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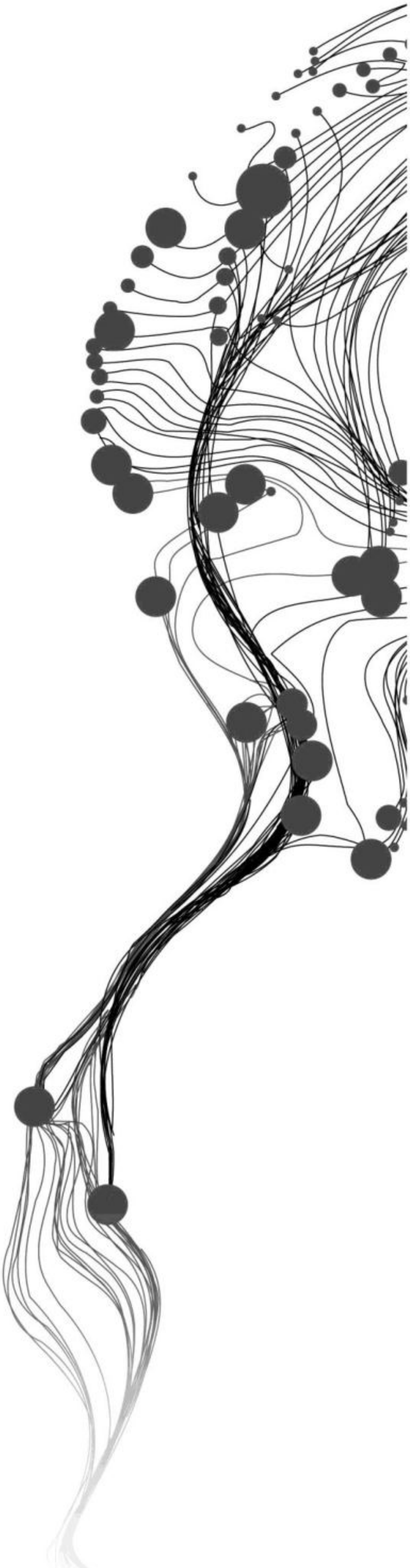

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NYASHA YVONNE MWENDERA
Enschede, the Netherlands, February, 2015

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

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ABSTRACT

Cheetah numbers and overall areas of occupancy have rapidly declined, relegating their conservation status to vulnerable. Factors contributing to the decline of the cheetah occupied range include the depletion of their wild prey base, conflict with humans, attacks by larger predators; and loss and disintegration of their preferred habitat. Sufficient information on the cheetah distribution and the factors affecting it is needed in order to achieve operative conservation strategies. The aim of this study was to understand the distribution of cheetah in Namibia in terms of biophysical and anthropogenic variables for evidence based species conservation. One objective was to identify the environmental variables important in explaining the cheetah spatial distribution. The environmental variables tested were elevation, slope, rainfall, temperature, vegetation, prey, large carnivores, management and land tenure. The study also to aimed to establish whether the bushland and desert areas of Namibia can further aid in determining the environmental variables which can be used to predict the presence of cheetah. The third objective of this study was to show the change in time of the cheetah occupied range. Species Distribution Models were used to establish the important environmental variables pertaining to predicting cheetah presence. Forward stepwise Maxent modelling was done to compute SDMs and the highest performing SDMs were taken to be representative. Variables for consideration in the modelling process were chosen based on correlation tests, chi-squared test, VIF analysis and jackknife of predictors. Models were evaluated using the AUC of the ROC plots, True Skills Statistic (TSS) and Kappa statistics. Species Distribution Modelling was done using Maxent software. The change in time of the occupied range was calculated using the kernel density estimations in ArcGIS and isopleth tools in Geospatial Modelling Environment (GME). The environmental variables important for explaining the cheetah spatial distribution were Elevation, Kudu, Land Tenure, Leopard, Lion and Vegetation. An SDM computed from these environmental variables performed significantly well and proved to be robust (AUC = 0.821). Elevations above 1500m were determined to be associated with a high probability of presence of cheetah. Cheetah presence probability increased with an increase in the number of Kudu per head per square kilometre. Cheetah presence increased with an increase in the number of larger carnivores but reduced as the numbers became significantly high. The Cheetah presence was found to be high associated with land tenure. Vegetation also has an impact on the cheetah presence. SDMs modelled in the desert areas proved to perform better than those modelled over the whole study area or the bush land alone. Results showed that the occupied range of the cheetah had decreased by approximately 52% over the years from 1982 to 2014.The findings of this study contribute to the baseline knowledge needed for effective cheetah conservation. The results can be used to establish which areas are useful for further conservation efforts, relocations and establish whether some conservation efforts already in place have a significant positive effect on cheetah range.

ACKNOWLEDGEMENTS

Firstly, I would like to thank NUFFIC for awarding me NFP fellowship to pursue this master's degree and making this research possible. I would like to thank ITC for awarding me a place to study at their institution. I learnt a lot, and it was an eye opening experience. Never to be forgotten.

I would like to thank my first supervisor Drs. Eddie Westinga for being patient, inspiring and guiding me. Thank you for introducing me to "Cheetahs in Namibia". Thank you for all the time and effort you dedicated to this research. It was quite an experience being under your wing. To my second supervisor, Dr. Thomas Groen, thank you for helping me untangle my thoughts from being "a bowl of spaghetti" into being clear and concise. To both of you, I really appreciate the heated discussions that took place in every meeting.

I would like to thank Dr Hein van Gils for his ideas, guidance, dedication and wonderful contributions. Words cannot express my gratitude. Thank you for assisting me in Namibia. My acknowledgements go to Angus Middleton and Katie Oxenham at the Namibia Nature Foundation (NNF) for inviting and allowing me to attend the annual LCMAN meeting. Thank you for connecting me to the relevant carnivore people in Namibia. I would also like to thank all the members of Large Carnivore Group in Namibia for all the informal discussions on cheetahs we had and all the suggestions they gave. Furthermore, I would like to thank the NNF, the Brown Hyena Research Group, N/a'ankuse Research Programme, Namib Rand Reserve, Neuhof Nature Reserve, Sandfontein Game Reserve and Weltevrede Guest Lodge for Cheetah observation data.

The friends I met in ITC, in my NRM/GEM class; those I met in Namibia, SADC-ITC family and "the Girls". These people made my ITC experience worthwhile. My friends, Xia and Rafael, thank you for supporting me always. My gratitude also goes to Petra Budde for her invaluable advice and driving expertise in the field. To Mxolisi "MX" Sibanda; thank you for all your advice, for connecting me to the right people, for allowing me to pick your brains and for encouraging me. Special thanks go to Ana Patricia for rubbing off her adventurous spirit onto me.

I would like to thank my family and friends for supporting my studies. To my mother- Mrs Chuchu; my uncle- Mr Chapwanya; Rumbidzai and Kudakwashe Mwendera, thank you all for the support.

Above all, I praise God for everything.

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1. INTRODUCTION

The cheetah is well known for its remarkable speed; and being the only species in an exclusive genus. Cheetah numbers have rapidly declined, relegating their conservation status to vulnerable (IUCN, 2013). The global population was approximately 30 000 in the 1970s; and by 1990 was estimated to be below 15 000 (Myers, 1975; Marker-Kraus & Grisham, 1993). Currently, approximately 7 500 cheetah remain in the wild (African Wildlife Foundation, 2013). In addition to declining numbers, the overall area they occupy is also decreasing (G. Purchase, Marker, Marnewick, Klein, & Williams, 2007). The cheetah habitat has decreased by approximately 76% over the last century (Ray, Hunter, & Zigouris, 2005). The range of the cheetah has been reduced mainly to East and Southern Africa. The largest population of the species is found in Namibia (Marker, Dickman, Jeo, Mills, & Macdonald, 2003). The Namibian cheetah population has been estimated at being between 2500-3000 individuals, of which 90% are said to be living outside protected areas (Marker, Kraus, Barnett, & Hurlbut, 1996; Marker-Kraus & Kraus, 1990; Morsbach, 1987). Various factors are contributing to the deterioration of the cheetah range. These include, but are not limited to, the depletion of their wild prey base, conflict with humans, attacks by larger predators; and loss and destruction of their preferred habitat (Nowell & Jackson, 1996; Marker, 2002). In order to achieve operative conservation strategies, there is need for sufficient information on the cheetah distribution.

Most studies on the spatial ecology of the cheetah were done in East Africa (Bissett & Bernard, 2007); and the few of Namibia have mainly focused on cheetah on freehold-livestock farms in the North-central parts of the country (Marker, Dickman, Mills, & Macdonald, 2010; Marker et al., 1996; Marker, Dickman, Mills, Jeo, & Macdonald, 2008; Marker, 2002; Marker, Dickman, Jeo, Mills, & Macdonald, 2003; Marker, Mills, & Macdonald, 2003). However, in the beginning of the twentieth century cheetah are reported to have occupied north-central; as well as southern parts of Namibia (Marker et al., 1996). Cheetah have been observed in both these places despite the fact that most of the cheetah distribution is now more concentrated in north-central Namibia, with a few patches being occupied in the south ("Environmental Information Service, Namibia," 2009; Stein, Kastern, & Andreas, 2012). Acquiring data on the Namibian cheetah is needed to understand how it is affected by continuous conflicts and habitat modifications (Marker et al., 1996; Muntifering et al., 2006).

In the early 20th century, cheetah was found in the north-central and southern parts of Namibia; these areas now harbour livestock farms (Marker et al., 1996). The presence of cheetah conflicts with livestock farming which resulted in most of the cheetah being killed or removed from farms (Marker, 2002). In the period 1980 to 1991, an estimated 6800 cheetah were trapped and killed or sold into captivity (Marker et al., 1996). In the south of Namibia, with dominantly small stock farming, the cheetah has trouble persisting. This is because there has been a more intensified eradication of predators including predator-proof fencing (Marker et al., 1996). Various studies have been conducted on the cheetah in Namibia. Focus was on, but not limited to, habitat suitability (Muntifering et al., 2006), farmland cheetah (Marker et al., 2008), cheetah demography (Marker, et.al. 2003) and population status (Marker, Dickman, Wilkinson, Schumann, & Fabiano, 2007). These studies have mostly been conducted in North-central Namibia. None have focused on cheetah in the whole country, thus the southern portion of the nation has remained largely unexplored.

1.1. Species Distribution Modelling

The potential distribution area of a species can be modelled using Species Distribution Models (SDM). An SDM relates a species occurrence at a certain geographical location with environmental characteristics of that location (Elith & Leathwick, 2009). SDMs have also been referred to as ecological niche models (Pearman et al., 2008; Rodrigues et. al., 2010) and habitat suitability models (Elith & Leathwick, 2009). Ecological niche modelling has been used to model areas suitable for conservation, translocation and protection of wildlife species (Peterson & Robins, 2003, Matawa et. al., 2012). However, the definitions of the ecological niche are varied and shrouded by much argument. One such definition of the ecological niche is the fundamental niche. The fundamental niche consists of an n-dimensional hyper-volume comprising environmental conditions of a species; species not under study are regarded as part of the environment as well (Hutchinson, 1957). However, to accurately model the fundamental niche of a species, there is need for the absence of biotic interactions, which cannot be possible in normal circumstances.

SDMs require as input presence only or both presence and absence point data; as well as environmental variables in grid or raster format. A widely-used SDM algorithm is Maxent. Maxent is a machine learning that has the ability to function without absence data and make inferences using incomplete information (Phillips, Anderson, & Schapire, 2006). The underlying idea behind Maxent is to estimate a target probability distribution by using maximum entropy to extrapolate the incomplete information concerning the target species (Phillips et al., 2006). Maxent computes a probability distribution with a statistical inference which is the least biased given limited knowledge. In addition to this, Maxent is able to calculate the presence of a species without any underlying assumptions on the environmental variables or the species itself (van Gils et al. 2014). Another advantage of using Maxent, is that it is robust in spatial resolution, also proving response curves which are helpful in ecological interpretation (van Gils, Conti, Ciaschetti, & Westinga, 2012).The ability of Maxent to produce jackknife tests of environmental predictors makes it a good choice in researches which have use for determining the responses of species to individual variables. Maxent is also able to fit complex relationships between response and predictor variables (Elith et al., 2006), as is the case when there are intertwined relationships in the real-life ecosystems. Model performance can be evaluated using Kappa statistics and Receiver Operating Characteristics (Deleo, 1993; Peterson, Papeş, & Soberón, 2008; Phillips et al., 2006) as well as the True Skill Statistic (TSS)(Allouche, Tsoar, & Kadmon, 2006). Maxent produces ROC plots with AUC values, which make it easier to evaluate the SDM performance.

In addition to understanding the national distribution of the cheetah, there is need to understand if the predictive models can be transferred to different areas so as to reveal other relationships and interactions between the response and predictor variables. This is termed transferability of species distribution models (Randin et al., 2006; Thomas & Bovee, 1993). Model transferability refers to the geographical cross-fitting of models (Randin et al., 2006; Thomas & Bovee, 1993; Wenger & Olden, 2012). Other researchers also found Maxent to perform well when transferred to other regions (Heikkinen, Marmion, & Luoto, 2012). This can be used to predict cheetah presence in different areas. Thus this method shall be used to determine which environmental factors are different in the geographical regions of Namibia. Model transferability asymmetry may be caused by environmental causes which are specific to a geographic region (Randin et al., 2006). Reasons for poor transferability may be differences in land-use practises (Randin et al., 2006).

1.2. Distribution modelling and the cheetah

The necessary variables to be considered when modelling terrestrial animals are climate, terrain, vegetation and human impact (van Gils et al., 2014). The environmental variables may be divided hierarchically according to the direct or indirect effects they are presumed to have on the distribution of the cheetah. These divisions may be termed logical subsets. The logical subsets in this research are Topography, Climate, Vegetation, Prey, Predators and Human Influence. It may be assumed that topography has a direct effect on the climate; and the climate a direct effect on the vegetation which in turn affects the prey base. The prey base may be assumed to have a direct impact on the predator subset which includes the cheetah. However, the topography, climate and vegetation may also be assumed to have an indirect impact on the predators.

The human influence subset has a direct effect on the vegetation, prey and predators. The human influence encompasses variables such human population density and livestock, which have an impact on the predators directly in addition to having an impact on the vegetation and prey base as well. Man have the ability to convert the aforementioned by activities such as modification of the environment, hunting activities, An SDM made up of the variables in each logical subset can be created. The SDM made up of variables with a more direct impact on the distribution of predators are expected to perform better. The hierarchy of classification of the logical subsets is shown in Figure 1. Species distribution modelling in a hierarchical mode produces a holistic understanding of the species, which is important to be able to establish a baseline of information (van Gils et al., 2014) .

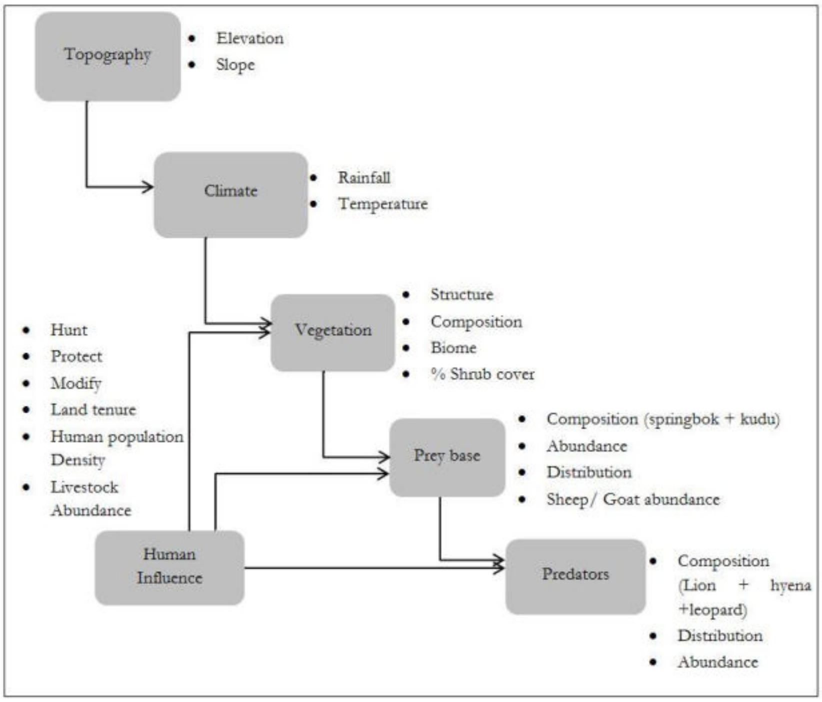


Figure 1: Logical Subsets

Cheetah has been observed in the Serengeti National Park (Gros, 2002) which is at altitude 920m-1850m; and in North-central Namibia (Marker et al., 1996; Marker et al., 2003), which is at altitudes 1800m on average (Marker, 2005). Cheetah is also found in Botswana (Houser et al., 2009; Boast & Houser, 2012), which is at average altitudes 500-1480m. The elevations of 800-1200m **(Helev$_1$)** were considered to be predictive of cheetah presence. Over the years, cheetah has been largely associated with flat plains such as in the Serengeti. This observation suggests that slope may be a predictor of cheetah presence **($Hslope_1$).** The presence of steep slopes may hinder movement of the species and reduce their hunting speed.

Animals respond to climate directly (Guisan & Zimmermann, 2000) or indirectly. Bioclimatic variables may provide a better fit than monthly or yearly means (Hirzel & Le Lay, 2008). Cheetah occurs in areas with variable rainfall, low annual rainfall and temperatures which reach up to 40^0C; classified as arid or semi-arid (Boast & Houser, 2012; Mills, Broomhall, & Toit, 2004). Rainfalls of Jwaneng, Botswana where previous cheetah studies have been conducted are on average 398mm annually (Houser et al., 2009). In Namibia, the Waterberg Plateau where cheetah studies have also been done has had a mean annual rainfall of 123mm in the dry season, and 348mm in the wet season. This suggests that aridity and high temperature variables may predictors for the presence of cheetah **($Hclim_1$).**

In addition to climate, vegetation has been known to affect the presence of cheetah for several reasons. Several studies have shown that the cheetah is able to utilize different vegetation structures. These encompass the open grasslands of East Africa (Bissett & Bernard, 2007), the open woodland savannah of Kruger National Park in South Africa (Mills et al., 2004), bush savannah in the panhandle of the Okavango Delta of Botswana (Houser et al., 2009), as well as the freehold-livestock farms with thorn bush of Namibia (Marker et al., 1996). This indicates the ability of the cheetah to adapt to different ecosystems (Mills et al., 2004). Cheetah has been known to occupy the open savannah (Gros & Rejmánek, 1999; Gros, 2002)); woodland savannah (Mills et al., 2004; Purchase & du Toit, 2000) and the thorn bush dominated by Acacia spp (Marker et al., 2008; Muntifering et al., 2006). Cheetah is assumed to choose habitats based on hunting requirements rather than prey abundance (Mills et al., 2004). Previous studies revealed that open patches with grasses of height 50-100cm (Gros & Rejmánek, 1999; Muntifering et al., 2006), and bordered by woodlands of cover of 25-50% (Gros & Rejmánek, 1999;Purchase & du Toit, 2000), are used for the prey chase and cover respectively during hunting. The woody cover is also used to reduce kleptoparasitism and juvenile mortality from large carnivores (Mills et al., 2004). In this regard, vegetation type appears to be assumed as an explanatory variable to the presence of cheetah. The assumption is that cheetah can be found in open areas with woody plants, and this may be thorn bush of cover 25-50% **($Hveg_1$)**. These semi-open habits were hypothesized to be needed by the cheetah for protection against weather and larger carnivores. However, considering the differences in habitats; the researchers argue that there is need to test this theory of vegetation preference in other African savannahs. The study area of Uganda is described as being a semi-arid thorn bush system (Gros & Rejmánek, 1999), which is similar to the current study area as well.

The distribution of cheetah may also be predicted by using the prey type, availability and density. Prey preferences differ from the East to the South of Africa for the cheetah due to the available species and their abundance. Hare and kudu which make up 40% and 43 % of the cheetah diet respectively in north-central Namibia (Marker, 2002). However, the impala is generally a large part of the cheetah diet as documented by (Purchase & du Toit, 2000) as it constitutes 86.6% of the cheetah diet in studies done in Zimbabwe as well 39% for studies done in South Africa (Bissett & Bernard, 2007). The springbok is highly abundant in Namibia even though there is no documentation to show that the cheetah considers it as prey. Research conducted in South Africa showed that it made up 39% of the cheetah prey as well, (Bissett & Bernard, 2007). The prey is also assumed to indirectly affect the cheetah range (Purchase & du Toit, 2000). This shows that the prey can be tested as a predictor of cheetah distribution **($Hprey_1$).**

Cheetah face predation of their cubs, competition for prey and kleptoparasitism from lion, spotted hyena and leopard (Durant, 1998). In Namibia, lion and spotted hyena have made the cheetah seek refuge in the freehold-livestock farms (Marker et al., 2008). It is also important to consider these large carnivores since they seem to have dietary overlaps with the cheetah. According to Hayward & Kerley (2008), cheetah and lion have a dietary overlap of 42.5%, with the spotted hyena of 59.9% and with the leopard of 68.7%. Based on Pianka's overlap of the actual prey, cheetah has the highest mean overlap of 4.75 when compared to that of leopard which is 5, spotted hyena of 5.5 and lion with the least niche overlap of 8 (Hayward & Kerley, 2008). The overlap in diet may be reflective of the competition which can arise between the cheetah and other large carnivores. However, since the cheetah is considerably smaller than the carnivores mentioned before, this competition may have a detrimental effect on the presence of cheetah. Large carnivores can be presumed to have a negative impact on the cheetah distribution **($Hpred_1$).**

Anthropogenic factors which affect the presence of cheetah include farming practises and protection of certain areas for the purposes of conservation. Land tenure in Namibia may be categorized as state land, communal land, communal conservancies, freehold farms and freehold conservancies. Freehold livestock farms in Namibia are focused on cattle or small stock ranching. The areas which practise cattle ranching or small stock are found to the north and to the south of the country respectively. This is determined by underlying factors such as rainfall amount and seasonality which in turn affects the vegetation. The farm management systems differ depending on the vulnerability of the livestock. Farmers rearing sheep and goats tend to put extra measures in place so as to keep carnivores off their property as the sheep and goats are easy prey for the carnivores, the cheetah included. The type of livestock reared on a farm; which results in protective management practises; may be attributed to be a factor contributing to the decline cheetah range. The management practises may consequently affect the cheetah probability of presence (**$Hmgt_1$**). Conservation practises are assumed to have had a positive impact on cheetah distribution in the period between 2004 and 2012, with an increase of 134% (Stein et al., 2012). Conservancies are one such initiative, amended to the Nature Conservation Ordinance in 1996 (Nowell, 1996). A conservancy is a collection of communities which work collectively for the aim of protecting and utilising wildlife on their joint properties. National Parks (NP), in state land, are protected areas which are there for wildlife conservation owned by the government. However, due to the high occurrence of predators in NPs, cheetah are said to occur more outside in the freehold farms. Therefore, land tenure can be assumed to be an explanatory variable in determining the occupied range of the cheetah **($Hten_1$).**

In Namibia, there are suggestions that habitat selection by the cheetah comes as a combination of preferred prey, better visibility and hunting efficiency (Muntifering et al., 2006). This study also showed that, patches most highly used by cheetah within bush-encroached farmlands were those with the better sighting visibility and good grass cover (P=0.000) in both accounts. However, the Namibian cheetah was found to have the highest home-range of 1700 km^2 ($^+/-$ 1600km^2), which has been attributed to prey and rainfall variability (Marker et al., 2008).

1.3. Occupied Range

For the purposes of its conservation, it is important to determine the areas the cheetah can occupy; and the characteristics of those areas. The occupied range of a species (van Gils, Westinga, Carafa, Antonucci, & Ciaschetti, 2014) or "area of occupancy" is the area of the actual suitable environment which a species inhabits (IUCN, 2012). Over time, the occupied range of the cheetah has been declining globally as well as on national scales. The occupied range of the cheetah can be computed using Kernel Density Estimations (van Gils et al. 2014), since it can be applied to animals which are constantly on the move such as the cheetah (van Gils et al., 2014; Worton, 1989).

1.4. Problem Statement

Cheetah status has been decreasing in terms of numbers and range (Marker-Kraus & Kraus, 1997). Efforts such as keeping them in enclosures in order to conserve them may not have the desired effect, since they do not fare well in protected areas and captivity (Marker et al., 1996; Dickman et al., 2006). To develop a sound conservation strategy, it is essential to establish baseline data on cheetah populations, distribution and occupied range (Marker-Kraus & Kraus, 1997). The knowledge base regarding cheetah outside of protected areas is lacking, and acquiring this knowledge can lead to the identification of other issues which affect the cheetah (Dickman et al., 2006).

Cheetah studies in Namibia lack information on the basic environmental factors which affect the species and; the impacts of certain land-uses and conservation management on cheetah populations. The Namibian cheetah has the largest known range of approximately 1.7 x10^3 sq. km, with 90% of them occurring outside protected areas (Marker, 2002). This results in conflicts with the farmers which result in removals (Marker, 2002). In addition to well documented conflicts with the farmers; cheetah face a reduction in prey base and habitat modifications in their occupied range. Bush encroachment and different farming practises are two such activities which are attributed to the alteration of their habitat and contributing towards conflict with farmers (Marker et al., 2007). However, there is need for extensive study into these causes.

Apart from farms, wildlife conservancies are present in Namibia. There is need to investigate their impacts on cheetah conservation, which has not been done before. Some of the increases in the general carnivore distribution in the country may be attributed to some wildlife conservation strategies that were put in place (Stein et al. 2012). Conservancies are one such strategy; and it is important for conservation efforts outside protected areas, to explore their contributions. It is important to focus on the effect of all these factors at once, and how the cheetah responds to these variables. In addition to this holistic approach into cheetah research, there is a need to determine the specific environmental conditions affecting the cheetah in order to establish a baseline of the conditions which affect the cheetah presence.

1.5. Aim

To understand the distribution of cheetah in Namibia in terms of biophysical and anthropogenic variables for evidence based species conservation

1.6. Objectives

1. To identify the most important environmental variables driving the cheetah distribution
2. To establish if these important variables are explaining the cheetah distribution in the Bushland and Desert parts of the country
3. To map the cheetah occupied range over time

1.7. Research Questions

1. Which environmental variables are the most important in explaining the cheetah spatial distribution?
2. Are these important variables the same in explaining the cheetah distribution in the Bushland and Desert parts of Namibia?
3. Is there a change in the occupied range of cheetah over time?

1.8. Hypothesis

Hypothesis 1

- **Helev_1:** Elevation of range 800-1200m serve as a predictor for the presence of cheetah

Hypothesis 2

- **Hslope_1:** Slopes above 24% are a negative predictor of cheetah presence

Hypothesis 3

- **Hclim_1:** Rainfall range 150mm - 450mm; and temperature range 0-40^{0}C serve as predictors for the presence of cheetah

Hypothesis 4

- **Hveg_1:** There is a positive relationship between Thornbush of cover 25-50% and the presence of cheetah

Hypothesis 5

- **Hprey_1:** There is a positive relationship between small buck densities (springbok and kudu) and cheetah presence

Hypothesis 6

- **Hcarn_1:** Large carnivores (lion, spotted hyena, brown hyena and leopard) are negative predictors of cheetah presence

Hypothesis 7

- **Hten_1:** Land tenure has an effect on cheetah presence

Hypothesis 8

- **Hmgt_1:** Sheep/goat density is a negative predictor of cheetah; cattle density a positive predictor

Hypothesis 9

- **Hbush/desert_1:** The bushland and desert areas may determine the most important variables affecting cheetah distribution

Hypothesis 10

- **Htime_1:** The cheetah occupied range in Namibia is decreasing significantly over time

2. MATERIALS AND METHODS

This chapter describes in detail the procedures undertaken in the research in order to achieve the set objectives. Species distribution modelling was done using Maxent software. Input into the SDM constituted cheetah presence-only data as well as environmental layers. Cheetah presence observations were obtained from various sources and

2.1. Study Area

The research area is Namibia with the exception of the Zambezi Region. This country is located in Southern Africa; sharing its northern boarders with Angola, north- eastern with Zambia and Zimbabwe, and Botswana in the east, while South Africa is in the south. The Atlantic Ocean is found on the western front of the country. Namibia is situated between 17.5 ^{0}- 29^{0}S and 11.5 ^{0}- 25.5^{0}E. It has a total area of 824 269 km2 (Sweet & Burke, 2006). It is largely an arid country with two deserts; the Namib Desert on the west coastal plain; and the Kalahari to the east. To the east of the Namib Desert is the central plateau. This is a mountainous area with elevation approximately between 1000 and 2500m. The climate of Namibia is dry; the rainfall is unpredictable and varies. The major vegetation types are savannah which is 64%, dry woodlands which are 20% and Namib Desert vegetation 16% (USAID, 2010). The Kalahari contains mostly bush savannah. The Nama - Karoo is found in the south and south-eastern parts of the country. This biome contains dwarf shrubs and grasses; and is commonly utilised for goat and sheep farming. The Zambezi region in the most north eastern part of the country receives the highest amount of rainfall (more than 600 mm) and has permanent rivers with floodplains as well as woodlands (Sweet & Burke, 2006). However, the Zambezi Region was excluded in this study. Figure 1 below shows the study area.

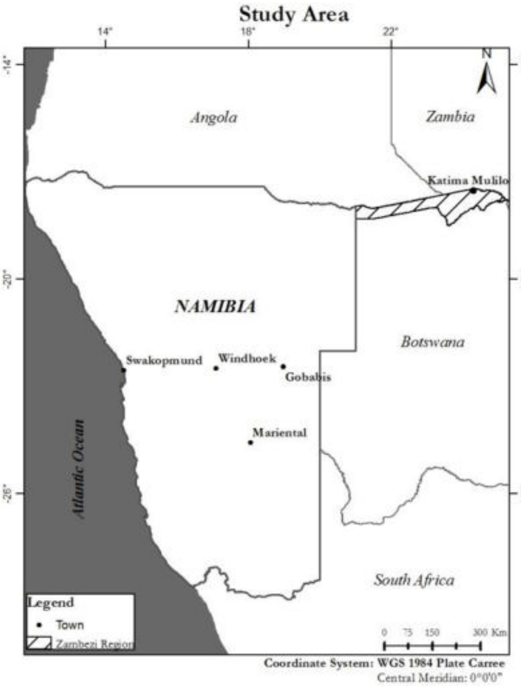


Figure 2: Study Area Map

2.2. Cheetah Observations

Secondary data was used in the research. This is because the research timeframe was not sufficient enough to allow for primary data collection. Available cheetah presence points, from the period 2001-2014, were 132. These were from the Carnivore Atlas, extracted from the Environmental Services Namibia website. Of the 132 points, 88 were in Quad degree system (QDS). For the period 2001-2003, there were 56 QDS points; and for the period 2010-2013, 32 QDS points were present. The QDS is the raster system of the Atlas of Namibia with a resolution of 27.8 km by 27.8 km. There were 44 GPS observations for the year 2013-2014, in degrees, minutes and seconds. Observations were taken by game reserve employees from various game and nature reserves; researchers, farmers, local residents and tourists.

Historical points were obtained from previous studies. The map images were clipped, geo-referenced and the points were digitized manually (Doko, Kooiman, & Toxopeus, 2008). Images were geo-referenced using the Namibian country administrative boarder. The rectification of the images was done using the 1st order polynomial affine transformation. The average total RMS error for the images was 370m when compared to the QDS resolution, it may be acceptable. 424 points were digitized from a farm survey map conducted by the Directorate of Natural Resources (DNR) in 1982 as reported by Joubert, 1984 cited in (Nowell, 1996). 522 points were digitized from the Large Carnivore atlases representing the period 1999-2004 (Stander & Hanssen, 2003, 2004). The digitized points were determined to have an accuracy of approximately 5km. 132 points are farms which reported conflicts with cheetah, and were digitized from the Carnivore Atlas of 2012 (Stein et al., 2012). These farms have an average resolution of 10km by 10km and these points can be said to be within 5km from that point.

The presence points were grouped into 3 sets for purposes of analysis of the occupied range in time; as well as the species distribution modelling. The time periods represented were 1982; 1999-2004 and 2005 to 2014. The 1982 dataset had a total of 424 points. In the 1999-2004, points were included those that had been digitized from two carnivore atlases of 2003 and 2004 as well as various sources which include the EIS. To avoid repetition, the points from the 2004 atlas were used. These points including the various observations resulted in a dataset with 250 presence points. The dataset representative of the 2005-2014 periods had 214 presence points. The dataset which was used to generate the SDMs had points from 1999-2014 which were 464 in total. A total of 1140 cheetah presence points were used in this research. A summary of the presence points and their sources is shown in table 1.

Table 1: Cheetah presence points

TIME PERIOD	FORMAT	SOURCE
2005-2014 **(214 points)**	– QDS – GPS – Digitized	– Environmental Services Namibia http://www.the-eis.com/index.php – N/a'ankuse Research Programme data – Namib Rand Reserve Data – Neuhof Nature Reserve Data – Sandfontein Game Reserve Data – Weltevrede Guest Lodge Data – (Stein et al., 2012)
1999-2004 **(250 points)**	– Digitized – QDS	– (Stander & Hanssen, 2003, 2004) – Environmental Services Namibia http://www.the-eis.com/index.php
1982	– Digitized	– Joubert, 1984 cited in (Nowell, 1996)

Cheetah surveys spanning the whole country have been conducted over the years which include the times under study. Farm surveys done in 1982, 2003, 2004 and 2012 covered the whole country. The last three were used to produce distribution maps of large carnivores (Stander & Hanssen, 2003, 2004; Stein et al., 2012).

Furthermore, the land tenure of Namibia can be classified into 5 categories which are mainly State Land, Communal Land, Communal Conservancies, Freehold farms and Freehold conservancies. The state land which includes national parks is sampled by having regular game counts which record species and the coordinate points. This is done by the Ministry of Environment and Tourism. Observations in the communal land are also noted. Communal Conservancies are registered under the Namibian Association of CBNRM Support Organisations (NACSO). Their game count results are also published by this organisation. Freehold conservancies and freehold farms have also been sampled previously. The farm surveys which have been done by the Ministry of Environment and Tourism (MET) in previous years prior to the publishing of the Large Carnivore Atlases have ensured this. These sampling efforts serve to confirm that the areas which seem as gaps, have actually been sampled, and are not as a result of under sampling or no sampling at all. The study area was sampled in different ways. The area which represents some difficulties on sampling efforts is the restricted diamond area -The Sperrgebiet. However, personal communication with the warden in charge reports that cheetah has been observed on the boarders of the Sperrgebiet; however none have been observed inside the area.

Cheetah presence points were subdivided into different categories. The presence points were first displayed in ArcGIS and exported as a shapefile. The cheetah presence shapefiles were projected from the Geographic Coordinate System GCS WGS 1984 to the Projected Coordinate System: WGS 1984 Plate Carree and the corresponding Plate Carree coordinates calculated. The points were then clipped using the study area boundary. A main database was created with points and environmental layers using the "Extract multi-values to points" tool in ArcMap 10.2.1. This database was exported as a .dbf file to be analysed with R-software.

The main cheetah database was divided into different sets for different analysis. Points for use in the determination of the occupied range were selected according to the time periods pre-1984; 1999-2004 and 2005 to 2014. These were used to calculate the occupied range. Points from 1999-2014 were extracted and combined into a database for use in the species distribution modelling. A .csv file with species name, x-coordinate and y-coordinate was made of these points. A .dbf file with the coordinates and environmental layers was also made.

Databases of the Bushland and Desert points where made by clipping the 1999-2014 points using the Bushland and Desert masks. The respective databases were exported. Files in .csv format were made with species name, x-coordinate and y-coordinate for each of the two areas. A .dbf file with the x- and y-coordinates and the environmental layers was exported for the Bushland and Desert areas respectively.

2.3. Environmental Variables

In total there were 33 environmental predictors. Table 3 shows a summary of all the potential environmental variables considered in the research. The environmental layers from (Mendelsohn, Jarvis, Roberts, & Robertson, 2002) have a database downloadable from EIS website (www.the-eis.com). Livestock; prey and predators were measured in terms of the number of heads per sq. km. The land tenure had 5 categories which included state land, communal land, communal conservancies, freehold land and freehold conservancies. The visualization and pre-processing of all presence data and environmental layers was done in ArcMap 10.2. All layers need to be in the same projection and for this study the World Plate Carree projection was used. The environmental layers were re-sampled to the average farm resolution (10 by 10km). Layers originally in raster format such as the bioclimatic variables and the Digital Elevation Model (DEM) were first projected from the Geographic Coordinate System GCS WGS 1984 to the Projected Coordinate System: WGS 1984 Plate Carree. The resulting layers were clipped using the study area boundary and then resampled to a resolution of 10km by 10km. Vector layers were first defined their geographic projection which was Geographic Coordinate System GCS WGS 1984. The resulting layers were then projected to the Projected Coordinate System: WGS 1984 Plate Carree. All vector layers clipped using the study area then converted to raster based on the field which was applicable to the study. After the conversion they were resampled. All the raster layers with a resolution of 10km by 10km were converted to .ascii format, for use in Maxent. Appendix 1 shows the maps of the categorical environmental variables used in the study. Appendix 2 shows the main key to the categorical variables used in the modelling.

Elevation

The Elevation (DEM) was established from the NASA Shuttle Radar Topographic Mission (SRTM version 4.1) of cell resolution 90 m. The tiles were downloaded from the Consultative Group on International Agricultural Research (CGIAR-CSI) website and mosaicked. They were in Geotiff format, datum WGS84, with decimal degree units.

Land Tenure

This layer was compiled from a combination of 3 different layers. These layers were Land Allocation of 2002, Freehold Farms and Communal Conservancies. These layers were projected to the Projected Coordinate System: WGS 1984 Plate Carree. They were then clipped to the study area boundary. Land allocation of 2002 had the classes: state land, communal land and freehold land. The communal conservancies were updated with the study area map and the boundaries dissolved using the Dissolve Data Management Tool in ArcGIS. The freehold conservancies were selected from the freehold farms and dissolved into one layer and were used to separate the freehold farm classes in the land allocation layer into freehold farms and freehold conservancies. The resulting three layers were then merged into one. This resulted in the 5 category layer. The new categories were State land, Communal Land, Communal Conservancies, Freehold Farms and Freehold Conservancies.

Vegetation

The vegetation map was made from the vegetation type layer downloaded from the EIS website. The original had 26 vegetation classes. There was lack of data in some polygons of the original vegetation map. These polygons were some parts of the Kalahari Desert in the south-west and the Kalahari Desert in the central-east. Errors in terms of vegetation classification were also present in the case of the North-eastern Desert which was defined to have 26-50% shrub cover. Investigation of this polygon using other data sources confirmed that this area was almost bare and had been misclassified. The selection and reclassification was based on the shrub cover, shrub height, grass cover, grass height. The resulting layer had: 6 classes Salt Pans, Desert, Karoo, Shrubland, Escarpment and Woodlands. Table 2 provides a summary of the vegetation classes and their attributes.

Table 2: Vegetation Class Selection Criteria

Category	**Class**	**Shrub Cover (%)**	**Shrub Height (m)**	**Grass Cover (%)**	**Grass Height**	**Dominant Species**
1	Salt Pans	0	none	2-10	< 0.5	Sporobulus salsus
2	Desert	< 0.1	1-2	< 0.1	< 0.5	extremely diverse
3	Karoo	2-10	1-2	< 0.1	< 0.5	Rhigozum trichotomum
4	Shrubland	26-50	1-2	26-50	0.5-1	extremely diverse
5	Escarpment	2-10	1-2	51-75	0.5-1	extremely diverse
6	Woodlands	11-25	1-5	51-75	0.5-1	Hyphaena petersiana

The Slope

The slope was computed from the Elevation (DEM) using the Slope tool in Spatial Analyst range in Arc GIS 10.2. It was calculated on the basis of recent rise with a 90m by 90m cell resolution. The slope was divided into 5 classes based on Universal Soil Loss equation. The relationship of the cheetah observation points and slope was done by overlaying the presence points over the reclassified slope. The more accurate presence points were selected and cleaned removing by duplicate points. This resulted in a data asset of 18 points. The points which made up the data set included 14 from camera traps set up in the Brown Hyena Research Project conducted in the southern part of Namibia. The slope was not included in the suite of environmental layers which was input into the model because resampling the slope from to a finer resolution would result in the averaging of essential finer detail. In addition to this, the GPS points which have a better accuracy were only 18 and these were not enough to produce a significant result.

Table 3: Potential environmental predictors

Environmental Variable	Data Type	Units	Source
Brown Hyena	Categorical	Head/km^2	(Mendelsohn et al., 2002)
Bioclimatic variables	Continuous	°C and mm	www.worldclim.org
Cattle	Categorical	No /km^2	(Mendelsohn et al., 2002)
Dorper sheep	Continuous	No /km^2	(Mendelsohn et al., 2002)
Elevation (DEM)	Continuous	m	www.cgiar-csi.org
Goats	Continuous	No /km^2	(Mendelsohn et al., 2002)
Human Population Density	Categorical	People/ km^2	www.uni-koeln.de
Karakul sheep	Continuous	No /km^2	(Mendelsohn et al., 2002)
Kudu	Categorical	No of head/km^2	(Mendelsohn et al., 2002)
Land Tenure	Categorical	5 categories	(Mendelsohn et al., 2002)
Leopard	Categorical	No of head/km^2	(Mendelsohn et al., 2002)
Lion	Categorical	No of head/km^2	(Mendelsohn et al., 2002)
Slope	Continuous	%	Derived from the Elevation
Spotted Hyena	Categorical	No of head/km^2	(Mendelsohn et al., 2002)
Springbok	Categorical	No of head/km^2	(Mendelsohn et al., 2002)
Vegetation	Categorical	6 classes	(Mendelsohn et al., 2002)

2.4. Selection of Important Environmental Variables

The algorithm Maxent was used according to instructions explained more in detail in (Phillips et al., 2006). Each model was trained using 70% of the dataset and validated using 30% of the dataset. A maximum of 10 000 background points, 500 iterations and 10 iterations were the settings selected. The models were evaluated using the Receiver Operating Characteristic (ROC) curve as measured by the Area under the Curve (AUC), as well as the True Skills Statistic (TSS) and Kappa statistics. The values of AUC range from 0-1, with values closer to 1 indicating a near perfect fit (Baldwin, 2009). The variables from the best performing SDM were assumed to be the most important variables **(Objective 1).**

The full model had 33 environmental variables which included 19 bioclimatic variables. Other variables included predators, prey, land tenure, elevation, slope, livestock, vegetation and human population density.

To improve the quality of the model, correlated variables were removed. These were identified using a VIF calculation and a correlation test in R-software. Correlation was done for the continuous variables. Cross tabulation was done for the categorical variables to show which variables were associated.

In total 33 environmental layers were available for use in modelling the distribution of the species. The bioclimatic variables were computed as an average of the years 1950 -2000. The digital elevation model was derived from the Shuttle Radar Topography Mission (SRTM) of the year 2000. Vegetation, prey, predators, livestock, Namibian country boundary and human population density were made in the year 2002. The land teure layer was made from a combination of the land allocation of 2002, the freehold conservancies of 2010, private reserves of 2010 and the communal conservancies as at 2013.

The database of cheetah presence points constituted points collected over the years from the years 1984 to 2014. The points were divided into three time periods; those 1982, 1999-2004 and 2005-2014. These are the time periods which were used to compute the occupied range of the cheetah and to calculate the differences in the range over time. However, presence points between 1999-2014 were the only one used to create an SDM of the cheetah. These are the points which are in the same time period as the environmental layers, therefore more reflective of the conditions affecting the species at the time of study.

2.4.1. Variable Selection

A multi-collinearity test was done on the variables so as to remove highly correlated variables. The database which contained the x- and y- coordinates and the values of each environmental layer on each point was analysed in R. The predictors for the species were screened by applying the following statistical techniques:

1. Multi-collinearity Analysis
   - Spearman's rank correlation co-efficient
   - Variance Inflation Factor Analysis (VIF)
2. Chi-squared test of association between categorical variables
3. Jackknife test of variable importance

Multi-collinearity Analysis

Multi collinearity refers to the correlation among predictor variables. It affects the approximations of regression coefficients and induces bias responses between outputs and predictor variables(Dormann et al., 2013). Multi-collinear predictors present difficulties in SDM interpretations because they may cause outputs false as they offer spurious relationships (Graham, 2003). Correlation tests were done on all continuous data, and all variables with a correlation of higher than 0.5 were removed depending on the jackknife and the following Variance Inflation Factor (VIF) analysis. A VIF analysis was done on the continuous variables. The following equation 6 shows the calculation of VIF.

Equation 1: VIF $=\left(\frac{1}{1-R^2}\right)$

Where: R is the coefficient of determination

Variables with a VIF of more than 10 were removed (Kutner, Nachtsheim, Neter, & Li, 2004) and those left were used to determine the overall SDM. The resulting dataset with presumed independent predictor variables was used to compute SDMs of 3, 4, 5 and 6 variables with a VIF of below 10. A forward stepwise Maxent regression modelling was done starting with the best predictive model of 3 variables.

Variables were subsequently added one by one until the best SDM was obtained at the different environmental variable levels. The jackknife was used to select variables which contributed the most in AUC of the resulting SDMs.

Chi-squared Test

A cross-tabulation was done for all categorical variables. These variables were Brown Hyena, Human Population Density, Kudu, Land Tenure, Leopard, Lion, Spotted Hyena, Springbok and Vegetation. A chi-squared test of association was done on each resulting cross-table.

Jackknife of Variable Importance

This feature was selected in the Maxent model runs. It produces alternate approximations of variable importance. A model is created each time a variable is omitted from the model run in turn. Another model is also created using each variable alone. At the same time a model with all the variables in that SDM is also created. The AUC of each model is recorded and all the values plotted together in the jackknife. The jackknife thus shows the AUC of the model with (1) all the variables (2) without one variable (3) and with the one variable in isolation that had been omitted before. Comparing the 3 values gives an indication of the importance of each variable in predicting the species. The values of jackknife bars of a single variable's model may help to determine the association between the variables as well.

2.4.2. Model Evaluation and Selection

The SDMs produced were evaluated using the Receiver Operating Characteristic (ROC) (Deleo, 1993) and Kappa Statistics (Landis & Koch, 1977) and TSS(Allouche et al., 2006). The ROC curves are generated by plotting sensitivity against 1-specificity. The Area under the Curve (AUC) of the ROC plot shows the accuracy or how well the model performs(Deleo, 1993). This was generated by the algorithm as part of the outputs. ROC curves are independent of threshold values (Allouche et al., 2006; Guisan & Thuiller, 2005), but for purposes of species conservation methods which depend on a selected threshold need to be employed as well (Allouche et al., 2006). The methods which depend on threshold values are Cohen's Kappa and TSS. The AUC values were ranked based on (Hosmer & Lemeshow, 2000). AUC values range between 0 and 1. Models with an AUC of above 0.7 were compared and the SDM selected depending on the criteria of SDM being considered. An error matrix is used to calculate the corresponding values of the sensitivity, specificity, the Kappa statistic and TSS. Table 2 below shows the error matrix which relates predicted presences and absences versus respective observed values.

Table 4: Error Matrix Schema

	OBSERVED	
	Present	**Absent**
MODEL PREDICTION		
Present	a	b
Absent	c	d

Equation 2: n $= a + b + c + d$

Equation 3: Sensitivity $= \frac{a}{a+c}$

Equation 4: Specificity $= \frac{b}{b+d}$

Equation 5: Kappa Statistic $= \frac{\left(\frac{a+d}{n}\right) - \frac{(a+b)(a+c)+(c+d)(d+b)}{n^2}}{1 - \left((a+b)(a+c) + \frac{(c+d)(b+d)}{n^2}\right)}$

Equation 6: TSS $= \text{sensitivity} + \text{specificity} - 1$

Where: a is the number of correctly predicted presences
b is the number of falsely predicted presences
c is the number of falsely predicted absences
d is the number of accurately predicted absences
n is the total of all predictions

The Kappa Statistic (Cohen's Kappa) compares the agreement against that which may be expected by chance. Kappa statistic values range from -1 to +1, with values of less than 1 indicative of a model performance which is worse than random (Allouche et al., 2006). The Kappa statistic was calculated in R-software for every model run. The average Kappa statistic over ten runs was computed and taken to be representative of that particular SDM. Kappa statistics are highly dependent on prevalence; and are used to evaluate the accuracy of presence-absence models. In this research, background points as generated by Maxent were taken to be absence points, however this was not truly reflective of the species. Thus, TSS and AUC which is not dependant on prevalence such as Kappa were used to evaluate the accuracy of the model as well. TSS adjusts for dependency but still retaining all of the advantages of Kappa(Allouche et al., 2006). There is need to set a threshold for calculating Kappa and TSS. The threshold used to calculate maximum Kappa was used to calculate both the Kappa statistic and the TSS value (Freeman & Moisen, 2008). This threshold was chosen because it minimizes prevalence. Models were selected according to well their AUC, TSS and Kappa Statistics performed when compared to other models in the same category.

2.5. Bushland versus Desert SDM

SDMs were also trained and evaluated using presence points of cheetah in the Bushland and Desert areas **(Objective 2)**. The SDMs from the Maxent stepwise modelling and logical subsets were trained using points and the corresponding environmental variables in the bushland and desert areas. These models were evaluated using AUC, TSS and Kappa. The model evaluation statistics were plotted for Bushland, Namibia (represented by study area) and Desert. They were compared to see which variables were important and how well these models were able to predict cheetah probability of presence in each area.

The bushland versus desert delineation was done based on the percentage of shrub cover of the Vegetation layer from the EIS. The Bushland constitutes areas with >10% shrub cover and the Desert has areas with <10% shrub cover. The best performing SDMs of 3, 4, 5 and 6 explanatory variables were trained with the presence data of the Bushland and Desert areas and the resulting AUC, Kappa Statistics and Jackknives plotted against each other. The same procedure was applied using the SDMs from the ecological subsets.

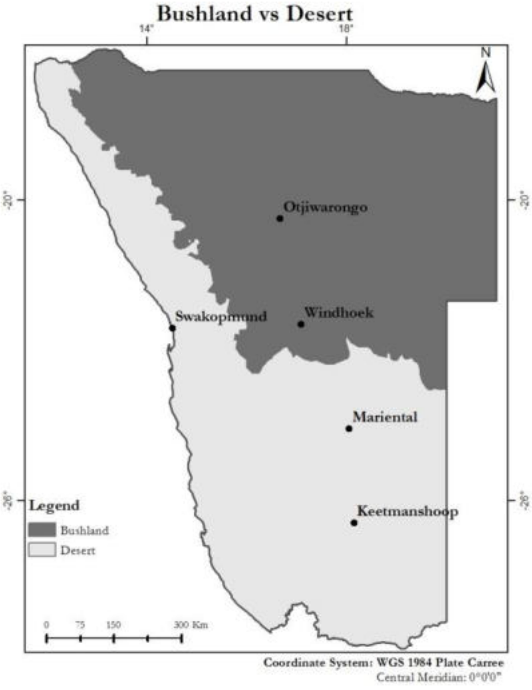


Figure 3: Bushland/Desert

2.6. Analysis of the Change in Time of the Occupied Range

The occupied range was determined using the Kernel Density Estimation (KDE) in ArcGIS 10.2 and Isopleth tools in Geospatial Modelling Environment (GME) (Beyer, 2014). GME is an extension of ArcGIS. KDE raster was generated from the presence points in ArcGIS. A search radius of 28km was used, which is within the documented home range radius of approximately 40km^2 and the QDS raster resolution size. The output was a raster layer with a cell size of 10km by 10km. This result cell size was based on the resolution used in the modelling. The Isopleth tool in GME was run on the resulting KDE raster so as to generate the occupied range raster of the species. A 95% isopleth was used which produced a 95% kernel polyline. The 95% isopleth represents the area which has a 0.95 probability of being occupied by a cheetah. This analysis was computed for the time periods 1982; 1999-2014 and 2005-2014.

All kernel density raster layers and 95% isopleths were clipped to the study area boundary. The 95% isopleth was converted from polyline to polygon using the Feature to Polygon, Data Management tool so as to obtain a polygon feature. The resulting polygons were used to clip the respective kernel density estimation rasters so as to remain with only the areas which have a 95% chance of being occupied by a cheetah. These areas were classified using natural breaks into 3 classes to distinguish areas with low, medium and high occupancy. The area occupied by the cheetah in the three different time periods was calculated and the percentage differences computed **(Objective 3).**

3. RESULTS

3.1. Environmental Variables

Variables were first screened using a multi-collinearity analysis, chi-squared test and jackknife of variable importance. Various SDMs were run so as to determine which variables are important in determining the distribution of the cheetah. SDMs of 3, 4, 5, and 6 variables were constructed and evaluated. Furthermore, the environmental variables were split into different subsets and SDMS were computed from the subsequent subsets.

3.1.1. Variable Selection

Multi-collinearity Analysis

Variables were first screened using a multi-collinearity analysis. This was done to eliminate any collinear variables which would have a bias effect on the SDMs which would be used to determine the important environmental variables driving the cheetah distribution **(Objective 1).** This was done by assessing the correlations between the continuous variables and their VIF values. Those with correlations of greater than 0.5 were removed as well as those with a VIF higher than 10. The results of the correlation are shown in a correlation matrix in Appendix 3. Table 5 below shows the results of the VIF calculations.

Table 5: VIF Calculation

Environmental Variable	VIF
Annual Precipitation	7.265388
Elevation	6.418702
Annual Mean Temperature	5.996970
Temperature Seasonality	4.254473
Isothermality	2.752088
Precipitation of Driest Month	2.431811
Cattle	2.005861
Goats	1.532840
Dorper Sheep	1.297426
Karakul Sheep	1.172825

Chi-squared Test

The chi-squared test was done to determine the association between all categorical variables. The results showed that all categorical variables were strongly associated ($p < 2.2 \times 10^{\wedge -16}$). This value was consistent when all the categorical variables were tested for association between each other; one by one.

Jackknife

An initial model of all the 33 variables was initially run so as to determine the variables which may be important in determining the SDMs. The model had an overall AUC of 0.897. The jackknife in figure 8 represents the full model values. The blue bars represent the overall AUC of an SDM run using that variable only. The cyan bars represent the model performance without that particular variable. The blue bars indicate that every variable has a different effect on model performance and this may indicate the importance of that variable in overall model performance. The cyan bars all show the same level of performance indicating that there are highly correlated variables in the model. Correlated variables continuous variables were removed after correlation test and a VIF analysis. A second SDM was run using the resulting layers which were presumably uncorrelated. The resulting jackknife of this SDM is shown in figure 5. The continuous variables which were determined to be unrelated and having a VIF below 10 were considered in the overall modelling process. The cyan bars show different levels of contribution to the overall model indicating that the eliminating of most variables resulted in a suite of continuous variables which had uncorrelated variables. The categorical variables were not eliminated by using the multi-collinearity analysis.

The full variable jackknife in figure 4 gives indications on which variables may be important to select in the stepwise Maxent modelling. The environmental variable with highest gain when used in isolation was Leopard. It thus seemed to have the most useful information by itself. Vegetation decreased the gain the most when omitted appearing therefore to have the most information that is not present in the other variables. The environmental variable with highest AUC gain when used in isolation was Vegetation. It thus seemed to have the most useful information by itself. Lion decreased the AUC gain the most when omitted appearing therefore to have the most information that is not present in the other variables. Therefore, these variables were considered for use in the stepwise Maxent modelling.

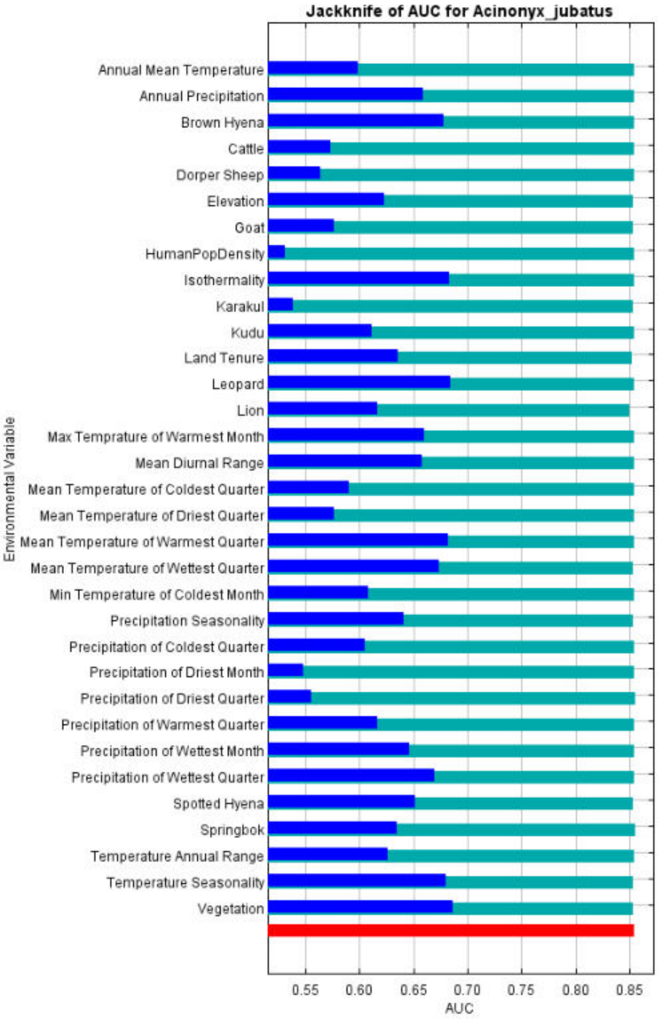


Figure 4: Jackknife of all variables

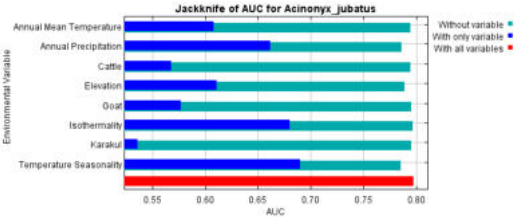


Figure 5: Jackknife after VIF calculation

Various SDMs were run so as to determine which variables are important in determining the distribution of the cheetah. SDMs of 3, 4, 5, and 6 variables were constructed and evaluated. The SDMs which performed better were taken to be representative and their variables as predictors.

SDM of 3 variables

The best performing 3 variable SDM of consisted of Land tenure, Lion, and Leopard. The lion proved to be the variable which decreased the gain when left out in the model run. This means that it contains the most information which is absent in other variables in this SDM. The Leopard had the highest gain in AUC when used in isolation. Figure 6 below shows the jackknife of the environmental variables used in the SDM. The ROC plot of this SDM is shown in figure 7.

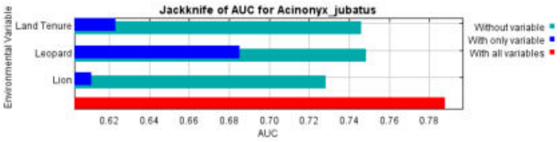


Figure 6: Jackknife of 3 Variables SDM

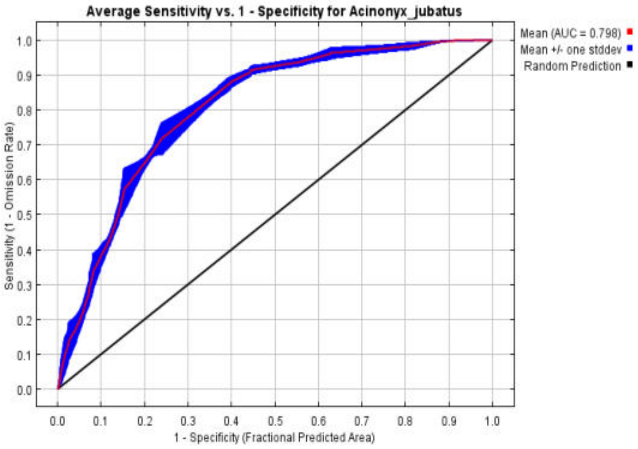


Figure 7: ROC Plot of 3 Variables SDM

SDM of 4 Variables

The best performing SDM of four variables had Elevation, Kudu, Lion and Vegetation. The lion proved to be the variable which decreased the gain when left out in the model run. The Vegetation had the highest gain in AUC when used in isolation. Figure 8 below shows the jackknife of the environmental variables used in the SDM. The model had an AUC of 0.811 as shown in figure 9, Kappa statistic of 0.268 and a TSS of 0.435.

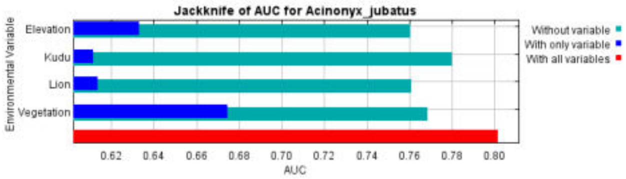


Figure 8: Jackknife of 4 Variables SDM

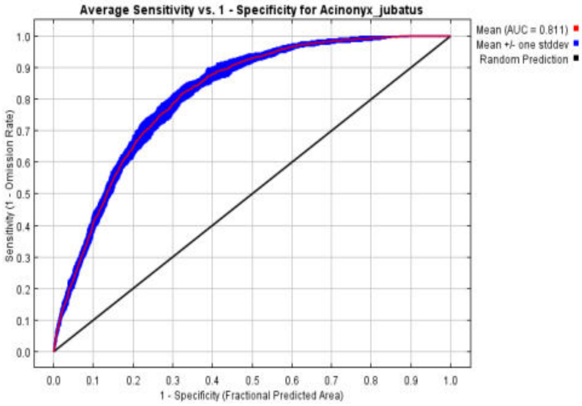
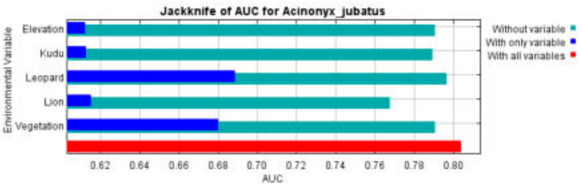


Figure 9: ROC Plot of 4 Variables SDM

SDM of 5 Variables

The SDM of five variables which was better than most consists of the variables- Elevation, Kudu, Leopard, Lion and Vegetation. The lion proved to be the variable which decreased the gain when left out in the model run. The leopard had the highest gain in AUC when used in isolation. Figure 10 below shows the jackknife of the environmental variables used in the SDM and figure 11 shows the ROC curve. The model had an AUC of 0.818, Kappa statistic of 0.292 and TSS of 0.484.

Figure 10: Jackknife of 5 Variables SDM



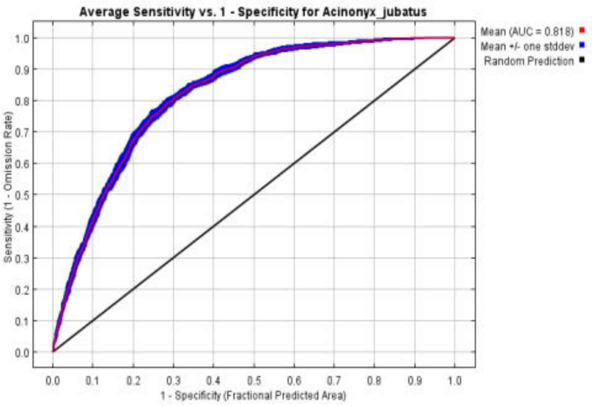


Figure 11: ROC Plot of 5 Variables SDM

SDM of 6 Variables

The SDM of six variables consists of Elevation, Kudu, Land Tenure, Leopard, Lion and Vegetation. The lion proved to be the variable which decreased the gain when left out in the model run. The leopard had the highest gain in AUC when used in isolation. Figure12 below shows the jackknife of the environmental variables used in the SDM and figure 13 shows the ROC curve. The model had an AUC of 0.827, Kappa statistic of 0.286 and TSS of 0.485. Table 6 shows a summary of all stepwise model evaluations.

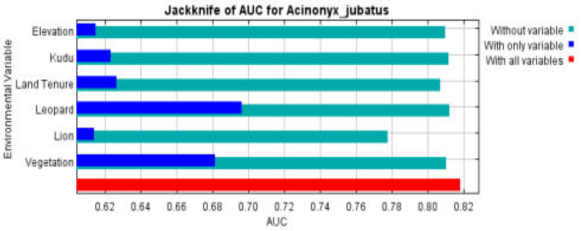


Figure 12: Jackknife of 6 Variables SDM

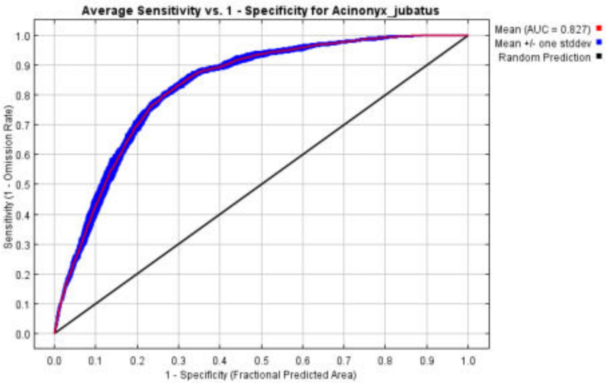


Figure 13: ROC Plot of 6 Variables SDM

Table 6: AUC of SDM of Stepwise modelling

SDM	AUC	TSS	KAPPA
3	0.798	0.412	0.230
4	0.811	0.435	0.268
5	0.818	0.484	0.292
6	0.827	0.485	0.286

Logical Subsets

The environmental variables were split into different subsets and SDMS were computed from the subsequent subsets. Figures 14-16 show the result of the different logical subset SDMs evaluation for the different areas. The results generally show an increase in model performance with the exception of vegetation. Human influence is a subset which has an influence on three other variables. Predators are more able to predict the presence of the cheetah than any other as all other variables influence the presence of these carnivores which have an effect on each other. The performance of the vegetation model is higher in the desert as compared to the bushland and the whole study area. Human influence model generally performed better in the bushland than in the deserts.

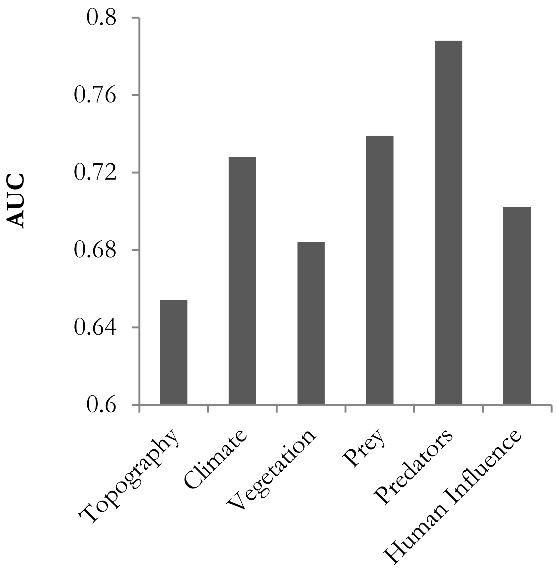


Figure 14: AUC of logical subset SDMs

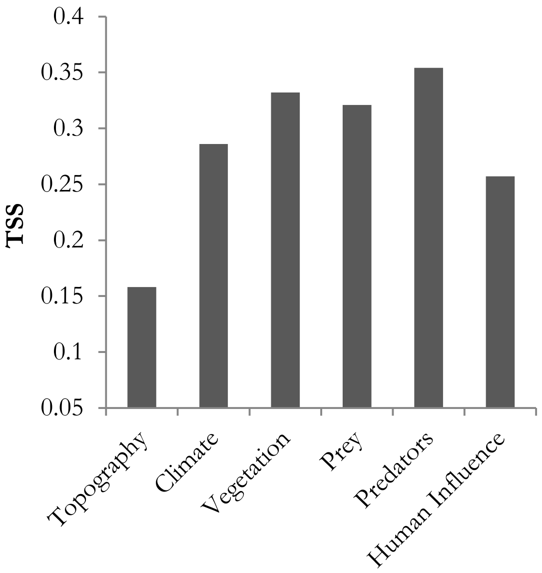


Figure 15: TSS of logical subset SDMs

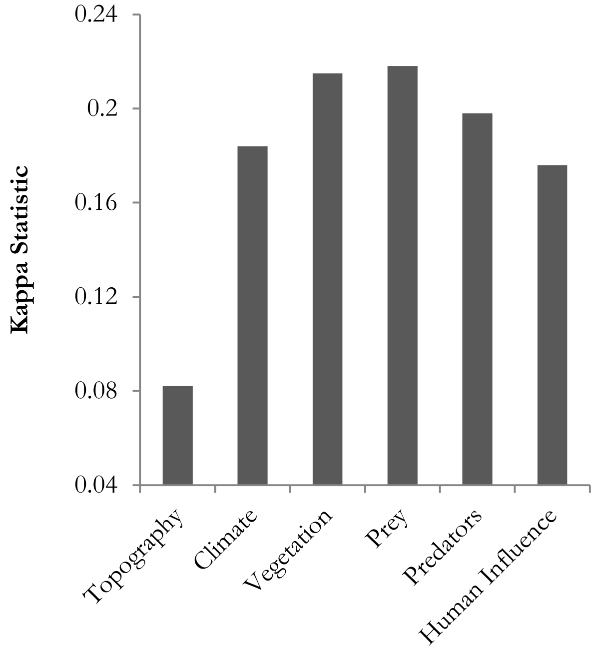


Figure 16: Kappa Statistics of logical subset SDMs

3.1.2. Species response to important variables

Maxent is able to produce individual response curves of the species under study, as it creates an SDM with only that corresponding variable. These curves help to explain the response of the species with respect to that one variable especially if there is high collinearity among the variables (Phillips et al., 2006). The red line/graph represents the average response of the species over the ten replicated runs, and the blue shows the standard deviations of the response. The standard deviation for categorical variables are shown as dark blue for (+) and cyan for (-) values.

Topography

Cheetah was observed mostly on flat slopes as shown in the map in figure 17 (**Hslope$_1$**). The slope class with the highest frequency of observation is the 2- 7% class. In steep slopes of above 19% there appeared to be no cheetah sightings as shown by the frequency table in figure 18. At elevations between 1500m and 1800m is where the cheetah probability of presence is high (Helev$_1$). At elevations above 1800m, the probability of finding a cheetah is relatively high though with much uncertainty as shown by the high standard deviations. This is reflected in figure 19.

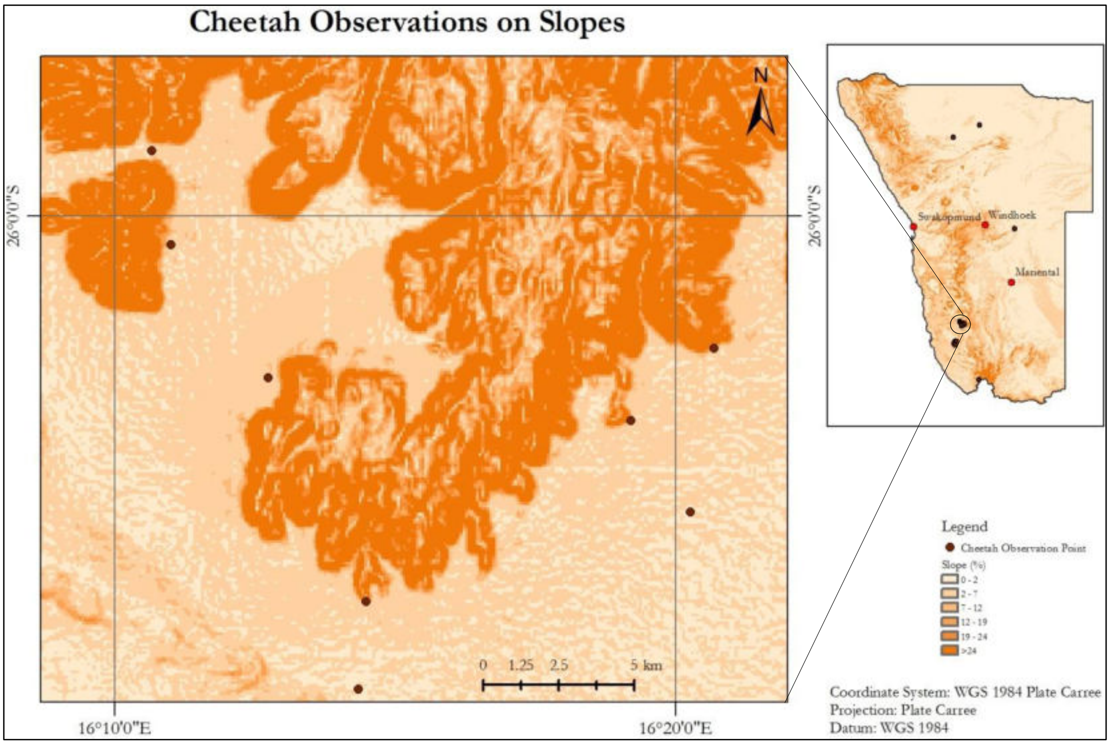


Figure 17: Cheetah on slopes

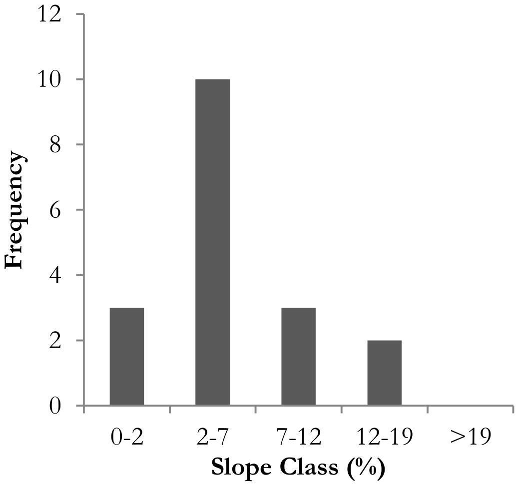


Figure 18: Frequency of cheetah on slope classes

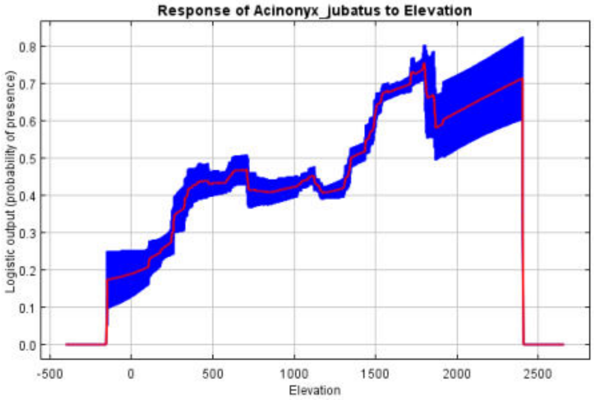


Figure 19: Response of cheetah to elevation

Climate

The model showed that probability of finding the cheetah is better in temperature range between 14 – 23 ^{0}C as represented in figure 20. The probability of presence of cheetah in this temperature range is on average 0.5. Temperatures below 18 ^{0}C also showed high probabilities however, the standard deviations are high. Areas with rainfall below 250mm and above 500m (figure 21) may not be ideal for cheetah persistence (**Hclim$_1$**).

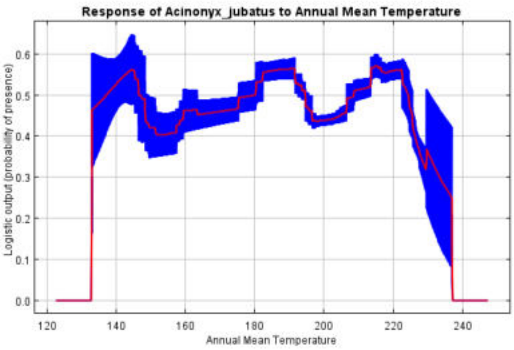


Figure 20: Response of cheetah to annual temperature

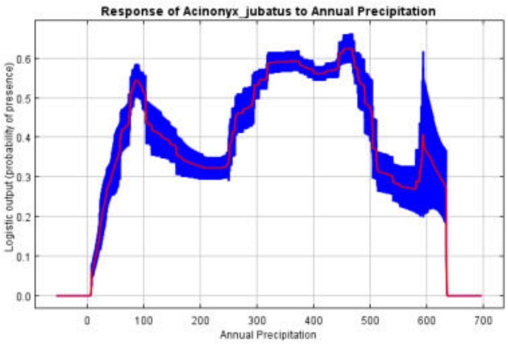


Figure 21: Response of cheetah to annual precipitation

Vegetation

The model showed that the salt pans (Class 1), shrubland (Class 4) and the escarpment (Class 5) had the highest probability of presence in increasing order **(Hveg$_1$).** The shrub height in classes 4 and 5 is 1-2m with a shrub cover of 26-50% and 2-10% respectively. The Class1 has no shrub cover. The response of the cheetah to vegetation is shown in figure 22.

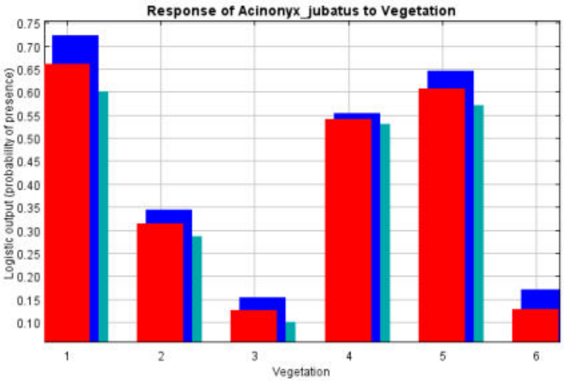


Figure 22: Response of Cheetah to vegetation

Prey

The model showed that the probability if cheetah presence increased with an increase in all prey densities (**Hprey**$_1$), even though only the kudu was determined to be the most influential determinant prey. Figures 23 and 24 show the cheetah response to kudu and springbok respectively.

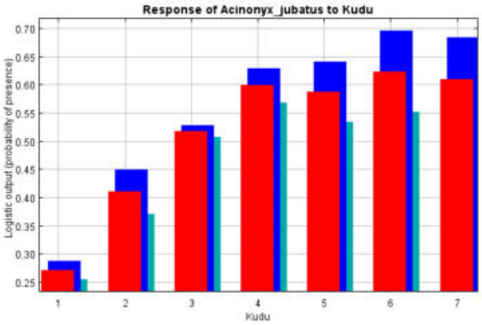


Figure 23: Response of the Cheetah to Kudu

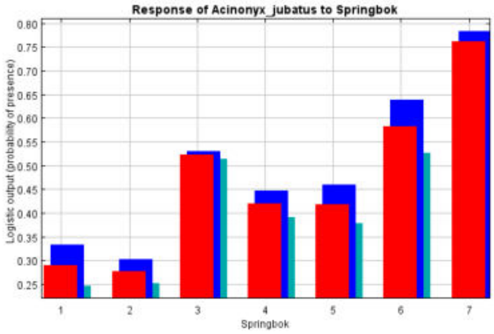


Figure 24: Response of the Cheetah to Springbok

Carnivores

The response of cheetah to other carnivores is shown in figures 25-28 (**Hcarn**$_1$). Generally the probability of presence increased with an increase in number of other carnivores. Probability of presence was higher in areas with high numbers of leopards which are between 1.5 to 3.8 leopards per 100 km, and areas with medium number of lions of between 0.4 – 1.4 lions per 100 km. The presence declined slightly in areas with the highest numbers of lions.

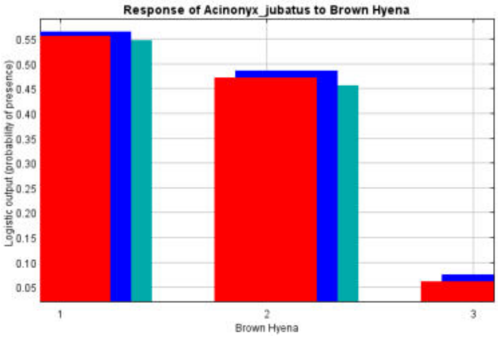


Figure 25: Cheetah response to brown hyena

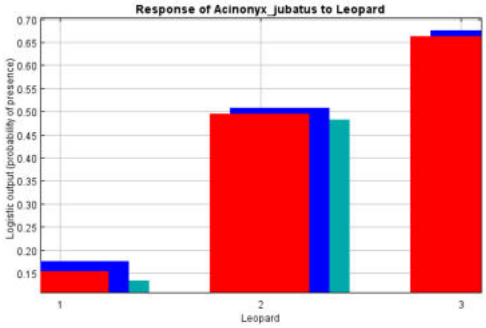


Figure 26: Cheetah response to Leopard

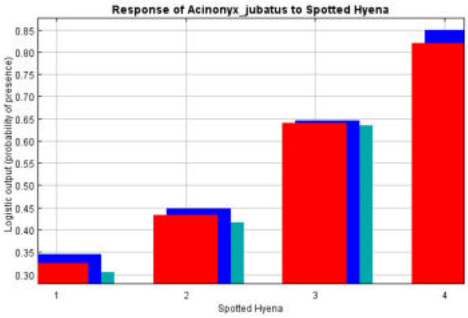


Figure 27: Cheetah response to Spotted Hyena

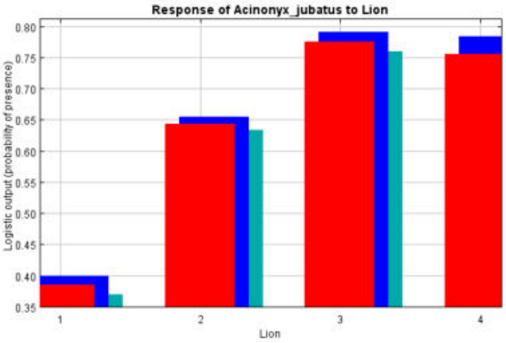


Figure 28: Cheetah response to Lion

Human Influence

The response of the cheetah to land tenure (**Hten₁**) is shown in fig 29. The freehold conservancies (Class 5) proved to be the class that showed the highest probability presence of cheetah followed by the state land (Class 1) which includes national parks. The probability of cheetah presence in communal conservancies (Class 3) was not much different from state land. The livestock which was the proxy for land management (**Hmgt₁**) is shown in figures 30-33. Overally, the probability of cheetah presence decreased as the livestock numbers increased. At higher numbers of sheep, the probability increased slightly however, it was coupled with high standard deviations.

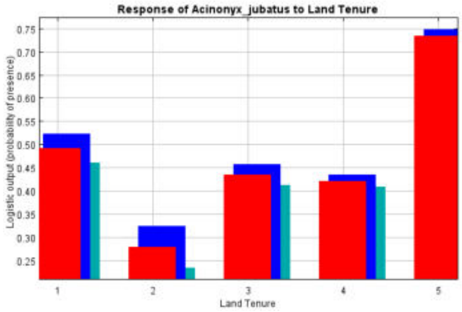


Figure 29: Cheetah response to land tenure

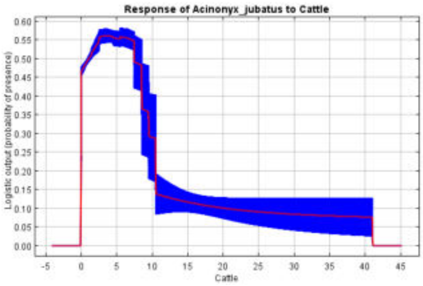


Figure 30: Cheetah response to cattle

Figure 31: Cheetah response to Dorper sheep

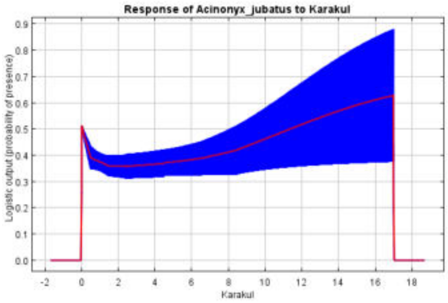


Figure 32: Cheetah response to Karakul sheep

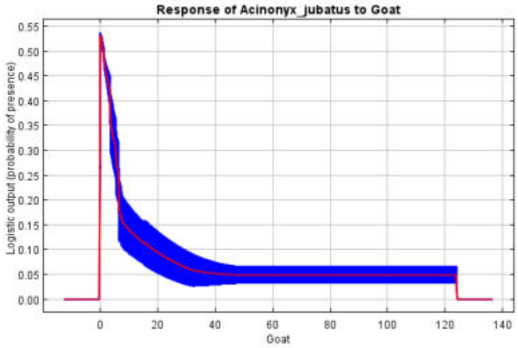


Figure 33: Cheetah response to goat

3.2. Bush versus Desert Modelling

Stepwise modelling

The 4 SDMs were trained using the datasets partitioned into Bushland and Desert. The results were measured in terms of overall AUC, TSS and Kappa statistic of each model against that of the full study area. Figures 34-36 show the statistical evaluation of these models in comparison with each other. Overally models fitted in the desert performed better than the rest of the country and the bushland in general.

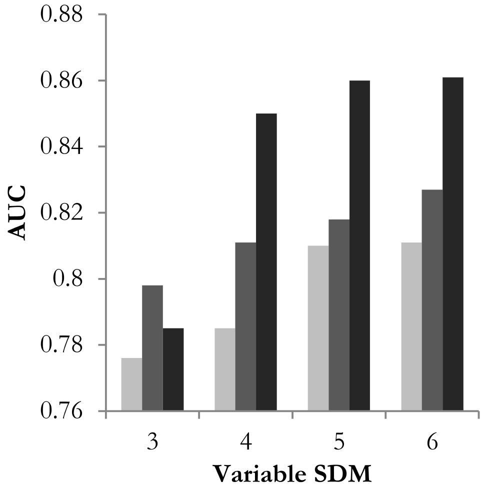


Figure 34: AUC in different modelled areas

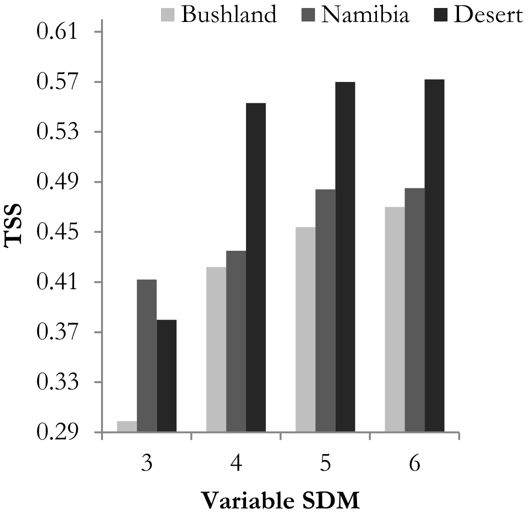


Figure 35: TSS of models in different areas

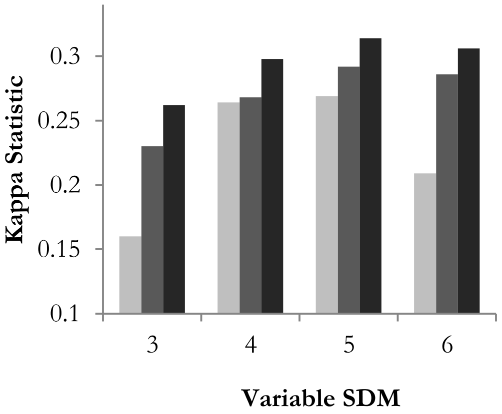


Figure 36: Kappa Statistic of models in different areas

Logical Subset Modelling

Human influence is a subset which has an influence on three other variables. Predators are more able to predict the presence of the cheetah than any other as all other variables influence the presence of these carnivores which have an effect on each other. The performance of the vegetation model is higher in the desert as compared to the bushland and the whole study area. Human influence model generally performed better in the bushland than in the deserts. Graphs in figures 37-39 show the results of model evaluations.

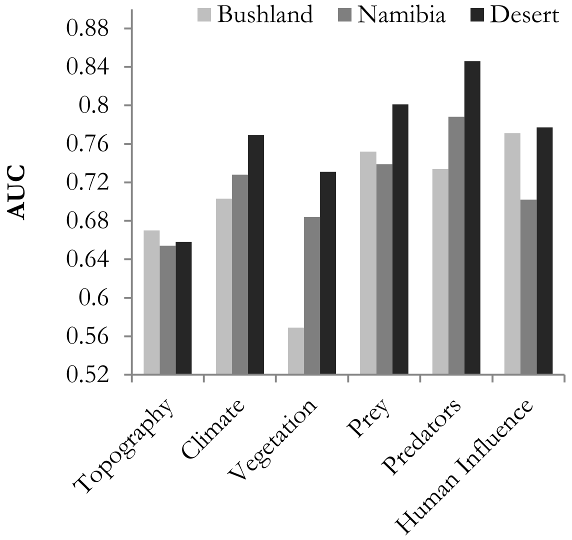


Figure 37: AUC of logical subsets

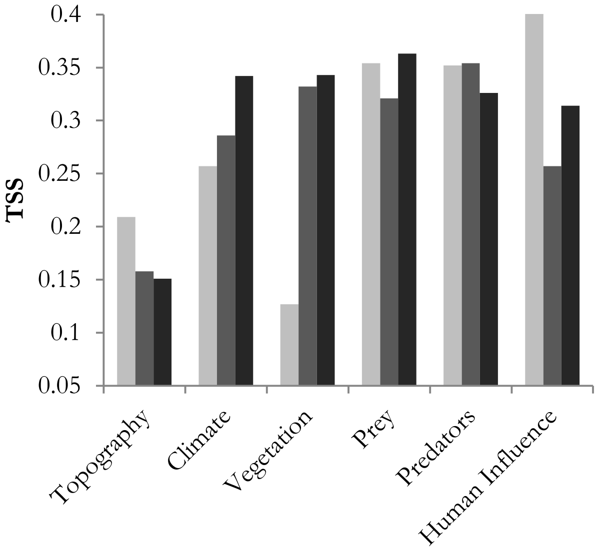


Figure 38: TSS of logical subsets

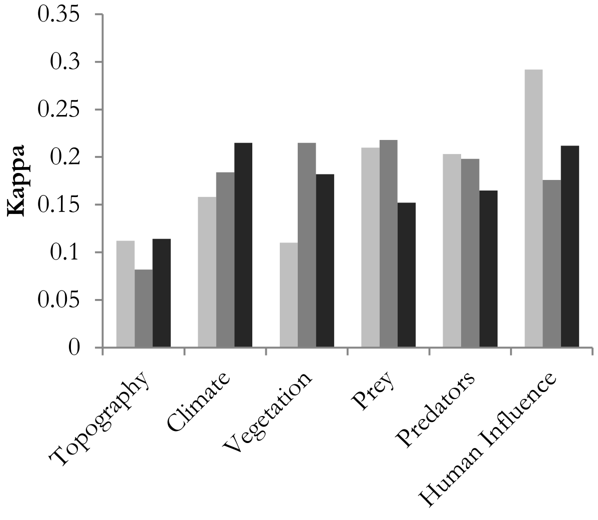


Figure 39: Kappa Statistic of logical models

3.3. Occupied Range over Time

The occupied range of the cheetah was taken to be within the 95% kernel. These are the areas in which it is estimated that the probability of finding a cheetah is 0.95. Figure 40 shows the extent of occupation by the cheetah in 1982, based on the cheetah observation points of that same year. The total area of occupation is estimated to be 407 300km². However, a decline is noted as time progresses **(Htime$_1$).** The occupied range reduced to approximately 251 200km² in the period 1999 – 2004 as shown in figure 41 and an estimated 195 400 km² in the years 2005 – 2014 as shown in figure 42. Over the past three decades, the cheetah occupied range has decreased by approximately 52%. The areas of high occurrence have become fragmented and smaller. The occupied range is consistent with predicted presence map. The areas occupied by the cheetah as found in the analysis, are similar to those predicted by the best result SDM of 6 variables as shown in figure 43.

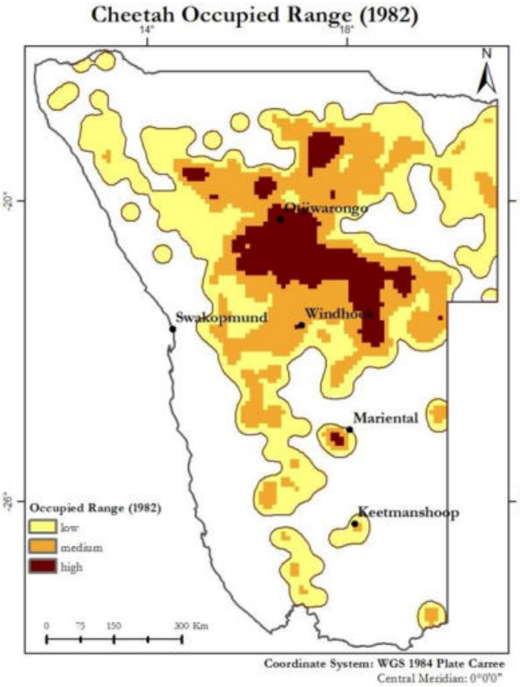


Figure 40: Cheetah Occupied Range in 1982

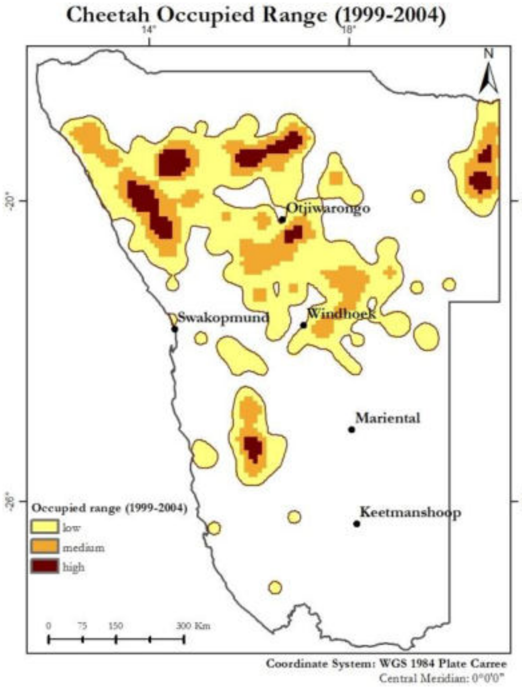


Figure 41: Cheetah Occupied Range (1999-2004)

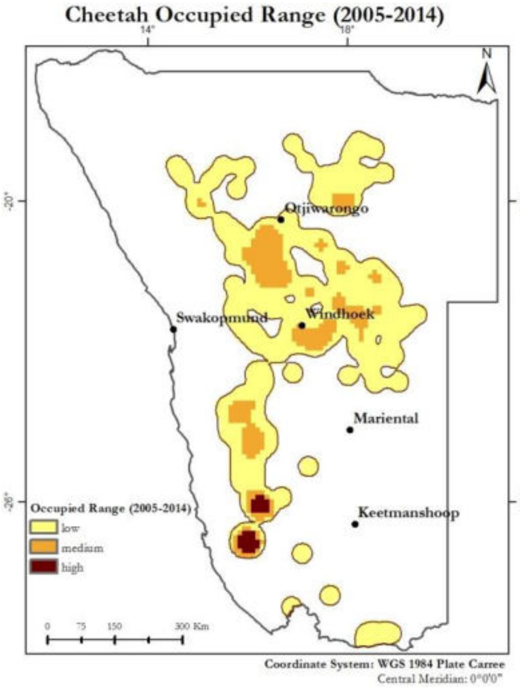


Figure 42: Cheetah Occupied Range in 2014

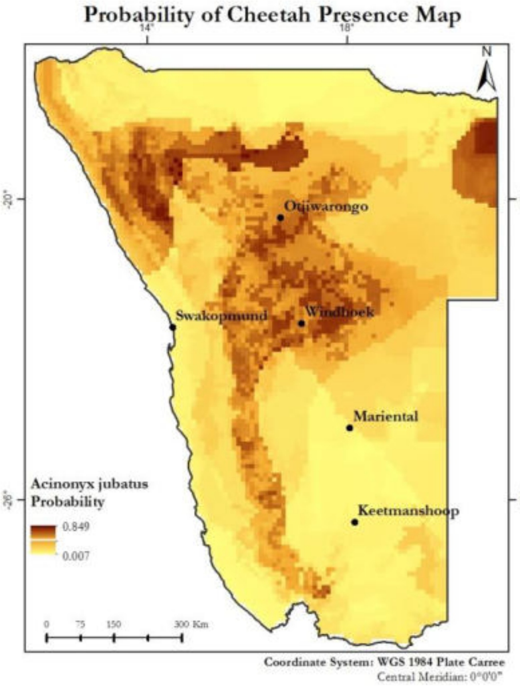


Figure 43: Cheetah Probability Range by predicted by 6 variables SDM

4. DISCUSSION

4.1. Environmental Variables

The objectives of the study were to determine the variables which were important in explaining the distribution of the cheetah. This research modelled the cheetah distribution using land tenure related variables, prey and predators in addition to the frequently used vegetation and bioclimatic variables. The results of this also included response of cheetah probability of presence to the environmental variables used in this study.

4.1.1. Variable Selection

The emergence of predators and prey in the high performing SDMs explains the importance of these variables in explaining the presence of the cheetah. Environmental variables which are expected to influence the presence of cheetah include vegetation, predators and prey (Bissett & Bernard, 2007).The ecosystem interactions among predators and prey cannot be ignored.

The AUC increased from 0.801 with 3 variables to 0.821 with 6 variables. The initial model had 3 variables and the addition of a single variable in a stepwise approach did not increase the model performance by a significant margin. This is because Maxent, as a machine learning technique, improves its predictions as it obtains more information. This increase is expected, however, the increase is very slight. Therefore, SDMs with fewer variables can be said to be able to explain the cheetah presence equally well. Modelling the distribution of a species can be done with variables 2 or less (van Gils et al., 2012). Overally the SDMs performed significantly well with an AUC of >79%.

The variables were split into categories which can be representative of subsets with direct and indirect effects on the cheetah distribution. The subsets higher in the hierarchy chain were expected to perform better as they had more direct effects. The variables were categorized as; in increasing order; topographic, climatic, vegetation, prey and predators. Human influence is a category which has both direct and indirect direct effects on the final subset which has the cheetah. It is not directly a part of the hierarchy as it influences more subsets than one at the same time. The model evaluation of the logical subsets showed a steady increase in the robustness of the models produced. The anomaly was vegetation model, which performed lower than its influencers. This can be attributed to poor data quality in terms of the vegetation map used. A more detailed and accurate map may be expected to produce better results. Human influence variables also provide an anomaly as they are not directly a part of the chain. However, the increase in model performance is consistent with the overall prediction models which have predators, prey, land tenure and vegetation.

4.1.2. Response of the Cheetah to different variables

The results indicate high probability of cheetah presence at elevations between 1500-1800m **(Helev$_1$)**, and observations on are mainly on flat slopes **(Hslope$_1$)**. This is consistent with previous studies which showed cheetah being observed in study areas which are between 900 – 1850 m in the Serengeti (Gros, 2002) and the North-central Namibia (Marker, 2005). The results of this study indicate that elevations above 1800m can also be considered as being suitable for determining cheetah presence however, this is highly uncertain. The uncertainty of cheetah presence being predicted at high slopes can be attributed to the steep slopes found at higher altitudes in Namibia. The slope appears to be an environmental predictor of cheetah presence upon visualization. However, it is dependent on the spatial resolution and may only emerge as an important predictor if a finer spatial resolution is used in the analysis. This result is in line with the uncertain probability of presence in elevations above 1800m, where the slopes may be steeper.

Probability of presence increased as height increased. However, the probability of finding cheetah is highly uncertain at elevations higher than 1800m. Display of the accurate GPS cheetah presence points on slopes revealed that slope could be a predictor. These GPS presence points were obtained from camera traps. This reduces the possibility of observation bias.

Bioclimatic variables which were taken to represent the climatic conditions of the study area did not have the highest performing SDMs **($\mathbf{Hclim_1}$)**. The temperature range of 18-23 °C showed the highest probability of cheetah presence with a peak of 0.75 +/- 0.05. This range greatly narrows the assumptions that cheetah can be found in a wide temperature range of 0 – 40 °C. Areas with rainfall between 250 – 500mm have been shown to have a high cheetah probability of presence, these results are in line with other authors who classified the cheetah habitat preference as being dry; and semi-arid to arid (Boast & Houser, 2012). Deserts generally have low minimum temperatures of below 0°C and maximum temperatures which may reach up to 45°C. Bushland areas which contain vegetation generally do not have large differences in the minimum and maximum temperatures. The probability of presence of cheetah is higher in areas which may be said to be bushland and lower in the desert.

The response of the cheetah in response to the vegetation is higher in salt pans (0.65 +/- 0.06), followed by the escarpment (0.60 +/- 0.04) and the shrubland (0.54 +/- 0.01) **($\mathbf{Hveg_1}$)**. The salt pan vegetation class is present in Etosha National Park (Figure 44). The Escarpment and Shrubland vegetation classes, with shrub cover of classes 2-10%, and 26- 50% indicate that these vegetation cover types are important in predicting presence of cheetah. These areas have grasses of height 1-2m. This result is slightly similar with that of Uganda (Gros & Rejmánek, 1999), in which the species was found to utilize woodlands of cover 25-50%. The results from this study may be used to confirm the theory that cheetah is able to adapt to different vegetation types (Mills et al., 2004).

In figure 44, some presence points are located in the salt pans. Some of these points are from the QDS and their real location can be anywhere within 14km from that point. The digitized points, with an inaccuracy of 5km were also used in this research. These positional errors, added to the errors in the method of geo-coding and actual digitizing. This result has an effect on the overall quality of the model. This would make most points observed in Etosha National Park and surrounding areas fall within the salt pan vegetation class. The probability of presence is also relatively high in the escarpments and the shrubland, which surround the saltpans. The spatial relationship of these vegetation classes added to the errors in accuracy of the points could have resulted in salt pans coming out as relevant.

In addition to errors encountered in the cheetah observation points, there was also lack of data in some polygons of the vegetation map obtained from the EIS. These areas included some parts of the Kalahari Desert in the south-west parts of the country and the Kalahari Desert in the central eastern areas as well. Errors in terms of vegetation classification were also noted as observations were made in the case of the North-eastern Desert which was defined to have 26-50% shrub cover. Investigation of this polygon using other data sources such as proved that these areas were almost bare and had been misclassified. All these findings show that the vegetation map may be said to be unreliable in some areas.

Etosha National Park is part of State land, a land tenure category. State land appeared to also have a considerably high predicting power of cheetah presence. Thus a combination of these factors and others such as the lion, kudu, elevation and leopard would result in salt pans having the highest predictive probability of presence. The Park also has high densities of animals due to its purpose of conserving animals. The results of this model also reflect that areas with medium numbers of carnivores and high numbers of prey have a high probability of predicting cheetah presence.

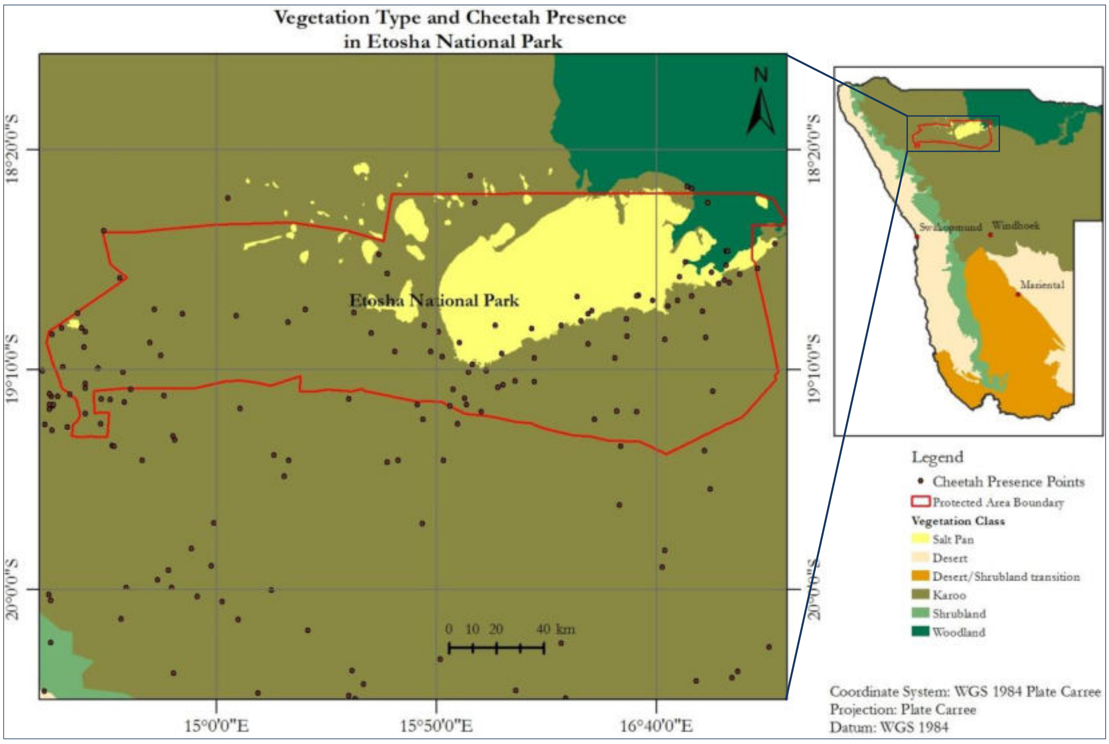


Figure 44: Cheetah presence in salt pans

The ability of the prey logical subset SDM to have a model performance reflects that prey may be used as a determinant of cheetah presence **($Hprey_1$)**. The kudu was able to emerge as a determinant of cheetah presence, with areas having 0.75-1 head per square kilometre (Category 6) being able to predict cheetah presence significantly well (0.62 +/- 0.09). This is consistent with previous studies of Namibia which showed Kudu as the main prey of preference of cheetah in Namibia (Marker, 2002). The abundance of springbok and its failure to emerge as a valid predictor of cheetah suggests that it may not be the prey of choice for the Namibian cheetah. Areas occupied by the cheetah and areas with high kudu abundance; above 0.5 head per square kilometre; spatially coincide. This could be one of the reasons why the kudu is comes up as a valid predictor. Springbok prefer flat grasslands in drier areas whereas kudus are browsers which are found mostly in bushveld or woodlands (Mattiello, Zanoni, Plessis, Heinzl, & Crimella, 2004). The habitat preference of the kudu and that of the cheetah coincide. The results of the habitat preference of the cheetah in study show that the probability of finding cheetah is considerably high in areas with shrubland cover of 11% and above.

The carnivore categories with medium numbers showed the probability of presence of cheetah as being higher than those with low or none. This is also reflected by the logical subset modelling which showed carnivore subsets as being the best predictors **($Hcarn_1$)**. Consequently, carnivores are not generally a negative predictor of cheetah as previously suspected. Marker et al., (2008) reported that large carnivores have made the cheetah seek refuge in the freehold-livestock farms; however, these large carnivores are also found in these farmlands as illustrated in their distribution maps shown in Appendix 1. The cheetah probability of presence slightly decreased only with a high number of lions. Areas with medium numbers had probability of 0.78 +/- 0.01 and those with high numbers had probability of 0.76 +/- 0.04, of predicting cheetah presence. Cheetah being carnivores, they share a dietary overlap with other carnivores(Hayward & Kerley, 2008). This means that they can be found in areas where there are considerable numbers of large carnivores since they need the same prey and may mutually benefit from each other's hunting efforts. However, as reflected by the cheetah response to the lion variable, they may avoid areas with extremely high numbers of other carnivores due to the reasons such as kleptoparasitism and cub killing.

The freehold conservancies (Class 5) proved to be the class that showed the highest probability presence (0. 74 +/- 0.01) of cheetah followed by the state land (Class 1) which includes national parks (0.49 +/- 0.03) **(Hten1)**. Cheetah is reported to occurring more outside of protected areas(Marker et al., 2008). These results of this research are in line with their observations. The probability of cheetah presence in communal conservancies (Class 3) was slightly less than in state land (0.40 +/- 0.02). This result may be taken as to indicate that conservation areas outside of protected areas may be contributing quite significantly to the overall status of the species.

The livestock, constituting of the cattle, sheep and goats, which was the proxy for land management showed that cheetah presence decreased overally with an increase in livestock numbers **(Hmgt$_1$)**. Overally, the probability of cheetah presence decreased as the livestock numbers increased. Marker, (2002) pointed out that presence of cheetah conflicts with livestock farming. The results of this study are contrary to the initial hypothesis which stated that cattle are positive predictor of cheetah presence. The probability of presence decreased as the cattle density increased. An explanation for this result is that there are different types of farming taking place in the freehold farms. This was not taken into account due to the lack of supporting data. The freehold farms can be split into game farms and livestock farms. This may have an effect which is shown by the fact that as cattle numbers increase the cheetah presence decreases. A farmer may have large numbers of game and wildlife and lower numbers of cattle and vice versa. At higher numbers of sheep, the probability increased slightly however, it was coupled with high standard deviations. Sheep and goats are mainly raised in the southern parts of the country and these are the areas which have had the largest number of cheetah removals (Marker, 2002). These areas have lower numbers of human population and less landscape disturbances due to human influence. Therefore it is natural that some higher numbers of sheep and goat would show a probability or presence which has a high standard deviation reflecting a high uncertainty in the results. This means that these areas have other environmental conditions which make them suitable for supporting cheetah presence. The sheep and goat densities occur more in the south which is mostly desert.

4.2. Bush versus Desert

The overall SDMs of 3-6 variables as well logical subsets were trained on Bushland and Desert areas so as test how accurately the SDMs can be used to predict cheetah presence in different areas **(Hbush/desert$_1$)**. The ability of Maxent models to be transferred in the two different areas is concurrent with Heikkinen et al (2012) who found that Maxent could be accurately transferred as well. The desert SDMs performed better than the models trained in the bushland. This result shows that models which are spatially based in the desert can be used to explain the cheetah distribution more than the whole country or the bushland. The reason for this may be the lack of complex relationships in the desert. The prey and predator populations are less in the desert. Human influences are also less in the desert.

4.3. Occupied Range

The results of the study show that the area occupied by the cheetah has decreased significantly over time **(Htime$_1$)**. The overall decrease of approximately 52% over three decades, serves to confirm that the cheetah range is indeed decreasing as suggested by Ray et al. (2005). The lesser decrease in Namibia may be attributed to the country's conservation efforts as compared to the rest of the world, as also reported by Stein et al., 2012. However, in contrast with general reports of an overall increase in large carnivore range in general (Stein et al., 2012), the cheetah occupied range continues to decline with time. The occupied range showed that the species is mostly found in North-central Namibia as previously suggested by (Marker et al., 1996; Marker, et al., 2003). The range in North –central continues to decline as well, but some areas in the South have shown some small changes in the increase in the range. This can be attributed to the different protected areas in the areas which improves the conservation efforts of the species. Areas with predicted as having high probability of cheetah presence are consistent with the occupied range determined using the kernel density estimations.

The occupied range and the probability of presence predictions differ much in the North-East and North-West parts of the country. The probability of presence of cheetah in the North-East, where Kaudum Game Park is situated is relatively high. However in the occupied range map of 2014, these areas are not occupied. This observation is similar to the one that can be made in the North-East of the country, in Damaraland. This area contains a large number of communal conservancies within the communal lands. The range in this area is shown to be non-existent. This could be as a result of lack of data from these places in this time range, since the predictive model illustrates them as being potential areas of being occupied by the cheetah.

5. CONCLUSION AND RECOMMENDATIONS

The aim of this research was to understand the biophysical and anthropogenic variables driving the cheetah distribution. This was necessary so as to establish a baseline of information to enable for evidence based species conservation. The underlying problem is the decline in cheetah range and numbers.

The first objective of this study was to determine the most important environmental variables driving the cheetah distribution. This was done through the use of Maxent software which produces SDMs. These SDMs were used to predict the probability of presence of the cheetah, and their performance measured. The environmental variables in the best performing SDMs were determined to be the most important environmental variables driving the cheetah distribution. There was no significant difference in the model performance as the number of variables was increased from 3 up to 6 variables. The most important environmental variables were found to be Elevation, Kudu, Land Tenure, Leopard, Lion and Vegetation. In addition, this research has shown that cheetah SDMs with predator, prey, vegetation and human influence variables may be developed elsewhere and be used to predict cheetah presence.

Furthermore, this research established that the cheetah in Namibia may be able to persist in areas with an average annual temperature of 18-23°C; and annual rainfall of 250mm to 500mm. The model also showed that cheetah may persist at elevations of 1500- 1800m. The probability of finding cheetah at higher elevations is there, however, there is need to test whether the slope indeed hinders the movement of the species. In future, the model may encompass the slope at a finer resolution, with more accurate GPS points (more than the 18 used in this study), so as to establish the effect of the slope on the species.

This research established that the cheetah in Namibia has a higher chance of being found in areas with shrub cover 26-50%. The lack of data and the inaccuracy of data in some polygons of the vegetation map need to be rectified in future. This would assist greatly in establishing more concrete conclusions as far as vegetation is concerned. In addition to this, it can be said that cheetah do not totally avoid predators since they are found in areas with medium number of other large carnivores. They are not found in areas with no other carnivores, since the lack of other carnivores may indicate the shortage of prey as well.

Hence, in regard of carnivore effect, this research also established the areas of high occurrence of cheetah as those having kudu with number above 0.5 head per km^2. Springbok and kudu are abundant in similar numbers in Namibia, though in different areas. Since the results did not show the importance of springbok as a modelling variable, it may be concluded that the prey of preference determines the presence of the species. Another conclusion is that, the kudu and the cheetah abundance spatially coincides. It would be more insightful if a model could be done which encompasses other prey of preference in Namibia such as the hare.

The determination of land tenure as an important variable indicates that importance of conservation strategies. The cheetah indeed occurs more in the freehold land, and in particular freehold conservancies. The contribution of state land, in particular national parks cannot be totally ignored. However, there are various factors to be considered in future such as game farming and the effects it has on the distribution of the cheetah. Livestock farming was established to have a negative effect on cheetah presence. Furthermore, it would be recommended to train and evaluate an SDM of cheetah in the desert as the SDMs of these areas performed better.

The third objective of this study was to map the cheetah occupied range over time and analyse the differences in total area occupied. Results showed that the occupied range of the cheetah in Namibia can be said to have decreased by approximately 52% over the period 1982 to 2014. Compared to the global estimate of a rate of 75% decline, this figure indicates some difference in the conservation strategies and status of the species in Namibia. The occupied range was shown to be indeed decreasing. However, a more accurate assessment may be done using more accurate GPS points and other methods. In future it would also be recommended to model the occupied range in those specific time ranges so as to determine the causes of change.

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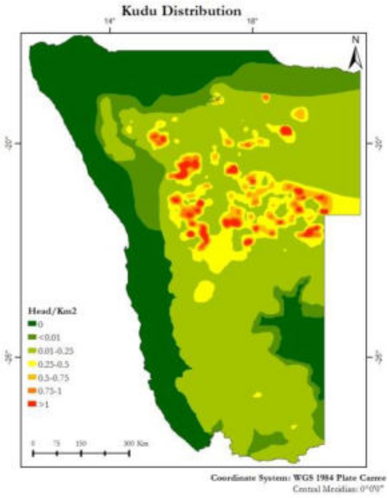
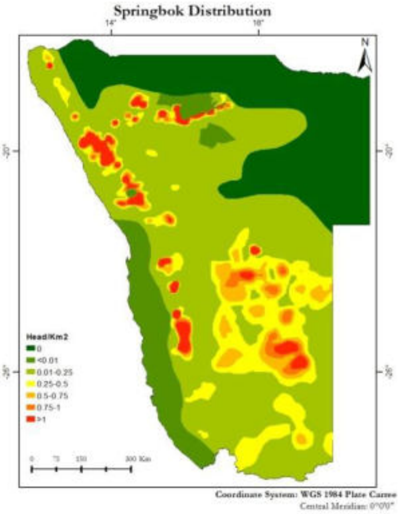
APPENDIX 1

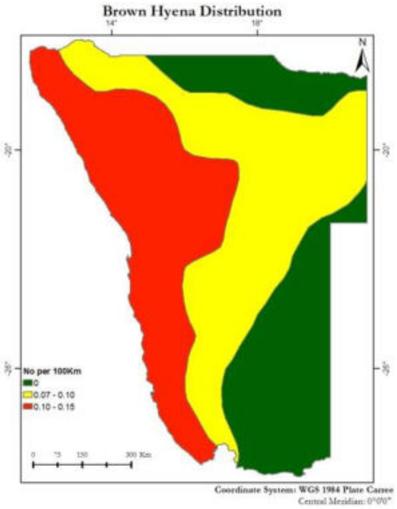
Environmental variable maps for:
(a) Kudu
(b) Springbok
(c) Brown Hyena
(d) Leopard
(e) Lion
(f) Spotted Hyena
(g) Vegetation
(h) Land tenure



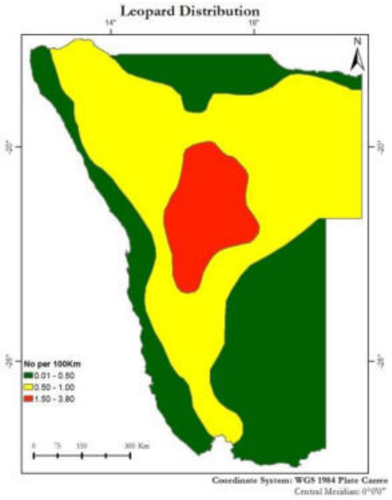
(a)



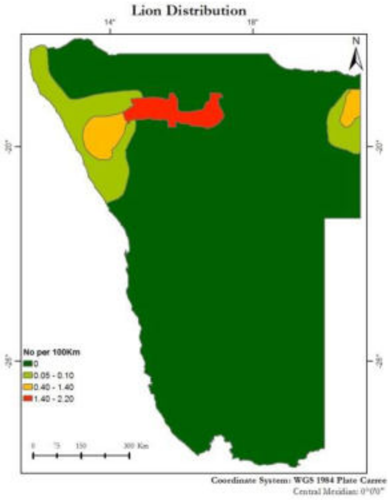
(b)



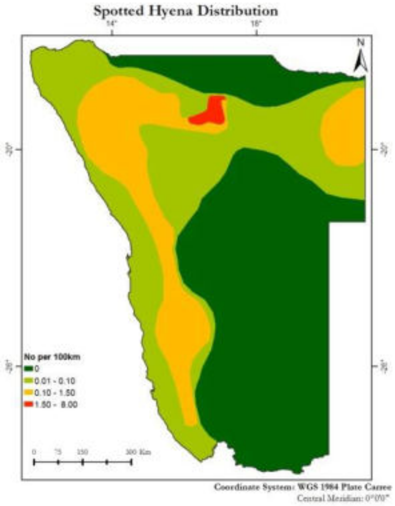
(c)



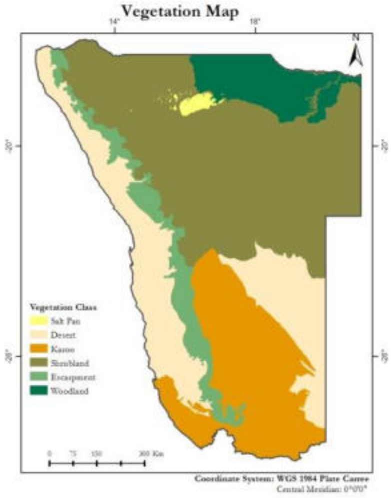
(d)



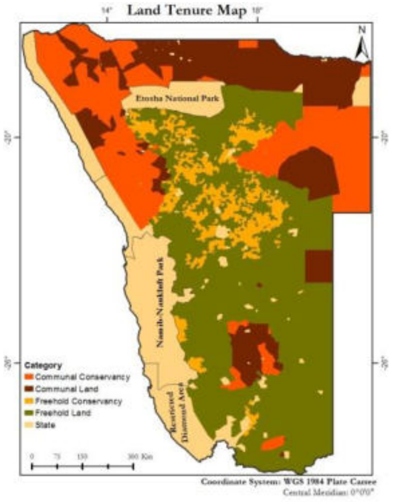
(e)



(f)



(g)



(h)

APPENDIX 2

KUDU

Category	Head per km. sq.
1	0
2	<0.01
3	0.01-0.25
4	0.25-0.5
5	0.5-0.75
6	0.75-1
7	>1

SPRINGBOK

Category	Head per km. sq.
1	0
2	<0.01
3	0.01-0.25
4	0.25-0.5
5	0.5-0.75
6	0.75-1
7	>1

BROWN HYENA

Rank	Category	No per 100km
None	0	0
Low	1	0.07- 0.10
Medium	2	0.10 – 1.50

SPOTTED HYENA

Rank	Category	No per 100km
None	0	0
Low	1	0.01- 0.10
Medium	2	0.10 – 1.50
High	3	1.5 – 8.00

LEOPARD

Rank	Category	No per 100km
Low	1	0.01- 0.50
Medium	2	0.50 – 1.50
High	3	1.50 – 3.80

LION

Rank	Category	No per 100km
None	0	0
Low	1	0.05- 0.10
Medium	2	0.10 – 1.40
High	3	1.4 – 2.20

LAND TENURE

Category	Class
1	State
2	Communal Land
3	Communal Conservancy
4	Freehold Land
5	Freehold conservancy

APPENDIX 3

Correlation Matrix of Variables after Collinearity Analysis

	Annual Mean Temperature	Annual Precipitation	Precipitation of Driest Month	Isothermality	Temperature Seasonality	Cattle	Dorper Sheep	Elevation	Goats	Karakul Sheep
Annual Mean Temperature	1	0.478196	-0.55529	0.40657	0.065431	0.034552	-0.0305	-0.12761	0.169418	-0.07439
Annual Precipitation	0.478196	1	-0.46967	-0.14087	0.604852	0.472572	0.020735	0.627547	0.07771	-0.08467
Precipitation of Driest Month	-0.55529	-0.46967	1	-0.24763	0.117624	-0.21979	0.083395	-0.11657	-0.12273	0.054921
Isothermality	0.40657	-0.14087	-0.24763	1	-0.29769	-0.10769	-0.06896	-0.06198	0.080233	-0.04482
Temperature Seasonality	0.065431	0.604852	0.117624	-0.29769	1	0.39559	0.284272	0.672185	-0.08924	0.138742
Cattle	0.034552	0.472572	-0.21979	-0.10769	0.39559	1	0.166857	0.543526	0.409536	0.001968
Dorper Sheep	-0.0305	0.020735	0.083395	-0.06896	0.284272	0.166857	1	0.159976	0.171331	0.314311
Elevation	-0.12761	0.627547	-0.11657	-0.06198	0.672185	0.543526	0.159976	1	0.037049	0.02835
Goats	0.169418	0.07771	-0.12273	0.080233	-0.08924	0.409536	0.171331	0.037049	1	0.044613
Karakul Sheep	-0.07439	-0.08467	0.054921	-0.04482	0.138742	0.001968	0.314311	0.02835	0.044613	1