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

BY

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Project summary

The black rhino of northwestern Namibia is a desert-adapted sub-species (*Diceros bicornis bicornis)* restricted to a narrow 20,000 km2 range in the Kunene region. Due to uncontrolled poaching and a devastating drought in the early 1980s, this sub-population crashed to less than 50 individuals. Through innovative conservation measures, particularly eliminating the poaching pressure, the population is slowly recovering. To bolster this process, the Ministry of Environment and Tourism in Namibia has initiated an ambitious program to translocate 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 completed through April – June 2006 in the Kunene Region, northwestern Namibia. Three study sites were selected: Palmwag concession, Torra conservancy and ≠Khoadi //Hoas conservancy. 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. Analysis 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. ≠Khoadi //Hoas conservancy exhibited higher browse availability than in Torra and Palmwag concessions. Canonical Correspondence Analysis showed that elevation and rainfall significantly influenced browse availability of selected plant species, but slope was insignificant. At a landscape level, this study found that areas closer to major rivers, perennial springs, higher rainfall, elevation and slope characterized black rhino high use habitat. However the probability of a habitat being used by black rhinos could also be attributed to other underlying factors such as slope, hydrology, soil moisture, soil properties, soil nutrients and land use patterns and these warrant further investigation. This study provides fundamental habitat information to guide black rhino re-introductions into communal conservancies. 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, individually or through interaction, influence the browse availability and therefore habitat use by black rhinos in northwestern Namibia.

BACKGROUND

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 natural 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).

Thus, 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 compliment these findings, I sought to assess habitat quality for black rhinos at multiple scales and specifically:

(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 date.

MATERIALS AND METHODS

Study Area

This study was carried out in the Kunene Region, northwest Namibia. The Region is one of the 13 political regions of Namibia. The Kunene region is about 144255 km^2 and has a current estimated 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.

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 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.

Sampling design and plot demarcation

Plot-level

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). Circular plots were then randomly sampled in each strata for: plant diversity, density and browse availability.

Landscape-level

Using point location data from Save the Rhino Trust's database, probability kernel home ranges for six female black rhinos from 2003 – 2005 within the Palmwag concession. The probability surfaces allowed spatially explicit categorization of sites into either high probability use (within kernels) or low probability use level (outside kernels).

I then compared landscape and resource proximity variables by characterizing randomly generated points with a geographic information system (GIS) between high and low probability use areas. These were elevation, slope, aspect, rainfall and distance to main and minor rivers, and springs.

RESULTS

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 revealed 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 the 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	0.98 ± 0.13	5.42 ± 0.66
KSR	0.99 ± 0.11	5.45 ± 0.43
KNR	0. 73 ± 0.08	5.05 ± 0.49
TMR	0.67 ± 0.19	5.25 ± 0.80
TSR	1.25 ± 0.07	8.93 ± 0.39
TNR	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 pruinoides* and *Catophractes alexandri,* whereas the forbs 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 *C. 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 all are 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. 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).

Euclidean distance

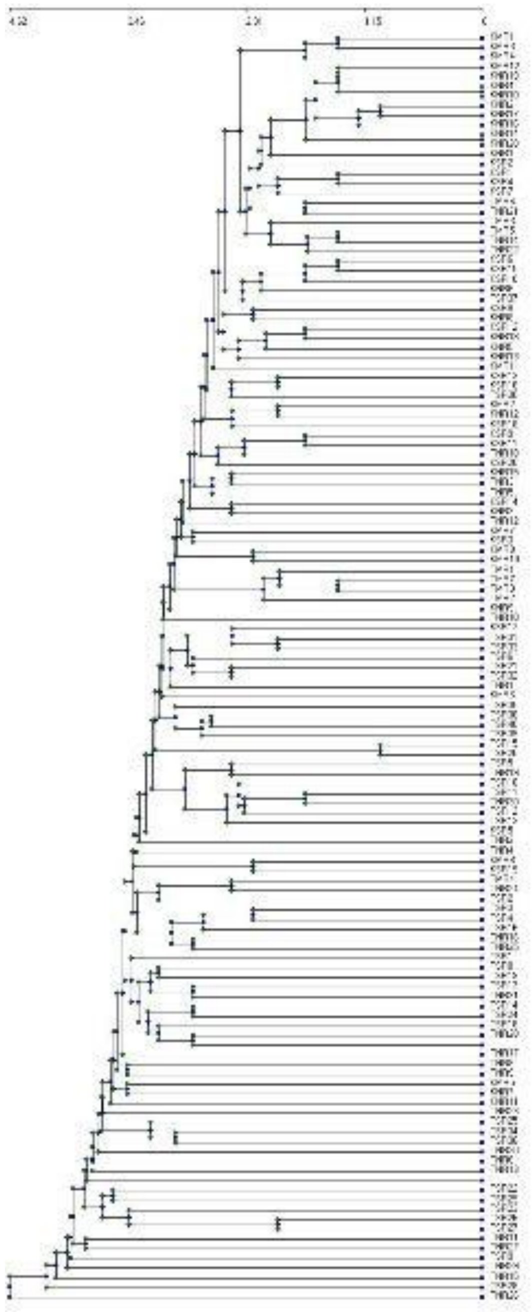


Figure 3: Hierarchical cluster analysis (HCA) dendrogram showing a classification of vegetation plots in Khoadi Hoas and Torra conservancy based on species absence and presence. The codes, KMR represents ≠Koadi //Hoas major rivers, KSR; ≠Khoadi //Hoas Secondary Rivers and KNR; ≠Khoadi //Hoas Non-Rivers. 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.

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 differed significantly among Torra and Palmwag concession (Z= -1.274, p= 0.203).

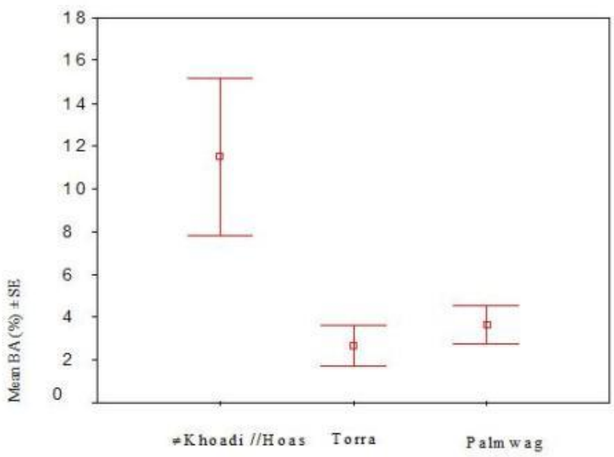


Figure 4: Mean of browse availability (± SE) in ≠Khoadi //Hoas conservancy, Torra conservancy and Palmwag concession.

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.

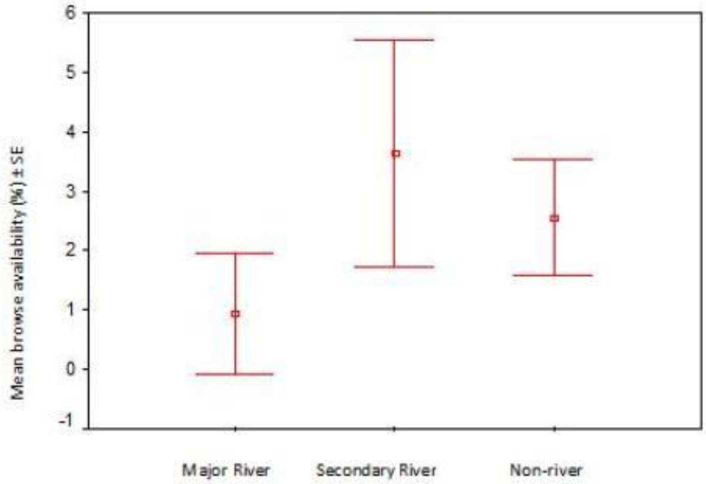


Figure 5: Mean browse availability among habitat categories in Torra conservancy in percentage (± SE).

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).

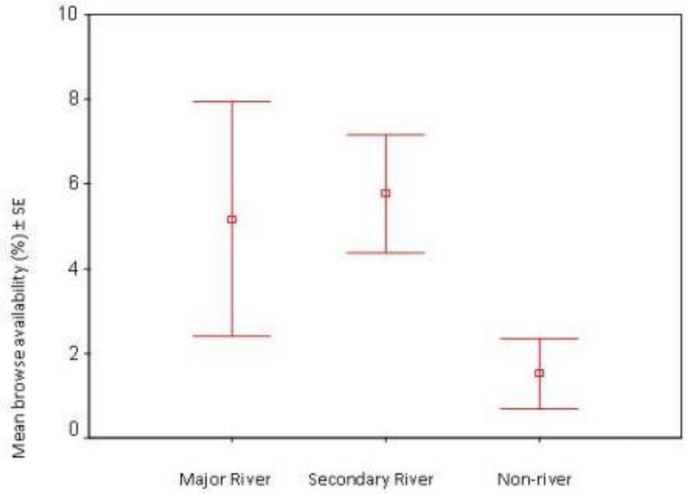


Figure 6: Mean browse availability among habitat categories in Palmwag concession in percentage (± SE).

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

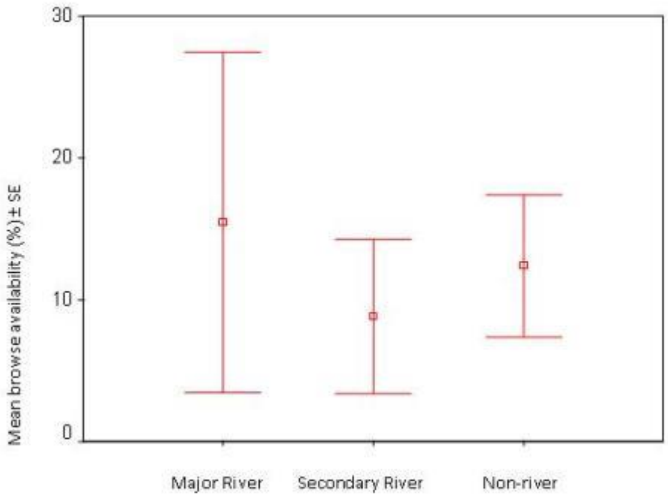


Figure 7: Mean browse availability in percentage (± SE) of different habitat categories in ≠Khoadi //Hoas conservancy.

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.

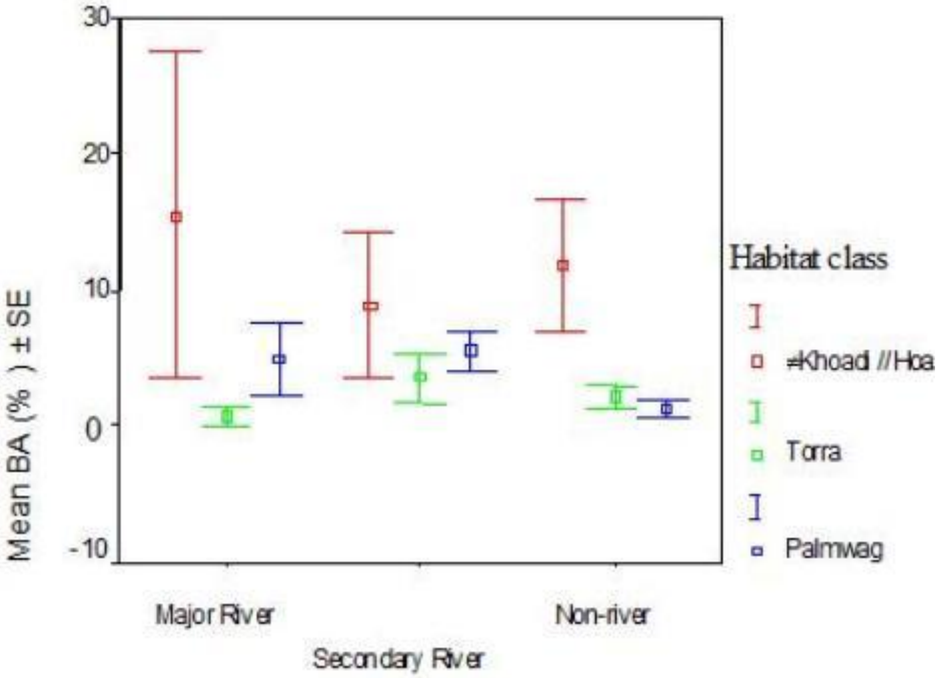


Figure 8: Comparison of browse availability (± SE) among different habitat types across the study sites.

4.4 Browse availability of selected plant species: local scale

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 9.4 and axis 3 was 10.4. The eigenvalue for the first 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 may imply that the environmental data explains 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 environmental variables, and percentage variances of species and species environmental relationship derived from CCA.

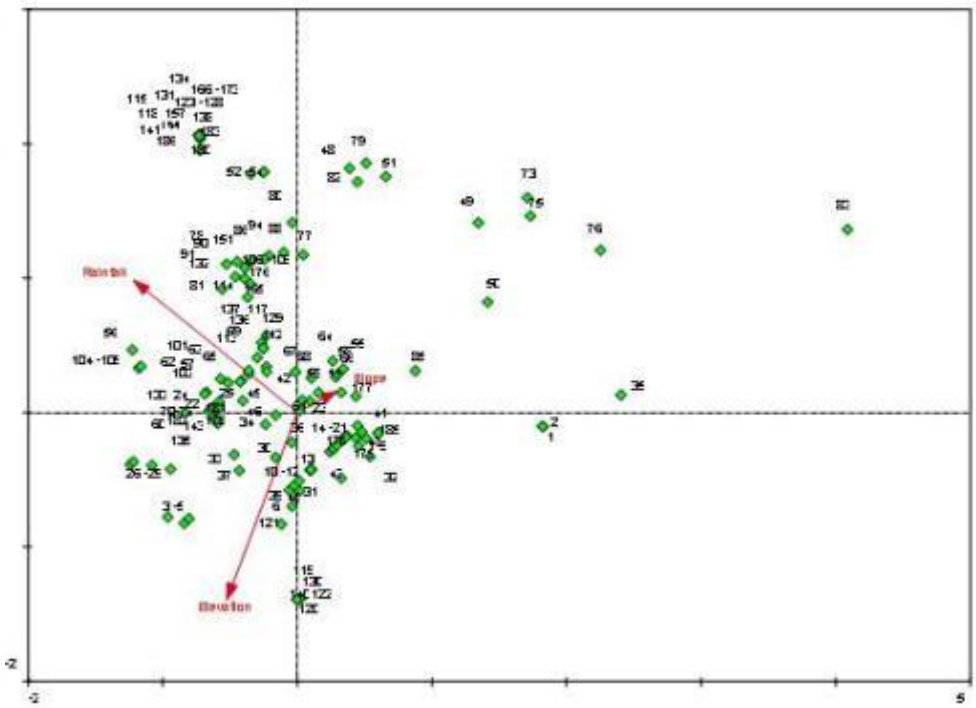
Canonical axis	Eigen values	Species-environment correlations	Cumulative % variance of species environment relations	Cumulative % variance of species data
1	0.435	0.682	53.6	5.6
2	0.273	0.347	100	10.4
3	0.082	0.000	0.00	22.4

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.

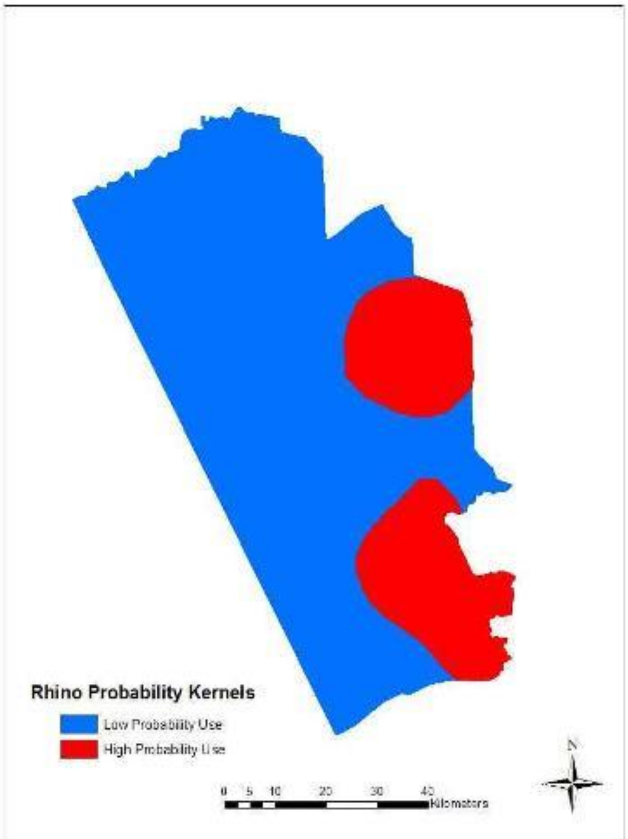
Overall, the results indicate that browse availability of selected plants in Torra conservancy, Palmwag concession and Khoadi //Hoas conservancy was largely influenced by elevation and rainfall.

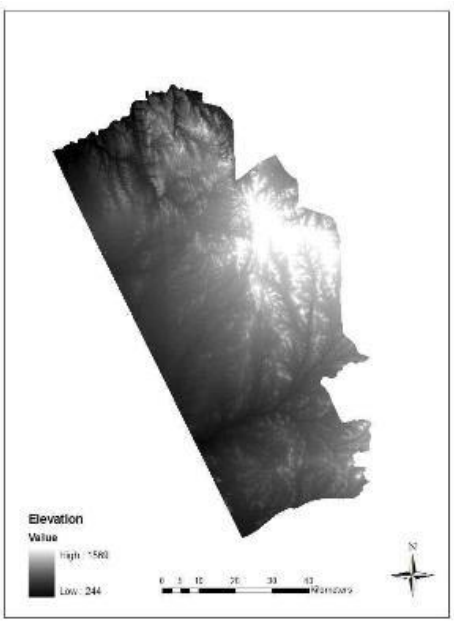
Figure 9:



CCA ordination diagram indicating the influence of elevation, rainfall and slope on browse availability of selected plant species. The samples (plots) are shown by ◊ sign and the environmental variables are shown by arrows. Samples from ≠Khoadi //Hoas are number from 1 – 49, Torra conservancy 50 -101 and Palmwag 102 -188.

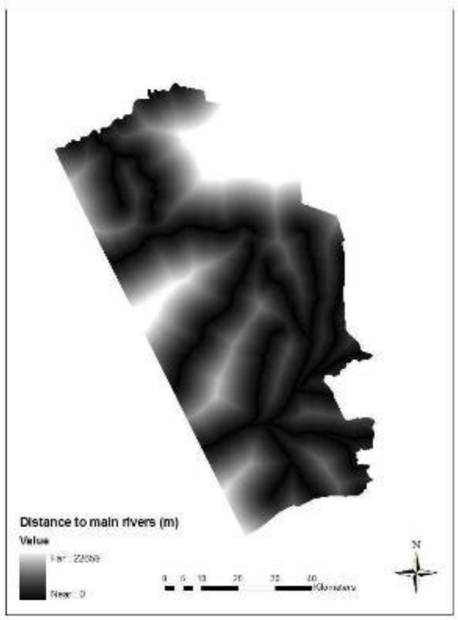
Habitat use by black rhinos in relation to environmental variables in Palmwag Concession.





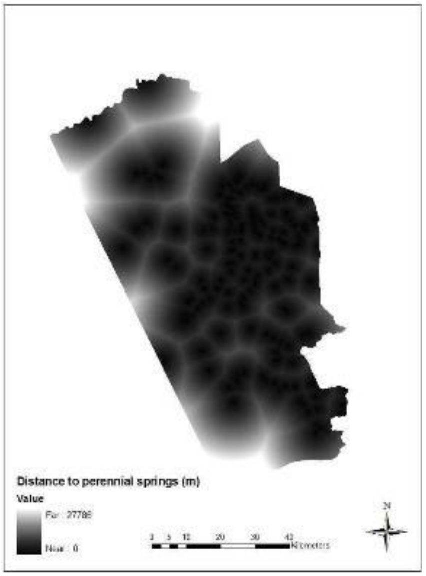
A 95% fixed width probability kernel (FWPK) categorized the habitat use by black rhinos into low and high probability use in Palmwag concession. The results indicated that high probability use (red area) falls within the 95% FWPK, while the low probability habitat use (blue area) falls outside the 95% 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.

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).

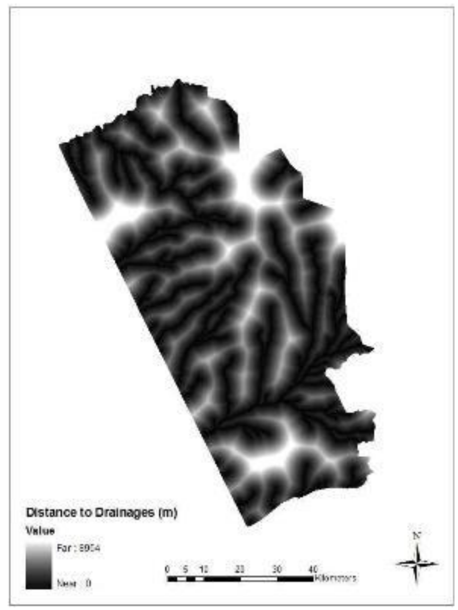


There was a significant difference in mean distance to main rivers between the low and high probability habitat use by black rhinos in Palmwag concession, ($Z = -8.748$, $p < 0.001$). The high probability habitat use was closer to the main rivers, whereas the low habitat use by black rhinos were located 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).

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.



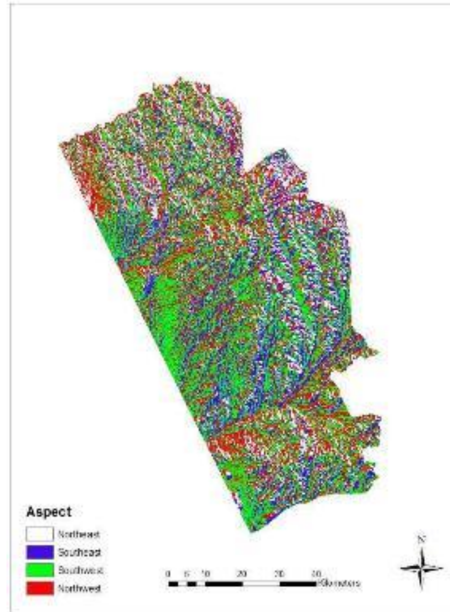
Slope differed significantly between the low and high probability habitat use by black rhinos in Palmwag concession, (Z = -5.018, p = 0.001). The high probability habitat use fell in the areas of steeper slope, while the low probability habitat use fell in the gentle slope. The low probability use area 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).



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.

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).

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 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.



Aspect did not significantly differ between the low and high probability habitat use by black rhinos 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.

DISCUSSION

Plot-level habitat characteristics

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, anthropocentric and physical conditions. Possible climatic and physical conditions include rainfall, soil, elevation, slope and human land uses as discussed below.

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 turns determines the occurrence and persistence of a certain plant species in a certain area.

It was hypothesized that species richness, diversity and composition will differ among the study sites as well as among different habitats due to varying climatic conditions. 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 species rich and diverse as 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. pruinoides* and

C. alexandri 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. pruinoides* and *C. apiculatum* showed frequent occurrence in the high rainfall area of northwest Namibia. Overall, species composition in Torra conservancy was 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.

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 spp*.), 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 habitats soils are likely to have more moisture content as 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.

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, while ≠Khoadi //Hoas conservancy had an elevation range of 814-1348 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 as 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 prefer or 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. 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 (Pugnaire and Låzaro, 2000). Thus, the same concept could apply in this study, where possibly the Torra conservancy being more located in the arid environment may had seed banks and could have germinated as the result of the above normal rainfall of 2006 observed in northwest Namibia and Namibia in general.

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 as 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 (Hiernaux and Herault, 2000) and leading to low species diversity and richness. Campbell (1996) noted that the effects of intensive grazing on rangelands often results in the removal of native species and the consequent are the replacement with the 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 justify the influence of wild herbivores on species diversity, richness and composition in the northwest of Namibia.

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 could have a 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.

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) as well as primary productivity, which in turn contribute to plant biomass. Rainfall determines plant height, leaf size, and eventually browses 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/primary productivity.

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/decreased productivity.

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. 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, 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.

This study has however discovered an interesting trend. ≠Khoadi //Hoas conservancy which appeared to have high number of livestock depicted high browse availability in any case. It is therefore premature to conclude that high livestock densities are large enough to cause significant influence browse availability in northwest Namibia.

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 a degree of influence. A study by Birkett (2002), found giraffe browsing to influence 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.

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. For instance, the pores between clay particles are very small; therefore the movement of air and water will be very slow, resulting on the soil to hold water for a long time, which may enhance plant production. On the negative side, these soils can also become water logged and thus limit plant growth and production.

Additionally, pores between the sand particles can hold little water, thus making the water to move fast or draining very fast. Soil water content is 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; Appendix 10). 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 controlling 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.

Landscape –scale habitat use by black rhino

Influence of environmental variables on habitat use by black rhinos

It was hypothesized that environmental variables are vital factors that determine habitat use by black rhinos, and this hypothesis holds in this study. 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. 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, figure 6 and 8) revealed that riverine habitats in Palmwag concession yielded high browse availability. Another reason, worth commenting is that black rhinos might be utilizing riverine habitat because of the availability of shade and bedding sites (bedding sites maybe a critical component for rhinos). 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. 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.

CONCLUSION AND RECOMMENDATION

This study has highlighted the differences in species diversity, richness and composition among the sampled sites as well as among habitat categories. The differences may be related to factors such as rainfall, soil characteristics, elevation and different human land uses. Local scale analysis identified browse availability to differ significantly among the study sites. ≠Khoadi //Hoas conservancy exhibited high browse availability when compared to 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 selected plants. These plant species were selected on the basis that, they are known to be preferred by black rhinos in northwest Namibia.

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 such as geology, temperature and soil characteristics, it is evident that rainfall and elevation are major factors that drive the production of this arid ecosystem, which consequently dictates water and resource availability (both for fauna and flora).

In light of conservation status of *Diceros bicornis bicornis* and future re-introduction of this sub-species into community conservancies for tourism purposes, this study provides valuable information. This study has highlighted that Torra conservancy, ≠Khoadi //Hoas conservancy and Palmwag concession have heterogeneous landscapes, hence the differences in species diversity, richness, composition as well as browse availability. Thus, these remarkable findings will guide towards the creation or building of black rhino habitat suitability models that are specific for each conservancy. 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.

In the future, the distribution of black rhinos in northwest Namibia will be affected by increasing human population, climate change, and many unforeseeable changes to the environment. Hence, it is crucial that the habitat use by black rhinos is fully understood.

Recommendations

a. Based on browse availability findings in ≠Khoadi //Hoas conservancy, this study signifies 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 (individually and through interaction). 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 slope 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 and livestock activities as well as densities.

b. This study has highlighted the current state 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 or the mostly frequently browsed plant species to avoid misleading browse availability values. This could be strengthened a comprehensive feeding observation of black rhinos in the area concerned. Additionally, browse availability analysis should also be linked to the in-depth analyses on the quality of browse.

c. Due to the scope of this study and time limitation, the influence of livestock and 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.

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