Research in the southern Kalahari, which utilized questionnaires as surveys on faunal distributions in relation to environmental attributes, revealed that rainfall is a major factor affecting springbok behaviour and herd size (Stapelberg *et al.,* 2008).

Aerial census surveys are important in national parks, such as KGNP, as they facilitate in informed decision making, mainly with the respect to the monitoring of priority species, or species that are endangered, as well as the translocation and possible sale of surplus faunal species, particularly species that are of high value (Castley, 2013). Aerial census is important for management, in regions such as KGNP, so that a balance of wildlife together with other biodiversity can be maintained. Aerial census monitoring in KGNP is a useful method of recording faunal species populations and distributions as large open areas can be covered in minimumal time and the sparsely vegetated areas make it easier for obervers to survey the area (Castley, 2013).

3.6 Conclusion

It is important to understand the increasing effects of long-term climate change on faunal distribution. Although aerial census techniques allow for large scale monitoring of herbivore population dynamics, distributions and behaviours, ground level monitoring observations, using webcam imagery, allow for an understanding of faunal water requirements and drinking behavioural patterns locally. Therefore, it is important and necessary that a study is undertaken to understand all of these factors in the semi-arid Kalahari, and more specifically, KGNP.

Chapter 4

Methodology



4 Methodology

This project assesses past long-term climatic patterns throughout the southern KGNP and surrounding areas, and the relation of shorter-term climatic influences on fauna observed from webcam imagery at the Nossob artificial water trough in KGNP (October 2012 - December 2014). Rainfall and temperature (T_{avg}, T_{max} and T_{min}) patterns over the past ~40 years or more are determined for Twee Rivieren, Mata-Mata, Nossob and Upington. Influences of recent climatic factors, such as rainfall and temperature, are explored in relation to mammal visitation behaviour and across species. This was achieved using high temporal resolution webcam imagery, which is located at the Nossob artificial water trough in KGNP, and the extent to which contemporary climate temporally controls water trough utilisation by wild fauna. It is also important to determine the extent to which the proportional visitation by mammals at the water trough is representative of the broader population within the park, so as to determine if relationships have broader application. Mammal species' distributions are assessed in relation to rainfall patterns within the broader KGNP over the past decade.

This chapter describes the data collection process and outlines details of how the data were acquired. This is followed by a discussion on the methodology used to analyse the long-term climatic patterns, to determine the relationships between mammal visitation patterns and climate variables, and the relationship between rainfall and the broader mammalian population across the park.

4.1 Data

4.1.1 Data Collection

SANParks have set up webcams at different national parks across South Africa as a tourism service initiative, which allows for real-time viewing of images by various spectators worldwide. These webcam images contain important information that can contribute valuable scientific data. Webcams that capture images at 30 - second intervals were placed at water troughs in Satara, KNP (webcam est. 2005) and KwaMaritane, Pilanesberg (webcam est. 1999). Faunal behaviour/drinking patterns and relative abundance per species located within the parks were compared across

these two sites (Hayward and Hayward, 2012).

Given that few studies have used webcam imagery to study mammal behaviour, there is no standard methodology to follow. The methodology formulated for this project has therefore been developed from various studies with similar climate-associated ecological aims (Mills and Retief, 1984; Van Rooyen *et al.,* 1994; Valeix *et al.,* 2008; Verstraeten *et al.,* 2010; Birkett *et al.,* 2012; Hayward and Hayward, 2012)

4.1.1.1 Long-term Climate

Long-term climate records are used to explore the effects of climate change in the region. This is important as it provides a background to the contemporary fauna-climate interactions observed for KGNP from the webcam data. Moreover, the contemporary climate is a factor of climate change that has occurred over past decades. Temperature and precipitation data were obtained from the South African Weather Services (SAWS) for a selection of weather stations KGNP and stations within the Northern Cape in close proximity to the park (*Table 4.1*). The data sets were chosen from a list provided by the SAWS, which outlines the various weather stations, and the historic data that are available from these weather stations. These four weather stations contained long-term continuous data, which would facilitate analysis of climate change for the region. The remaining 12 SAWS stations for the region spanned a short period or were incomplete. These were used for comparison with the census data, using a subsect of the complete data from 2003-2014. SAWS weather stations were selected for consistency in data. The data contain daily average, maximum and minimum long-term temperatures (T_{avg}, T_{max} and T_{min}, respectively) and daily rainfall (mm) from within KGNP for Twee Rivieren from 1940 - 2013, Nossob from 1975 - 2013 and Mata-Mata from 1960 - 2013, and in surrounding areas in the Northern Cape for Upington from 1883 - 2013. In order to obtain the most temporally complete rainfall data set, historical archives were sourced at the SAWS in Pretoria.

Table 4.1: South African Weather Services weather stations located in and adjacent to KGNP. Weather stations in bold indicate long-term records.

Climate Number	Weather station	Data record received	Latitude (°S)	Longitude (°E)	Altitude (m)
0461208 4	**Twee Rivieren**	1940 - 2014	-26,4717	20,6104	882
0460691 3	Kamqua	1999 - 2014	-26,4053	20,0158	958
0461071 6	Auchterlonie	1999 - 2014	-26,1875	20,5616	927
0460338 8	Klein Skrij	1999 - 2014	-26,1439	20,2119	953
0461491 3	Kij Kij	1999 - 2014	-26,1819	20,7894	922
0497019 2	**Mata-Mata**	1960 - 2014	-25,8146	20,0208	1000
0461541 5	Kransbrak	1999 - 2014	-26,0225	20,8297	934
0498374 8	Dikbaardskolk	1999 - 2014	-25,7439	20,7269	970
0497800 4	Moravet	1999 - 2014	-25,7197	20,5111	947
0497673 4	Bitterpan	1999 - 2014	-25,7139	20,3908	966
0535175 5	**Nossob***	1975 - 2014	-25,4203	20,5969	1000
0534629 0	Sewe panne	1999 - 2014	-25,4919	20,3564	927
0616287 8	Bayip	1999 - 2014	-25,2917	20,1658	1009
05340169	O'Kuip	1999 - 2014	-25.2750	20.0150	992
0534028 X	Drievendas	1999 - 2014	-25,4181	20,0311	938
0573048 4	Unie End	1999 - 2014	-24,7978	20,0319	1058
0534726 3	Grootbrak	1999 - 2014	-25,0947	20,4167	1006
0317447AX	**Upington**	1900 - 2014	-28,4636	21,2503	793

4.1.1.2 Webcam Imagery

The selected webcam for this study is positioned at the Nossob artificial water source, and captures images at 15 second intervals over an 18 - hour (4:00am to 23:00pm) period each day. This period is inhibited by the operational time of the generator. Floodlights illuminate the water trough during nocturnal hours, which allows for continuous image capturing at night. The Nossob webcam over-looking the artificial water trough became operational in 2005 (*Table 4.2; Figure 4.1*). Webcam panning and zooming closer to the water trough began in February 2014. The most recent image in real-time is featured on the SANParks website: (http://www.sanparks.org/webcams/cams.php?cam=nossob).



Figure 4.1: Webcam image of the Nossob artificial water trough located at Nossob rest camp in KGNP.

Table 4.2: Details of Nossob water trough located within KGNP

Site	Description	Location	GPS Co-ordinates	Altitude	Size
Nossob	Concrete Water trough	Nossob rest camp	-25.420923S, 20.598127E	963m	(Length: 3.5m; Width: 1.7m)

A large amount of computer data storage was required to archive the imagery captured at the 15 second intervals on a daily and monthly basis, as each image is ~35 Kilobytes (kb). An agreement was made with the SANParks E-Commerce Department in 2013 to forward the ~2500 daily images from the Nossob webcam to a database for processing (*Table 4.3*). This imagery was sent to the WITS FTP server from which retrieval and analysis was possible using the WinSCP (Windows Secure Copy) programme. Each of these images includes a time stamp (*Figure 4.1*), which contains the date/time of when the image was captured, making it easier for recording species and counting individuals utilizing the water trough.

Table 4.3: Webcam details of total images captured at Nossob from October 2012 - December 2014.

Site	Study Period	No. of days captured	No. of webcam Images archived
Nossob	1 October 2012- 30 December 2014	805	2.093.000

Data analysis, which utilised the webcam imagery captured over the 26 - month period, involved the identification of all mammals drinking at the water trough. Mammal at the water trough were identified, the number of individuals counted, and the date and time of visitation documented. Certain individuals per species could not be identified due to the low webcam image resolution. Some mammalian species that frequented the water trough on rare occasions were captured but not counted, as well as all avian species, as they would not be statistically appropriate for analysis (*Table 4.4*). Cape turtle doves and Cape crow could not be counted due to the large numbers congregating together, which makes it difficult to distinguish which individuals are actually drinking. Also, it was difficult to count numbers due to the poor webcam resolution.

Mammal species were recorded on *Microsoft Excel* spreadsheets for easy storage, analysis and calculation. If a mammal species was observed at the water trough, the first sighting of the individual/s were counted, and thereafter, a zero was used to display the duration of those same individuals at the water trough over time (Trent, 2015). However, if another mammalspecies arrived at the water trough, their appearance would be recorded and the additional number of individuals replaces the zero (Trent, 2015).

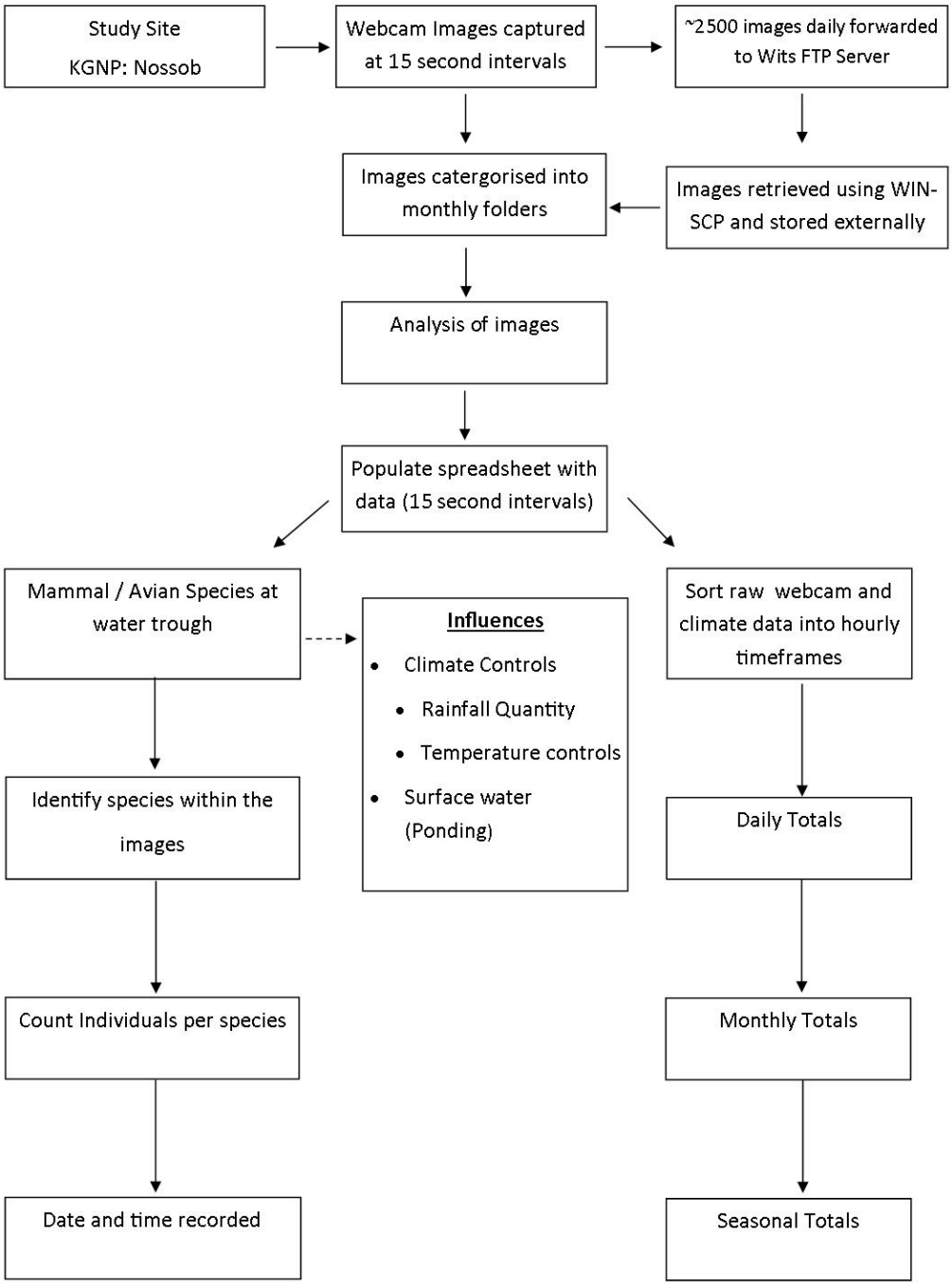


Figure 4.2: Schematic flow chart of the webcam imagery data collection and subsequent analyses.

Table 4.4: Avian and Mammalian species that were observed on rare occasions at the Nossob water trough from October 2012 - December 2014, but excluded from analysis.

Species not analysed during the study period		
Scientific Name	**Common Name**	**Observed over the entire period**
Corvus capensis	Cape Crow	-
Cynictis penicillata	Yellow Mongoose	26
Felis silvestris lybica	African Wild Cat	6
Mellivora capensis	Honey Badger	16
Otocyon megalotis	Bat-eared Fox	47
Sagittarius serpentarius	Secretary Bird	1794
Streptopelia capicola	Cape Turtle Dove	-
Suricatta suricatta	Meerkat	2
Taurotragus oryx	Eland	
Terathopius ecaudatus	Bateleur	85
Tragelaphus strepsiceros	Greater Kudu	2
Tyto alba	Barn Owl	2
Vulpes chama	Cape Fox	3

The sum function was used to calculate the total number of individuals per species at the water trough per day. The frequencies of mammal species visitation data (15 seconds) were then condensed into hourly time periods for each day and each month in order to establish the water trough utilisation per species per hour. Further, the raw mammal visitation data were grouped into seasonal, monthly and daily totals to facilitate correlation analyses with the appropriate climatic variables (*Figure 4.2;* Trent, 2015).

4.1.1.3 Climate Data

Climate data were used to explore relationships between temporal differences in mammal species' water trough utilisation and recent climate variables. As mentioned, climate data were sourced from the Nossob weather station, which is situated in close proximity (140m) to the Nossob water trough.

4.1.1.3.1 Temperature Data

Daily temperature data (T_{avg}, T_{max}, T_{min}) for Nossob, for the period spanning October 2012 - December 2014, were sourced from the South African Weather Services (SAWS) and the Agricultural Research Council (ARC). Climate data from the ARC were used to supplement the missing rainfall and temperature data supplied by the SAWS. The SAWS use robust climate recording gauges and the data undergo thorough analyses and inspection criteria in order to eliminate any errors that may occur before the data are distributed to the public.

4.1.1.3.2 Rainfall Data

Daily rainfall data for the period spanning October 2012 - December 2014 were obtained from the SAWS station located at Nossob (*Table 4.1*). SAWS performed checks in order to eliminate climatic data errors, such as miss-calculations, that may have occurred in the data collection processes. Data from the ARC were used to substitute any gaps in the SAWS data.

4.1.1.4 Census Data

Wildlife census data are valuable as they provide scientific information on the location of mammal/avian species within national parks, and can provide a regional comparison to the local and site-specific webcam counts. SANParks has recorded aerial census data in KGNP for the past decade, which was obtained from Dr Marna Herbst at SANParks in Phalaborwa. Large herbivores in the surveys include gemsbok, red hartebeest, springbok, steenbok, blue wildebeest and eland. The survey recorded all large mammals that are visible from the aircraft. For the purpose of KGNP aerial census data surveys, a fixed wing Cessna 206 aircraft was used, flown at a maintained height of 300 feet above ground and at a speed of 90mph.

Wildlife in KGNP is surveyed twice a year during the wet (April) and the dry (September) seasons using a sample count strategy (Pendleton, 1995). Due to insufficient funding, the aerial census data were not captured during the months of September 2010 and April 2013. Sample counts aim to estimate the number of fauna in a total area within the census units from the number counted in a smaller area

(sample unit/transect). It is important to assume that all the fauna in the sample area have been observed and accurately counted (WWF-Southern Africa Regional Programme Office, 2000).

Twenty-three transects evenly spaced at approximately 8km intervals are flown across the park in three strata (*Figure 4.3*). These strata are divided according to the broad vegetation communities within the park and the dry riverbeds are used as strata boundaries (Ellis and Herbst, 2012; Castley, 2013). The strip transects are recorded in three distance categories away from the aircraft: 0 - 200m, 200 - 500m, and >500m (Castley, 2013). Only the observations from the first two categories are used in estimating population sizes, which give an effective strip width of 1km. For the purpose of this project, the estimated population sizes from the >200m category have been used. Population estimates from the >200m distance category provide a more accurate estimate for smaller species, such as Steenbok, as the observation of these might be difficult at further distance from the aircraft. Transects are orientated along an East to West gradient. A grid was placed over the park by Scientific Services (Arid Ecosystems Research Unit – AERU; Port Elizabeth office) in order to calculate start and end positions and to ensure that transects flown do not end in the centre of any grid square (*Figure 4.3*).

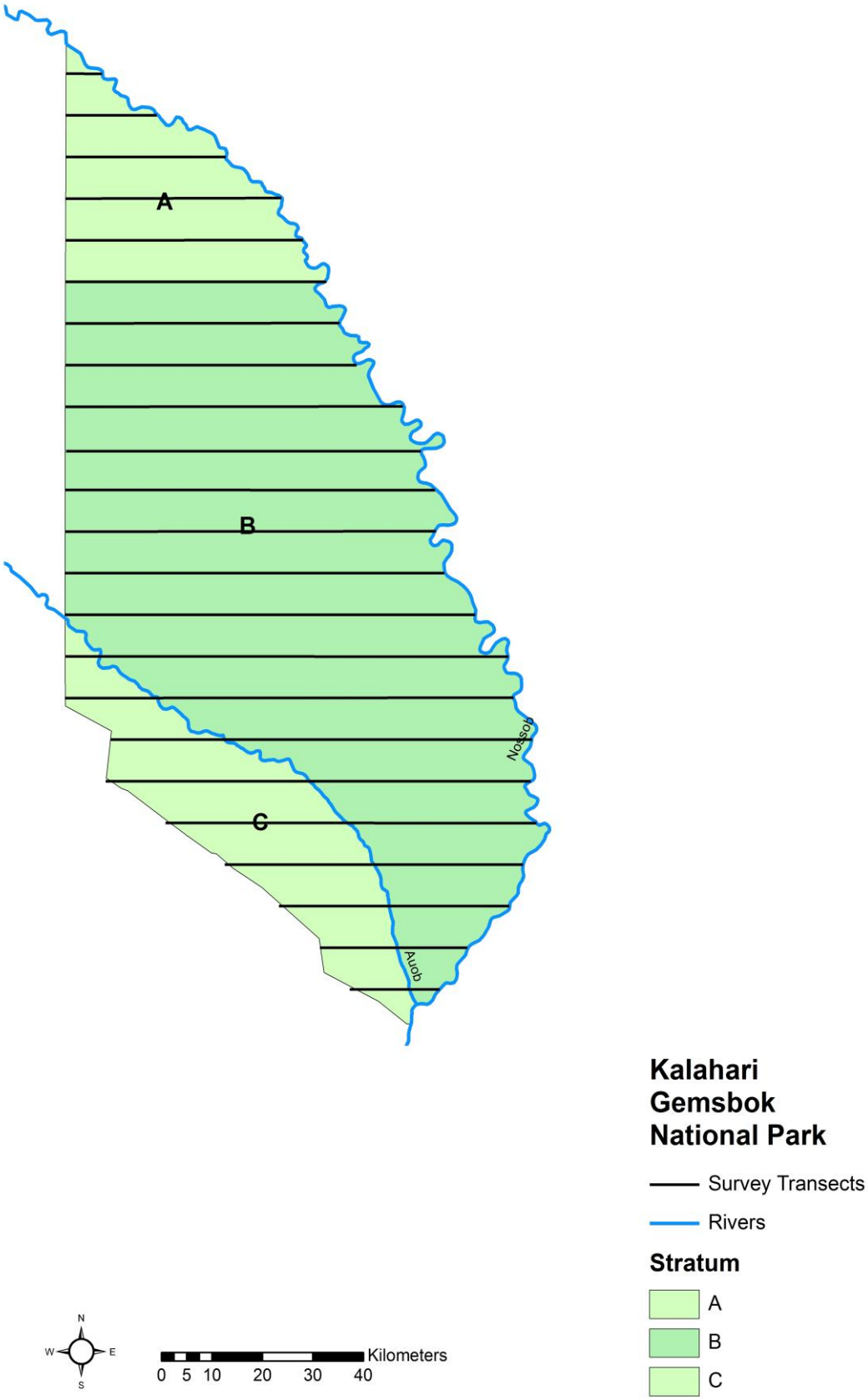


Figure 4.3: Survey flight lines (Transects) across KGNP - SANParks area. Map reconstructed from Castley, 2013.

4.2 Data Analysis

Long-term climate data were used to determine historic rainfall and temperature ($T_{avg,}$ T_{max} and T_{min}) trends, as well as short-term rainfall trends over the past decade. Statistical analyses were performed using *Microsoft Excel 2011* for this section of the results.

The mammal visitation data were used to determine species-specific visitation patterns at the water trough and the influences certain climate controls (rainfall and temperature) have on these visitation patterns. Webcam images that contained interesting and relevant information, such as surface water and grass growth, were saved so that they can be used during the results and discussion chapters of this dissertation. Census data were analysed in relation to rainfall using Pearson Correlation Coefficient's and univariate linear regression to establish whether faunal distributions are related to rainfall patterns at specific weather stations within the park. Most of the statistical analyses were calculated in *Microsoft Excel.* However, the more specialised statistical procedures were processed using the coding platform R, whereby the running scripts where developed by Dr Jennifer Fitchett.

4.2.1 Long-Term Climate

The raw climatic data constituted daily rainfall, T_{max} and T_{min}. The analysis of raw climate data included the comparison of rainfall, T_{max} and T_{min} across the four study sites. Trends in annual rainfall and the long-term annual mean were calculated for each of the four study sites so as to ascertain annual peaks in rainfall and long-term trends over the study period (Nash and Endfield, 2002).

Determining the average conditions for each variable over the entire study period of each of the study sites was established by calculating the arithmetic mean of the sample set:

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

Equation 4.1:

(Lomax, 2007; Underhill and Bradfield, 2009)

By calculating the range, it determined the spread of the data on either side of the mean. This helps to classify any values that are considered to be outliers, especially when comparing data for different study sites (Palaniswamy and Palaniswamy, 2006; Lomax, 2007).

In order to make comparisons or establish relationships between two data sets, correlation analysis was calculated (Manly, 2009). Rainfall and temperature were correlated with the number of years for each station for the purpose of establishing relationships over the study period (Fitchett, 2013). In order to determine the direction of the trend, the rate of change is determined. The Pearson Correlation Coefficient for time trends in climatic variables and the year over time was calculated using the following equation:

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

Equation 4.2:

(Manly, 2009; Underhill and Bradfield, 2009)

After determining the significance of the trend in climate variables (rainfall, T_{max} and T_{min}) over the entire study period, it is important to determine the rate of change over that same period for each study site. Regression analysis was used to determine the rate of change over time; where-by a best-fit linear trend line is added to the data set (Manly, 2009). The best fit line for the rainfall, T_{max} and T_{min} trends are calculated as follows:

$$y = ax + b$$

Equation 4.3:

(Lomax, 2007; Manly, 2009)

The calculation of the values for the constants *a* and *b* have to be determined. Firstly, the magnitude of the y intercept, *b* needs to be established. This is calculated as:

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

Equation 4.4:

(Manly, 2009; Underhill and Bradfield, 2009, Fitchett *et al.,* 2014)

By determining the y intercept, the coefficient of the x can now be calculated. This value indicates the amount by which the climatic variable is increasing or decreasing over time in response to a one-unit increase in the independent variable, which is each year over time (Fitchett *et al.,* 2014). It is calculated as follows:

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

Equation 4.5:

(Manly, 2009; Underhill and Bradfield, 2009, Fitchett *et al.,* 2014)

It is necessary to determine the statistical significance of the strength and direction of the climatic trends over the entire time period, together with the amount by which the dependent variable increases or decreases per year. Statistical significance is a measure of the probability that the results obtained could have occurred as a result of coincidence of random sampling (Motulsky, 2003). Statistical significance is calculated for the trends in rainfall, T_{max} and T_{min} per year over the entire study period for each of the four study sites. The larger the dataset, the greater the chance a strong correlation will accurately represent an existing strong relationship, therefore, high statistical significance occurs in results of strong correlations (high *r values*) where the dataset has large inputs (Manly, 2009).

The *p value* is the measure of statistical significance and this probability has a range from 0 to 1, where the smaller the value means it is less likely that the result has not occurred as a result of random sampling, and the result of the data over the study period is taken as accurate (Motulsky, 2003; Manly, 2009). The *p* values for this study were calculated using the standard correlation coefficient table, where critical values of the correlation coefficient for one-sided tests of the null hypothesis $H_0 : p = 0$ (where degrees of freedom = sample size - 2) (Underhill and Bradfield, 2009). Temperature extremes were analysed monthly on an annual temporal scale at T_{max} thresholds >40°C, T_{min} thresholds <0°C and rainfall thresholds >100mm. These extremes were calculated by counting the monthly average T_{max} thresholds >40°C, T_{min} <0°C and rainfall thresholds >100mm annually.

4.2.1.1 Recent Temperature and Rainfall Trends (1975 - 2014)

The available data acquired for Nossob spanned from 1975 to 2014. Due to this, recent trends were calculated for all four sites (Twee Rivieren, Mata-Mata, Nossob and Upington) over the time period 1975 - 2014 to determine an accurate comparison of trends over the same temporal scale between all of the locations. The annual averages were calculated over the entire period per study site to allow for a comparison over time. The change over time in climate variability (rainfall, $T_{avg,}$ T_{max} and T_{min}) is calculated using Pearson Correlation Coefficient's, to determine the strength of the trend, which is described in the earlier section (*Equation 4.2*). The best-fit linear regression line is then applied in order to establish the rate of change over time per year over the entire study period (*Equations 4.3, 4.4 and 4.5*).

4.2.1.2 Cyclic Rainfall Patterns

Cyclic rainfall patterns were explored for all four of the study sites: Twee Rivieren, Mata-Mata, Nossob and Upington. This helped to determine the difference between large, medium and small cyclic patterns of rainfall over the entire study period. These cyclic patterns were identified with the use of a 5 - year running mean, a standard statistical test for cyclicity (Underhill and Bradfield, 2009), used commonly in precipitation studies (Fitchett and Grab, 2014). These 5 - year running means are calculated independently for all four-study sites, in order to determine the specific drivers of each cyclic pattern over the entire period (*Equation 4.6*; Goldenberg *et al.,*

2001; Fitchett and Grab, 2014). The mean amplitude and periodicity were recorded and results compared to those reported in the literature for the region. Specific drivers were determined from the literature based on these mean periodicities in order to explain the causes of the magnitude of the peaks over the entire study period for each study site.

$$\bar{x}_{5\,yr} = \frac{x_i \ldots + x_{i+5}}{5}$$

Equation 4.6:

(Underhill and Bradfield, 2009)

4.2.1.3 Number of Rainfall Days per Year

Rainfall days are defined as all days with rainfall > 0mm. The total number of rainfall days per year was calculated for Twee Rivieren, Mata-Mata and Nossob. Given the lack of daily rainfall data for Upington, as only monthly data are available, this study site has been excluded for this particular set of tests. The mean, maximum and minimum number of rainfall days was calculated over the entire period for each study site in order compare values across sites. The mean, maximum and minimum number of consecutive days of rainfall was calculated so as to establish patterns across all of the study sites. The total number of consecutive days of rain-free days was established in order to determine the mean, maximum and minimum consecutive days where no rainfall occurred at each site.

4.2.1.4 Number of Days between 10°C and 30°C Temperature Threshold

Temperature thresholds are defined for the purpose of this study as days with average temperatures between 10°C and 30°C. These are temperatures, which fauna can withstand without severe heat stress or suffering excessive cold (Fuller *et al.,* 2014). Daily temperature data were sorted and categorised using Microsoft Excel. Days with temperatures outside of this threshold were counted for each year to give an annual total. The change over time is explored using Pearson Correlation Coefficient's and linear regression (*Equations 4.2 and 4.3, 4.4 and 4.5*).

4.2.1.5 Recent Spatio-Temporal Rainfall Patterns: 2003 - 2014

Shorter spatio-temporal rainfall patterns have been analysed for the period 2003 - 2014 across 16 sites (*Table 4.1*). The climate data includes the year prior to the census data (2003) in order to determine whether there were anomalous climatic events, and 2014 was used to ensure that the data was up to date. These are used for comparison with the aerial census data, available for the past decade. Annual totals were utilised for the purpose of comparison across all of the rainfall stations, and years, which had missing rainfall data, were not included in this section. Mean inter-annual rainfall over the period 2003 - 2014 was calculated for each of the rainfall stations so as to make comparisons between each of these sites (*Equation 4.1*). The inter-annual rainfall for each of the 16 rainfall stations for KGNP was calculated for the period of 2003 - 2014, so as to ascertain the spread of the data across this time period for each of the sites. A box and whisker plot was produced using STATA 11 to compare the annual mean, range and outliers for all sites. Temperature data has not been included in the shorter-term climatic patterns, as it is not being compared with the aerial census data over the past decade.

Correlation analysis was used to calculate and compare the trends across each site over the period of 2003 - 2014 (*Equation 4.2*). The strength of the trend (change over time in mm/year) is determined and compared across all of the sites (*Equation 4.3, 4.4 and 4.5*). However, these trends have a low probability of being statistically significant due to the low number of test sites.

4.2.1.6 Webcam Imagery

The total faunal (n) water trough utilisation was calculated hourly over the period October 2012 to December 2014. Faunal water trough utilisation was then determined at an hourly temporal scale. Total animal counts over a 26 - month period were established for both wet (September to February) and dry seasons (March to August). Distribution curves are then analysed to establish seasonal patterns and preferential use of the water trough for a variety of species.

4.2.1.7 Classification of Peak Mammal Water Trough Utilisation Periods

For the purpose of this study, the hourly interval data were used to analyse temporal visitation patterns of wild fauna. The 18 - hour day was separated into four distinct periods according to the major mammal species' water trough utilisation periods, so that predominant visitation periods could be established (Hayward and Hayward, 2012). Mammal species were separated according to their highest percentage of water trough utilisation throughout the 18 - hour period and associated water-dependence. The total number of sightings was calculated for each mammal species per hour for the period October 2012 - December 2014. The percentage distribution of each species was then calculated and grouped according to their related time period, so that peak water trough utilisation times could be established per species.

These results were statistically examined, using non-hierarchical cluster analysis and Principal Component Analysis (PCA) to establish whether the visitation times agreed or disagreed with the peak water visitation hours. Cluster and PCA have been used in a variety of studies to isolate specific groups that have similar behavioural characteristics (Gandiwa, 2013; Lu and Lei, 2015). Therefore, in order to accurately test trends and patterns in mammal water trough utilisation, an unconstrained cluster analysis was performed using the Euclidean methods, with the distance between species calculated using Ward's D methods, where the hourly percentages for each mammal species were used (Manly, 2009; Trent, 2015). A silhouette plot was used to determine the number of significant groups. Unconstrained cluster analysis was performed on the range of species to allow true associations across the guilds and other known implicit groupings (Trent 2015). The cluster analysis produced a dendrogram, which has been interpreted in conjunction with the specific water trough utilisation time categories (Lu and Lei, 2015).

In order to further statistically explore major mammal species' visitation patterns, the PCA has been used in conjunction with the cluster analysis (Gandiwa, 2013; Kaholongo and Mapaure, 2014). Time is classified as the vector and mammal species as the points. Species were clustered in groups according to overlapping water trough utilisation times driven by the specific time vectors. The PCA statistically determined which species utilise the water trough simultaneously and the

time period, which drove these patterns of concurrence (Manly, 2009; Trent, 2015). The statistical analyses of cluster analysis and PCA have been compared to mammal species' water trough utilisation patterns.

4.2.1.8 Census Data

As explained in the data collection section (4.2.1.4), aerial census counts were taken in a series of transects spanning the entire park. Regional (the sum of all census data from all transects) and local census data were compared to webcam survey data (mammal drinking frequency at Nossob). This was firstly to determine the extent to which the webcam is representative of the broader mammal distribution in the park, and secondly, to establish the preferential use of the water trough by specific mammals. The relationship between rainfall and proportional representation of fauna in wet and dry months (April and September) have been analysed to ascertain whether there is a relationship between broad faunal proportional representation and rainfall within KGNP.

4.2.1.9 Census Transect Data Correlated with Rainfall

Rainfall in KGNP is unpredictable temporally and spatially; therefore, it is important to explore faunal distribution in relation to rainfall patterns in order to determine mammal species' distribution patterns (Thouless, 1998). The regional aerial census that is flown in transects is correlated to short-term rainfall records. As mentioned in the data acquisition section, aerial census was only conducted during the wet month of April and the dry month of September each year. The relationship between rainfall and proportional representation of fauna during wet and dry months (April and September) are analysed in order to ascertain whether there is a relationship between broad faunal proportional representation and rainfall within KGNP. Particularly strong correlations between rainfall and each species are tested at the 99% and 95% significance levels for each rainfall station over the period 2003 - 2014. These correlations indicate whether water requirements for each of the species are seasonally controlled or not. Water-dependant faunal species are observed more frequently at the water trough during the dry season (Ayeni, 1977).

4.2.1.10 Seasonal Water Trough Utilisation

To establish seasonal water trough utilisation for each of the mammal species, percentage visitation per species is divided into the wet (hot) and dry (warm/cool) seasons. November to April were categorised as the wet (hot) season and the months May to October as the dry (warm/cool) season (Bergstrom and Skarpe, 1999). This demonstrates whether species' percentage water trough utilisation occurs more frequently during the dry or wet seasons. The total sightings per month were grouped according to each season (*Table 4.5*). Seasonal water trough utilisation was determined by the percentage of mammal species observed during each season from October 2012 - December 2014. Mammal and species were explored graphically over the entire study period so that peaks of water trough utilisation per species could be identified. Species with similar peaks could then be grouped together according to monthly preferential water trough utilisation.

Table 4.5: Months of the year, which classify each season

Season	Months
Summer	December, January, February
Autumn	March, April, May
Winter	June, July, August
Spring	September, October, November

4.2.1.11 Relationship between Mammal Water Trough Utilisation and Climate

It has been observed that climatic variables (temperature and rainfall) influence mammal species' behavioural patterns according to both temperature thresholds and quantity of rainfall and surface water following rainfall (Mills and Retief, 1984; Thouless, 1998; Fuller *et al.,* 2014). The climate patterns that occurred during the study period were explored through monthly means calculated for temperature and rainfall. The occurrence of standing surface water (ponds) after rainfall events are explored to determine the rainfall quantity required to form a pond and produce an adequate surface water supply for fauna.

4.2.1.12 Water Trough Utilisation and Temperature

The mean daily water trough utilisation trends were calculated using the total mammal species' sightings for time period October 2012 - December 2014. This was plotted against the daily T_{avg} for the study period, so that the relationship between peak water trough utilisation times and coinciding temperatures could be explored. The time was calculated as the difference between the time when peak sightings occurred, and the time of peak temperature (Trent, 2015).

The relationships between hourly categories of carnivore and herbivore species' peak timing of visitations, is explored for temperature thresholds, and established as 5°C daily T_{avg} groupings. Six temperature intervals were chosen according to daily T_{avg} across the study period (2 - years): 5°C - 9.9°C; 10°C - 14.9°C; 15°C - 19.9°C; 20°C - 24.9°C; 25°C - 29.9°C and 30°C - 34.9°C. These temperature thresholds were used to determine shifts in carnivore and herbivore water trough utilisation, and whether these shifts occurred earlier or later during different temperature thresholds. The lowest measured T_{avgs} fell in the category of 5°C - 9°C and occurred during July with minimum daily T_{avg} of 4.15°C and maximum daily T_{avg} of 19.45°C while the highest T_{avgs} fell in the category of 30°C - 34.9°C and occurred during January with minimum daily T_{avg} of 30.1°C and maximum daily T_{avg} of 34.98°C. All of the days for the study period are categorised into these groups by their T_{avg} and for each day the hourly distribution of animals is recorded and averaged per group.

It is important to determine the relationship between hourly peak appearance per day per species and T_{avg}, T_{max} and T_{min} to establish whether specific mammal species shift their peak water trough utilisation patterns in relation to daily temperatures (Trent, 2015). The peak appearance (hour) of each day and total mammal species are correlated with daily T_{avg}, T_{max} and T_{min} for the period October 2012 - December 2014 (*Equation 4.2*). Negative correlation values indicate that when the temperature increases, mammal species frequent the water trough earlier during the day, while positive correlations indicate that as temperatures increase on a given day, fauna utilise the water trough later than normal.

The relationship between monthly water trough utilisation patterns per mammal species were calculated using the total daily water trough utilisation patterns for each species. Daily mammal water trough utilisation patterns were then correlated with daily T_{avg} to determine species-specific monthly and seasonal patterns over the study period.

4.2.1.13 Water Trough Utilisation and Rainfall

It is important to explore the relationship between mammal water trough utilisation with rainfall events, quantity and the presence of natural surface water (Mills and Retief, 1984). To establish whether there is a relationship between total number of faunal sightings at the Nossob water trough during and immediately after rainfall events, the total mammal sightings were sorted in response to rainfall categories: one and two days before the rainfall event, on the day of the rainfall event, and one to two days after the rainfall event. The Pearson Correlation Coefficient was used to test whether a relationship exists between total rainfall for each of these categories, and the total mammal water trough visitations during these rainfall categories (*Equation 4.2*). The relationship was investigated for each species during the rainfall category that had the most significant correlation.

4.2.1.14 Water Trough Utilisation after Rainfall Events

It is important to determine the extent to which rainfall quantity affects mammal species' water trough utilisation. Rainfall was categorised according to certain quantities that occurred during rainfall events over the study period: 1 - 9mm; 10 - 19mm; 20 - 29mm and ≥30mm. The total number of fauna per species was counted for each rainfall category. More days were observed during the lower rainfall categories, which would mean a disproportional number of fauna occurring during these lower rainfall categories. Therefore, for the calculation to be accurate, the total number of fauna was then averaged according to the number of days per rainfall category. Percentage water trough utilisation for each mammal species and water trough utilisation within each category of rainfall was demonstrated graphically to ascertain the effects of certain quantities of rainfall on water trough utilisation.

4.3 Conclusion

Long-term climatic data (T_{min}, $T_{max,}$ and rainfall) are analysed to determine climatic changes over the past ~40 years or more until present, and to establish trends and cyclic patterns. It is important to determine the extent to which webcam data are representative of the mammal distribution within the region. The relationship between rainfall during the wet and dry months (April and September) and proportional faunal distributions have been analysed to determine whether there is a relationship between rainfall and broad faunal proportional representation within KGNP. Faunal water trough utilisation patterns are explored in order to ascertain recent climatic controls (T_{avg}, T_{min}, T_{max} and rainfall) on mammal species behavioural patterns and water trough utilisation. Temperature thresholds are used to determine shifting patterns in mammal species water trough utilisation over the study period. Rainfall quantity categories are explored to determine the rainfall quantities that affect mammal species water trough utilisation.

Chapter 5

Results



5 Results

This chapter consists of three sections: i) Climate change over the last ~100 years, ii) Relationships between faunal distribution and rainfall over recent years (2004 - 2013), and iii) Faunal waterhole utilisation over a two-year period (October 2012 - December 2014). The Kalahari Gemsbok National Park experiences low annual rainfall (avg = 230mm) and is vulnerable to climate change (Tews *et al.,* 2004; Meadows, 2006; Mphale *et al.* 2014). Climate change adversely affects the environment and biodiversity, which causes changes in taxa, including shifts in phenology, distribution and demography (Ackerly *et al.,* 2010; Vittoz *et al.,* 2013). Rainfall and T_{max} / T_{min} trends are presented for Twee Rivieren (1940 - 2014), Mata-Mata (1961 - 2014), and Nossob (1975 - 2014), and compared with the longest available regional record from Upington (1883 - 2014), some 265 km south of the park. Aerial census data (2004 - 2013) relative to weather stations within the park are correlated to establish relationships with rainfall. Relationships between faunal water trough utilisation and T_{avg} thresholds and rainfall quantity are established so as to ascertain influences on faunal water requirements at the Nossob water trough. Determining faunal water requirements in national parks, specifically arid and semi-arid regions where fauna are exposed to high temperatures and low rainfall, is especially important (Derry and Dougill, 2008)

5.1 Long-term Annual Rainfall Patterns

Each weather station contains years of missing rainfall data, which are detailed in *Table 5.1*. Twee Rivieren, Mata-Mata, Nossob and Upington all have similar mean annual precipitation over the full period of available data (193.71mm, 199mm, 201.3mm and 195.36mm, respectively; *Table 5.2, Figure 5.1 - 5.4*). The highest rainfall for all four stations occurs between the periods 1974 - 1976 (559.8mm, 738.4mm, 602.3mm and 500mm, respectively; *Figure 5.1 - 5.4*). However, the highest rainfall recorded for Upington occurs in 1950 (565mm; *Table 5.*2, Figure *5.1 - 5.4*). Mean inter-annual rainfall for Mata-Mata between the absolute maximum year and the absolute minimum year demonstrated considerable inter-annual range (721.3mm), with a maximum of 738mm in 1976 and a minimum of 17.1mm in 1997 (*Table 5.2, Figure 5.2*). In contrast, Twee Rivieren demonstrated the smallest inter-

annual range (497.4mm) in mean annual precipitation, with a maximum of 559.8mm in 1974 and a minimum of 62.4mm in 1947 (*Table 5.2, Figure 5.1*).

Table 5.1: Weather stations within KGNP (Nossob and Upington) that contain missing annual data.

Nossob	Upington
1992	1883, 1889, 1891, 1893, 1895, 1896, 1897, 1898, 1908, 1909, 1912, 1913, 1914, 1915, 1916, 1917, 1918, 1919, 1947, 1951

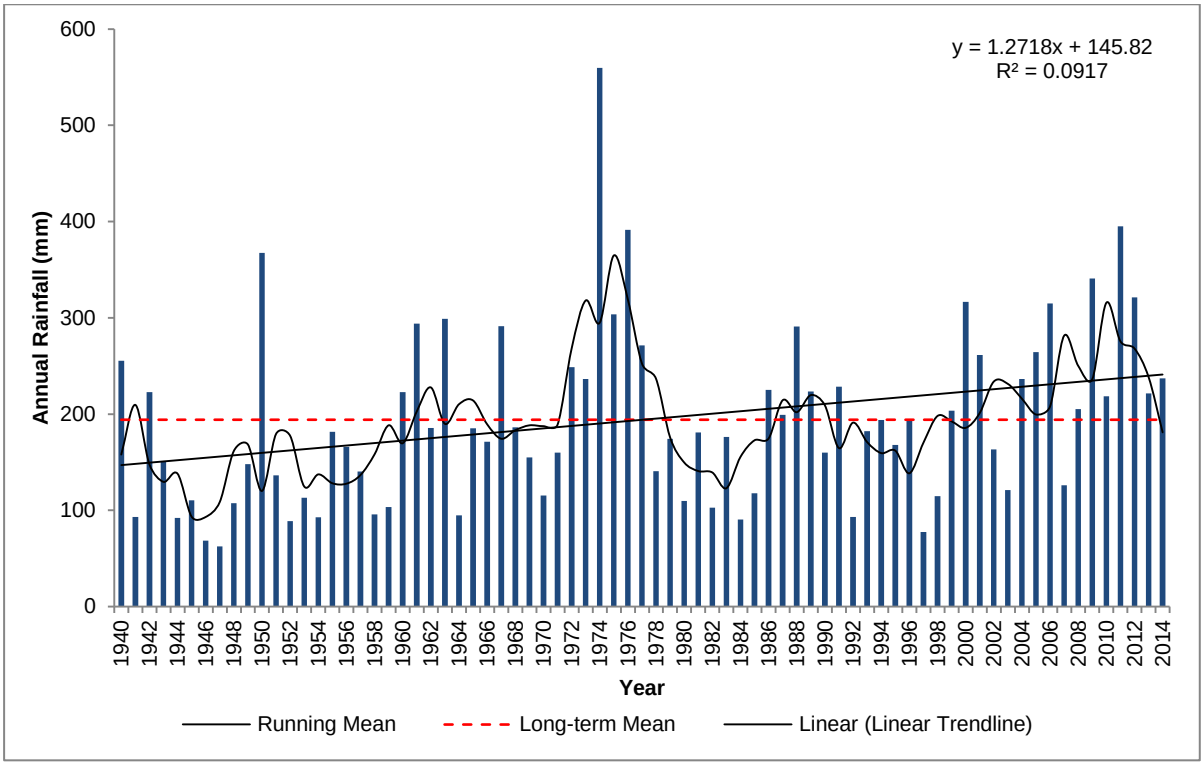


Figure 5.1: Long-term rainfall trends for Twee Rivieren: 1940 - 2014.

Statistical variance between stations differed slightly, with the most considerable variance calculated for Mata-Mata ($\sigma = 128$) and the smallest for Twee Rivieren ($\sigma = 90.18$; *Table 5.2*). Time trends indicate a slight increase in mean annual precipitation in Upington (0.23mm/year) but a large decrease at Twee Rivieren (1.27mm/year). For both these stations, there is a weak correlation between mean annual precipitation and time ($r = 0.09$, $p < 0.2$ and $r = 0.04$, $p > 0.4$, respectively; *Table*

5.2). Despite a weak correlation for the time trend, rainfall at Mata-Mata demonstrated the strongest decreasing trend (1.71mm/year; r = -0.2, p > 0.1) of any of the stations assessed.

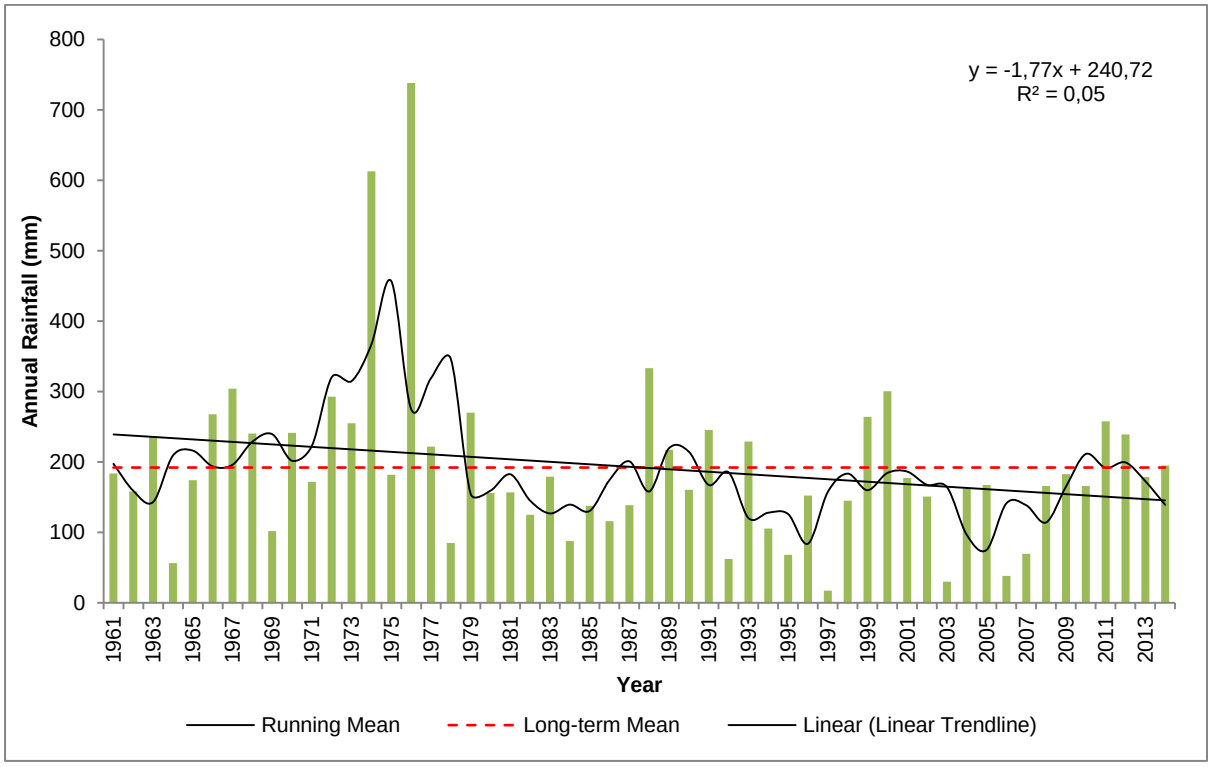


Figure 5.2: Long-term rainfall trend for Mata-Mata: 1961 - 2014.

A 5 - year running mean was used for the purpose of this study to determine the cyclic patterns, as this is the standard de-trending function (Kane, 2009; Fitchett and Grab, 2014). The cycles with the greatest kurtosis (amplitudes of 144.8mm) are classified as high kurtosis cycles and have an average periodicity of 13 years observed from the running mean for Mata-Mata (*Table 5.3*). These cycles between periods of extreme mean annual precipitation can be associated with greater storm occurrences, potentially linked to tropical depressions, although these generally make landfall considerably further east on the Mozambique coast (Tyson and Crimp, 1998; Huang *et al.,* 2015; van Wilgen *et al.,* 2015).

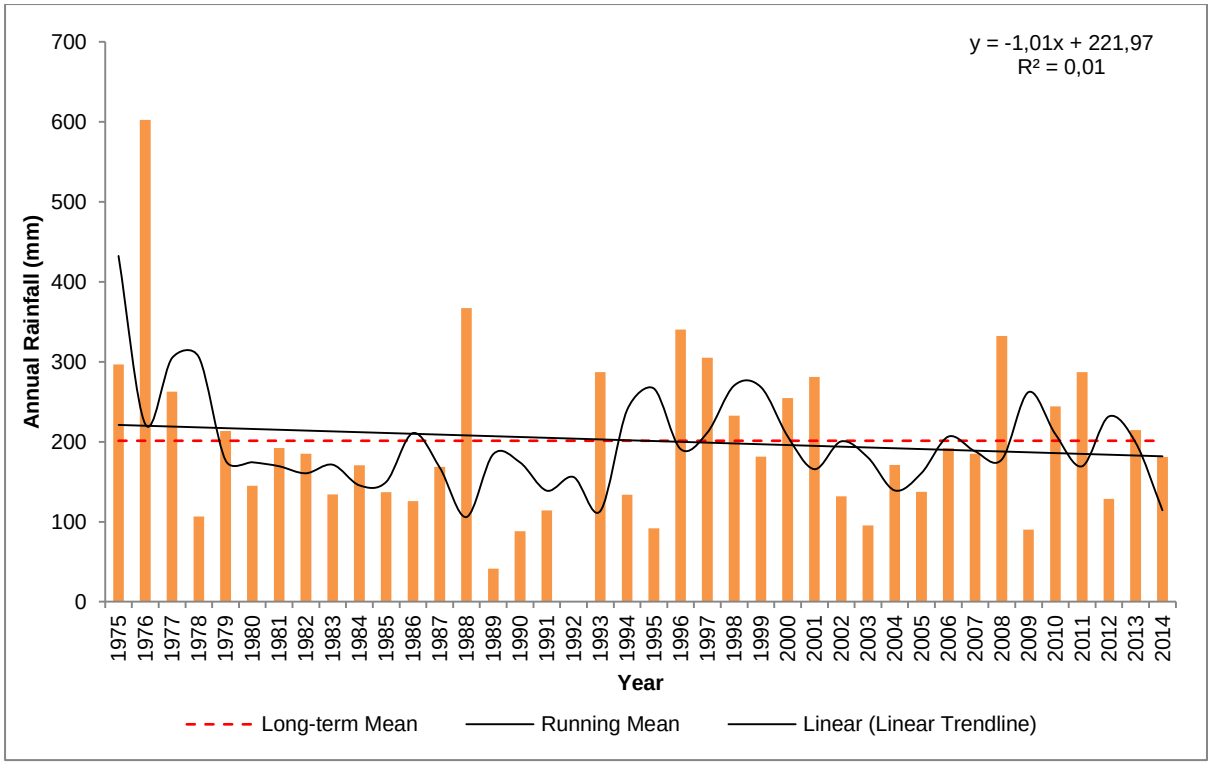


Figure 5.3: Long-term rainfall trends for Nossob: 1975 – 2014.

The station with the lowest kurtosis cycles for mean annual precipitation is Nossob at 48.9mm amplitude with an average periodicity at 13 years *(Table 5.3*). The 6.4 - year cycle at Upington can be linked from the literature to ENSO, which has a cycle of 2 - 7 years (Nash and Endfield, 2008). Cycles with a moderate and low kurtosis are classified as having maximum cyclic amplitudes of 53.8mm and 20.2mm respectively for Upington (*Table 5.3*). For Mata-Mata, these categories are considerably lower at 8.6mm and 4.3mm respectively (*Table 5.3*). The 14.4 - year cyclic periodicity at Twee Rivieren is apparently linked to the long-term full ENSO cycle (Neelin *et al.,* 2000).

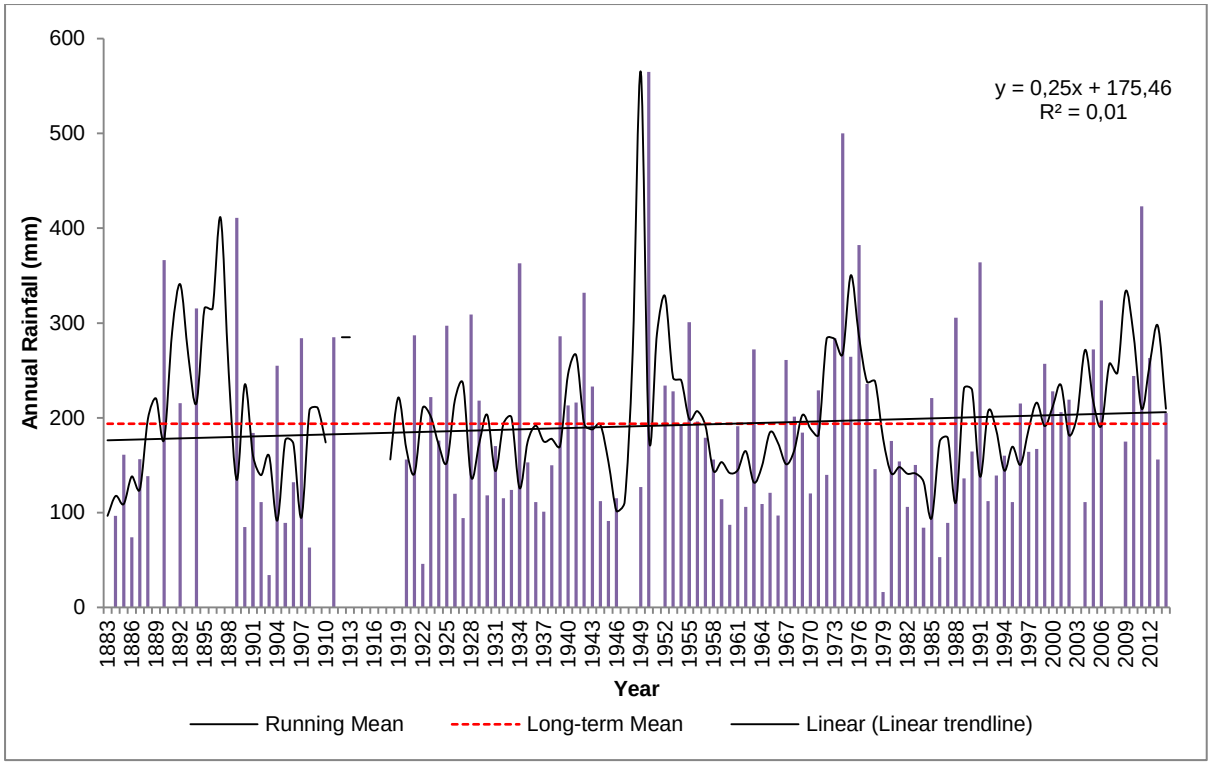


Figure 5.4: Long-term rainfall trends for Upington: 1883 - 2014.

The low kurtosis at Nossob have a periodicity of 15.5 years, which can be tentatively related to the luni-solar cycle, as well as the Indian Ocean Dipole (IOD) (Neelin *et al.,* 2000; Nash and Endfield, 2002; Ashok *et al.,* 2003; *Table 5.3*). The high kurtosis cycles for Upington demonstrate an average periodicity of 18.7 years and an average amplitude of 133mm, which is connected to the phenomenon of (IOD) (Ashok *et al.,* 2003; *Table 5.3*). It is no that the stations are located close to each other, yet have different cyclic drivers. What is more likely is that the inter-annual rainfall trends for each site highlight different driving forces based on their micro-topography (Saeidabadi *et al.,* in press).

Table 5.2: Annual average T_{max}, T_{min} and rainfall (mm). Statistically significant correlations ($p < 0.05$) are indicated with an asterisk; particularly strong correlations ($p < 0.01$) with a double asterisk.

Annual averages for T_{min}, T_{min} and Rainfall (mm)				
		1940 - 2014		
Twee Rivieren		**Tmax**	**Tmin**	**Rainfall**
	Annual Average	30.07	11.33	191.70
	Sample size (n)	48	50	54.00
	Range	5.4	3.5	497.4
	Variance	1.09	0.77	90.18
	Change over time (°C or mm/year)	0.05	0.01	1.27
	Strength of trend (r)	**0.8	0.2	0.03
		1961 - 2014		
Mata-Mata		**Tmax**	**Tmin**	**Rainfall**
	Annual Average	30.27	10.52	199
	Sample size (n)	32	28	46
	Range	3,77	3,77	721.3
	Variance	0.84	1.09	128
	Change over time (°C or mm/year)	0.06	0.06	-1.77
	Strength of trend (r)	**0.8	*0.5	0.2
		1975 - 2014		
Nossob		**Tmax**	**Tmin**	**Rainfall**
	Annual Average	30.49	11.0	201.30
	Sample size (n)	32	34	38
	Range	2.8	4.2	561.00
	Variance	0,73	0.9	103.44
	Change over time (°C or mm/year)	0.05	<-0.01	<-1.01
	Strength of trend (r)	**0.7	-0.1	-0.12
		1883 - 2014		
Upington		**Tmax**	**Tmin**	**Rainfall**
	Annual Average	29.10	11.02	193.71
	Sample size (n)	49	55	108
	Range	3	2.5	531
	Variance	0.63	0.55	96.72
	Change over time (°C or mm/year)	0.01	0.09	0.23
	Strength of trend (r)	0.12	*0.5	0.08

Table 5.3: Rainfall (mm) cyclic patterns for Twee Rivieren, Mata-Mata, Nossob and Upington over the entire period.

	Amplitude (mm)	Periodicity (average)	Range	Possible Causes
Twee Rivieren				
High Kurtosis	76.7	14.4	11 - 14	Long-term full ENSO cycle (Neelin *et al.,* 2000).
Moderate Kurtosis	21.1	16	2 - 16	No clear cause.
Low Kurtosis	8.4	12.3	2 - 21	No clear cause.
Mata-Mata				
High Kurtosis	8.55	13	11 - 14	Greater storm occurrences (Fitchett and Grab, 2014; Huang *et al.,* 2015; van Wilgen *et al.,* 2015).
Medium Kurtosis	8.6	17.7	17 - 30	Indian Ocean Dipole (IOD) (Ashok *et al.,* 2003).
Low Kurtosis	4.3	44	44	No clear cause.
Nossob				
High Kurtosis	48.9	13	5 - 13	Greater storm occurrences (Fitchett and Grab, 2014; Huang *et al.,* 2015; van Wilgen *et al.,* 2015).
Medium Kurtosis	46.9	9	9	No clear cause
Low Kurtosis	15.6	15.5	8 - 15	Indian Ocean Dipole (IOD) (Ashok *et al.,* 2003), Luni-Solar Cycle (Neelin *et al.,* 2000, Nash and Endfield, 2002)
Upington				
High Kurtosis	113	18.7	8 - 19	Indian Ocean Dipole (IOD) (Ashok *et al.,* 2003)
Medium Kurtosis	53.8	15.3	3 - 14	No clear cause
Low Kurtosis	20.2	6.4	2 - 12	El Niño Southern Oscillation (ENSO) (Neelin *et al.,* 2000)

5.1.1 Recent Trends (1975 - 2014)

The period of overlap (1975 - 2014) in rainfall records between the four stations, due to Nossob only recording rainfall data from 1975, these more recent rainfall records are used for comparison between Twee Rivieren, Mata-Mata, Nossob and Upington. Annual average rainfall (1975 - 2014) for all four stations ranges from 176.94mm at Mata-Mata to 208.98mm at Twee Rivieren (*Table 5.4, Figure 5.5A and B*). Both Mata-Mata (2mm/year) and Nossob (1.01mm/year) demonstrate statistically strong decreasing trends ($r = 0.62$, $p > 0.0005$; $r = 0.64$, $p > 0.0005$, respectively; *Table 5.4, Figure 5.5B and C*). Increasing trends are calculated for Twee Rivieren (1.6mm/year) and Upington (1.1mm/year), with the latter being significant ($r = 0.47$, $p > 0.001$, $r = 0.23$, $p > 0.1$; *Table 5.4, Figure 5.5A and D*).

Table 5.4 Recent climatic trends (T_{max}, T_{min} and rainfall) for Twee Rivieren, Mata-Mata, Nossob and Upington: 1975 - 2014. Statistically significant correlations ($p < 0.05$) are indicated with an asterisk; particularly strong correlations ($p < 0.01$) with a double asterisk.

	(1975 - 2014)		
Twee Rivieren	**Tmax**	**Tmin**	**Rainfall**
Annual Average	30.3	11.5	208.96
Sample size (n)	37	36	40
Range	5.3	3.1	317.8
Variance	1.1	0.8	81.91
Change over time (C° mm/year)	0.05	<-0.01	1.6
Strength of trend (r)	**0.8	-0.01	0.23

Mata-Mata	**Tmax**	**Tmin**	**Rainfall**
Annual Average	30	10.5	176.94
Sample size (n)	32	28	40
Range	3.8	3.8	721.3
Variance	0.8	1.1	116.64
Change over time (C° mm/year)	0.06	0.07	-2.0
Strength of trend (r)	**0.8	*0.5	-0.2

Nossob	**Tmax**	**Tmin**	**Rainfall**
Annual Average	30.5	11	201.3
Sample size (n)	32	34	38
Range	2.8	4.2	561.00
Variance	0.7	0.9	103.44
Change over time (C° mm/year)	0.05	<-0.01	<-1.01
Strength of trend (r)	**0.7	-0.1	-0.12

Upington	**Tmax**	**Tmin**	**Rainfall**
Annual Average	29.3	11.2	194.14
Sample size (n)	24	26	40
Range	2.7	2	370.2
Variance	0.6	0.5	84.33
Change over time (C° mm/year)	0.03	0.02	1.5
Strength of trend (r)	*0.5	*0.6	0.15

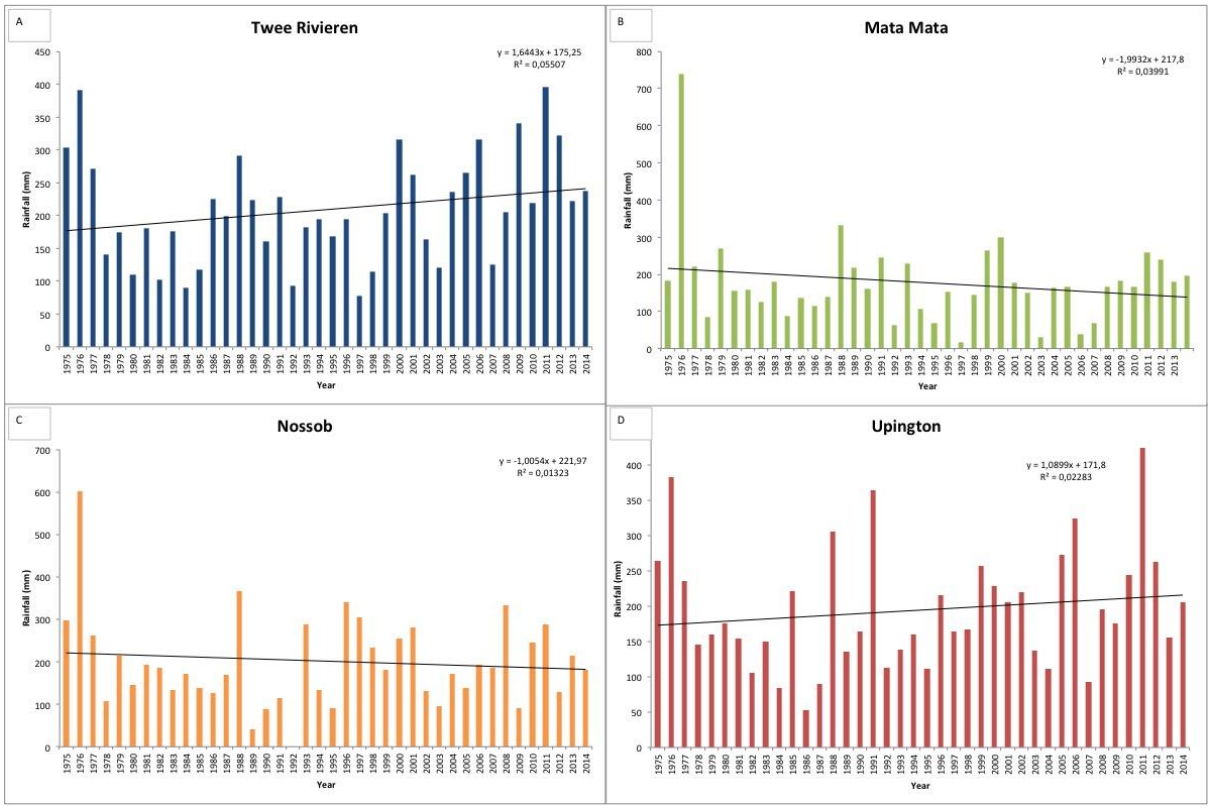


Figure 5.5: Recent rainfall trends for Twee Rivieren, Mata Mata, Nossob and Upington (1975-2014).

5.1.2 Number of Rainfall Days per Year

The average number of rainfall/non-rainfall days annually over the entire period has been calculated for Twee Rivieren, Mata-Mata and Nossob (*Table 5.5*). However, due to the lack of daily rainfall data for the Upington weather station, rainfall days for Upington have not been calculated. The average number of rain days over the entire period is similar for all three weather stations in KGNP (28, 23 and 28 days respectively; *Table 5.5*). The maximum number of rain days occurred during 1974 (53 days) and 1976 (76 days) for Mata-Mata and Nossob respectively (*Table 5.5*). In addition, the maximum number of consecutive days of rainfall for Mata-Mata and Nossob occur in 1976 (9 and 8 days respectively; *Table 5.5*). Extensive flooding resulted from La Niña events occurring during the years 1949 - 50, 1973 - 1976 and 2011 (Huang *et al.,* 2015). All three weather stations have similar average total number of consecutive rain free days over the entire period. However, Mata-Mata has the highest number of consecutive rain free days (142 days; *Table 5.5*).

Table 5.5: Number of rain days per year, total number of consecutive rain and non-rainfall days per year for the stations Twee Rivieren, Mata-Mata and Nossob.

	Twee Rivieren	Year	Mata-Mata	Year	Nossob	Year
Number of rain days (per year)						
Mean	28		23		28	
Max	75	2011	53	1974	76	1976
Min	6	1941	4	2006	7	2009
Max number of consecutive days of rain						
Mean	3		3		4	
Max	7	2011	9	1976	8	1976
Min	1	1941; 1948	2	1964; 68; 80; 87; 95; 97; 98; 2002; 03)	1	2006
Total number of consecutive non-rainfall days						
Mean	128		142		130	
Max	250	1989	298	2006	265	2006
Min	37	1961	47	1979	47	1978

5.2 Long-term Annual Temperature Patterns

The mean annual T_{max} for Twee Rivieren, Mata-Mata, Nossob and Upington are similar over the study period (30.07°C, 30.27°C, 30.49°C and 29.10°C, respectively; *Table 5.2, Figures 5.6 - 5.9*). The mean annual T_{avg} are increasing for Twee Rivieren, Mata-Mata, Nossob and Upington (0.04°C/year, 0.06°C/year, 0.04°C/year and 0.01°C/year; respectively; *Figure 5.6 - 5.9*). The mean annual T_{min} are also similar for the four stations (11.33°C, 10.52°C, 11.10°C and 11.02°C, respectively; *Table 5.2, Figures 5.6 - 5.9*). The mean annual T_{max} occurs in 2010 for Twee Rivieren, Mata-Mata and Upington (33.4°C, 31.9°C and 30.6°C, respectively) and in 2008 for Nossob (31.8°C; *Figure 5.6 - 5.9*). The mean annual T_{max} range occurs at Twee Rivieren (5.4°C), with a maximum of 33.4°C in 2010 and a minimum of 28°C in 1974 over the study period. The greatest T_{min} range occurs at Nossob (5.94°C) with a maximum of 14.1°C in 2004 and a minimum of 8.2°C in 2008 (*Table 5.2, Figures 5.6 and 5.8*).

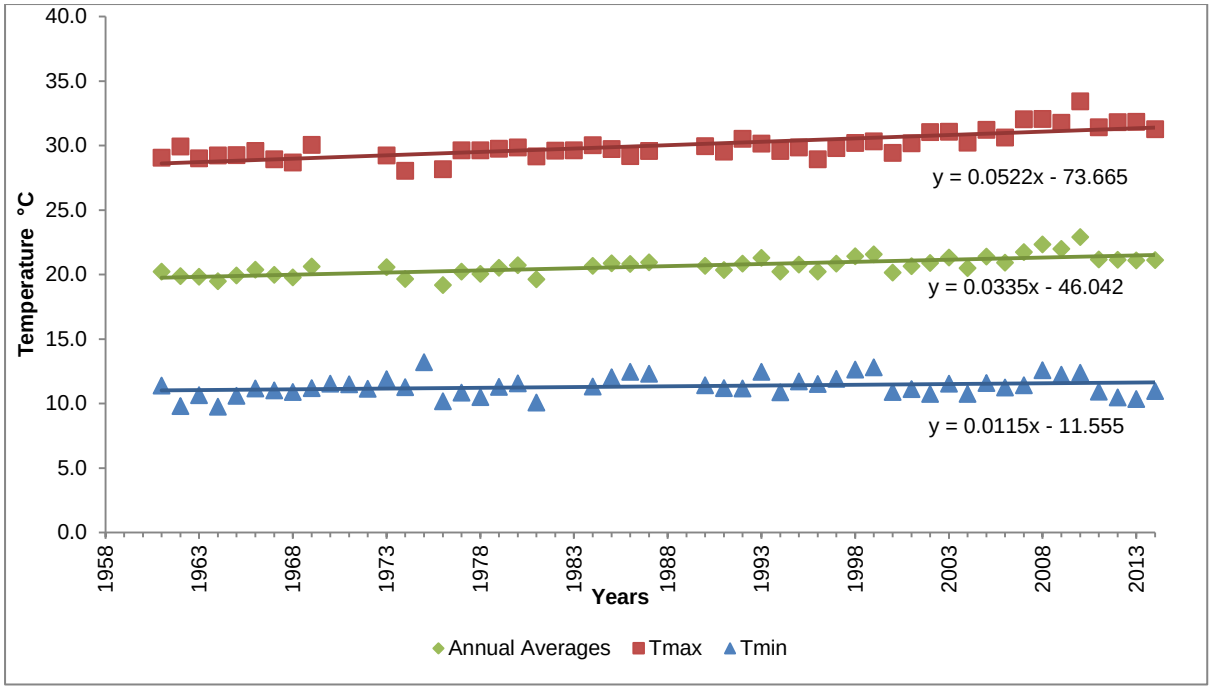


Figure 5.6: Temperature averages, T_{max} and T_{min} trends for Twee Rivieren: 1961 - 2014.

The T_{max} variance for all the stations over the entire period have slight differences, with the greatest variance for Twee Rivieren at σ = 1.09 and the smallest variance for Upington at σ = 0.63 (*Table 5.2*). The T_{min} variance differs slightly with Mata-Mata having the greatest variance at σ = 1.09 and Upington having the smallest variance at σ = 0.55 (*Table 5.2*). Trends in T_{max} over time demonstrate a considerable increase for Twee Rivieren at 0.05°C/year, Mata-Mata at 0.06 °C/year and Nossob at 0.05°C/year (r = 0.8, p > 0.0005 and r = 0.7, p > 0.0005, respectively). Statistically weaker increasing trends for T_{max} over the entire period are demonstrated for Upington at 0.01°C/year (r = 0.12, p = 0.2). T_{min} annual mean over the entire period demonstrate statistically significant increasing trends for Mata-Mata at 0.06°C/year and Upington at 0.09°C/year (r = 0.5, p > 0.0025 and r = 0.5, p > 0.0005; *Table 5.2*). Twee Rivieren (increasing at 0.01°C/year) and Nossob (decreasing at -0.004°C/year) demonstrate weak T_{min} time trends over their respective study periods (r = 0.2, p > 0.1 and r = -0.1, p > 0.3; *Table 5.2*).

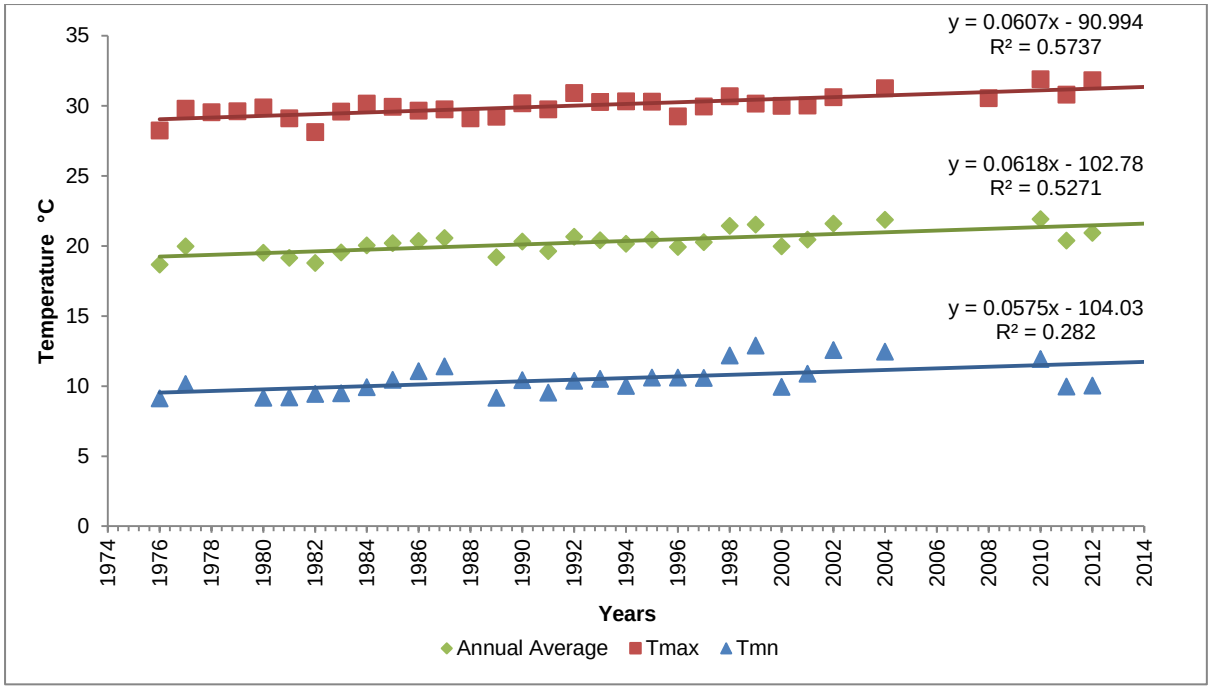


Figure 5.7: Temperature averages, T_{max} and T_{min} trends for Mata-Mata: 1975 - 2014.

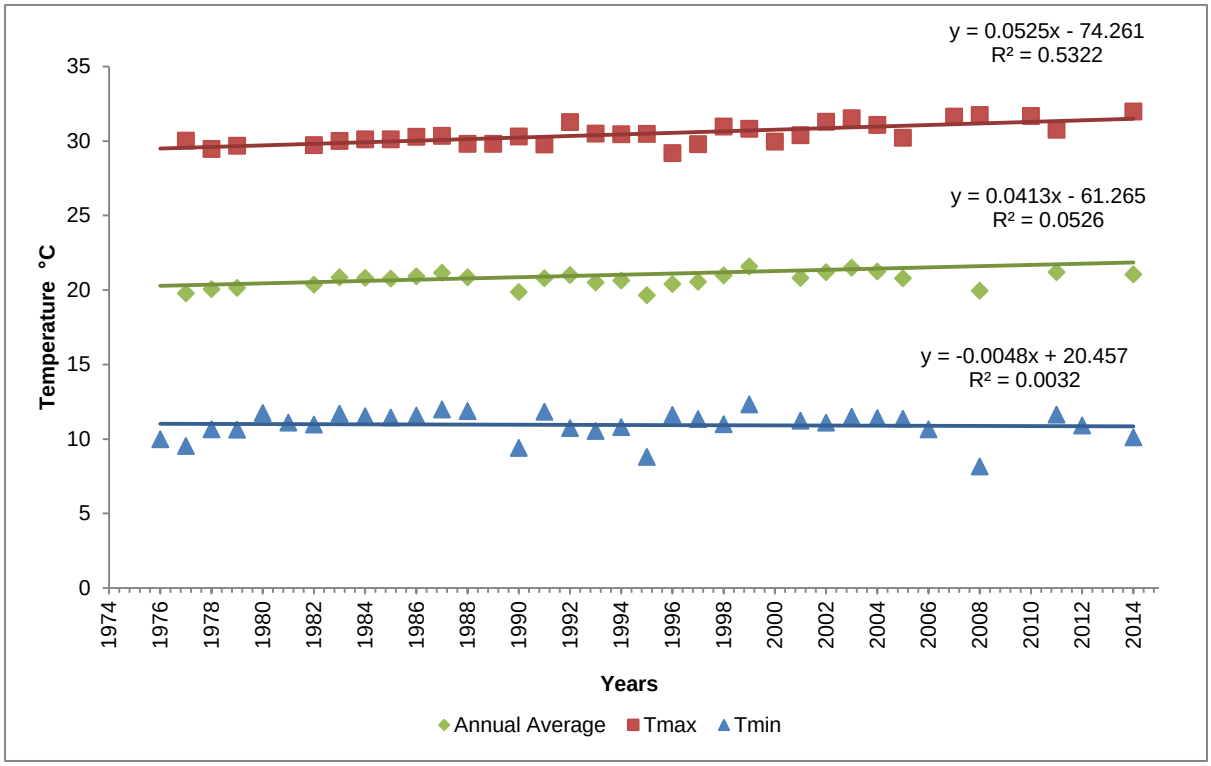


Figure 5.8: Temperature averages, T_{max} and T_{min} trends for Nossob: 1975-2014.

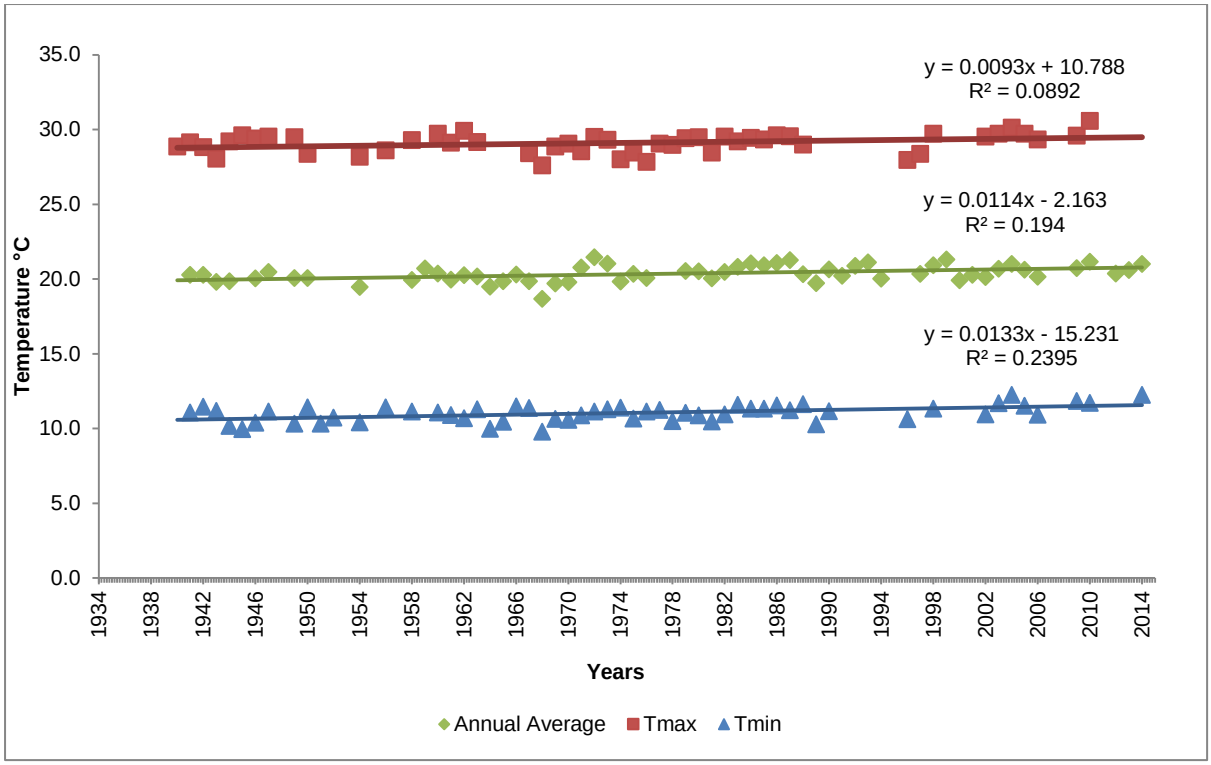


Figure 5.9: Temperature averages, T_{max} and T_{min} trends for Upington: 1940-2014.

5.2.1 Recent Temperature Trends 1975 - 2014

The period of common data for T_{max} and T_{min} for all four stations occurs from 1975 to 2014. Twee Rivieren (0.05°C/year), Mata-Mata (0.06°C/year), Nossob (0.05°C/year) and Upington (0.03°C/year) demonstrate statistically strong increasing trends in T_{max} over time ($r = 0.8$, $p > 0.0005$; $r = 0.7$ $p > 0.0005$ and $r = 0.5$, $p > 0.0005$ respectively; *Table 5.4; Figure 5.10 A, B, C and D).* However, decreasing trends for T_{min} are calculated for Twee Rivieren (-0.001°C/year; $r = -0.01$, $p < 0.4$) and for Nossob (-0.004°C/year, $r = -0.1$, $p > 0.3$; *Table 5.4, Figures 5.11A and C*). However, Mata-Mata (0.07°C/year) and Upington (0.02°C/year) demonstrate strong statistical increases in T_{min} over time ($r = 0.5$, $p = 0.025$ and $r = 0.6$, $p > 0.005$; *Table 5.4, Figure 5.11B and D*). It is notable that for some stations there are increases over this period while for others there are decreases. This is not unusual in the climate change literature and can be attributed to regional rainfall variability (Fitchett *et al.,* 2014).

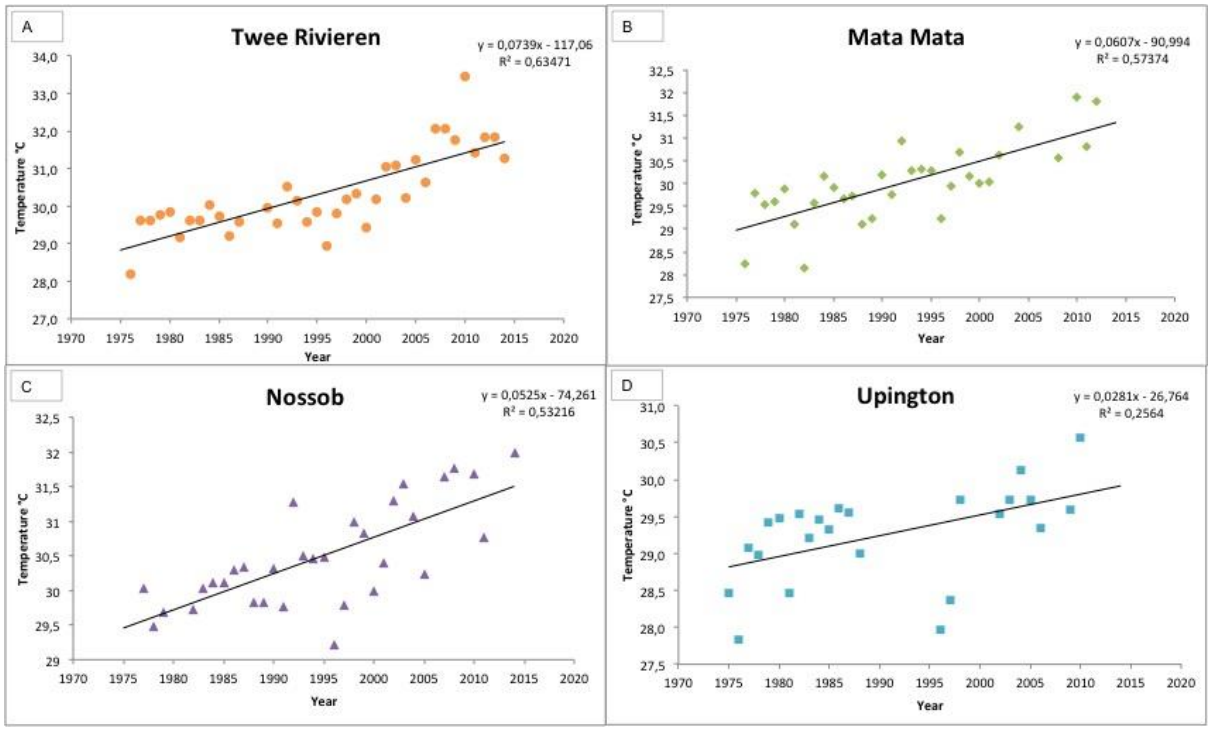


Figure 5.10: Recent temperature T_{max} trends for Twee Rivieren: 1975 - 2014.

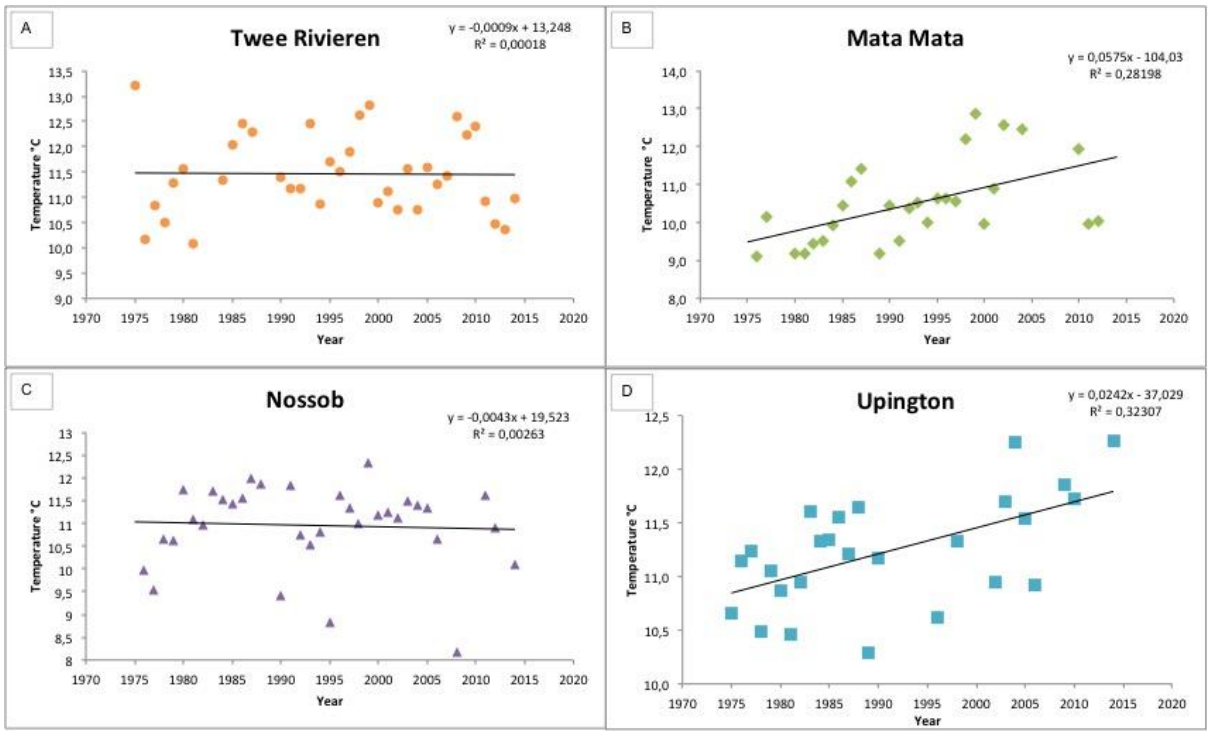


Figure 5.11: Recent temperature T_{min} trends for Twee Rivieren: 1975 – 2014.

5.2.2 Number of Days within Acceptable Temperature Thresholds

Acceptable temperatures for fauna are defined in the methods chapter. The average number of days with T_{avg} <10°C and >30°C has been calculated for Twee Rivieren, Mata-Mata and Nossob (*Table 5.6*). However, only monthly temperature data were available for Upington, so this weather station has not been included. The mean number of days <10°C (average of 28 days across all stations) is higher than >30°C (average of 19 days across all stations; *Table 5.6*). The mean number of days <10°C over the entire period for all three weather stations is similar, with the highest at Mata-Mata (31 days) and the maximum occurring at Nossob with 83 days in 1992 (*Table 5.6*). The minimum occurs at Twee Rivieren with an average of 7 days (2008) over the entire period (*Table 5.6*). The mean number of days > T_{avg} 30°C are similar across all three stations with the maximum occurring at Twee Rivieren in 1982 (76 days; *Table 5.6*).

Table 5.6: Number of T_{avg} days <10°C and >30°C per year for the stations Twee Rivieren, Mata-Mata and Nossob with full data sets. The year with the maximum number of days is in brackets under each station.

	Twee Rivieren	Mata-Mata	Nossob
No. of days below T_{avg} 10°C			
Mean	24	31	29
Max	43 (1994)	64 (1982)	83 (1992)
Min	7 (2008)	10 (1979)	8 (2008)
No. of days above T_{avg} 30°C			
Mean	20	20	18
Max	76 (1982)	62 (1979)	63 (2003)
Min	1 (1976)	2 (1996)	0 (1976)

5.3 Long-term Seasonal Patterns

5.3.1 Long-Term Seasonal Rainfall Patterns

The Kalahari Gemsbok National Park receives summer rainfall (Derry and Dougill, 2008), with the majority (92.9%) occurring from October to April. Within this period, the bulk of the rainfall (68.3%) occurs between December and March. The cooler winter months (May to September) receive only 7.12% of the annual rainfall. June, July and August are the driest months, collectively receiving just 2.6% of the annual

rainfall. Peak average monthly rainfall over the respective periods occurs during February for Twee Rivieren and Mata-Mata (40.8mm and 42.5mm, respectively) and during March for Nossob and Upington (36.1mm and 41.5mm, respectively; *Table 5.7, Figure 5.12 - 5.15)*. The greatest range in monthly rainfall for Twee Rivieren and Nossob occurs in January (219.3mm and 197.5mm, respectively) and in March for Mata-Mata and Upington (298.4mm and 188.21mm, respectively; *Table 5.7*).

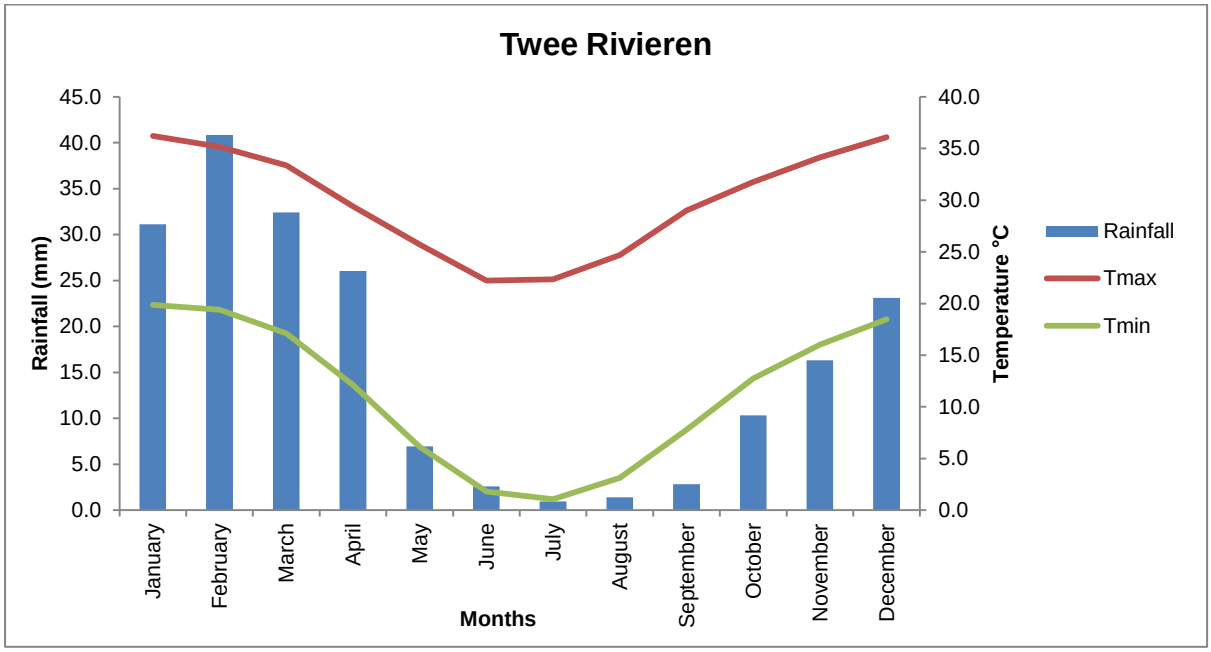


Figure 5.12: Monthly average rainfall (mm), T_{max} and T_{min} for Twee Rivieren: 1940 - 2014.

Long-term trends in annual rainfall are not statistically significant for any of the four stations. However, for certain months, trends in monthly rainfall are statistically significance. December was the only month for Twee Rivieren that demonstrates a significant increasing trend (0.42mm/year) in rainfall ($r = 0.3$, $p > 0.01$; *Table 5.7*). The strongest decreasing trends in monthly rainfall for Mata-Mata occur during April at 0.66mm/year and August at 0.03mm/year ($r = -0.3$, $p > 0.025$; *Table 5.7*). Significant decreasing trends for Nossob occur during August at 0.11mm/year and November at 0.47mm/year ($r = -0.3$, $p > 0.025$; *Table 5.7*). The statistically significant trend in monthly rainfall for Upington occurred during May as rainfall is decreasing at 0.01mm/year ($r = 0.33$, $p > 0.001$; *Table 5.7*). The weakest decreasing trends in monthly rainfall occur at Twee Rivieren in September at 0.02mm/year and during June for Upington at 0.02mm/year ($r = 0.07$, $p < 0.4$ and $r = 0.07$, $p > 0.2$; *Table 5.7*).

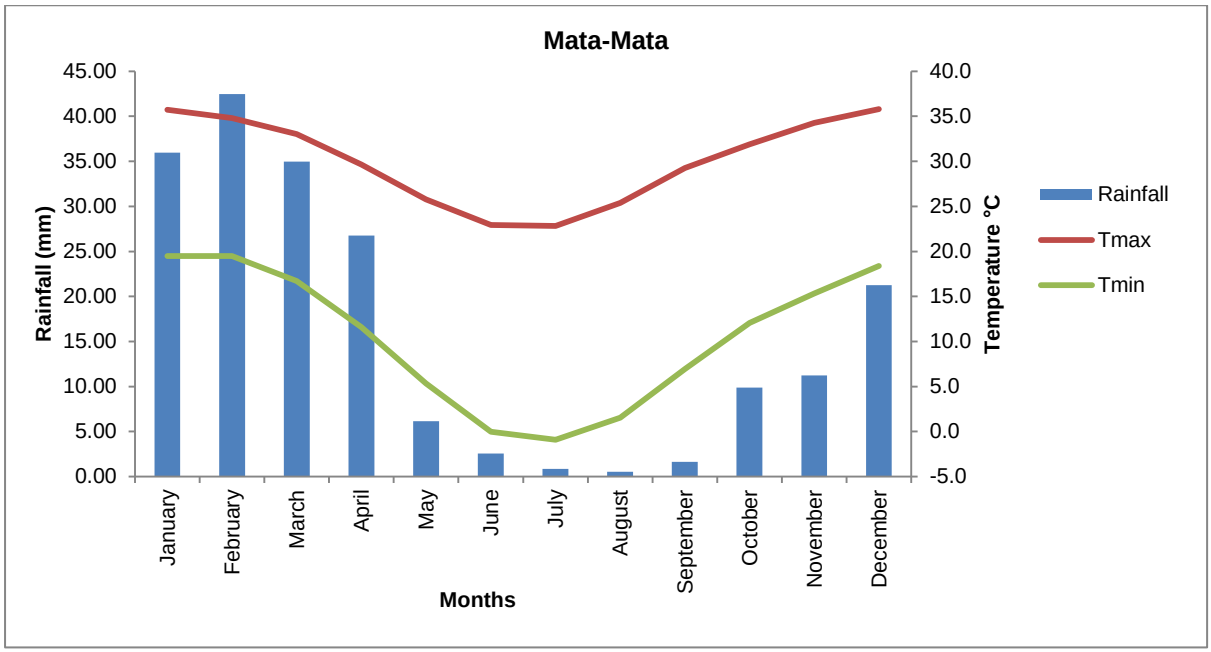


Figure 5.13: Monthly average rainfall (mm), T_{max} and T_{min} for Mata-Mata: 1940 - 2014.

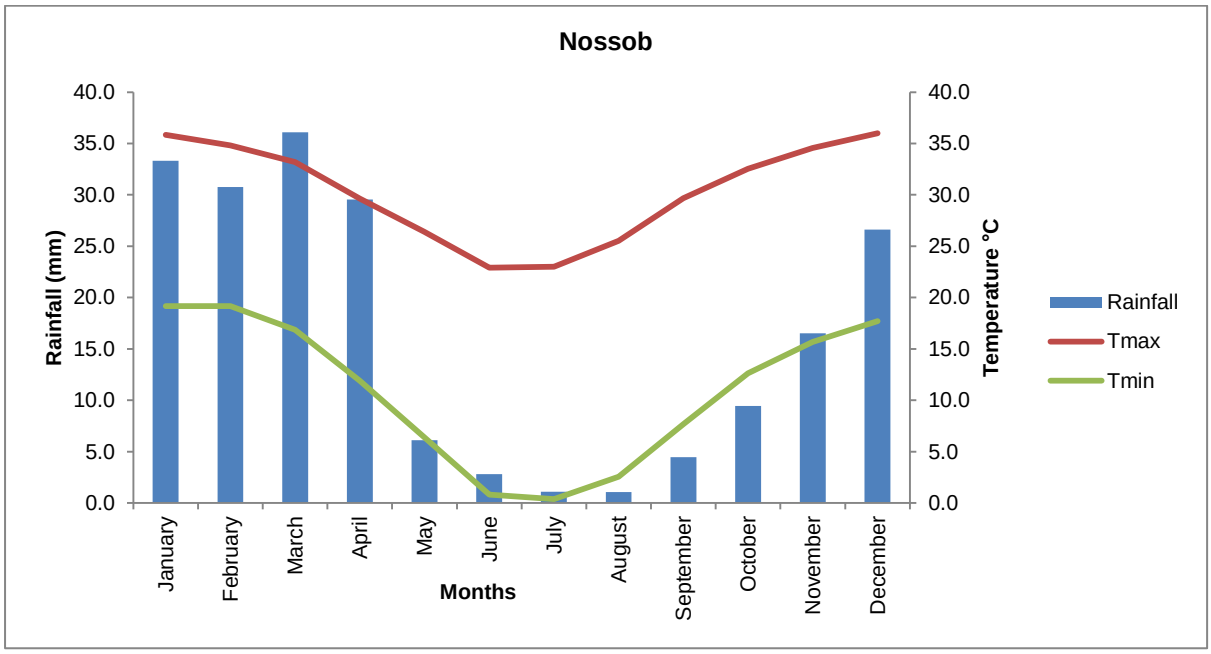


Figure 5.14: Monthly average rainfall (mm), T_{max} and T_{min} for Nossob: 1940 - 2014.

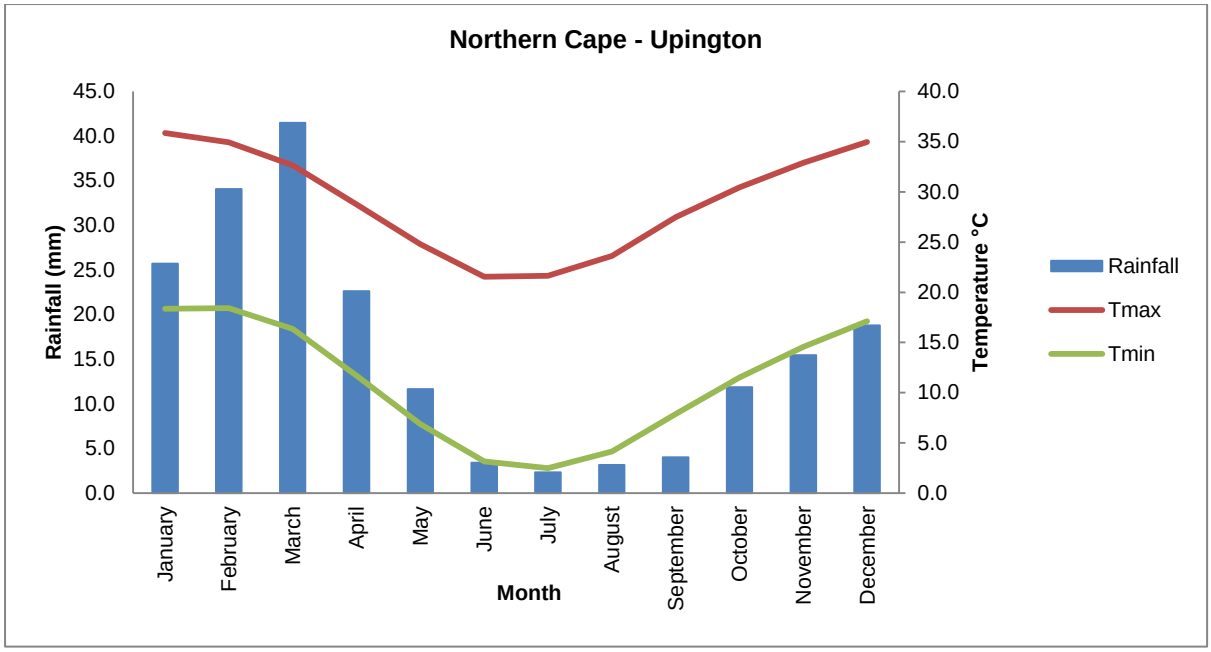


Figure 5.15: Monthly average rainfall (mm), T_{max} and T_{min} for Upington: 1940 - 2014.

5.3.2 Long-Term Seasonal Temperature Patterns

The highest T_{max} average temperatures over the entire period for Twee Rivieren, Mata-Mata, Nossob and Upington all occur between the summer months of December (35.7°C), January (35.9°C) and February (34.9°C; *Table 5.7*). The lowest T_{min} average temperatures over the entire period occur during the winter months of June (1.4°C), July (0.8°C) and August (2.8°C). The highest mean monthly T_{max} for the whole period is calculated at Twee Rivieren (36.2°C), whilst the lowest average T_{max} occurs during June at Upington (21.5°C; *Table 5.7, Figures 5.12 and 5.15*). The largest range in monthly T_{max} of 10.1°C is calculated for March at Nossob, ranging from 36.9°C in 2013 to 26.8°C in 1982, and the smallest range occurs in June at Nossob (4.1°C) ranging from 25.5°C in 1999 and 21.4°C in 1989 (*Table 5.7, Figure 5.14)*. Nossob also has the highest T_{min} monthly range over the entire period in October (14°C) spanning from 19.3°C in 2004 and 5.3°C in 2009. However, the lowest T_{min} monthly range over the entire period occurs at Twee Rivieren in January (4.3°C) spanning from 22.1°C in 2006 and 17.8°C in 2000 (*Table 5.7, Figure 5.12*).

Table 5.7: Monthly rainfall (mm), T_{min} and T_{max} averages for four weather stations located in or near KGNP in the Northern Cape, South Africa. Statistically significant correlations ($p < 0.05$) and particularly strong correlations ($p < 0.01$) are highlighted in light and dark grey respectively.

Seasonal climate													
		Twee Rivieren (1961 - 2014)			Mata-Mata (1975 - 2014)			Nossob (1976 - 2014)			Upington (1940 - 2014)		
		T_{max}	T_{min}	Rainfall	T_{max}	T_{min}	Rainfall	T_{max}	T_{min}	Rainfall	T_{max}	T_{min}	Rainfall
January	Mean	36.2	19.9	31.1	35.7	19.5	36	35.8	19.2	33.3	35.9	18.4	25.7
	Years (n)	53.0	52.0	74.0	36.0	36.0	52.0	39.0	40.0	36.0	61.0	61.0	97
	Change over time (°C or mm/year)	0.04	0.02	0.33	0.04	0.03	0.52	0.04	-0.04	-0.019	0.01	0.02	0.12
	Variance	1.8	1.1	42.9	1.9	1.4	47.2	2.3	1.9	37.9	1.3	1.2	31.34
	Range	9.2	4.3	219.3	9.4	6.3	209.4	9.5	8.9	197.5	7.1	5.2	168.7
	Strength of trend (r)	*0.4	*0.3	0.2	0.2	0.2	-0.2	0.2	*-0.3	0.0	0.2	*0.3	0.15
February	Mean	35.2	19.4	40.8	34.8	19.5	42.5	34.8	19.2	30.8	34.9	18.4	34.1
	Sample size (n)	55.0	54.0	74.0	38.0	36.0	54.0	36.0	38.0	37.0	58.0	57.0	97
	Change over time (°C or mm/year)	0.05	0.04	0.29	0.09	0.07	-0.34	0.23	-0.02	-0.32	0.02	0.01	0.15
	Variance	1.9	1.4	103.9	2.0	1.4	43.2	2.4	2.0	31.6	1.5	1.4	34.23
	Range	9.1	6.8	177.7	9.7	7.7	209.7	9.3	5.5	124.4	7.0	6.8	152.6
	Strength of trend (r)	*0.4	0.1	0.2	*0.3	*0.4	-0.1	*0.4	-0.2	-0.2	0.2	0.2	0.16
March	Mean	33.4	17.1	32.4	33.0	16.7	35	33.2	16.9	36.1	32.6	16.3	41.5
	Sample size (n)	55.0	55.0	75.0	39.0	38.0	54.0	39.0	38.0	37.0	57.0	61.0	98
	Change over time (°C or mm/year)	0.05	0.02	0.09	0.07	0.04	-0.34	0.07	0.02	0.23	0.02	0.001	-0.04
	Variance	1.6	1.3	28.7	1.6	1.4	47.2	2.0	1.6	37.9	1.5	1.4	38.41
	Range	8.4	5.3	111.3	7.2	5.8	298.4	10.1	6.5	181.6	6.9	8.1	188.21
	Strength of trend (r)	*0.5	0.1	0.1	*0.5	*0.4	-0.1	*0.4	0.1	0.0	*0.3	0.02	-0.04
April	Mean	29.4	12.1	26.0	29.7	11.6	26.7	29.7	11.6	29.6	28.7	11.7	22.6
	Sample size (n)	55.0	54.0	75.0	40.0	40.0	54.0	40.0	40.0	38.0	58.0	58.0	97
	Change over time (°C or mm/year)	0.05	0.02	0.17	0.05	0.05	-0.66	0.04	-0.005	0.16	0.01	0.01	-0.015
	Variance	1.7	1.6	28.8	1.9	2.5	34.0	1.6	2.0	35.9	1.4	1.4	28.95
	Range	6.4	6.9	97.2	9.9	10.8	134.4	6.4	9.3	156.3	6.4	6.6	167
	Strength of trend (r)	*0.5	0.1	0.1	*0.3	0.2	*-0.3	*0.3	-0.02	0.1	0.2	0.2	-0.102

May	Mean	25.7	6.1	7.0	25.8	5.4	6.2	26.4	5.3	6.1	24.8	6.9	11.7
	Sample size (n)	54.0	54.0	75.0	38.0	37.0	54.0	38.0	38.0	38.0	58.0	57.0	94
	Change over time (°C or mm/year)	0.07	0.03	0.07	0.05	0.07	-.0.16	0.06	0.03	0.13	0.02	0.01	-0.03
	Variance	1.7	1.6	10.9	2.5	2.0	11.3	1.4	2.1	9.9	1.2	1.6	14.83
	Range	7	6.1	45.5	8.4	7.5	45.3	5.6	9.7	44	6.6	8.2	74
	Strength of trend (r)	*0.6	0.2	-0.1	*0.4	*0.4	-0.2	*0.4	0.2	0.2	*0.4	0.2	-0.08
June	Mean	22.2	1.8	2.6	22.9	-0.01	2.6	22.9	-0.01	2.8	21.5	3.2	3.4
	Sample size (n)	55.0	54.0	75.0	39.0	38.0	54.0	40.0	40.0	38.0	58.0	58.0	96
	Change over time (°C or mm/year)	0.05	0.005	0.01	0.04	0.03	-0.07	0.03	-0.006	0.26	0.002	0.001	0.02
	Variance	1.5	1.8	6.9	1.3	2.2	7.8	1.0	1.7	12.5	1.2	1.4	5.84
	Range	8.2	7.7	42.3	5.2	11.1	41.5	4.1	6.9	77.1	6.7	6.8	29
	Strength of trend (r)	*0.5	*0.4	0.03	*0.4	0.2	-0.1	*0.4	-0.04	0.2	0.03	0.02	0.12
July	Mean	22.4	1.1	1.0	22.8	-0.9	0.9	23.0	-0.9	1.1	21.6	2.5	2.3
	Sample size (n)	54.0	54.0	74.0	39.0	39.0	54.0	39.0	40.0	39.0	58.0	58.0	93
	Change over time (°C or mm/year)	0.04	0.006	0.02	0.05	0.05	0.02	0.04	0.005	-0.02	0.001	0.03	-0.003
	Variance	1.4	1.7	3.4	1.6	1.7	4.8	1.2	1.9	4.4	1.4	1.3	5.60
	Range	7.4	7.1	27.2	7.5	7.2	34.5	6.0	7.6	26	7.8	5.8	29
	Strength of trend (r)	*0.4	*0.4	0.1	*0.4	*0.4	0.1	*0.3	0.03	0.0	-0.02	0.2	-0.02
August	Mean	24.7	3.1	1.4	25.4	1.5	0.5	25.5	1.5	1.1	23.6	4.1	3.2
	Sample size (n)	55.0	54.0	74.0	38.0	38.0	54.0	39.0	40.0	39.0	58.0	57.0	96
	Change over time (°C or mm/year)	0.05	0.01	0.04	0.05	0.02	-0.03	0.04	-0.02	-0.11	0.03	0.01	-0.01
	Variance	1.6	1.5	5.7	1.6	1.7	1.9	1.7	1.8	4.1	1.5	1.2	7.32
	Range	9.0	6.7	41.9	7.8	7.5	10.5	9.2	9.0	24.7	6.9	5.6	47
	Strength of trend (r)	*0.5	0.2	-0.2	*0.4	0.1	*-0.3	*0.3	-0.1	*-0.3	-0.0003	0.009	-0.06

September	Mean	29	7.8	2.8	29.3	6.9	1.6	29.6	6.9	4.5	27.5	7.9	4.0
	Sample size (n)	54.0	54.0	74.0	36.0	36.0	54.0	37.0	36.0	38.0	58.0	59.0	95
	Change over time (°C or mm/year)	0.08	0.005	0.02	0.07	-0.01	0.03	0.06	0.04	-0.08	0.01	0.001	-0.007
	Variance	1.9	2.5	6.4	1.8	2.4	4.6	1.7	2.6	11.0	1.7	1.3	7.33
	Range	8.8	14.2	37	8.4	10.0	23.3	7.3	12.1	56	7.5	6.4	41
	Strength of trend (r)	*0.4	0.2	-0.07	*0.5	0.0	0.1	*0.4	-0.17	-0.1	0.2	0.02	-0.03
October	Mean	31.8	12.7	10.3	31.9	12.1	9.9	32.5	12.1	9.5	30.4	11.5	11.9
	Sample size (n)	54.0	54.0	74.0	36.0	36.0	53.0	37.0	37.0	38.0	60.0	60.0	95
	Change over time (°C or mm/year)	0.1	0.02	0.01	0.1	0.02	-0.07	0.09	-0.04	-0.01	0.01	0.02	-0.03
	Variance	1.6	2.3	17.2	1.6	2.3	12.6	1.5	2.9	11.6	1.3	1.6	17.38
	Range	6.6	14.2	130.5	7.1	10.4	46.7	6.7	14.0	41.5	5.4	8.8	88
	Strength of trend (r)	*0.6	*0.5	-0.03	**0.7	0.1	-0.1	*0.6	-0.15	0.0	0.2	*0.3	-0.07
November	Mean	34.1	16	16.3	34.3	15.3	11.2	34.6	15.3	16.5	32.9	14.6	15.4
	Sample size (n)	55.0	54.0	74.0	37.0	37.0	53.0	39.0	40.0	38.0	60.0	57.0	95
	Change over time (°C or mm/year)	0.05	0.01	0.9	0.08	0.04	-0.16	0.06	-0.01	-0.47	0.08	0.01	0.0007
	Variance	1.5	2.2	17.8	1.6	2.7	13.6	1.5	2.3	17.4	1.4	1.5	17.10
	Range	6.9	15.2	67.2	6.6	12.0	48.4	6.6	10.1	65.6	6.8	8.9	82
	Strength of trend (r)	*0.5	0.1	0.1	*0.5	0.2	-0.2	*0.4	-0.15	*-0.3	0.1	0.2	0.01
December	Mean	36.1	18.4	23.1	35.8	18.4	21.3	36.0	18.4	26.6	35.0	17.1	18.8
	Sample size (n)	53.0	54.0	74.0	39.0	39.0	53.0	38.0	40.0	38.0	59.0	57.0	93
	Change over time (°C or mm/year)	0.12	0.02	0.42	0.04	0.05	0.4	0.07	-0.05	0.2	0.02	0.03	0.04
	Variance	1.5	1.6	26.6	1.4	1.7	29.9	1.7	2.1	24.8	1.3	1.0	22.59
	Range	7.4	11.2	129.2	6.0	8.7	162.2	6.9	10.8	93.2	6.3	4.9	99.06
	Strength of trend (r)	*0.4	0.1	*0.3	*0.4	*0.4	0.2	*0.4	-0.24	0.1	*0.3	0.08	0.06

All trends for monthly T_{max} at Twee Rivieren demonstrate statistically significant time trends. The strongest time trends for monthly T_{max} at Twee Rivieren demonstrate increasing trends over the entire period during May at 0.07°C/year and October at 0.1°C/year ($r = 0.6$, $p > 0.0005$ for both; *Table 5.7*). Mata-Mata and Nossob also demonstrate statistically significant monthly T_{max} trends for all months over the entire period, however, January demonstrates a slight increase over time at 0.04°C/year for both stations ($r = 0.2$, $p < 0.1$; $r = 0.2$, $p < 0.2$; respectively; *Table 5.7*). Particularly strong correlations in monthly T_{max} are demonstrated for October at Mata-Mata with an increasing trend of 0.1°C/year ($r = 0.7$, $p > 0.0005$; *Table 5.7*). Twee Rivieren has four months with statistically strong correlations, however, the strongest T_{min} monthly correlation is during October with an increasing trend of 0.02°C/year ($r = 0.5$, $p > 0.0005$; *Table 5.7*). Trends in monthly T_{min} in January are significant for Twee Rivieren (0.02°C/year), Nossob (-0.04°C/year) and Upington (0.02°C/year; $r = 0.3$, $p < 0.005$; $r = 0.3$, $p < 0.025$; $r = 0.3$, $p < 0.005$ respectively); therefore, all these T_{min} trends in January are increasing over time, except for Nossob (*Table 5.7*).

5.3.2.1 Extreme T_{max} and T_{min} thresholds >40°C and <0°C and Rainfall >100mm

Temperature extremes were analysed monthly on an annual temporal scale at T_{max} thresholds >40°C, T_{min} thresholds <0°C and rainfall thresholds >100mm. T_{max} extremes >40°C occur during the months of January 2013 and December 2009 for Twee Rivieren and December 2009 for Nossob (*Table 5.8*). It can be tentatively said that T_{max} extremes are increasing annually due to climate change (van Wilgen *et al.,* 2015). T_{min} thresholds <0°C occurred during July through to August for Twee Rivieren, Mata-Mata and Nossob, Upington (*Table 5.8*). Majority of the T_{min} years below freezing occurring during the month of July for all four weather stations, with the lowest mean T_{min} occurring during 2004, 1988, 1977 and 1947 for Twee Rivieren, Mata-Mata, Nossob and Upington, respectively (*Table 5.8*). The majority of rainfall extremes >100mm are recorded during January through to April for all four weather stations. The highest rainfall >100mm occurs between 1974 and 1976 for all four weather stations (*Table 5.8*).

Table 5.8: Monthly mean T_{max} thresholds >40°C, T_{min} thresholds <0°C and rainfall thresholds >100mm (1883 - 2014).

Weather Station		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Twee Rivieren (1941 - 2014)	Tmax Threshold (>40°C)	1	0	0	0	0	0	0	0	0	0	0	1
	Tmin Threshold (<0°C)	0	0	0	0	0	7	16	1	0	0	0	0
	Rainfall threshold (>100m)	6	7	3	0	0	0	0	0	0	1	0	2
Mata-Mata (1960 - 2014)	Tmax Threshold (>40°C)	0	0	0	0	0	0	0	0	0	0	0	0
	Tmin Threshold (<0°C)	0	0	0	0	0	22	31	6	0	0	0	0
	Rainfall threshold (>100m)	6	6	1	3	0	0	0	0	0	0	0	1
Nossob (1975-2014)	Tmax Threshold (>40°C)	0	0	0	0	0	0	0	0	0	0	0	1
	Tmin Threshold (<0°C)	0	0	0	0	0	11	14	3	0	0	0	0
	Rainfall threshold (>100m)	1	2	3	2	0	0	0	0	0	0	0	0
Upington (1883 - 2014)	Tmax Threshold (>40°C)	0	0	0	0	0	0	0	0	0	0	0	0
	Tmin Threshold (<0°C)	0	0	0	0	0	2	1	0	0	0	0	0
	Rainfall threshold (>100m)	4	5	9	4	0	0	0	0	0	0	0	0

5.4 Summary

The Northern Cape, where KGNP is situated, has a warm to hot semi-arid climate with strong mean seasonal temperature variability between winter and summer for the whole study period (-0.9°C - 36.2°C) and rainfall patterns that are highly seasonal (late summer), erratic and spatially highly variable. For instance, mean annual rainfall varied from 17.1mm (1997) to 738.44mm (1976) at Mata-Mata. Between the years 1974 and 1976, all four stations received 100% more rainfall than the average annual rainfall (449 - 738.4mm), resulting in flooding of the Auob River in KGNP (*Figure 5.1 - 5.4*) (Mills and Retief, 1984; Quinn and Woodward, 2015).

Mean annual rainfall over the period of assessment is decreasing for Nossob and Mata-Mata, whilst mean annual precipitation for Twee Rivieren and Upington is increasing over time. The annual average temperatures over the entire period demonstrate an increasing trend for Twee Rivieren, Mata-Mata, Nossob and Upington. Mata-Mata demonstrates the largest increase in T_{max} over the period of assessment (1961 - 2014) at 0.06°C/yr ($r = 0.8$, $p > 0.0005$; *Figures 5.6 - 5.9*). At Twee Rivieren, all months demonstrate significant trends between increasing T_{max}

and time (0.04 - 0.12 °C/yr over the period 1961 - 2014), combining to give an increase in mean annual T_{max} of 0.05°C/yr.

5.5 Recent Spatio-Temporal Rainfall Patterns: 2003 - 2014

5.5.1 Introduction

This section investigates recent (2003 - 2014) short-term rainfall patterns over KGNP. Mean annual rainfall is compared between 16 individual sites for the recent decade to ascertain the nature of rainfall distribution ('patchiness'), as well as time-trends within KGNP. These short-term rainfall data will then be used in a later section (aerial census data) to quantify the relationships between mammal movements and their spatial distribution (SANParks census data, 2003 - 2013) within KGNP.

5.5.2 Rainfall Patterns: 2003 - 2014

The average short-term annual rainfall for all four stations over the period of 2003 - 2014 is 180.76mm (*Table 5.9*). Mean inter-annual rainfall varies across KGNP from Twee Rivieren at 251.41mm to 131.4mm at Bitterpan (*Table 5.9*). Inter-annual variability over the 11 - year period ranged from σ163.36 at Drievendas to the smallest at σ74.25 for Dikbaardskolk (*Table 5.9*). Following this, the stations that have the next highest inter-annual variability are O'Kuip with σ131.11 and Bayip with σ127.74 and the lowest at Mata-Mata with σ74.61 and Kij Kij with σ76.77 (*Table 5.9*). Drievendas has the largest inter-annual rainfall range of 559mm, which spans from 30mm in 2013 to 589mm in 2006 (*Table 5.9, Figure 5.16I*). In contrast to this, Mata-Mata is considerably lower and has the smallest range at 227.60mm from 257.6mm in 2011 to 30mm in 2003 (*Table 5.9, Figure 5.16E*).

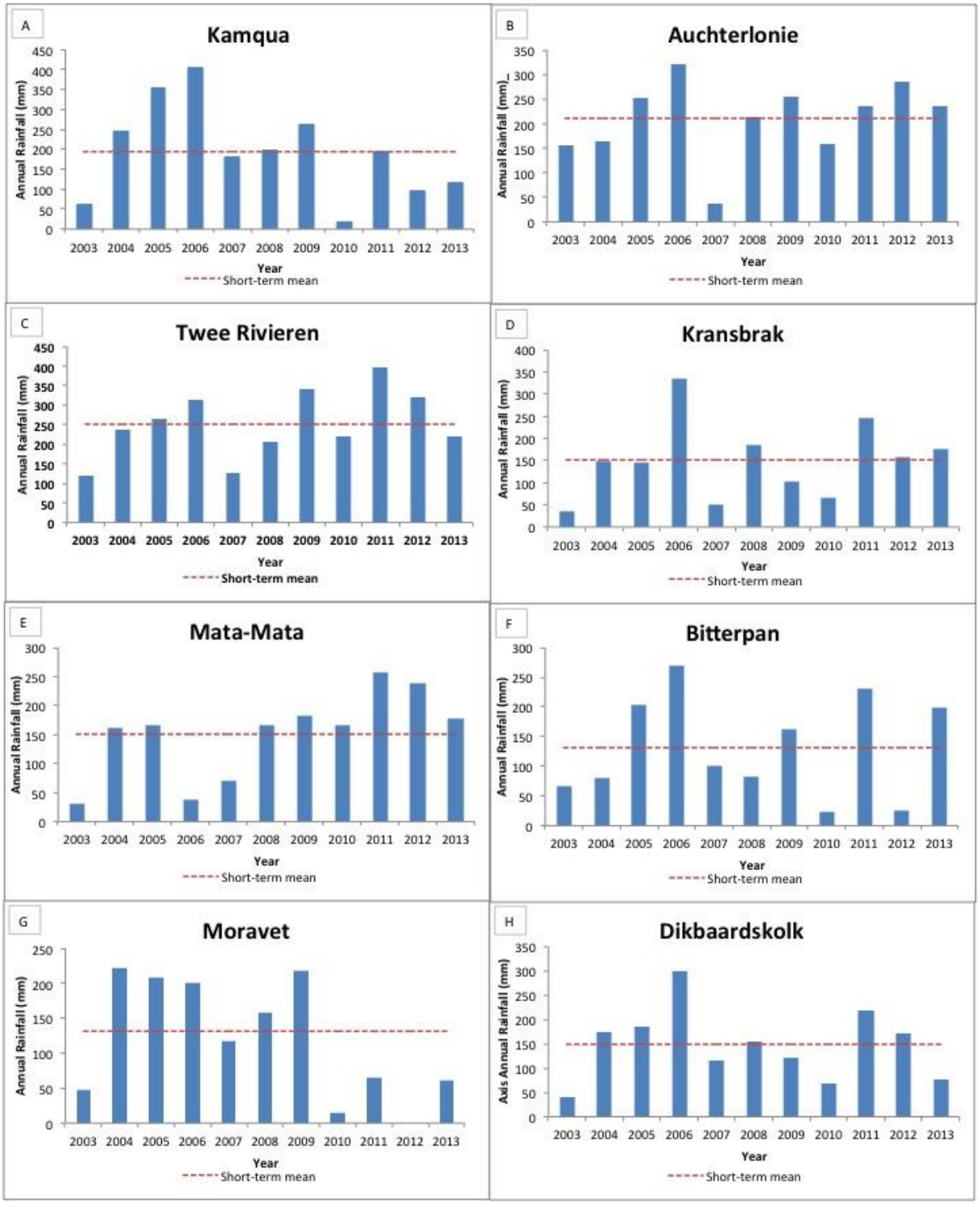


Figure 5.16: Short-term annual rainfall (mm) averages: 2003 - 2013 (A - H).

The year with the highest rainfall and greatest range across all of the areas is recorded in 2006 at 550.6mm from 589mm for Drievendas to 38.4mm for Mata-Mata (*Figure 5.17*). The smallest rainfall range occurred during 2003 for all the areas at 138.3mm, from 155.1mm for Auchterlonie to 16.8mm for O'Kuip (*Figure 5.17*). Over the entire period of 2003 - 2013, Mata-Mata is recorded as the station with the

strongest significant increasing trend at 15.37mm/year (r = 0.68, p = 0.005; *Table 5.9, Figure 5.16E*). Twee Rivieren demonstrates a non-significant increasing trend of 11.42mm/year (r = 0.44, p > 0.1; *Figure 5.16A and 5.16G*).

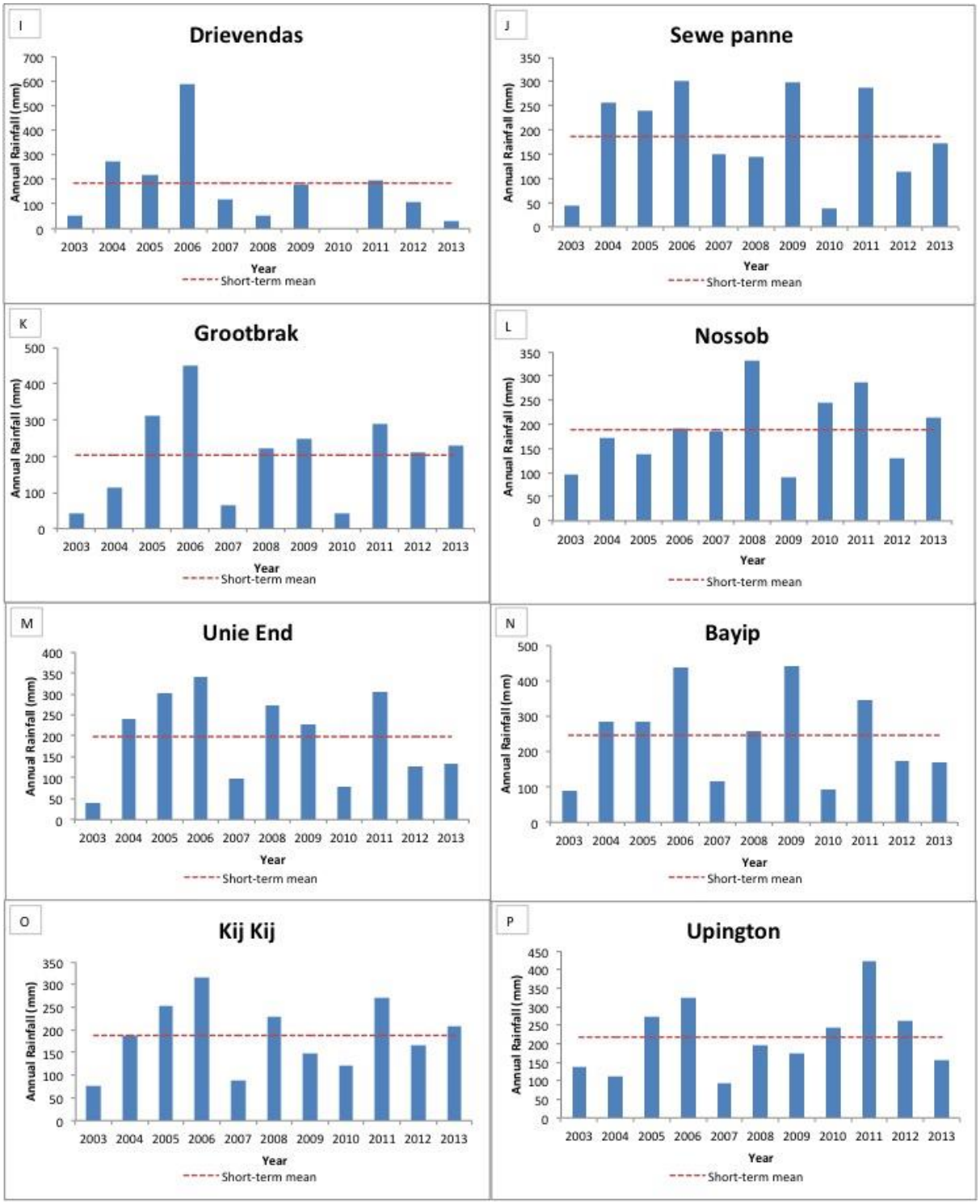


Figure 5.16 continued: continued: Short-term annual rainfall (mm) averages: 2003 - 2013 (I - P).

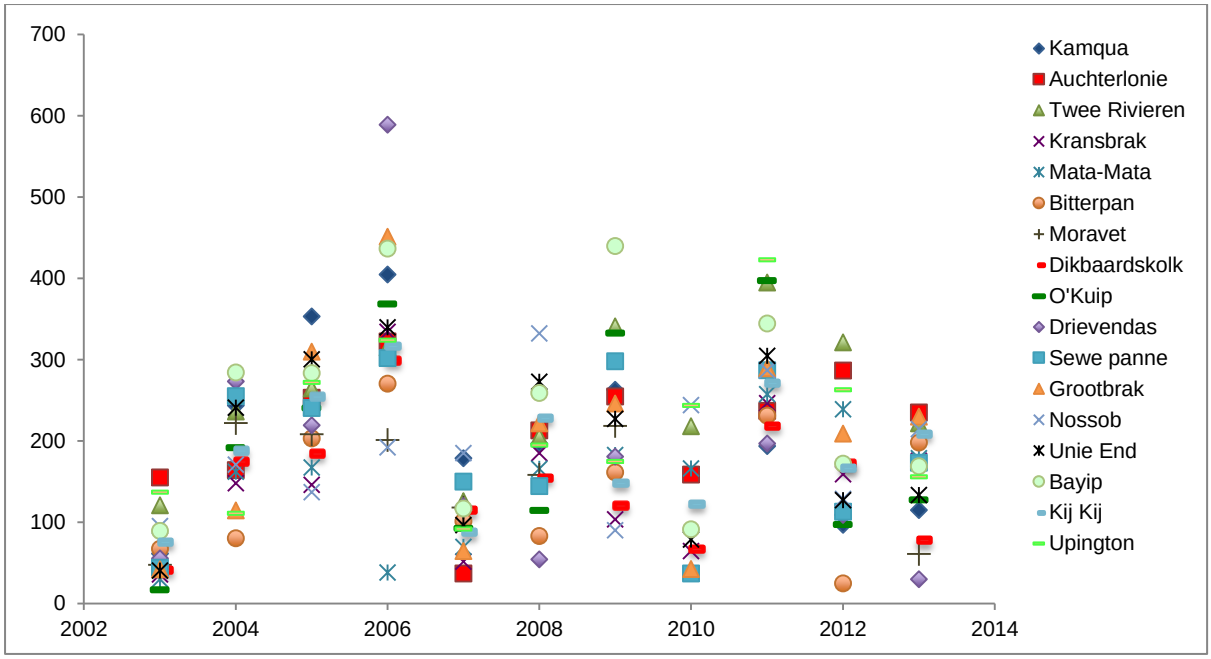


Figure 5.17: Annual precipitation (mm) for the period 2003 - 2014 for 16 weather stations in KGNP.



Figure 5.18: Box-and-Whisker Plot demonstrating inter-annual rainfall variability for 16 weather stations in KGNP over the period 2003 - 2013. The mid-line represents the median with the box representing quartiles and the whiskers represent the minimum and maximum. The outliers are represented by a red dot.

Table 5.9: Annual average short-term rainfall (mm) time trends: 2003 - 2013. Statistically significant correlations (p < 0.05) are highlighted.

Annual short-term rainfall (mm)

	Annual Average	Sample size (n)	Range	Variance	Change over time (mm/year)	Strength of trend (r)
Kamqua	210.81	10	343.20	118.93	-10.44	-0.38
Auchterlonie	210.75	11	285.20	78.34	6.64	0.28
Twee Rivieren	251.41	11	274.20	86.52	11.42	0.44
Kransbrak	150.06	11	298.40	87.99	5.07	0.19
Mata-Mata	150.73	11	227.60	74.61	15.37	0.68
Bitterpan	131.44	10	245.50	85.21	0.74	0.03
Moravet	154.51	8	174.40	79.99	-5.07	-0.43
Dikbaardskolk	147.49	11	257.70	74.25	1.65	-0.07
O'Kuip	197.83	10	380.20	131.11	5.15	0.13
Drievendas	182.89	10	559.00	163.36	15.19	-0.32
Sewe panne	186.04	11	265.20	97.37	-1.51	-0.05
Grootbrak	201.94	11	409.10	127.28	5.63	0.15
Nossob	188.93	11	242.40	76.89	8.05	0.35
Unie End	196.74	11	299.10	104.30	-3.36	-0.11
Bayip	244.33	11	350.70	127.74	-2.14	-0.06
Kij Kij	187.87	11	241.10	76.77	2.73	0.12

5.6 Webcam Monitoring at Nossob Water Trough

5.6.1 Introduction

This section analyses faunal species, which were observed over the entire study period. The first section evaluates the total species over the whole period, investigating which species occur most frequently. The next section analyses the species percentage peak water trough utilisation according to morning, midday, early afternoon and evening time periods. These peak times are then compared to a cluster analysis to statistically evaluate the groupings of species according to particular time periods. The last section analyses the Principal Component Analysis (PCA) and describes which time vectors drive specific groups of animals.

5.6.2 Total Species Over the Entire Period (October 2012 - February 2014)

Species recorded over the 18 - hour period each day during which webcam images were available are from 04:00 to 22:00. There are a total of 12 different faunal species observed over the entire time period (*Table 5.10, Appendix, A.2*). The total

observed individuals recorded over the entire period are 34276 (*Table 5.10, Appendix A.1* and *A.2)*. Springbok are most frequently recorded (11 677, mean of 294/day), followed by jackal (11 295, mean of 565/day, *Table 5.10*). However, leopard are least frequently recorded (24), followed by cheetah (59, *Table 5.10*). Blue wildebeest occur at the water trough mainly during the cooler drier months of the year. This is because this species depends on the water source more often during the dry months of the year (Auer, 1997).

5.6.3 Wet and Dry Season Faunal Distribution

Total faunal distributions are analysed for the wet seasons in 2012/2013 (October 2012 - February 2013) and 2013/2014 (September 2013 - February 2014) and the dry seasons 2013 (March 2013 - August 2013) and 2014 (March 2014 - August 2014) as to establish shifting faunal drinking patterns over the entire study period (*Figure 5.19*). Peak water trough usage occurs during the dry seasons 2013 and 2014 with the hourly peak in 2013 at 19:00 - 20:00 (14%) and in 2014 at 12:00 - 13:00 (14%, *Figure 5.19*). A statistical Two-Sample (t-test) Assuming unequal variances is used to test the reliability of these results. The dry season 2012 is the same as the dry season 2013 ($t = -0.55$, $p > 0.05$). Both the wet season water trough usage peaks occurs during the evening with 2012/2013 at 21:00 - 22:00 (8%) and 2013/2014 at 20:00 - 21:00 (11%). Wet season 2012 is significantly different to wet season 2013 ($t = 2.90$, $p < 0.05$). The mean of the wet season 2012/2013 is the same as the mean of the dry season 2013 ($t = 1.75$, $p > 0.05$). The mean of the wet season 2013/2014 is also the same as the mean of the dry season 2014 ($t = -1.11$, $p > 0.05$).

Table 5.10: Total faunal species over the study period (October 2012 - December 2014) per hour. The hour with the most animals per species is marked with an asterisk.

Total fauna (n) water trough usage over the whole period (October 2012 - December 2014)										
	Black-backed Jackal	**Lion**	**Blue Wildebeest**	**Springbok**	**Gemsbok**	**Spotted Hyena**	**Brown Hyena**	**Leopard**	**Cheetah**	**Red Hartebeest**
04:00 - 05:00	252	36	28	1	6	8	13	2	2	0
05:00 - 06:00	625	*99	41	30	12	27	54	3	7	9
06:00 - 07:00	424	66	113	82	6	15	25	3	4	17
07:00 - 08:00	510	41	443	314	6	3	23	1	4	130
08:00 - 09:00	431	24	712	538	5	10	9	1	9	180
09:00 - 10:00	305	33	597	737	18	0	3	0	0	*212
10:00 - 11:00	188	4	788	799	38	9	3	2	0	195
11:00 - 12:00	237	3	653	1011	33	1	2	0	0	201
12:00 - 13:00	134	10	*681	*1457	26	5	2	0	0	170
13:00 - 14:00	99	3	619	1394	30	4	2	1	0	132
14:00 - 15:00	115	5	417	1253	11	0	1	1	1	104
15:00 - 16:00	137	17	309	1039	19	0	2	0	2	41
16:00 - 17:00	228	15	191	978	17	0	2	0	0	51
17:00 - 18:00	507	32	105	907	16	8	1	0	2	14
18:00 - 19:00	1238	49	120	488	49	11	17	1	6	7
19:00 - 20:00	1882	76	33	300	101	24	51	3	*12	1
20:00 - 21:00	*1898	96	24	141	95	*29	91	1	9	2
21:00 - 22:00	1680	71	4	190	*133	26	*130	*5	1	5
22:00 - 23:00	401	17	1	18	22	7	24	0	0	0
23:00 - 00:00	4	1	0	0	0	0	9	0	0	0
TOTAL	**n = 11295**	**n = 698**	**n = 5879**	**n = 11677**	**n = 643**	**n = 187**	**n = 464**	**n = 24**	**n = 59**	**n = 1471**

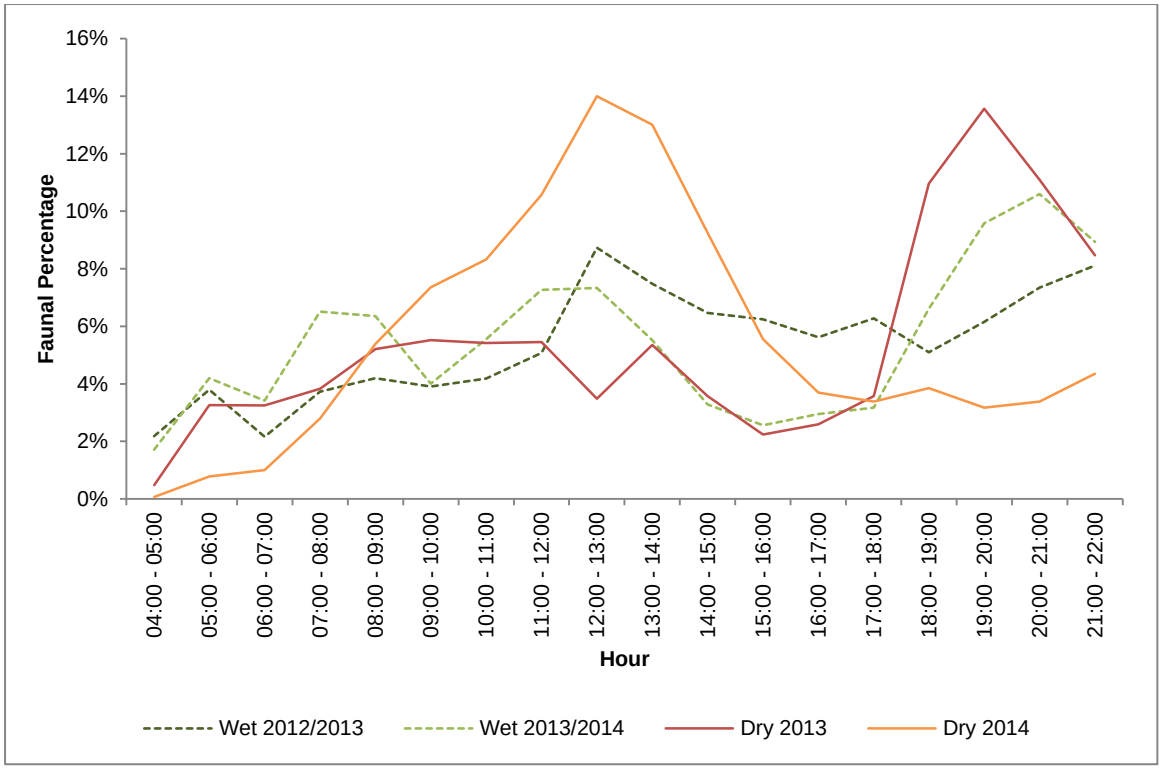


Figure 5.19: Species water trough usage during the wet and dry seasons (October 2012 - August 2014).

5.7 Peak Utilisation During Morning, Afternoon and Evening

Faunal species have been separated into four primary visitation times over the 18 - hour period: morning (05:00 - 09:00), afternoon (09:00 - 15:00) and evening (18:00 - 22:00). Faunal species have been separated according to their peak water trough usage during the day over the whole period and not clustered according to carnivore and herbivore species. The morning and nocturnal hours are typically characterized by carnivore species, whereas the afternoon hours are comprised of herbivore/prey species.

5.7.1 Morning Peak

Analysing the average daily percentage distribution of observations, the following carnivore species were observed at the water trough most frequently during the morning (05:00 - 09:00): Jackal (22.55%), lion (38%), spotted hyena (33.69%), brown hyena (27.37%) and leopard (41.67%, *Table 5.11*). The carnivores demonstrate two peaks, with the morning being the first. The predominant visiting

time for jackal, lion, spotted hyena, brown hyena and leopard is between 05:00 - 06:00 (5.53%, 14.18%, 14.44%, 11.64%, 12.50% respectively), with the peak period for leopard extending to between 06:00 - 07:00 (12.50%). The second highest peak for lion, spotted hyena and brown hyena occurs at 06:00 - 07:00 (9.46%, 8.02%, 5.39%, respectively), and that for leopard (8.33%) at 04:00 - 05:00 and jackal (4.52%) at 07:00 - 08:00 (*Table 5.11*).

5.7.2 Afternoon Peak

The highest peak of water trough usage across the whole day occurs from (09:00 - 15:00) by the following herbivore: Blue wildebeest (64.01%), springbok (67.92%) and red hartebeest (60.77%; *Table 5.11*). Peak water trough drinking patterns occur during the hour 12:00 - 13:00 for both springbok (12.48%), with the second highest greatest water trough utilisation occurring one hour later during 13:00 - 14:00 for both these species (11.94% and 26.20%, respectively; *Table 5.11*) which falls more into an afternoon category, despite demonstrating similar patterns. Blue wildebeest (13.40%) and red hartebeest (13.26%) were observed mostly during 10:00 - 11:00. Blue wildebeest have the second highest peak during the hour 11:00 - 12:00, whilst red hartebeest occurs directly after the highest peak (11.58% and 13.66%, respectively; *Table 5.11*).

5.7.3 Evening Peak

The highest peak of water trough usage across the whole day occurs from (18:00 - 22:00) by the following species: Jackal (67.34%), lion (48.85%), spotted hyena (56.15%), brown hyena (69.50%), leopard (41.67%) and cheetah (50.85%) have a second peak water trough utilisation during the nocturnal hours. Gemsbok (31.97%) also frequents the water trough during the nocturnal hours and occurs most frequently between 21:00 - 22:00 (*Table 5.11*). Jackal, lion and spotted hyena occur mostly frequently between 20:00 - 21:00 (16.80%, 15% and 15.51%, respectively), whilst brown hyena, leopard and gemsbok between 21:00 - 22:00 (28.02%, 20.83% and 20.68% respectively), with cheetah (20.34%) occurring between 19:00 - 20:00 (*Table 5.11*). The second highest peak visitation is between 19:00 - 20:00 by jackal (16.66%), lion (11.88%), leopard (12.50%) and gemsbok (15.71%), whilst brown hyena (19.61%) and cheetah (15.25%) are observed between 20:00 - 21:00, with

spotted hyena (13.90%) between 21:00 - 22:00 (*Table 5.11*). The sudden decrease of all species recorded between 22:00 - 23:00 (*Table 5.11*) may be due to early generator shut off on some of the days.

Table 5.11: Total number of animals (%) during the morning, afternoon and evening. Percentage peaks are highlighted: dark orange (peak hour), lighter organge (second highest peak hour) and the light orange (third highest peak hour).

Peak	Hour	Jackal	Lion	Spotted hyena	Brown hyena	Leopard	Cheetah	Gemsbok	Blue hildebeest	Springbok	Red hartebeest
Morning	04:00 - 05:00	2.23%	5.16%	4.28%	2.80%	8.33%	3.39%	0.93%	0.48%	0.01%	0.00%
	05:00 - 06:00	5.53%	14.18%	14.44%	11.64%	12.50%	11.86%	1.87%	0.70%	0.26%	0.61%
	06:00 - 07:00	3.75%	9.46%	8.02%	5.39%	12.50%	6.78%	0.93%	1.92%	0.70%	1.16%
	07:00 - 08:00	4.52%	5.87%	1.60%	4.96%	4.17%	6.78%	0.93%	7.54%	2.69%	8.84%
	08:00 - 09:00	3.82%	3.44%	5.35%	1.94%	4.17%	15.25%	0.78%	12.11%	4.61%	12.24%
Afternoon	09:00 - 10:00	2.70%	4.73%	0.00%	0.65%	0.00%	0.00%	2.80%	10.15%	6.31%	14.41%
	10:00 - 11:00	1.66%	0.57%	4.81%	0.65%	8.33%	0.00%	5.91%	13.40%	6.84%	13.26%
	11:00 - 12:00	2.10%	0.43%	0.53%	0.43%	0.00%	0.00%	5.13%	11.11%	8.66%	13.66%
	12:00 - 13:00	1.19%	1.43%	2.67%	0.43%	0.00%	0.00%	4.04%	11.58%	12.48%	11.56%
	13:00 - 14:00	0.88%	0.43%	2.14%	0.43%	4.17%	0.00%	4.67%	10.53%	11.94%	8.97%
	14:00 - 15:00	1.02%	0.72%	0.00%	0.22%	4.17%	1.69%	1.71%	7.09%	10.73%	7.07%
Unclassified - No peak	15:00 - 16:00	1.21%	2.44%	0.00%	0.43%	0.00%	3.39%	2.95%	5.26%	8.90%	2.79%
	16:00 - 17:00	2.02%	2.15%	0.00%	0.43%	0.00%	0.00%	2.64%	3.25%	8.38%	3.47%
	17:00 - 18:00	4.49%	4.58%	4.28%	0.22%	0.00%	3.39%	2.49%	1.79%	7.77%	0.95%
Evening	18:00 - 19:00	10.96%	7.02%	5.88%	3.66%	4.17%	10.17%	7.62%	2.04%	4.18%	0.48%
	19:00 - 20:00	16.66%	10.89%	12.83%	10.99%	12.50%	20.34%	15.71%	0.56%	2.57%	0.07%
	20:00 - 21:00	16.80%	13.75%	15.51%	19.61%	4.17%	15.25%	14.77%	0.41%	1.21%	0.14%
	21:00 - 22:00	14.87%	10.17%	13.90%	28.02%	20.83%	1.69%	20.68%	0.07%	1.63%	0.34%

5.8 Statistical Cluster Analysis

Cluster analysis was performed on the full sample of all observed faunal species. This includes two avian species that will not be discussed further, but are statistically required to be included as part of the sample group. Based on the cluster analysis on the visiting times of the 12 species, two discreet cluster groups (sub-group A and sub-group B) are defined and divide the species up into herbivores (5) and carnivores, where gemsbok is the exception (7) (*Figure 5.20*). Species found within sub-group A are gemsbok, jackal, lion, spotted hyena, brown hyena, leopard and cheetah. All of them occur during the morning and nocturnal hours, or both (*Figure 5.20*). Sub-cluster B consists of springbok, blue wildebeest, red hartebeest, secretary bird and bateleur, occurring in the afternoon (*Figure 5.20*). The statistical cluster dendrogram indicates distinct similarities and differences with hourly water trough utilisation. The results of the cluster diagram demonstrate strong evidence that there is a division between morning, afternoon and evening peaks. This is evident in the two main sub-group splits (A and B) where species are divided into clear groupings of carnivores, with the exception of gemsbok, and herbivores.

Two clusters have been identified from sub-group A (sub-groups A.1 and A.2). Sub-group A1 consists of (5) species comprising of gemsbok, jackal, lion, spotted hyena and brown hyena; whilst sub-group A2 consists of leopard and cheetah (*Figure 5.20*). Leopard and cheetah demonstrate a strong relationship in the cluster diagram in the sub-group (A.2), which corresponds to the percentage utilisation during the evening hours between 19:00 - 22:00 (20.34% and 20.83%, respectively; *Table 5.11, Figure 5.20*). Within these two clusters, the first cluster (A.1) is divided into sub-group (A.1.1), which includes gemsbok. Due to gemsbok occuring at a peak during the nocturnal hours (17:00 - 23:00), it has been split into an independent sub-group (A.1.1; *Table 5.11, Figure 5.20*). Two other sub-groups classify subgroup (A.1.2) further (A.1.2.1 and A.1.2.2). Jackal and lion are grouped together under group (A.1.2.1) and spotted hyena and brown hyena are grouped under (A.1.2.2). Jackal and lion (A.1.2.1) and brown and spotted hyena (A.1.2.2) demonstrate strong links (*Figure 5.20*). These strong links demonstrate similarities as these four carnivore species occuring during the same peak hours in the morning (05:00 - 06:00) as well as the evening (20:00 - 21:00; *Table 5.11*).

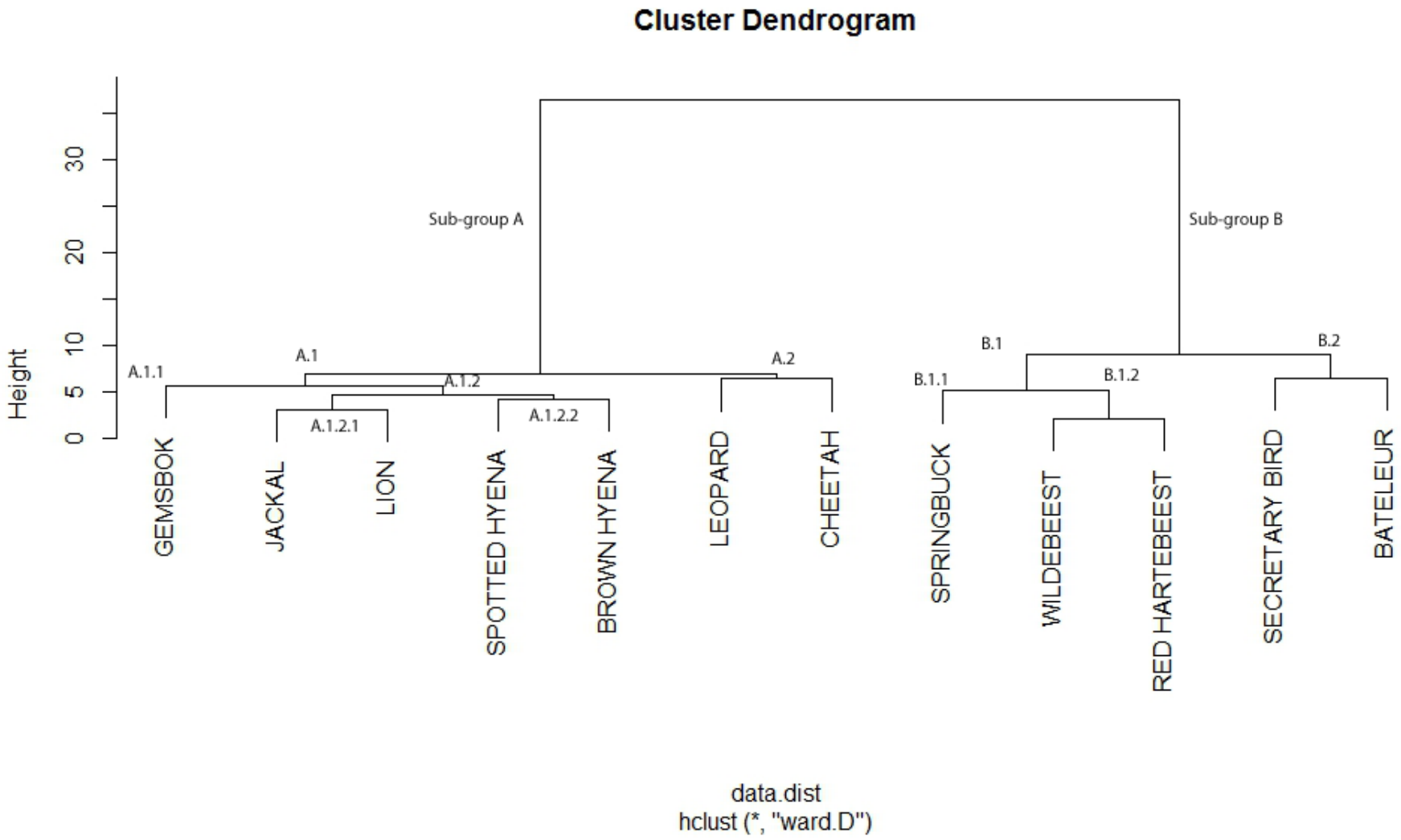


Figure 5.20: Cluster analyses of animals grouped according to the distribution of visiting times.

Sub-group (B) can be divided up into two clusters (sub-groups B.1 and B.2). Sub-group B.1 categorises three species: springbok, blue wildebeest and red hartebeest (*Figure 5.20*). Further to this, B.1 is divided up into two more sub-groups (B.1.1 and B1.2). The sub-group B.1.1 is comprised of springbok and B.1.2 also includes blue wildebeest and red hartebeest (*Figure 5.20*). Springbok are categorized under an independent sub-group (B.1.1), which corresponds to the peak morning hour (12:00 - 13:00; *Table 5.11, Figure 5.20*). Wildbeest and red hartebeest (sub-group B.2.2) demonstrate a strong relationship in the cluster dendogram, which can be confirmed by the similar percentage (13.40% and 13.26%, respectively) and peak hour during which they occur (10:00 - 11:00; *Table 5.11, Figure 5.20*).

5.9 Principal Component Analysis (PCA)

Principal component analysis was performed on the species recorded during the peak water trough utilisation times. The first separation of PC1 is gemsbok, brown hyena, jackal, spotted hyena, leopard, lion and cheetah and the second is bateleur, secretary bird, springbok, blue wildebeest and red hartebeest. The PC1 is interpreted as the division between the groups of species occurring during diurnal and nocturnal hours. There is no clear relationship with PC2 as it cannot be confirmed which factors are separating the species groups (*Figure 5.21*). The PCA biplot describes six main clusters of species (A-E) according to specific time vectors, which drive species (*Figure 5.21*). The nocturnal species are separated into three groups with gemsbok (A) being the first; brown hyena, jackal and spotted hyena the second (B); and leopard, lion and cheetah making up the final cluster (C; *Figure 5.21*). The diurnal species are separated into springbok (E) and the second group into blue wildebeest and red hartebeest (F; *Figure 5.21*).

Springbok occur in an independent cluster driven by the time vector 12:00 - 13:00. The PC2 and PC1 axes separate these species into the afternoon time period. The time vectors driving red hartebeest and blue wildebeest occur from 09:00 - 12:00. Therefore, the PC2 and PC1 axes demonstrate a separation of late morning to early afternoon hours (*Figure 5.21*). Lion, leopard and cheetah are driven by morning hours (05:00 - 08:00). Jackal, brown hyena and spotted hyena are driven by evening

hours (18:00 - 23:00) as well as the morning hours (04:00 - 05:00). Gemsbok is in an independent cluster, separated by PC1 and PC2 axes by the late nocturnal hours (22:00 - 23:00; *Figure 5.21*).

Groups of animals that are distributed at 90 - degree angles from each other on the PCA analysis are mutually exclusive, which demonstrates the species do not visit the water troughs at the same times. The PCA demonstrates that leopard, lion and cheetah do not frequent the water trough at the same time as blue wildebeest and red hartebeest (*Figure 5.21*). Even though gemsbok is a herbivore/prey, the PCA confirms that this animal visits the water trough during the nocturnal hours at the same time as carnivores. Therefore, gemsbok peak utilisation does not occur at the same time at all as the other herbivore species (springbok, blue wildebeest and red hartebeest; *Figure 5.21*).

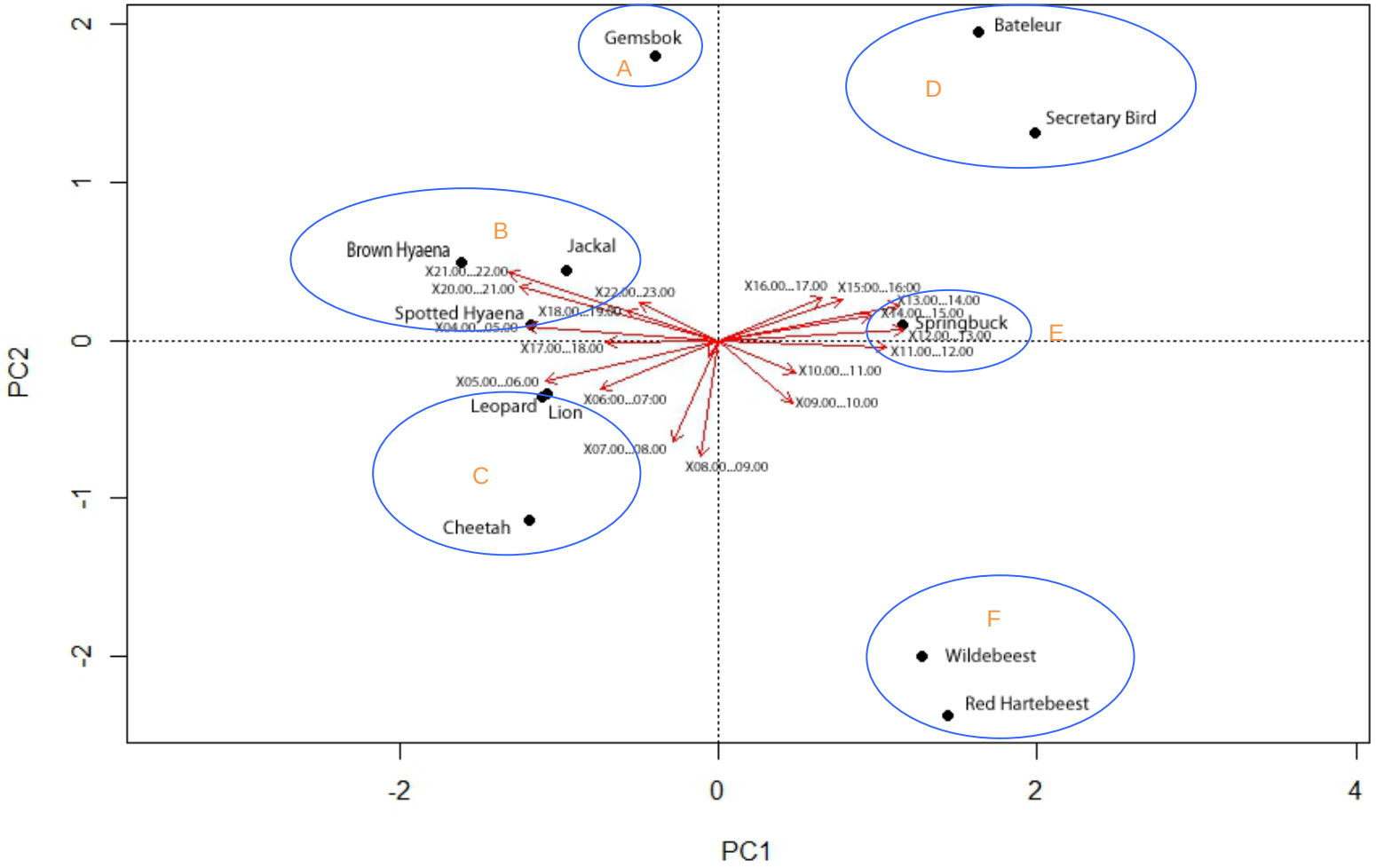


Figure 5.21: PCA analysis demonstrating the time vectors, which drive individual species water trough usage.

5.10 Summary

Clear peaks have been established for each species during the day (morning, afternoon and evening). The statistical analysis (cluster analysis and PCA) of the distribution of visiting times agrees and disagrees with the peak visitation hours. The cluster dendrogram has demonstrated clear groupings of species according to their nocturnal and diurnal habits; however, some of these habits and groupings are not temporally consistent due to the objective approach that cluster analysis takes. Therefore, the PCA analysis is more statistically significant as it defines species water trough utilisation by specific time vector drivers. Species are classified into clear groups of nocturnal and diurnal utilisation times, and are further categorised into species groupings influenced by specific time vector drivers.

5.11 Census Results: Introduction

Aerial census counts are considered to be an important tool for wildlife management due to the vast expanse and remote locations of many wildlife areas in Africa (Jachmann, 2002). Aerial census counts were taken in a series of transects spanning the entire park. Census data are compared with rainfall data to explore the relationship and shifting patterns of fauna in relation to rainfall patterns.

5.11.1.1 Census Transect Data and Rainfall

The aerial census is flown in transects and is correlated with short-term rainfall data. The rainfall data were collected from weather stations within each transect, spanning the same period as the census data (2004 - 2013). The relationship between rainfall and proportional representation of fauna in wet and dry months (April and September) are analysed in order to ascertain whether there is a relationship between broad faunal proportional representation and rainfall within KGNP.

5.11.1.2 Census Transect Data Correlated with Rainfall

The census data are only captured for September and April. Particularly strong correlations significant at the 99% level are found for blue wildebeest in April at Auchterlonie ($r = 0.81$, $p > 0.001$), Drievendas ($r = 0.88$, $p > 0.0005$) and Unie End ($r = 0.96$, $p > 0.0005$). For Unie End, significant strong correlations are also observed

in September (r = 0.99, p > 0.0005; *Table 5.12*). These patterns are similar for steenbok during April at Auchterlonie (0.81, p > 0.001) and September at Kransbrak (r = 0.81, p > 0.001). The proportional representation of steenbok has a strong correlation at Unie End for September (r = 0.99, p > 0.0005), but not for April (*Table 5.12*). It can be tentatively said that the strong correlations occurring at Kransbrak in September 2004 - 2013 for blue wildebeest and steenbok could be due to Kransbrak experiencing low rainfall for the month of September over the period 2004 - 2013 (1.9mm), and these species become more reliant on the water troughs along the riverbeds. Springbok also demonstrate a particularly strong correlation during April at O'kuip (r = 0.82, p > 0.0025) and Drievendas (r = 0.97, p > 0.0005; *Table 5.12*). Blue wildebeest tend to be more sedentary along the riverbeds, relying on the water troughs when rainfall does not occur (Mills and Retief, 1984).

The strong relationship in April for blue wildebeest and steenbok at Auchterlonie and Unie End is representative of the wet summer months of high rainfall and reasonably good water availability in the Auob riverbed. The only species that was calculated as having statistical significance at Mata-Mata is gemsbok during September (r = 0.78, p > 0.005; *Table 5.12*). This is potentially because Mata-Mata is situated on the banks of the Auob River resulting in a lower direct reliance on rainfall. Gemsbok and blue wildebeest have a statistically significant correlation at the 95% level at Moravet (r = 0.52, p >0.1; r = 0.53, p > 0.1 respectively; *Table 5.12*). Gemsbok are also significantly correlated (95% significance) with rainfall during April at Sewe panne (r = 0.52, p > 0.1; *Table 5.12*).

Table 5.12: Relationship of census and rainfall data: 2004 - 2013. Statistically significant correlations (p < 0.05) are highlighted in light green and particularly strong correlations (p < 0.01) are highlighted in dark green.

Correlation of census and rainfall						
Site	**Gemsbok**	**Red Hartebeest**	**Springbok**	**Steenbok**	**Blue wildebeest**	**Eland**
Auchterlonie						
April	0.14	0.00	-0.48	0.81	0.81	0.00
September	0.03	0.00	-0.14	0.65	-0.21	0.00
Twee Rivieren						
April	-0.04	0.00	0.15	-0.22	-0.14	0.00
September	-0.24	0.00	-0.36	-0.24	-0.32	0.00
Kij Kij						
April	0.21	0.00	-0.36	0.40	-0.21	0.00
September	-0.02	0.00	0.65	0.10	-0.25	0.00
Kransbrak						
April	0.05	0.00	-0.01	-0.16	0.00	0.00
September	0.27	0.00	0.47	0.81	0.99	0.00
Mata-Mata						
April	0.27	0.00	0.00	0.15	0.00	0.00
September	0.78	0.00	0.00	0.27	-0.26	0.00
Moravet						
April	0.52	0.00	0.00	-0.32	0.53	0.00
September	0.01	0.00	0.00	-0.31	-0.14	0.00
O'kuip						
April	-0.35	0.00	0.82	-0.33	-0.12	0.00
September	-0.36	0.00	-0.14	-0.27	0.09	0.00
Drievendas						
April	-0.02	0.00	0.97	0.03	0.88	0.00
September	0.00	0.00	-0.26	-0.37	-0.24	0.00
Sewe panne						
April	0.52	0.00	0.00	-0.30	-0.20	0.00
September	-0.35	0.00	0.00	-0.25	-0.25	0.00
Grootbrak						
April	-0.23	0.00	-0.36	-0.05	0.00	0.00
September	-0.14	0.00	0.00	0.55	-0.14	0.00
Unie End						
April	0.28	0.00	-0.20	-0.48	0.96	0.00
September	-0.14	0.00	-0.14	0.99	-0.22	0.00
Bayip						
April	-0.05	0.00	-0.27	-0.44	-0.18	0.00
September	0.54	0.00	-0.24	0.21	-0.17	0.00

5.12 Temperature and Rainfall Controls on Water Trough Usage

5.12.1 Introduction

Faunal species have varying water requirements, which should reflect in their water trough utilization. Species utilise water troughs variably through the year, depending on season and availability of surface water (Knight, 1995). Percentage visitation by species is divided into wet (hot) and dry (warm/cool) seasonal water trough usage. Temperature metrics (T_{max}, T_{min} and T_{avg} and temperature thresholds) were correlated firstly with species peak daily water trough usage; secondly with the total species frequenting the water trough each day; and thirdly with monthly water trough usage. Further, water trough usage was correlated with rainfall for a specific rainfall event, as well as with rainfall between 1 - 2 days before and after an event.

5.12.2 Wet/Dry Water Trough Usage

November to April were categorised as the wet (hot) season, and months May to October as the dry (warm/cool) season (Bergstrom and Skarpe, 1999). Herbivores were observed at the water trough more frequently during the dry season than during the wet season. The most observed species during the dry season were red hartebeest (84.46%). The second most observed species was springbok (74.36%; *Table 5.13*).

During the wet season, lion were observed most frequently at the water trough (90.13%), followed by cheetah (90%; *Table 5.13*). These carnivores are considered to be water-independent, acquiring most of their water requirements through bodily fluids of prey species during the dry season, which explains their relative absence at the water trough during the dry season (Eloff, 1973b). Jackal and spotted hyena visited the water trough approximately equally during the dry (50.35% and 51.65%, respectively) and wet (49.65% and 48.35%, respectively) seasons (*Table 5.13*). This indicates that water requirements for these species are not seasonally controlled, and thus utilise the water trough evenly throughout the year.

Table 5.13: Wet (November to April) and dry (May to October) season water trough usage. Variations >50% for each species are highlighted.

		Wet	Dry
Carnivores	**Brown Hyena**	39.39	60.61
	Cheetah	90.00	10.00
	Jackal	50.35	49.65
	Lion	90.13	9.87
	Leopard	31.82	68.18
	Spotted Hyena	51.65	48.35
Herbivores	**Gemsbok**	22.55	77.45
	Red Hartebeest	15.54	84.46
	Springbok	25.64	74.36
	Blue wildebeest	34.34	65.66

5.12.3 Seasonal Water Trough Usage (2013 - 2014)

The seasons have been divided up according to the months, which comprise each season (i.e. summer [Dec - Feb], Autumn [March - May], winter [June - Aug], spring [Sept - Nov]). Preferential faunal water trough usage in 2013 was similar for summer (23.79%) and spring (27.24%), differing by 3.45%, while autumn visitations were higher (33.72%) and winter visitations the lowest (15.25%; *Table 5.14*). By contrast, the preferential water trough usage during 2014 differed considerably between seasons, ranging from a maximum of 55.71% in spring to a minimum of 4.63% in autumn, with the second highest preferential water trough usage occurring during winter (28.02%; *Table 5.14*).

The increased activity during spring could be due to the increased heat stress in this season, a shortage of food sources and no natural water availability (Shresta *et al.,* 2012). The high frequency of visitation during winter suggests that fauna are concentrated around the permanent surface waters during the dry months, when no natural surface water is available (Franz *et al.,* 2010). A cumulative of 0.8mm rainfall occurs during winter 2013, however, 0mm occurs during winter 2014. Contrasting patterns were observed for collective water trough usage between 2013 and 2014. The peak monthly water trough usage occurred during March (8.87%) in 2013, but during October (9.42%) and August (9.28%) in 2014 (*Table 5.14*).

Preferential water trough usage at Nossob by the carnivore species jackal (31.9%), lion (37.6%), brown hyena (24.2%), leopard (20%) and cheetah (75.61%) occurs during the summer/autumn months of January to March 2013, whilst the preferential water trough usage at Nossob for spotted hyena occurs during November 2013 (14.7%; *Figure 5.22 A, B, D, E, F*). During 2014, spotted hyena (7.6%), brown hyena (9.4%) and jackal (3.2%) demonstrated preferential water trough at Nossob during August, however, for lion (12.1%) this occurs during December. Over the entire study period, leopard and cheetah demonstrate sporadic visitations (no real pattern) at the Nossob water trough (*Figure 5.22, E, F*).

Table 5.14: Seasonal and monthly percentage faunal water trough usage (2013 - 2014).

Seasonal water trough usage (2013 - 2014)		
Month/Season	**2013**	**2014**
November	6.34%	1.22%
December	1.81%	1.81%
January	3.73%	2.79%
Summer	**23.79%**	**11.63%**
February	7.56%	0.39%
March	8.87%	1.56%
April	0.40%	0.38%
Autumn	**33.72%**	**4.63%**
May	2.59%	2.42%
June	2.44%	3.57%
July	2.58%	8.05%
Winter	**15.25%**	**28.02%**
August	5.29%	9.28%
September	4.69%	9.19%
October	3.62%	9.42%
Spring	**27.24%**	**55.71%**

The species that prefer to utilise the Nossob water trough during the months of July and August 2014 are the herbivore species (springbok, blue wildebeest, gemsbok and red hartebeest; *Figure 5.22 G, H, I, J*). Preferential water trough utilisation at Nossob during 2014 for the herbivore species occurs during the follow months:

October for springbok (20.5%); and July for blue wildebeest (10.9%), red hartebeest (19.1%) and Gemsbok (24.3%). However, during 2013, blue wildebeest (7.2%) and red hartebeest (3.9%) favoured the Nossob water trough in March and during the months of April 2013 to October 2013, there were no springbok observed utilising the water trough. Therefore, a cyclic seasonal pattern (autumn/winter) is observed for blue wildebeest, as they prefer to utilise the Nossob water trough during the months of July to October for both 2013 and 2014 (*Figure 5.22 G*).

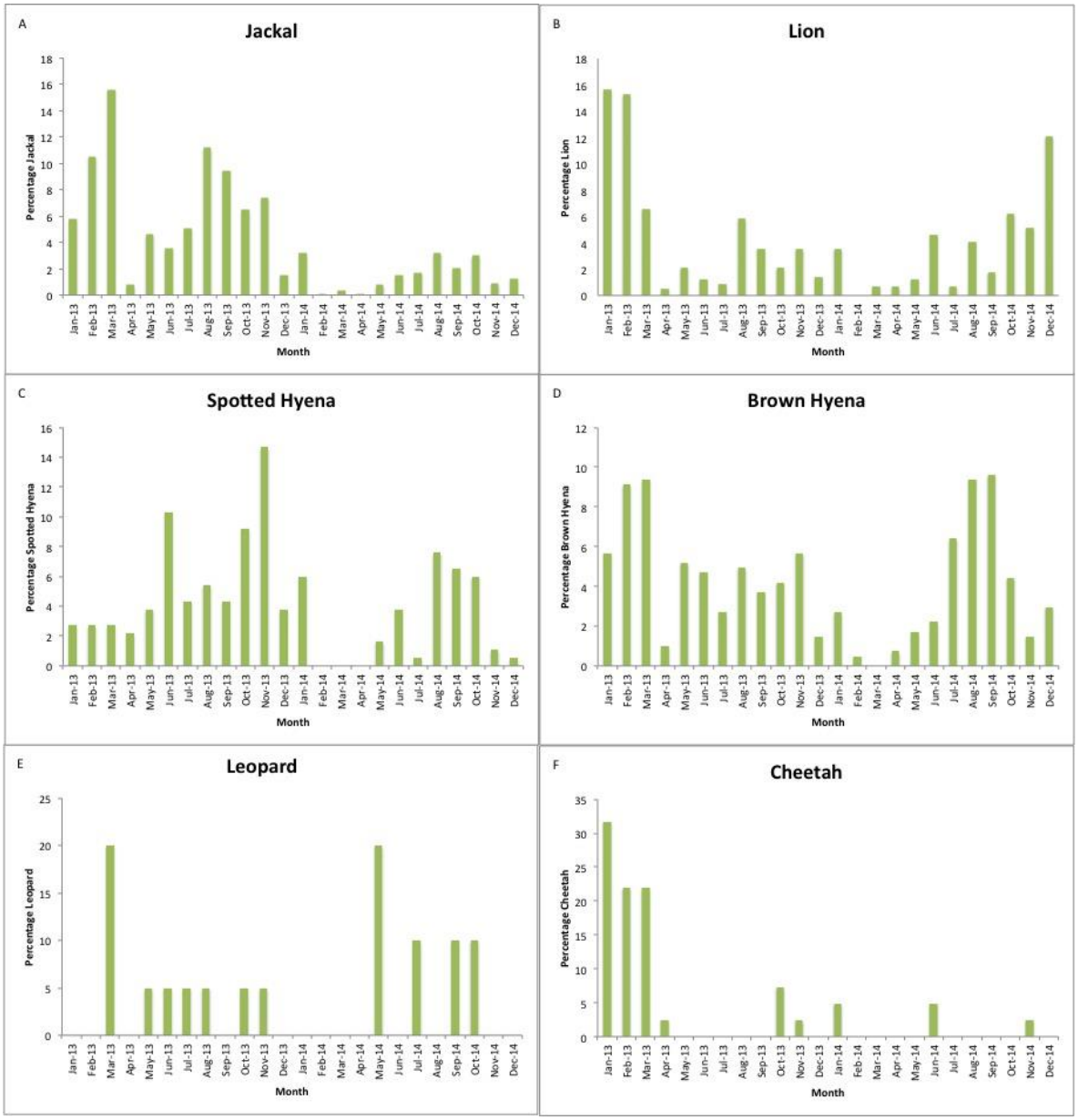


Figure 5.22: Number of fauna utilising the water trough over the study period (January 2013 - December 2014).

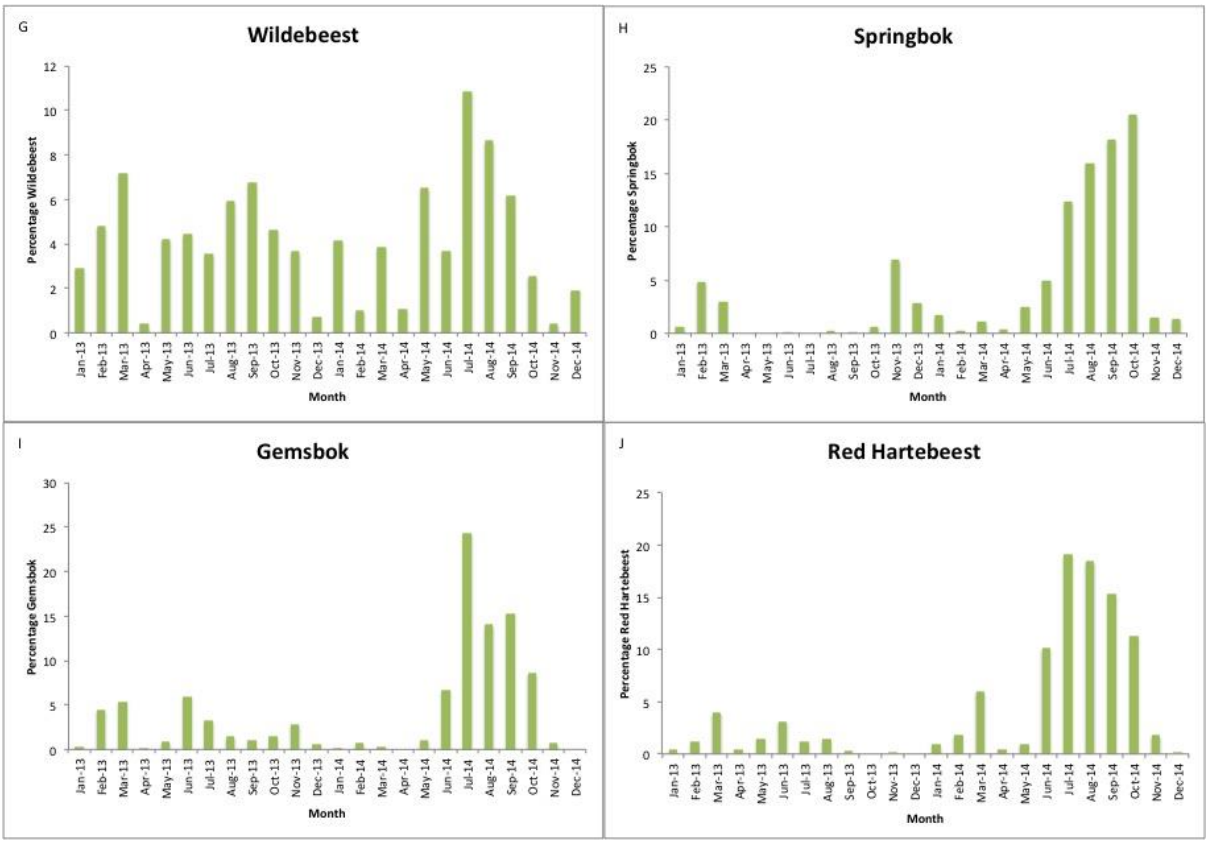


Figure 5.22 continued: Number of fauna utilising the water trough over the study period (January 2013 - December 2014.

5.12.4 Relationship Between Visitation and T_{avg}

The preferential carnivore water trough usage for the T_{avg} thresholds 20°C - 24.9°C (8%), 25°C - 29.9°C (7%) and 30°C - 34.9°C (11%) occurs during 05:00 - 06:00. The peak visitation on days falling into the cooler T_{avg} thresholds (5°C - 9.9°C and 10°C - 14.9°C) occurs during the hour 06:00 - 07:00 (4%) and 08:00 - 09:00 (5%), respectively (*Figure 5.23*). This suggests that on warmer days, carnivores preferentially drink earlier by 6 min/°C, in the cooler hours of the morning. Carnivores frequented the water trough earliest in the evenings (17:00-18:00; 15%) during the lowest T_{avg} threshold (5°C - 9.9°C; *Figure 5.23*). The latest peak being between 21:00 - 22:00 during the T_{avg} threshold 30°C - 34.9°C (19%; *Figure 5.23*). Therefore, the carnivore's preferential water trough usage shifts to later in the evening by 4 min/°C ($r = 0.92$, $p = 0.0005$) as temperatures become higher on average, and thus seem to wait for temperatures to decrease after sunset before drinking.

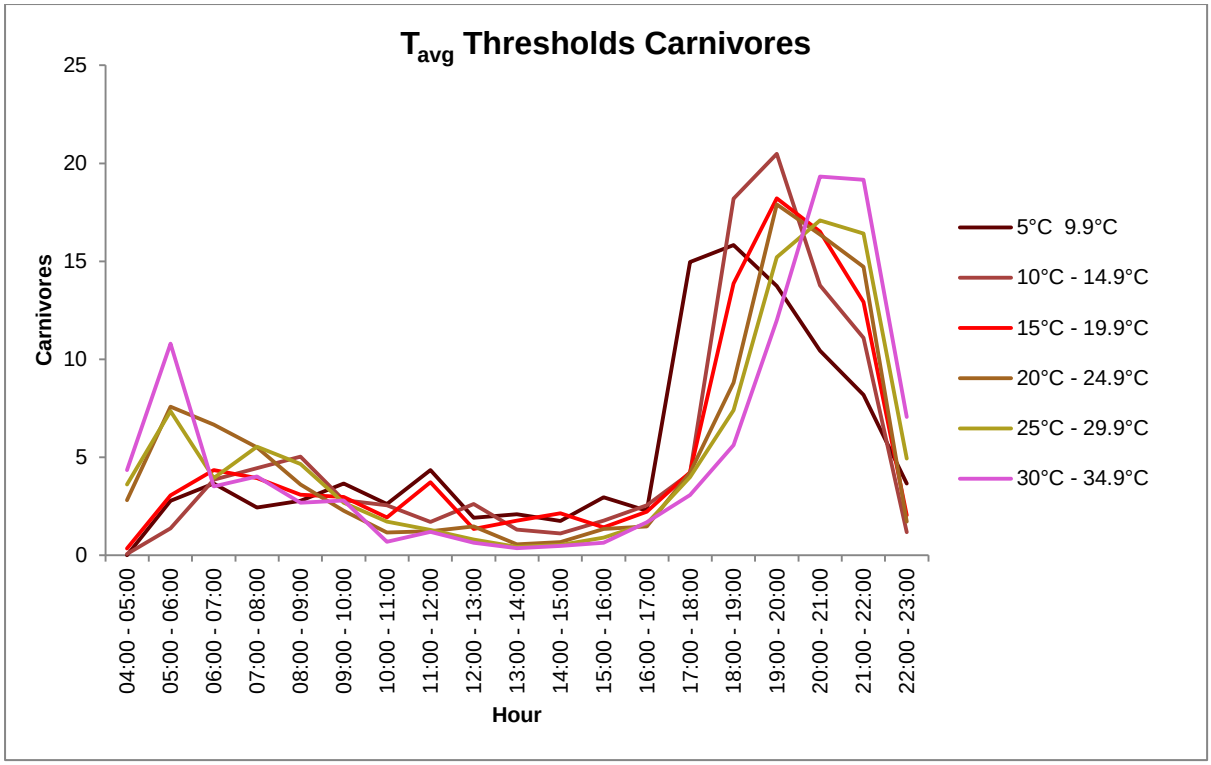


Figure 5.23: Carnivore temperature thresholds and percentage faunal water trough usage.

The latest peak water trough usage (15:00 - 16:00) by herbivores (11.8%) occurs during the hottest T_{avg} threshold 30°C - 34.9°C. Peak water through usage for herbivores (9.3%) under the T_{avg} threshold 30°C - 34.9°C also occurs earlier in the day at 10:00 - 11:00. Two peaks of water trough utilisation occur for the T_{avg} threshold 25°C - 29.9°C, first during the hour 08:00 - 09:00 (9.2%) and second from 14:00 - 15:00 (9.7%; *Figure 5.24*). This suggests these species preferential water trough usage during days with hotter T_{avg} occurs either earlier or later in the day when temperatures are cooler, shifting to later in the afternoon past midday at a rate of 8 min/°C ($r = 0.78$, $p = 0.01$). Herbivore peak water trough usage (24.2%) occurs from 12:00-13:00 during the T_{avg} threshold 10°C - 14.9°C and during 11:00 - 12:00 (13.8%) for the T_{avg} threshold 5°C - 9.9°C (*Figure 5.24*). Therefore, the greatest kurtosis occurs between 10°C - 14.9°C, which means that this threshold has a very specific time that is suitable for herbivores. Thus, the herbivore species preferential water trough usage occurs during midday on the T_{avg} thresholds that are cooler.

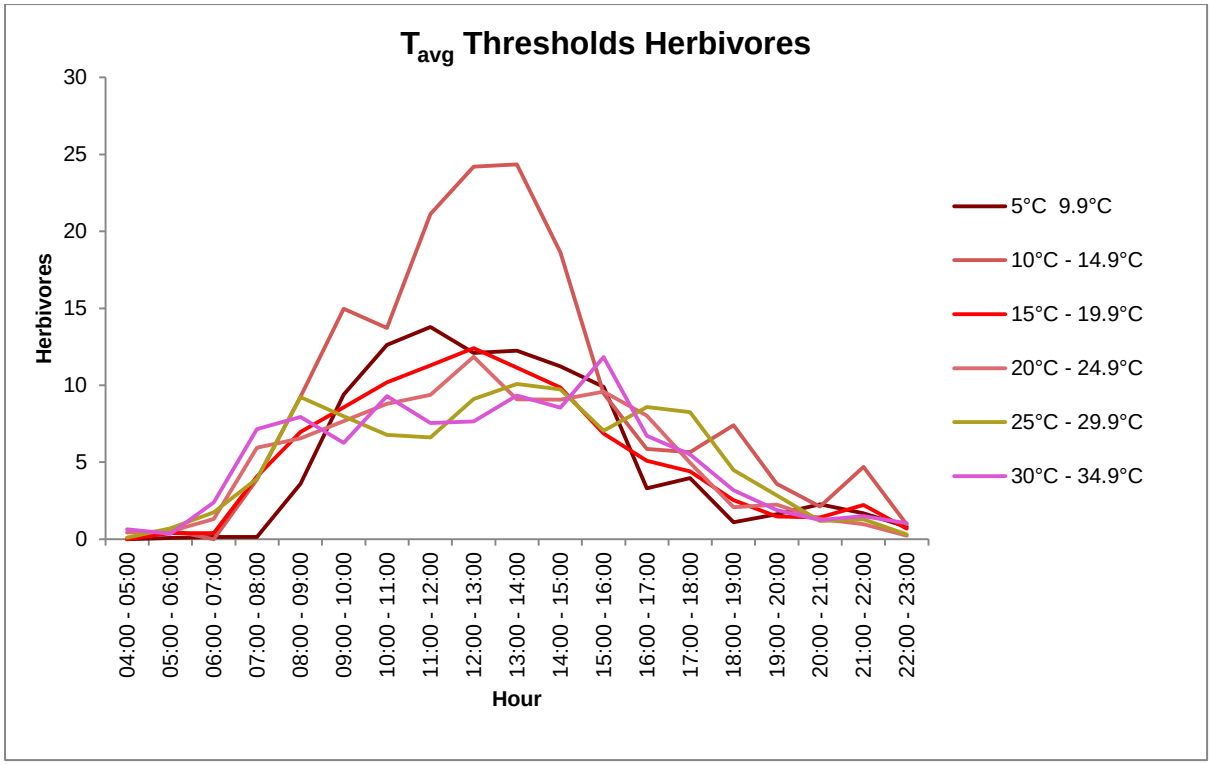


Figure 5.24: Herbivore temperature thresholds and percentage faunal water trough usage.

The herbivore peak water trough utilisation occurs between 11:00am and 14:00pm. However, the preferential water trough utilisation of carnivores occurs during the evening, and shifts later as the T_{avg} thresholds get hotter. Therefore, the water trough usage during midday for herbivores appears deliberate in order to avoid predator/prey associations. This demonstrates that these species override their physiological attributes in order to escape predation (Ayeni, 1975).

5.12.5 Temperature and Water Trough Usage

Peak hourly water trough usage per species was statistically correlated with $T_{max,}$ T_{min} and T_{avg} over the whole period. The most significant negative correlations are calculated for blue wildebeest at T_{min} ($r = -0.35$; $p < 0.05$) and T_{avg} ($r = -0.33$, $p < 0.05$; *Table 5.15*). Such negative correlations indicate that when it gets hotter, the fauna frequent the water trough earlier during the day. Positive correlations suggest that when it gets hotter, the fauna visit the water trough later during the day. Weak correlations were calculated for the remainder of the species, which suggests that $T_{max,}$ T_{min} and T_{avg} are not a major control on species water trough usage (*Table 5.15*).

Similarly, the total faunal species water trough usage is weakly correlated with temperature for each species. This analysis compares the time of day when the majority of each species visit, to the temperature on that day; a positive correlation therefore means that as temperatures increase, fauna arrive later. The weakest correlation existed for brown hyena ($r = -0.01$, $p < 0.4$) at T_{max}, springbok ($r = -0.01$, $p < 0.4$) at T_{min} and springbok ($r = 0.04$, $p < 0.4$) at T_{avg} (*Table 5.16*).

Table 5.15: Correlation of peak hour water trough usage and temperature (T_{max}, T_{min} and T_{avg}). Statistically significant correlations (5% level) are highlighted, negative in green and positive in orange.

	Peak hour water trough utilisation and temperature			
	Faunal Species	**T_{max}**	**T_{min}**	**T_{avg}**
Carnivores	**Jackal**	-0.04	-0.20	-0.14
	Lion	0.20	0.17	0.20
	Spotted Hyena	-0.07	-0.09	-0.08
	Brown Hyena	-0.01	-0.08	-0.05
	Leopard	-0.03	-0.06	-0.05
	Cheetah	0.17	0.14	0.17
Herbivores	**Blue wildebeest**	-0.25	-0.35	-0.33
	Springbok	0.12	-0.01	0.04
	Gemsbok	-0.14	-0.24	-0.21
	Red Hartebeest	-0.14	-0.17	-0.17

Table 5.16: Correlation of total faunal water trough usage and temperature (T_{max}, T_{min} and T_{avg}).

	Total faunal species water trough utilisation and temperature			
	Faunal Species	**T_{max}**	**T_{min}**	**T_{avg}**
Carnivores	**Jackal**	0.17	0.01	0.09
	Lion	0.21	0.19	0.21
	Spotted Hyena	-0.03	-0.03	-0.04
	Brown Hyena	0.02	-0.04	-0.01
	Leopard	-0.01	-0.02	-0.02
	Cheetah	0.17	0.13	0.16
Herbivores	**Blue wildebeest**	-0.06	-0.15	-0.10
	Springbok	0.08	-0.06	0.00
	Gemsbok	-0.13	-0.20	-0.18
	Red Hartebeest	-0.19	-0.20	-0.21

5.12.6 Temperature and Monthly Water Trough Usage

The strongest positive correlations between temperature and water trough utilization exist for jackal and blue wildebeest. The strongest correlations for jackal and temperature occur during March 2013 ($r = 0.51$, $p > 0.0025$), November 2013 and October 2014 ($r = 0.58$, $p > 0.001$ for both; *Table 5.17*). These strong correlations occur during the hotter months of the year, which suggests that there are more jackal individuals during these months as temperatures increase. For blue wildebeest, strong correlations are reordered for September 2014 ($r = 0.58$, $p > 0.001$, *Table 5.17*). The majority of statistically significant correlations occur during January 2013 for jackal, brown hyena ($r = 0.44$, $p = 0.01$), leopard ($r = 0.33$, $p > 0.05$), blue wildebeest and springbok ($r = 0.38$, $p = 0.025$; *Table 5.17*). Positive correlations suggest that when the temperatures increase, more animals will frequent the water trough.

No strong negative correlations occur for any of the species. The majority of the statistically significant negative correlations occur during October 2012 for jackal ($r = -0.31$, $p > 0.1$), spotted hyena ($r = -0.30$, $p > 0.1$), brown hyena ($r = -0.36$, $p < 0.025$) and blue wildebeest (-0.34, $p < 0.025$; *Table 5.17*). Jackal have the most statistically significant negative correlations, which are calculated for October 2012 ($r = -0.31$, $p > 0.1$), July 2013 and May 2014 ($r = -0.42$, $p > 0.025$), September 2013 ($r = -0.38$, $p = 0.025$; *Table 5.17*). Negative correlations suggest that when the temperatures increase, fewer animals occur at the water trough.

Table 5.17: Correlation of monthly water trough usage and temperature (T_{avg}). Statistically significant negative correlations are highlighted in green and positive in orange (95% level) with particularly strong correlations (99% level) highlighted in dark orange.

Monthly species water trough usage and temperature										
Date	Jackal	Lion	Spotted Hyena	Brown Hyena	Leopard	Cheetah	Red Hartebeest	Blue wildebeest	Springbok	Gemsbok
Oct-12	-0.31	-0.21	-0.30	-0.36	0.22	0.00	0.00	-0.34	-0.25	-0.07
Nov-12	0.26	0.16	-0.10	-0.31	0.00	0.14	0.00	0.02	0.23	0.00
Dec-12	0.28	0.08	0.00	0.06	0.00	0.10	0.15	-0.20	0.11	0.15
Jan-13	0.44	0.23	0.11	0.44	0.00	0.33	-0.04	0.38	0.38	0.24
Feb-13	0.00	0.11	0.12	0.05	0.00	0.16	0.13	0.05	-0.10	-0.20
Mar-13	0.51	0.26	-0.17	0.20	0.08	0.04	0.33	0.34	0.17	0.30
Apr-13	-0.20	-0.03	-0.17	0.41	0.00	-0.02	0.02	0.04	0.00	0.02
May-13	-0.06	-0.29	-0.02	-0.22	-0.45	0.00	0.16	0.38	0.00	0.14
Jun-13	0.02	-0.11	0.21	-0.07	-0.20	0.00	0.23	0.13	0.15	0.29
Jul-13	-0.42	0.36	0.20	-0.21	0.13	0.00	0.35	-0.23	0.00	0.25
Aug-13	-0.12	0.11	-0.18	-0.22	0.33	0.00	-0.31	-0.05	0.28	-0.05
Sep-13	-0.38	-0.16	0.18	-0.15	0.00	0.00	0.19	0.39	0.20	0.07
Oct-13	0.35	0.25	-0.19	-0.23	0.26	0.33	0.00	0.21	0.44	0.32
Nov-13	0.58	-0.05	0.05	-0.12	0.00	0.09	0.15	-0.17	0.45	0.05
Dec-13	-0.11	-0.01	-0.04	-0.02	0.00	0.00	0.00	0.14	-0.03	-0.02
Jan-14	0.38	0.26	0.25	0.18	0.00	0.36	0.16	0.42	0.10	0.29
Feb-14	0.08	0.00	0.00	0.08	0.00	0.00	0.04	-0.04	-0.03	0.00
Mar-14	0.34	0.03	0.00	0.00	0.00	0.00	0.26	0.29	0.19	0.00
Apr-14	-0.11	0.09	0.00	-0.21	0.00	0.00	-0.07	0.12	0.00	0.00
May-14	-0.42	-0.21	-0.29	-0.04	0.30	0.00	0.20	-0.28	0.22	0.12
Jun-14	0.41	0.33	-0.02	-0.16	0.00	0.14	-0.12	-0.04	-0.12	0.12
Jul-14	0.14	0.29	0.25	-0.08	-0.11	0.00	0.05	-0.12	0.09	-0.08
Aug-14	-0.21	-0.03	-0.20	-0.12	0.00	0.00	-0.12	0.02	-0.25	-0.06
Sep-14	0.03	0.02	-0.06	0.01	0.29	0.00	0.02	0.58	0.41	-0.27
Oct-14	0.58	0.45	0.10	0.15	-0.29	0.00	-0.03	-0.04	0.43	0.01
Nov-14	0.09	0.20	-0.02	0.11	0.00	-0.02	0.30	0.13	0.15	0.37
Dec-14	0.13	0.27	-0.29	0.02	0.00	0.00	-0.03	-0.08	-0.09	0.00

5.12.7 Rainfall and Water Trough Usage

The overlap of rainfall and faunal sighting time series demonstrate a distinct disappearance of fauna at the Nossob water trough during and immediately after notable rainfall events, with a higher disappearance during and after the occurrence of higher rainfall. After the rainfall event, depending on the quantity of the rainfall, the fauna species visitations at the water trough slowly start to increase, when natural

surface water is no longer available (*Figure 5.25*). Therefore, a relationship between faunal sightings and rainfall at the Nossob water trough does exist, however, this is confirmed statistically through correlation of rainfall and faunal sightings. Faunal water trough utilisation habits are less frequent/ non-existent during and after rainfall events with higher rainfall quantities.

Faunal water trough usage is correlated to the timing of rainfall, relative to a current rainfall event. Statistically significant negative correlations exist between water trough usage and one day after the rainfall event ($r = -0.31$, $p = 0.001$; *Table 5.18*). This negative correlation indicates that water trough usage decreases immediately following rainfall events, likely because they prefer to drink from natural surface water (Rudee, 2011). The second highest correlation with water trough usage existed two days after the rainfall event ($r = -0.26$, $p = 0.005$; *Table 5.18*), suggesting a gradual return to utilising the water trough as the natural surface water dries up.

Table 5.18: Correlation of all rainfall days occurring over the study period and water trough usage for all species combined. Statistically significant correlations ($p < 0.05$) are marked with an asterisk.

Rainfall and Water Trough usage Rainfall Days	Total Animals	Correlation	No. of rainfall events
Two Days Before	3247	-0.03	87
One Day Before	3173	-0.14	87
Day Of Rainfall	2178	-0.16	87
One Day After	1359	*-0.31	87
Two Days After	1944	-0.26	87

Given the significant correlation between total water trough usage and previous rain day, this relationship was investigated for each species. Certain species, such as jackal ($r = -0.29$, $p > 0.005$) were particularly responsive to rainfall and strongly avoided the water trough whilst surface water was available (*Table 5.19*). This suggests jackal prefer to consume water form a natural source after the rainfall event rather than utilise the artificial source of water.

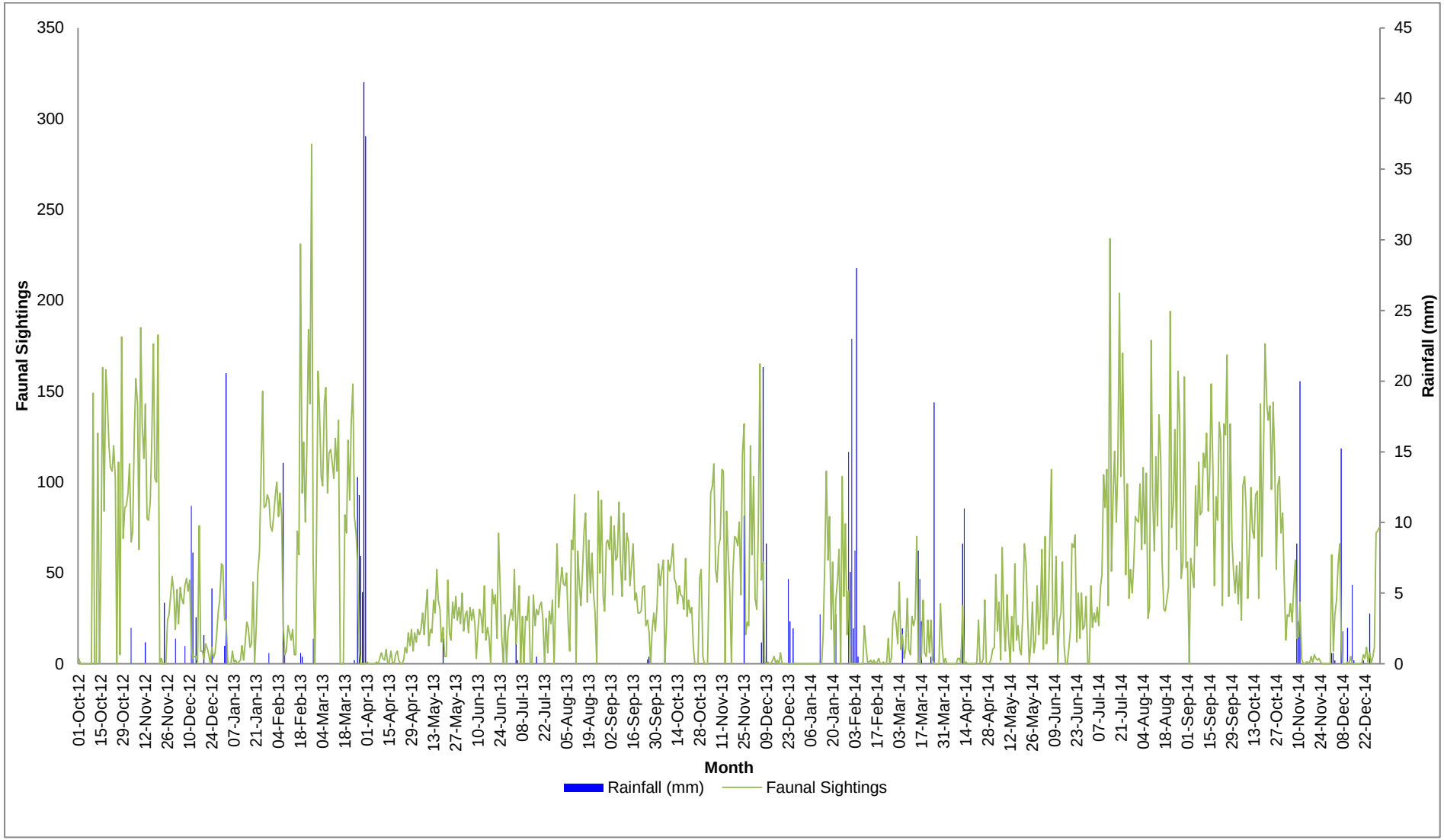


Figure 5.25: Faunal water trough usage during and after rainfall events.

Table 5.19: Correlation one day after the rainfall event and water trough usage. Statistically significant correlations (p < 0.05) are marked with an asterisk.

Correlation of species water trough usage one day after the rainfall event (no. of rainfall events = 87)			
	Species	**Species Totals**	**Correlation**
Carnivore	**Jackal**	524	*-0.29
	Lion	70	-0.18
	Spotted Hyena	8	-0.10
	Brown Hyena	33	-0.18
	Leopard	0	0.00
	Cheetah	1	-0.07
Herbivore	**Blue wildebeest**	157	-0.17
	Springbok	384	-0.20
	Gemsbok	42	-0.12
	Red Hartebeest	43	-0.13

Rainfall is categorised according to certain quantities that occur during rainfall events (e.g. 1 - 9mm, 10 - 19mm, 20 - 29mm and ≥ 30mm). Fauna are averaged according to the number of days per rainfall category and are then compared to rainfall categories to explore which rainfall quantities effect water trough utilisation. It is observed that none of the preferential water trough utilisation occurs during the rainfall category ≥ 30mm (*Figures 5.26 A-J*). Therefore, rainfall events ≥ 30mm produce a generous amount of natural surface water for fauna to consume. Jackal and brown hyena demonstrate similar patterns during the rainfall categories with majority water trough usage occurring during 10 - 19mm (48% for both; *Figure 5.26 A, D*). Leopard preferential utilisation at the water trough occurs between the rainfall category 1 - 9mm (100%), but during the heavier rainfall events (>10mm), leopards were not observed at the water trough (*Figure 5.26 E*).

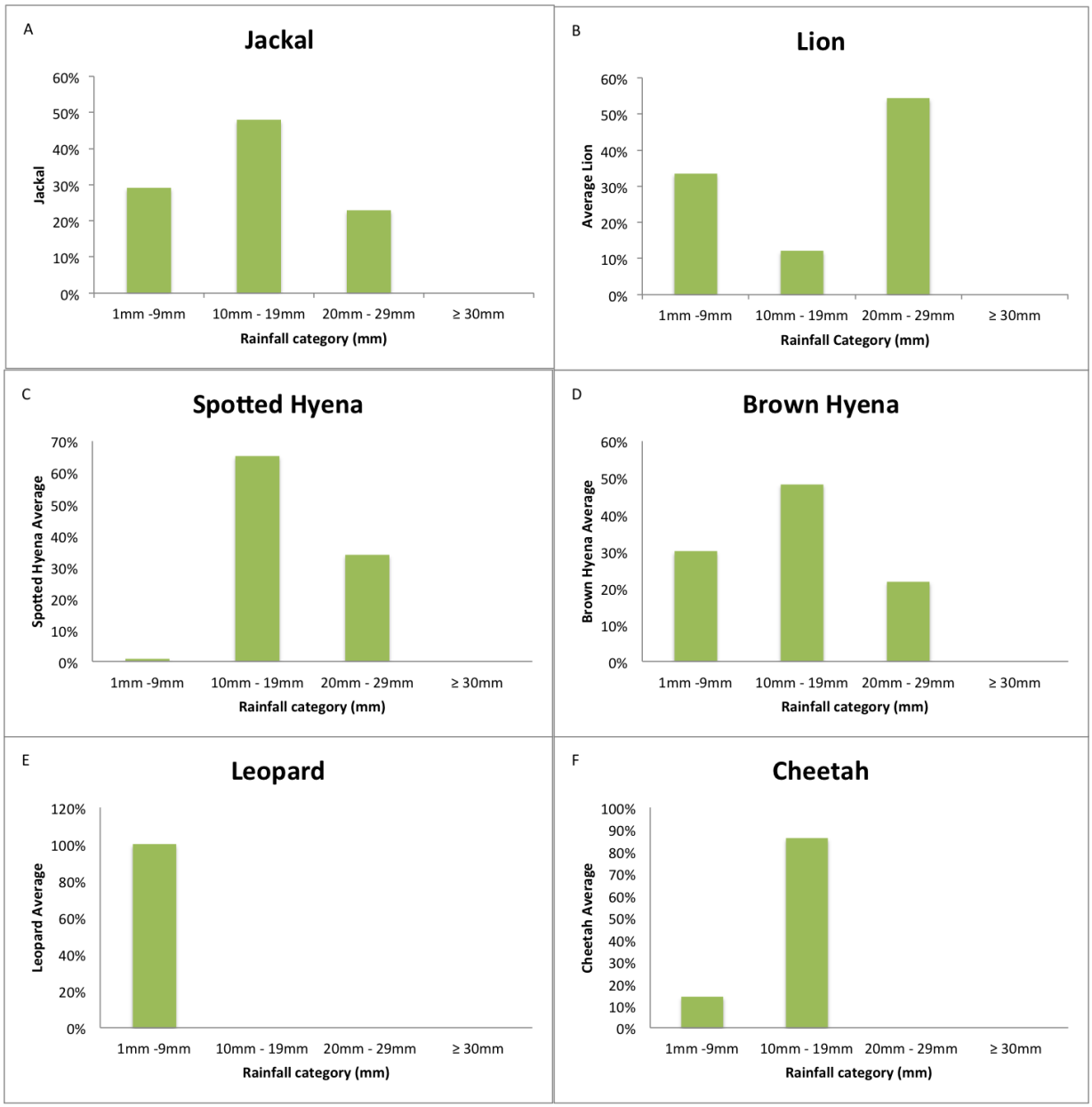


Figure 5.26: Percentage specific species water trough usage during and after specific rainfall quantities, of which four events were recorded ≥30mm.

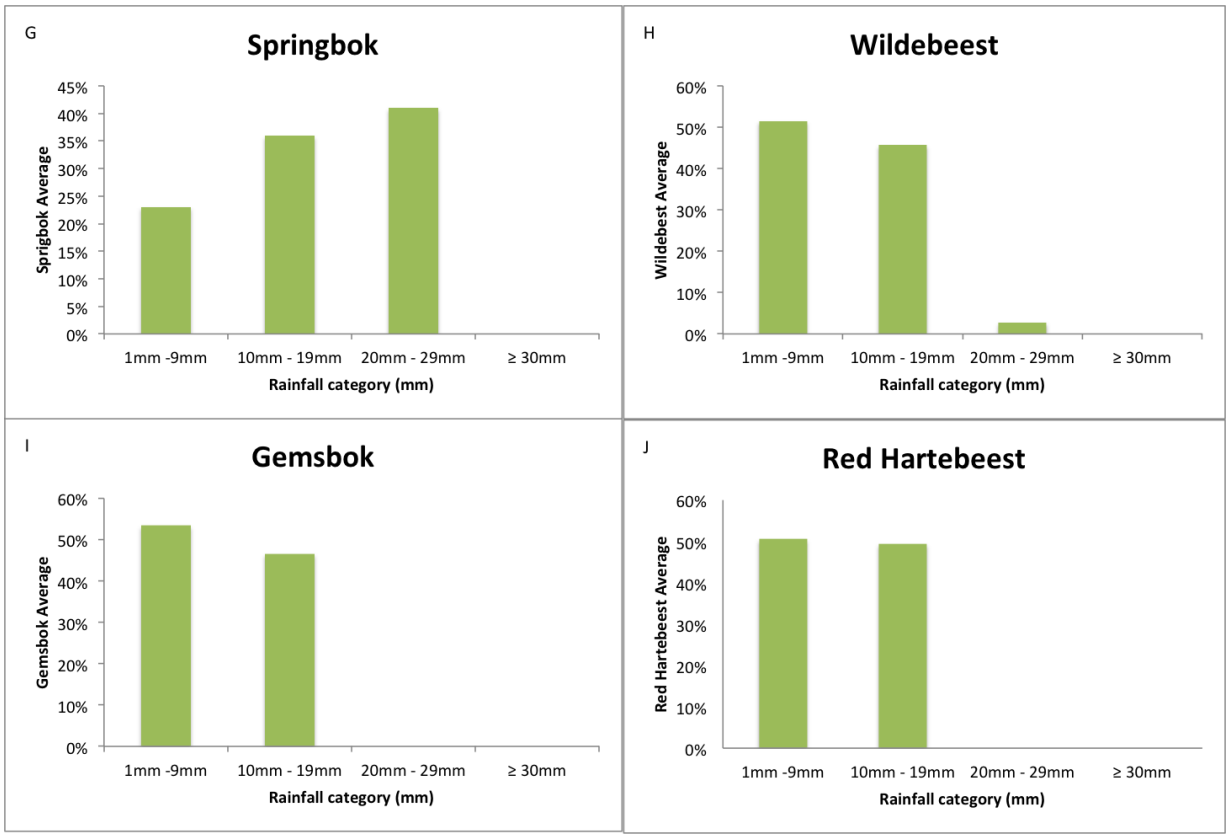


Figure 5.26 continued: Percentage specific species water trough usage during and after specific rainfall quantities, of which four events were recorded ≥30mm.

Blue wildebeest, gemsbok and red hartebeest herbivores are observed at the water trough during 1 - 9mm (51%, 53% and 50% respectively) but low or no water trough utilisation during rainfall events ≥ 20mm (2.8% and 0% respectively; *Figure 5.27 H - J*). However, springbok water trough usage increases as rainfall quantity increased (23%, 36% and 41%) but no springbok occur during the rainfall category ≥ 30mm (0%; *Figure 5.27 G*).

The relationship between faunal visitations and shrinking surface water revealed strong patterns of water trough avoidance after heavy rainfall events. Rainfall events were categorized according to rainfall volume (*Figure 5.27*). The results demonstrate that as rainfall events become heavier (>20mm) faunal visitations one day after the rainfall event are minimal (n = 4). It has been observed during excessive rainfall events (20 - 85mm), the natural surface waters occupy a larger surface area and therefore, it takes a longer time to evaporate. Minimal rainfall (0 - 14mm) has an

insignificant impact on water trough usage, as these smaller rainfall events are not sufficient enough to create an adequate amount of surface water for fauna. High faunal water trough usage 4 days after the rainfall event for categories 0-4mm, 10-14mm, 15-19mm and 20-25mm is due to large herds of wildebeest utilising the water trough (*Figure 5.27*).

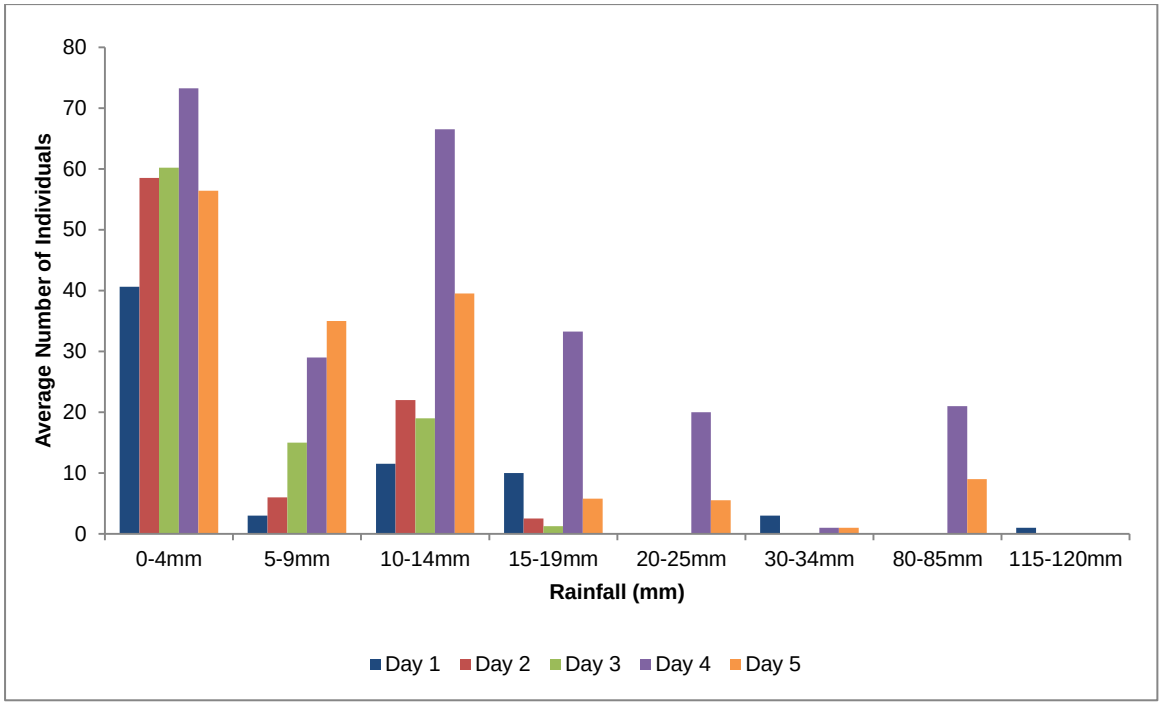


Figure 5.27: Average faunal sightings observed up to 5 days after specific rainfall events natural surface water dissipates (October 2012 - December 2014).

5.13 Summary

This chapter explores patterns in the visitation of fauna at the water trough throughout the day and across months and seasons of the year. These patterns are related to climate variables, which are additionally explored independently over long time periods. The chapter additionally explores the relationship between webcam and census data to determine the regional significance of these results. Inferences on behaviour and the reasons behind statistical relationships have been made in this chapter relating back to appropriate literature. A general discussion of the relevance of these results and broader debates of wildlife management in water scarce parks such as KGNP is presented in the following chapter.

Chapter 6

Discussion



6 Discussion

6.1 Introduction

This discussion establishes ecological relationships between faunal species and climatic influences, and outlines the future, broader implications. The final section of this discussion explores the limitations experienced during data collection and methodologies through to data and statistical analysis.

6.2 Analysis of results

6.2.1 Regional Climatic Trends

The results demonstrate that T_{max} has increased on average by 0.04°C/annum over the region during the last half century, based on temperature increases at Twee Rivieren (1960 - 2014; 0.05°C/yr), Mata-Mata (1975 - 2014; 0.06°C/yr), Nossob (1975 - 2014; 0.05°C/yr) and Upington (1941 - 2014; 0.01°C/yr). Therefore, the increase in T_{max} is higher in KGNP (avg = 0.05°C/yr) than the average for the region, which includes the relatively small increase in Upington (avg = 0.04°C/yr). This suggests that future increases in T_{max} might be higher in KGNP than predicted climate change for the region. Temperature increases for T_{min} are observed for Twee Rivieren (0.01°C/yr), Mata-Mata (0.07°C/yr) and Upington (0.02°C/yr) and decreases for Nossob (0.04°C/yr; *Table 5.2, Figures 5.6 - 5.9*). Results have also demonstrated that rainfall is decreasing for Mata-Mata (1.71mm/yr) and Nossob (1.01mm/yr) but increasing at Twee Rivieren (1.27mm/yr) and Upington (0.23mm/yr; *Table 5.2, Figures 5.6 - 5.9*). A T_{max} increase of 2.6°C over the past 50 years across the three stations in KGNP is not unexpected, as other studies have documented an increase of 2°C with decreasing rainfall since 1960 in KGNP (Mackellar *et al.,* 2014; Huang *et al.,* 2015; van Wilgen *et al.,* 2015).

6.2.1.1 Rainfall Trends in KGNP

Over the study period, slight variations in mean annual precipitation were observed for Twee Rivieren (193.71mm), Mata-Mata (199mm), Nossob (201.3mm) and Upington (195.36mm). Of particular interest is the high regional rainfall during the

summer of 1975 - 1976, including Twee Rivieren (559.8mm), Mata-Mata (738.4mm), Nossob (602.3mm) and Upington (500mm; *Figure 5.1 - 5.4*). In addition, the maximum numbers of rain days were measured in 1975 (53 days) and 1976 (76 days) for Mata-Mata and Nossob, respectively, and with the maximum number of consecutive rainfall days for these two stations occurring in 1976 (9 and 8 days, respectively; *Table 5.5*).

These results are consistent with numerous published climatic studies for southern Africa, which emphasise that La Niña events that prevailed in the Pacific Ocean as well as anomalous sea surface temperature conditions, which caused above-average rainfall during 1974 - 1976 (Woodward and Lomas, 2004; Jury and Mpeta, 2005; Washington and Preston, 2006; Mackellar *et al.,* 2014). A plot of seven-year running means of summer-rainfall values by Kane (2009) reported that years of maximum rainfall occurred in 1910, 1920, 1937, 1941, 1956, 1976 and 2000 in South Africa. However, few publications exist that discuss rainfall variability for KGNP region. The peaks in rainfall in South Africa between 1910 and 1956 (Kane, 2009) are seen in the trends for Upington, suggesting that the country-wide pattern likely holds true for KGNP region. Unfortunately, supporting records do not exist for Twee Rivieren, Mata-Mata and Nossob. As a result of the prevailing La Niña conditions, extensive flooding occurred along both the Nossob and Auob Rivers during January 1974 (Huang *et al.,* 2015).

Decreasing rainfall volume has been reported across southern Africa literature for the past century (Hoffman and Vogel, 2008; Derry and Dougill, 2008; Reddy *et al.,* 2010; Hetem *et al.,* 2014). However, statistically insignificant decreasing rainfall trends are recorded for Mata-Mata (-2mm/yr) and Nossob (-1.01mm/yr) in this study. Conversely, Twee Rivieren (1.6mm/yr) and Upington (1.5mm/yr) demonstrate statistically insignificant increasing trends (*Table 5.2, Figure 5.1 - 5.4*). These heterogeneous rainfall trends between the 4 weather stations studied here occur as a result of reported rainfall variability across the region (Mphale *et al.,* 2014). Mphale *et al.* (2014) reports heterogeneous trends in seasonal rainfall of −1.097, 0.029, −0.407, and −1.327 mm/yr for Maun, Ghanzi, Tsabong, and Tshane, respectively, in the Kalahari Transect over the period 1950 - 2008. These cycles differ in both amplitude and periodicity when comparing each of the weather stations,

demonstrating some degree of sub-regional variability within KGNP (*Table 5.3*).

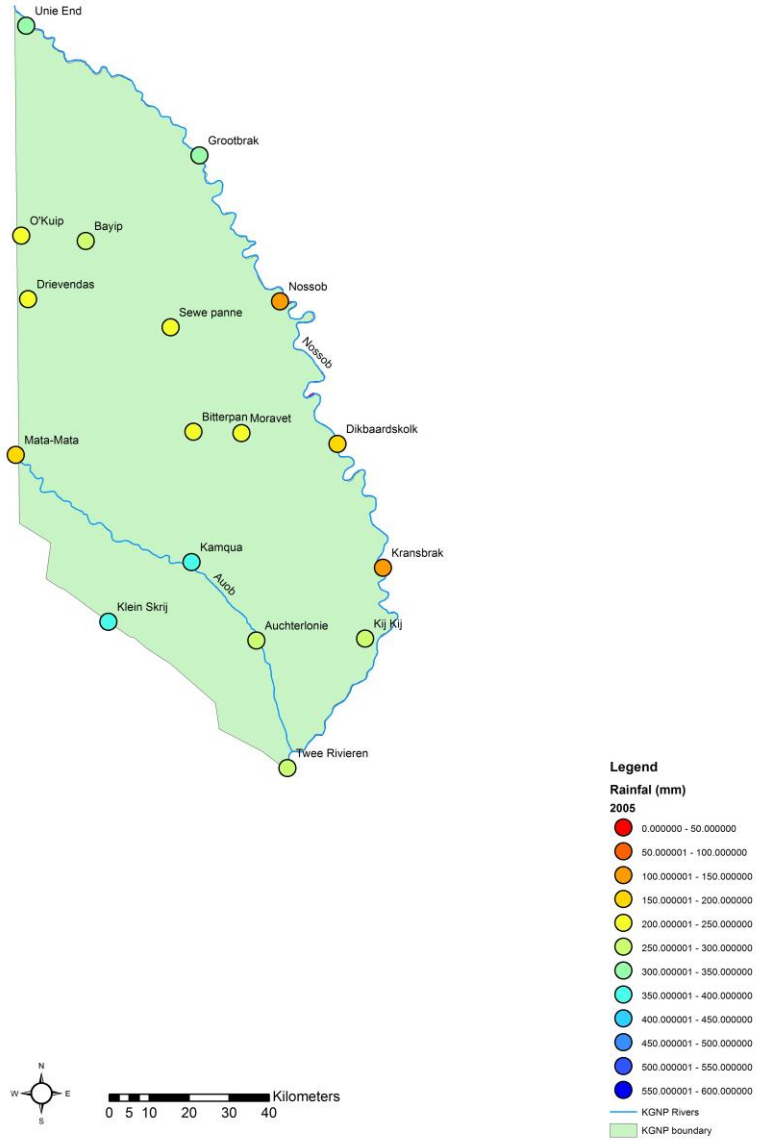
Analyses of recent rainfall revealed regional inter-annual variability between the weather stations located within KGNP and adjacent (Upington), from Twee Rivieren at 251.41mm to 131.4mm at Bitterpan, averaged between 2004 and 2014 (*Table 5.9, Figure 5.17*). Rainfall patterns within semi-arid environments are characterized by their high temporal and spatial variability (IPCC, 2007). Limited research has been published on regional rainfall variability in KGNP. Mean annual rainfall reported within the Kalahari, Botswana, ranges in the south-west (Tsabong) at 312.1mm to the north (Kasana) at 574mm where KGNP is located SSW of the Botswana Kalahari Transect (Mphale *et al.,* 2014). This regional rainfall variability is confirmed in the results section by the large inter-annual rainfall range that occurs during some years between localities. For instance, in 2006, which was a relatively wet year, Mata-Mata only recorded 38.4mm, while Drievendas, 42km to the north-west recorded 589mm. During 2006, rainfall was particularly localised and highest (avg = 382.8mm) in the northern KGNP sector, while the central and southern sectors received 177.8mm and 343.24mm respectively (Drievendas, Bayip, O'Kuip, Grootbrak and Unie End; *Table 6.1, Figures 5.18 and 6.1C*). During 2011, Twee Rivieren, O'Kuip and Klein Skrij received substantial rainfall, whilst below average rainfall was received at Moravet average rainfall occurring across the region at other stations (*Figure 6.1H*). This demonstrates regional rainfall variability across KGNP. Despite strong differences being demonstrated between various stations in KGNP in particular years, the average across KGNP over the period 2004 - 2013 demonstrates rainfall variability between 100mm and 250mm (*Figure 6.2*). This is typical in semi-arid regions, where climatic conditions, such as rainfall variability on an inter-annual time scale, influence the distribution of surface water across the landscape (Chamaille-Jammes *et al.,* 2007a). Therefore, faunal species would be required to migrate throughout the landscape between areas of low and higher inter-annual rainfall.

Table 6.1: Stations within the northern, central and southern sectors of KGNP. Sectors divided by particular latitudes.

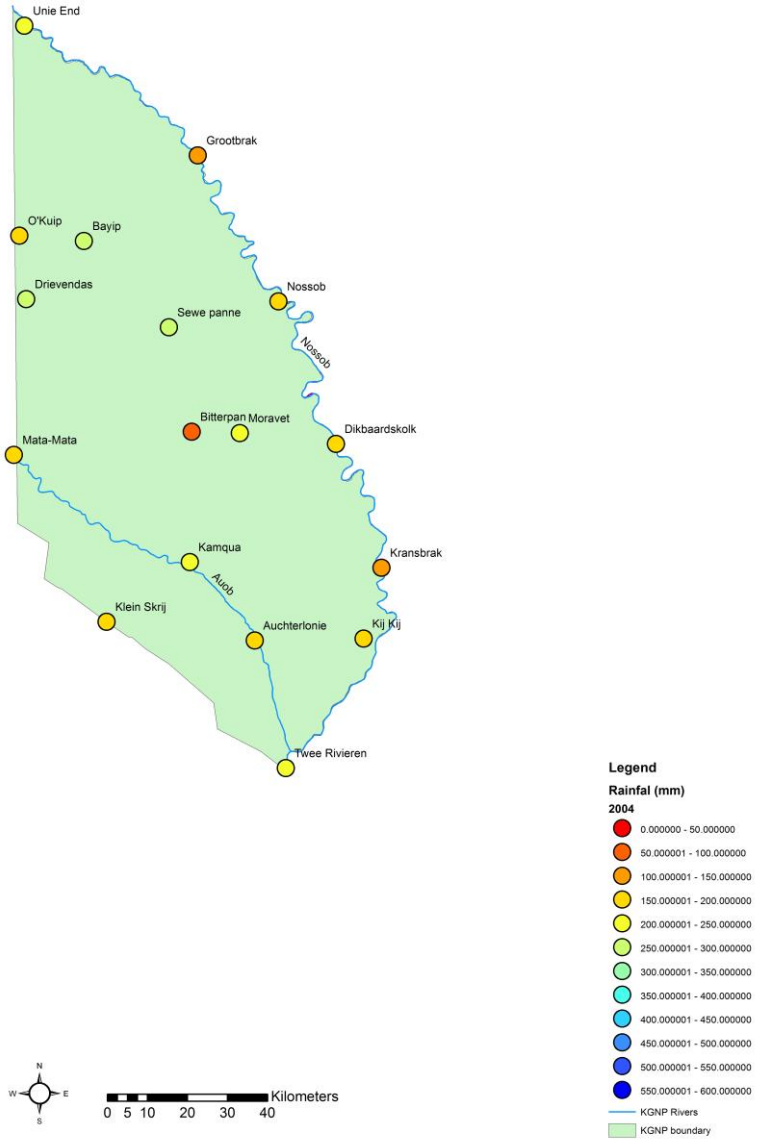
Northern (Latitudes -24.7978 to -25.2917)	
Unie End	O'Kuip
Grootbrak	Bayip
Central (Latitudes -25.2917 to -25.8146)	
Nossob	Moravet
Sewe panne	Dikbaardskolk
Mata-Mata	Drievendas
Bitterpan	
Southern (Latitudes -25.8146 to -26.4717)	
Klein Skrij	Auchterlonie
Kransbrak	Twee Rivieren
Kij Kij	Kamqua

Decreasing and increasing rainfall trends are represented over the period of 2004 - 2013 (*Figure 6.3*). Although it is not customary to do a trend over such a short period, these trends serve simply for comparison between sites and to determine whether trends over the 10 years are similar between sites. Variability is demonstrated within KGNP, as sites exhibit increasing, stable and decreasing trends averaged over the past 10 years. Majority of the sites display stable or increasing trends, with strong/moderate/weak decreasing rainfall trends at Moravet, Drievendas and Unie End, respectively. Strong/weak increasing rainfall trends are demonstrated at Mata-Mata and Nossob, respectively (*Figure 6.3*). These trends demonstrate that the southern parts of KGNP are getting wetter. The patterns within the northern and central parts of KGNP are varied, as certain sites are getting drier whilst others are getting wetter. A general north-south gradient pattern is demonstrated in KGNP, with obvious outliers within the northern/central sections of the park. The most northern part of the park (Unie End) is getting drier, whilst the central sites are stable, with Moravet and Drievendas decreasing, and the southern parts are getting wetter.

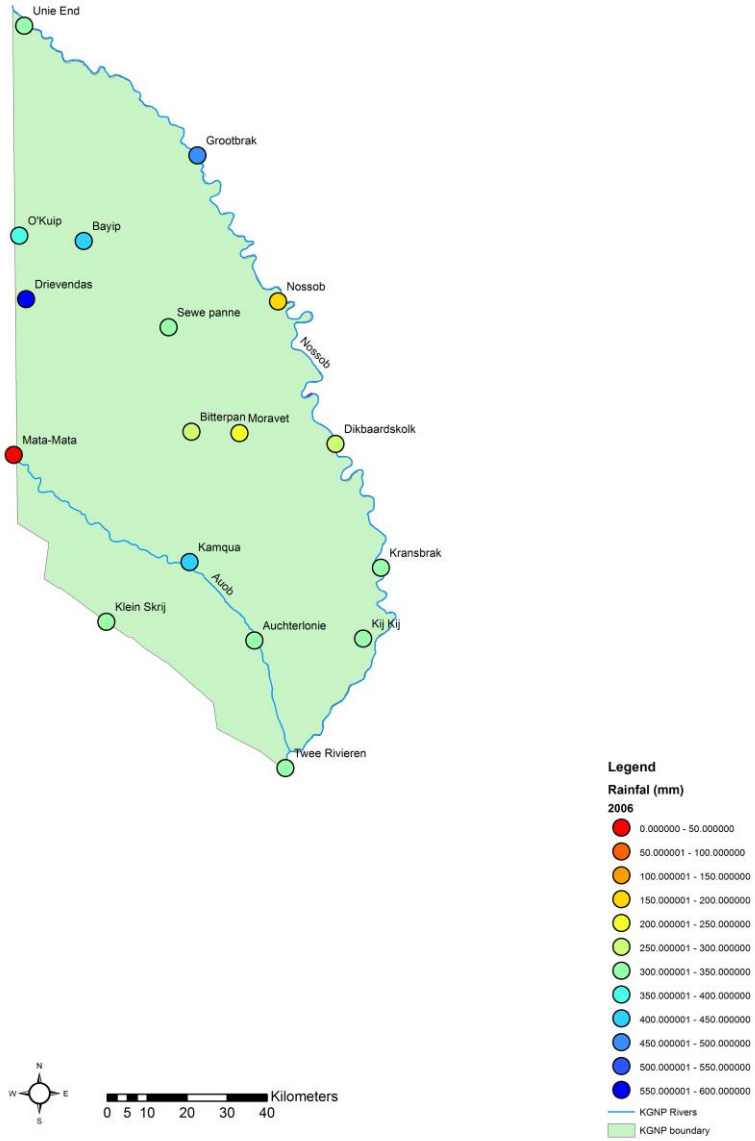
A


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Auob
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
Kilometers
0 5 10 20 30 40
Legend
Rainfal (mm)
2005
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

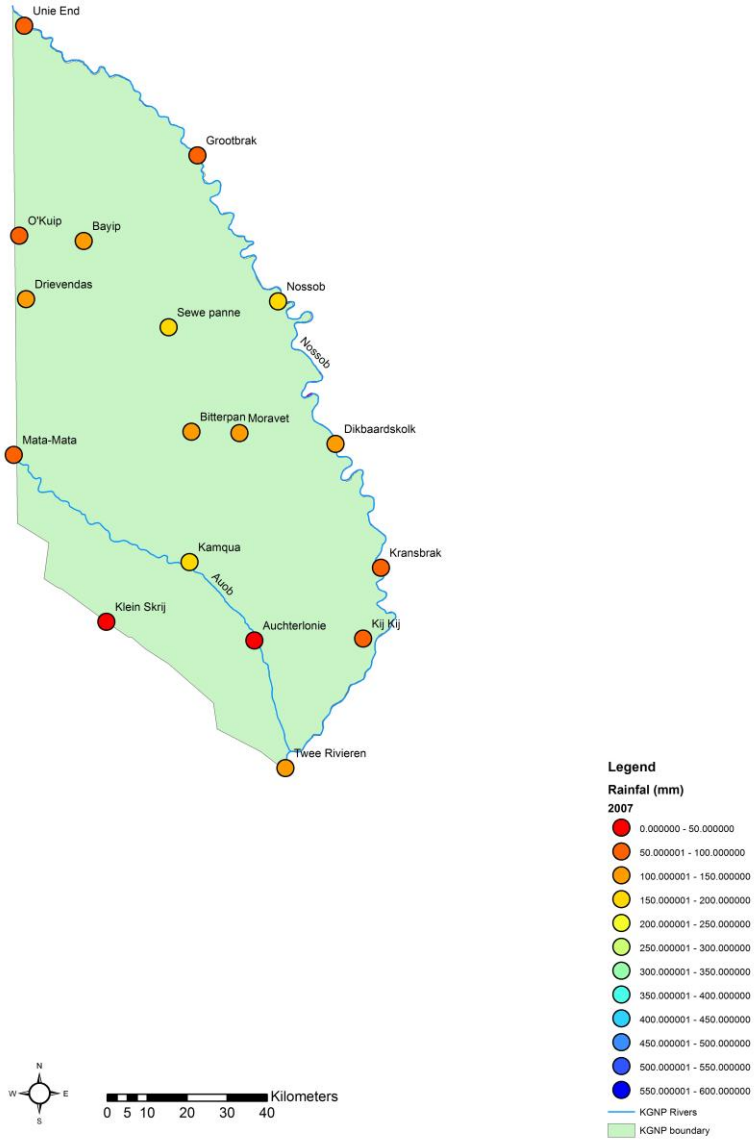
B


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Auob
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
Kilometers
0 5 10 20 30 40
Legend
Rainfal (mm)
2004
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

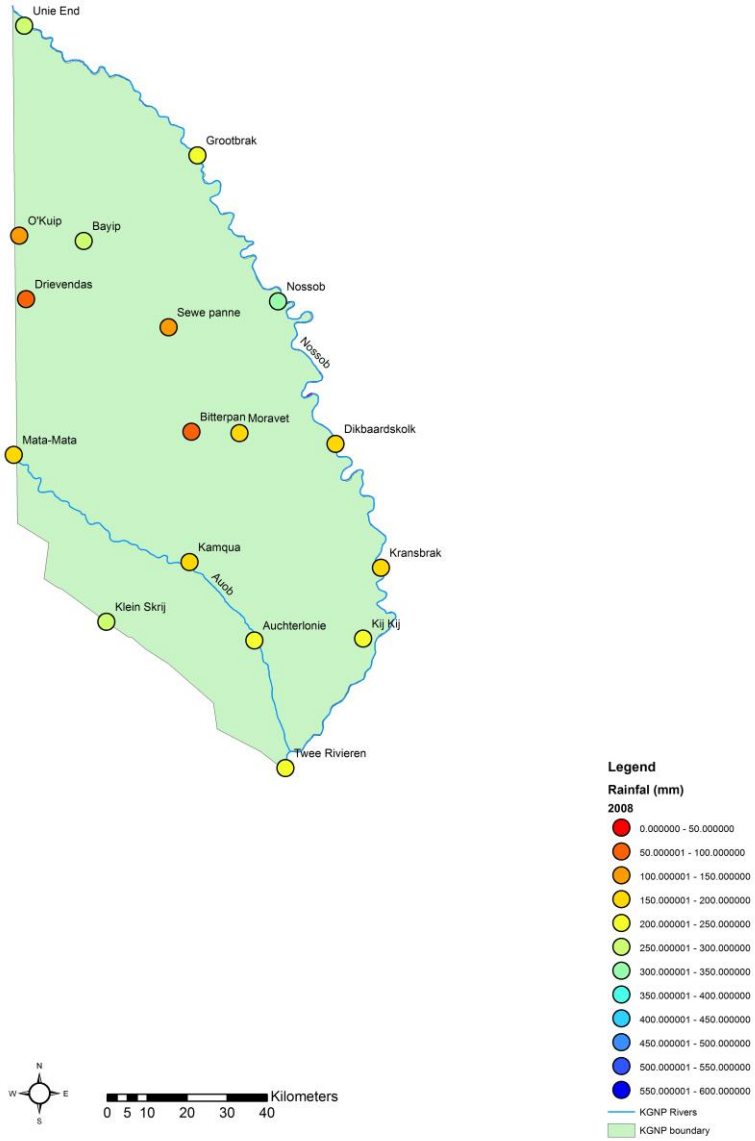
C


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
0 5 10 20 30 40
Kilometers
Legend
Rainfal (mm)
2006
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

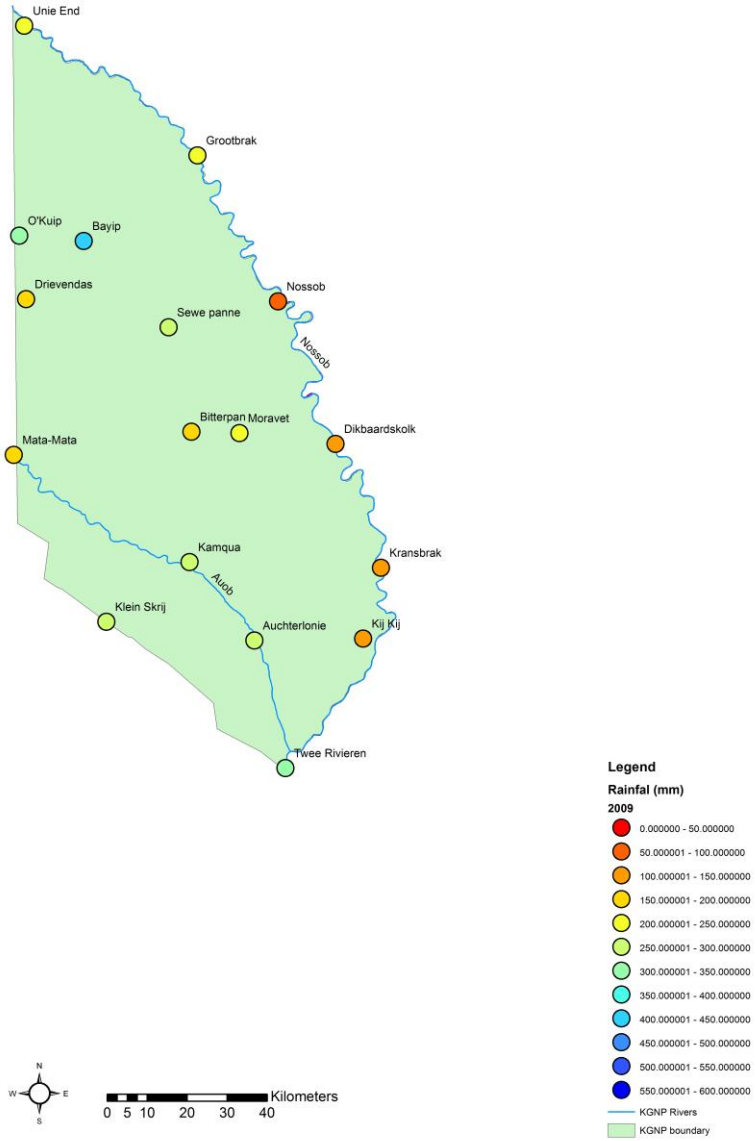
D


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
0 5 10 20 30 40
Kilometers
Legend
Rainfal (mm)
2007
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

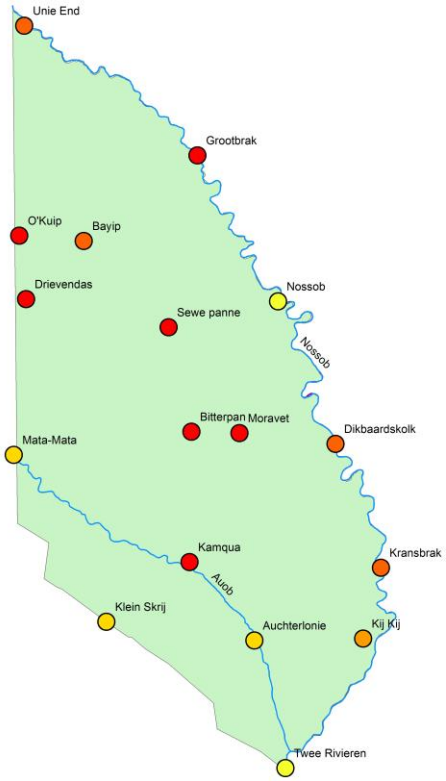
E

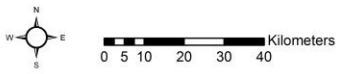

Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
0 5 10 20 30 40
Kilometers
Legend
Rainfal (mm)
2008
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

F


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren
N
W
E
S
0 5 10 20 30 40
Kilometers
Legend
Rainfal (mm)
2009
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

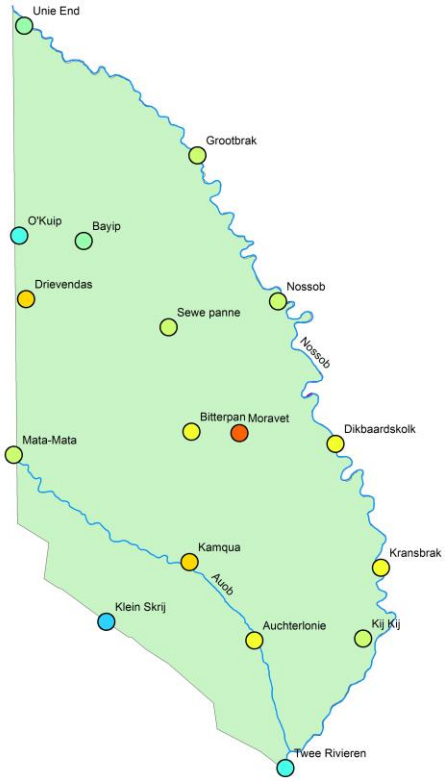
G

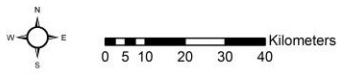

Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren


N
W
E
S
Kilometers
0 5 10 20 30 40


Legend
Rainfal (mm)
2010
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

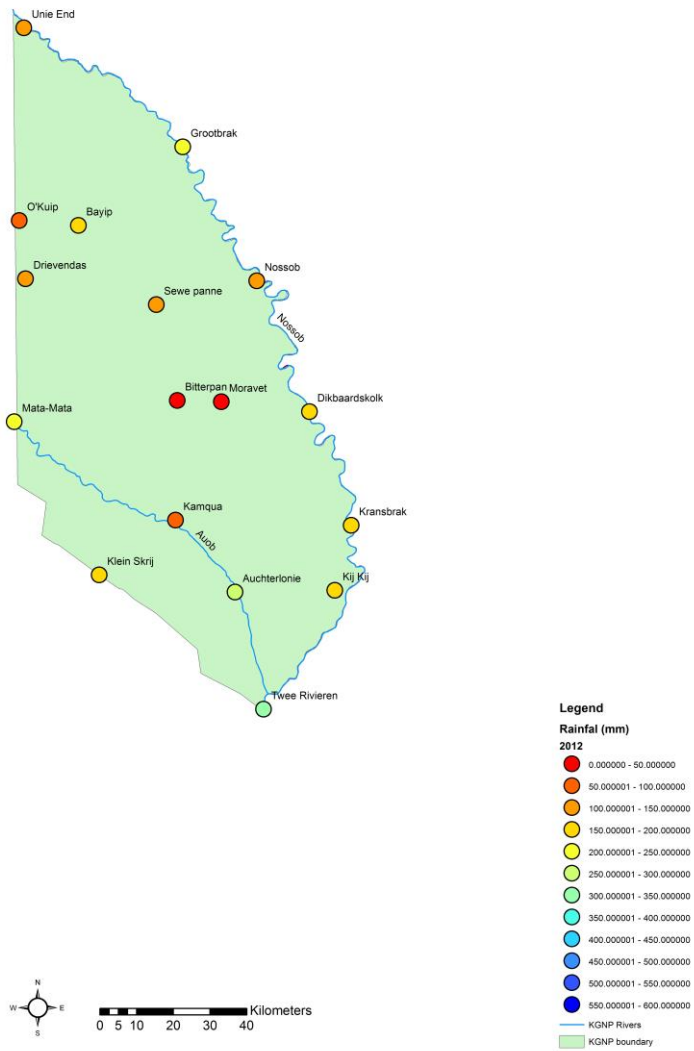
H


Unie End
Grootbrak
O'Kuip
Bayip
Drievendas
Nossob
Sewe panne
Nossob
Bitterpan
Moravet
Dikbaardskolk
Mata-Mata
Kamqua
Kransbrak
Aub
Klein Skrij
Auchterlonie
Kij Kij
Twee Rivieren


N
W
E
S
Kilometers
0 5 10 20 30 40


Legend
Rainfal (mm)
2011
0.000000 - 50.000000
50.000001 - 100.000000
100.000001 - 150.000000
150.000001 - 200.000000
200.000001 - 250.000000
250.000001 - 300.000000
300.000001 - 350.000000
350.000001 - 400.000000
400.000001 - 450.000000
450.000001 - 500.000000
500.000001 - 550.000000
550.000001 - 600.000000
KGNP Rivers
KGNP boundary

I



J

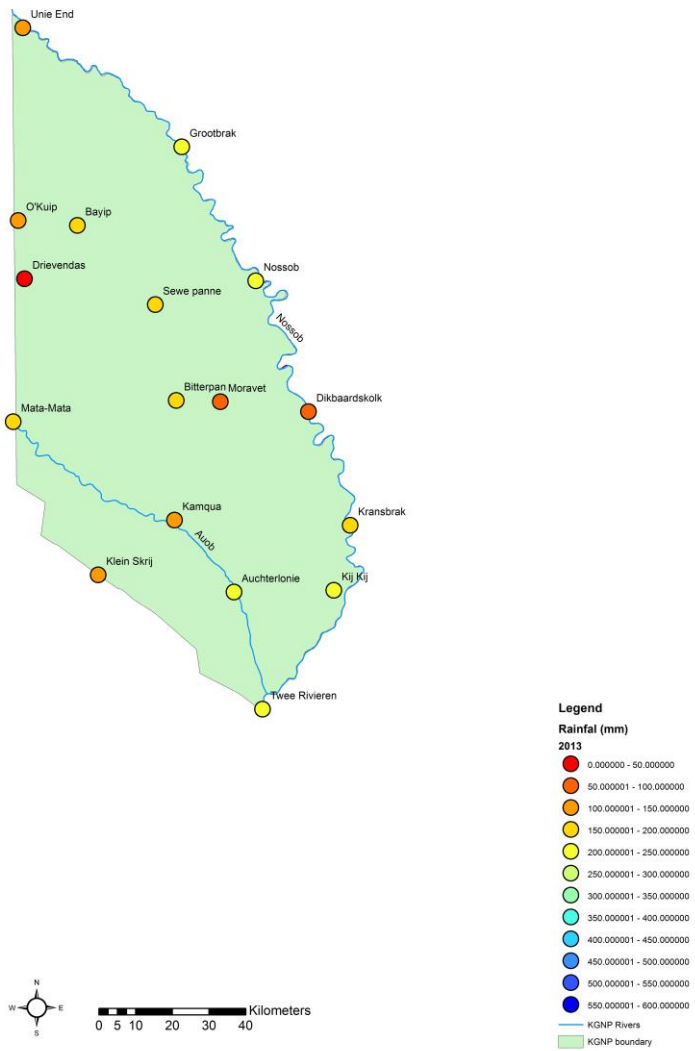


Figure 6.1: Inter-annual rainfall variability (mm) across KGNP for the period 2004-2013 (A-J).

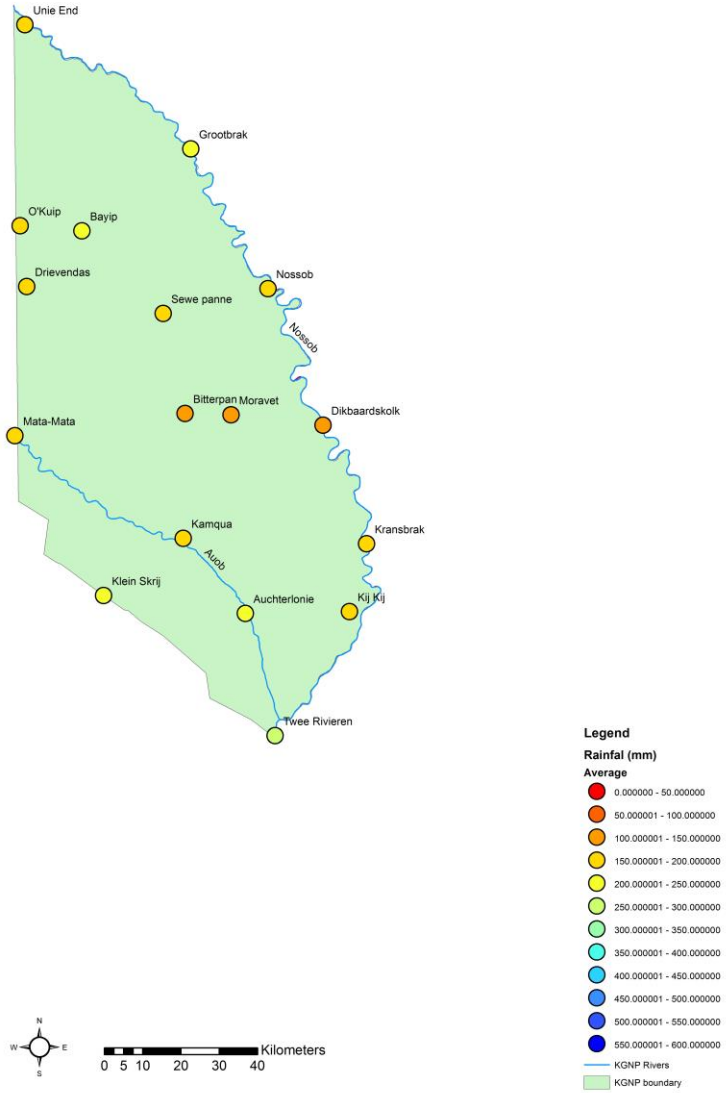


Figure 6.2: Average rainfall variability (mm) across KGNP for the period 2004-2013.

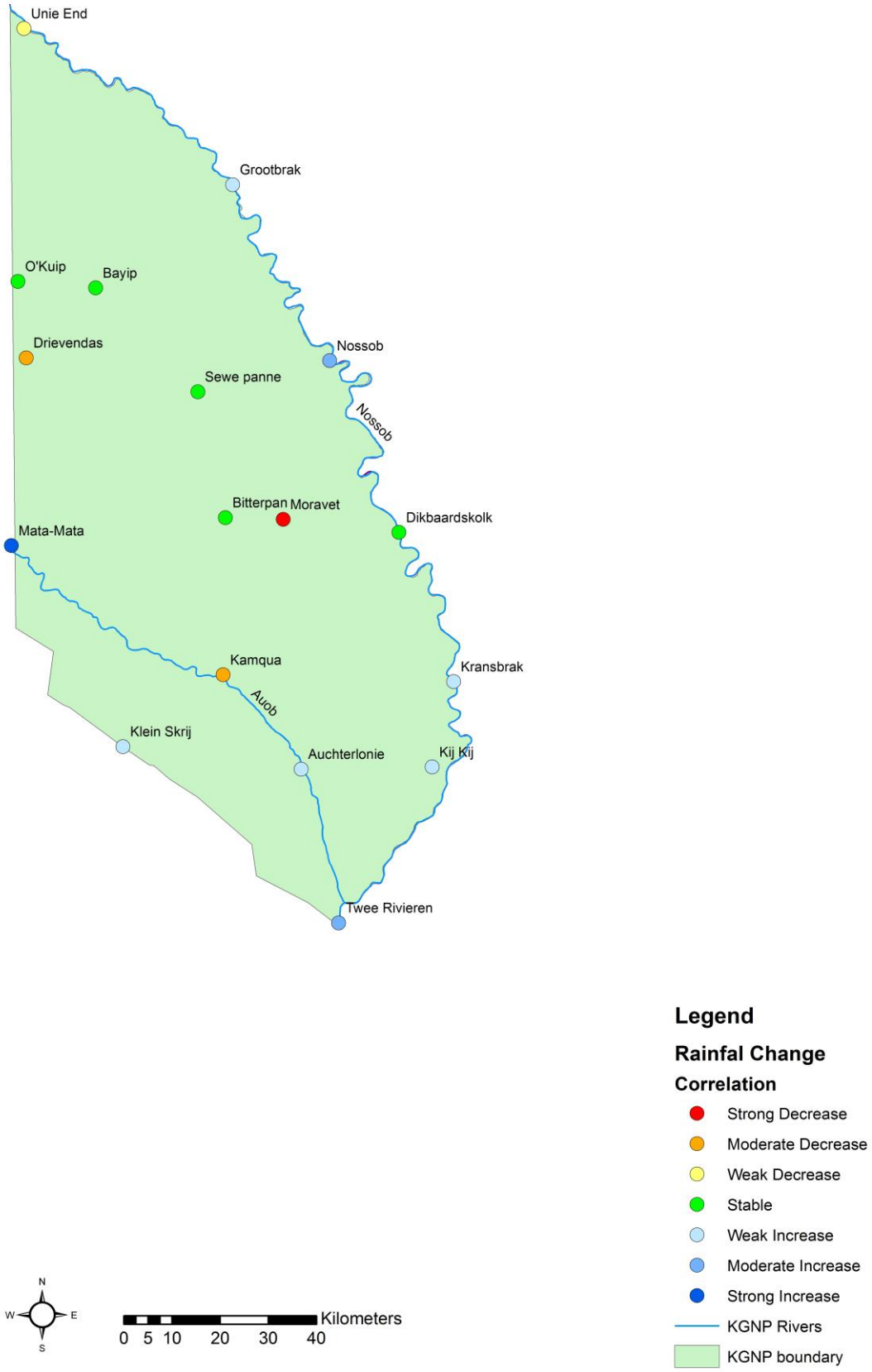


Figure 6.3: Map indicating decreasing, stable and increasing rainfall trends over the period 2003 - 2004 in KGNP.

6.2.1.2 Temperature Trends in KGNP

The mean annual T_{max} for Twee Rivieren (1960 - 2014), Mata-Mata (1975 - 2014), Nossob (1975 - 2014) and Upington (1940 - 2014) are similar, differing by less than 1.5^{o}C. (*Table 5.2, Figures 5.6 - 5.9*). Further, statistically significant increases in mean annual T_{max} of 0.05°C/yr, 0.06°C/yr, 0.05°C/yr and 0.01°C/yr exist for Twee Rivieren, Mata-Mata, Nossob and Upington (*Table 5.2, Figures 5.6 - 5.9*). These results support those in the literature; van Wilgen *et al.,* (2015) reports the rate of change in temperature maximums to be 0.039°C/yr from Twee Rivieren, KGNP. Temperature increases for T_{min} are observed for Twee Rivieren (0.01°C/yr), Mata-Mata (0.07°C/yr) and Upington (0.02°C/yr), over the same periods above. This is expected, as other studies have recorded increases across parts of southern Africa with positive trends in annual maximum and minimum temperatures (Kruger and Shongwe, 2004; Reddy *et al.,* 2010; Kruger and Sekele 2013; van Wilgen *et al.,* 2015). These increases are most evident in the almost 2°C change in mean maximum temperature since 1960 in KGNP (Kruger and Sekele, 2013; Hetem *et al.,* 2014; Mackellar *et al.*, 2014; Mphale *et al.,* 2014; van Wilgen *et al.*, 2015). These increases are further emphasized by the range in mean annual T_{max} for Twee Rivieren being 5.4°C with a maximum of 33.4°C in 2010 and a minimum of 28°C in 1974 (*Figure 5.6*). The results highlight similar increasing trends for T_{min}. Yet, T_{max} and T_{min} data from the period of overlap between the stations (1975 - 2014) have demonstrated similar increases in temperature trends (*Figure 5.10*).

Seasonal variations further demonstrate these increasing temperature trends. The highest monthly range, being the year with the highest T_{max} minus the lowest T_{max}, is calculated at 10.1°C for March at Nossob, ranging from 36.9°C in 2013 to 26.8°C in 1982. This demonstrates increasing temperatures for March from 1982 to 2013. The highest monthly T_{min} range, exists for Nossob, with October temperatures spanning 14°C from 19.3°C in 2004 to 5.3°C in 2009 (*Table 5.7, Figures 5.12 and 5.14*). Specific months over the study period had an average T_{max} that exceeded 40°C. These months occurred during January 2013 and December 2009 for Twee Rivieren and December 2009 for Nossob. Over the study period, there has been a marked increase in the number of months with a T_{max} average exceeding 40°C, which are

noted for Twee Rivieren (1940 - 2014) and Nossob (1975 - 2014). van Wilgen *et al.,* (2015) previously established this, demonstrating that the number of days where T_{max} exceeds 35°C have increased in KGNP since the mid-late 1990s. The results observed during this study did not demonstrate any significant increase/decreases for monthly T_{min} thresholds <0°C. However, van Wilgen *et al.,* (2015) has highlighted that days with temperatures below 0°C are becoming significantly less common in KGNP (-0.26 days/yr) since 1960 to 2009.

The results of this study have indicated warming by almost 2°C over KGNP from 1960 until present. Other studies have demonstrated relatively strong warming trends in most western parts of South Africa, including the Northern Cape (Kruger and Sekele, 2013). Continuing temperature increases are hypothesised to result in greater reliance on the water troughs by faunal species. As previously mentioned, the reduction of precipitation will result in desertification in the region. Therefore, less surface water availibility will negatively affect faunal species. These climate changes are largely consistent with the southern African region (Rutherford, 1999; Nkomo, 2006; Kruger and Sekele, 2013; Mphale *et al.,* 2014; van Wilgen *et al.,* 2015). However, it is more pronounced for KGNP due to its position within the North-western region and the present arid conditions. The results of the study have also indicated reductions in cold extremes, which are being experienced in KGNP. This is consistent with recent literature, which explains that reductions in cold extremes could possibly result in a range expansion of species that were previously restricted by cold winter temperatures (Kruger and Sekele, 2013; van Wilgen *et al.,* 2015). These likely increasing events of warming, highly variable rainfall and decrease in cold extremes will have negative effects on biodiversity through habitat loss as a result of increasing evaporation and desertification (Foden *et al.,* 2007; Kruger and Sekele, 2013).

6.2.1.3 Summary

KGNP is a semi-arid region affected by changes in mean annual rainfall, inter-annual rainfall variability and increasing T_{avg}, T_{max} and T_{min} as a result of climate change (Tews *et al.,* 2004; Moalafhi *et al.*, 2012; Mphale *et al.,* 2014). Analyses of long-term climate data confirm that long-term regional rainfall is unchanged (a non-significant

decrease of 1.5mm/yr). Of greatest concern are the long-term broad patterns of significant increasing T_{max} at an average of 0.04°C/yr and T_{min} at an average of 0.05°C/yr KGNP. These trends will increase the likelihood of extreme events such as droughts, thus increasing desertification, which negatively affects the semi-arid savanna ecosystems of KGNP. This all contributes to depleting water sources, which affect vegetation and impact fauna negatively (Noble and Gitay, 1996; Batisani and Yarnal, 2010; Hisali *et al.,* 2011). Results in short-term (2003 - 2014) mean inter-annual rainfall demonstrate regional variability within the region of KGNP. Rainfall variability averaged over 10 years demonstrate that some sites getting wetter in the southern region and others getting drier in the northern region, whilst the central region remains reasonably stable.

6.2.2 Faunal Observations

6.2.2.1 Regional Distribution of Fauna

During the study period (October 2012 - December 2014), a total of 23 mammal species were observed visiting the Nossob water trough. However, the drinking water-use behaviours of only 10 mammalian species were analysed as the other species visited only rarely, for the remaining 11 mammalian species, please refer to *Table 4.4*. Child *et al.* (1971) reported these same species seen during the census (red hartebeest, blue wildebeest and gemsbok) along the Nossob River utilising the artificial water troughs. The daily and seasonal migration patterns of mammals are dependent on spatial and temporal surface water distribution (Western 1975; Epaphras *et al.,* 2008). Steenbok are not dependent on surface water and are predominately browsers (Roodt, 2015). These species are the most evenly distributed due to their sedentary lifestyle with preferential dune inhabitancy (Mills and Mills, 2013). Eland are intermediate feeders and are not dependent on surface water. These species rarely come into the riverbeds and only do so to cross from the South African side to the Botswana side of larger KTP (Mills and Mills, 2013).

Blue wildebeest populations are either migratory or resident, with migratory populations staying aggregated while engaged in local or long-distance movements in search for greener pastures. Alternatively, resident populations are more sedentary and dispersed in small, segregated herds (Estes, 1991). These sedentary

populations have been reported by Leistner (1959), Bothma (1972) and Kasiringua (2010) to reside close to water sources, even if not directly observed drinking water, which likely explains their high relative abundance in the Nossob area. Knight (1995) reported that water troughs offer water and grazing opportunities, which attract sedentary blue wildebeest (*Figure 6.4*).



Figure 6.4: Blue wildebeest utilising the natural surface water in the Nossob riverbed after heavy rainfall in March 2014.

Gemsbok utilises areas that can only be used by other grazers during the rainy season (such as duneveld areas) (Estes, 1991), which explains their expansive regional abundance in KGNP. Gemsbok are nomadic and exist within gregarious mixed herds, which is an adaptation in semi-arid environments where sparse and unpredictably distributed forage favours nomadism and very low population density. Gemsbok travel great distances in semi-arid environments, occasionally congregating in a locality where a thunderstorm has stimulated the growth of grass (Estes, 1991). These are demonstrated in the aerial census data as gemsbok are

distributed widely throughout the landscape in KGNP, and inhabit a variety of ecological zones (duneveld, riverbeds, pans and plains). Mills and Mills (2013) have reported that gemsbok show a high preference for water troughs that are highly mineralised, such as the Melkvlei and Grootbrak water trough.

Stapelberg *et al.* (2008) argue that springbok are considered to be water-independent, but when water is available - as through artificial sources, springbok drink regularly. The usual ungulate wet season dispersal and dry season congregation is reversed for springbok. This species tends to aggregate in the rains due to the presence of short green pastures and disperse in small groups during the dry season. If the plant species (trees and bushes) that sustain springbok populations during the dry season diminishes, springbok may evacuate their normal range in large herds (Estes, 1991).

6.2.2.2 Patterns in the Timing of Appearance

Water is essential for the survival of wildlife in protected areas, and thus the provision of artificial water sources in semi-arid regions, such as in KGNP, are important to supply water for fauna throughout the year (Western 1975; Epaphras *et al.,* 2008; Hayward and Hayward, 2012). This study observed a total of 10 mammalian in the webcam images at the Nossob artificial water trough. Observations over an 18 - hour daily period revealed visitation peaks in the timing of water trough usage by mammalian species (morning, afternoon and evening). Statistically, PCA separated species into nocturnal and diurnal peak visitation groupings, with the dendrogram demonstrating strong evidence of a division between morning, afternoon and evening peaks.

Species visiting during the morning (04:00 - 09:00) were limited to the carnivores, which were also observed during the evening (18:00 - 22:00). Two main sub-groups (A and B) classify the cluster dendrogram where species are divided into clear groupings of carnivore species, with the exception of gemsbok, and herbivore species (*Figure 5.20*). These carnivores are typically nocturnal and utilise the water trough during the cooler hours of the morning and evening to avoid heat stress (*Figures, 5.22;* Hayward and Hayward, 2012). Carnivores in Tsavo, Kenya, as also

displayed peak water trough usage at night and during dusk/morning (Ayeni, 1975). Jackals were observed most frequently in the morning between 05:00 and 09:00 (18%) and in the evening between 19:00 and 22:00 (48%; *Table 5.11*). Personal observations have confirmed that jackal utilise the Nossob water trough early in the morning, as they prey on Cape Turtle Doves and sand grouse (*Pers. Obs*., 2015; *6.5*). These behavioural patterns by jackals were also observed at other water troughs (Cubitjie Quap and 13th waterhole; *Figure 6.6* and *6.7*).



Figure 6.5: Observation of successful predation by jackal on sand grouse at Nossob (Annette Laursen, 2015).



Figure 6.6: Jackal hunting at the Cubitjie Quap water trough at dawn (06:27) (Maraschin, 2015).



Figure 6.7: Successful Jackal hunting at the Cubitjie Quap water trough at dawn (Annette Laursen, 2015).

Cheetah were the only carnivore that had one peak time of water trough usage, which occurred during the nocturnal hours (n = 27, 18:00 - 21:00). A large proportion of a cheetah's diet consists of springhares (Mills and Mills, 2013), which are nocturnal species and usually reside in the riverbeds. Furthermore, this hunting pattern may explain the use of the water trough usage by cheetah during the nocturnal hours (Mills and Mills, 2013).

Gemsbok peak water trough usage differed from other herbivores in KGNP, with the former visiting only during nocturnal hours. An explanation for this is that gemsbok limits their activity during the heat of the day to conserve water. Thus, its most active times are at dawn and dusk (Mills and Hes, 1997). This species was observed most frequently (59% of visitations) between 19:00 and 22:00, overlapping with carnivore drinking hours. However, gemsbok did not drink at the water trough whilst other carnivores were consuming water (*Figure 6.8*). Gemsbok are well adapted to withstand high temperatures and allow their body temperature to fluctuate in response to environmental stress. When exposed to temperatures above 45°C, they do not sweat, instead they allow their body temperatures to rise to more than 40°C saving a significant amount of water. As their body temperature becomes higher than the outside temperature, heat will flow from the gemsbok into the environment during the nocturnal cooler air (Mills and Mills, 2013). During this study, gemsbok are often

observed utilising the water trough individually or in pairs and are seldom observed visiting the water trough with other ungulate species (*Figure 6.8*). Mills and Mills (2013) describe that gemsbok utilise the water troughs in the semi-arid KGNP for the minerals they obtain, rather than for moisture. This could explain the irregular use of the Nossob water trough by this species.



Figure 6.8: Gemsbok pair visiting at the water trough during the nocturnal hours.

Species that consume water regularly have an advantage if they utilise the water troughs during the cooler hours of the day when their water losses are at their minimum. However, most herbivores at Nossob were observed to have peak water trough visitation during midday between 12:00 - 13:00 (14%) for October 2012 to December 2014 (*Table 5.10*), likely to avoid predators (*pers. obs*., 2015). The literature has reported similar findings, where ungulate species avoid drinking during the nocturnal hours due to perceived predation risk (Ayeni, 1975; Valeix *et al.,* 2007; Valeix *et al.,* 2008; Hayward and Hayward, 2012; Crosmary *et al.,* 2012). De Boer *et al.* (2010) examined predation rates in African lions and concluded that these

carnivores were located near water sources frequently, not only for water, but also for prey availability. Water troughs have been suggested to be “predation traps” where visiting ungulates are likely to be ambushed by predators (Simpson *et al*, 2011). In Tsavo, Kenya, prey species utilise the water trough primarily during the daylight hours as their eyesight is better and this enhances the chances of the prey species to escape predation at or on their way to the water troughs (Ayeni, 1975). When herd size increases, the probability of drinking increases and the time spent accessing water decreased (Valeix *et al.,* 2007). Herds of blue wildebeest and springbok were observed at the water trough over the study period (*Figures 6.9, 6.10*). This demonstrates that these species occur in herds to avoid being vulnerable to predators.



Figure 6.9: A herd of blue wildebeest (n = 12) at the water trough.

During this study, prey and predator species were not observed at the Nossob water trough during the same time periods. The webcam’s main focal point is on the water trough, therefore, it was difficult to establish whether carnivores were located in the surrounding area along the Nossob riverbed whilst ungulates were utilising the water trough. Another reason for afternoon water trough usage during maximum temperatures (afternoon) by Springbok, red hartebeest and blue wildebeest is to

compensate for water loss in the form of perspiration (Mills and Mills, 2013).



Figure 6.10: A herd of springbok (n = 22) at the water trough.

Analysing faunal visitation during the wet (hot) seasons and dry (warm/cool) seasons established clear patterns of water trough usage. Peak water trough usage during the dry seasons of 2013 and 2014 (14%) occurred during 19:00 - 20:00 and 12:00 - 13:00 (*Table 6.2*). Results demonstrate increased water trough usage during the dry seasons of 2013 and 2014, which is to be expected due to the low water and plant moisture availability. During the dry season, faunal species consume water more regularly (58%) than during the wet season (41%). This is so that faunal species can meet their body requirements when less natural surface water is available (Epaphras *et al.,* 2008). In Ruaha National Park, Tanzania, faunal species congregate around the artificial water sources during the dry season, as this is the only permanent source of water when the Great Ruaha River ceases to flow (Mtahiko *et al.,* 2006). Blue wildebeest, red hartebeest and springbok are considered to be water-dependent and are based around permanent water sources during the dry seasons (Ayeni, 1975). During the dry season, drinking frequency increases due to the low plant moisture content and relatively high temperatures (Auer, 1997; Rudee, 2011).

Table 6.2: Classification of wet and dry seasons, and peak water trough usage during the study period.

	Wet and Dry season	Peak usage Time	Peak Usage %
Wet Season	October 2012 - February 2013	12:00 - 13:00	9%
	September 2013 - February 2014	20:00 - 21:00	11%
Dry Season	March 2013 - August 2013	19:00 - 20:00	14%
	March 2014 - August 2014	12:00 - 13:00	14%

6.2.2.3 Seasonal Water Trough Usage

Seasonal water trough usage was categorised into the wet (hot) season from November to April, and into the dry (warm/cool) season for the months of May to October (Bergstrom and Skarpe, 1999). Results demonstrate that herbivores utilise the water trough more during the dry rather than wet season (75%: 25%; respectively). Blue wildebeest, red hartebeest and springbok are considered to be water dependent and are based around permanent water sources during the dry seasons (August - October 1973) (Ayeni, 1975). Valeix (2011) has established that most herbivore species in Hwange National Park, Zimbabwe, require access to drinking water to complement the lack of forage consumption during the dry season when forage quality and water content is low.

Cheetah and lion were mostly observed at the water trough during the wet season rather than the dry season (90% and 10%, respectively, for both species). Springbok are highly congregated in the riverbeds during the wet season due to the availability of grass. A large proportion of the cheetah's diet consists of springbok, which may explain the abundance of cheetahs at the Nossob water trough during the wet season (Mills and Mills, 2013). However, brown hyena (39%: 61%, respectively) and leopard (32%: 68%, respectively) were observed more frequently during the dry rather than the wet season. In terms of leopard, this may suggest a preference for the Nossob water trough as a result of increased herbivore (prey) density (*Table 5.13*). These carnivores acquire most of the water requirements through the bodily fluids of their prey, which explains their relative absence from the water trough during the dry season (Eloff, 1973a; Simpson *et al.*, 2011; Hayward and Hayward, 2012). Both jackal and spotted hyena (utilise the water trough approximately equally during the wet and dry seasons; therefore, the visitation behaviour of these species is not

seasonally controlled (*Table 5.13*).

During 2013, maximum water trough usage occurred during autumn (33.72%), with the second highest water trough utilisation occurring in spring (27.24%; *Table 5.14*). The following year of 2014 differed considerably, with the highest water trough utilisation in spring (55.71%), and the lowest in autumn (4.63%; *Table 5.14*). The increased water trough activity during spring 2014, and to a lesser degree in spring 2013, may be due to increasing heat stress, a shortage of food sources and no natural water availability (Shresta *et al.,* 2012). Results are similar to Valeix (2011), as herbivore species during 2004 peak water trough usage occurred during September. The high frequency of visitation during winter 2014 (28.02%) and spring 2014 (55.71%) suggest that fauna are concentrated around permanent surface waters during the dry months, when no natural surface water is available (*Table 5.14*) (Franz *et al.* 2010). Conversely, low visitation during summer (11.63%) and autumn (4.63%) in 2014 suggest that fauna are making use of the natural surface water during the wet season rather than the artificial water trough (*Table 5.14*) (Epaphras *et al.,* 2008; Valeix, 2011).

Preferential water trough usage for carnivores (jackal, lion, brown hyena, leopard and cheetah) in 2013 occurs late summer and early autumn, and during November for spotted hyena. Sporadic visitations by cheetah and leopard suggest these species drink opportunistically when water is available (Bothma, 2005). Labuschagne (1979) has reported that cheetah in the southern Kalahari drank water infrequently and sporadically, despite water being readily available within their ranges. This is possibly because carnivores get most of their moisture requirements from prey species, and thus mainly utilise the water troughs for hunting grounds (Simpson, *et al.,* 2011). However, there is no evidence of carnivores using the water trough as hunting grounds based on the available images and observations that were viewed during the study. It has been observed during 2014, that peak water trough utilisation for jackal, spotted hyena and brown hyena occurs during winter and spring (July to October) and during December for lion. Drinking patterns in 2013 differ to those in 2014, as water trough utilisation peaks occur later in 2014 than in 2013 for carnivores (*Figure 5.22 A, B, C and D*). No rainfall occurred during October and November 2013, while 39.2mm of rainfall occurred during these months in 2014.

The low rainfall in October and November 2013 could account for fauna having utilised the water trough more frequently / earlier peak visitation during these months in 2013 than 2014.

Maximum water trough usage by herbivores (blue wildebeest, springbok, gemsbok and red hartebeest) occurs during June to October 2014. Therefore, these species are demonstrating a heavy reliance on the water trough during the dry months of the year, when no surface water is available (Ayeni, 1975; Chamaille-Jammes *et al.,* 2007a; Valeix *et al.,* 2011). Herbivores seen at the water trough are grazers and are typically water-dependent and therefore, are more reliant on the artificial watering points during the dry season than the wet season, when natural water sources and grazing are not available (Derry, 2004; Derry and Dougill, 2008). A study by Bothma (1971) has established that springbok are relatively abundant along the Nossob River bed, in the immediate vicinity of the Nossob water trough. The only herbivore that demonstrates a pattern of water trough usage is blue wildebeest, as visitation during 2013 is similar to 2014 (between the months of June to October for both years). This species consumes water every second/third day at water troughs and are poorly adapted to dry conditions because of their physiology (Nagy and Knight, 1994; Auer, 1997; Schmidt-Nielsen, 1997).

During 2013, springbok disappeared from the water trough from April to October, which may be a result of migration to another region of KGNP. These results support the findings of Mills and Retief (1984), who showed that springbok disappear into the Auob riverbed in late summer to early winter each year. Earlier, Bothma (1971) had also noted that springbok disappear from most of the Nossob River valley during the dry season. Further, springbok were located in zones without water than in zones with water during the dry season (Mills and Retief, 1984). The high abundance of springbok, red hartebeest and gemsbok at the water trough during July to October 2014, compared to the same time period 2013, could be attributed to multiple variables (i.e. water quality, vegetation and predator presence) of which are unknown due to the lack of quantifiable data.

6.2.3 Relationship between Fauna and Climate

Semi-arid regions, such as KGNP, receive limited and variable annual rainfall, with high ambient temperatures (Kos *et al.,* 2012). Such rainfall supplies resources sporadically during the wet summer months (Chesson *et al.,* 2004). Therefore, fauna have to adapt accordingly to these dry conditions in order to survive (Phillipson, 1975). The results of this study demonstrate the influence of rainfall and temperature on mammal/avian drinking patterns at the Nossob water trough.

6.2.3.1 Rainfall and Fauna

Various studies have analysed faunal distributions in relation to rainfall. A study in the KNP has confirmed that elephant movements are affected by seasonal changes in rainfall (Birkett *et al.,* 2012). Similarly, a study in Amboseli, Kenya established that the total biomass of fauna within the dry season show a close relationship to rainfall (Western, 1975).

In particular, studies in the southern Kalahari and KGNP have reported that a strong link exists between rainfall events and ungulate species abundance. These ungulate species abundance are positively correlated with wet-season rainfall (Bergstrom and Skarpe, 1999). Parris (1984) has reported that a number of ungulate species, particularly the large herd species (springbok, red hartebeest and blue wildebeest), can sense rainfall and move to where the rain has fallen. The results of the current study revealed significant, strong correlations during April between rainfall and blue wildebeest, steenbok and springbok distribution/abundance (*Table 5.12, Figure 6.11A*). Further, research has concluded that the largest mean herd sizes (n = 40, in 329 herds counted) of springbok have been recorded during May, June, July and August and smallest (n = 19, in 326 herds counted) during the September, October, November and December (Stapelberg *et al.,* 2008). These strong correlations are linked to various weather stations in the northern (Drievendas and Unie End) and southern (Auchterlonie) regions of KGNP, where 20 - 40mm of rainfall occurred in these areas during April on average over the past 10 years (*Figure 6.11A*).

In addition, previous research in KGNP has documented a strong link between rainfall events and ungulate relocations to riverbeds, due to increased vegetation

growth in both the short- and long-term (Mills and Retief, 1984; Park and Sohn, 2009). Therefore, the strong relationship in April for blue wildebeest and steenbok at Auchterlonie and Unie End is representative of the wet summer months of high rainfall and reasonably good water availability in the Auob riverbed (*Figure 6.11A*). In contrast to this, statistically insignificant calculations for all species in April at Bayip suggest that fauna (blue wildebeest and springbok) are barely observed in the dunes, and are mainly located in the riverbeds (*Figure 6.11A*). Bayip is located in the duneveld, ±30km from the Nossob riverbed. Ungulate species congregate in the riverbeds during the wet season in response to vegetation growth (grass species), which justifies the lack of faunal presences at Bayip. The reason for the weaker gemsbok and rainfall correlations during April is because this species responds slowly to rainfall and reaches their highest peaks around riverbeds in years of high rainfall when grasses are tall (Mills and Retief, 1984).

In addition, strong correlations were also seen during September between rainfall and faunal species, over the period 2004 - 2013 at Kransbrak for blue wildebeest and steenbok. This could be due to low rainfall (1.9mm) occurring in this area resulting in these species becoming more reliant on the water troughs along the riverbed (*Figure 6.11B*). However, rainfall is low across the whole park during September, which might explain a higher abundance of faunal species along the riverbeds at the water troughs in particular. During the aerial census, Ellis and Herbst (2012) reported that blue wildebeest and springbok were mainly recorded in the Nossob and Auob riverbeds, relying on the artificial water troughs located along these drainage systems.

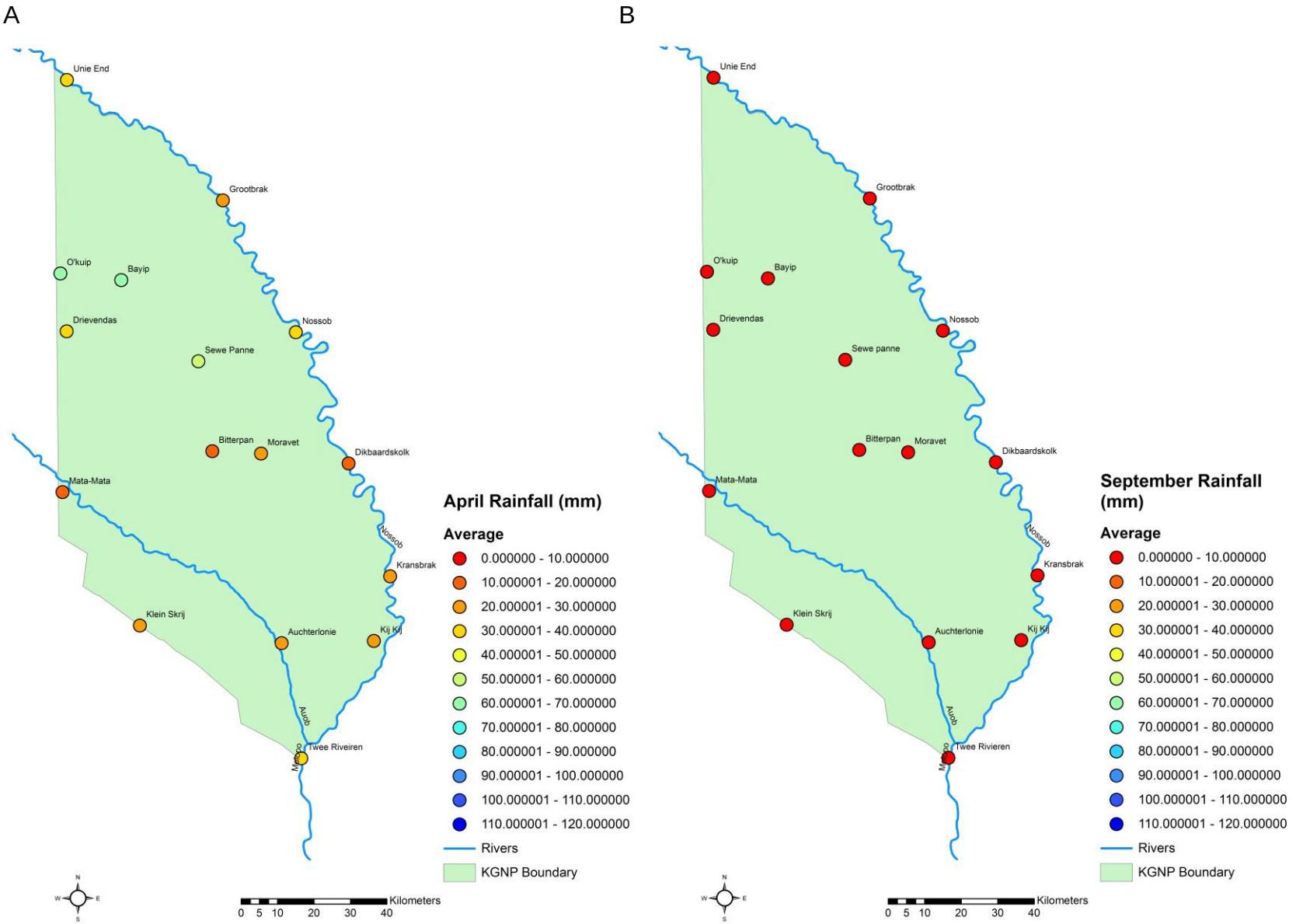


Figure 6.11: Average rainfall for April (A) and September (B) across KGNP over the period 2003 - 2014.

Hayward and Hayward (2012), one of the only other studies to assess the influence of rainfall on waterhole use, demonstrated that ungulates consume water from the natural surface waters when it is available. The current study has revealed similar patterns, with fauna disappearing from the Nossob water trough during and immediately after rainfall events (*Figure 5.25*). Statistically significant negative correlations exist between water trough usage and one-day following a rainfall event, suggesting that faunal water trough usage decreases due to the availability of natural surface water, and possibly the preferential consumption of this water (Epaphras *et al.,* 2008; Rudee, 2011).

Depending on the quantity of water during a rainfall event, fauna gradually return to utilising the water trough when the natural surface water dries up. The results showed that quantity of rainfall of at least 20mm or more needs to occur for mammals to consume natural surface water, in preference to the water trough (*Figure 5.26*). Further, all mammals individuals of each species disappeared from the water trough after rainfall events of ≥30mm (*Figure 5.26 H, I, J*), making use of natural surface water during such conditions. Few journal articles have published such observed results (Bothma, 1972; Ayeni, 1975; Parris, 1984; Epaphras *et al.,* 2008; Valeix, 2011). Of these, Valeix (2011) established that herbivores utilised the water trough at Nossob more intensively during the drought year of 2003 than in 2004, suggesting that the underlying mechanism for this is the quicker shrinking of surface water sources in a dry year, forcing herbivores to utilise the artificial water sources. Ungulates are known to congregate around the Nossob riverbed after heavy rainfall due to enhanced water availability and better grazing opportunities (*Figure 6.12;* Olff *et al.,* 2002). This is also confirmed by other studies in other regions of southern Africa (Bothma, 1972; Bergstrom and Skarpe, 1999; Park and Sohn, 2009).

The results demonstrate that faunal species start to utilize the water trough again 4 days later after a heavier rainfall event (20 - 85mm). Faunal visitations at the water trough decreased significantly after rainfall events >115mm, with fauna utilizing the water trough a considerable amount of days after the rainfall event. The water trough contains highly mineralised water as it is pumped from the groundwater, which

contains a high concentration of salts and minerals (Wanke and Wanke, 2007). Therefore, species will prefer to drink natural surface water when available (Auer, 1997). The above average rainfall also promotes the growth of grass. Herbivore species can then acquire their moisture from vegetation and do not need to consume water at the water trough (*Figure 6.12*).



Figure 6.12: Springbok and blue wildebeest grazing on vegetation to obtain moisture and food.

Mammal species were not directly related to rainfall, as expected, but related to the growth of vegetation within each stratum. Stratum B includes both the Nossob and Auob riverbeds and the central duneveld, which consists of grass vegetation. The aerial census data demonstrates that blue wildebeest, red hartebeest and springbok herbivores are mainly located within the riverbeds, with gemsbok residing in the duneveld as well as the riverbeds. The high grass availability in the riverbeds and duneveld might explain the higher abundance of grazer species within this stratum (B). Springbok and blue wildebeest rely on the short sweet grass (*Stipagrostis* spp: Bushmans grasses), which is highly concentrated along the river terraces. Stratum A includes the northern Nossob riverbed, consisting mainly of grass species and the

low and undulating duneveld, which comprises of open tree savanna (woodland species). Red hartebeest prefer to eat short to medium grasses (*E. lehmanniana* and *P. coloratum*), which are located in the low dunes and riverbeds, in strata A and B, north of Nossob where this species is highly abundant. A smaller abundance of species are located within stratum A than stratum B. Species are concentrated in the Nossob riverbed in this stratum (A) due to the grass availability, with low abundance in the duneveld. Irregular high duneveld and parallel duneveld are the ecological zones comprising stratum C. Gemsbok favour *S. Obtusa* and *E. lehmanniana* along the riverbeds, which might explain the high abundance of this species in stratum C. Species abundance and distribution are related to the effects of rainfall, such as the emergence of specific vegetation groups, within the landscape.

6.2.3.2 Temperature and Fauna

Ungulates living in semi-arid environments have to endure high solar radiation and a lack of water and vegetation cover, unpredictable food sources and the challenges these factors present for thermoregulation and water balance (Feldhamer *et al.,* 1999; Cain *et al.,* 2006). Consequently, it has been shown that during days which have higher ambient temperatures than usual, fauna visit water sources earlier or later in the day to prevent experiencing heat stress at the ordinary visitation time (Cain *et al.,* 2006). It is hypothesized that on hotter days fauna will visit the water trough earlier when they are already experiencing warmer temperatures than usual, in order to prevent experiencing heat stress at their ordinary visiting time (Cain *et al.,* 2006). Moreover, the timing of carnivore visitation controls the timing of herbivore visitation as they are attempting to avoid danger.

The results from this study suggest that on warmer days, carnivores preferentially consume water when temperatures are cooler, either earlier in the morning at 05:00 - 06:00, and later in the evening at 21:00 - 22:00 (*Figure 5.23*). Carnivores are nocturnal species and thererfore, will consume water during the evening hours. However, these nocturnal drinking patterns are affected by temperature increases. Therefore, it can be concluded that carnivores' preferential water trough usage shifts later in the evening by 4 min/°C and earlier during the morning peak by 6 min/°C. Carnivores tended to wait for temperatures to decrease after sunset (<34.9°C)

before drinking. Likewise, they drank before sunrise before temperatures increased above 20°C. The timing of carnivore visitations impacts the timing of herbivore visitations to a certain extent, as they will avoid predator prey interactions (Valeix *et al.,* 2007; Epaphras *et al.,* 2008; Simpson *et al.,* 2011; Hayward and Hayward, 2012).

Higher T_{avg} thresholds also influenced herbivore water consumption patterns, and during hotter days above 29.9°C, herbivores consume water later during the day when temperatures are cooler (*Figure 5.24*). Ungulate water consumption shifts to later in the afternoon, past midday, at a rate of 8 min/°C (*Figure 5.24*). During cooler T_{avg} thresholds (5°C - 9.9°C), ungulate water trough usage is high during midday, from 12:00 - 14:00. Species utilising the water troughs during midday are more exposed to direct solar radiation than at any other time during the day. This demonstrates that ungulates override their desire for water in order to avoid predation (Ayeni, 1975). Valeix *et al.* (2007) stipulates that during higher temperatures, the time spent by herbivores accessing water to drink decreased as temperature increased.

This study calculated peak hourly water trough usage per species in correlation with $T_{max,}$ T_{min} and T_{avg} over the study period. Even though not significant, negative correlations exist for blue wildebeest at T_{min} and T_{avg}, which indicates that, as temperatures get hotter, blue wildebeest frequent the water trough earlier during the day (*Table 5.*10). The results for temperature and monthly water trough usage correlations demonstrate that the strongest positive correlations exist for jackal (March 2013, November 2013 and October 2014) and blue wildebeest (September 2014). These strong correlations occur during hotter months of the year, suggesting that water trough usage increases as temperatures increase (Epaphras *et al.,* 2008).

6.3 Implications of Results

Long-term historic climatic trends from 1975 to 2014 in KGNP reveal significant increasing temperatures for Twee Rivieren, Nossob and Mata-Mata, averaged at 0.05°C/yr. Decreasing rainfall at Nossob and Mata-Mata over the same period is averaged at 1.4mm/yr, however, rainfall in Twee Rivieren demonstrates increasing

trends at 1.27mm/yr. Therefore, long-term trends indicate that the southern areas of KGNP are possibly becoming hotter and wetter, whilst the central and possibly the northern regions are becoming hotter and drier. The IPCC climatic models predict an increase in extreme dry events across the Kalahari of up to 30% by 2100 (IPCC, 2007). A temperature increase of 1.5°C - 3°C is predicted by 2050 with a decrease in rainfall by ~10% in the Kalahari (IPCC, 2007; Wang *et al.,* 2006). The impacts of temperature increases and changing rainfall patterns will have a great impact on faunal water trough usage and distribution in KGNP. Changes over the past decade demonstrate that the northern region of KGNP are becoming drier, whilst the central region remains reasonably stable, with the southern region becoming wetter. Therefore, if these patterns continue, ungulate species may be forced to shift their distribution ranges from the northern parts to the southern wetter parts of KGNP or even further into the larger part of KTP, Botswana. Understanding shifting patterns of faunal species in terms of temperature increases and rainfall variability will help park management to determine whether park expansion might be necessary (Gilson *et al.,* 2013).

Consequently, as parks cannot alleviate the problem of climate change, it is important that park management provide adaptation strategies to ensure the survival of faunal species (van Wilgen *et al.,* 2015). Therefore, it is pertinent that a park-scale evidence base for current climate trends are established so as to contribute towards effective policy and management (Gillson *et al.,* 2013; van Wilgen *et al.,* 2015). Analysing historic local climatic trends will help park management determine the extent (high or low exposure) to which the park is vulnerable to climate change (Gillson *et al.,* 2013). Parks, such as KGNP, which are highly vulnerable to climate change, require management interventions focused on enhancing heterogeneity and resilience in faunal species (Gillson *et al.,* 2013; van Wilgen *et al.,* 2015). It is important to understand the resilience of faunal species so as to ascertain the level (low or high) of management intervention needed (Gillson *et al.,* 2013).

Changes in climate can have three effects on fauna and flora, namely changes in distribution, changes in number and changes in genetic makeup (Root *et al.,* 2003; Thomas *et al.,* 2004; Ackerly *et al.,* 2010; GIllson *et al.,* 2013; Hetem *et al.,* 2014; van Wilgen *et al.,* 2015). For fauna, changes in distribution and range are the most

easily observed effect because fauna are mobile. For example, blue wildebeest initially migrated out of KGNP into the wetter regions of Botswana during the dry season. Due to the negative impacts of fencing, these species are restricted to KTP, the larger part of KGNP. Where migration is not possible, changes in rainfall and temperature might have a direct impact on KGNP region, as it may increase the rate of mortality for particular species (Tews *et al.,* 2004).

The results of this present study will contribute towards an understanding of which species demonstrate sufficient physiological plasticity to cope with the outcomes of climate change. This will allow management to make more informed decisions as to which species are highly vulnerable to climate change within KGNP (Hetem *et al.,* 2014). Moreover, this study contributes towards an understanding on the certain level of water dependency of faunal species. Therefore, management can understand which species will be most affected by increasing temperatures and changing rainfall variability. In particular, blue wildebeest exhibit physiological attributes that might make them vulnerable to climate change. Therefore, these highly water dependent grazers rely heavily on water troughs within the park during the dry season as they cannot migrate sufficiently far. Under sustained climate change, the capacity to provide water troughs may be compromised. Moreover, water troughs only address shortages in water for the faunal species and cannot improve conditions of extreme temperatures.

Furthermore, as a result of increasing temperatures and decreasing rainfall within KGNP, blue wildebeest and other faunal species will become more reliant on the water troughs and heavily congregate around them. As a result, these water troughs may not be able to sustain the particularly large populations and the groundwater that pumps into these troughs may become dry. Furthermore, greater population pressure at the water troughs may lead to changes in the avoidance patterns between species and may lead to greater mortality due to predation.

Springbok and red hartebeest are not as reliant on the water troughs as blue wildebeest, and therefore are not as threatened at present. If temperatures continue to increase in KGNP, these ungulate species may adopt similar nocturnal drinking habits to gemsbok in order to avoid heat stress during the afternoon. Gemsbok are

the least threatened herbivore species because of their advanced adaptations in semi-arid regions, such as thermoregulation and are not reliant on water sources. Carnivores are the least effected faunal species in KGNP as they minimise their diurnal activity, utilising the water trough during the nocturnal hours, avoiding the possibility of heat stress. Carnivores may benefit from the future shift in herbivore diurnal water trough usage patterns to nocturnal hours affording these species more hunting opportunities during the nocturnal hours.

Understanding mammal species drinking times at the Nossob water trough can contribute towards management purposes. The results of this study have demonstrated that fauna prefer natural surface water rather than artificial water sources. Changing and decreasing rainfall patterns may contribute towards the declining availability of natural surface water. Management needs to ensure that water quality in the water troughs is maintained and well managed to provide adequate water for faunal species. Addressing the concerns raised above, an understanding of the climate-fauna relationship can ensure that sufficient water is always available at the water trough. If the water trough becomes over populated, a second water trough could be established in the region, providing that the groundwater allows for this. Continued analysis of webcam data at multiple water troughs will allow for this over population to be detected timeously.

Information on the relationship between temperatures during the day and the faunal sightings will enhance the likelihood of tourists observing wild fauna at specific times. Management can use the information on species-specific water trough usage to inform tourists on faunal viewing opportunities during specific times of the day. However, this is more a suggestion to tourists as faunal species are unpredictable and their behaviour cannot be predicted. Water troughs have particular value in tourism as they concentrate faunal species into areas of good visibility and improve the game viewing and photographic experience (Ayeni, 1975; Van Wyk, 2011).

The further use of webcams could contribute towards management by providing information on specific water trough usage throughout KGNP at the various water troughs. This could provide knowledge on faunal water trough preferences, which in turn would assist in determining which water troughs should remain active or not,

thus conserving both water and financial resources.

6.4 Limitations

This project encountered various limitations during the data collection phase as well as the data analysis phase. This section highlights these limitations that were encountered during the study period and explains how some of these limitations were resolved, where possible.

6.4.1 Technical Limitations

The accuracy of data may have potentially been affected by various technical limitations that may have occurred in the climatic, aerial census and webcam data. Climatic data for this study were sourced from the SAWS from 17 weather stations within KGNP and surrounding regions. These weather stations use manual daily weather recording gauges. Consistency of these data are often affected by mechanical faults and weather station malfunctions, which may often take a few days to resolve, resulting in a large number of missing/ technical errors within the data set.

During the study period, various webcam technical limitations occurred, which may have obscured the accuracy of certain results. These webcam technical faults are to be expected, as this webcam is located in a harsh outdoor environment, which may cause malfunctions. Adverse weather conditions, such as heavy rainfall or intense rainfall events, may cause malfunctions in the webcam, causing it to shutdown resulting in daily images not being captured. These malfunctions occurred once during heavy rainfall in December 2013 and January 2014. These technical faults are often not resolved immediately, which results in the further loss of webcam images. The webcam and floodlights at the Nossob water trough are powered by a generator, which only provides electricity for an 18 - hour daily period (04:00 - 22:00), resulting in loss of nocturnal data for a 6 - hour period (22:00 - 04:00). Valuable information on nocturnal drinking habits of certain species, such as the bat-eared fox, was not captured, and therefore such observations contribute towards gaps in faunal observations and could not be analysed in the results. A further

contribution to loss of webcam data is the obstruction of a glare during the early hours of the morning, for approximately 60 minutes. This glare changes throughout the year according to the angle of the sun and the seasons, and is usually worse during January - March, making certain images impossible to interrupt (*Figure 6.13*).



Figure 6.13: Webcam image being obstructed by sun glare during January 2014.

The resolution of the webcam images is low, which occasionally makes it difficult to identify the observed species at the water trough. This is especially difficult for smaller mammals observed at the water trough. During February 2013, the panning/zooming of the webcam was introduced. Whilst the zooming function of the webcam has been advantageous in determining certain mammal species that were difficult to identify (*Figure 6.15*), the panning function away from the water trough occasionally may have resulted in a certain species not being observed (*Figure 6.16*).



Figure 6.14: Image demonstrating a full view of the water trough.



Figure 6.15: Image demonstrating the webcam zoom/pan to the right.



Figure 6.16: Image demonstrating the webcam zoom/pan to the left.

6.4.2 Data Limitations

This section assesses the limitations that were experienced during the data collection and analysis process. Various data errors have been observed in the climatic data, aerial census data as well as the webcam data. Various limitations in the climatic data (received from SAWS) are associated with both the long-term and short-term temperature and rainfall data sets. Certain weather stations contain missing daily and monthly data for both temperature and rainfall, which may have resulted from faults in the weather station, or human errors when dealing with the manual daily recordings (*Table 6.3*). It has to be trusted that these climatic data are complete and rainfall/temperature values are not missing due to human error. SAWS was only able to provide daily data for the purpose of this project, therefore, hourly data could not be used for the purpose of this project. The most common mistake in human error take the form of entries with an extra digit (e.g. rainfall reading of 120mm, which could be the incorrect entry of 12mm), which can be easily rectified and is explained later on in this chapter, or the imputation of the incorrect rainfall or temperature reading (e.g. 120mm instead of 121mm). It is not always possible to determine what the correct value would have been; therefore, the accuracy of the data from SAWS has to be trusted.

Table 6.3: Missing rainfall and temperature data for each weather station. Weather stations with long-term data are bold.

Station	Years of data	Missing rainfall days	% missing rainfall	% Missing T_{min}	% Missing T_{max}
Twee Rivieren	1940 - 2013	67	0.4	3.5	2.01
Kamqua	2000 - 2013	33	0.6		
Auchterlonie	2000 - 2013	17	0.3		
Kij Kij	2000 - 2013	2	0.04		
Mata-Mata	1960 - 2013	350	1.8	20.2	11.8
Kransbrak	2000 - 2013	2	0.04		
Dikbaarskolk	2000 - 2013	33	0.6		
Moravet	2000 - 2013	32	0.6		
Bitterpan	2000 - 2013	2	0.04		
Nossob	1975 - 2013	590	4.6	10.1	11
Sewe panne	2000 - 2013	34	0.7		
Bayip	2000 - 2013	36	0.7		
O'Kuip	2000 - 2013	34	0.7		
Drievendas	2000 - 2013	31	0.6		
Unie End	2000 - 2013	4	0.1		
Grootbrak	2000 - 2013	34	0.7		
Upington	1883 - 2013	1131	3.3	0.42	0.6

SANParks provided aerial census data for the period of 2004 - 2013, during the months April (wet season) and September (dry season). However, due to insufficient funding, an aerial census was not flown during April 2013 and September 2010. April 2005 and September 2005 aerial census could not be used for the purpose of this project due to incomplete raw data (Ellis and Herbst, 2012). This project has to trust that no human errors occurred during the aerial census counts and the analysis of the data by SANParks and Scientific Services. Due to the small numbers of predators occurring together at the same time, most of these species were not counted, as they were difficult to see. Consequently, only large herds of herbivores have been used for the purpose of this project. A disadvantage to obtaining census data via aerial counts is that population size is often underestimated and certain individuals within a herd may not be counted. Aerial census data could not be digitised due to insufficient coordinate data for transects as well as the faunal species.

A large proportion of images are missing monthly when images are captured at a 15 second time interval (*Table 6.4*). Missing images are calculated per month according to the total amount of monthly images that should be received on a 15 second time scale. However, during image capture at 15 second intervals, the webcam often switches to capturing at 30 - second intervals, which demonstrates a larger proportion of missing images. The highest number (14) of missing days per month occurred during January 2012, and December 2013 being the second highest (12; *Table 6.5*). These missing days could have results in webcam malfunction due to the heavy rainfall event occurring over December 2013 and January 2014. Due to financial reasoning, this project could only utilise data from one webcam at the Nossob water trough, and could not add more at various water troughs across the landscape.

Table 6.4: Missing webcam images on a monthly time scale.

	Month	Images Received	Percentage Missing
2012	**October**	37011	45%
	November	47050	27%
	December	62457	7%
2013	**January**	54663	16%
	February	60788	50%
	March	68515	49%
	April	71847	45%
	May	72616	46%
	June	63973	51%
	July	57599	57%
	August	73397	45%
	September	78680	39%
	October	66362	50%
	November	68009	48%
	December	46401	65%
2014	**January**	34302	74%
	February	68610	43%
	March	62069	54%
	April	40648	69%
	May	53428	60%
	June	49434	62%
	July	55990	58%
	August	57086	57%
	September	57025	56%
	October	61177	54%
	November	48643	62%
	December	62026	54%

Table 6.5: Missing days per month for the webcam image data.

	Month	No. of Missing Days	Percentage Missing Days
2012	**October**	4	13%
	November	4	13%
	December	1	3%
2013	**January**	2	6%
	February	1	4%
	March	5	16%
	April	0	0%
	May	0	0%
	June	4	13%
	July	6	19%
	August	2	6%
	September	1	3%
	October	4	13%
	November	3	10%
	December	12	39%
2014	**January**	14	45%
	February	0	0%
	March	3	10%
	April	6	20%
	May	3	10%
	June	3	10%
	July	1	3%
	August	0	0%
	September	1	3%
	October	0	0%
	November	5	17%
	December	1	3%

6.4.3 Statistical Limitations

The primary limitation in statistical analyses, and their ability to accurately model and demonstrate patterns, results from gaps in the data set. It is very likely that the missing data will cause obscurities in time trends and the relationships with climate variables. For this reason, these missing climatic data were omitted from the study (*Table 6.2*). The high percentage of missing images may influence the accuracy of the results and statistics; however, this issue could not be resolved. This project relies heavily on statistical analysis; therefore, any observed assumptions established could be incorrectly interpreted if statistical models and patterns are not accurate. The calculation of statistical significance for each trend mitigated the possibility of missing values changing the nature of the observed trends without the compromised strength being acknowledged (Fitchett *et al.*, 2014). “The *p value* is calculated as a measure of statistical significance, determining the probability that the calculated trends and relationships would still hold in a greater dataset” (Fitchett, *et al.,* 2014: 270). If not omitted, missing days, months or years will decrease the relative statistical significance, requiring a particularly strong correlation for a result to be designated as significant.

6.4.4 Addressing the Limitations

Certain limitations that were encountered during the study period could be rectified. It is difficult to rectify technical faults with weather stations and the webcam; therefore, these limitations could not be resolved for the purpose of this project. The use of alternative webcams with higher resolution will make it easier to interrupt fauna within an image, especially during the nocturnal hours. Adding a camera trap to the study site will capture lost data during nocturnal hours when the generator is shut off (22:00 - 04:00). Images skipping 15 second capture could be resolved for future use by calibrating the system and making sure that 15 second interval images are not missed. In order to better understand the distribution of faunal species within the landscape at various water troughs, the allocations of webcams at various water troughs would contribute towards a better understanding of faunal water trough usage.

In order to rule out aerial census bias in the number of individuals counted after the census was conducted, a formula was used to account for possible human errors where faunal species may not have been counted. The missing raw data for 2005 could not be located; unfortunately this year was excluded from this project. Unfortunately, the loss of predator census information could not be rectified due to species not being counted during the aerial census. In order to address this problem for future research, the use of photographic aerial census would be useful, so that the faunal species can be recounted if missed during the actual aerial census process (Sutherland, 2006; Rowat *et al.,* 2009). Unfortunately, this is a problem that is difficult to address for future aerial census counts in KGNP, and due to insufficient funding, it would be difficult to incorporate photographic instruments.

Missing climatic data for the various weather station data used during the study period was rectified in some instances, such as Twee Rivieren and Mata-Mata, by making use of other online sources which contain historic climatic annually, monthly and daily data (*Table 6.6*) Unfortunately, it was difficult to locate long-term climatic data for Nossob from other sources; therefore, the missing rainfall and temperature data were excluded from this project. Historic archives from the SAWS in Pretoria were used to fill as many data gaps as possible in the Upington temperature and rainfall records. The imputation of incorrect rainfall data was experienced for Twee Rivieren (1953 - 1960), for which rainfall data were captured without using a decimal and rainfall values were out by a factor of 10. Multiplying the rainfall value by a factor of 10 rectified this problem. The SAWS were only able to provide daily/monthly and annual climatic data for the purpose of analysing hourly faunal drinking patterns. Rectifying this limitation for future research would involve installing Tiny Tag temperature loggers at the water trough, which will provide 15 - minute interval data to determine the influence of temperature on faunal water trough usage patterns.

Table 6.6: Online climatic sources that were used to fill gaps in Twee Rivieren and Mata-Mata climatic data records.

Organisation	Website URL
KNMI Climate Explorer	http://climexp.knmi.nl
National Oceanic and Atmospheric Administration	https://www.ncdc.noaa.gov
Weather Underground	http://www.wunderground.com/history/

Chapter 7

Conclusion



7 Conclusion

7.1 Background

The study of mammal distributions in relation to climatic patterns, including fluctuations in rainfall and temperature, is of great interest in disciplines such as climate change and ecological science (Erasmus *et al.,* 2002). An understanding of historical climate records is important to ascertain climatic trends, and temporal fluctuations. Such past climates have been reconstructed for rainfall and temperature variations in the Kalahari region, more specifically KGNP, where changing climatic patterns have been established (Nash and Endfield, 2002; Nicholson, 2014). Climate change poses serious threats to the survival of many species, especially in African semi-arid environments, as this is one of the most vulnerable regions to climate change due to minimal surface water availability, and a relatively low adaptive capacity (Amouzou, 2010). Understanding contemporary faunal distributions and behaviour has the potential to contribute towards further management of species in conservation areas (Hetem *et al.,* 2014). If biodiversity is to be conserved in protected areas, an understanding of how species behavior and distribution are likely to change under conditions of climate change is crucial (Erasmus *et al.,* 2002). Numerous ecology studies have highlighted the effects of climate change on species distributions and behaviour, and the extent to which specific species react to climate change over the past century.

The primary aim of this study was to contribute towards the discipline of ecology and climate change science through the examination of specific faunal species in the KGNP region. Through the analysis of long-term changing climatic patterns and the influence of climatic patterns on species distribution in the KGNP, this study contributes knowledge globally to better understand species-specific distributions in response to a changing climate. Additionally, it provides information on how changing rainfall patterns in the short term impacts faunal distributions, as well as the impacts of the temperature and rainfall on faunal drinking behaviour locally.

Firstly, this chapter describes the extent to which the aims and objectives have been achieved, and highlights the main results that were attained within each objective.

This is followed by a discussion on the implications for management and how these results can contribute towards management procedures within the KGNP. This chapter concludes with suggestions for future work on species behaviour and distribution ecology in the KGNP, as well as towards the broader ecological and climate change science discipline as a whole globally.

7.2 Achievement of Study Objectives

1. *To establish historic patterns in rainfall and temperature changes for the KGNP over the period 1900 - 2013.*

This research demonstrating changing temperature and rainfall patterns over the past century. In summary, mean annual rainfall over the period of assessment is decreasing for Nossob (-1.01mm/year) and Mata-Mata (-2mm/year), which demonstrates that the central and possibly northern regions of KGNP are becoming drier. However, rainfall patterns demonstrate that the southern parts of KGNP are becoming wetter as mean annual precipitation for Twee Rivieren (1.6mm/year) and Upington (1.1mm/year) are increasing over time. Unusual above average rainfall were identified for all four-rainfall stations during the year 1976 (559.8mm, 738.4mm, 602.3mm and 500mm, respectively). These results are consistent with numerous published climatic studies for southern Africa, which emphasised that La Niña phenomenon caused above average rainfall for this year, resulting in the Nossob and Auob rivers to flow (Woodward and Lomas, 2004; Jury and Mpeta, 2005; Washington and Preston, 2006; Mackellar *et al.,* 2014).

The T_{max} increases at Twee Rivieren (0.05°C/year), Mata-Mata (0.06 °C/year), and Nossob (0.05°C/year) and T_{min} increases at Mata-Mata (0.06°C/year) and Upington (0.09°C/year) demonstrate that rapid warming is taking place within KGNP (Kruger and Sekele, 2013; Hetem *et al.,* 2014; Mackellar *et al.*, 2014; Mphale *et al.,* 2014; van Wilgen *et al.*, 2015). Average T_{max} was >40°C in the following months: December 2009 and January 2013 for Twee Rivieren and December 2009 for Nossob. The findings of this study demonstrate a trend towards decreased rainfall in certain regions of KGNP (northern and central regions), with increasing temperatures. Therefore, drier conditions within KGNP results in even greater rainfall variability, which increases the likelihood of dry events and droughts (Batisani and

Yarnal, 2010; van Wilgen *et al.,* 2015). These climate changes are detrimental for a semi-arid environment, resulting in increased desertification and a further decrease in surface water, which will impact faunal species negatively.

2. *To establish recent patterns in rainfall over the period 2004 - 2013 for KGNP.*

Inter-annual rainfall variability differed spatially across the park, resulting in variations between annual averages over the study period. The highest rainfall during 2006 occurred at Drievendas (589mm) and the lowest at Mata-Mata (38.4mm). As expected, these results demonstrate the regional rainfall variability that exists within KGNP. These above average rainfall events at Drievendas are not representative of the annual average rainfall for this area. Trends over the past 10 years within KGNP demonstrate that the northern regions are becoming drier, whilst the central regions demonstrate stable rainfall trends with the southern region becoming wetter. A general north-south gradient pattern is demonstrated in KGNP, but with obvious outliers within the northern and central sections of the park.

3. *To establish a spatio-temporal relationship between faunal distribution and patterns of rainfall within the KGNP from 2004 - 2013.*

This analysis involved establishing the relationship between rainfall and proportional representation of fauna in wet and dry months in KGNP. The daily and seasonal migration patterns of mammals are dependent on spatial and temporal surface water distribution (Western 1975; Epaphras *et al.,* 2008). Particularly strong correlations were found during April for steenbok, blue wildebeest and springbok against rainfall at Auchterlonie, O'Kuip, Drievendas and Unie End. As expected, the strong relationship in April for blue wildebeest and steenbok at Auchterlonie and Unie End is representative of the months receiving high rainfall and reasonably good water availability in the Auob riverbed. A number of ungulate species, particularly the large herd species (springbok and blue wildebeest) congregate in the riverbeds after heavy rainfall, due to the availability of surface water and vegetation (Parris, 1984; Bergstrom and Skarpe, 1999).

Particularly strong correlations were found during September for steenbok, blue wildebeest, gemsbok and springbok against rainfall for Auchterlonie, Kransbrak, Mata-Mata and Unie End. The strong correlations at Kransbrak in September during

the study period 2004 - 2013 for blue wildebeest and steenbok against rainfall could be due to this area receiving low annual average rainfall, which results in these species becoming more reliant on water troughs along the riverbeds. As previously mentioned, a notable change in annual long-term rainfall variability has been demonstrated for KGNP. An increase in drought events in KGNP may lead to a decrease in vegetation. Sedentary grazing herbivores and selective feeders, such as blue wildebeest and springbok populations, are identified as particularly vulnerable to droughts and reduced rainfall during the dry season as the forage availability is less (Tews *et al*., 2004; Duncan *et al.,* 2012; van Wilgen *et al.,* 2015,).

Therefore, reduced rainfall is potentially a further threat to these species. The nomadic nature of these species demonstrates their large distribution throughout the KGNP landscape and the ability of gemsbok to inhabit a variety of ecological zones. This demonstrates that these species are well adapted in semi-arid regions and are able to travel long distances within KGNP due to the unpredictable distribution of forage. Therefore, blue wildebeest and to a certain extent springbok, are the most vulnerable ungulate species to climate change due to their heavy reliance on water sources. Gemsbok are the least vulnerable to climate change due to their resilience in semi-arid regions and their water independency. If the KGNP northern regions continue to become drier, with the southern regions becoming wetter, it is predicted that mammals, in particular ungulate species may shift their ranges in a north-south direction.

4. *To establish faunal drinking patterns at an artificial water point over daily to seasonal time scales.*

The predominant visitation period during morning (05:00 - 06:00) was by carnivores: jackal, lion, leopard, spotted and brown hyena. As expected, these same carnivore species, including gemsbok, dominated the evening peak period (21:00 - 22:00). The carnivores are nocturnal species, therefore, would be expected to frequent the water trough during the morning and evening to avoid heat stress and excess water loss (Bothma, 2005; Hayward and Hayward, 2012). Carnivore species are not typically water dependent, however, they will drink water regularly when it is available (Bothma, 2005). The species utilising the water trough during afternoon (12:00 - 13:00) were mostly herbivores consisting of blue wildebeest, springbok and red

hartebeest. There are three reasons that could explain these drinking patterns. Firstly, herbivores are avoiding predators during nocturnal hours. Secondly, these species consume water during maximum temperatures to compensate for perspiration. Thirdly, during the daylight hours, eyesight is better and this enhances the chances of the prey species to escape predation at or on their way to the waterholes (Ayeni, 1975; Mills and Mills, 1997; de Boer *et al.,* 2010).

Different wet and dry seasonal water trough usage by mammal species across the study period has been found. Herbivores frequent the water trough more during the dry rather than the wet season. These species rely on the water troughs during the dry season due to the low plant moisture content and relatively high temperatures (Auer, 1997; Rudee, 2011). Consequently, a piospheres effect is created from the high abundance of herbivores in the locality water troughs during the dry season (Valeix, 2011). As a result of further decreasing rainfall within KGNP, herbivores will be forced to utilise the permanent surface waters more regularly, especially during the dry season. Subsequently, herbivores will congregate in large herds around the water troughs, which will be detrimental to the surrounding environment, as habitat degradation will increase.

The carnivores, cheetah and lion, utilise the water trough throughout the year. These species acquire most of their moisture requirements from prey species; thus, additionally supplementing their water intake when necessary (Simpson *et al.,* 2011). Brown hyena and leopard were observed more frequently during the dry rather than the wet season. However, leopards are water independent but are often located within the Nossob riverbed during the dry season due to abundance of prey (Bothma and Le Riche, 1984). The high frequency of visitation during spring and winter suggests that fauna are concentrated around the water troughs during the dry months, when no natural surface water is available (Franz *et al.,* 2010).

5. *To determine the influence of spatio-temporal rainfall patterns within KGNP on faunal drinking behaviour over a two - year period (October 2012 until December 2014).*

Climatic variables (temperature and rainfall) were compared to mammal species' behavioural patterns associated with both temperature thresholds and quantity of rainfall (and resultant surface water). Water trough usage by carnivores shifts to later in the evening by 4 min/°C and earlier during the morning peak by 6 min/°C as temperatures become higher on average, avoiding the heat of the day. Water trough usage by herbivores during days with hotter T_{avg} shifts at a rate of 8 min/°C in the afternoon, when temperatures are cooler. Increasing temperatures, as a result of climate change, will change herbivore drinking patterns and force herbivores to frequent the Nossob water trough later in the evening, increasing prey and predator interactions. The most significant negative correlations between peak hourly usage and temperature are calculated for blue wildebeest at T_{min} and $T_{avg.}$ Negative correlations indicate that when it gets hotter the fauna frequent the water trough earlier in the day. Positive correlations suggest that when it gets hotter, the fauna visit the water trough later during the day. This is expected as faunal species avoid using the water trough during the heat of the day.

The occurrence of rainfall demonstrates a distinct disappearance of fauna at the Nossob water trough during and immediately after notable rainfall events (≥20mm), with a higher disappearance during and after the occurrence of higher rainfall (≥ 30mm). Significant correlations existed between water trough usage and one day after the rainfall event, which indicates faunal species are drinking from the natural surface water and not the water trough. Herbivore species do not frequent the water trough when surface water is available. Fauna frequent the water trough less regularly as the duration of natural surface water increases. Therefore, due to the preferential use of natural surface water, faunal species will disperse within the riverbeds during and after heavy rainfall events. The groundwater supplied to fauna in the water troughs contains a wide variety of salts in toxic concentrations, which might explain the preferential use of surface rather than the water in the water troughs (Meyer, 1999). As a result of climate change, more specifically increasing evaporation rates and decreasing rainfall, the availability of surface water to faunal species will diminish. Therefore, forcing faunal species within KGNP to rely more

heavily on these water troughs, even if the water quality is poor (Wanke and Wanke, 2007).

7.3 Implications for Management

This study contributes to understanding the responses of wildlife behaviour distribution to climatic change in KGNP, with a further understanding on faunal water requirements locally. An understanding of species-specific vulnerability to climate change aids management practices in conservation to protect species that are more vulnerable than others in the KGNP. This study has demonstrated that the blue wildebeest are the most vulnerable to climate change within KGNP and will become more reliant on the permanent water troughs when temperatures increase and rainfall decreases.

This study can inform management in the KGNP on changing climatic factors, such as the increasing rate of temperature extremes above certain threshold values (i.e. >40°C), and decreasing rainfall quantities. Temperatures are increasing at an average rate of 0.04°C/year, with rainfall decreasing in Mata-Mata and Nossob, and increasing in Twee Rivieren and Upington. Climatic data, such as hourly temperature/rainfall records, would have provided more detail on faunal water trough usage. Gaps in the weather station data should be urgently prioritized for new weather stations as well as the continued maintenance of currently operational weather stations, as this will better the understanding of climate change impacts and mechanisms (van Wilgen *et al.,* 2015). Climatic patterns will affect faunal species distributions over the long-term (i.e. the next century), and understanding of species water requirements becoming more imperative. Therefore, long-term historical climatic trends can assist management in further interpretation of future changing rainfall and temperature trends and understand how faunal species might shift their ranges within KGNP.

The use of aerial census provides management and rangers with important information on faunal distributions, shifting patterns on an annual basis. Recent climate change studies have predicated a decrease in mean precipitation of 5-15% by the year 2050 (Tews *et al.,* 2004; Wang *et al.,* 2006; IPCC, 2007) and an increase

in the frequency and variability of extreme rainfall events in southern Africa. These rainfall changes will have profound effects on specific species birth, dispersal and mortality processes (Tews *et al.,* 2004). Therefore, it is important to understand broader species population numbers across the park during the wet (April) and dry seasons (September). This increases an understanding of species-specific distribution patterns in relation to changing rainfall patterns and whether water dependence is increasing in certain species.

This study has demonstrated that webcams provide useful information on faunal behaviour and drinking patterns at artificial water troughs. Further studies involving the application of webcams could provide additional knowledge in other conservation areas on faunal behaviour (i.e. faunal drinking patterns, species interactions and predator prey relations). Webcams provide remote information to researchers and management without requiring constant access to the study site. This study established peak water trough utilisation times with the use of webcam imagery at 15 second intervals. This is useful for management to provide tourists with information about species-specific viewing opportunities during the day at the Nossob water trough. This study has demonstrated drinking behaviours and the climatic controls thereof. This does support management strategies in understanding which particular temperature thresholds influence specific species to utilise the water trough more frequently. Management can establish shifting faunal water trough patterns according to temperature extremes (30°C - 34.9°C).

7.4 Future Work

Considerable research in the literature exists on the changing climatic patterns in various national parks globally. However, understanding long-term changing climatic patterns in KGNP requires continued research to understand the further implications on faunal species. Continued research into the assessment of the impacts of temperature increases and changing rainfall patterns in KGNP are increasingly need to inform management on the extent of conservation planning needed (Mawdsley *et al.,* 2009; van Wilgen *et al.,* 2015). It would be valuable for research to determine the predicted changing climates of KGNP region, as this type of research is scarce in the current literature. Predicting climate change in this region fills knowledge gaps about

whether rainfall and temperature patterns will continue to increase/decrease, as these effects could be devastating for faunal species within KGNP. Temperature thresholds presently influence faunal drinking patterns as faunal species utilize the water trough later/earlier in the day when temperatures become hotter. Furthermore, an understanding of future increasing temperature trends will help to determine how faunal species drinking patterns might be altered even more.

This study has aimed at understanding mammal species distribution patterns in relation to rainfall, which demonstrates the extent to which species utilise the landscape in response to rainfall. There have been few studies (Relton, 2015), which have made use of Normalized Difference Vegetation Index (NDVI) in the Kalahari. These NDVI are compared to aerial census data to understand how faunal species are shifting in relation to 'greenness', which is essentially good grazing for herbivorous species. In addition to this, the use of Normalized Difference Wetness Indices (NDWI) can contribute valuable information on species distribution in relation to 'wetness'. However, due to the poor retention of surface water, an aerial census would be required immediately after a rainfall event.

Possible future research may include the comparison between webcam data in different regions, such as the KNP and Addo Elephant National Park, with the results from this study. This will contribute towards a further understanding on water trough usage by the same species under different environmental conditions. In the event of climatic conditions changing, this detailed knowledge on how a species copes with different environment conditions would be beneficial for management. Further comparisons could be made to similar semi-arid environments, which already have webcams in place, such as the Central Kalahari Game Reserve, Mashatu and Chobe. Further knowledge can be achieved on species-specific drinking behaviours in semi-arid environments.

Placing more webcams throughout KGNP will provide useful information on species-specific uses of different artificial water troughs, preferential water trough usage by certain species and an understanding of how species are distributed throughout the park in relation to water trough usage. In order for accurate results to be established from these webcam images, resolution and quality of these webcams needs to be

substantially improved. However, it would be more appropriate if temperature loggers could be placed at water troughs to ascertain localised hourly temperature data. Possible future work could include the comparison between water trough frequency and water quality within these same water troughs. This will help management determine which water troughs are not being used due to poor water quality. Therefore, the use of webcams to study faunal water trough usage and drinking behaviour is a valuable method for inclusion in future research.

8 References

Abbott, I. and Le Maitre, D. (2010) Monitoring the impact of climate change on biodiversity: The challenge of megadiverse Mediterranean climate ecosystems. *Austral Ecology,* 35, 406-422.

Abere, S.A. and Oguzor, N.S. (2011) Adaptation of Animals to Arid Ecological Conditions. *World Journal of Zoology,* 6(2), 209 - 214.

Ackerly, D.D., Loarie, S.R., Cornwell, W.K., Weiss, S.B., Hamilton, H., Branciforte, R. and Kraft, N.J.B. (2010) The geography of climate change: implications for conservation biogeography. *Diversity and Distributions,* 16, 476-48.

Adedoyin, A. and Mphale, K. (2002) Climate variability: its impact and mechanism within the Kalahari Transect of Southern Africa, *Mali Symposium on Applied Sciences, Bakamo.* 2002.

Aldemo, C. (2011) *Effects of elephants and other browsers on woody vegetation around artificial water troughs in Savuti, northern Botswana*. Masters Thesis, Uppsala University, Botswana.

Amouzou, K.E. (2010) Impact of Climate Change upon Ungulates and Biodiversity in Sub-Saharan Africa. *Galemys, 22,* 185-192.

Archer, S.R. and Predick, K.I. (2008) Climate Change and Ecosystems of the Southwestern United States, *Rangelands,* 30(3), 23-28.

Ashok, K., Guan, Z. and Yamagata, T. (2003) A Look at the Relationship between the ENSO and the Indian Ocean Dipole, *Journal of the Meteorological Society of Japan.* 81(1), 41-56.

Auer, C. (1997) Water availability and chemical water quality as important factors for sustainable wildlife management in the Etosha National Park and for domestic stock in farming areas of Namibia*. Research Discussion Paper,* 26, 1-30.

Ayeni, J.S.O. (1975) Utilization of water troughs in Tsavo National Park (East). *East African Wildlife Journal,* 13, 305-323.

Ayeni, J.S.O. (1977) Waterholes in Tsavo National Park, Kenya. *Journal of Applied Ecology,* 14, 369-378.

Batisani, N. and Yarnal, B. (2010) Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. *Applied Geography,* 30, 483-489.

Bergstrom, R. and Skarpe, C. (1999) The abundance of large wild herbivores in a semi-arid savanna in relation to seasons, pans and livestock. *African Journal of Ecology,* 37, 12-26.

Birkett, P. J., Vanak, A. T., Muggeo, V. M., Ferreira, S. M., and Slotow, R. (2012) Animal perception of seasonal thresholds: changes in elephant movement in relation to rainfall patterns. *PloS one*, *7*(6), e38363.

Bobich, E.G., Wallace, N.L. and Sartori, K.L. (2014) Cholla Mortality and Extreme Drought in the Sonoran Desert. *Madrono,* 61(1), 126-136.

Boone, R.B., Thirgood, S.J. and Hopcraft, J.G.C. (2006) Serengeti Wildebeest Migratory Patterns Modelled from Rainfall and New Vegetation Growth. *Ecology,* 87(8), 1987-1994.

Bothma, J.D.P., (1971) Notes on river habitat use by the larger ungulates in the Kalahari Gemsbok National Park. *Koedoe*, *14*(1), 33-48.

Bothma, J.D.P. (1972) Short-term response in ungulate numbers to rainfall in the Nossob River of the Kalahari Gemsbok National Park. *Koedoe*, *15*(1), 127-133.

Bothma, J. Du P. and Mills, M.G.L. (1977) Ungulate adbundance in the Nossob River Valley, Kalahari Desert. *XIIIth International Congress of Game Biologists. Of Game Biology,* 90-102.

Bothma, J.D.P. and de Graaff, G., (1973) A Habitat Map of the Kalahari Gemsbok National Park. *Koedoe,* 16, 181-188.

Bothma, J.D.P. and Le Riche, E.A. (1984) Aspects of the ecology and the behaviour of the leopard Panthera pardus in the Kalahari Desert. *Koedoe*, *27*(2), 259-279.

Bothma, J.D.P. (2005) Water-use by southern Kalahari leopards. *South African Journal of Wildlife Research*, *35*(2), 131.

Bradley, E.S., Toomey, M.P., Still, C.J. and Roberts, D.A. (2010) Multi-scale Sensor Fusion With an Online Application: Integrating GOES, MODIS, and Webcam Imagery for Environmental Monitoring. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 3(4), 497-506.

Bradley, E.S. and Clarke, K.C. (2011) Outdoor Webcams as Geospatial Sensor Networks: Challenges, Issues and Opportunities. *Cartography and Geographic Information Science,* 38(1), 3-19.

Bregas, J. (1998) Ecological Impacts of global change on drylands and their implications for desertification. *Land Degradation and Development,* 9, 393-406.

Brits, J., Van Rooyen, M.W. and Van Rooyen, N. (2002) Ecological impact of large herbivores on the woody vegetation at selected watering points on the eastern basaltic soils in the Kruger National Park. *African Journal of Ecology,* 40, 53-60.

Cain, J.W., Krausman, P.R., Rosenstock, S.S. and Turner, J.C. (2006), Mechanisms of Thermoregulation and Water Balance in Desert Ungulates. *Wildlife Society Bulletin,* 34(3), 570-581.

Campbell, A. (1981) A comment on Kalahari and the Kukhe Fence. *Botswana Notes and Records,* 13, 111-118.

Caro, T.M. (1999) Conservation monitoring: estimating mammal densities in woodland habitats. *Animal Conservation,* 2, 305-315.

Castley, J.G. (2013) *Standard operating procedures for conducting aerial surveys in South African National Parks - Southern parks*, Griffith University, Australia.

Caughley, G. (2006) Bias in Aerial Survey. *The Journal of Wildlife Management,* 38 (4), 921-933.

Chamaille-Jammes, S., Fritz, H. and Murindagomo, F. (2007a) Climate-driven fluctuations in surface-water availability and the buffering role of artificial pumping in an African savanna: Potential implication for herbivore dynamics. *Austral Ecology,* 32, 740-748.

Chamaille-Jammes, S., Fritz, H. and Murindagomo. (2007b) Detecting climate changes of concern in highly variable environments: Quantile regressions reveal that droughts worsen in Hwange National Park, Zimbabwe. *Journal of Arid Environments,* 71, 321-326.

Chesson, P., Gebauer, R.L.E., Schwinning, S., Huntly, N., Wiegand, K., Ernest, M.S.K., Sher, A., Novoplansky, A. and Weltzin, J.F. (2004) Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia* 141, 236-253.

Child, G., Parris, R. and Le Riche, E. (1971) Use of mineralised water by Kalahari wildlife and its effects on habitats. *East African Wildlife Journal,* 9, 125-142.

Chown, S.L. and Gaston, K.J. (2004) Macrophysiology for a changing world. *Proc. Biol. Sci.,* 275, 1469-1478.

Cromsigt, J.P., van Rensburg, S.J., Etienne, R.S. and Olff, H. (2009) Monitoring large herbivore diversity at different scales: comparing direct and indirect methods. *Biodiversity and Conservation*, *18*(5), 1219-1231.

Crosmary, W.G., Valeix, M., Fritz, H., Madzikanda, H. and Cote, S.D. (2012) African ungulates and their drinking problems: hunting and predation risks constrain access to water. *Animal Behaviour,* 83, 145-153.

Crowe, D.M. (1995) Status of selected wildlife resources in Botswana and recommendations for conservation actions. In: K. Legget (Eds), *Proceedings of a Symposium on the Present Status of Wildlife and its Future in Botswana*, The Kalahari Conservation Society and the Chobe Wildlife Trust, Gaborone.

Cutler, T.L. and Swann, D.E. (1999) Using Remote Photography in Wildlife Ecology: A Review. *Wildlife Society Bulletin,* 27(3), 571-581.

D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S. and Runyan, C.W. (2012) Global desertification: Drivers and Feedbacks. *Advances in Water Resources,* 51, 326-344.

Davis, D.E. (1982) *CRC Handbook of Census Methods for Terrestrial vertebrates,* CRC Press, Florida.

De Boer, W.F., Vis, M.J., de Knegt, H.J., Rowles, C., Kohi, E.M., van Langevelde, F., Peel, M., Pretorius, Y., Skidmore, A.K., Slotow, R. and van Wieren, S.E. (2010) Spatial distribution of lion kills determined by the water dependency of prey species. *Journal of Mammalogy*, 91(5), 1280-1286.

De Leeuw, J., Waweru, M.N., Okello, O.O., Maloba, M., Nguru, P., Said, M.Y., Aligula, H.M., Heitkonig, I.M.A. and Reid, R.S. (2001) Distribution and diversity of wildlife in northern Kenya in relation to livestock and permanent water points. *Biological Conservation,* 100, 297-306.

DEA (Department of Environmental Affairs)*,* (*2013*) *Long-term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa, Climate change implications for the biodiversity sector in South Africa*, Department of Environmental Affairs, Pretoria.

Derry, J.F. and Dougill, A.J. (2008) Water location, piospheres and a review of evolution in African ruminants. *African Journal of Range and Forage Science,* 25(2), 79-92.

Derry, J.F. (2004) *Piospheres in semi-arid rangeland: consequence of spatiality constrained plant-herbivore interactions*, Unpublished PhD Dissertation, The University of Edinburgh, Edinburgh.

Desanker, P.V. and Magadza, C. (2001) Africa Chapter 10 of the IPPC Working Group II, Third Assessment Report*,* In: United Nations (Eds), *Third Assessment Report of the IPCC,* United Nations, Geneva, 490-531.

Dolan, B.F. (2006) Water Developments and Desert Bighorn Sheep: Implications for Conservation. *Wildlife Society Bulletin,* 34(3), 642-646.

Duncan C, Chauvenet ALM, McRae LM, Pettorelli N. (2012) Predicting the future impact of droughts on ungulate populations in arid and semi-arid environments. *PLoS One 7*: e51490.

Dunham, K.M., Rovertson, E.F. and Grant, C.C. (2004) Rainfall and the decline of a rare antelope, the tsessebe *(Damaliscus lunatus lunatus*), in Kruger National Park, South Africa. *Biological Conservation,* 117, 83-94.

Easterling, D.R., Evans, J.L., Groisman, P.Y., Karl, T.R., Kunkel, K.E. and Ambenje, P. (2000) Observed variability and trends in extreme climate events: A brief review*. Bulletin of American Meteorological Society*. 81, 417-425.

Ellis, G. and Herbst, M. (2012) *Kalahari Gemsbok National Park Aerial Census Report: April and September 2012*, SANParks, Phalaborwa.

Eloff, F. C. (1973a). Lion predation in the Kalahari Gemsbok National Park. *J. S. Afr. Wildlife Management Association,* 3, 59-63.

Eloff, F.C. (1973b) Water use by the Kalahari Lion *Panthera Leo Vernayi.* 16, 149-154.

Epaphras, A.M., Gereta, E., Lejora, I.A., Meing'ataki, G.E.O., Ng'umbi, G., Kiwango, Y., Mwangomo, E., Semanini, F., Vitalis, L., Balozi, J. and Mtahiko, M.G.G. (2008) Wildlife water utilization and importance of artificial water troughs

during dry season at Rhuaha National Park, Tanzania. *Wetlands Ecology and Management,* 16(3), 183-188.

Erasmus, B.F.N., Van Jaarsveld, A., Chown, S.L., Kshatriya, M. and Wessels, K.J. (2002) Vulnerability of South African animal taxa to climate change. *Global Change Biology,* 8, 679-693.

Eriksen, S., O'Brien, K. and Rosentrater, L. (2008) Climate change in Eastern and Southern Africa: Impacts, vulnerability and adaptation. In: R.D. Estes (Eds.), (1991) *Climate change in Eastern and Southern Africa: impacts, vulnerability and adaptation*, *The Behavior Guide to African Mammals*, University of California Press, California.

Farmer, H. (2010) *Understanding impacts of water supplementation in a heterogeneous landscape*. Doctoral dissertation, University of the Witwatersrand, Johannesburg.

Feldhamer, G.A., Drickamer, L.C., Vessey, S.H. and Merritt, J.F. (1999) *Mammalogy: adaptation, diversity, and ecology.* WBC McGraw-Hill, Boston, USA.

Fitchett, J.M. (2013) *Phenological Response of Citrus Flowering to Climate Variability and change in Iran 1960-2010*. Masters Thesis, University of the Witwatersrand, Johannesburg.

Fitchett, J. M. and Grab, S.W (2014) A 66-year tropical cyclone record for south-east Africa: temporal trends in a global context, *International Journal of Climatology,* 34(13), 3604-3615.

Fitchett, J.M., Grab., S.W., Thompson, D.I. and Roshan G. (2014) Spatio-temporal variation in phonological response of citrus to climate change in Iran: 1960 - 2010. *Agricultural and Forest Meteorology,* 198-199, 285-293.

Foden W., Midgley G.F., Hughes G., Bond W.J., Thuiller W., Hoffman M.T., Kaleme P and Underhill L.G. (2007) A changing climate is eroding the geographical range of the Namib Desert tree Aloe through population declines and dispersal lags. *Diversity and Distributions,* 13(5), 645–653, DOI: 10.1111.

Franz, M., Kramer-Schadt, S., Kilian, W., Wissel, C. and Groeneveld, J. (2010) Understanding the effects of rainfall on elephant-vegetation interactions around waterholes. *Ecological Modelling,* 221, 2909-2917.

Fuller, A., Hetem, R.S., Maloney, S.K. and Mitchell, D. (2014) Adaptation to Heat and Water Shortage in Large, Arid-Zone Mammals. *American Physiological Society,* 29, 159-167.

Funston, P. J., Frank, L., Stephens, T., Davidson, Z., Loveridge, A., Macdonald, D. M., Durant, S., Packer, C., Mosser, A. and Ferreira, S.M. (2010) Substrate and species constraints on the use of track incidences to estimate African large carnivore abundance. *Journal of Zoology*, 281(1), 56-65.

Gadd, M.E. (2011) Barriers, the beef industry and unnatural selection: a review of the impacts of veterinary fencing on mammals in southern Africa. In: Hayward, M. and Somers, M.J (Eds.), *Fencing for Conservation: Restriction of Evolutionary Potential or a Repost to Threatening Processes,* Springer Science and Business Media, London.

Galanti, V., Tosi, G., Rossi, R. and Foley, C. (2000) The use of GPS Radio-Collars to track elephants (*Loxodonta Africana*) in the Tarangire National Park (Tanzania). *Hystrix, the Italian Journal of Mammalogy* 11(2), 27-37.

Gandiwa, E. (2013) Vegetation factors influencing density and distribution of wild large herbivores in a southern African savanna. *African Journal of Ecology,* 52(3), 1-10.

Gaston, K.J., Charman, K., Jackson, S.F., Armsworth, P.R., Bonn, A., Briers, R.A., Callaghan, C.S.Q., Catchpole, R., Hopkins, J., Kunin, W.E., Latham, J., Opdam, P., Stoneman, R., Stroud, D.A. and Tratt, R. (2006) The ecological effectiveness of protected areas: the United Kingdom. *Biological Conservation,* 132, 76-87.

Gebrehiwot, T., can der Veen, A. and Maathuis, B. (2011) Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. *International Journal of Applied Earth Observation and Geoinformation,* 13, 309-321.

Georgiadis, N., Hack, M. and Turpin, K. (2003) The influence of rainfall on zebra population dynamics: Implications for management. *Journal of Applied Ecology,* 40(1), 125-136.

Gillson, L., Dawson, T.P., Jack, S. and McGeoch, M.A. (2013) Accomodating climate change contingencies in conservation strategy. *Trends Ecology Evolution,* 28, 135-142.

Goldenberg, S. B., Landsea, C. W., Mestas-Nuñez, A. M. and Gray, W. M. (2001) The recent increase in Atlantic hurricane activity: Causes and implications, *Science*, *293*(5529), 474-479.

Greco, S., Moss, R.H., Viner, D. and Jenne, R. (1994) *Climate Scenarios and Socioeconomic Projections for IPCC WGGII Assessment,* IPCC-WMO and UNEP, Washington DC, 67.

Gusset, M. and Burgener, N. (2005) Estimating larger carnivore numbers from track counts and measurements. *African Journal of Ecology*, 43, 320-324.

Haacke, W.D. (1984) The Herpetology of the southern Kalahari domain. *Koedoe,* 171-186.

Handcock, R.N., Swain, D.L., Bishop-Hurley, G.J., Patison, K.P., Wark, T., Valencia, P., Corke, P. and O'Neill, C.J. (2009) Monitoring Animal Behaviour and Environmental Interactions Using Wireless Sensor Networks, GPS Collars and Satellite Remote Sensing. *Sensors,* 9, 3586-3603.

Hannah, L., Midgley, G., Andelman, S., Araujo, M., Hughes, G., Martinez-Meyer, E., Pearson, R. and Williams, P. (2007) Protected area needs in a changing climate. *Frontiers in Ecology and the Environment,* 5, 131-138.

Hayward, M.W. and Hayward, M.D. (2012) Water trough use by African Fauna. *South African Journal of Wildlife Research,* 42(2), 117-127.

Hetem, R.S., Fuller, A., Maloney, S.K. and Mitchell, D. (2014) Responses of large mammals to climate change. *Temperature,* 1(2), 115-127.

Hillyard, S.D., Podrabsky, J.E. and van Breukelen, F. (2015) Desert Environments. *Extremophile Fishes,* 59-83.

Hisali, E., Birungi, P. and Buyinza, F. (2011) Adaptation to climate change in Uganda: Evidence from micro level data. *Global Environmental Change,* 21, 1245-1261.

Hitchcock, D. (1996) Wildlife observed in Kutse Game Reserve, Botswana, at pans with either artificial or natural water sources. *African Journal of Ecology,* 34, 70-74.

Hoffman, T. and Vogel, C. (2008) Climate Change Impacts on African Rangelands. *Rangelands,* 30(3), 12-17.

Hounam, C.E., Burgos, J.J., Kalik, M.D., Palmer, C.W. and Rodda, J. (1975) *Drought in Agriculture Technical Note no.138*, World Meteorological Organisation, Geneva.

Huang, B., Banzon, V.F., Freeman, E., Lawrimore, J., Liu, W., Peterson, T.C., Smith, T.M., Thorne, P.W., Woodruff, S.D. and Zhang, H.M. (2015) Extended Reconstructed Sea Surface Temperature Version 4 (ERSST. v4). Part I: Upgrades and Intercomparisons. *Journal of Climate*, *28*(3), 911-930.

Huey, R.B., Kearney, M.R., Krockenberger, A., Holtum, J.A., Jess, M. and Williams, S.E. (2012) Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *367*(1596), 1665-1679.

Hughes, D.A., Kingston, D.G. and Todd, M.C. (2011) Uncertainty in water resources availability in the Okavango River basin as a result of climate change. *Hydrology and Earth System Sciences.* 15, 931-941.

Hulme, P.E. (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology,* 42, 784-794.

Humphries, M.M., Umbanhowar, J. and McCann, K.S. (2004) Bioenergetic Prediction of Climate Change Impacts on Northern Mammals. *Integrative and Comparative Biology,* 44, 152-162.

IPCC. (2007) Climate Chamge 2007: The Physical Science Basis. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, *Cambridge University Press,* Cambridge.

Jachmann, H. (2002) Comparison of aerial counts with ground counts for large African herbivores. *Journal of Applied Ecology,* 39, 841-852.

Jacobs, N., Burgin, W., Fridrich, N., Abrams, A., Miskell, K., Braswell, B.H., Richardson, A.D. and Pless, R. (2009) The Global Network of Outdoor Webcams: Properties and Applications. *ACM GIS,* 1-10.

James, C.D., Landsberg, J. and Morton, S.R. (1999) Provision of watering points in the Australian arid zone: a review of effects on biota. *Journal of Arid Environments*, 41, 87-121.

Jeltsch, F., Milton, S.J., Dean, W.R.J. and van Rooyen, N. (1997) Simulated pattern formation around artificial water troughs in the semi-arid Kalahari. *Journal of Vegetation Science,* 8, 177-188.

Juarez, E.I.A., Mace, G.M., Cowlishaw, G., Cornforth, W.A. and Pettorelli, N., (2013) Assessing exposure to extreme climatic events for terrestrial mammals. *Conservation Letters,* 6, 145-153.

Jury, M.R. and Mpeta, E.J. (2005) The annual cycle of African climate and its variability. *Water South Africa*, *31*(1), 1-8.

Kahil, M.T., Dinar, A. and Albiac, J. (2015) Modeling water scarcity and droughts for policy adaptation to climate change in arid and semiarid regions. *Journal of Hydrology,* 522, 95-109.

Kaholongo, I.K. and Mapaure, I. (2014) Vegetation Composition, Diversity, and Structure in Uukolonkadhi Community Forest of North Western Namibia. *Journal of Agriculture and Biodiversity Research,* 3(3), 41-50.

Kamanda, M., Ndiweni, V., Imbayarwo-Chikosi, V.E., Muvengwi, J. and Musakwa, A. (2008) The impact of tourism on sable antelope (hippotragus niger) vigilance behavior at artificial waterholes during the dry season in Hwange national park. *Journal of Sustainable Development in Africa*, *10*(3) 199-314.

Kamphof, I. (2011) Webcams to save nature: Online space as Affective and Ethical Space, *Foundations of Science,* 16, 259-274.

Kane, R.P. (2009) Periodicities, ENSO effects and trends of some South African rainfall series: an update. *South African Journal of Science*, *105*(5-6),199-207.

Kasiringua, E.A. (2010) *The effects of artificial water holes on the distribution of elephants and other mammalian herbivores in Savuti, Northern Botswana.* Masters Thesis, Hedmark University College, Norway.

Kays, R., Tilak, S., Kranstauber, B., Jansen, P.A., Carbone, C., Rowcliffe, M., Fountain, T., Eggert, J. and He, Z. (2011a) Camera traps as sensor networks for monitoring animal communities. *International Journal of Research and Reviews in Wireless Sensor Networks,* 1(2), 19-29.

Kays, R., Tilak, S., Crofoot, M., Fountain, T., Obando, D., Ortega, A., Kuemmeth, F., Mandel, J., Swenson, G., Lambert, T., Hirsch, B. and Wikelski, M. (2011b) Tracking Animal Location and Activity with an Automated Radio Telemetry System in a Tropical Rainforest. *The Computer Journal,* 1-18.

Kiffner, C., Stoner, C. and Caro, T. (2012) Edge effects and large mammal distributions in a national park. *Animal Conservation,* 16, 97 - 107.

Knight, M.H. (1995) Drought-related mortality of wildlife in the southern Kalahari and the role of man. *African Journal of Ecology,* 33, 377-394

Komp. K.U. (1983) Aerial Photo interpretation in Managua, *Cities,* 1, 28-38.

Kos, M., Baskin, C.C. and Baskin, J.M. (2012) Relationship of kinds of seed dormancy with habitat and life history in the Southern Kalahari flora. *Journal of Vegetation Science,* 23, 869-879.

Kovats, R.S., Bouma, M.J. and Haines, A. (1999) Protection of the Human Environment: Task Force on Climate and Health. *El Nino and Health,* 1-46

Krausman, P.R., Rosenstock, S.S. and Cain, J.W. (2006) Developed waters for wildlife: Science, Perception, Values, and Controversy. *Wildlife Society Bulletin,* 34(3), 563-569

Krebs, C.J. (1999) *Ecological methodology* (Vol. 620). Benjamin/Cummings, California.

Kreulen, D.A. (1985) Lick use by large herbivores: a review of benefits and banes of soil consumption. *Mammal Review*, 15(3), 107-123.

Kruger, A.C. and Sekele, S.S. (2013) Trends in extreme temperature indices in South Africa" 1962 - 2009. *International Journal of Climatology,* 33, 661-676.

Kruger, A.C. and Shongwe, S. (2004) Temperature trends in South Africa: 1960 - 2003. *International Journal of Climatology,* 24(15), 1929 - 1945.

Labuschagne, W. (1979) '*n Bio-ekologiese en gedragstudie van die jagluiperd Acinonyx jubatus jubatus* (Schreber, 1776). M.Sc dissertation, University of Pretoria, Pretoria.

Lawler, J.J., Shafer, S.L., White, D., Kareiva, P., Maurer, E.P. Blaustein, A.R. and Bartlein, P.J. (2009) Projected Climate-Induced Faunal Change in the Western Hemisphere. *Ecology,* 90(3), 588-597.

Le Houérou, H.N. (1996) Climate Change, drought and desertification. *Journal of Arid Environments,* 34, 133-185.

Lee, T.M. and Jetz, W. (2008) Future battlegrounds for conservation under global change. *Proc. R. Soc.* 275, 1261-1270.

Leistner, O.A. (1959) Notes on the vegetation of the Kalahari Gemsbok National Park with special reference to its influence on the distribution of antelopes. *Koedoe,* 2, 128-151.

Leistner, O.A. (1967) The plant ecology of the southern Kalahari. *Memoirs of the Botanical Survey of South Africa,* 38.

Liang, S.H.L., Croitoru, A. and Tao, C.V. (2005) A distributed geospatial infrastructure for Sensor Web. *Computers and Geosciences,* 31, 221-231.

Lioubimtseva, E. (2004) Climate change in arid environments: revisiting the past to understand the future. *Progress in Physical Geography,* 28(4), 502-530.

Locke, S.L., Cline, M.D., Wetzel, D.L., Pittman, M.T., Brewer, C.E. and Harveson, L.A. (2005) From the Field: A web-based digital camera for monitoring remote wildlife. *Wildlife Society Bulletin,* 33(2), 761-765.

Lohmann, D., Tietjen, B., Blaum, N., Joubert, D. and Jeltsch, F. (2012) Shifting thresholds and changing degradation patterns: climate change effects on the simulated long-term response of a semi-arid savanna to grazing. *Journal of Applied Ecology,* 49, 814-823.

Lomax, R. (2007) *An Introduction to Statistical Concepts, second edition*. Lawrence Erlbaum Associates Inc. Publishers*,* New Jersey, 33-34, 93-101, 361-415.

Lord, R., Bellorse, F. and Cochran, W. (1962) Radio telemetry of the respiration of a flying duck. *Science,* 137, 39-40.

Lu, Z. and Lei, S. (2015) Amphibian and reptilian distribution patterns in the transitional zone between the Euro-Siberian and Central Asia Sub-realms. *Journal of Arid Land,* 7(4), 555-565.

MacKellar, N., New, M. and Jack, C. (2014) Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *South African Journal of science*, *110*(7-8), 1-13.

Maggini, R., Lehhmann, A., Kery, M., Schmid, H., Beniston, M., Jenni, L. and Zbinden, N., 2011, Are Swiss birds tracking climate change? Detecting shifts using response curve shapes, *Ecological Modelling,* 222, 21-32.

Makhabu, S.W., Marotsi, B. and Perkins, J. (2002) Vegetation gradients around artificial water points in the Central Kalahari Game Reserve of Botswana, *African Journal of Ecology,* 40, 103-109.

Maliva, R. and Missimer, T. (2012) Chapter 38: Overview and Impacts on Arid Land and Water Resources, *Arid Lands Water Evaluation and Management,* 976-999.

Manly, B. (2009) Statistics for environmental science and management. *Chapman and Hall,* Florida, 68-74, 113, 182-184.

Maputla, N.W., Chimimba, C.T. and Ferreira, S.M. (2013) Calibrating a camera trap-based biased mark-recapture sampling design to survey the leopard population in the N'wanetsi concession, Kruger National Park, South Africa. *African Journal of Ecology*, *51*(3), 422-430.

Maraschin, NMR. (2013) *Faunal distribution in relation to rainfall patterns in the Kalahari Gemsbok National Park: 2004-2013*. Honours Thesis, University of Witwatersrand, Johannesburg.

Marnewick, K., Funston, P.J. and Karanath, K.U. (2008) Evaluating camera trapping as a method for estimating cheetah abundance in ranching areas. *South African Journal of Wildlife Research,* 38(1), 59-65.

Mawdsley, J.R., O'Malley, R. and Ojima, D.S. (2009) A review of climate-chamge adaptation strategies for wildlife management and biodiversity conservation. *Conservation Biology,* 23, 1080-1089.

Mbaiwa, J.E. and Mbaiwa, O.I. (2006) The effects of veterinary fences on wildlife populations in Okavango Delta, Botswana. *International Journal of Wilderness,* 12 (3), 17-41.

Mcneely, J.A. (1995) *Expanding Partnerships in Conservation,* Island Press, California.

Meadows, M.E. (2006) Global change and Southern Africa. *Geographical Research,* 44(2), 135-145.

Meyer, M.D. and Valone, T.J. (1999) Foraging under multiple costs: the importance of predation, energetic, and assessment error costs to a desert forager. *OIKOS*, 87, 571-579.

Mills, G. and Hes, L., (1997) *The Complete Book of Southern African Mammals*, Struik Publishers, Cape Town.

Mills, G. and Mills, M. (2013) *A Natural History Guide to the Arid Kalahari: Including the Kgalagadi Transfrontier Park,* Black Eagle Media, Cape Town.

Mills, M.G.L. and Retief, P.F. (1984) The Response of Ungulates to Rainfall along the Riverbeds of the Southern Kalahari 1972-1982. *Koedoe,* 129-141.

Moalafhi, D.B., Tsheko, R., Atlhopheng, J.R., Odirile, P.T. and Masike, S. (2012) Implications of climate change on water resources of Botswana. *Advanced Journal of Physical Science,* 1(2), 4-13.

Mordi, A.R. (1989) The Future of Animal Wildlife and its habitat in Botswana. *Environmental Conservation,* 16(20), 147-156.

Motulsky, H. (2003) The InStat guide to choosing and interpreting statistical tests. *GraphPad Software Inc:* San Diego, 12-14, 92, 97-100.

Mphale, K.M., Dash, S.K., Adedoyin, A. and Panda, S.K. (2014) Rainfall regime changes and trends in Botswana Kalahari Transect's late summer precipitation. *Theoretical and Applied Climatology,* 116, 75-91.

Mtahiko, M.G.G., Gereta, E., Kajuni, A.R., Chiombola, E.A.T., Ng'umbi, G.Z., Coppolillo, P. and Wolanski, E. (2006) Towards an ecohydrology-based restoration of the Usangu wetlands and the Great Ruaha River, Tanzania. *Wetlands Ecology and Management,* 14, 489-503.

Mukaru, W.C. and Mapaure. I. (2012) Impacts of large herbivores on plant species diversity and range condition around water points in Waterberg plateau park, central Namibia. *Journal of Research in Conservation Biology,* 1(1), 041-048.

Nagy, K.A. and Knight, M.H. (1994) Energy, Water, and Food Use by Springbok Antelope (Antidorcas Marsupialis) In the Kalahari Desert. *Journal of Mammalogy,* 75, 860-872.

Nangula, S. and Oba, G. (2004) Effects of artificial water points on the Oshana ecosystem in Namibia. *Environmental Conservation,* 31(1), 47-54.

Nash, D.J. and Endfield, G.H. (2002) A 19th Century chronology for the Kalahari region of central southern Africa derived from missionary correspondence. *International Journal of Climatology,* 22, 821-841.

Nash, D.J. and Endfield, G.H. (2008) 'Splendid rains have fallen': links between El Niño and rainfall variability in the Kalahari, 1840-1900. *Climatic Change*, 86 (3-4), 257-290.

Neelin, J.D., Jin, F.F. and Syu, H.H. (2000) Variations in ENSO Phase Locking*. *Journal of climate*. *13*(14), 2570-2590.

Nevin, O.T. and Gilbert, B.K. (2005) Perceived risk, displacement and refuging in brown bears: positive impacts of ecotourism?. *Biological Conservation,* 121, 611-622.

New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C.A., Masisi, D.N., Kululanga, E. and Mbambalala, E. (2006) Evidence of trends in daily climate extremes over southern and west Africa. *Journal of Geophysical Research: Atmospheres*, *111*(D14).

Nicholson, S.E. (2014) Spatial teleconnections in African rainfall: A comparison of 19th and 20th century patterns. *The Holocene,* 24(12), 1840-1848.

Nicholson, S.E., Leposo, D. and Grist, J. (2001) The relationship between El Niño and Drought over Botswana. *American Meteorological Society,* 14, 323-335.

Nkomo, J.C., Nyong, A.O. and Kulindwa, K. (2006) The impacts of climate change in Africa. *The Stern Review on the Economics of Climate Change,* 1-51.

Noble, I.R. and Gitay, H. (1996) Chapter 3: Desserts in a Changing Climate: Impacts, *Cambridge University Press*, 159-170.

Noble, J.C., Habermehl, M.A., James, C.D., Landsberg, J., Langston, A.C. and Morton, S.R. (1998) Biodiversity implications of water management in the Great Artesian Basin. *Rangel. J.,* 20, 275-300.

Ogutu, J.O. and Owen-smith, N. (2003) ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. *Ecology letters,* 6, 412-419.

Ogutu, J.O., Owen-Smith, N., Piephi, H-P., Kuloba, B. and Edebe, J. (2012) Dynamics of ungulates in relation to climatic and land use changes in an insularized African savanna ecosystem. *Biodiversity and Conservation,* 21, 1033-1053.

Ogutu, J.O., Piepho, H.P., Dublin, H.T., Bhola, N. and Reid, R.S. (2008) Rainfall influences on ungulate population abundance in the Mara-Serengeti ecosystem. *Journal of Animal Ecology,* 77, 814-829.

Olff, H., Ritchie, M.E. and Prins, H.H.T. (2002) Global environmental controls of diversity in large herbivores. *Nature,* 415, 901-904.

Paine, D.P. and Kiser, J.D. (2012) *Aerial Photography and Image Interpretation,* John Wiley and Sons, New Jersey.

Palaniswamy, U. and Palaniswamy, K. (2006) Handbook of Statistics for teaching and research in plant and crop science. *Haworth Reference Press:* New York, 59, 207-265.

Palmer, A.R. and van Rooyen, A.F. (1998) Detecting vegetation change in the southern Kalahari using LandsatTM data. *Journal of Arid Environments*, 39, 143-153.

Park, H.S. and Sohn, B.J. (2009) Recent trends in changes of vegetation over East Asia coupled with temperature and rainfall variations. *Journal of geophysical research,* 115, 1-12.

Parris, R. and Child, G. (1973) The importance of pans to wildlife in the Kalahari and the effect of human settlement on these areas. *Journal of Southern African Wildlife Management Assessment,* 3(1), 1-8.

Parris, R. (1976) A study of the major components of the Kalahari pan ecosystem, M.S.c Thesis, University of Pretoria, Pretoria.

Parris, R. (1984) Pans, Rivers and Artificial waterholes in the protected areas of the South-western Kalahari. *Koedoe,* 63-82.

Peck, L.S., Clark, M.S., Morley, S.A., Massey, A. and Rossetti, H. (2009) Animal temperature limits and ecological relevance: effects of size, activity and rates of change. *Functional Ecology,* 23, 248-256.

Pendleton, G.W. (1995) Effects of Sampling Strategy, Detection Probability, and Independence of Counts on the Use of Point Counts. *USDA Forest Service General Technical Report,* 131-133.

Peterson, D.P., Yao, J., Sala, O.E. and Anderson, J.P. (2012) Directional climate change and potential reversal of desertification in arid and semi-arid ecosystems. *Global Change Biology,* 18-151-163.

Peterson, A.T., Radocy, T., Hall, E., Peterhans, J.C.K. and Celesia, G.C. (2014) The potential distribution of the Vulnerable African lion *Panthera leo* in the face of changing global climate. *Oryx,* 48(4), 555-564.

Pettorelli, N., Chauvenet, A.L.M., Duffy, J.P., Cornforth, W.A., Meillere, A. and Baillie. J.E. (2012) Taking the effect of climate change on ecosystem functioning using protected areas: Africa as a case study. *Ecological Indicators,* 20, 269-276.

Phillipson, J. (1975) Rainfall, primary production and “carrying capacity” of Tsavo National Park, Kenya. *East African Wildlife Journal,* 18(4), 171-201.

Pollock, K.H., Nichols, J.D., Simons, T.R., Farnsworth, G.L., Bailey, L.L. and Sauer, J.R., (2002) *Large scale wildlife monitoring studies: statistical methods for design and analysis.* 13, 105-119.

Porter, J., Lin, C.C, Smith, D.E. and Lu, S.S. (2010) Ecological image databases: From the webcam to the researcher. *Ecological Informatics,* 5, 51-58.

Quinn, J. and Woodward, S., 2015: *Earth's Landscape: An Encyclopedia of the World's Geographic Features,* ABC-CLIO, California

Ramutsindela, M. (2007) *Transfrontier Conservation in Africa: At the confluence of Capital, Politics and Nature,* CABI, United Kingdom.

Rango, A., Tartowski, S.L., Laliberte, A., Wainwright, J. and Parsons, A. (2005) Islands of hydrologically enhanced biotic productivity in natural and managed arid ecosystems. *Journal of Arid Environments,* 65, 235-252.

Reddy, V.R., Brown, P., Bandi, M., Chiranjeevi, T., Reddy, R. and Roth, C., (2010) Adapting to Climate Variability in Semi-arid Regions: A Study Using Sustainable Rural Livelihoods Framework. *CSIRO,* 1-40.

Redfern, J.V., Grant, C.C., Gaylard, A. and Getz, W.M. (2005) Surface water availability and the management of herbivore distributions in an African savanna ecosystem. *Journal of Arid Environments*, *63*(2), pp.406-424.

Relton, C. (2015) *Movement Ecology of the Gemsbok in the Central Kalahari in Response to Vegetation Greenness as assessed by Satellite Imagery.* Masters Thesis, University of the Witwatersrand, Johannesburg.

Ringrose, S., Matheson, W., Wolski, P. and Huntsman-Mapila, P. (2003) Vegetation Cover Trends along the Kalahari Transect. *Journal of Arid Environments,* (54), 297-317.

Roberts, C.W., Pierce, B.L., Braden, A.W., Lopez, R.R., Silvy, N.J., Franks, P.A. and Ransom, D. (2006) Comparison of camera and road survey estimates for white-tailed deer. *J. of Wildlife Management,* 70(1), 263-267.

Rodrigues, A.S., Gregory, R.D. and Gaston, K.J. (2000) Robustness of reserve selection procedures under temporal species turnover. *Proceedings of the Royal Society London,* 267, 49-55.

Roodt, V. (2015) *Grasses and Grazers of Botswana and the surrounding savanna,* Struik Nature, South Africa.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C. and Pounds, J. A. (2003) Fingerprints of global warming on wild animals and plants. *Nature*, *421*(6918), 57-60.

Rowat, D., Gore, M., Meekan, M.G., Lawler, I.R. and Bradshaw, C.J.A. (2009) Aerial survey as a tool to estimate whale shark abundance trends. *Journal of experimental marine biology and ecology,* 368, 1-8.

Rowcliffe, J.M. and Carbone, C. (2008) Surveys using camera traps: are we looking to a brighter future?. *Animal Conservation,* 11, 185-186.

Rowcliffe, J.M., Carbone, C., Jansen, P.A., Kays, R. and Kranstauber, B., (2011) Quantifying the sensitivity of camera traps: an adapted distance sampling approach. *Methods in Ecology and Evolution*, 2, 464-476.

Rudee, A. (2011) *Comparative Ecology and Population Dynamics of Ungulates in Botswana.* Masters Thesis, California.

Rutherford, M.C., Powerie, L.W. and Schulze, R.E. (1999) Climate Change in Conservation Areas of South Africa and Its Potential Impact on Floristic Composition: A First Assessment. *Diversity and Distribution,* 5(6), 253-262.

Saeidabadi, R., Najafi, M.S., Roshan, G., Fitchett, J.M. Abkharabat, S. (In Press). Modelling spatial, altitudinal and temporal variability of annual precipitation in mountainous regions: The case of the Middle Zagros, Iran. *Asia - Pacific Journal of Atmospheric Sciences.*

SANParks. (2008) Kalahari Gemsbok National Park Management Plan, SANParks. Retrieved on 8 March 2015 from: https://www.sanparks.org/assets/docs/conservation/park_man/kalahari_approved_plan.pdf

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. and Walker, B. (2001) Catastrophic shifts in ecosystems. *Nature,* 413, 591-596.

Schlesinger, W.H., J.F. Reynolds, G.I. Cunningham, L.F. Huennecke, W.M. Jarrell, R.A. Virginia, and W.G. Whitford (1990) Biological feedbacks in global desertification. *Science*, 247, 1043-1048.

Schmidt-Nielsen, K. (1997) *Animal Physiology: Adaptation and Environment,* Cambridge University Press, United Kingdom.

Scholes, R.J., Dowty, P.R., Caylor, K., Parsons, D.A.B., Frost, P.G.H. and Shugart, H.H. (2002) Trends in savanna structure and composition along an aridity gradient in the Kalahari. *Journal of Vegetation Science,* 13, 419-428

Shresta, A.K., van Wieren, S.E., van Langevelde, F., Fuller, A., Hetem, R.S., Meyer, L.C.R., de Bie, S. and Prins, H.H.T. (2012) Body temperature variation of South African antelopes in two climatically contrasting environments. *Journal of Thermal Biology*, 37, 171-178.

Silberbauer, G.B. (1981) *Hunter and Habitat in the Central Kalahari Desert,* Cambridge University Press, United States of America.

Simpson, N.O., Stewart, K.M. and Bleich, V.C. (2011) What have we learned about water developments for wildlife? Not Enough! *California Fish and Game,* 97, 190-209.

Sitati, N., Lekishon, K., Bakari, S., Warinwa, F., Mwiu, S.N., Gichohi, N., Bitok, E., Mwita, M., Ija, H.K. and Mukeke, J. (2014) Wildebeest Connochaetes taurinus) Population Densities and Distribution in Dry and Wet Season in the Kilimanjaro landscape. *Natural Resources*, 5, 810-821.

Skiles, J.W. and Hanson, J.D. (1994) Responses of arid and semi-arid watersheds to increasing carbon dioxide and climate change as shown by simulation studies. *Climate Change,* 26, 377-397.

Smit, I.P.J. and Grant, C.C. (2009) Managing surface-water in a large semi-arid savanna park: Effects on grazer distribution patterns. *Journal for Nature Conservation*, 17, 61-71.

Smit, I.P.J., Grant, C.G. and Devereux, B.J. (2007) Do artificial water troughs influence the way herbivores use the landscape? Herbivore distribution patterns around rivers and artificial surface water sources in a large African savanna park. *Biological Conservation,* 136, 85-99.

Smouse, P.E., Focardi, S., Moorcroft, P.R., Kie, J.G., Forester, J.D., Morales, J.M. (2010) Stochastic modelling of animal movement. *Philosophical Transactions of the Royal Society of London B: Biological Sciences,* 365, 2201-2211.

Stapelberg, H., Van Rooyen, M., Bothma, J.D.P., Van Der Linde, M.J. and Groeneveld, H.T. (2008) Springbok behaviour as affected by environmental conditions in the Kalahari. *Koedoe,* 50, 145-153.

Strauch, A.M. (2013) The role of water quality in large mammal migratory behaviour in the Serengeti. *Ecohydrology,* 6, 343-354.

Sutherland, W.J. (2006) *Ecological Census Techniques,* Cambridge University Press, Cambridge.

TAWIRI. (2013) Aerial Census of Large Animals in the Selous-Mikumi Ecosystem, Dry Season, 2013, Population Status of African Elephant, the Serengeti Ecosystem. *Conservation Information and Monitoring Unit,* 1-60.

Tews, J., Blaum, N. and Jeltsch, F. (2004) Structural and Animal Species Diversity in Arid and Semi-arid Savannas of the southern Kalahari. *Annals of Arid zone,* 43(3&4), 413-425.

Therrell, M. D., Stahle, D. W., Ries, L. P., and Shugart, H. H. (2006) Tree-ring reconstructed rainfall variability in Zimbabwe. *Climate Dynamics*, *26*(7-8), 677-685.

Thomas, C.D., Cameron, A. Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., Ferreira de Siqueira, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Peterson, T.A., Phillips, O.L. and Williams, S.E. (2004) Extinction risk from climate change. *Nature*, 427(6970), 145-148.

Thomas, D.S.G. and Leason, H.C. (2005) Dunefield activity response to climate variability in the southwest Kalahari. *Geomorphology,* 64, 117-132.

Thomas, D.S.G. and Shaw, P.A. (1991) *The Kalahari Environment,* Cambridge University Press, Cambridge.

Thondhlana, G., Shackleton, S. and Muchapondwa, E. (2011) Kgalagadi Transfrontier Park and its land claimants: a pre- and post-land claim conservation and development history. *Environ. Res,* 6, 1-6.

Thouless, C.R. (1998) Large Mammals Inside and Outside Protected Areas in the Kalahari. *Transactions of the Royal Society Of South Africa,* 53(2), 245-255.

Thrash, I., Theron, G.K. and Bothma, J.D.P. (1993) Impact of water provision on herbaceous community composition in the Kruger National Park, South Africa. *African Journal of Range & Forage Science,* 10(1) 31-35.

Thuiler, W. (2007) Climate change and the ecologist. *Nature*, *448*(2), 550-552.

Trent, A. (2012*) The Value of Webcam Imagery in Savanna Ecology: Climate Impacts on Faunal Use of Artificial Water troughs in the Kruger National Park*. Honours Thesis, University of Witwatersrand, Johannesburg.

Trent, A. (2015) *Mammal Utilisation of Artificial Water Sources in the Central Kruger National Park: Contemporary Seasonal Patterns and Implications for Climate Change Scenarios,* Masters Thesis, University of the Witwatersrand, Johannesburg.

Tyson, P.D. and Crimp, S.J. (1998) The climate of the Kalahari Transect. *Transactions of the Royal Society of South Africa*, *53*(2), 93-112.

Tyson, P.D. and Preston-Whyte, P.A. (2000) *The Weather and Climate of Southern Africa,* Oxford University Press, Oxford.

Underhill, L. and Bradfield, D. (2009) Introstat, *Juta and Co. Ltd:* Cape Town, (211) 299-353.

Unganai, S.L. (1996) Historic and future climatic changes in Zimbabwe. *Climate Research,* 6, 137-145.

Valeix, M., Chamaille-Jammes, S. and Fritz, H., (2007) Interference competition and temporal niche shifts: elephants and herbivore communities at waterholes, *Oecologia,* 153, 739-748.

Valeix, M., Fritz, H., Chamaille-Jammes, S., Bourgarel, M. and Murindagomo, F. (2008) Fluctuations in abundance of large herbivore populations: insights into the influence of dry season rainfall and elephant numbers from long-term data, *Animal Conservation,* 11, 391-400.

Valeix, M., Fritz, H., Matiska, R., Matsvimbo, F. and Madzikanda, H. (2008) The role of water abundance, thermoregulation, perceived predation risk and interference competition in water access by African herbivores. *African Journal of Ecology.,* 46, 402-410.

Valeix, M. (2011) Temporal dynamics of dry-season water- hole use by large African herbivores in two years of contrasting rainfall in Hwange National Park, Zimbabwe. *Journal of Tropical Ecology,* 27, 163-170.

Van Heezik, Y., Ismail, K. and Seddon, P.J. (2003) Shifting spatial distributions of Arabian oryx in relation to sporadic water provision and artificial shade. *Oryx,* 37(3), 295-304.

Van Jaarsveld, A.S. and Chown, S.L. (2001) Climate change and its impacts in South Africa. *TRENDS in Ecology and Evolution,* 16(1), 13-14.

Van Rooyen, M.M. and Van Rooyen, M.M. (1998) Vegetation of the South-Western Klahari: An Overview*. Transactions of the Royal Society of South Africa,* 53(2), 113-140*.*

Van Rooyen, N., Bredenkamp, G.J. and Theron, G.K. (1991) Kalahari vegetation: veld condition trends and ecological status of species. *Koedoe,* 34(1), 61-72.

Van Rooyen, N., Bredenkamp, G.J., Theron, G.K., Bothma, J.D.P. and Le Riche, E.A.N. (1994) Vegetational gradients around artificial watering points in the Kalahari Gemsbok National Park. *Journal of Arid Environments,* 26, 349-361.

Van Rooyen, M.M., Van Rooyen, N., Bothma, J.D.P. and Van Den Berg, H.M. (2008) Landscapes in the Kalahari Gemsbok National Park, South Africa. *African Protected Area conservation and Science,* 50(1), 99-112.

Van Sickle, W.D. and Lindzey, F.G. (1991) Evaluation of a cougar population estimator based on probability sampling*. Journal of Wildlife Management*, 55, 738-743.

van Wilgen, N.J., Goodall, V., Holness, S., Chown, S.L. and McGeoch, M.A. (2015) Rising temperatures and changing rainfall patterns in South Africa's national parks. *International Journal of Climatology*.

Van Wyk, P. and Le Riche, E.A.N. (1984) The Kalahari Gemsbok National Park: 1931-1981. *Koedoe,* 21-31.

Van Wyk, L. (2011). *Review of the ecological implications of artificial waterhole closures in the Kruger National Park and the effect thereof on tourism* (Doctoral dissertation).

Verlinden, A., Perkins, J.S., Murray, M. and Masunga, G. (1998) How are people affecting the distribution of less migratory wildlife in the southern Kalahari of Botswana? A spatial analysis, *Journal of Arid Environments,* 38, 129-141.

Verstraeten, W.W., Vermeulen, B., Stuckens, J., Lhermitte, S., Van der Zande, D., Van Ranst, M. and Coppin, P. (2010) Webcams for Bird Detection and Monitoring: A Demonstration Study. *Sensors,* 10, 3480-3503.

Vetter, S. (2009) Drought, change and resilience in South Africa's arid and semi-arid rangelands. *South African Journal of Science,* 105, 29-33

Vittoz, P., Cherix, D., Gonseth, Y., Lubini, V., Maggini, R., Zbinden, N., Zumbach, S. (2013) Climate change impacts on biodiversity in Switzerland: A review. *Journal for Nature Conservation,* 21, 154-162.

Wang, H., Yang, Z., Saito, X., Lui, J.P. and Sun, X. (2006) Interannual and seasonal variation of the Huanghe (Yellow River) water discharge river the past 50 years: connections to impacts from ENSO events and dams. *Global and Planetary Change,* 50, 212-225.

Wanke, H. and Wanke, A. (2007) Water quality for game in drylands: A case study from the Khaudum National Park. Namibia, *Journal of Arid Environments,* 553-559.

Washington, R. and Preston, A. (2006) Extreme wet years over southern Africa: Role of Indian Ocean sea surface temperatures. *Journal of Geophysical Research: Atmospheres*, *111*(D15).

Wawerla, J., Marshall, S., Mori, G., Rothley, K. and Sabzmeydani, P. (2009) BearCam: Automated Wildlife Monitoring At The Arctic Circle. *Machine Vision and Applications,* 20(5), 303-317.

Werger, M.J.A. (1978) Vegetation structure of the southern Kalahari. *Journal of Ecology,* 66, 933-941.

Western, D. (1975) Water availability and its influence on the structure and dynamics of a savanna large mammal community. *East African Wildlife Journal,* 13, 265-286.

Wichmann, M.C., Jeltsch, F., Dean, R.J., Moloney, K.A. Wissel, C. (2003) Implication of climate change for the persistence of raptors in arid savanna. *Oikos,* 102, 186-202.

Williams, S. and Wells, R.T. (1986) *Providing water for native fauna arid habitats,* Cambridge University Press, Canberra.

Williamson, D., Williamson, J. and Ngwamotsoko, K.T. (1988) Wildebeest migration in the Kalahari. *African Journal of Ecology,* 26(4), 269-280.

Willis, K.J., Bennett, K.D., Burrough, S.L., Macias-Fauria, M. and Tovar, C. (2013) Determining the Response of African Biota to climate change: Using the past to model the future, 368(1625), *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 1-9.

Willis, S.G., Hole, D.G., Collingham, Y.C., Hilton, G., Rahbek, C. and Huntley, B. (2009) Assessing the impacts of future climate change on protected area networks: A method to simulate individual species' responses. *Environmental Management*, *43*(5), 836-845.

Wilson, D.E.C., Nichols, R.F., Rudran, J.D., Rasanayagam Foster, M.S., Cole, F.R., Nichols, J.D., Rudran, R. and Foster, M.S. (1996) *Measuring and monitoring biological diversity standard methods for mammals* (No. 599.05248 M4).

Winsemius, H.C., Dutra, E., Engelbrecht, F.A., Archer Van Garderen, E., Wetterhall, F., Pappenberger, F. and Werner, M.G.F. (2014) The potential value of seasonal forecasts in a changing climate in southern Africa. *Hydrology and Earth System Sciences*, *18*(4), 1525-1538.

Woodward, F.I. and Lomas, M.R. (2004) Simulating vegetation processes along the Kalahari transect. *Global Change Biology*, *10*(3), 383-392.

WWF. (2000) *Counting Wildlife Manual: Wildlife Management Series*. Southern African Regional Programme Office (SARPO), Zimbabwe.

Yasuda, M. and Kawakami, K. (2002) New method of monitoring remote wildlife via the Internet. *Ecological Research,* 17, 119-124.

9 Appendix

A. 1: Hourly faunal counts per month over the period October 2012 – December 2014.

Month	04:00 - 05:00	05:00 - 06:00	06:00 - 07:00	07:00 - 08:00	08:00 - 09:00	09:00 - 10:00	10:00 - 11:00	11:00 - 12:00	12:00 - 13:00	13:00 - 14:00	14:00 - 15:00	15:00 - 16:00	16:00 - 17:00	17:00 - 18:00	18:00 - 19:00	19:00 - 20:00	20:00 - 21:00	21:00 - 22:00	22:00 - 23:00	23:00 - 00:00	Monthly Total
Oct-12	35	40	52	118	110	136	120	107	170	141	136	126	130	180	134	109	53	81	7	2	1987
Nov-12	13	52	56	89	102	106	132	143	250	257	217	194	247	241	144	111	86	68	13	2	2523
Dec-12	33	45	8	18	33	12	18	53	56	38	24	36	26	20	33	58	90	113	26	7	747
Jan-13	50	81	24	34	48	16	26	55	87	55	37	39	21	18	24	81	148	153	85	5	1087
Feb-13	55	105	44	59	64	63	60	74	181	146	137	137	55	76	99	165	249	276	145	10	2200
Mar-13	28	119	89	126	156	121	150	136	104	185	93	38	83	71	139	283	283	241	128	4	2577
Apr-13	0	7	4	3	10	2	3	1	3	2	13	3	2	2	7	18	12	16	9	4	121
May-13	0	16	18	18	59	74	31	53	33	31	33	14	12	27	83	76	80	69	23	9	759
Jun-13	0	10	5	14	18	66	79	43	16	27	25	25	23	35	98	106	57	55	6	19	727
Jul-13	0	5	20	22	35	22	34	27	24	45	24	11	15	42	108	140	105	71	0	8	758
Aug-13	3	53	73	63	57	70	52	91	44	54	42	53	32	53	270	250	177	93	5	10	1545
Sep-13	0	30	47	86	54	53	92	85	62	56	14	41	38	42	178	206	152	120	4	8	1368
Oct-13	4	49	47	81	46	31	16	51	65	23	39	36	37	25	68	154	147	124	9	17	1069
Nov-13	68	66	40	106	87	62	117	193	197	115	65	42	43	64	78	144	190	159	3	27	1866
Dec-13	16	25	18	13	98	51	15	26	35	40	9	7	25	16	36	17	46	28	5	7	533
Jan-14	9	67	42	61	64	33	73	64	33	73	44	24	10	35	16	21	64	75	2	11	821
Feb-14	0	1	0	21	11	0	0	15	33	3	9	1	12	0	0	1	2	1	2	0	112
Mar-14	2	6	13	30	31	6	53	70	53	81	20	18	17	34	2	3	4	9	0	0	452
Apr-14	0	1	3	27	11	6	21	20	0	0	1	10	0	0	1	2	3	3	0	0	109
May-14	2	3	11	21	41	46	67	65	74	92	91	49	18	3	22	25	16	54	2	3	705
Jun-14	1	4	11	11	40	46	86	94	136	75	94	60	47	63	95	43	52	77	0	7	1042
Jul-14	0	15	11	16	151	165	195	156	341	374	280	137	118	35	88	80	89	85	0	1	2337
Aug-14	0	28	24	100	121	270	188	370	422	331	192	133	71	113	74	79	84	91	3	14	2708
Sep-14	3	21	49	100	272	242	236	222	250	247	211	205	209	192	33	63	52	60	1	12	2680
Oct-14	4	32	34	161	181	168	169	184	301	205	255	204	197	164	124	209	79	60	4	11	2746
Nov-14	6	14	3	35	20	29	43	27	20	29	14	11	13	21	15	14	17	21	3	2	357
Dec-14	16	13	9	45	1	22	41	53	39	41	51	13	12	27	21	25	50	42	5	1	527
Hourly Total	348	908	755	1478	1921	1918	2117	2478	3029	2766	2170	1667	1513	1599	1990	2483	2387	2245	490	201	

A. 2: Total faunal counts per hour over the period October 2012 - December 2014.

Hours	Blue Wildebeest	Brown Hyena	Cheetah	Gemsbok	Jackal	Leopard	Lion	Red Hartebeest	Spotted Hyena	Springbok	Total
04:00 - 05:00	28	13	2	6	252	2	36	0	8	1	348
05:00 - 06:00	41	54	7	12	625	3	99	9	27	30	908
06:00 - 07:00	113	25	4	6	424	3	66	17	15	82	755
07:00 - 08:00	443	23	4	6	510	1	41	130	3	314	1478
08:00 - 09:00	712	9	9	5	431	1	24	180	10	538	1921
09:00 - 10:00	597	3	0	18	305	0	33	212	0	737	1918
10:00 - 11:00	788	3	0	38	188	2	4	195	9	799	2117
11:00 - 12:00	653	2	0	33	237	0	3	201	1	1011	2478
12:00 - 13:00	681	2	0	26	134	0	10	170	5	1457	3029
13:00 - 14:00	619	2	0	30	99	1	3	132	4	1394	2766
14:00 - 15:00	417	1	1	11	115	1	5	104	0	1253	2170
15:00 - 16:00	309	2	2	19	137	0	17	41	0	1039	1667
16:00 - 17:00	191	2	0	17	228	0	15	51	0	978	1513
17:00 - 18:00	105	1	2	16	507	0	32	14	8	907	1599
18:00 - 19:00	120	17	6	49	1238	1	49	7	11	488	1990
19:00 - 20:00	33	51	12	101	1882	3	76	1	24	300	2483
20:00 - 21:00	24	91	9	95	1898	1	96	2	29	141	2387
21:00 - 22:00	4	130	1	133	1680	5	71	5	26	190	2245
22:00 - 23:00	1	24	0	22	401	0	17	0	7	18	490
23:00 - 00:00	`	9	0	0	4	0	1	0	0	0	14
Total	5879	464	59	643	11295	24	698	1471	187	11677	34276