MULTI-SCALE ASSESSMENT OF HABITAT USE BY BLACK RHINOS (*Diceros bicornis bicornis* Linnaeus 1758) IN NORTHWEST NAMIBIA

BY

BASILIA ANDOROONE SHIVUTE

MARCH 2008

MULTI-SCALE ASSESSMENT OF HABITAT USE BY BLACK RHINOS (*Diceros bicornis bicornis* Linnaeus 1758) IN NORTHWEST NAMIBIA

A thesis submitted in partial fulfilment of the requirements for the degree of
Master of Science in Biodiversity Management and Research at
University of Namibia and Humboldt-Universität zu Berlin

By

Basilia Andoroone Shivute

Supervisor: Dr. I. Mapaure (University of Namibia)
Co-supervisors: Dr. J.S Lalley (University of the Witwatersrand)
Mr. J.R. Muntifering (Round River Conservation Studies)

March 2008

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

Acknowledgements

I would like to extend my sincere appreciation to Rufford Small Grants (UK) the Wilderness Trust (South Africa) for their generous financial support. Special thanks go to the Smithsonian Institute, Washington D.C and Wilderness Safaris Namibia, especially Dave van Smeerdjik for enormous support and understanding while pursuing my studies.

I am grateful to my supervisors; Dr. Isaac Mapaure, Dr. Jennifer Lalley and Mr. Jeffrey Muntifering for their constructive and valuable comments during the design of my field methods as well as for reviewing my drafts. Special thanks to my field assistants (Willy Kasupi, Sokoi Kasaona, Paolo Awarab, Sem Gaseb, Wilhelmina, Palmwag tour guides and Round Rivers' students) for their enormous help.

My thanks go to Save the Rhino Trust (SRT) for recording and providing rhino locality data that I was able to use during my analysis. I am grateful to the German student exchange program, the Humboldt-University and Potsdam University in Berlin for the financial and kind support during my student internship in Germany. My thanks also go to the Department of Biological Sciences, University of Namibia for their valuable input during the course of my studies. Last but not least I would like to thank my parents for their inspiration and may God bless you! To my siblings and friends, thanks for the moral support you have shown throughout the duration of my studies.

ABSTRACT

The black rhino of northwestern Namibia is a desert-adapted sub-species *Diceros bicornis bicornis.* The Ministry of Environment and Tourism in Namibia has initiated an ambitious program to re-introduce black rhino into areas within their historic range. As an aid to this program, a multi-scale habitat assessment for black rhinos based on vegetation and environmental relationship analyses was carried from April to June 2006 in the Kunene Region, northwestern Namibia. Three study sites were selected: Palmwag concession, Torra conservancy and ≠Khoadi //Hoas conservancy. In all three study sites, three general habitat types were selected; major river, secondary river and non-river habitats. At a local scale, data on plant species name, richness and browse availability were collected and analyzed. At a landscape level, the significance of environmental variables in the low and high probability of habitats used by black rhino in the Palmwag concession was also investigated. Analyses on species diversity, richness and composition and browse availability illustrated a significant difference among the sampled sites as well as the different habitats. Torra conservancy exhibited significantly higher species diversity and richness than ≠Khoadi //Hoas conservancy. Furthermore, ≠Khoadi //Hoas conservancy exhibited higher browse availability than Torra and Palmwag concessions. The significant differences could be due to factors such as elevation and rainfall. Canonical Correspondence Analysis showed that elevation and rainfall significantly influenced browse availability of selected plant species. The direction and influence of elevation was more important in plots from ≠Khoadi //Hoas and the influence of rainfall was more important in Torra concervancy, and Palmwag concession. At a landscape level, this study found significant differences between the probability of rhino habitat use and the following habitat characteristics: distance to major rivers, distance to perennial springs, rainfall, elevation and slope. However the probability of a habitat being used by black rhinos could also be attributed to other underlying factors such as slope, soil properties and land use patterns and these warrant further investigation. Investigation into slope steepness for example, may reveal links to hydrology and therefore the occurrence of certain plant species. Based on higher browse availability in ≠Khoadi //Hoas conservancy, this study demonstrated that re-introduction of black rhinos is possible. However this study recommends further research into browse availability in other communal conservancies that are possible rhino re-introduction sites. This study also recommends research into factors which influence the browse availability and therefore habitat use by black rhinos in northwestern Namibia.

Key words: Black rhinos, browse availability, environmental variables, ≠Khoadi //Hoas, probability of habitat use, Palmwag concession, species diversity, species richness, species composition and Torra conservancy

Declarations

I, Basilia Andoroone Shivute, hereby declare that this study is a true reflection of my own research, and this work, or part thereof has not been submitted for a degree in any other institution of higher education.

No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g. electronic, mechanical, photocopying, recording or otherwise) without the prior permission of the author, or The University of Namibia and Humboldt-Universität zu Berlin in that behalf.

I, Basilia Andoroone Shivute, grant The University of Namibia and Humboldt - the right to reproduce this thesis in whole or in part, in any manner or format, which the University of Namibia and Humboldt Universität zu Berlin may deem fit, for any person or institution requiring it for study and research; providing that The University of Namibia and Humboldt- Universität zu Berlin shall waive this right if the whole thesis has been or is being published in a manner satisfactory to the Universities.

………………………………… ………………………………

CHAPTER 1

1. INTRODUCTION

1.1 General introduction

The African black rhinoceros, once widespread across Africa, has suffered a massive reduction both in numbers and range during the 20th century, mainly due to intensive poaching (Harley *et al.,*2005) and due to the conversion of suitable habitat for agricultural use (Hearn, 2004). The SADC Rhino Management Group (RMG) made up of four countries; South Africa, Namibia, Swaziland and Zimbabwe, has a target to conserve an estimated 81% of Africa’s remaining rhinos, which includes conservation of 100% of Namibia’s black rhino (*Diceros bicornis bicornis*) (Harley *et al*. 2005). In South Africa, there is a growing concern that some wildlife species may face extinction if the use of natural resources by rural people in the nature reserves destroys the habitat of wildlife (Harley *et al*., 2005). Through habitat destruction and subsequent fragmentation of populations, the ecological groupings of black rhinoceros have become separated for at least the last century and possibly longer. It is no doubt that habitat assessment is one of the conservation vehicles for wildlife management. Ecological and genetic studies that provide data on the environmental factors influencing the distribution and viability of wildlife populations are therefore crucial for science-based conservation planning (Banks *et al.,* 2005).

In general, habitats vary in their geomorphological characteristics such as topography, geological formations and soil types, as well as the associated vegetation. The availability of water plays an important role in habitat preference for animals (Bothma, 1990), especially in arid regions.

Habitat selection is usually a behavioral consequence of animals actively selecting where they live, or passively persisting in certain habitats. Ultimately, however, resource-use patterns are a consequence of the influence of selection on survival and reproduction, which determine fitness in various habitats (Boyce and McDonald, 1999). Woodland-grassland ecosystems appear to be dynamic, with factors such as browsing, fire and rainfall being critical in determining whether habitat will be stable or subject to rapid change (Birkett, 2002). Species composition and structure are the components of the vegetation that form an important part of the habitat. The plant species that constitute the vegetation will determine the suitability of a habitat. Habitat choices by large herbivores are especially associated with abundance of high quality food resources and hence with nutrient-rich soils.

A reaction of a population to the environment can also be determined through observational data on condition of animals in relation to available resources (Hearn, 1999). Findings by Muya *et al.* (2000) suggest that a key habitat factor important in black rhinoceros conservation includes diverse plant species with low levels of phenols and alkaloids. Black rhinos are known to inhabit a variety of habitats, ranging from deserts through wooded grasslands to woodland of *Acacia* savannas (International Rhino Foundation, 2002). A study in northwest Namibia found that black rhinos occupied 12 different habitats, but mostly favored *Euphorbia* basalt foothills and *Euphorbia* basalt plateau habitats (Hearn, 2004). The distribution is believed to be influenced by water availability, as well as the presence of the range of plant species which the black rhinos prefer.

1.2 Problem statement

The Ministry of Environment and Tourism (MET) in Namibia has initiated an ambitious plan to translocate black rhinos back to areas within their historical range in order catalyze the stagnant growth rate and diversify local community livelihoods by enhancing non-consumptive tourism through rhino tracking safaris. However, there is a need to identify the most suitable sites to prioritize re-introduction. A study by Uri-Khob (2004) investigated attitudes and perceptions of local communities towards the re-introduction of black rhino (*Diceros bicornis bicornis*) in their historical range in northwest Kunene Region. The study found that respondents in the study sites support the re-introduction of black rhinos into their conservancies.

To date Save the Rhino Trust (SRT) has GPS location data for individual rhinos in the northwest of Namibia and large-scale descriptors of habitat. However, black rhino locality records within their water- and human-limited range do not necessarily provide a clear picture of habitat use. Smith (2005) analyzed the influence of water and human settlements on distribution patterns of black rhinos by using a spatial habitat suitability map for the black rhinos in the northwest Namibia. The study found that black rhinos were more likely to occur in areas that were close to springs, areas that were furthest from where people lived, and areas of higher altitudes.

Loutit *et al*. (1987) and Hearn *et al*. (2000) have shown the influence of browse availability on black rhino distribution but there have been no local scale studies on vegetation within the known black rhino range. No studies have been done to determine a local scale habitat use and preferences of black rhino *(Diceros bicornis bicornis*) through field biophysical assessments. This study aimed at building a foundation to inform a regional (Kunene Region) black rhino habitat use for re-introduction purposes. Therefore, the main objective of this study was to characterize black rhino habitat use based on vegetation and environmental variable analysis.

1.3 Specific objectives

(a) To determine and compare plant species diversity, richness and composition in selected study sites and habitats,

(b) To quantify and compare mean browse availability among the selected study sites and habitats.

(c) To investigate the influence of environmental variables (slope, elevation, rainfall) on browse availability of selected browse plants, and

(d) To investigate the influence of environmental variables (slope, elevation, and distance to perennial springs, aspect) on the probability of habitat use by black rhinos in Palmwag concession. Palmwag concession was chosen because of the available sufficient black rhino location data.

1.4 Key questions

The study intended to address the following questions:

(a) How do plant diversity, plant richness and composition differ in different conservancies and habitats?

(b) Does browse availability differ among the study sites, between habitat categories across sites between habitats?

(c) Do local scale environmental variables influence browse availability contribution of selected browsed plants?

(d) Do landscape environmental variables (elevation, distance to major rivers, and distance to perennial springs, slope, and distance to drainage, browse availability, aspect and rainfall) significantly differ between the low and high probability habitat use by black rhinos in Palmwag concession.

1.5 Research predictions

a) It is expected that there will be a significant difference in species diversity and richness in different study sites (that vary in altitude and rainfall) as well as across the habitat types (Major rivers, Secondary Rivers and Non-river habitat). ≠Khoadi //Hoas is expected to show an overall high species diversity and richness, because it is located on a higher rainfall range than Torra conservancy. Additionally, major rivers and secondary rivers are likely to have a high species diversity and richness because of the moisture availability along the riverine habitat compared to the non-river habitats.

b) Species composition would differ among the study sites and habitat categories. The reason for the expected difference is because samples from the same study site and same habitat are likely to have similar prevailing climatic and physical conditions.

c) Browse availability will significantly differ among the study sites and between habitat categories. ≠Khoadi //Hoas is likely to show overall higher browse availability than Torra and Palmwag. The significant difference would be attributed to differences in rainfall and location. Riverine habitats will yield higher browse availability than the non-riverine habitats.

d) Local scale environmental variables (slope, elevation and rainfall) are expected to significantly influence browse availability contribution by selected plant species. This is due to the fact that in semi-arid tropics rainfall is one of the major factors that governs plant biomass, herein referred to as browse availability. Furthermore, elevation influences air temperature and precipitation which directly influence plant growth and biomass. Slope is expected to significantly influence browse availability either because of solar radiance, soil moisture and functions of slope. Gentle slopes are likely to result in higher browse availability, because these slopes receive more solar radiation.

e) Distance to major rivers, distance to perennial springs, distance to drainage, rainfall, elevation, slope and aspect will differ significantly between the high and low probability habitat use by rhinos in the Palmwag concession. Black rhinos are expected to use areas that are close to rivers, springs, water drainage/channels and areas of higher rainfall because of water and other resources availability. Black rhinos are expected to utilize areas that receive more solar energy than the shadowy sides, because areas that receive more solar energy are likely to yield more plant biomass.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Background on black rhinoceros

A rhino is a large mammalian herbivore in the Order Perrissodactyla and belongs to the family Rhinocerotidae. There are two species: black rhino (*Diceros bicornis*) and white rhino (*Ceratotherium simum*). Black rhino (*Diceros bicornis*) is derived from a Greek word, *di*- which means two and *ceros* meaning horn (International Rhino Foundation, 2002). Although the rhino is referred to as “Black” it is actually more of grey/white color in appearance. The name of the species was chosen to distinguish it form the white rhinoceros (*Ceratotherium simum*), which imply wide mouth (squared lips) not white. However, the black rhinoceros is much smaller than the white rhinoceros, and has a pointed prehensile upper lip which they use to grasp leaves and twigs when feeding while white rhinoceros have square lips used for grazing. Furthermore, black rhinoceros do not have a distinguished shoulder hump like white rhinoceros. There are four subspecies of black rhinoceros; *Diceros bicornis minor* (Southcentral), *Diceros bicornis bicornis* (Southwestern), *Diceros bicornis michaeli* (East Africa) and *Diceros bicornis longipes* (Western), International Rhino Foundation (2002).

Estes, (1992) reported that an adult black rhinoceros is about 143 – 160 cm high at the shoulder and 2.86 – 3.05 m in body length. An adult weighs from 800 to 1400 kg, with the females being smaller than the males. A single calf weighs about 35 – 50 kg at birth. The horns are made out of keratin and can be up to 132 cm long, with the larger front horn typically 50 cm long; exceptionally up to 140 cm. Horns may also vary in length, depending on the habitat (IUCN, 2006). Horns of the black rhinos in Kunene Region (Namibia) tend to be straighter and the anterior horn commonly grows longer (Hearn, 1999). Skin colour depends more on local soil conditions and their wallowing behaviour than anything else, so rhinoceros from Etosha National Park and from Kunene Region might look slightly different because of the variation of soil conditions. The adults are solitary in nature, coming together only for mating. Rhinos do not have a seasonal pattern of mating but births tend to be towards the end of the rainy season in drier environments (Estes, 1992). The gestation period ranges between 15 – 16 months. The long gestation period stretches critical periods influencing offspring survival across different periods, of the year, so there is no strong selective pressure to favor any particular time for reproduction (Hearn *et al.*, 2000). In Natal (South Africa), it was found that black rhino females normally have an inter-calving period of 30 to 44 months. In an arid climate like Namibia, black rhino females produce a calf every three to four years.

2.2 Distribution of black rhinoceros: historical and current range

Black rhinos were previously widespread in sub-Saharan Africa (International Rhino Foundation, 2002). However, currently they occur in small isolated pockets of sub-Sahara Africa. *Diceros bicornis longipes* (western) was historically found in savannas of central western Africa, but is presently confined to Cameroon.

Diceros bicornis michaeli (eastern) was historically found in Sudan, Ethiopia, and Somalia, through Kenya to north central Tanzania, but is currently mostly found in Kenya. There are a small numbers in Rwanda and Tanzania, and in a game reserve in South Africa, which is well outside its range.

Diceros bicornis bicornis (southwestern) was historically found in Namibia, Southern Angola, Western Botswana, and southwestern part of South Africa. It currently occurs in deserts and arid savannas of Namibia. There are reintroduced populations in South Africa and other parts of Namibia and possibly a few in Angola. A few animals may still exist in Angola (International Rhino Foundation, 2002). There are also healthy growing populations in intensive protection zones in Zimbabwe (Mapaure, 2005).

Diceros bicornis minor (south-central) historically occurred in West and South Tanzania through Zambia, Zimbabwe and Mozambique to North and South East Africa. However it is currently distributed in South Africa and Zimbabwe. There are fewer populations in Swaziland, South Tanzania, and Mozambique. South Africa remains the strong hold of this subspecies, (International Rhino Foundation, 2002).

2.3 Conservation and management

Black rhinoceros have been poached to the brink of extinction due to the demand for their horn (Erb, 1997). The horns are mostly used as a symbol of wealth in many countries and also in Chinese traditional medicine. Human invasion and disturbance also posed a threat to rhino populations. It is estimated that between 1970 and 1992, around 96% of the black rhinoceros population was lost (Uri-khob,2004)

The early decline (1970's and 1980's) in the number of black rhinoceros was attributable mainly to the conversion of suitable habitat for agricultural use (Hearn, 2004). In more recent years the most influential factor in the decline has been poaching for rhino horn for Chinese traditional medicine (International Rhino Foundation, 2002, Hearn, 2004, Uri-khob, 2004).

The decline in black rhinoceros numbers instigated the International Union for the Conservation of Nature (IUCN, 2006) to recommend that black rhinoceros receives a conservation status. Overall, the black rhinoceros is classified as critically endangered. Convention on International Trade in Endangered Species on fauna and flora (CITES) has listed Black rhinos on Appendix 1. The subspecies, Southwestern black (*Diceros bicornis bicornis*) is classified as vulnerable. The western black rhinoceros (*Diceros bicornis longipes*) is classified as critically endangered. However recently in July 2006, the world conservation union declared *D.bicornis longipes* to be tentatively extinct (IUCN, 2006).

The eastern black rhinoceros (*Diceros bicornis michaeli*) is classified as critically endangered; South-central black rhinoceros (*Diceros bicornis minor*) is classified as critically endangered (International Rhino Foundation, 2002).

Several conservation approaches have been adopted resulting in the stabilization and partial recovery of population in a number of countries (IUCN, 2006). The African

Rhino Specialist Group of the IUCN advocates that an active and intensive management policy regarding rhino should supplement the existing conservation measures and in some cases replace them in order to conserve a long-term viable population in natural habitats (Erb, 1997). There are currently approximately 3 610 black rhinos surviving in Africa (International Rhino Foundation, 2002). However, Namibia and South Africa population of black rhino have continued to increase since the 1980's (Uri-Khob, 2004).

2.4 General ecology and habitat preference

Black rhinoceros are known to inhabit a variety of habitats. These habitats range from deserts through wooded grasslands to woodland of *Acacia* savannas (International Rhino Foundation, 2002). The wide variety of habitats in which black rhinos still occur, and the variety of plant species utilized, is a reflection of their adaptability. However, only a small proportion of browse species and biomass available makes up their diet. The highest densities of black rhinos occur in scrub-bush and open woodland habitats (Hearn, 2004).

A study based on current and previous black rhino range in the Kunene Region found that black rhinos occupied twelve vegetation zones, but favored mostly *Euphorbia* basalt foothills and *Euphorbia* basalt plateau habitats (Hearn, 2004). However, they are not found in closed canopy forests. The black rhinoceros is essentially a browser, and the long prehensile upper-lip, almost a small trunk, is designed for browsing. Therefore, the leaves and small roots form its food (Joubert, 1996). According to a study carried out in Kenya (Goddard, 1967) black rhinos have been found to browse on variety of plant species, 191 species from 49 botanical families and are selective for non-woody dicots. Furthermore, the finger *Euphorbia* (*Euphorbia tirucalli*) found in Kenya constituted 25% of a black rhino's diet during the wet season and make up over 70% of the diet during the dry season. In another study (Muya and Oguge, 2000) 34 plant species were identified as potential black rhino browse, whose availability differed significantly. A study in northwest Namibia by Loutit *et al.* (1987) revealed that rhinos browse on a variety of plant species and of the 103 species of plants encountered, 74 were moderately browsed by black rhinos.

2.5 Browse availability

Diceros bicornis is practically a pure browser and mostly prefers leguminous herbs and shrubs (Estes, 1992). Plant materials that are available to black rhinos in the northwest of Namibia include *Acacia robysiana, Colophospermum mopane, Eurphobia damarana, Euphorbia virosa, Petalidium* species among others. Adcock *et al*. (2006) defined a broad scale variables which determine African browse. They argued that browse growth depends on its species composition, competition between plants in thick bush areas, the amount of soil-water available to plants, soil fertility and, temperature conditions that are necessary for nitrogen mineralization and plant growth. Plant available water is determined by rainfall patterns and soil texture. Browse availability can also be impacted upon by competing browser species and fire.

2.6 Namibia's desert –adapted black rhinos

Significant populations of *Diceros bicornis bicornis* have remained in the desert and arid savanna areas of Namibia, which is today the stronghold of this subspecies. In recent years, some populations have been re-established elsewhere in Namibia and in the southwestern part of South Africa. The black rhino population of northwest Namibia is internationally important, because it is the only remaining population in an unfenced area (Smith, 2005). Lands degazetted from National Parks status in 1970 and currently under management of indigenous people now contain one of the few unfenced populations of black rhinoceros (*Diceros bicornis bicornis*) remaining in Africa (Berger, 1997). Historically, the black rhino in Namibia was once widely distributed across this Kunene Region occurring from the Kunene River in the North to the Erongo mountain range in the south (Hearn, 2004). Currently, a high percentage of Namibia's black rhinos reside between Ugab and Hoarusib Rivers (Uri-khob, 2004), in the districts of Brandberg, Khorixas, Sesfontein and Opuwo. Two small groups have been introduced into private land under the custodianship schemes (Erb, 1997).

Following population declines through poaching in the 1970s, the overall numbers of black rhinos in Namibia appeared to stabilize in the late 1980s, and since then the national black rhino population has grown at a rate just over 5% per annum (Hearn *et al*., 2000). There are about 1238 black rhinos in Namibia and a total of 3610 in Africa (Table 1). Namibia has drawn-up a detailed National Conservation Plan for black rhinos, which is reviewed regularly and updated. This conservation plan forms the basis of a short-term action plan. A monitoring programme for black rhino in the area utilizing community game guards was developed in the early 1980s (Erb, 1997). This supplemented the ongoing monitoring, law enforcement activities and extension work by Save the Rhino Trust, government and other NGOs (Erb, 1997).

Table 1: Provisional 2003 continental African Rhinoceros numbers compiled by IUCN SSC African Rhino Specialist Group. *Source: International Rhino Foundation*, www.rhino-irf.org. The question marks (?) in the table were not explained by the source.

Species	**White rhino**				**Black rhino**					
Subspecies	*C.s.cottoni (northern)*	*C.s.simum (southern)*	Total	Trend	*D.b.bicornis (south-western)*	*D.b.longipes (western)*	*D.b.michaeli (eastern)*	*D.b.minor (southern-central)*	Total	Trend
Botswana		67	67	Up+Intro				5	5	Intro
Cameroon						5?			5?	?
DR Congo	10		22	Down						
Ethiopia							4 *D.b.bruceii*?		4	?
Kenya		218	218	Up			439		437	Up
Malawi								8	8	Up+Intro
Mozambique		2	2	?				0?	0	Extinct?
Namibia		186	186	Up	1238				1238	Up
Rwanda							1		1	Down
South Africa		10536	10536	Up*	71		36	1177	1284	Up
Swaziland		61	61	Up				15	15	Up
Tanzania							42	24	66	Up
Zambia		3	3	Down				5	5	Intro
Zimbabwe		250	250	Up				536	536	Up
Totals	10	11320	11330	Up*	1310	5?	520	1770	3610	Up

Table excludes speculative guesstimates
Numbers primarily compiled at (SADC RPRC and WWF funded) IUCN SSC AfRSG Meeting held in Kenya 6-11 June 2004
Numbers of *Diceros bicornis minor* in Tanzania, *Diceros bicornis bicornis* in Namibia, *D.b.michaeli* in Kenya, *Diceros bicornis longipes* in Cameroon and *C.cottoni* in DRC may be higher but this requires confirmation.
White rhino trend is up but total numbers down 2.5% compared to 2001 due to estimate for largest population of southern white rhino (Kruger NP) declining substantially due to using more conservative figure for 2003 than 2001, and possibly in part due to sampling error (95% conf. levels around the 2003 estimate = ±23.3%).
S.African total = 2003 figures used for State and Defence force areas and 2002 figures for Private, Municipal, Zoo & Biosphere reserves
The South African southern white rhino total using only 2002 figures was 10,306 (quoted in earlier country totals).
The numbers of southern white rhinos outside Kruger has increased by 809 (+13.5%) over the last 2 years and there is no evidence of an actual decline in Kruger.
Subspecies totals >500 rounded to nearest 10 rhino.
Exact Swaziland numbers of *Diceros bicornis minor* given to AfRSG but are being kept confidential until authority is obtain to release them. In the meantime the table shows an approximation to the true number.
Poaching continues in Garamba National Park, Republic of Congo and the latest estimate as of September 2004 is only 15.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Study area

Namibia is one of the driest countries south of the Sahara. Namibia has an area of 824 000 km^2 and a population of 1.8 million people, making it sparsely populated (Seely, 2005). Namibia is located between two climate systems, the intertropical convergence zone, which feeds in moist air from the north, and the subtropical high-pressure zone, which pushes the moist air away. Most rain falls during sporadic storms in the summer months from September to February and total annual rainfall varies greatly from year to year (Mendelsohn *et al.* 2002).

The moist and tropical areas in the northeast have the greatest overall number of species, most species endemic to Namibia occur in more arid areas in and around the escarpment and on isolated highlands. A defined east-west rainfall gradient influences flora, fauna and the livelihoods of some Namibian people. The majority of people are directly dependent on natural resources obtained from the land, and more land is used for Agriculture than for any other purpose (Mendelsohn *et al.*, 2002).

This study was carried out in the Kunene Region, northwest Namibia (Figure 1). The Region is one of the 13 political regions of Namibia. The Kunene Region is about 144 255 km^2 and has a current estimated human population of 63 000 and it is projected to decrease to 61 600 by 2010. The low population and the large area give a low average population density of 0.55 persons per km^2 (Kunene Regional Council, 2005).Tourism, agriculture, mining, and trade and industry are the major economic sectors in the Kunene Region, with tourism being identified as a key sector development for the Kunene Region.

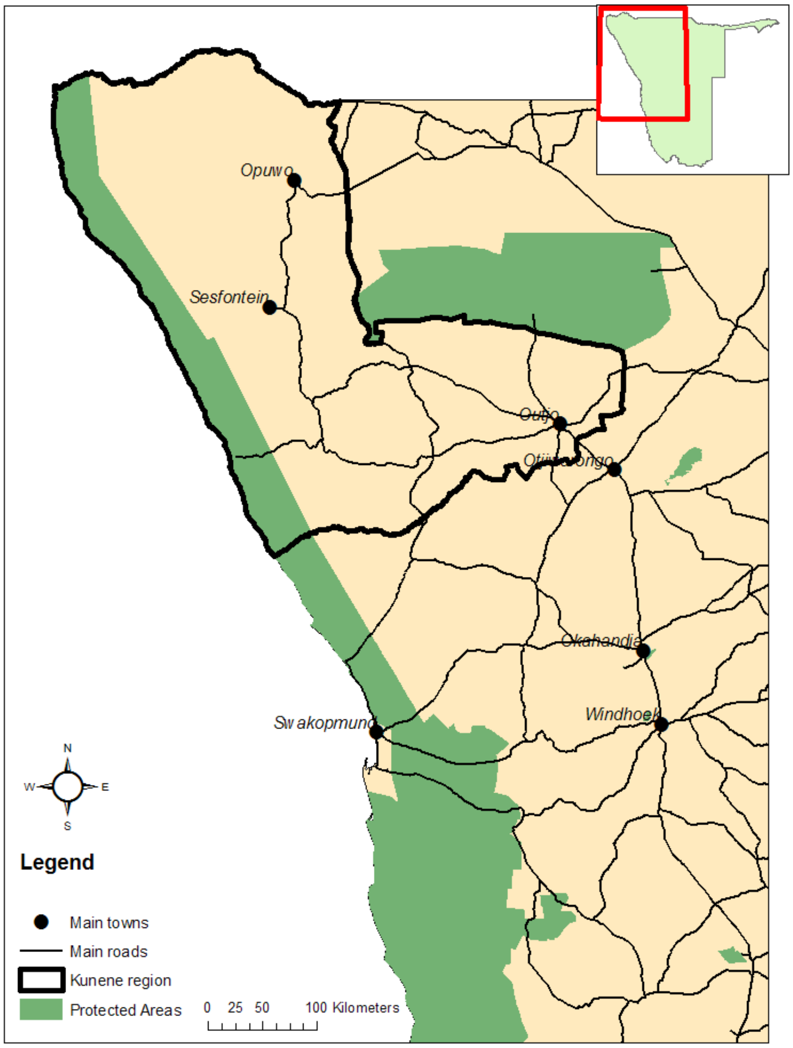

Figure 1: Map of Namibia showing the location and extent of Kunene Region, northwest Namibia.

3.2 Climate

There are three distinctive seasons in northwest Namibia, functionally and broadly defined as: wet season (January – May); cold dry season (June – September); and hot dry season (October – December) (Leggett, 2006). The western part is characterized by cool, dry air that originates from the coast. This results in low rainfall that occurs during the months of December to March. Rainfall increases from the coast to inland (i.e. west to east). In the arid northwest, rainfall is spatially and temporally variable. Seasonal rainfall is highly variable and the average values do not necessarily serve as a good indicator of the amount of rainfall than can be expected in any given season (Leggett *et al.*, 2003). Average rainfall of 125 mm and 500 mm has been recorded in the Uniab and Ugab catchments, respectively. Moreover, the rainfall pattern is highly variable; for example, the mean annual rainfall in Khorixas fluctuated between 22 and 500 mm over a period of 37 years (Jacobson *et al.*, 1995). Average annual rainfall recorded at Etendeka Mountain Camp, Kunene Region, Namibia from 1992 - 2005 ranged between 40 – 290 mm over these fourteen years (Save the Rhino Trust, 2005). The 2005/6-rainfall season was exceptional and some local communities observed some of the water springs flowing and most of the springs have not flowed in years. Despite the unpredictable and low rainfall, the ephemeral rivers of northwest Namibia and their associated springs, wetlands and vegetation form linear oases for wildlife and people in this arid ecosystem

3.3 Geomorphology

The area is mostly mountainous with a few plains covered with groups of rocks known as the Damara sequence, which was formed approximately 850 – 500 million years ago. The most distinctive topographical features of the area are the flat-topped mountains, the Etendekas (Save the Rhino Trust, 2005). They were formed from massive flooding of the molten lava out of major volcanic centers, leading to the formation of basalt plateau approximately 130 million years ago (Grunert, 2000).

3.4 Flora and fauna

The region falls in one of three floristic regions of Namibia, namely the Karoo-Namib regional centre of endemism (Hearn, 2004). A vegetation gradient from east to west in Kaokoland which corresponds with east-west rainfall gradient, with mixed *Colophospermum mopane* vegetation type dominates the area that corresponds to the 100 – 350 mm rainfall zone (Leggett *et al.*, 2003).

There is a highly diverse faunal life in the Kunene Region and these include *Galarella nigrita, Xerus princes, Equus burchell* (plains Zebra), *Petromycus collinus, Petromus typicus, Gerbillurus setzeri, Elephantulus intufi, Giraffa camelopardis, Oreotragus oreotragus, Equus burchelli, Equus zebra hartmannae* (mountain zebra), *Diceros bicornis* and *Loxodonta africana* (Save the Rhino Trust, 2005).

3.5 Specific study sites

Three sites were selected within the Kunene Region: Palmwag concession, ≠Koadi //Hoas conservancy and Torra conservancy (Figure 2). These areas were selected on the basis that Palmwag concession and Torra conservancy contain at least 90% of black rhinoceros in the northwest of Namibia, while ≠Koadi //Hoas is earmarked as a black rhino re-introduction site, with a re-introduction trial already started (Du Preez, 2006).

Palmwag concession (S 19.75506, E 13.83314) is a privately managed land, leased by Palmwag Pty (Ltd) from the government and covers 450 000 hectares of land. The area is managed exclusively for non-consumptive tourism. Within the concession there is an established lodge, two tented camps and about four to five Save the Rhino Trust (SRT) base camps. Palmwag concession borders with Sesfontein conservancy to the north, Etendeka concession to the east, Skeleton Coast National Park to the west and Torra conservancy to the south. The concession is cut off from Torra conservancy by a veterinary fence, which was aimed at controlling livestock diseases in the past. Palmwag concession is situated on the *Euphorbia* basalt foothills, plateaus and gravel plains habitats (Hearn, 2004).

Torra conservancy (S 19.97451, E 13.99973) is about 352 000 hectares and is adjacent to the Skeleton Coast Park. The conservancy houses 1200 people, of whom 450 are registered members of the conservancy (Namibian Association of CBNRM Support Organizations, (NACSO) 2004). The area is managed for consumptive, non-consumptive tourism and livestock husbandry. There are several human settlements within the conservancy and an administrative settlement. Torra was one of the first conservancies to be registered in 1998 in Namibia (NACSO, 2004). The area is characterized by *Euphorbia* basalt foothills and gravel plains (Hearn, 2004).

≠Khoadi //Hoas (S 19.87721, E 14.42211) conservancy covers 350 000 hectares and is managed for non-consumptive tourism, consumptive tourism and livestock husbandry. This conservancy has also adopted an integrated approach to natural resource management, bringing together livestock, wildlife and tourism into one management system. The conservancy is zoned into four main areas: tourism concession area, agriculture and multiple–use area and exclusive wildlife area (NACSO, 2004). The conservancy is characterized by the rocky hills and part of the conservancy falls in the dolomite escarpment.

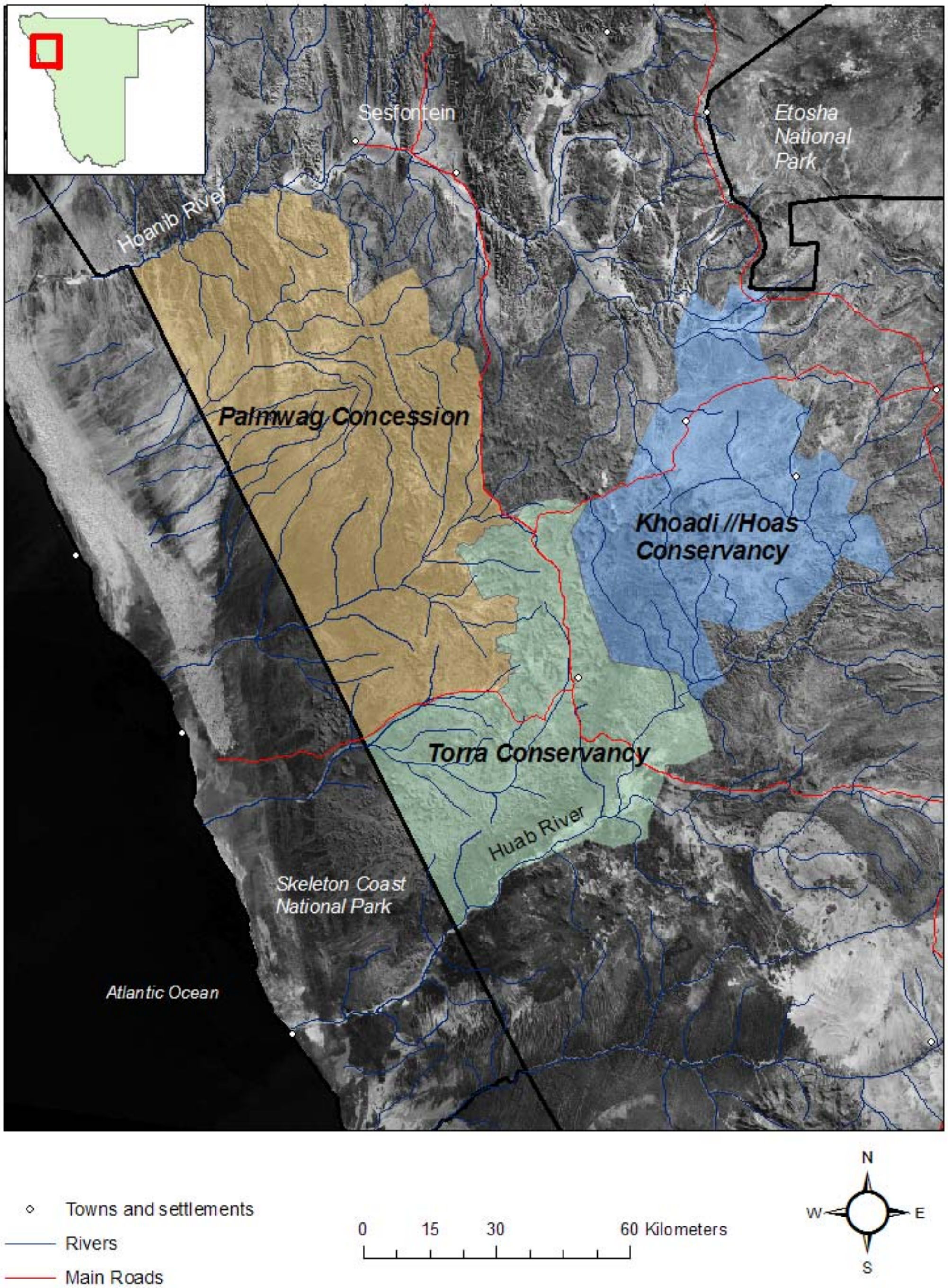

Figure 2: Location of three study sites Torra conservancy, ≠Khoadi //Hoas conservancy and Palmwag concession.

3.6 Sampling design and plot demarcation

The area was stratified into distinctive habitats that were identified within the study areas: Major Rivers (MR), secondary rivers (SR) and Non-river habitats (NR). The major rivers included the rivers that have bigger catchments and some flow into the ocean. Secondary Rivers included all the small channels that dissect the landscape; whereas the Non-River habitat refers to the mountains, gravel plains and all other land features that do not fall within the river channels.

Time constraints and the area's rugged terrain and inaccessibility warranted establishing a sampling regime that was limited to road/routes access. Arcview GIS (version 3.2, ESRI,) was used to create 2 kilometer buffers around all tracks within the study sites. A random point generating script was then used to establish 25 random points within these buffers as non-river sample plots (Appendices 1, 2 and 3). The major and secondary rivers that intersected the routes were also identified using Arcview. Five secondary drainage and five major rivers were randomly selected for sampling in each conservancy. Four vegetation plots were sampled along one river channel, two upstream and two downstream, from channel intersection with the survey routes. The plots in all river habitats were demarcated at the edge of the channel.

Each plot was circular with 20 m diameter and an area of 314 m^2. Circular plots were used because they have a smaller edge to area ratio than either rectangular or square plots of the same size. Hence, relatively fewer plants would occur along the edges of a circular plot than along the edges of other plot shapes. Therefore, the potential errors in judging whether a plant was within or outside the plot were reduced in circular plots (Rudran, 2004).

3.7 Data collection

3.7.1 Plant inventories

Plant composition was determined by identifying the different species present in each plot. The plants were identified by the use of plants field guide books (nomenclature follows Graven and Marais, 1986; Graven and Marais, 1992; Burke, 2003; Burke, 2005; Curtis and Mannheimer, 2005; Burke, 2007). Only dicotyledonous plants were recorded because black rhinos are essentially browsers. The numbers of individual plants per species present in each plot were counted. Plants that could not be identified in the field were collected, pressed and sent to the herbarium for further identification and verification. All plant data were entered in data sheet form (Appendix 4).

3.7.2 Measurement of browse availability

Browse availability was obtained by measuring the canopy diameter and canopy depth. The canopy diameter (D1) for every plant species in the plot was measured using a measuring pole or tape and diameter (D2) was then measured perpendicular to D1, which was then summed and divided by two to give average canopy diameter. The canopy depth was obtained by measuring the plants vertical fill of 0 – 2 m. The canopy depth was limited to 2 m because black rhinos generally browse up to 2 m, anything above 2 m is unavailable, unless the plants are bent or pushed down (Adcock *et al.*, 2006).

Browse availability in percentage of selected plants in relation to local scale/plot scale environmental variables for selected plant species were put together. The names of selected species are listed on Appendix 5. The plant species were selected because they are known to be the most preferred by black rhinos (Hearn *et al.*, 2000). Plot scale elevation estimates were obtained from GPS II Garmin, whereas slope was determined by sighting down or along a slope with compass-clinometers. The habitat types were Major Rivers, Secondary Rivers and Non-Rivers as per plot scale sampling regime. Average annual rainfall was obtained from the Namibian Atlas database (Mendelsohn *et al.*, 2002). The location of each individual plot was matched with the corresponding rainfall range.

3.7.3 Black rhino habitat use level in relation to landscape variable

Save the Rhino Trust has accumulated over 15 years of point location data for male and female individually-identified black rhinos in the Kunene Region. Regular vehicle and foot patrols visit known rhino ranges approximately once per month to locate each rhino in the area using GPS technology. In more inaccessible ranges, camel patrols are employed to obtain individual rhino location points.

Using location data from 2003 – 2005, 20 random points for selected six female rhinos were pooled to minimize temporal change in habitat and used to define suitable or high probability use areas. All other rhinos that had less than 20 location data were disregarded in order to minimize bias. Breeding females were chosen to highlight characterizing optimal breeding areas for habitat use assessment. Using these point location data from Save the Rhino Trust's database, 95% fixed width probability kernels (FWPK) for six female black rhinos from 2003 – 2005 within the Palmwag concession were calculated using the animal movement extension in Arcview 3.2. A 95% probability kernel takes the smallest area that contains 95% of these location points (Bailey and Anthony, 1995). A 95% FWPK was chosen as opposed to Minimum Convex Polygon (MCP) and location points/presence, because a kernel explains the probability and has a good assumption that there is a high probability of a certain area being used. Furthermore, the kernels were considered to lessen bias that may have accrued due to *ad hoc* rhino locating methods. The 95% FWPKs allowed spatially explicit categorization of sites into either high probability use level for habitat use (within 95% FWPKs) or low probability use level (outside 95% FWPKs).

3.7.4 Determination of landscape variables

Elevation, slope and aspect were obtained from an existing Digital Elevation Model (DEM) for the whole Kunene Region (Shuttle Radar Topography Mission, 2005). The DEM was then clipped to fit the area of interest, Palmwag concession, using a spatial analysis tool in Arcview. Location of major rivers, perennial springs and drainage was obtained from existing GIS database for Palmwag concession. Distances to major rivers, perennial springs and drainage to the high/low habitat use were based on the mean distance (± SE) of the pixels which was achieved by the use of distance analysis tool in Arcview.

Browse availability in Palmwag was extrapolated from plot-scale assessment and applied to two habitat categories; rivers and non-river habitats. The secondary river and major rivers were combined, because it was difficult to differentiate the secondary drainages from the main rivers from the DEM. Average annual rainfall based on two categories; 0-100 mm and 100 -200mm was obtained from National database (Ministry of Environment and Tourism, 2006) and clipped to Palmwag concession.

3.8 Data manipulation and analyses

3.8.1 Species diversity and richness

Analysis of species diversity and richness was obtained by using the Shannon-Weiner index in Species Diversity and Richness, Pisces Conservation Software, (2002). Species diversity index values were tested for significant differences using t-test (two-sample, assuming unequal variances), while species richness was tested for significance using Z-test (among study sites) and Kruskal-Wallis test (among habitats).

Shannon Weiner Index is denoted as $H' = -\sum_{i=1}^{s} (p_i)(\ln_2 p_i)$ where:

H' = Information content of sample, which is the index of species diversity, s is the number of species and p_i is the proportion of total sample belonging to the *ith* species. Shannon-Wiener index approaches the measure of species diversity through information theory and should be used on random samples drawn from a large community in which the total numbers of plants are known (Krebs, 1994). Only Torra and ≠ Khoadi //Hoas conservancy were included in the analysis for species diversity (Appendix 6 and 7), because there was no detailed information recorded in Palmwag concession.

3.8.2 Comparison of species composition

Hierarchical Cluster Analysis (HCA) using average linkage (Mapaure, 2001) was performed on a matrix of 133 plots with 140 plant species, using species presence and absence data. This was done to produce a classification identifying similarities amongst plots based on species composition. This analysis was achieved by the use of Community Analysis Package (CAP) 2.04 Pisces Conservation Software (2002).

3.8.3 Browse availability

The measured average canopy diameter and average canopy depth were then calculated to give proportional canopy cover and proportional vertical fill that eventually gives browse availability. Browse availability per species was calculated from an existing formula. Browse availability as a percentage is depicted as proportional vertical fill x proportional canopy cover. Proportional vertical fill = Average canopy depth/2, whereas proportional canopy cover is = ((PI (area of the plot)*(average canopy diamter/2) ^{2})*number of plants)/area of the plot, (Adcock *et al.*, 2006). Proportional vertical fill is the average canopy depth divided by two; two refers to the 2-meter browse line limit. Proportional canopy cover was estimated from the reference table adopted from the report on visual assessment (Adcock *et al.*, 2006). The summed up browse availability per plant species then gives total browse availability per plot. Browse availability data per plot (see Appendix 8) were analyzed using SPSS version 10.0 Software (SPSS Inc., Chicago, USA). Kolmogorov-Smirnov tests revealed that browse availability data were not normally distributed, thus a non-parametric test was deemed necessary. Browse availability was compared between the study sites (overall) and between habitat categories using Kruskal-Wallis test and a *post hoc* test – Mann-Whitney test was used to determine where the significant differences were.

3.8.4 Influence of environmental variables on browse availability of selected plant species

Canonical Correspondence Analysis (CCA) was used to investigate the relationship between browse availability of selected browse plant species and environmental variables using the program CANOCO, version 4 for Windows package. CCA is a direct gradient analysis technique, where the axes interpretation is done within the ordination algorithm using a set of supplied environmental variables (Kremen, 1992; Mapaure, 2001). The explanatory variable data set consisted of three variables namely; (a) slope (degrees), (b) elevation (m) and (c) average annual rainfall (mm) categorized as 1, 2, 3, 4, 5, 6 and 7 (300 – 350, 250 – 300, 200 – 250, 150 – 200, 100 – 150, 50 – 100 and < 50 mm, respectively). The dependent variable or species data set included the browse availability contribution by selected plant species. Forward selection (all default settings used) for each environmental variable was performed using Monte Carlo permutation test. The permutation test determines which variables significantly influence the variation of browse availability contribution of selected plant species in selected study sites. The overall first canonical axis and all environmental canonical axes were tested for significance using the Monte Carlo permutation test.

3.8.5 Influence of environmental variables on the probability of habitat use by black rhino: Landscape scale

Using only the Palmwag concession sites, independent variables (elevation, distance to major rivers, distance to perennial rivers, and distance to drainage, slope, browse availability, aspect and average annual rainfall) were packed on a GIS raster format. Arc Info was used to create a table linking all low probability and high probability use areas by black rhinos with the eight independent variables. Two hundred random sites were then chosen from each probability use category for analysis in SPSS version 10.0 software.

All the independent variables were tested for normality using Kolmogorov-Smirnov test, which revealed that the data were not normally distributed, thus non-parametric statistics were deemed necessary. Mann-Whitney U test was employed to test whether elevation, distance to major rivers, distance to perennial rivers, slope and plot-scale browse availability were significantly different between the two probability use areas in Palmwag concession. Furthermore, Pearson Chi-square test was employed to test whether aspect and average annual rainfall significantly differed between the two use levels.

CHAPTER 4

4. RESULTS

4.1 Species diversity and richness

Species diversity significantly differed between Torra and ≠Khoadi //Hoas conservancy, ($t = 3$, $df = 120$, $p < 0.001$). Torra conservancy was more species diverse than ≠Khoadi //Hoas conservancy. Torra conservancy had a mean diversity of 1.22 (±0.12 SE), while ≠Khoadi //Hoas conservancy had a mean 0.90 (± 0.10 SE). Furthermore, species diversity significantly differed between Torra and ≠Khoadi //Hoas secondary river habitats, ($t=2.373$, $df= 36$, $p <0.05$), Torra and ≠Khoadi //Hoas non-river habitats ($t= 4.180$, $df= 48$, $p<0.001$), but not significantly different between Torra and ≠Khoadi //Hoas major river habitats ($t= 1.369$, $df=14$, $p > 0.05$). Secondary river and non-river habitats in Torra conservancy were more diverse than secondary and non-river habitats in ≠Khoadi //Hoas.

Similarly, species richness significantly differed among the study sites ($Z = -5.439$, $p < 0.05$). Furthermore, species richness was significantly different among habitat types in Torra and ≠Khoadi //Hoas conservancies ($H = 8.470$, $p < 0.05$). In ≠Khoadi //Hoas conservancy, secondary rivers exhibited the highest mean species richness of 5.45 (± 0.43 SE), while Non-River habitats showed the lowest mean species richness of 5.05 ± (0.49) (Table 2). In Torra conservancy, Non-River habitats had the highest mean species richness of 9.09 (± 0.68 SE) and the Major Rivers the least mean species richness of 5.25 (± 0.79 SE) (Table 2). Overall Torra conservancy had a mean species richness of 7.76 (± 0.62 SE) per plot, while ≠Khoadi //Hoas had a mean of about 5.31 (± 0.53 SE).

Table 2: Mean species diversity (H´) and mean number of species (±SE) in different habitat categories within ≠Khoadi //Hoas and Torra Conservancy. The codes are KMR (≠Khoadi //Hoas Major Rivers), KSR (≠Khoadi //Hoas Secondary Rivers), KNR (≠ Khoadi //Hoas Non-River), TMR (Torra Major River), TSR (Torra Secondary River) and TNR (Torra Non-River).

Habitat type	**Species diversity (H') ± SE**	**Number of species (±SE)**
KMR (N=12)	0.98 ± 0.13	5.42 ± 0.66
KSR (N=20)	0.99 ± 0.11	5.45 ± 0.43
KNR (N=20)	0. 73 ± 0.08	5.05 ± 0.49
TMR (N=8)	0.67 ± 0.19	5.25 ± 0.80
TSR (N=41)	1.25 ± 0.07	8.93 ± 0.39
TNR (N=34)	1.28 ± 0.11	9.09 ± 0.68

4.2 Species composition

Hierarchical Cluster Analysis separated the vegetation into five main groups (Figure 3). The cluster shows that plots from the same habitat as well as plots from the same study sites were clustered together.

Cluster 1: This group consisted of vegetation sampled in ≠Khoadi //Hoas conservancy, of which 53% is from Non-river habitats and the remaining were secondary and major rivers. The frequent tree layer consisted of *Acacia robysiana, Colophospermum mopane, Combretum apiculatum, Terminalia prunioides* and *Catophractes alexandri*, whereas the forb layer consisted of annuals such as *Crotalaria cf. colorata, Monsonia umbellata* and *Heliotropium ovalifolium.*

Cluster 2: This cluster consisted entirely of vegetation sampled in Torra Major Rivers and Non-Rivers habitats. This group consisted of annual forbs and perennial shrubs. The most frequent annual forbs includes *Tribulus zeyheri, Sesamum triphyllum, Sesbania pachycarpa, Indigofera schimperi, Indigofera teixeirae, Herminia amabilis, Cleome foliosa*, *Blepharis pruinosa* and *Blepharis gigantea* as well as the ground mat like plant *Zygophyllum simplex.* The most frequent perennial shrubs were *Calicorema. capitata*, *Tamarix usneoides* and *Petalidium variable.*

Cluster3: This group consisted of vegetation sampled in ≠Khoadi //Hoas and Torra conservancy. The most frequent layers in this cluster were a mixture of tree species, annual forbs and perennial shrubs. The tree species that occurred frequently in this cluster included *C. alexandri,* and *C. mopane,* while the annual forbs included

Crotalaria colorata, Monechma cleomoides, Monsonia umbellata, Tephrosia species, with *Petalidium variable* being the most frequent perennial shrub.

Cluster 4: This cluster consisted of vegetation plots sampled in Torra conservancy, 77% of which are all from the Secondary Rivers habitat, while 23% of the group consisted of the vegetation sampled in ≠Khoadi //Hoas. The vegetation layer consisted mainly of annual forbs such as *Amarathus praetermissus, Blepharis pruinosa, Blepharis gigantea, Chamaesyce glanduligera, Cleome foliosa, Indigofera schemperi* and *Indigofera teixeirae,* while *C. mopane* was the most frequent tree.

Cluster 5: This cluster consisted mainly of plots sampled in Torra conservancy. About 92% (both from secondary and Non-river habitats) were from Torra conservancy, while 8% of the samples were from ≠Khoadi //Hoas. The cluster consisted of a mixture of vegetation, mainly annual forbs and shrubs *Cataphractes alexandri*, *Commiphora saxicola*, *Commiphora namaensis* and *Commiphora tenuipetiolata* were the commonest shrubs. *Welwitchia mirabilis* and *Euphorbia damarana* also occurred in this cluster. However these later species were absent in plots sampled in ≠Khoadi //Hoas conservancy.

Preliminary HCA revealed an outlier (TNR 7= Torra Non-River 7). This plot did not show big variation in terms of vegetation composition when compared to the other cluster groups and was considered an outlier. However this plot had the forb *Montinia caryophylace* which was absent in other clusters. The results presented in

Figure 3 are based on the Hierarchical Cluster Analysis without the outlier (TNR 7 = Torra Non-River 7).

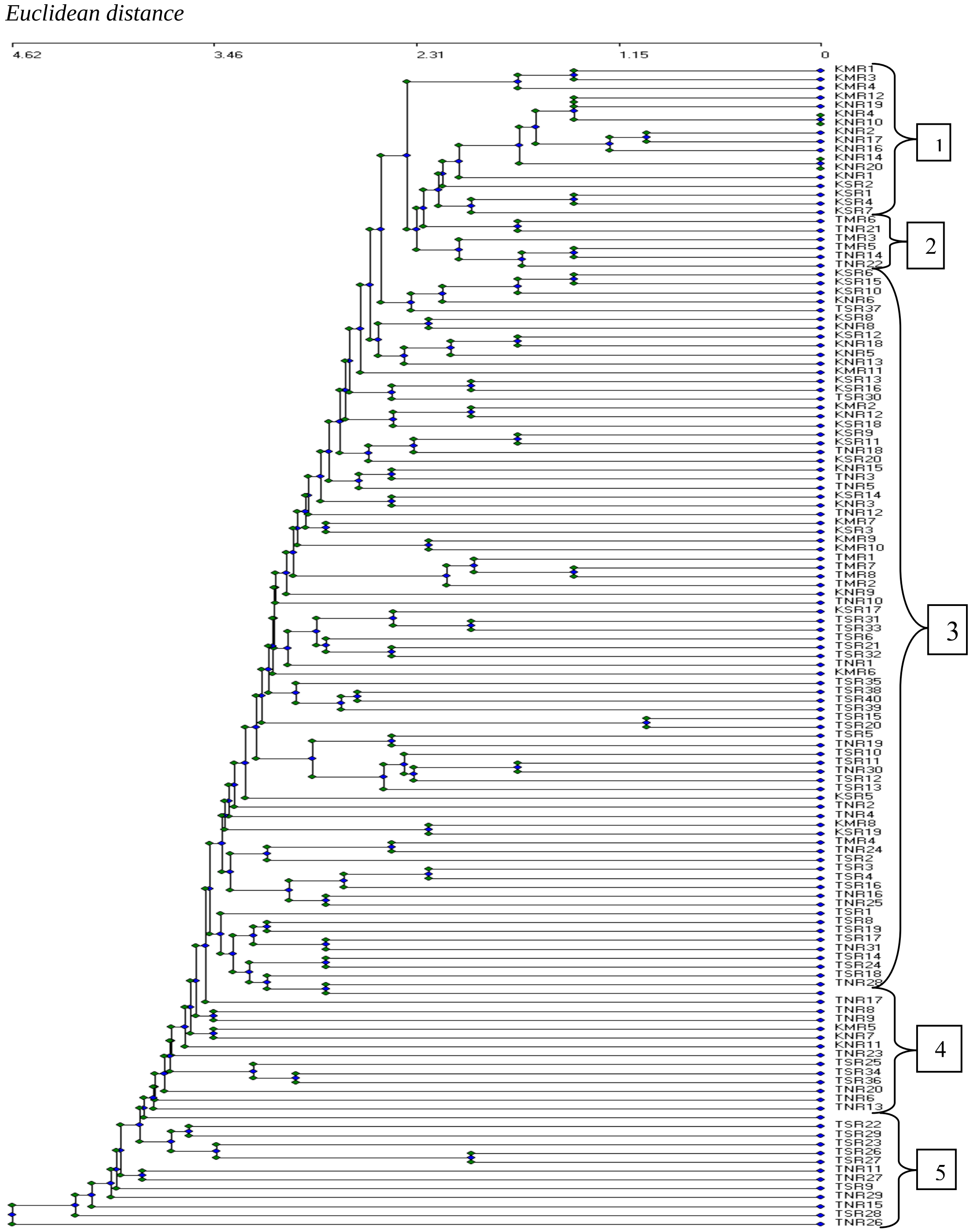

Figure 3: Hierarchical cluster analysis (HCA) dendrogram showing a classification of vegetation plots in Khoadi Hoas and Torra conservancy based on species absence and presence. The codes, KMR represents ≠Koadi //Hoas major rivers, KSR; ≠Khoadi //Hoas Secondary Rivers and KNR; ≠Khoadi //Hoas Non-Rivers. TMR; Torra Major Rivers, TSR; Torra Secondary Rivers and TNR; Torra Non-River habitats. The number next to the cluster is the plot ID or number.

4.3 Browse availability

Overall, browse availability was significantly different among study sites (H = 31.939, df = 2, p < 0.001). ≠Khoadi //Hoas showed a higher mean browse availability of 11 %, while Torra exhibited a lower BA of about 2.8% (Figure 4).

Furthermore, *post hoc* analysis revealed that browse availability did not differ significantly among Torra and Palmwag concession (Z= -1.274, p= 0.203).

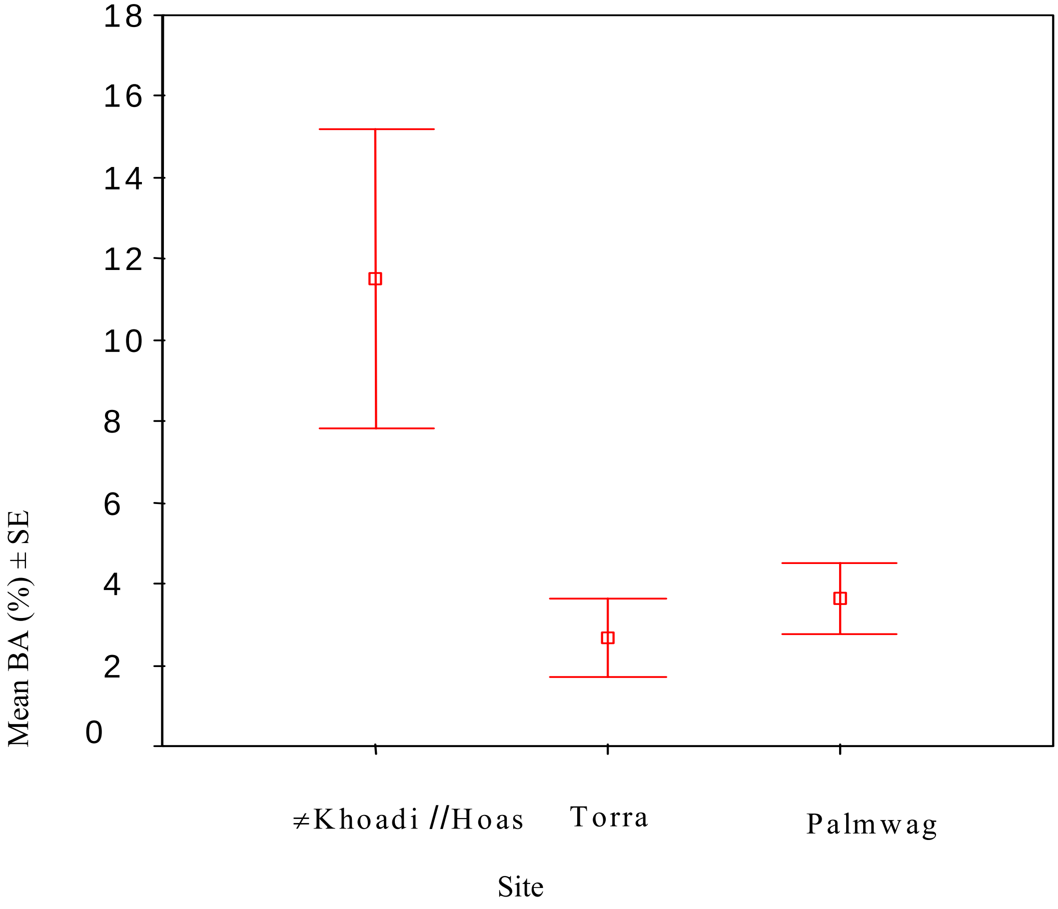

Figure 4: Comparison of mean browse availability (± SE) among different study sites.

Browse availability was significantly different among habitat categories in Palmwag (H = 28. 29, df = 2, p = 0.000) and Torra conservancy (H = 6.89, df = 2, p = 0.032), but not significantly different in ≠Khoadi //Hoas conservancy (H = 1.98, df = 2, p = 0.371). The secondary rivers in Torra conservancy exhibited the highest mean browse availability of 3.5% (± 0.92 SE), while the major rivers exhibited the lowest mean browse availability of 0.7% (± 0.28 SE) as shown by Figure 5.

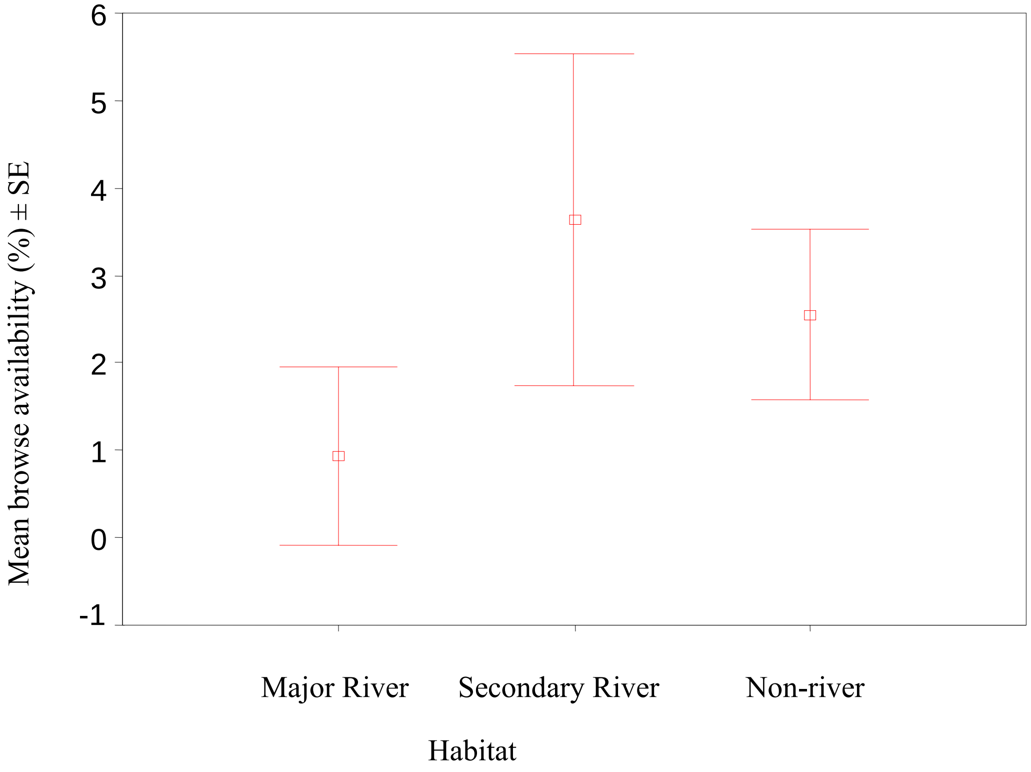

Figure 5: Comparison of mean browse availability (± SE) among habitats in Torra conservancy.

In Palmwag concession, major rivers exhibited the highest mean browse availability of 4.90% (± 1.28 SE), while the Non-river habitat exhibited the lowest mean of 1.22 % (± 3.41 SE) as shown in Figure 6.

However, *post hoc* analysis further revealed that in Palmwag concession that there was no significant difference in browse availability among major rivers and secondary rivers (Z = -0.941, p = 0.347).

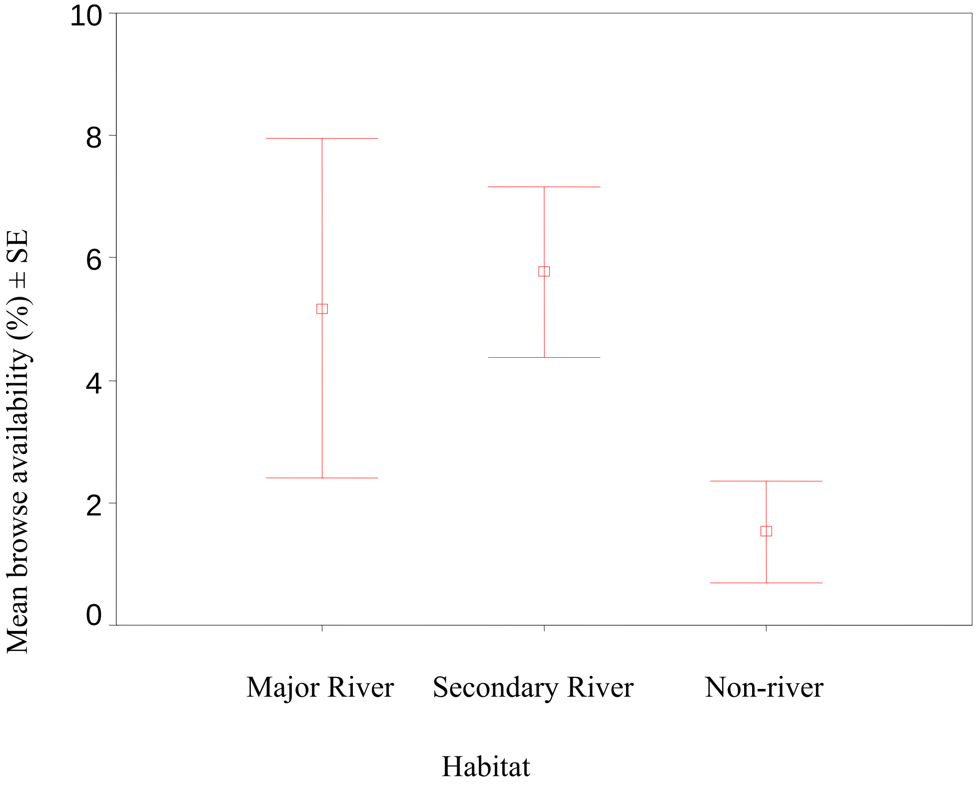

Figure 6: Comparison of mean browse availability (± SE) among different habitats in Palmwag concession.

In ≠Koadi //Hoas, the major rivers exhibited the highest mean browse availability of 15.47% (± 5.45 1 SE), while the secondary rivers demonstrated the lowest mean browse availability of 8.83% (± 2.6 1 SE), Figure 7

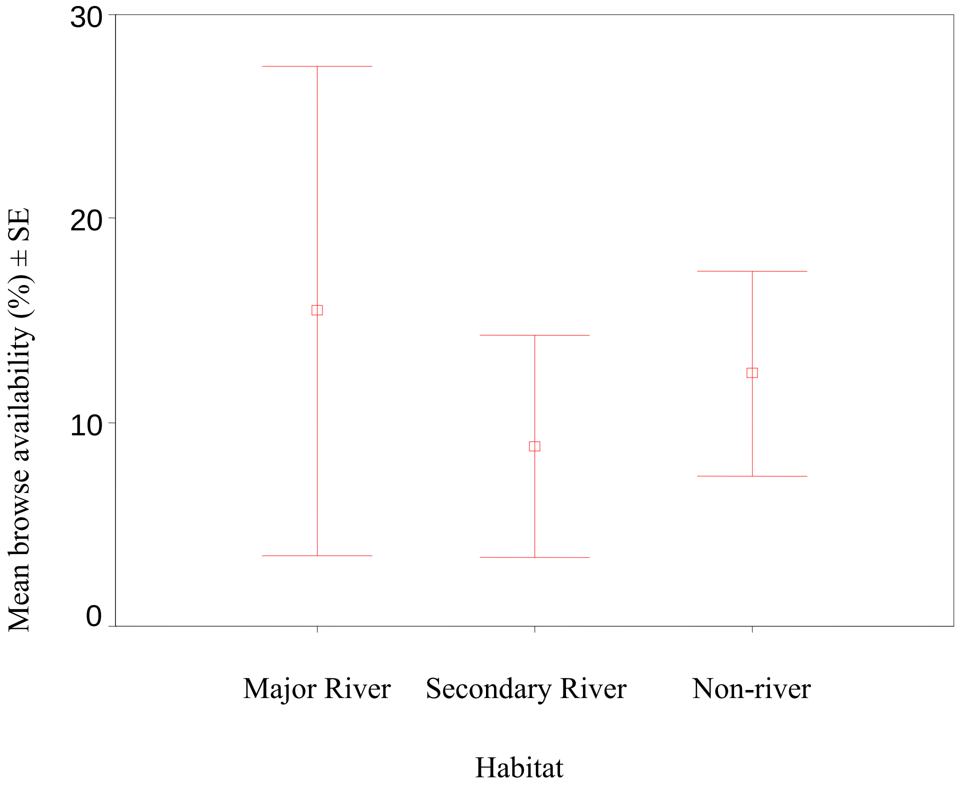

Figure 7: Comparison of mean browse availability (± SE) among different habitats in ≠Khoadi //Hoas conservancy.

Browse availability for each habitat type differed significantly across the three sites. Major Rivers (H = 13.370, df = 2, p= 0.001); Secondary Rivers (H = 8.204, df = 2, p = 0.017) and Non-River (H = 28.258, df = 2, p = 0.001). The Major Rivers in ≠Khoadi //Hoas showed the highest mean browse availability of 15.47% (± 5.45 SE), while the major rivers in Torra showed the lowest browse availability of 0.7% (± 0.28 SE). Secondary rivers in ≠Khoadi //Hoas again showed the highest mean browse availability of 8.83% (± 2.60 1 SE) while secondary rivers in Torra showed mean browse availability of 3.5 %(± 0.92 SE). In the case of the Non-River habitat, ≠Khoadi //Hoas revealed the highest mean browse of 11.77% (± 2.36 SE), while Palmwag concession showed the lowest mean browse availability of 1.22% (± 0.34 SE), Figure 8.

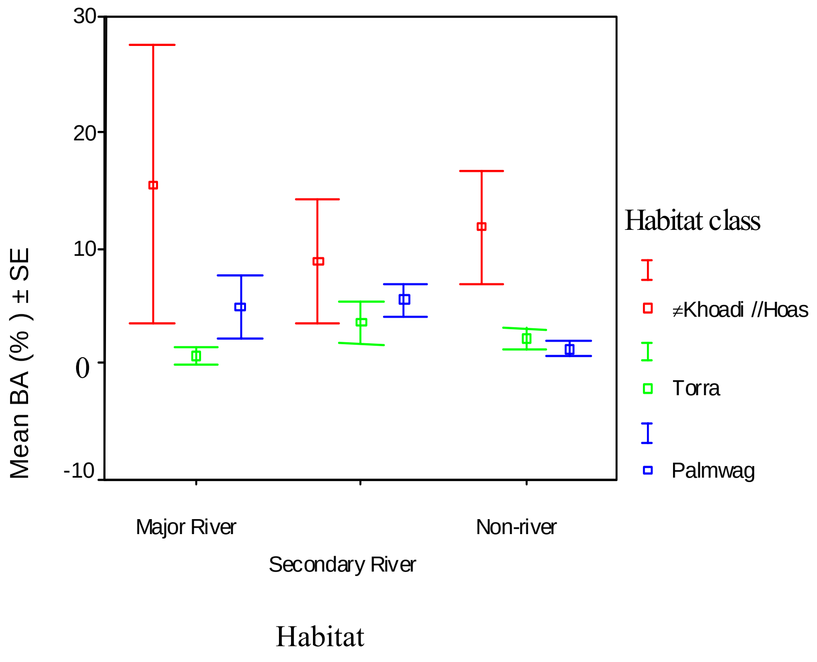

Figure 8: Comparison of browse availability (± SE) among different habitat types across the study sites.

4.4 Browse availability of selected plant species

The explanatory variables which significantly influenced browse availability of selected plants species were rainfall (F = 4.22, $p< 0.05$) and elevation (F = 4.21, $p<0.05$). The influence of slope was insignificant (F=1.93, $p>0.05$). The relative importance of each gradient seems to vary along axes. The variation in species data accounted for along axis 1 was 5.6%, axis 2 was 10.4 and axis 3 was 22.4. The eigenvalue for the first axis was fairly high, implying that the first axis represented a fairly strong influence on browse availability of selected plants, while axis 2 is intermediate and axis 3 is much weaker. The sum of all eigenvalues was 7.77, which is quite high and implies that the environmental data explain a large amount of variance in the browse availability data. The strength of environmental influence on browse availability was further emphasized by high species-environmental coefficients associated with each axis (Table 3).

Table 3: Correlations between axes and environment variables, and percentage variances of species and species-environmental relationship derived from CCA.

Canonical axis	Eigen values	Species-environment correlations	Cumulative % variance of species environment relations	Cumulative % variance of species data
1	0.435	0.682	53.6	5.6
2	0.273	0.347	100	10.4
3	0.082	0.000	0.00	22.4

The positioning of the environmental variables in Figure 9 shows that the explainable variation of browse availability of selected plants along the first axis was negatively correlated with elevation. The second axis was positively correlated with rainfall and negatively correlated with elevation.

Direction and influence of elevation indicated that elevation influence on browse availability of selected plants was more important in plots from ≠Khoadi //Hoas conservancy, while the direction and influence of rainfall influence of browse availability was more important in Torra conservancy and Palmwag concession. Overall, the results indicate that browse availability of selected plants in Torra conservancy, Palmwag concession and Khoadi //Hoas conservancy was largely influenced by elevation and rainfall.

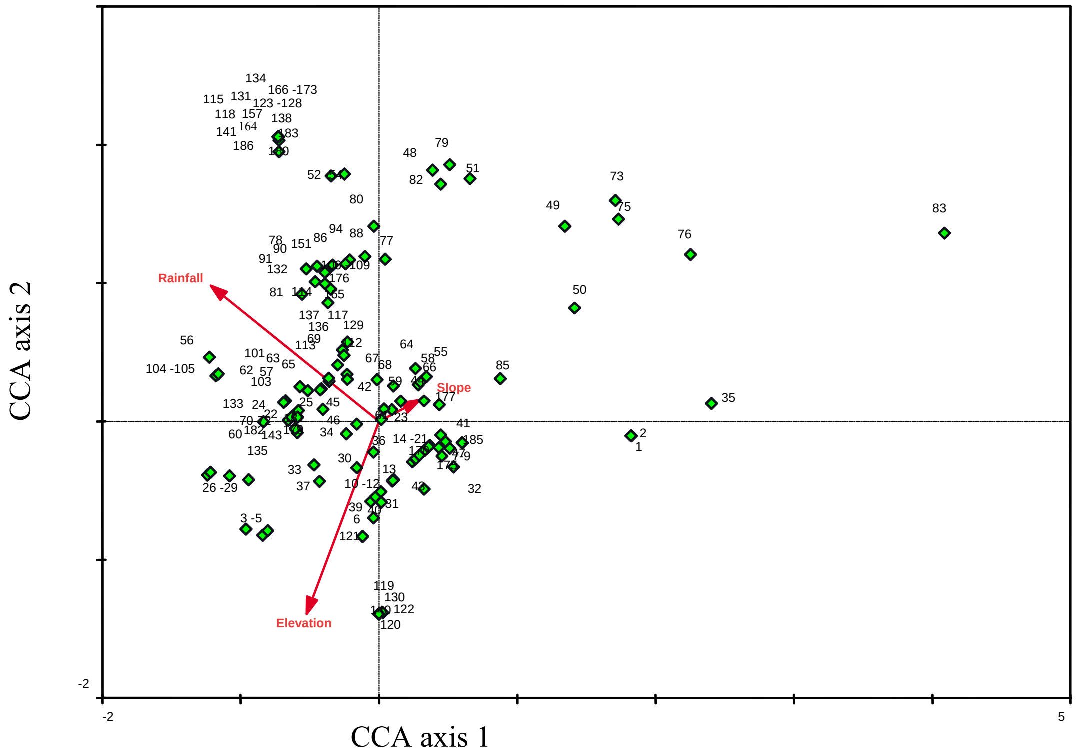

Figure 9: CCA ordination diagram indicating the influence of elevation, rainfall and slope on browse availability of selected plant species. The green diamond sign indicates the sample plots and the red arrows indicate the environmental variables.

4.5 Habitat use by black rhinos in relation to environmental variables in Palmwag Concession.

A 95% fixed width probability kernel (FWPK) categorized the habitat use by black rhinos into low and high probability use in Palmwag concession. The results indicated that high probability use (red area) falls within the 95% FWPK, while the low probability habitat use (blue area) falls outside the 95% FWPK (Figure 10). A large portion of the concession is categorized as the low habitat use by black rhinos, while a small portion of the concession is categorized as high probability (more on the Northeast and Southeast side of the concession). The influence of landscape variables in relation to probability habitat use by black rhinos are presented in the subsequent pages.

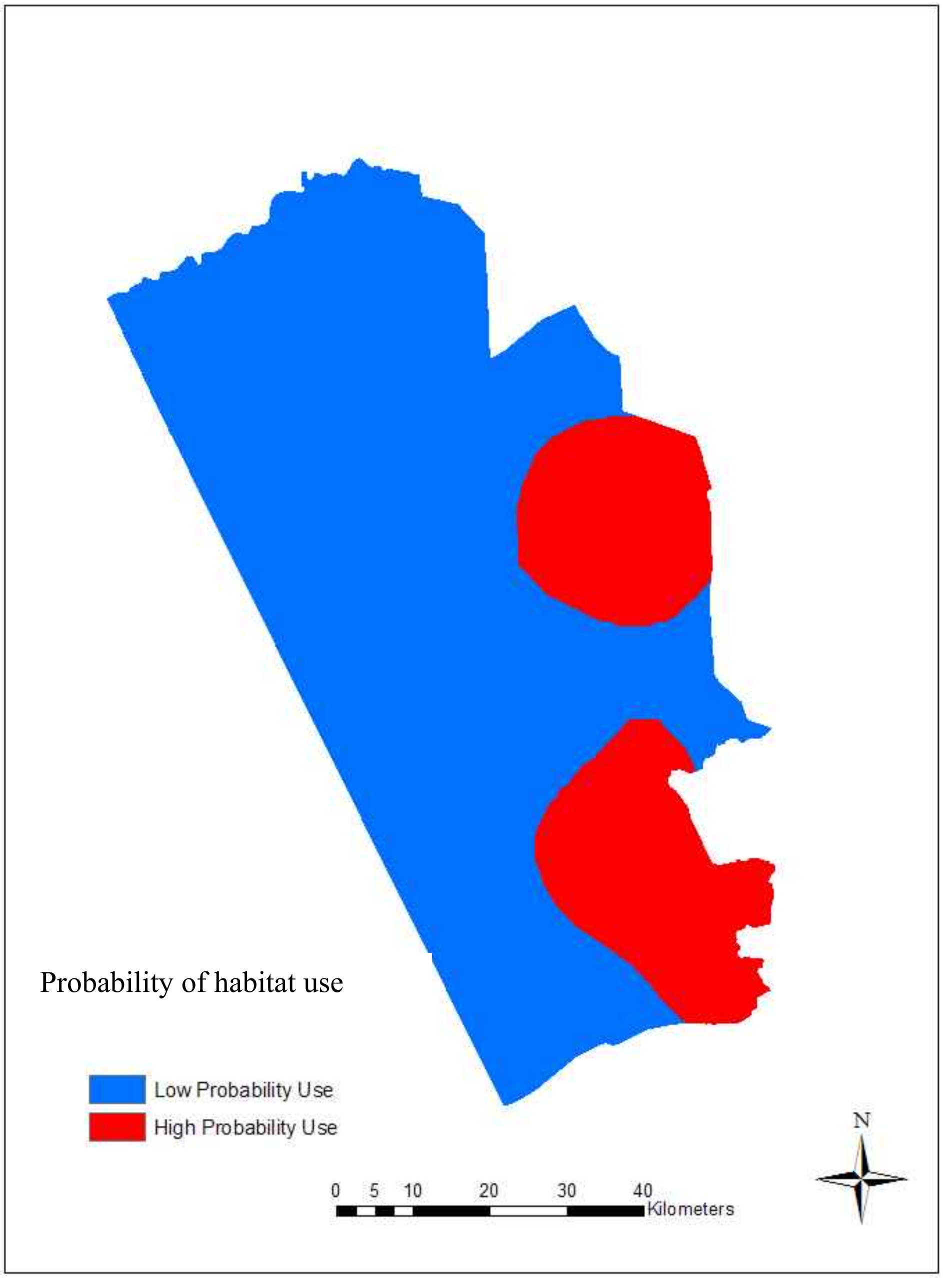

Figure 10: Black rhino 95% probability of habitat use in Palmwag concession. The blue area represents the low probability use area, while the red represents the high probability use area.

There was a significant difference in elevation between the low and high probability habitat use by black rhinos in Palmwag concession (Z = -10.001, p < 0.001). The high probability habitat use had a mean elevation of 950 meters (± 15.795 SE), whereas the low probability use area had a mean elevation of 710 meters (± 12.895 SE) (Figure 11).

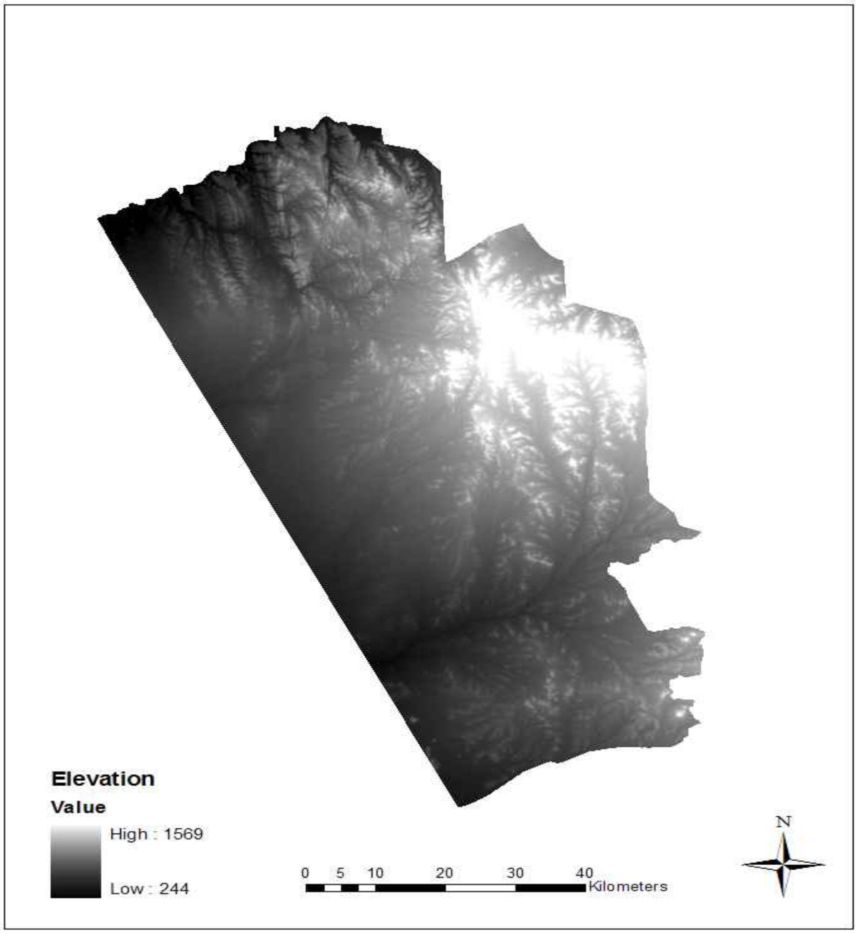

Figure 11: Elevation (meters) in Palmwag Concession. The light areas represent high elevation and the dark areas represent areas of low elevation.

There was a significant difference in mean distance to main rivers between the low and high probability habitat use areas in Palmwag concession, (Z = -8.748, p < 0.001). The high probability habitat use was closer to the main rivers, whereas the low habitat use by black rhinos were located farther from the main rivers. The high probability use area had a mean value of 2500 meters (± 127.25) while the low probability use level had a mean distance of 6000 meters (± 294.74) (Figure 12).

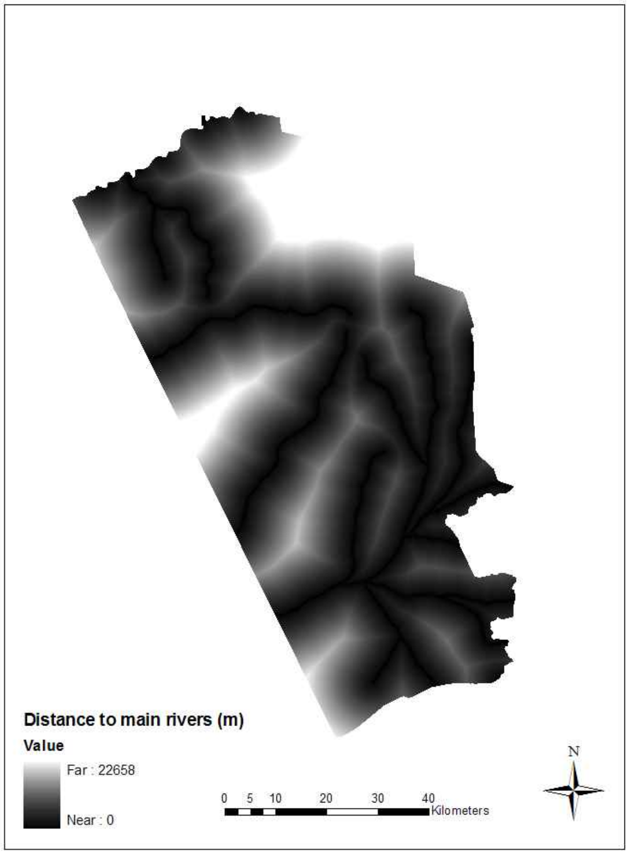

Figure 12: Distance to main rivers in Palmwag Concession. The dark areas indicate the closest distance to the high habitat use, whereas the light ones indicate the farthest distance to main rivers.

Distance to perennial springs significantly differed between the low and high probability habitat use by the black rhinos in Palmwag concession. ($Z = -11.009$, $p < 0.001$). The high probability habitat use was closer to the perennial springs, while the low probability habitat use was the farthest from the perennial springs. The high probability use area had a mean distance of 2300 meters (± 128.83 SE) from the springs, while the low probability use area had a mean distance of 6500 meters (± 361.66) from the springs (Figure 13).

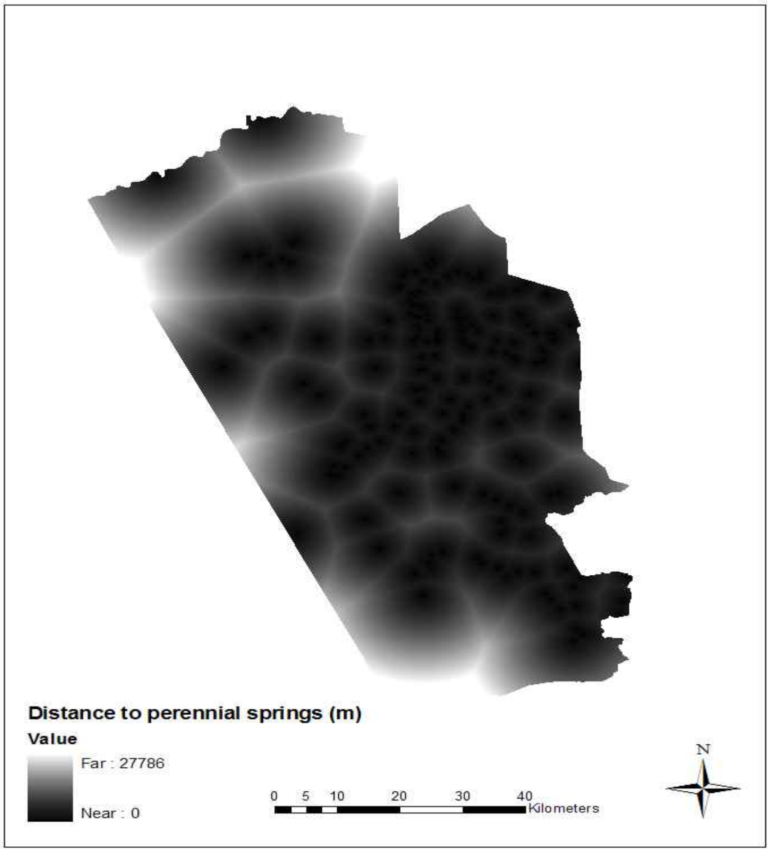

Figure 13: Distance to perennial springs (m) in Palmwag concession, the dark area indicates farthest distance and light part indicates closest distance.

Slope differed significantly between the low and high probability habitat use by black rhinos in Palmwag concession, ($Z = -5.018$, $p < 0.001$). The high probability habitat use fell in the areas of steeper slope, while the low probability habitat use fell in the gentle slope. The low probability use area had a gentle slope, with mean value of 5 degrees (± 0.40 SE), whereas the high probability use area had a steeper slope with the mean value of 7 degrees (± 0.445), Figure 14.

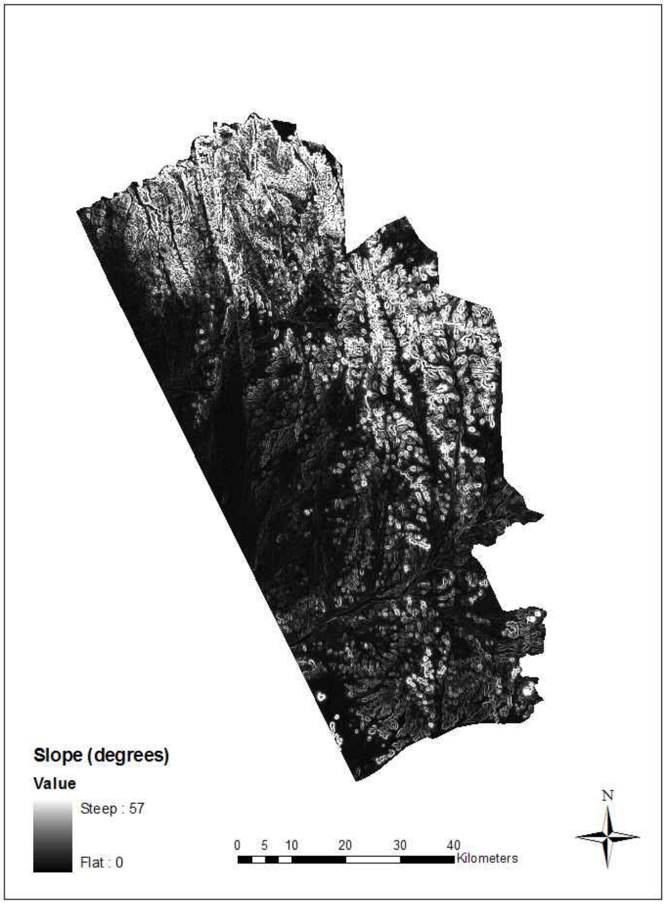

Figure 14: Slope (degrees) across Palmwag concession, the dark area indicates a more gentle slope, whereas the white areas represents steep slope.

There was no significant difference in distance to drainage between the low and high probability habitat use by black rhinos (Z = -0.032, p > 0.05). The mean distance from the high probability habitat use was 2250 meters (± 115.73 SE) away from the drainages, whereas the low probability use area was 2310 meters (± 126.15 SE) away from the drainages (Figure 15).

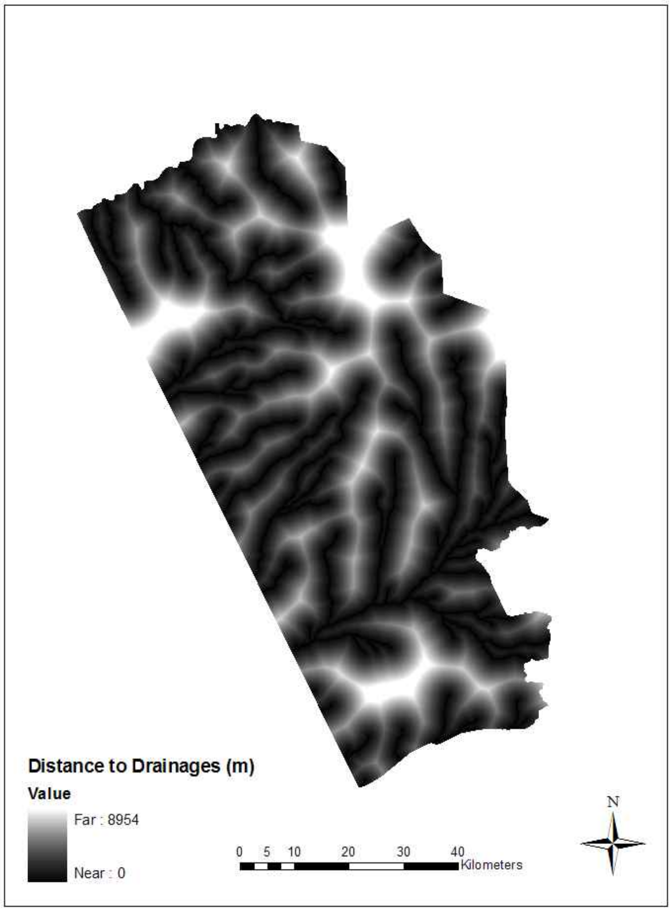

Figure 15: Distance to drainage (m) in Palmwag concession. The dark areas indicate furthest distance and the light part indicate closest distance.

There was no significant difference in mean browse availability between the low and high probability habitat use by black rhinos in the Palmwag concession, ($Z = -0.337$, $p > 0.05$). The mean browse availability for non-river habitats was 1% (± 0.34) and the mean browse availability for river habitat was 5 % (± 0.61) in the whole area (Figure 16).

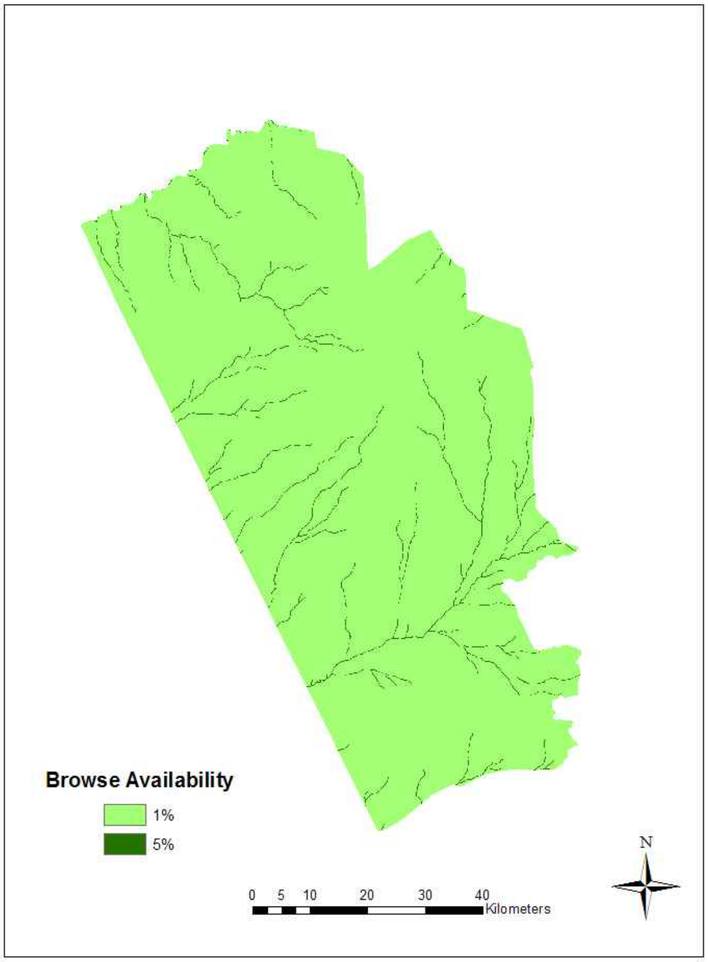

Figure 16: Mean Browse Availability (BA) in Palmwag Concession. The light green represents browse availability in Non-River habitats. The dark green represents the browse availability along Rivers (secondary and major rivers).

Average annual rainfall (mm) significantly differed between the low and high habitat use by black rhinos in Palmwag concession ($\chi^2 = 60.391$, $p < 0.001$). A high percentage of rhino points in the low use area were within the 0-100 mm rainfall, whereas a high percentage of rhino points in the high habitat use area were within 100 –200 mm rainfall range. This suggest that the higher the rainfall, the higher the habitat use, the lower the rainfall, the lower the habitat use (Figure 17 A and B).

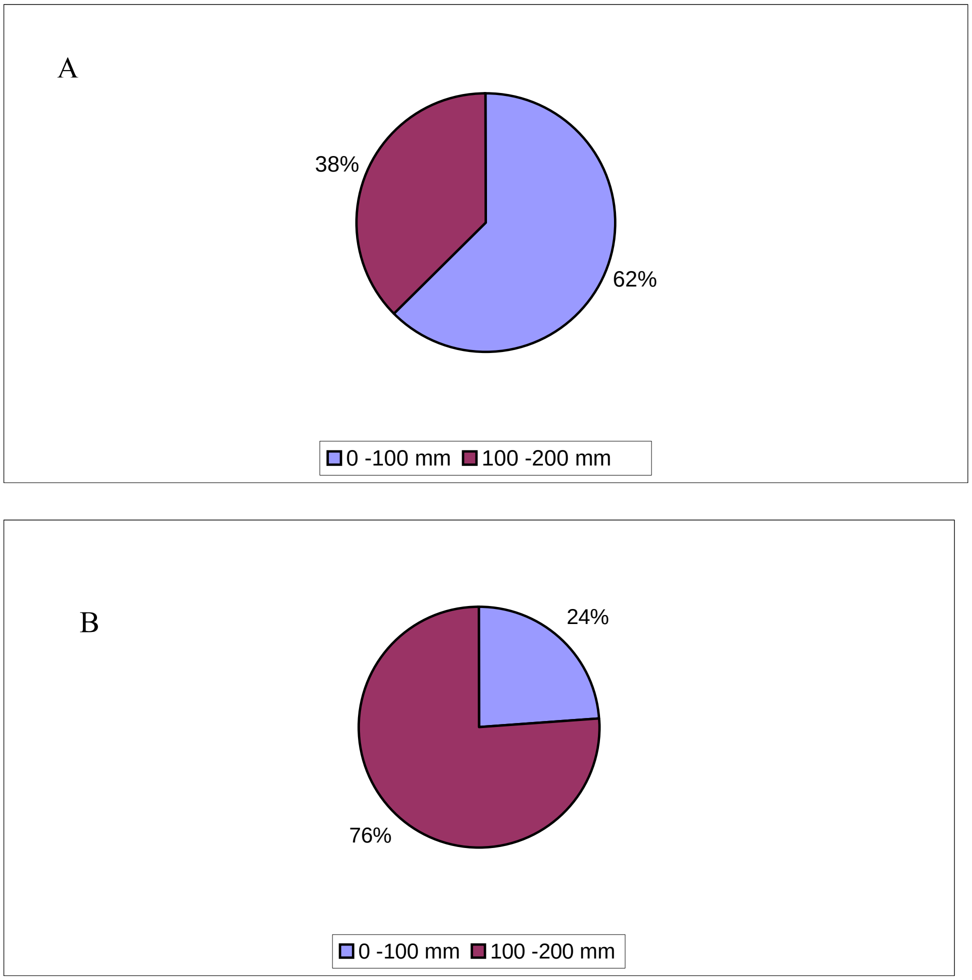

Figure 17: Proportions of rhino points in different rainfall ranges. A is low and B is high probability use area

Aspect did not significantly differ between the low and high probability habitat use areas in Palmwag concession. ($\chi^2 = 4.940$, $p > 0.05$). Results show that the low probability use area had a high count of South West (SW) facing slope, followed by South East, North West and North East. The high probability use area also showed a similar trend, hence no significant differences between the use levels. This suggests that the direction of slopes does not affect the probability of habitat use by black rhinos in Palmwag concession (Figures 18 and 19).

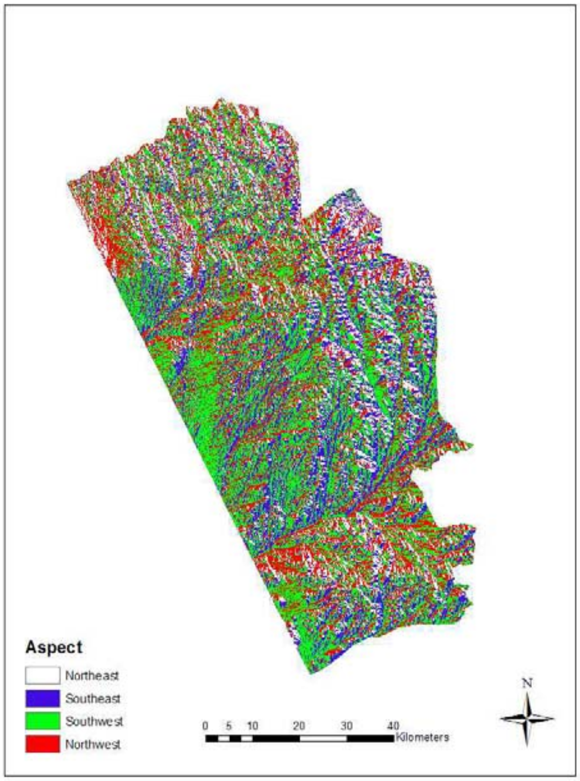

Figure 18: Aspect categories in Palmwag Concession, white represents the Northeast facing slope, Blue represents Southeast facing slopes, Green represents Southwest facing slope and Red represents Northwest facing slope.

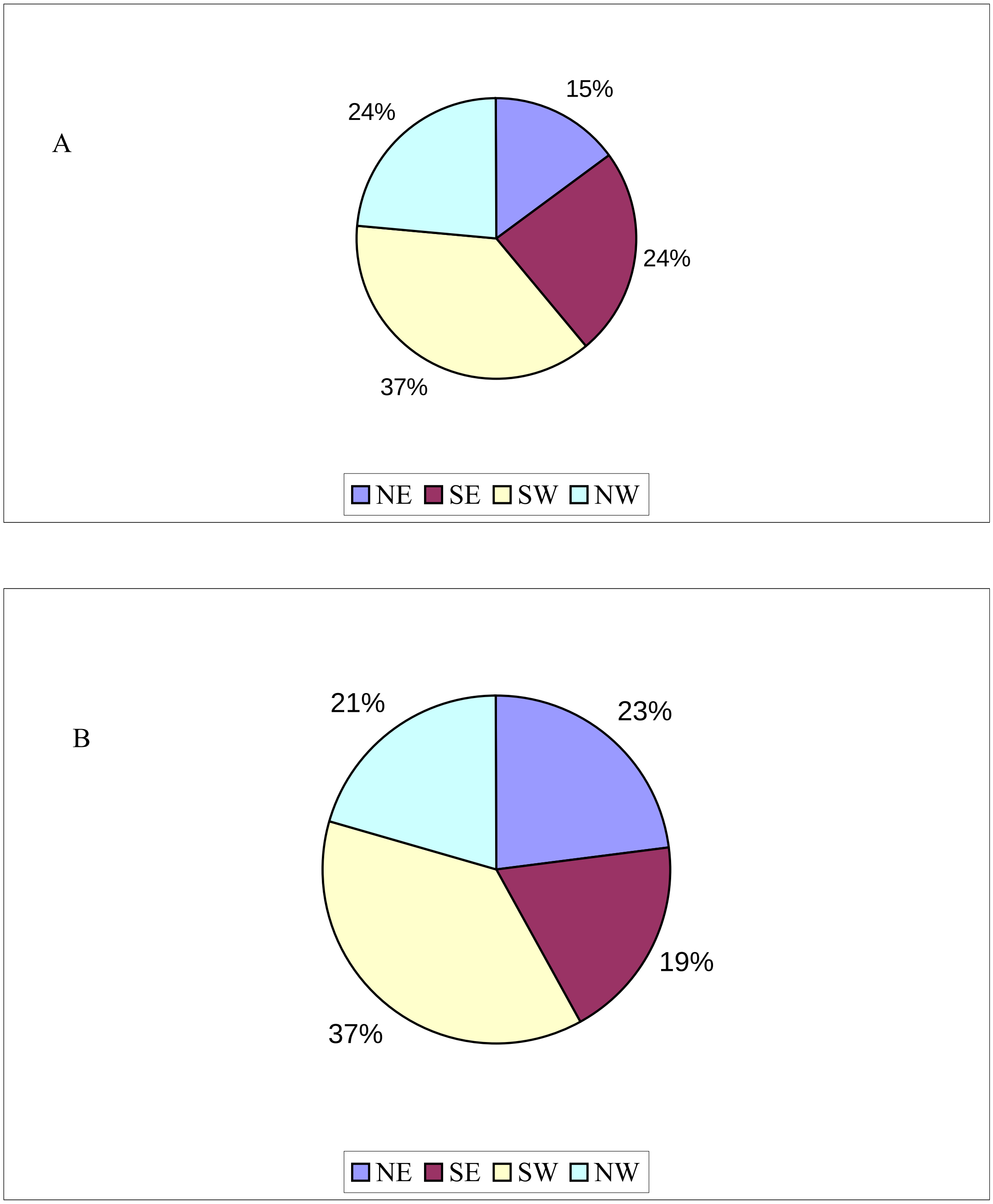

Figure 19: Proportions of rhino points in different aspect categories. A is low and B is high probability habitat use.

CHAPTER 5

5. DISCUSSION

5.1 Species diversity, richness and composition

Quantitative analyses of species diversity, richness and composition illustrated a significant difference among Torra conservancy, ≠Khoadi //Hoas conservancy as well as among habitat types. Torra conservancy exhibited significantly higher species diversity and richness than ≠Khoadi //Hoas conservancy. Hierarchical Cluster Analysis (Figure 4) classified the vegetation composition in Torra and ≠Khoadi //Hoas conservancy into 5 different vegetation layers. The different clusters indicate a variation of species composition in different sites as well as habitats. Therefore the nature of the vegetation needs to be considered at several scales when addressing habitat use by black rhinos.

It was hypothesized that plant species diversity, richness and composition will differ among the study sites as well as among different habitats, because of the differences in climatic, anthropogenic and physical conditions. Possible climatic and physical conditions include rainfall, soil, elevation, slope and human land uses as discussed below.

5.1.1 Influence of rainfall

Rainfall is the most important factor that governs species richness, species diversity and richness. Rainfall quantity during each rainfall event influences seed germination of plants, especially annuals in arid regions of Namibia. Sufficient water is required to trigger plant growth and reproduction, which in turn determines the occurrence and persistence of a certain plant species in a certain area.

Considering influence of rainfall on vegetation distribution, it would be expected that ≠Khoadi //Hoas, located in a high rainfall range (see Appendix 9) will be more species rich and diverse than Torra conservancy. A study by Gutierrez *et al*., (1998) in Atacama desert revealed that mean annual rainfall accounted for a large part of variation in plant species richness. Similarly, Linder (2001) reported that variation in species richness in sub-Saharan Africa is strongly related to rainfall. However the positive relationship between rainfall and plant species richness does not appear to hold in this study. In contrast, this study revealed that Torra conservancy located in the low rainfall range was more species rich and diverse compared to ≠Khoadi //Hoas conservancy. These findings are similar to what is reported by Barbour and Burk (1987) that greater species diversity can be found in semi-arid grasslands and deserts than in savanna woodland or forest. This could be related to the patchy unpredictable nature of rainfall in deserts (Whitford, 2002; Reynolds *et al*., 2004). Furthermore, the differences could be related to the transition between the arid Kaokoland and the hyper arid region (Torra conservancy). This is in agreement with Bruke (2005) who reported that even though this area is regarded as the most arid part (less rainfall); it is however regarded as the center (core area) of plant diversity.

In terms of species composition, hierarchical cluster analysis classified the vegetation in ≠Khoadi //Hoas into woodland with *A. robysiana*, *C. mopane*, *C. apiculatum*, *T. prunioides* as the common trees. The frequent occurrence of these tree species may also be related to the rainfall. This pattern also follows a similar trend as reported by Leggett *et al*. (2001) where *C. mopane*, *T. prunioides* and *C. apiculatum* showed frequent occurrence in the high rainfall area of northwest Namibia. Overall, species composition in Torra conservancy comprised almost entirely of annual forbs and shrubs, with *Zygophyllum simplex* being the abundant species in all habitats. This could be related to the theory that desert and hyper-arid vegetation is mostly made up of annuals, because the seeds of these plants can survive in the soil for a long time, lying dormant and germinate during periods when water is available.

5.1.2 Influence of soil characteristics

It was hypothesized that different physical conditions could lead to differences in species richness and composition. Soil fertility (Khedr and Lovett-Doust, 2000) and soil texture (Sperry and Hacke, 2002) are factors that are known to influence species richness and plant growth. Differences in soil characteristics among habitat types and study sites could lead to differences in species diversity. Soil quality or type determines how much water the soil can retain, the depth to which the plant can grow as well as the nutrient content that can support growth (Whitford, 2002). Different plants have different soil requirements, so their distribution can be closely linked to variations occurring in soil characteristics. Some plants can thrive in higher salinity, such as the salt bush (*Salsola* sp.), while some species are not able to survive. The species list shows that Torra conservancy had a total count of 3078 individual plants of *Zygophyllum simplex* (a ground succulent plant) a plant that mostly occurs in saline soils (Graven and Marais, 1992), while in ≠Khoadi //Hoas, there was no record of *Zygophyllum simplex.* This pattern could suggest that the soil in Torra conservancy could be more saline than ≠Khoadi //Hoas, thus possibly contributing to the difference in species composition and the high number of *Zygophyllum simplex* in Torra conservancy.

Furthermore, tree species in Torra conservancy only frequently occurred along the Riverine habitats, while in ≠Khoadi //Hoas these species were uniformly present in all habitats. The variability of soil moisture content among the study sites as well as among habitats may be responsible for the occurrence of trees along the riverine habitats. Generally riverine soils are likely to have more moisture content compared to the Non-river habitats. Soil available moisture is vital for species diversity, richness and composition, because it affects plant survival and reproduction. Mendelsohn *et al*. (2002) reported that Namibian soils vary greatly, both at broad and local scales and it is no doubt that Torra and ≠Khoadi //Hoas conservancies could vary in terms of soil types, which subsequently determine the differences in species diversity, species richness and composition. Similarly, it has been reported by Sperry and Hacke (2002) that there could be dramatic shifts in vegetation across changes in soil texture both at local and broad scales. It is very clear which Namibia soil type's supports high diversity, but soil rich in plant nutrients are more likely to support high species diversity. Goldblatt and Manning (2002) reported that coarse-grained sandy soils are poor in nutrients, while clay soil poses intermediate plant nutrients. Due to time limitation and scope of this study, no soil samples were collected, however it will be worth investigating the soil characteristics in Torra and ≠Khoadi //Hoas conservancies.

5.1.3 Influence of elevation

The difference in species diversity, richness and composition could be attributed to differences in elevation among the study sites. Torra conservancy exhibited the highest mean species diversity and richness. Torra conservancy had an elevation range of 417 – 1090 meters and an average elevation of 793.02 m, while ≠Khoadi //Hoas conservancy had an elevation range of 814-1348 m and an average elevation of 1111.40 meters. These average elevations only serve as guidance, given that no statistical test was performed.

Elevation is indirect factor that governs precipitation and air temperature. An increase in elevation causes a decline in air temperature and temperature consequently influences the distribution of species through survival, reproduction, development of seedlings and saplings (Krebs, 1994). In general, it has been documented that there is a gradient of increasing species diversity and richness from higher elevations to low elevations (Barbour and Burk, 1987). Furthermore, the plants that grow best at cooler temperature might be found at higher elevation. A study in Atacama Desert found that sites located between an elevation of 0 – 1500 meters showed a lower species richness, higher plant cover and higher herbaceous productivity than the upper part of the altitudinal gradient (Gutierrez *et al.*, 1998). This could be due to the hyper arid climate along the coast (similar to Namibia) and as altitude increases so does distance from fog moisture increase. However the relationship between species diversity, richness and higher elevation and low air temperature is not stable especially in dissected topography (Barbour and Burk, 1987). Based on visual field observations, Torra conservancy appeared to have a more varied topography compared to ≠Khoadi //Hoas conservancy. A similar phenomenon could be occurring in this study, whereby Torra conservancy with a low average elevation and a more dissected topography depicted a higher mean species richness and diversity compared to ≠Khoadi //Hoas conservancy.

Furthermore the patterns could be related to the cold air associated with a high pressure system over the Southern Atlantic Ocean and the cold Benquela current. This system consequently creates a coast-inland gradient in terms of temperature and humidity. Humidity is high at the coast and decreases when moving inland, while temperatures are low at the coast and increases when moving inland, thus contributing to differences in species diversity, richness and composition. Species that are adapted to low humidity and high temperatures are likely to more in land and *vice versa*.

Rainfall is also related to elevation. Typically, rainfall increases with elevation (Barbour and Burk, 1987). A study in Tanzania found a significant relationship between elevation and rainfall, with every 100 m rise in elevation corresponding to an increase in 35 mm in annual rainfall (Prins and Loth, 1988). Rainfall can influence seed banks and species emergence as the extent of germination depends on rain. In arid ecosystem, some annual species may not be present for years in the standing vegetation, but may eventually germinate when conditions are favorable (Prugnaire and Låzaro, 2000).

5.1.4 Influence of land use

Differences in species richness, diversity and composition could be attributed to different land use activities among the study sites. Different land use types in sampled sites (refer to section 3.5) and modification of landscape through farming activities can alter the spatial heterogeneity and facilitate the invasion of alien species, which in turn affect the diversity of species. Field observations in Torra conservancy and ≠Khoadi //Hoas conservancy indicated that ≠Khoadi //Hoas had more livestock activities compared to Torra conservancy. A community member (Anonymous, pers.comm. 2006) revealed that there has been an influx of livestock farmers in ≠Khoadi //Hoas from other regions. Furthermore, (Gabriel Goagoseb, pers.commm, 2007), indicated that generally, Torra conservancy has less livestock compared to ≠Khoadi //Hoas conservancy. The high number of livestock may result in increased grazing pressure, especially for annuals and consequently lead to low species diversity and richness. The movement of cattle can cause soil compaction, eventually limiting germination of soil seed bank (Hieraux and Herault, 2000) and leading to low species diversity and richness. Campbell (1996) noted that the effects of intensive grazing on rangelands often result in the removal of native species and the consequent replacement by introduced species. These trends could be occurring in this study, whereby the high stocking rates in ≠Khoadi //Hoas conservancy could be playing a role in the reduction of the native annual plants. This is in agreement with Burke (2005) who observed in the northern Namib (northwest Namibia) that selective grazing led to disappearance of tasty, palatable species and subsequent proliferation of weedy species such as *Geigeria acaulis* and *Ornativ*a

The impact of wild herbivores on species diversity, richness and composition is also one factor that is worth noting. Herbivores may influence the occurrence of a plant species either by reducing its abundance or eliminating it. Additionally, wild herbivores may influence the species diversity, richness and composition through seed dispersal. The perspective of seed dispersal could be viewed either from a positive or negative point. Marquis (2005) noted that in Africa, elephants, giraffes, wildebeest and other antelopes, particularly at high densities, all have shown to have major effects on vegetation. A study by Mapaure (2001) indicated that elephant herbivory significantly influenced small scale variations in the species composition of miombo woodlands in Sengwa (Zimbabwe). The descriptions by Marquis (2005) as well as the findings by Mapaure (2001) could be general or broad since it is applicable to Africa in general; and the miombo woodlands are vastly different from the northwest Namibia. However these findings could be applicable to the northwest of Namibia; and wild herbivores could be governing the difference in species diversity, richness and composition among Torra and ≠Khoadi //Hoas conservancy. A detailed study is crucial to investigate the influence of wild herbivores on species diversity, richness and composition in the northwest of Namibia.

5.2 Browse availability

Quantitative analysis of browse availability illustrated a significant difference of browse availability among sampled sites as well as habitat types in different study sites. ≠Khoadi //Hoas exhibited higher browse availability than Torra conservancy and Palmwag concession. In ≠Khoadi //Hoas conservancy, the occurrence of plants was uniform across habitat types, whereas in Torra and Palmwag, the thick vegetation such as *C. mopane* and several perennial woody species were more confined to the riverine habitats. This suggests that the presence of these species uniformly across ≠Khoadi //Hoas is likely to influence or contribute to more browse availability as a result of a high volume of leaves and twigs. The low browse availability areas (the Non-river habitats in Torra and Palmwag) were characterized by annual non-woody plant species with low volume of twigs and leaves, resulting in lower browse availability. Even though there were perennial non-woody plants such as *E. damarana* and *Petalidium* species; this did not appear to significantly influence browse availability in these areas.

The high value of browse availability in #Khoadi //Hoas conservancy does not necessarily suggest that most of the browse is preferred by black rhino food. In ≠Khoadi //Hoas conservancy, for example, no *E. damarana* was recorded. This plant is known to make up a major portion of black rhino diet in arid environments, especially during the dry season (Loutit *et al.*, 1987). Goddard (1968) as cited by Hearn (1999) found that *Euphorbia* species in Olduvai (typically a habitat rich in leguminous forbs) makes up 25% of black rhino diet in the gorge habitat in the wet season and 70% in the dry season, despite the fact that this species is not a dominant species. Hearn (1999) found that the dominance of *E. damarana* in at least one of the habitats sampled in northwest Namibia and its relative abundance and high browse category emphasizes its importance as a bulk food species.

The CCA analysis found that elevation and rainfall significantly influenced browse availability of selected plant species across the different sampling sites, while slope was insignificant (Figure 9). Several other factors are known to influence browse includes soil fertility, temperature, presence of livestock and other wild animals (Adcock *et al.*, 2006). The influence of rainfall, elevation and other factors are discussed below.

5.2.1 Influence of rainfall on browse availability

In the semi-arid tropics, rainfall is one of the major factors governing production of forage (Prins *et al.*, 1988), which in turn contribute to plant biomass. Rainfalls determine plant height, leaf size, and eventually browse availability (biomass), and rainfall is an important vegetation determinant (Palmer and Van Staden, 1992). This trend of rainfall governing primary production appears to hold in this study. ≠Khoadi //Hoas conservancy which is situated on a higher rainfall range (Mendelsohn *et al.*, 2002; Appendix 9) exhibited high browse availability, while Torra and Palmwag situated on a low rainfall range exhibited low browse availability. Furthermore, CCA results indicated a significant influence of rainfall on browse availability of selected plants. The CCA findings support the trend of rainfall governing biomass or primary productivity.

5.2.2 Influence of elevation on browse availability

The relationship found between browse availability and elevation support the hypothesis that elevation is one of the significant factors that influences browse availability. Based on the CCA findings, it is not unanticipated that elevation is a significant factor that governs browse availability of selected plants in different study sites. Furthermore, the ordination diagram revealed the influence of elevation on browse availability was more important in plots from #Khoadi //Hoas conservancy compared to Torra conservancy and Palmwag Concession.

Elevation is an indirect factor, which influences plant growth through correlated changes in direct variables (Palmer and Van Staden, 1992). These direct variables are temperature and precipitation. Elevation influences air temperature which directly influences plant growth and browse availability. An increase in elevation causes a decline in air temperature. Air temperature consequently influences available soil moisture and, transpiration, thus resulting in either increased or decreased productivity.

5.2.3 Presence of other browsers: livestock and wild animals

The presence of livestock and other wild animals could also play a major role in explaining the differences in browse availability. High stocking rates in arid rangelands can increase the pressure on available grazing materials (Kakujaha-Matundu, 1996). Consequently, increased pressure on grazing materials may force livestock that are occasional browsers to opt only for browse materials. Recent studies have indicated that it is inappropriate to deal exclusively with browsing in isolation from grazing as most livestock depend to a large extent on browsing material due to reduced grass cover (Kakujaha-Matundu, 1996). In semi-arid savannas, goats prefer to browse from trees which show signs of previous browsing activities (Skarpe *et al.*, 2007). The subsequent result of this is that, livestock might end up feeding on the same browse materials as other browsers such as the black rhino, and then lead to competition for resources.

Wild animals such as elephants and giraffes can impact or influence browse availability either positively or negatively. These animals can either destroy the plants, thus limiting browse availability or bend down unavailable browse (beyond 2 m browse line), thus making it available to black rhinos.

The current study did not quantify the influence of other wild animals on browse availability for black rhinos. However several studies have indicated an influence on browse availability by other wild animals. A study by Birkett (2002) reported that giraffe browsing influences browse availability for black rhinos by reducing plant growth. Another investigation by Guldemond and Van Aarde (2007) in Maputaland, South Africa suggested that elephants had a clear influence on vegetation at the species level. The relationship between other wild animals and browse availability for black rhinos in northwest Namibia needs to be investigated, to generate substantial vindication in this regard.

5.2.4 Influence of other factors on browse availability

Factors such as soil fertility, soil texture and temperature (not measured here) are known to influence the growth pattern of plants which indirectly determines browse availability (Adcock *et al*., 2006). Fertile soils are vital for plant growth and biomass production. Fertile soils are the source of essential microorganisms, micro and macro nutrients. Nutrients such as nitrogen, phosphorus and potassium can directly enhance plant growth and biomass production. A deficiency of those nutrients may result in failure for plant growth and production.

Soil texture on the other hand is an important property that affects soil porosity. The pores between the soil particles determine soil porosity, and this varies from soil types. As result soil porosity will determine the movement of water as well as how much water the soil can hold, consequently determining plant growth.

Soil water content is also vital for biomass production. Water is a transport agent of nutrients and essential minerals. Solbrig (1990) noted that plant available nutrients and plant available moisture individually and interactively influence plant productivity.

Due to time limitation and the research scope, this study did not collect soil samples to explore whether soil fertility and soil texture differs among study sites as well as among habitat categories. However, it has been noted that Namibian soils (and soils in general) vary greatly both at local scales and broad scales (Mendelsohn *et al.*, 2002). Therefore, soil fertility and soil texture could vary among Torra conservancy, Palmwag concession and ≠Khoadi //Hoas conservancy as well as among habitat categories.

Another factor that could influence browse availability in different study sites is temperature. Atmospheric and soil temperature can be directly or indirectly related to plant growth and production. Temperature may affect the plants at any life stage and may limit biomass production through factors such as survival. It has been noted that when proceeding up a mountain temperature decreases, while rainfall increases (Krebs, 1994), consequently contributing to increase biomass production. Excessive soil and atmospheric temperature during the day can also hamper plant growth. Abrami (1972) also noted that temperature is the most important short term variable influencing plant development and growth. It is not clear or there are no studies that support that there could be a significant difference in mean atmospheric and air temperature among the study sites as well as among habitats. Although, certain points in the topography (gorges) might experience lower temperatures at night, possibly below the survival thresholds of certain plants.

5.3 Probability of habitat use by black rhinos

5.3.1 Influence of environmental variables on habitat use by black rhinos

This study revealed that elevation, slope, rainfall, distance to major rivers, and distance to perennial springs were significant factors that influence habitat use by black rhinos in Palmwag concession, while aspect , distance to drainage and browse availability were not significant factors. Habitat use by animals is usually a behavioural consequence of animals actively selecting where they live or passively persisting in certain habitats (Boyce and McDonald, 1999).

The utilization of areas within closer proximities to water sources emphasizes the importance of water for rhino's survival in an arid environment like the northwest of Namibia. The utilization of these areas might be related to their need to drink daily. Furthermore, it could be related to the availability of browse materials along the riverine habitat. This study (Section 4.4, Figures 6 and 8) revealed that riverine habitats in Palmwag concession yielded high browse availability. Another reason is that black rhinos might be utilizing riverine habitat because of the availability of shade and bedding sites (bedding sites may be a critical component for rhinos(Rice and Jone, 2006). A study in Kenya found that *Euclea divinorum* to be the most common shrub in the bedding site of black rhinos (Rice and Jone, 2006).

The issue of black rhinos using riverine habitats and areas closer to water sources is in agreement with several studies. Adcock *et al*., (1994) as reported by Hearn (1999) found riverine habitat as important for black rhinos in Hluhlume (Kenya), especially during the dry season. Similarly, Smith (2005) reported that black rhinoceros occur in areas closer to springs. Hearn *et al.* (2000) suggested that black rhinoceros fecundity in Erongo and Kunene Regions is limited by available water and food sources, which in turn is limited by the variable geology occurring in these areas. Geology has a direct effect on water, for example, the availability of groundwater is directly related to the geology of the area. For instance, sandstones rocks are normally major sources of ground water. Furthermore, the porosity of different classes of rocks is important in ground water yield.

It has been documented that there is a positive correlation between mean rainfall and biomass of large herbivores (Prins *et al*., 1998). Similarly, Adcock *et al.* (2006) reported that rainfall may influence the carrying capacity of an ecosystem. Their findings might be related to abundant forage production in higher rainfall areas. In the case of this study, this could also mean that high rainfall areas may yield more biomass as compared to low rainfall areas, thus high probability of habitat use by black rhinos.

Another significant finding is that black rhinos in Palmwag concession utilize areas of higher elevation rather than areas of low elevations. This could be linked to factors such as temperature and rainfall, which are closely related to elevation. As previously mentioned, temperature and rainfall determines to biomass production and plant distribution. Mean atmospheric temperature decreases with increasing elevation. Consequently, temperature then influences seed germination, seedlings establishment and plant production. Schulze (1997) reported temperature parameters are vital controls by which the distribution of vegetation is frequently limited. It is likely that black rhinos would utilize these areas mainly because of the underlying factors such as abundant biomass or the distribution of the preferred plant species, such as the *Euphorbia damarana*. This finding is in agreement with Smith (2005) who reported that black rhinos are utilizing areas of higher elevations, but no reason was established why black rhinos prefer areas of high elevations.

Rainfall tends to positively correlate with elevation, thus areas of higher elevations tend to have more rainfall. As a result, areas of higher rainfall tend to be more productive and possibly likely to exhibit higher browse availability. However, considering the distance of high probability use by black rhinos in Palmwag concession from the coast, elevation in this case may not necessarily influence rainfall.

This study also revealed that black rhinos in Palmwag concession utilized areas of steeper slopes than gentle slopes. The utilization of steep slopes by black rhinos might be related to the underlying factors such as soil properties (soil moisture, soil organic content); runoff and the amount of solar radiation, which in turn may influence biomass production or the distribution/availability of preferred plant species. Furthermore these underlying factors may also influence the browse quality; hence black rhinos as large mammals may find steeper slopes undesirable for mobility, but possibly will use these areas due to the quality of browse or the presence of certain preferred plants species. Therefore, the negative influences of steepness on black rhinoceros movement could become less important.

Lau (1997) reported that slope is a major factor affecting the distribution of NDVI /biomass (Normalized Difference Vegetation Index). He further noted that NDVI had a small value in flat/gentle areas and then reached a maximum value at 40 degree slopes. This study did not look at the relationship between slope and NDVI, however generally NDVI is used to determine biomass (mainly green biomass). There is no available literature based on why black rhinos are likely to utilize areas of steeper slopes. Therefore, it would be interesting to investigate the relationship between slopes and browse quality as well as the abundance of preferred plant species by black rhinos.

CHAPTER 6

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

a. This study has highlighted the differences in species diversity, richness and composition among the sampled sites as well as among habitat categories. The differences are related to rainfall, soil characteristics, elevation and different human land uses.

b. Local scale analysis identified browse availability to differ significantly among the study sites. ≠Khoadi //Hoas conservancy exhibited higher browse availability than both Torra conservancy and Palmwag concession. These differences may be related to the east-west rainfall gradient evident in the northwest and Namibia in general. Furthermore, canonical ordination identified rainfall and elevation to be significant factors that influence browse availability of plant species known to be preferred by black rhinos in northwest Namibia.

c. The landscape level assessment characterized high probability habitat use by black rhinos in Palmwag concession as areas of high elevation, areas that are closer to major rivers and springs, areas of high rainfall and areas of relatively steep slopes. The utilization of areas that are in close proximity to water sources emphasizes the importance of water for black rhinos in semi-arid and arid environments such as the northwest of Namibia. Black rhinos might be utilizing areas of high elevation and relatively steep slopes due to underlying factors. Slope steepness is related to geology and hydrology and therefore the occurrence of certain plant species as well water availability.

d. In light of conservation status of *Diceros bicornis bicornis* and future re-introduction of this sub-species into communal conservancies for tourism purposes, this study provides valuable information. This information is anticipated by the Ministry of Environment, communal conservancies, Save the Rhino Trust, and other line ministries and NGOs to guide the planning of black rhino re-introduction projects.

6.2 Recommendations

a. Based on the higher biomass of browse species ≠Khoadi //Hoas conservancy, this study demonstrated that re-introduction of black rhinos is possible. However before re-introduction, there is need for a comprehensive vegetation study that incorporates a more depth analysis of factors such as climatic, topographic and soil properties. These investigations may reveal links to other factors that directly influences vegetation and habitat use by black rhinos. Investigation into slope steepness for example, may reveal links to hydrology and therefore the occurrence of plant species. Furthermore, cautions should be exercised on how the current land-use activities will impact on black rhinos. It may be crucial to introduce the black rhinos in areas of less human activities and livestock densities.

b. This study has highlighted the difference of browse availability in the three sampled sites. It is recommended that, the study should be replicated in other communal conservancies that are also earmarked as re-introduction sites. Furthermore, browse availability analyses should concentrate on the preferred plant species to avoid misleading browse availability values. This could be strengthened by comprehensive feeding observational studies of black rhinos in the area concerned. Additionally, browse availability analysis should also be linked to the in-depth analyses of browse quality**.**

c. Due to the limited scope of this study and time limitation, the influence of livestock and other herbivores on species diversity, richness, composition and browse availability was not investigated. Therefore, a detailed study is essential to justify the influence of these factors on vegetation.

REFERENCES

Abrami, G. 1972. Optimums mean temperature for plant growth calculated by a new method of summation. *Ecology,* 53: 893 -900.

Adcock, K. 1994. The relevance of "Terretorial" behavior in black rhino to their population management. In: rhinos as game ranch animals (ed. B.L. Penzhorn and N.P.J. Kriek), South Africa Veterinary Association. Onderstepoort.

Adcock, K., Amin, R., Okita, B. and Khayale, C. 2006. Habitat characteristics and carrying capacity relationships of 9 Kenyan black rhino areas. Darwin initiative project.

Anymynous.2006.Personal communication. Community member of ≠Koadi //Hoas conservancy.

Bailey, T.C. and Anthony, C. G. 1995. *Interactive Spatial Data Analysis.* Reading, Massachusetts: Addison-Wesley Publishers.

Barbour, G.M., and Burk, J.H. 1987. Terrestrial Plant Ecology, Second edition. Benjamin/Cummings publishing Company, Inc. California, USA.

Berger, J.1997. Population constraints associated with the use of black rhino as an umbrella species for desert herbivores. *Conservation Biology*, 11: 69-78.

Birkett, A.2002.The impact of giraffe, rhino and elephant on the habitat of a black rhino sanctuary in Kenya. *Journal of ecology*, 40:267-282.

Bothma, J. P .Ed. 1990. Game Ranch Management. A practical guide on all aspects of purchasing, planning, development, management and utilization of modern game in Southern Africa. J.L van Schaik Pty, Ltd, Pretoria.

Boyce, M.S. and McDonald, L.L. 1999. Relating populations to habitats using resource selection functions. *Trends in Ecology and Evolution*, 7: 268 – 272.

Burke, A. 2003. Wild flowers of the central Southern Namib. Namibian Scientific Society, Windhoek, Namibia.

Burke, A. 2005. Wild flowers of the Northern Namib. Namibian Scientific Society, Windhoek, Namibia

Burke, A. 2007. Wild flowers of the central highlands. Namibian Scientific Society, Windhoek, Namibia.

Campbell, N.A. 1996. Biology, Fourth edition. The Benjamin Cummings publishing company, Inc, California, USA.

Curtis, B.A and Mannheimer, C.A. 2005. Tree Atlas of Namibia. Windhoek: National Botanical Research Institute. 688 pp.

Du Preez, P. 2006. Kunene Black Rhinoceros Capture and Translocation, March and April 2006. Ministry of Environment and Tourism, Windhoek, Namibia.

Emslie, R. and Brooks, M. 1999. African Rhino. Status Survey and Conservation Action Plan. IUCN/SSC African Rhino Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. 92 pp

Erb, P.1997. Rhinoceros Conservation in Namibia. Namibia Environment, Desert Research Foundation, 1:153-156.

Estes, R.D .1992. The behavior guide to African mammals; including hoofed mammals, carnivores and primates. University of California Press, Ltd. Oxford, England.

Goddard, J .1967. Home range, Behavior and recruitment rates of two black rhinoceros populations. *East African Wildlife Journal*, 5:133-150.

Goddard, J.1968. Food preferences of black rhinoceros. *East African Wildlife Journal*, 6:1-18.

Goldblatt, P. and Manning, J.C. 2002. Plant diversity of Cape region, South Africa. *Annals of the Missouri Botanical Garden*, 89: 281 -302

Goagoseb, G.2007. Personal communication. Personeel, Ministry of Agriculture, water and forestry, Erwee Agricultural center, Kunene Region, Namibia.

Graven, P. and Marais, C.1986. Namib Flora. Gamsberg MacMillan Publisher, Windhoek, Namibia.

Graven, P. and Marais, C. 1992.Damaraland flora- Spitzkoppe, Brandberg, Twylefontein. Gamsberg MacMillan, Windhoek, Namibia.

Grunert, N. 2003. Fascination of Geology. Klaus Hess Publishers. Windhoek, Namibia .176 pp.

Guldemond, R. and Van Aarde, R. 2007. The impact of elephants on plants and their community variables in South Africa's Maputaland. *African Journal of Ecology*, 45: 327-335

Gutiérrez, J.R., Lópoz – Cortes, F. and Marquet, P. A.1998. Vegetation in an altitudinal gradient along the Rio Loa in the Atacama Desert of Northern Chile. *Journal of Arid Environments*, 40: 383 – 399.

Harley, E.H., Baumgarten, I., Cunningham, J. and O'Ryan, C. 2005. Genetic variation and population structure in remnant populations of black rhinoceros, *Diceros bicornis* in Africa. *Molecular Ecology*, 14: 2981-2990

Hearn, M. 1999. The desert-dwelling black rhinoceros *Diceros bicornis bicornis* of north-western Namibia: the role of density dependence and its management implications. A Report for Save the Rhino Trust Namibia, Kunene Region

Hearn, M.E., Loutit, B.D., and Uri-Khob, S. 2000. The black rhinoceros of north-western Namibia, *Diceros bicornis bicornis*: the role of density-dependence and its management implications. *Namibia Scientific Society Journal*, 48: 11-39.

Hearn, M.E.2004. Assessment of biological and human factors limiting the West Kunene rhino population. SADC Report.

Hieraux, P. and Herault, B. 2000. The influence of grazing regime by cattle on the soil seed stock and germination pattern in the annual rangelands of the Sahel.

Unpublished report, International Livestock Research Institute, ICRISAT, Niger and Foundation Universitaire Luxembourgeoise, Belgium. 3 pp.

International Rhino Foundation. 2002. South-Western Black Rhinos .*Diceros bicornis bicornis*.Http://www.rhino-sirf.org/rhinoinformation/blackrhinos/subspecies/.htm.

IUCN Red data list of Threatened Species: www.IUCN.org/themes/redlist2006.htm, accessed October 2006.

Jacobson, P.J., Jacobson, K.M. and Seely, M.K.1995. Ephemeral rivers and their catchments: sustaining people and development in western Namibia. Desert Research Foundation of Namibia, Windhoek.

Joubert, E. 1996. On the clover trial, the plight of the world’s rhinos. Gamsberg Macmillan publisher pty .Ltd. Windhoek.

Kakujaha-Matundu, O. 1996. Subsistence farmer’s perception of environmental problems and monetary estimates of Agricultural and Non-Agricultural Resources in the Okakarara Area. Desert Research Foundation Publication, paper 5:14.

Khedr, A. H. and Lovett-Doust, J. 2000. Determinants of floristic diversity and vegetation composition on the islands of lake Burollos, Egypt. *Applied vegetation Science*, volume 3:2 p147 -415.

Krebs C. J. 1994. Ecology, 4th edition. Harper Collins College publishers. New York.

Kremen, C. 1992. Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological applications*, 2: 203 -217.

Kunene Regional Council. 2005. Regional Development plan 2001/2002 – 2005/2006. Government of the Republic of Namibia, Windhoek.

Lau, C.1997. Geomorphologic Distribution of Normalized Difference Vegetation Index:www.gisdevelopment.net/aars/1997/ts1004pf.htm

Leggett, K., Fennessy, J. and Schneider, S. 2001. Hoanib River catchments study Northwest, Namibia. Desert Research Foundation, Windhoek, occasional paper No.17:26-99.

Leggett, K., Fennessy, J. and Schneider, S. 2003. Seasonal vegetation changes in the Hoanib River catchment, north-western Namibia: a study of a non-equilibrium system. *Journal of Arid Environments*, 53:99-113.

Legget, K. 2006. Home range and seasonal movement of elephants in the Kunene Region, northwestern Namibia. *African Zoology*, 41:17 -36.

Linder, H.P. 2001. Plant diversity and endemism in sub-Saharan tropical Africa. *Journal of Biogeography*, 28:169 – 182.

Loutit, B.D., Louw, G.N., Seely, M. K.1987. First approximation of food preferences and the chemical composition of the diet of the desert-dwelling black rhinoceros, *Diceros bicornis* L. *Madoqua*, 15 .1: 35-54.

Mapaure, I. 2001. Small-scale variations in species composition of miombo woodland in Sengwa, Zimbabwe: the influence of edaphic factors, fire and elephant herbivory. *Systematics and Geography of Plants*, 71: 935-947.

Mapaure, I. 2005. Functional Biodiversity of woodland and forest ecosystems. M. Sc lectures notes, University of Namibia, Windhoek.

Marquis, J. 2005. Impacts of herbivores on tropical plant diversity. In: Burslem, D.,Pinard, M.,Hartley, S.(Eds). Biotic interactions in the tropics, their role in the maintenance of species diversity. *Ecological reviews*, British Ecological Society,Pp.328-341

Mendelsohn, J., Jarvis, A., Roberts, C. and Robertson, T. 2002. Atlas of Namibia. A portrait of the land and its people. David Phillip Publishers, Cape Town, South Africa.

Ministry of Environment and Tourism.2006. :www.met.gov.na/programmes

Muya, S.M and Oguge, N.O. 2000. Effects of browse availability and quality on black rhino *Diceros bicornis michaeli* Groves 1967 diet in Nairobi National Park, Kenya. *African Journal of Ecology*, 38: 62-71.

Namibia Association of CBNRM support organizations. 2004. Namibia's communal conservancies: a review of progress and challenges. NACSO, Windhoek.

O´Brien, E.M. 1993. Climatic gradients in woody plant species richness: towards an explanation based on analysis of Southern Africa's woody flora. *Journal of Biogeography*, 20: 181-198.

Palmer, A.R and Van Staden, J.M. 1992. Predicting the distribution of plant communities using annual rainfall and elevation: An example from Southern Africa. *Journal of Vegetation Science*, 3: 261-266.

PISCES CONSERVATION LTD. 2002.Community Analysis Package (CAP) 2.04. Lymington, UK.

PISCES CONSERVATION Ltd.2002. Species diversity and richness 2.5. Lymington, UK.

Prins, H.H., and Loth, P.E. 1988. Rainfall patterns as background to plant phenology in northern Tanzania. *Journal of Biogeography*, 15:451-463.

Prugnaire, F.I and Lảzaro, R. 2000. Seed bank and understory species composition in a semi-arid environment: The effect of shrub and rainfall. *Annals of Botany*, 86: 807-813.

Reynolds, J.F, Kemp, P.R, Ogle, K. and Fernandez, R.J. 2004. Modifying the 'pulse reserve' paradigm for deserts of North America: Precipitation pulses, soil water, and plant responses. *Oecologia*, 141:194 -210.

Rice, M.B and Jone, M. 2006. Characteristic of black rhinoceros .*Diceros bicornis* bedding sites. *African Journal of Ecology*, 44: 452-457.

Rudran, R. 2004. Conservation Biology Handout, presented at Cheetah Conservation Fund. Smithsonian Institute, Washington D.C.

Save the Rhino Trust. 2005. Land use plan for Palmwag concession, a report for UNDP Fund. Kunene Region, northwest Namibia.

Schulze, R.E. 1997. Climate. In: Cowling, R.M., Richardson, D.M and Pierre, S.M. (Eds). *Vegetation of Southern Africa* .Cambridge University Press, UK. Pp.21-42.

Seely, M. 2005. Functional Biodiversity of arid ecosystems. Lecture notes, Desert Research Foundation of Namibia and Gobabeb Research station.

Shuttle Radar Topography Mission: Digital Elevation Model http://srtm.usgs.gov/products/elevation/dem/html, accessed April 2005.

Skarpe, C., Jansson, I., Seljeli, L., Bergstrom, R. and Roskaft, E.2007. Browsing by goats on three spatial scales in a semi-arid savanna. *Journal of Arid Environments*, 68:480-491.

Smith, B.2005. Developing a spatial habitat suitability map for black rhinos in northwest Namibia. Durell Institute of Conservation Education. University of Kent.UK.

Solbrig, O.T. (Ed). 1990. Savanna modeling for global change. *Biology International, special issue,* 24:1-48.

Sperry, J.S. and Hacke, U.G. 2002. Desert shrub water relations with respect to soil characteristics and plant functional type. *Functional Ecology* 16:367-378.

Uri-khob,S. 2004. Attitudes and perceptions of local communities towards the reintroduction of black rhino .*Dicores bicornis bicornis* into their historical range in northwest Kunene Region, Namibia. Master thesis, University of Kent, Durrel Institute for Conservation Education, UK.

Whitford, W.G. 2002. Ecology of Desert Systems. Academic Press, London.