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Woody plant species diversity in the last wild habitat of the Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847) in Niokolo Koba National Park, Senegal, West Africa

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The Niokolo Koba National Park (NKNP) in Senegal is the last refuge of the critically endangered antelope of the subspecies Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847). Woody plants, that provide shelters and forage for the Eland in NKNP, were assessed for their floristic diversity to characterize its confined habitat. Hence, 156 square plots of 20m x 20m were established randomly in the confined area of the Derby Eland. In each plot, list of plants species, their number of individuals, and the environmental factors (soil hardness and type, altitude, percentages of vegetation cover and fire occurrence) were noted. Fifty (50) trees species belonging to 40 genera and 29 families were recorded. The most represented families were *Combretaceae* (13.92%), *Leguminosae-mimosoideae* (12.66 %), *Leguminosae-caesalpinioideae* (11.39 %), *Leguminosae-papilionoideae* (7.59 %), *Rubiaceae* (7.59 %) and *Tiliaceae* (6.33 %). The most abundant species were *Combretum glutinosum* Perr. ex DC., (28.79%), *Pterocarpus erinaceus* Poir. (12.42%), *Crossopteryx febrifuga* (Afzel. ex G. Don) (7.30%), *Strychnos spinosa* Lam. (7.18%) and *Hexalobus monopetalus* (A. Rich.) Engl. & Diels (7.06 %). Altitude, fire occurrence and vegetation cover were the most important environmental factors influencing the distribution of plants species. Results suggest conservation defenders of Eland, for a sustainable management plan, to invest in in-*situ* fencing in order to increase possibilities of conservation of this critically endangered species in its native area.

Key words: Plant inventory, specie composition, confined habitat, wild, sustainable management.

INTRODUCTION

For millennia the earth's greatest diversity of ungulates has been carried by African savannahs that extend from

Senegal in the west to Ethiopia in the east. These biomes include tropical ecosystems characterized by a continuous grass layer occurring together with trees under a different climatic regime (Justice et al., 1994). These ecosystems provide shelters and food for wildlife. Unfortunately during these last decades, researches have shown that savannahs are undergoing degradation and fragmentation due to combined effects of fire, human activities and climate variation (Riggio et al., 2013). Consequently, some species are highly endangered and at risk of extinction among which the large mammals like ungulates are the most threatened (Baskaran et al., 2011). In West Africa particularly in Senegal, the Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847) is one of the mammalian species on the International Union for Conservation of Nature (IUCN) red list of critically endangered species and even close to extinction (UICN, 2008).

The Derby Eland was widespread to West African savannah and its historical range covered Cameroon – Gambian's axis (Dorst and Dandelot, 1970). Nowadays owing to natural and human pressures its wild habitat is solely restricted to the Niokolo Koba National Park (NKNP) and its neighbouring Faleme Hunting Zone both (East, 1998; IUCN, 2008). NKNP is Senegal's largest and oldest national park set on Sudano-Guinean savannah (Madsen et al., 1996; Mbow, 2000). Despite its already shrunk location, the Eland's natural habitat in the national park is currently undergoing degradation emphasizing its shrinking and the number of Eland individuals is decreasing (IUCN, 2008). In 1990, the population of Eland was estimated at 1000 individuals (Sournia and Dupuy, 1990) but its later estimation set between 400 to 800 individuals (East, 1998) and has been decreased to approximately 170 individuals in wildlife in the NKNP (Hájek and Verne, 2000; Renaud et al., 2006).

This continuous decreasing population puts Eland on the UICN critical list of endangered species (IUCN, 2008). In the light of this, some preservative measures were taken with the establishment of the first breeding ex-situ herd in Bandia reserve (Antoninova et al., 2004). Till recent date, little is known on the wild habitat of the Derby Eland in its last natural refuge. Researches had been done on the Western Derby Eland in wild but they had a narrow-scope, mainly oriented on aerial and ground survey in the NKNP (Galat et al., 1992; Hájek and Verne, 2000; Renaud et al, 2006) and on the diet constituents (Hejcmanová et al., 2010). There is lack of ecological information on its habitat which deserves to be filled. In contrast to the habitat of its relative, the Eastern Derby Eland (*Taurotragus derbianus gigas* Heuglin, 1863) which is dwelling in savannah vegetation is dominated by *Isoberlinia doka* (Bro-Jorgensen, 1997; East, 1998; Grazian and d'AlessiSilvio, 2004) is more documented.

Therefore it becomes urgent for a better conservation strategy and a sustainable management in the wild habitat to describe its last habitat. Hence this study aims to improve knowledge and information on the last worldwide wild habitat of the Western Derby Eland for its better ecological management and for decision making. Research focused on the species' composition and diversity in relation with the environmental factors in order to provide basic knowledge for the sustainable management of the Western Derby Eland population in NKNP. As the Derby Eland is a browser (Grazian and d'AlessiSilvio, 2004), the study hypothesized that it lives in habitat with a similar floristic composition.

MATERIALS AND METHODS

Study area

Stretching on 2485 km^2 the study area is located roughly at the centre-east of the NKNP between -13°23' and -12°51' W and 13°23' and 12°69' N (Figure 1). The rainfall regime is single modal from June to September with a mean annual rainfall of 900 to1100 mm. The average monthly temperature is 25°C from November to January and 33°C from April to May, and the relative humidity is between 69 and 97%. In NKNP anthropogenic, activities are strictly prohibited. Therefore vegetation in the park is supposed to be well protected from the anthropogenic factor but it has been strongly affected by the early fire's management (Mbow, 2000; Sonko, 2000). The confined habitat of the Derby Eland identified through a survey with the elder evicted villagers, the researchers and the retired elder and current park rangers, were divided in zone of medium probability of Eland occurrence (ZMPEO) and in zone of high probability of Eland occurrence (ZHPEO) (Figure 1).

Sampling design and data collection

Plant Inventory was made using a stratified random scheme at 2 levels. Stratification was based on a land cover map derived from a supervised classification of Landsat 8/OLI (Operational Land Imager) and a ground truth for validation. Landsat images were acquired in December, 2013 from Glovis (http://glovis.usgs.gov/). Squares plots of 250 m x 250 m size were randomly set on a net grid map of the study area. Within each selected plot, four square sub-plots of 20 m x 20 m size (400 m^2) were established using a random distance from the centre in compass directions (Figure 2). Plots size was justified by the fact that they were used successfully during previous studies (Hejcmanovā and Hejcman, 2006; Sambou et al., 2007; Sambou et al., 2008; Mbow, 2013). The sample size

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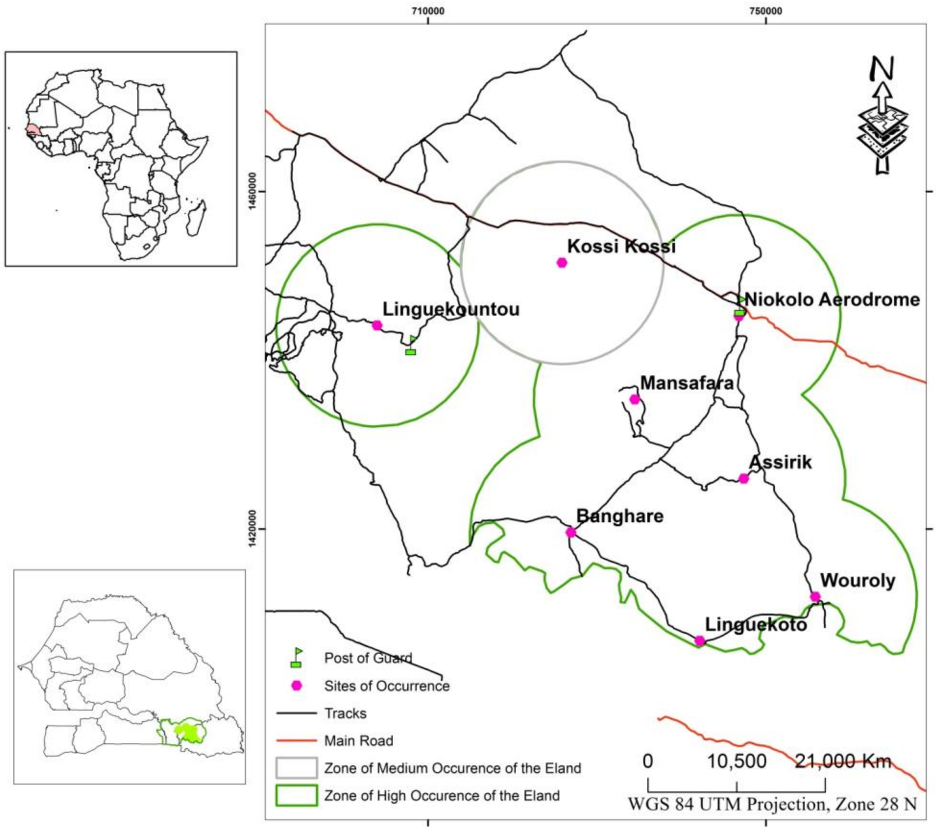

Figure 1. Location of the study sites.

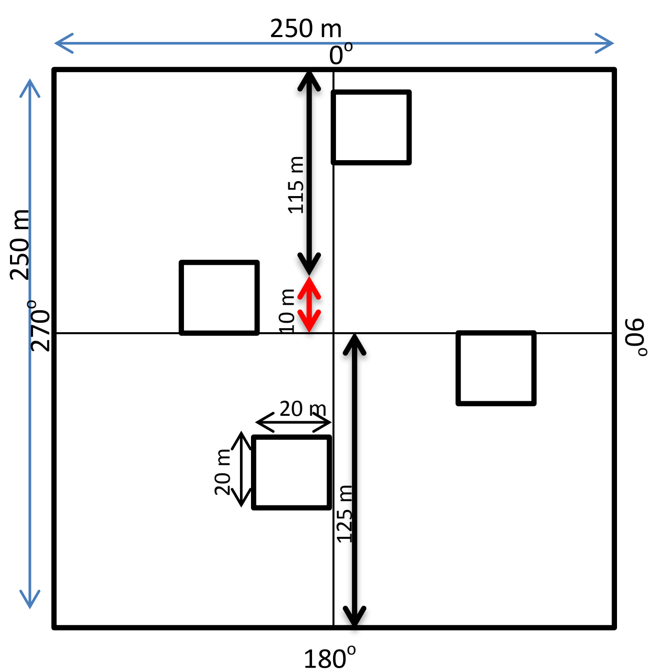

Figure 2. Sampling design.

(N=156 plots) was computed with a margin error of 9% using the following formula of (Dagnelie, 1998):

$$N = t^2_{1-\alpha/2} \frac{cv^2}{d^2} \quad (1)$$

Where N: sample size, $t^2_{1-\frac{\alpha}{2}}$ = 2.04 as value of the Student t distribution test at probability of 0.975 and Cv= 57 % as coefficient of variation of basal area from 30 trees' individuals randomly chosen during a pre-inventory.

Woody plants with dbh ≥5 cm were assessed for their species names and number following (Berhaut, 1967; Lebrun and Stork, 1991, 1997). The altitude and the soil hardness were recorded respectively with an altimeter and a penetrometer. The tree and herbaceous cover were estimated in percentage and the occurrence or not of fire was noted according to traces left.

Data analysis

To test discrimination of the zones of occurrence Derby Eland according to their plants species composition, the matrices of trees species abundance per plot were submitted to a non-metric multidimensional scaling (NMDS) which produces an ordination based on Bray-Curtis dissimilarity (Kruskal, 1964a; Kruskal and Wish, 1978). Confidence ellipses were built for each group of plots at 95%. Before analyses, data quality control led to removal empty and duplicated plots. Then species indicator value analysis, based zones of Derby Eland occurrence in rows and species abundance in columns were used to identify indicator species of each group of plots (De Cáceres et al., 2012). Indicator species are determined using an analysis of the relationship between the species abundance values from a set of sites and the classification of the same sites into site groups (zones of Eland occurrence in our case). The indicator value index (IndVal) is the product of two components, referred to as 'A' and 'B'. Component 'A' called the specificity or the positive predictive value of the species is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. The Component 'B' called the fidelity or sensitivity of the species is the probability of finding the species in plot belonging to the site group. Only the first five most significant species or species combinations were also reported. Alpha diversity indices were computed for each the global stand and for zone of Derby Eland's occurrence as follows:

1. Species richness (S) is the number of species recorded in each zone of occurrence and in the global stand.
2. Shannon-Wiener diversity index (H') was calculated using this formula**:**

$$H' = -\sum_{i=1}^{i=s} pi \, log_2 \, pi \quad (2)$$

Where p (i) = ri /R (ri is the mean number of individuals of the species i and R is the total number of individuals of all species).

3. Evenness coefficient or Pielou's evenness (E_H) measures the diversity degree of a stand compared with the possible maximum. Its value varies between 0 when one or few species have higher abundance than others to 1 when all species have equal abundance (Magurran, 2004). It is computed as following formula:

$$E_H = \frac{H'}{H_{max}} \text{ with } H_{max} = log_2 \, S \quad (3)$$

Where *H'* represents the Shannon-Wiener's diversity index, H_{max} is the maximum value of the diversity index and S the number of species recorded in plots.

A canonical correspondence analysis (CCA) was implemented (ter Braak, 1986; terBraak, 1987) to assess the relationship between the environmental factors and the floristic composition. The CCA model and the significance of the fitted environmental variables were evaluated by the Monte Carlo permutation test with 499 permutations (Hejcmanovā-Nežerková and Hejcman, 2006). These analyses were run in R 3.1.2 using packages vegan (Oksanen et al., 2002) for NMDS and CCA, while indicator species analysis was implemented in Indic species packages (De Caceres and Legendre, 2013). Tests of comparison were executed in Minitab 14.

RESULTS

Floristic composition and diversity

Fifty trees species belonging to 40 genera and 29 families were recorded (Appendix 1). The most represented families were Combretaceae *(*13.92%), Leguminosae-mimosoideae (12.66%), Leguminosae-caesalpinioideae (11.39%), *Leguminosae-papilionoideae (*7.59%), Rubiaceae (7.59%) and Tiliaceae (6.33%). The most abundant species were *Combretum glutinosum* Perr. ex DC., (28.79%), *Pterocarpus erinaceus* Poir. (12.42%), *Crossopteryx febrifuga* (Afzel. ex G. Don) (7.30%), *Strychnos spinosa* Lam. (7.18%) and *Hexalobus monopetalus* (A. Rich.) Engl. & Diels (7.06 %).

The non-metric multidimensional scaling (NMDS) indicated a very good ordination of the plots with r^2 = 0.943 and a stress value of 0.122 (Figure 3). Figure 3 indicates no clear discrimination of the plots, suggesting that floristic composition is quite similar among zones

The species richness and Shannon-Wiener diversity index are higher (S=50 and H'= 3.99) in ZHPEO than in ZMPEO (S=18 and H'=3.20) whereas Pielou's index is higher in ZMPEO (Eq= 0.77) than in ZHPEO (Eq= 0.71) (Table 1). Species indicator analysis (Table 2) reveals no indicator species in ZHPEO while the most indicator species or species combinations for ZMPE O included *Combretum glutinosum* + *Crossopteryx febrifuga, Crossopteryx febrifuga, Combretum glutinosum* + *Pterocarpus erinaceus, Crossopteryx febrifuga* + *Pterocarpus erinaceus* and *Combretum collimum* + *Crossopteryx febrifuga.*

Relationship species-environmental variables

The results of the CCA indicated that the first three axes accounted for 69.46% (29.39% for the first axis, 21.45%

Table 1. Floristic parameters of the zones of occurrence of the Derby Eland.

Parameters	Zone of occurrence of the Eland		Global (n = 140)
	Medium (n = 13)	High (n = 127)	
Specific Richness (S)	18	50	50
Shannon *Index* (H')	3.20	3.99	3.92
Pielou's evenness (Eq)	0.77	0.71	0.69

n is the total number of plots in each zone of Derby Eland occurrence.

Table 2. Indicator species of the zones occurrence of the Derby Eland.

Probability of Derby Eland occurrence	Species combinations	A	B	IndVal	p-value
	Combretum glutinosum + *Crossopteryx febrifuga*	0.817	0.692	0.752	0.002
	Crossopteryx febrifuga	0.787	0.692	0.738	0.002
Medium	*Combretum glutinosum* + *Pterocarpus erinaceus*	0.734	0.615	0.672	0.034
	Crossopteryx febrifuga + *Pterocarpus erinaceus*	0.811	0.461	0.612	0.005
	Combretum collimum + *Crossopteryx febrifuga*	0.932	0.385	0.599	0.001
High	-	-	-	-	-

A= specificity, it is the probability that the surveyed site belongs to the target site group given the fact that the species has been found; B= fidelity, it is the probability of finding the species in sites belonging to the site group; IndVal = Indicator Value Index.

Table 3. Correlation between axes and environmental variables.

Environmental variable	CCA1	CCA2	CCA3
Soil type	-0.031	-0.169	0.512
Fire	-0.287	0.508	-0.705
Altitude	-0.882	0.145	-0.041
Hardness	0.269	-0.089	-0.507
Herbaceous cover	-0.204	-0.073	0.743
Tree cover	0.087	0.828	-0.083

Values ≥ 0.5 presenting significant correlations with axes are in bold.

for the second one and 18.61% for the third one) of the total variation captured by the CCA. Most of the environmental variables showed high correlations (0.51 to 0.88) with the three axes (Table 3).Axis 1 is negatively correlated to altitude, while fire and tree cover are positively correlated to axis 2 (Table 3). Axis 3 is positively correlated to soil type and herbaceous cover and negatively correlated to fire and hardness (Table 3). Projections of these environmental variables on these three CCA axes with the plots (Figure 4a, b) showed that plots of ZMPEO are located in area with low altitude and low tree cover, less occurrence of fire and on short (sandy) to compact clay soils (less hard) whereas plots of the ZHPEO scattered showed a correlation with high altitude and high tree cover, more occurrence of fire and hard substrate (outcrop granite).

DISCUSSION

Floristic composition and diversity

Predominant families such as combretaceae, leguminosae-mimosoideae, leguminosae-caesalpinioideae, leguminosae-papilinoideae, rubiaceae and tilliaceae found are in accordance with findings run on the diets of Derby Eland in NKNP (Hejcmanová, et al., 2010). The richness of 50 woody species with dbh ≥ 5 cm assessed on 6.24 ha is different compare to the 59 species of trees and shrubs identified on an area of 5 km^2 (Hejcmanovā-Nežerková and Hejcman, 2006) but lower than the106 woody species found on an area of 228 km^2both in NKNP (Traore, 1997). This diversity is an important asset for herbivorous browsers such as Eland

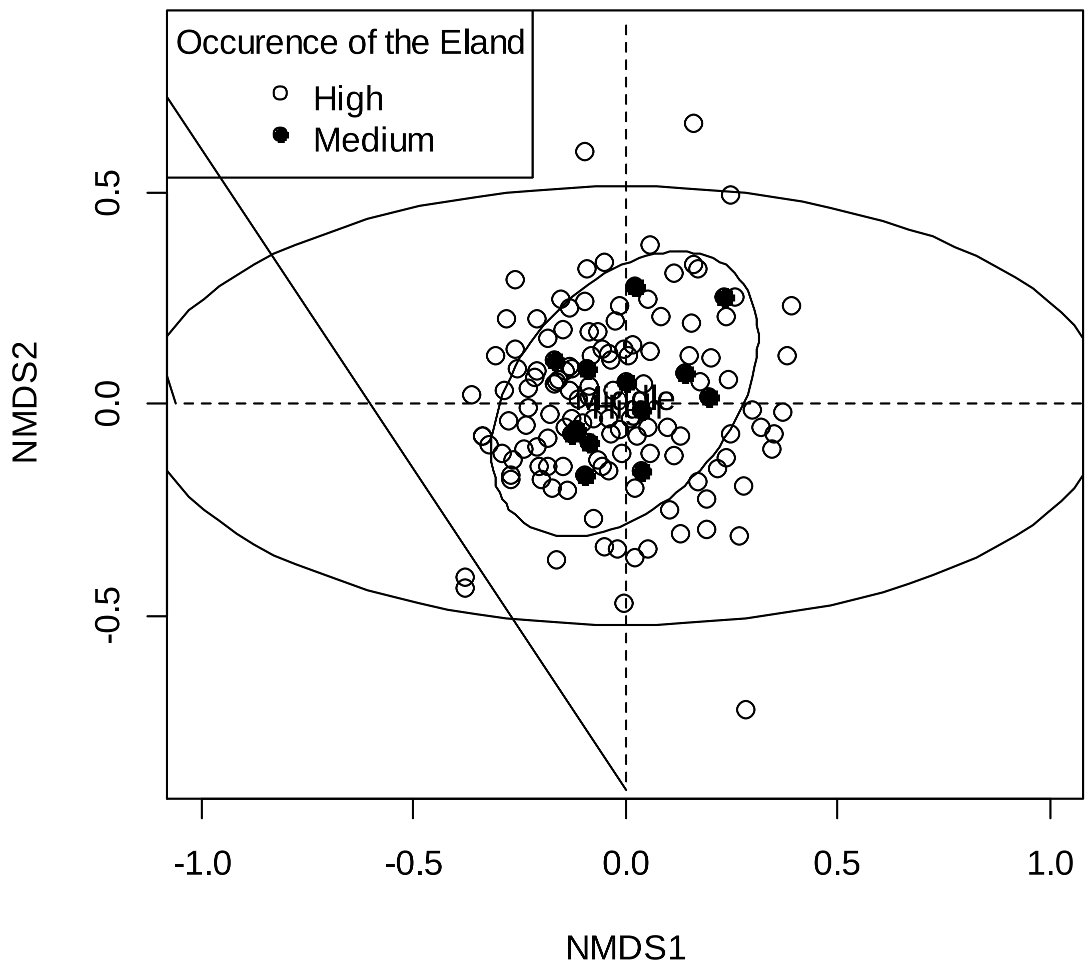

Figure 3. Non-metric multidimensional scaling of plots from zone of medium and high occurrence of Derby-Eland.

which find variate fodder within their habitat. However, this woody plant richness is very low compared to those found in of the Eastern Eland's (*T. d. gigas*) habitat. Indeed Grazian and d'AlessiSilvio (2004) recorded 212 species and Bro-Jorgensen (1997) noted less than 10 common species in the habitat of the Eastern Eland in Central African Republic. This difference may be attributed to data collection method, geographical location and local climatic conditions. Habitats of the Western and the Eastern Eland are also different in terms of species composition (Spinage, 1986; Bro-Jorgensen, 1997; Kingdon, 1997). The Eastern Eland is found in *Isoberlinia doka* (Craib & Stapf) savannah (Bro-Jorgensen, 1997; East, 1998) while this species is not recorded in Senegalese flora (Berhaut, 1967; Ba et al., 1997).

The NMDS analysis reveals that the vegetation of the confined area of the Derby Eland in NKNP harbours almost the same woody species (Figure 3). This finding supports hypothesis that the Eland frequents habitat with a quite similar floristic composition (Kruskal, 1964b). This floristic similarity is witnessed by the results of species indicator analysis. Indeed even though some species or combinations of species present specificity none fidelity of species recorded in the Derby Eland habitat (Dufrene and Legendre, 1997; De Cáceres and Legendre, 2009; De Cáceres et al., 2012) (Table 2).

Relationship species-environmental variables

The CCA analysis reveals that fire, soil type, altitude and trees cover are the most important environmental factors influencing the vegetation distribution. Overall, shrubs and small trees are found in ZMPEO whereas big trees are found in ZHPEO. Traore (1997) and Hejcmanovā-

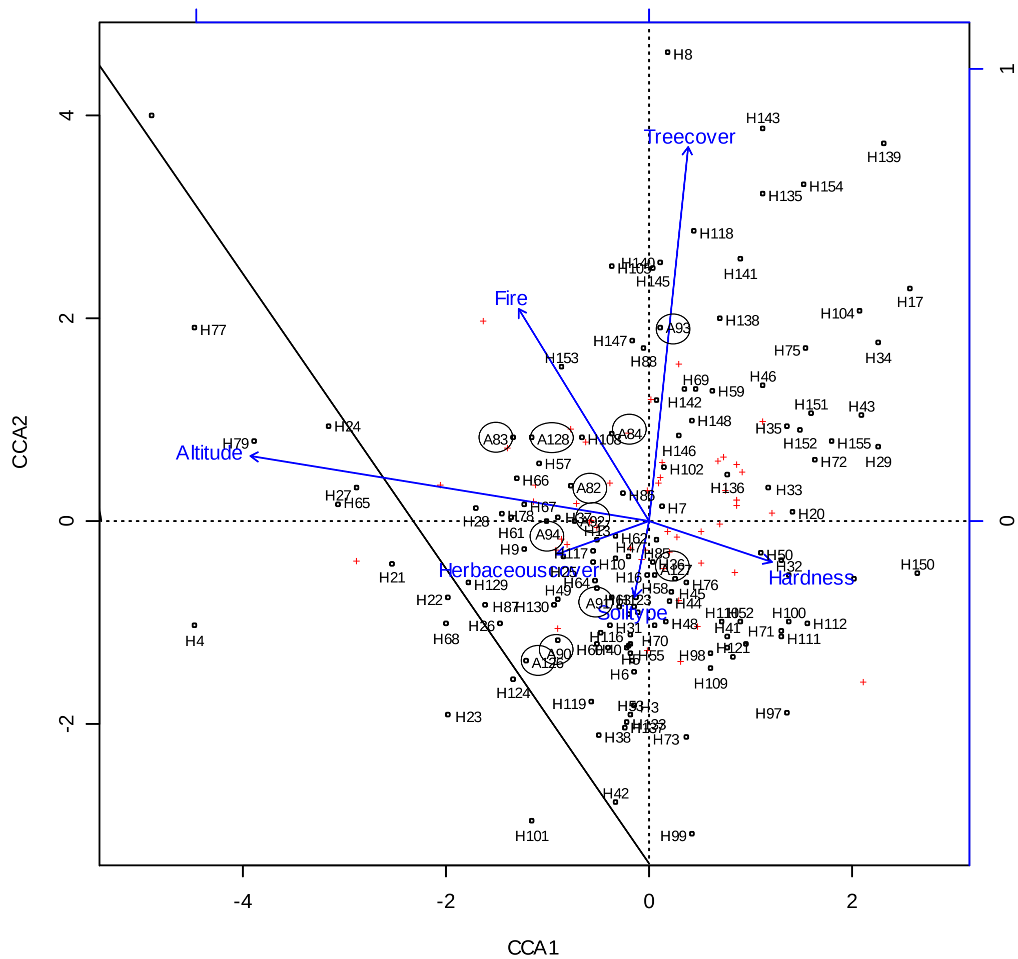

Figure 4a. Influence of environmental variables on the floristic composition in the (a) axes 1 and 2, (b) axes 1 and 3; Loading of sample units from zones of medium (A, black circle) and high (H) occurrence of Derby-Eland.

Nežerková and Hejcman (2006) identified soil type and topography as factors impacting the species composition of the NKNP. Topography was also described as key factors determining Eland habitat (East, 1998), and this is witnessed by park rangers' observations. Indeed migratory movements are noticed from low altitude and marshy areas to high altitude and hilly rocky areas from the dry season to the raining season (park rangers' observations).

Mbow (2000) identified fire as patter controlling the species composition in NKNP. Indeed early fires are used every year by park rangers as tool management to prevent damages of late fires occurring in the late dry with catastrophic consequences. These fires improve regrowth of some herbaceous species participating to herbivores feeding, increase sight possibilities for tourism and remove predation for herbivores. In NKNP apart from removal predation and preventing consequences of late fire, these early fires do not impact really on Derby Eland survival because Hejcmanová et al., (2010) found that the Western Derby Eland feeds on grasses less than 5%. In contrast Bro-Jorgensen (1997) admitted that Eastern Eland never feeds on grass while Hillman and Fryxell (1998) showed that Eastern Eland takes a few amount of fresh sprouting grass in the early wet season. Trochain (1940) and Lawesson (1995) argued that climatic conditions are the most important factors that determine the vegetation NKNP and habitat of Derby Eland.

CONCLUSION AND RECOMMENDATIONS

The zones of occurrence of the Derby Eland has a high floristic diversity of which Combretacea is the dominated

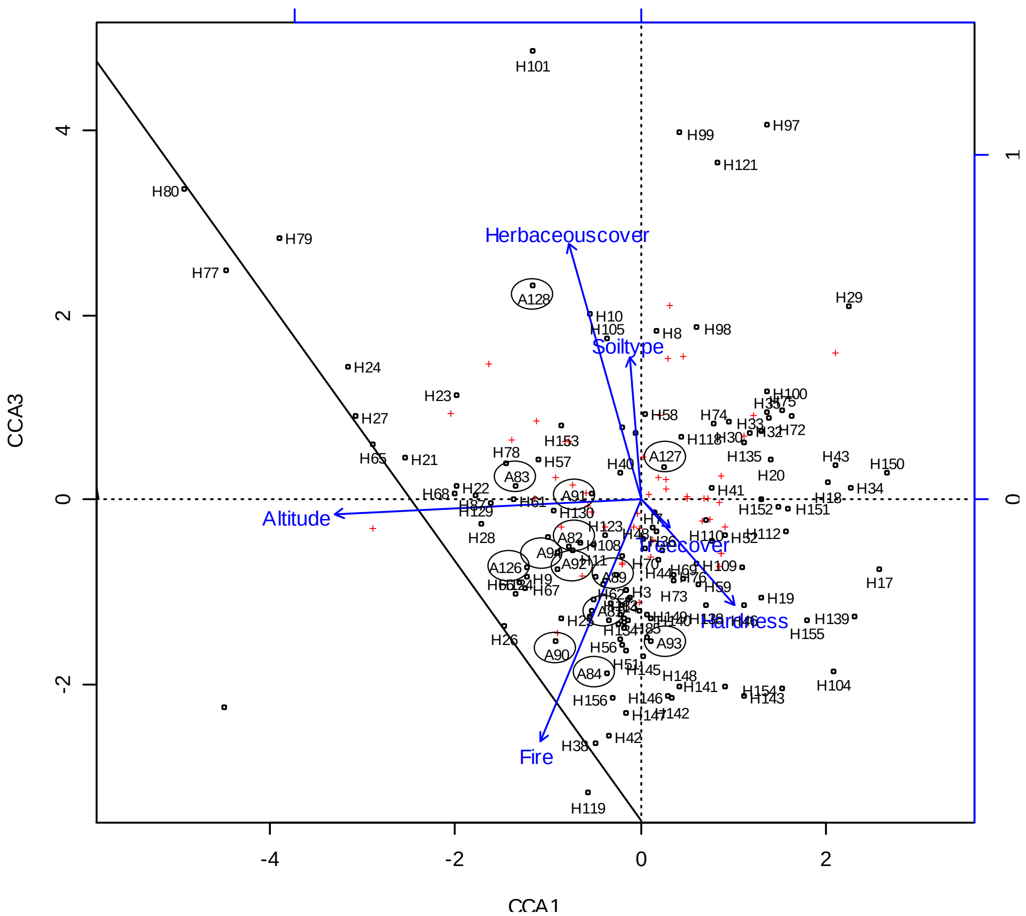

Figure 4b. Influence of environmental variables on the floristic composition in the (a) axes 1 and 2, (b) axes 1 and 3; Loading of sample units from zones of medium (A, black circle) and high (H) occurrence of Derby-Eland.

family even though the estimated number of plant species in NKNP is exceeding 1000 (Madsen et al., 1996). Altitude, fire occurrence and vegetation cover were the most important environmental factors influencing the distribution of these species. These factors were identified as influencing factors on the vegetation of NKNP but they seem not to have negative impact on the floristic composition because Hejcmanovā-Nežerková and Hejcman (2006) identified similar species richness. However, compare to the habitat of its relative relative the Eastern Derby Eland; the Habitat of the Western Derby Eland has less rich and diverse flora.

Nevertheless information on the floristic composition of Derby Eland's confined area is bedrock for its conservation, and will assist management decisions on the choice of new sites for future *in-situ* conservation fencing for the remaining wild population in NKNP and eventually for the *ex-situ* population at Badian and Fathala reserves. To enhance a sustainable management and conservation of the Derby Eland in NKNP, further to the settlement of the *in-situ* enclosure, it is highly recommend the use of telemetric tools like GPS collars and camera traps in order to enhance information in its last wild habitat.

Conflict of Interests

The authors have not declared any conflict of interests.

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