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Speciality: Climate Change and Biodiversity

Characterization of the Habitat of the Western Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847) in Relation to Climate Change within Niokolo Koba National Park (Senegal), its Last Wild Refuge

Mariama Camara

Public defense on 19th November 2016

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REPUBLIQUE DE COTE D'IVOIRE
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THÈSE

Présentée pour l'obtention du Titre de Docteur de L'Université Félix HOUPHOUËT BOIGNY

Spécialité: Changement climatique et Biodiversité

Caractérisation de l'Habitat de l'Eland de Derby Occidental (*Taurotragus derbianus derbianus* Gray, 1847) en Relation avec le Changement Climatique au sein du Parc National du Niokolo Koba (Sénégal), son Dernier Refuge Naturel

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Soutenue publiquement le 19 Novembre 2016

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DEDICATION

To my Family,

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Abstract

Endemic to West Africa, the Western Derby Eland (WDE) (*Taurotragus derbianus derbianus* Gray, 1847) the biggest antelope worldwide is critically endangered and close to extinction. This study aims to characterize the habitat of the WDE in its last wild refuge the Niokolo Koba National Park (NKNP), Senegal. This research was based on semi-structured interviews, remote sensing, woody plants inventory and modelling the distribution of the plants species consumed (PSC). Interviews revealed that the confinement area of the WDE is at the Centre-Eastern part of the NKNP where 50 trees species belonging to 40 genera and 29 families were recorded. Analysis of time series Landsat images showed that savanna vegetation dominated the land cover of the confinement area of the WDE. From 1973-2013 tree-savanna, gallery forest and bamboo forest increased by 11.35 %, 12.30 % and 13.36% respectively while shrub savanna and shrub-tree savanna decreased by 34.09% and 3.11 %, respectively. The current potential distribution of PSC showed that 30.26 %, 54.75%, 24.56 %, 25.55 % and 43.69 % of the park's extent are suitable habitats for *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. and *Zyzyphus mauritiana* Lam., respectively. However, GFDL-ESM, HadGEM2-ES and MPI-ESM-LR models predicted that on the five PSC *B. angustifolia* A. Rich., *H. acida* Juss. and *S. spinosa* Lam. would encounter an increase of their unsuitable areas or even extinction by the end of this century. This combined with the increase of woody vegetation could in turn impact negatively the survival of the WDE. Therefore, we highly recommend setting *in-situ* enclosures for its conservation. In addition, future research, using telemetric tools, should identify the full and home range, the total population and the ethology of the WDE in NKNP.

Key words: Critically Endangered, confinement area**,** land cover dynamics, plant inventory, modelling, conservation.

Résumé

Endémique à l’Afrique Occidentale, l’Eland de Derby Occidental (EDO), la plus grande antilope du monde est en danger critique et proche de l’extinction. Cette étude vise à caractériser l'habitat de l’EDO dans son dernier refuge sauvage, le Parc national du Niokolo Koba (PNNK), Sénégal. Elle est basée sur des entretiens semi-structurés, la télédétection, l’inventaire floristique des plantes ligneuses et la modélisation de la distribution des espèces appétées. Les interviews ont révélé que l’EDO demeure dans le centre-est du parc où 50 espèces d'arbres appartenant à 40 genres et 29 familles ont été recensées. L'analyse diachronique des images Landsat a montré que la savane domine la végétation de la zone d’occurrence de l’EDO. De 1973 à 2013, la Savane arborée, la forêt galerie et la forêt de bambou ont augmenté respectivement de 11,35%, 12,30% et 13,36%, tandis que la savane arbustive et la savane arbustive à arborée ont diminué respectivement de 34,09% et 3,11%. Les résultats de la distribution potentielle actuelle des espèces appétées ont montré que 30,26%, 54,75%, 24,56%, 25,55% et 43,69% de la surface du parc sont, respectivement, des habitats favorables pour *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. et *Zyzyphus mauritiana* Lam. Cependant, les modèles GFDL-ESM, HadGEM2-ES and MPI-ESM-LR prédisent que sur les cinq espèces appétées *B. angustifolia* A. Rich., *H. acida* Tul. et *S. spinosa* Lam. subiraient une diminution drastique de leur surfaces favorables, voire une extinction d'ici la fin du siècle. Ces potentielles disparitions des espèces appétées combinées à la densification de la végétation pourraient influencer négativement la survie de l'EDO. Ainsi, nous recommandons fortement la création de sites de conservation *in-situ* pour sa conservation. En plus, les futures recherches en s’appuyant sur la télémétrie, doivent identifier l’aire d’occurrence, le domaine vital et la population de l’EDO de même que son éthologie dans le PNNK.

Mots clés: En danger critique, aire de confinement, dynamique d’occupation du sol, inventaire floristique, modélisation, conservation.

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List of Acronyms

ANACIM: *Agence Nationale de l'Aviation Civile et de la Météorologie*

AUC: Area Under Curve

AOF: *Afrique Occidental Française*

CEM: Climate Envelope Modelling

DBH: Diameter at Breast Height

DNP: Directorate of National Parks

ECOWAS: Economic Community of West African States

IPCC: Intergovernmental Panel on Climate Change

IUCN: International Union for the Conservation of Nature

FST: Faculty of Sciences and Techniques

GCMs: General Circulation Models

GIS: Geographic Information System

GLC: Global Land Cover

GPS: Global Positionning System

HadCM: specific GCM including future climate simulations

IPNI: International Plant Names Index

MaxEnt: Maximum Entropy probability distribution model

NKNP: Niokolo Koba National Park

RCPs: Representative Concentration Pathways

RGB: Red, Green and Blue

ROIs: Regions of Interest

ROC: Receiver Operating Characteristic

SCD: Size Class Distribution

SPEW: Society for the Protection of the Environment and Wildlife

UCAD: University Cheikh Anta Diop of Dakar

UNESCO: United Nations Educational, Scientific and Cultural Organization

WDE: Western Derby Eland

ZHPOE: Zone of High Probability of Occurrence of the Eland

ZLPOE: Zone of Low Probability of Occurrence of the Eland

ZMPOE: Zone of Medium Probability of Occurrence of the Eland

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INTRODUCTION

For millennia the earth's greatest diversity of Ungulates has been carried by the African savanna that extends from Senegal in the west to Ethiopia in the east. This biome includes tropical ecosystems characterized by a continuous grass layer occurring together with trees under a different climatic regime **(Justice *et al*., 1994)**. These ecosystems provide several natural benefits which sustain human welfare through services such as food, medicine, shelter, etc. and also offer financial supply via eco-tourism amongst others **(Boyd & Banzhaf, 2007)** and likewise shelters and food for wildlife. Unfortunately, during these last decades, research has shown that savanna is undergoing degradation, fragmentation and huge biodiversity loss due to combined effects of fire outbreak, human activities and climate change and variation **(Riggio *et al*., 2013)**. Climate change is defined by the Intergovernmental Panel on Climate Change **(IPCC, 2007)** as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer, either by natural or human activity. Consequently, some species are highly endangered and at risk of extinction. It has been observed that large mammals like ungulates are the most threatened species **(Basrankan *et al.*, 2011)**. In West Africa, particularly in Senegal, the Western Derby Eland (WDE), *Taurotragus derbianus derbianus* Gray (1847), is one of the mammalian sub-species on the International Union for the Conservation of Nature (IUCN) red list, endangered and even close to extinction **(IUCN, 2008)**.

Conservationists in hope of preserving its genetic pools have moved some individuals, one male and five females, of this sub-species from their natural habitat, the Niokolo Koba National Park (NKNP) Southeast Senegal with Soudano-Guinean climate, to an *ex-situ* conservation site, the Bandia reserve Centre-West in the Senegalese Sahelian zone. This is the first captive breeding herd site worldwide for this sub-species **(Antoniva *et al.*, 2004).** The establishment of Bandia reserve was jointly undertaken by the Society for the Protection of the Environment and Wildlife (SPEW) in Senegal and the Directorate National Parks in 2000. The favourable response of the WDE within the confine of the Bandia reserve led to the creation of an additional *ex-situ* conservation site, the Fathala reserve.

Although, numerous studies have been conducted on the WDE, most of them were focused on the semi-captive populations. To date, very little is known about their wild habitat.

Conscious of the danger that the definitive loss of this species in the wild would have on biodiversity, its conservation and management become crucial. Therefore, this study a follow-up on past studies sets out to characterize the wild habitat of the WDE, *T. derbianus derbianus,* in its last wild refuge, the Niokolo Koba National Park (NKNP), South-East Senegal.

Background and Problem identification

Climate change and their impacts in Sub-Saharan Africa are a major global concern. The Sahel and Sudanian zones of West Africa have undergone recurrent drought periods since the early 1970s **(Nicholson, 2005; Mertz *et al*., 2010)**. **Hulme *et al.* (2001)** reported that annual rainfall in the Sahel fell between 20 and 30 % from 1930 to 1960. Moreover, the following 30-yr period (1961–1990), the Sahel experienced a significant drought (about 25 %) compared to previous decades of this century. Senegal like the other Sahelian countries experienced a tremendous decline in their natural ecosystems. This was subsequent to the rainfall decline observed from 1968 to 1993 which was related to climate change **Dai *et al.* (2004)**. Since then, annual rainfall has remained on average less than 200 – 1100 mm in comparison to periods before the drought when it fluctuated between 400 and up to 1600 mm **(Nicholson *et al.*, 2000; Dacosta *et al.*, 2002)**. An increasing trend in temperature was also reported after the droughts **(Lebel & Ali, 2009)**. **Leborgne (1988)** and **Dacosta *et al*. (1991)** reported a persisting falling of the precipitation on the entire country. Indeed the isohyets 500 and 1000 mm were shifted of 100 km and 150 km southward, respectively. Moreover, the isohyet 1500 mm disappeared completely on the territory. However, recent observations (roughly in the 2000s) have shown an uneven distribution in the intensity and frequency of the rainfall events over the country **(Salack *et al.*, 2011)**.

These fluctuations in rainfall patterns and drought periods have severe consequences on the country's natural vegetation cover. This is due to the fact that the Senegalese plants structure and growth are highly dependent on the prevailing climatic regime **(Trochain, 1940)**. The drought led to a disruption of biological activities within natural ecosystems, loss of plants species, shrinking and shifting southwards of the vegetative areas amongst others **(Poupon, 1980; Gonzalez, 1997; 2001)**. These negative changes on the plant communities, different in rates and magnitudes through the country, are related to short-term climate perturbations combined to longer-term anthropogenic activities such as logging, mining, extension of cultivation lands, poaching, livestock grazing, fire etc. **(Nicholson, 1989; Hulme, 1996; Goudiaby *et al*., 2004)** that in turn have drastic consequences on the survival of wild animals such as the Western Derby Eland in NKNP **(Antoninova *et al*., 2004; Basrankan *et al*., 2011)**.

The WDE commonly referred to as Lord Eland or Giant Eland is Critically Endangered and even close to extinction **(IUCN, 2008)**. Since 1996, the WDE is classified on the IUCN red list **(Bro-Jorgensen, 1997; East, 1998).** It constitutes with its Eastern relative, *Taurotragus derbianus gigas* Heuglin, 1863, the biggest Antelope worldwide. Endemic to West Africa **(Dorst & Dandelot, 1970; Hajek & Verne, 2000)**, it was initially found along the Cameroon – Gambian axis **(Dorst & Dandelot, 1970; Prince & Fisher, 1970)**. But the WDE has been considered extinct in Côte d'Ivoire in 1962 **(Gentry, 1971)**. It was stated nearly extinct in Gambia, extinct in Guinea-Bissau and Guinea and greatly in danger in Mali in the 1970s **(Prince Philip & Fisher, 1970)**. Nowadays, due to climate fluctuation and human pressures, such as heavy poaching among others **(Bro-Jorgensen, 1997)**, its wild habitat is only restricted to the NKNP and its neighbouring Faleme Hunting Zone in Senegal (**East, 1998**; **IUCN, 2008)**. Despite its already shrunken location, its natural habitat within the national park is currently undergoing degradation and the number of individuals is decreasing **(IUCN, 2008)**. Indeed, in the early 1990s its population was estimated at 1000 individuals of which 700 – 800 were in NKNP and the rest around the Faleme River **(Sournia & Dupuy, 1990)**. Later it was estimated between 400 – 800 individuals **(East, 1998),** but this has failed to approximately 170 individuals in the NKNP **(Hájek & Verne, 2000; Renaud *et al*., 2006)**. However, reasons of this population decline are under-explained scientifically.

The same phenomenon was observed about the Eastern Derby Eland populations and efforts were made by scientists in front of the declining number of individuals. **Bro-Jorgensen (1997)** conducted the first in-depth study on the Eastern giant Eland's ecology and ethology in northern Cameroon **(Neierkov *et al*., 2004)** in the wild. However to date, the threats and the lack of ecological knowledge on the wild WDE remain unexplained, misunderstood and under studied.

Studies have been conducted on the WDE in the wild but they had a narrow-scope and were mainly done on aerial and ground surveys in the National Park **(Galat *et al*., 1992; Hájek &**

Verne, 2000; Renaud *et al.*, 2006). Studies were also carried out in semi-captivity on the herd structure **(Antoninova *et al.*, 2004),** on the diet constituents (**Hejecmanova *et al.*, 2010)** and on the diet preference (**Galat *et al.;* 2011). Hejecmanova *et al.* (2011)** investigated the suckling behaviour and **Kolackova *et al.* (2011)** explored the population management in semi-captivity**.**

Notwithstanding the above, several questions about applicable ecological knowledge on wild WDE are indispensable to be answered for decision making on rangeland management and biodiversity conservation **(Watkinson & Ormerod, 2001; Hejecmanova *et al.*, 2010).** Hence, there is a necessity to know more on the natural habitats of the Lord WDE in its new shrunken wild location in order to understand the driving forces of its threats and to provide sound recommendations for the management of its population in NKNP. Therefore, there is an urgent need to assess the habitat of the wild WDE within the NKNP.

Research questions

This research seeks to answer the following questions:

- Where does the WDE occur in NKNP nowadays?
- What is the dynamics of vegetation in the confinement area since the occurrence of the drought from 1973 to 2013?
- What are the species composition, the vegetation structure and the regeneration status of the vegetation in the confinement area of the WDE within the NKNP?
- What is the impact of climate change on the distribution and shift of the plant species consumed by the WDE within the NKNP?

Objectives and hypotheses

Following the worry expressed by **Ruggiero (1990)** "Will the world's largest antelope, a shy inhabitant of the densely wooded savanna, become extinct without ever having been studied in the wild?"**.** The main objective of this study is to characterize the habitat of the Endangered WDE within its last wild refuge. In a view to provide a better understanding of its habitat and its threatening factors as well as to fill the lack of scientific knowledge on the WDE within NKNP. This characterization will provide a basis for decision makers and conservationists to improve its conservation on the chessboard of Senegalese and West African biodiversity. The specific objectives of the study and their respective hypotheses are to:

- Identify the zones of occurrence or the confinement area of the WDE in NKNP.

  Hypothesis: The anthropogenic pressures at the borders of the park confine the occurrence of the WDE within the NKNP.
- Determine the dynamics of the vegetation in the confinement area of the WDE in relation with climatic parameters from 1973 to 2013.

  Hypothesis: Rainfall fluctuation (drought and recovery) is the main driver of the dynamics of vegetation in the confinement area of the WDE from 1973 to 2013.
- Characterize the species composition, the vegetation structure, and the regeneration status of the vegetation in the confinement area of the WDE within the NKNP.

  Hypothesis: There is no significant difference in the floristic composition, the vegetation structure and the regeneration ability in the confinement area of the WDE in NKNP.
- Predict the impact of climate change on the distribution of the plant species consumed by the WDE within NKNP.

  Hypothesis: Climate change will not affect the distribution of the plant species consumed by the WDE in NKNP.

This dissertation is composed of four themed chapters. This dissertation begins by the introduction and ends by the conclusion and the recommendations. The first chapter examines the generalities on the WDE and the study area. Chapter 2 describes the methodology and the concepts used to collect data. The third chapter presents the findings obtained from the methodology used for this study. The fourth chapter presents the discussion of the mains results of this study.

Chapter 1:

GENERALITIES

1.1. Presentation of the Western Derby Eland

The Western Derby Eland belongs to the Antelope's group which is the most heterogeneous Mammals' ruminant group characterized by tiny and long legs, hallow and bow horn. Fearful, they rely on keen senses and their speed to avoid predators. Their eyes, with horizontally elongated pupil, on the sides of their heads are giving them a broad radius of vision with minimal binocular vision. They have also acute senses of smell and hearing which give them the ability to perceive danger at night out in the open, when predators are often on the prowl. These senses added to vocal communications such as loud barks, whistles, "moos", and trumpeting play an important role in the contact between individuals. Scent marking is also used to maintain contact with the members of the herd. The English word "Antelope" derived from the old French *Antelop* appeared first in 1417. It was itself derived from medieval Latin *ant (h) alopus*, which in turn comes from the Byzantine Greek word *anthólops,* first attested in Eustathius of Antioch (*circa* 336) (**Harper, 2008**). Antelope is referring to many even-toed Ungulate species indigenous to various regions in Africa and Eurasia distributed into 91 species occurred in about 30 genera different in size, weight, horn and coat. Africa has the highest diversity of Antelopes with seven sub-families including four endemic, Aepycerotinae, Alcelaphinae, Cephalophinae and Reduncinae **(Huffman, 2007)**.

1.1.1. Taxonomy

Taxonomic studies (**Huffman, 2007; Rubes *et al*., 2008; Groves *et al*., 2011**) put the WDE into the genus of ***Taurotragus*** (Wagner, 1855) with the common Eland (*Taurotragus oryx* Pallas, 1766). According to them the WDE's classification is as following:

Kingdom: Animalia
Phylum: Chordata
Sub-phylum: Vertebrata
Class: Mammalia
Sub-class: Theria
Infra-class: Eutheria
Super order: Laurasiatheria
Order: Cetartiodactyla

Family: Bovidae

Sub-Family: Bovinae

Genus: *Taurotragus* Wagner, 1855

Species: *T. derbianus* Gray, 1847

Sub-species: *T. d. dernianus*

Two sub-species, *Taurotragus derbianus derbianus* (Gray, 1847) endemic to West Africa and its relative *Taurotragus derbianus gigas* (Heuglin, 1863) endemic to East Africa, have been recognized. However, some authors classified the WDE in the ***Tragelaphus*** (Blainville, 1816) genus **(Baillie *et al*., 1996; East, 1999; Planton & Michaux, 2013)**. *Tragelaphus'* genus contains antelopes with spiralled horns and white stripes such as: Nyala *Tragelaphus angasii* (Gray, 1849), Mountain Nyala *Tragelaphus buxtoni* (Lydekker, 1910), Bongo *Tragelaphus eurycerus* (Ogilby, 1837), Lesser kudu *Tragelaphus imberbis* (Blyth, 1869), Kéwel *Tragelaphus scriptus* (Pallas, 1766), Sitatunga *Tragelaphus spekeii* (Sclater, 1863), Greater kudu *Tragelaphus strepsiceros* (Pallas, 1766) and Imbabala *Tragelaphus sylvaticus* (Blainville, 1816).

1.1.2. Ecology

The WDE is the biggest antelope worldwide inhabiting the Sudanese savanna and wooded grassland. The WDE is a generalist browser herbivore foraging on a large variety of trees and shrubs species, generally leaves and some fruits and rarely on grasses less than 5 % **(Hejecmanova *et al.*, 2010; Galat *et al.*, 2011)**. **Bro-Jorgensen (1997)** reported that the Eastern Derby Eland (*Taurotragus derbianus gigas* Heuglin, 1863) is not feeding on grasses. It has commonly been assumed that its body size is constraining to feed on grasses. The WDE has been observed in the wild either solitary or in herd. In case of herd they are mixed sex and size ranging from two to near seventy individuals. **Blancou (1960)** reported that the Eastern Derby Elands aggregate in big herds during the dry season and split them in small ones during the rainy season. In contrast, **Bro-Jorgensen (1997)** observed larger groups split into smaller ones in the early dry season and get together again in the late dry and early wet seasons. For now, the largest herd of the WDE observed in NKNP was during the late dry season with 69 individuals on Niokolo plates **(Renauld *et al.*, 2006)**. Its status of browser suggests a long list of plant species consumed. **Bro-Jorgensen (1997)** found that the Eastern Derby Eland in Cameroon consumes

65 plants species. **Galat *et al.* (2011)** observed that the semi-captive population in Bandia reserve feed on 33 plant species including *Grewia bicolor* Juss. and *Ziziphus mauritiana* Lam. which were among the most preferered species. In contrast, within NKNP only five plant species, *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. and *Ziziphus mauritiana* Lam., were described, using faeces analyses, as part of the diet of the WDE **(Hejcmanová *et al.*, 2010)**. To date, no information is available on their proportion and nutrient content level in dietary composition of the WDE. In addition, their contribution in the body mass, the basic metabolism and their nutritional value for the WDE in NKNP are also unknown. However, such kinds of data are required to comprehend the ecology of herbivore because they offer a better understanding of its physiology and ecology. This raises the entails to document the ecology of the WDE in the wild. Moreover, to our knowledge no study on social organisation, population trend, behaviour or home range for WDE in NKNP is available. The home range (HR) of an animal is the space that encompasses all the resources the animal requires to survive and reproduce **(Burt, 1943)**. **Graziani & d'Alessio (2004)** using GPS collars reported that the home range of its relative the Eastern Derby Eland is 8 278 ha and 47 517 ha for the female and the male, respectively.

1.1.3. Morphology

The WDE has a chestnut colour, sometimes with a tint of bluish grey. Adults grow a knot of brown hairs on the forehead. It has a black mane on its neck from which a black stripe continues along the entire length of the back (Fig. 1). From the chin to the chest, hangs an enormous black and white dewlap. This depends on the animal's age and the season. It has roughly nine to fifteen white stripes on its flanks while the Eastern sub-species (Fig. 2) which has thirteen. These white stripes like digital marks are different from one individual to another. It has a considerable body with a length of 290 cm for the male and 220 cm for the female. Its height at the withers is between 150 – 176 cm for the male and 150 cm for the female. It weighs 450 – 950 kg for the male and 440 kg for the female showing a sexual dimorphism. Both sexes have spiralled horns which can reach a length of up to 80 – 123 cm **(Dorst & Dandelot, 1970; Kingdon, 1997)**.

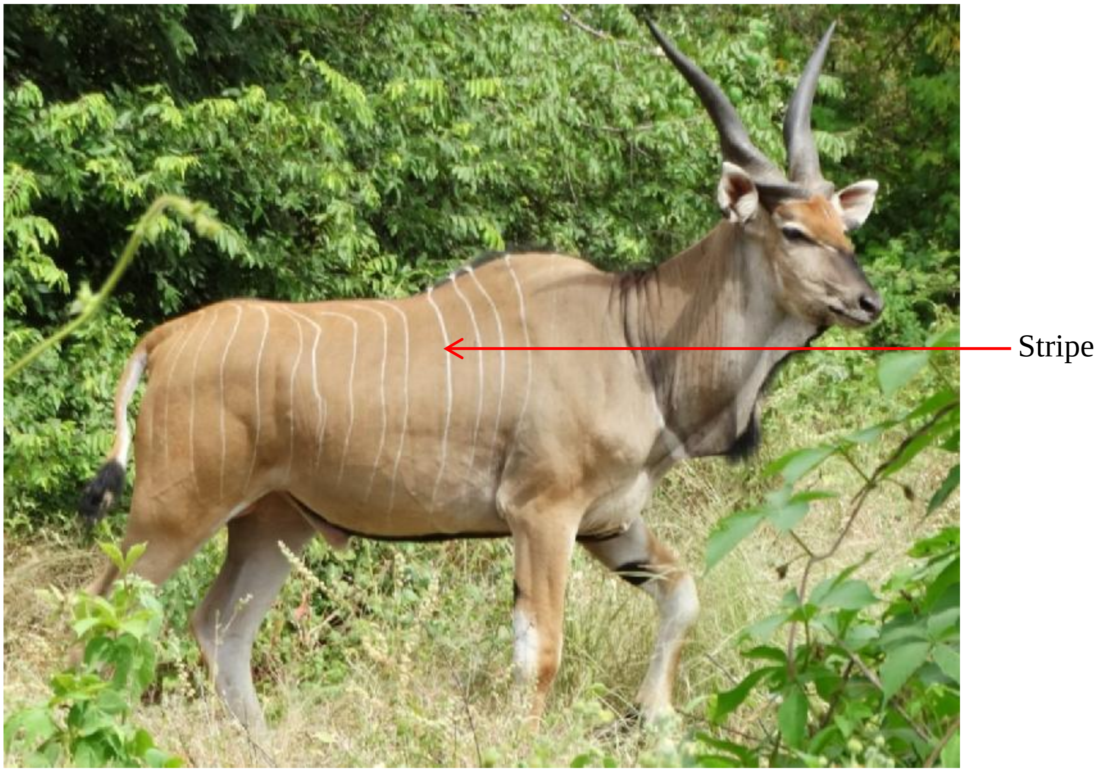


Figure 1: Photo of the Western Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847) with its 15 white stripes in Bandia Reserve (Camara, 2013)

Figure 2: Photo of the Eastern Derby Eland (*Taurotragus derbianus gigas* Heuglin, 1863) with its 13 white stripes (Johannesburg Zoo, 2011)

1.1.4. Geographical distribution

Initially found along the Cameroon – Gambian axis **(Dorst & Dandelot, 1970)** the original distribution of the Derby Eland probably was extended across the Sudanese-Guinea savanna from Senegal in the west to Sudan in the east, but has since been reduced to two separate ranges (Fig. 3) **(Gentry, 1971).** The historical documented distribution of the WDE ranged through Senegal, Gambia, Guinea Bissau, Guinea and Mali, **(East, 1999; Planton & Michaux, 2013)**. The recent geographical range of distribution has been, however, greatly shrunken in the wild to NKNP and Faleme Hunting zone **(East, 1999)**. Until now the only confirmed viable population of WDE occurs in NKNP although very small populations of WDE were reported from Mali and Guinea with dispersing individuals which are potentially associated with seasonal movements from the NKNP **(Koláčková *et al*., 2011; park rangers' observation)**. Beside the wild population, the first and second breeding herds are set in Bandia and Fathala reserves at roughly 620 and 400 km at the North-West from NKNP, respectively.

1.1.5. Status

Estimated earlier at 1000 individuals **(Sournia, 1990)** the population is decreasing through years. The last census gave around 170 individuals **(Renauld *et al*., 2006)**. Because of a lack of information, the real trend of the WDE population within NKNP is hard to assess rigorously. Since 1976 the giant Eland was recorded on the IUCN red list of threatened species as Critically Endangered **(Nowak & Paradiso, 1983)** but the last and current classification sets the WDE as Critically Endangered and even close to extinction **(IUCN, 2008)**. Among other criteria, this classification stands for taxa with population estimated to less than 250 mature individuals with continuing decline observed, projected, or inferred, in numbers of mature individuals and at least 90% of mature individuals in one subpopulation. This classification is fully justified because less than 200 individuals of WDE have been recorded in NKNP during the latest census **(Galat *et al*., 1992; Hájek & Verne, 2000; Renaud *et al*., 2006)**. This very low number of individuals threats the survival of the subspecies in NKNP. This persisting decline of the population of the WDE together with that of some big antelopes such as hartebeest and roan antelope among others may explain the reasons why NKNP was included on the list of World Heritage sites in danger in 2007 **(Howard *et al*., 2007).**

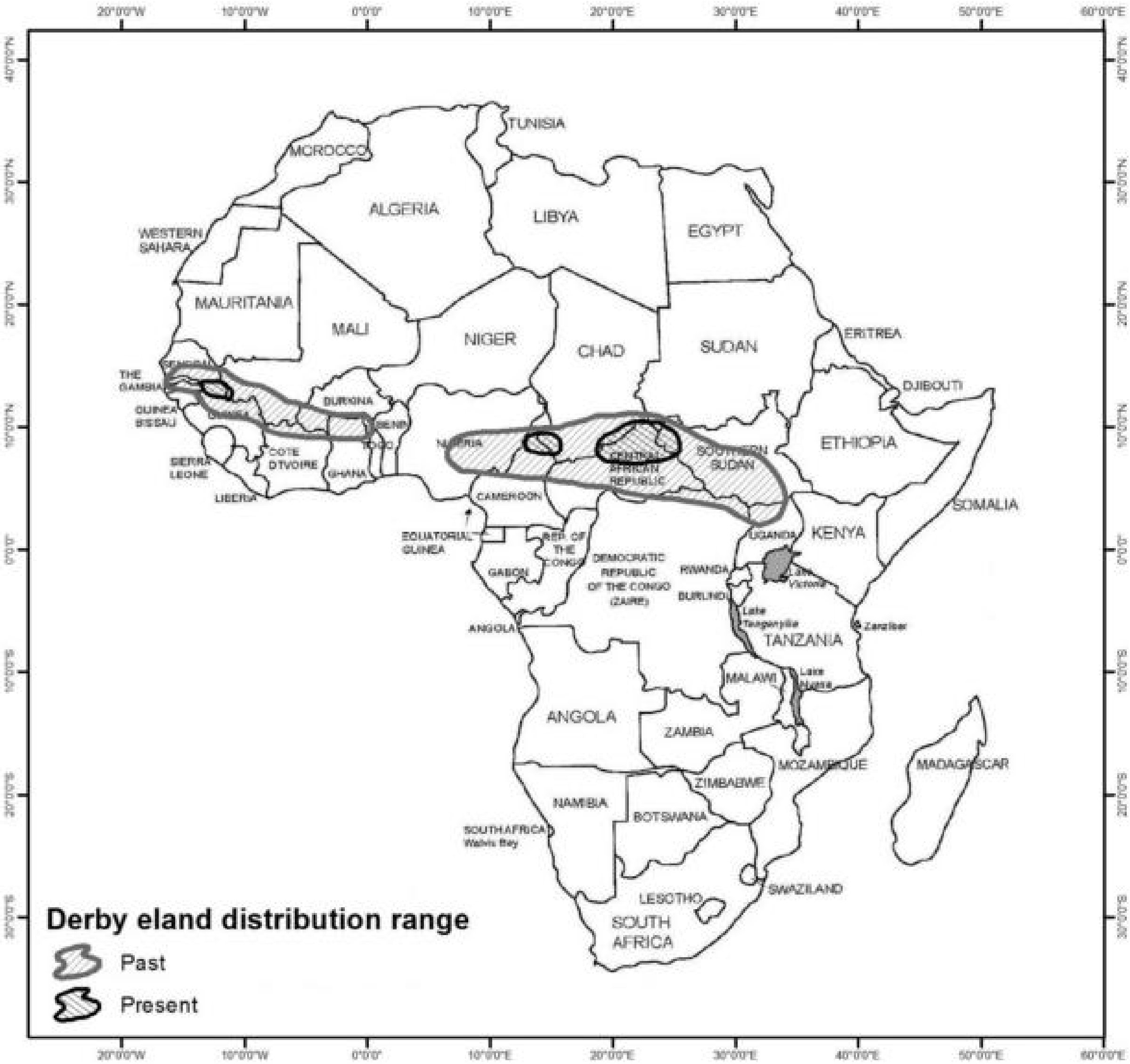


Figure 3: Past and current distribution range of the Western and the Eastern Derby Eland (Brandlová *et al*., 2013)

1.1.6. Values

1.1.6.1. Consumptive value

Despite its massive body size near the ton, the WDE is not used as meat resource by the surrounding population. It is rather replaced by livestock and/or other wildlife species **(Brandlová *et al*., 2013)** because of mystic beliefs and traditional consideration around the WDE. Indeed, local population are fearful to hunt and consume it. Therefore, its consumptive value is not significant. This could explain the ignorance of the potential that WDE's meat may play in animals protein supply while the Common Eland (*Taurotragus oryx* Pallas, 1766) is farmed for its important meat and milk production **(Rafferty, 2010)**. However, farming the Common Eland is difficult because of the large amount of space required, its ability to jump over the fences as high as 3 metres or to break through the enclosures using their body mass and the low survival of calves **(Pappas, 2002).**

1.1.6.2. Non-consumptive value

The WDE has huge interest and provides environmental goods and services for the livelihood of people e. g. tourism attractions, sociocultural and ecological values (e. g. scientific research). Indeed, till recent date little is known scientifically on it mostly in the wild. Hence, its limited range of distribution and the exclusiveness of seeing it in a natural environment only in NKNP increase its touristic and scientific attraction **(Brandlová *et al*., 2013)**. Thus, the WDE, a flagship species of NKNP, may play key role in the developement of ecotourism by providing or increasing of income for the local population as well as for the park. The WDE may also increase the scientific interest in projects of biodiversity conservation for decision making on rangeland management of the country **(Watkinson & Ormerod, 2001).** In Addition, it is believed that as a brower the WDE is an efficient seed disperser's agent which increases the regeneration and spatial heterogeneity of ecosystem. Consequently, the WDE contributes to increase the plant diversity within its habitat **(Olff & Ritchie, 1998)**.

1.2. Study area

1.2.1. History

Oldest park in Senegal, NPNK is a strictly controlled park. Its history started with the setting up of parks in Western French Africa **(Roure, 1956)**. Roughly at 650 km southeast from Dakar, the NKNP stretches on Kolda, Tambacounda and Kedougou's administrative regions from 12°30' to 13°20' North latitude and from 12°20' to 13°35' West longitude **(De Maeyer *et al.*, 2004)** with an area of 913 000 ha (Fig. 4). Created before the independence of Senegal in 1954, it was at the beginning in 1925 a cynegetic reserve located at the left side of the River Koulountou extended on 26 000 ha **(AOF, 1926).** Then one year later, it was a designated as a park of animals' refuge **(*Afrique Occidentale Française* (AOF), 1936)**. These acts were not applied until the London's conference in 1933 where it got a special statue and was recognized as Reserve near the Portuguese Guinea frontier with 34 000 ha. The executive order n° 1936 of the Ministry of Colony abrogated the previous arrangement and changed it in partial reserve of hunting **(AOF, 1936)**. In 1950, the protection of the wild fauna started with the decision of the General Governor of French West Africa who installed park managers inside 175 000 ha of forest **(AOF, 1950)**. Three years later, this forest was enlarged to 227 00 ha and was named wildlife reserve **(AOF, 1953)**. Finally it became the National Park of Niokolo Koba in 1954 **(AOF, 1954).** Afterward, the national park was extended successively in 1962, 1965, 1968 and 1969 at its current size 913 000 ha including its buffer zone of 100 000 ha.

Since 1995 with Badiar Park on 38 200 ha, the classified forest of Ndama on 67 000 ha and Badiar South on 8 600 ha located in Guinea Conakry, they constitute the international ecological complex and bi-corridors Niokolo-Badiar.

NKNP is classified in category II of IUCN and since 1981 it is a Reserve of Biospheres and World Heritage site of UNESCO with the conventions of 1972 and 1976. However, owing to its huge degradation NKNP is on the list of World Heritage site in Danger since 2007 **(Howard *et al.*, 2007)**.

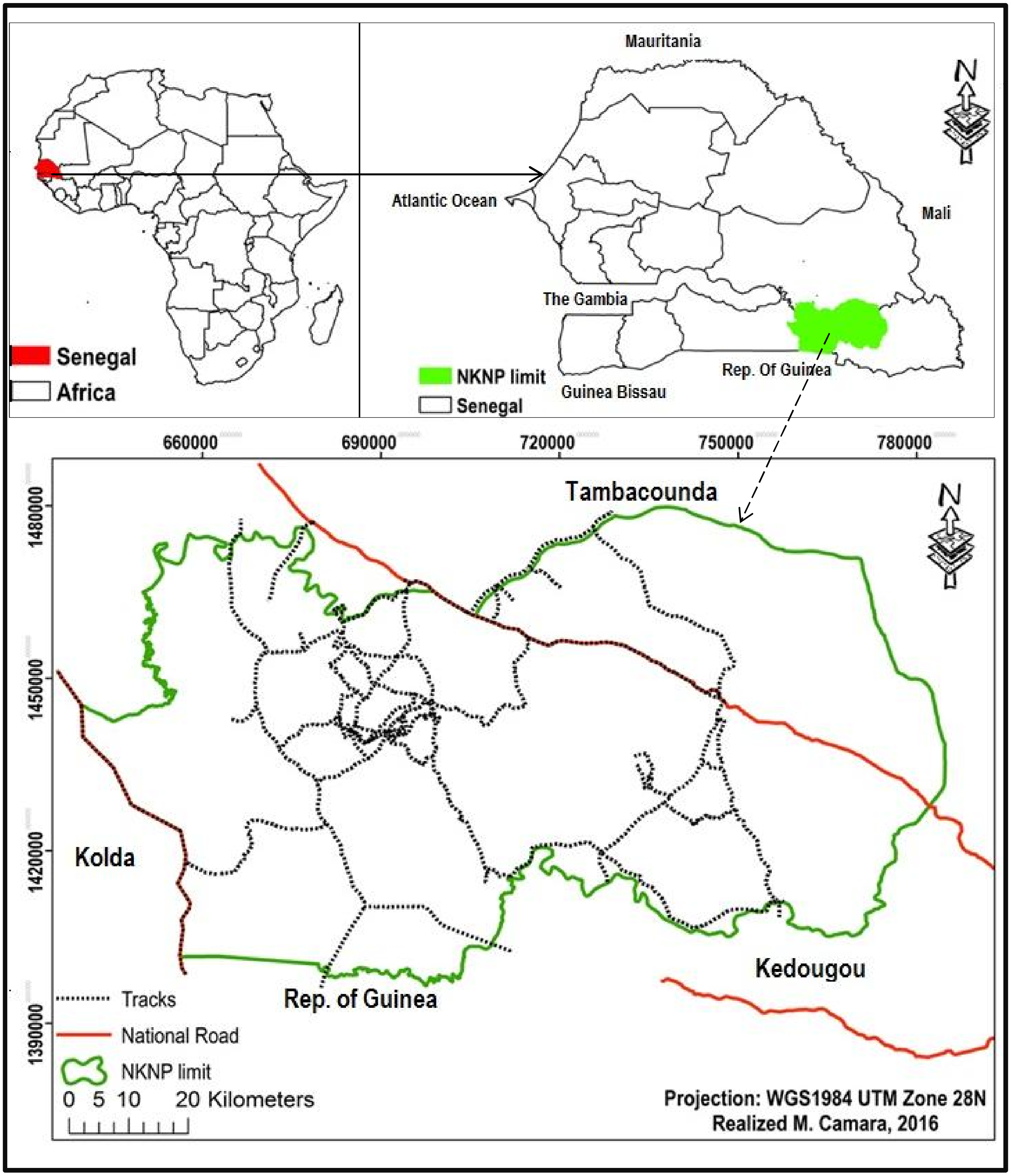


Figure 4: Location map of the study area

1.2.2. Climate

The parameters used to characterize the climate of NKNP are from the synoptic stations of Tambacounda at 13°46'N and 13°4l’W and Kedougou at l2°33' N and l2°11' W located in Sudanese and Sub-guinean zones respectively.

1.2.2.1. Rainfall

NKNP has two main alternate seasons: a long dry season from November to May and short rainy season from June to October with the peak in August’s (Fig. 5). The annual rainfall is 900-1100 mm with a North-South gradient in the space and the time. The Sudanian northern part is less watered than the Sub-Guinean southern part. The monthly rainfall difference is combined with an inter-annual variation with a regressive trend of the quantity of rainfall recorded in the two meteorological stations. The comparison of the quantity of rainfall recorded per three decades (1925-1954, 1955-1984 and 1985-2014) in the two stations shows a decreasing trend (Table I). This decrease reflects the drought occurred in the Sahelian region. A difference around 400 mm for each considered period was found between both stations for 235 km of separation distance. Although a recovery of rainfall was observed from 2000 to 2014; the normalized deviations of the rainfall from 1960 to 2014 of the two stations showed a decreasing trend (Fig. 6).

1.2.2.2. Temperature

Temperature varies throughout the park. Thus for a given time, it is different at the top of the plateau, in the gallery forest, in the woodland forest, or in the bare land. In general the mean temperature is around 29^{o} C. Through the year the temperature follows the climatic seasonality with a mean monthly temperature lower than 30^{o} C from July to February and around 35^{o} C from March to June (Fig. 7).

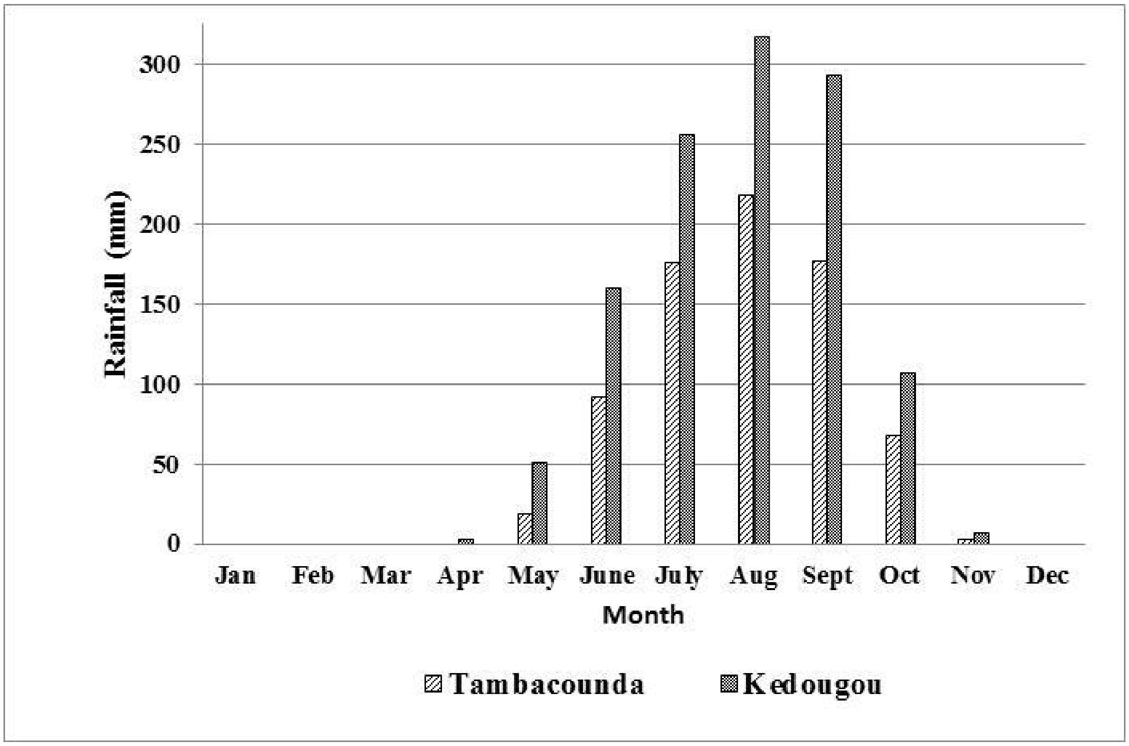


Figure 5: Variataion of the monthly mean rainfall recorded in the meteorological stations of Tambacounda and Kedougou between 1960 and 2014 (Source: ANACIM, 2015)

Table I: Variation of rainfall per three decades from 1925 to 2014 (Source: ANACIM, 2015)

Stations	1925-1954	1955-1984	1985-2014
Kedougou	1317.467	1220.763	1145.173
Tambacounada	919.1024	810.5267	736.1567

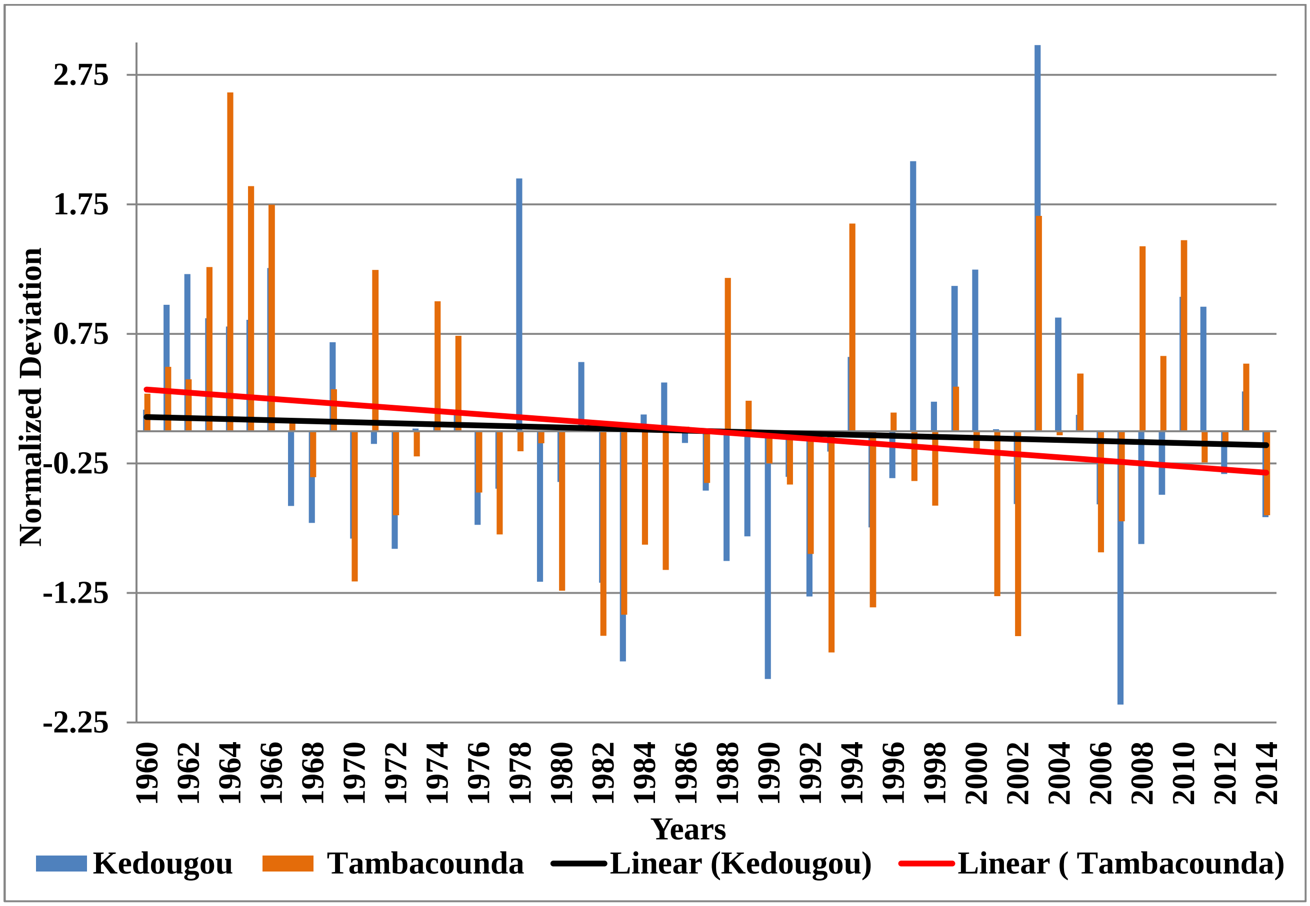


Figure 6: Normalized deviation of the annual mean rainfall recorded in the meteorological stations of Tambacounda and Kedougou from 1960 to 2014 (Source: ANACIM, 2015)

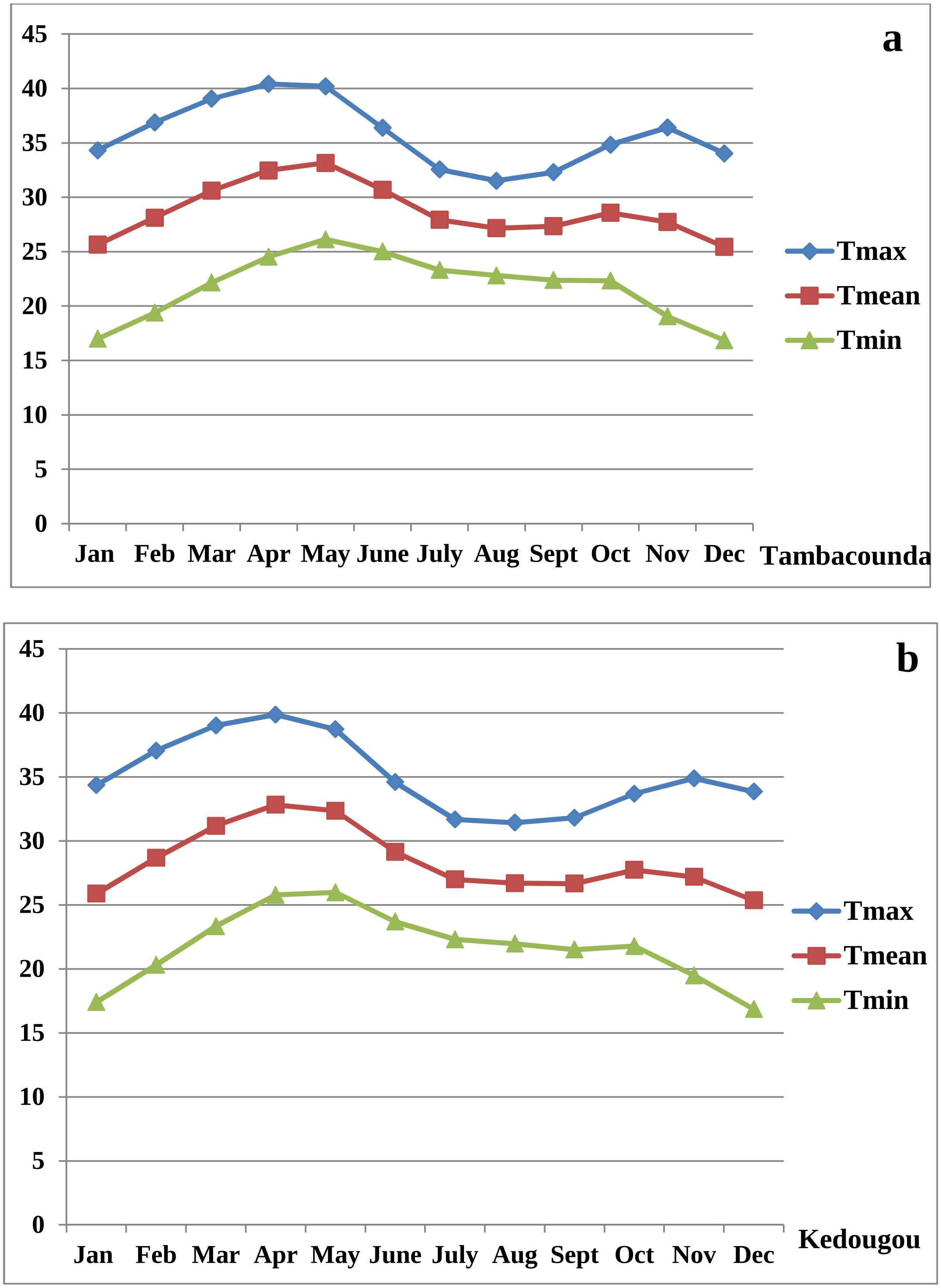


Figure 7: Variation of the monthly mean temperature recorded in the meteorological stations of Tambacounda (a) and Kedougou (b) between 1960 and 2014 (Source: ANACIM, 2015)

The mean thermic amplitude is higher in the dry season (15^o C) than in the rainy season (10^o C). Because of the rainfall, the cloud cover and the air humidity recorded, temperatures are relatively low during the wet season from July to September. While owing to the harmattan, a dry and dusty wind blowing from the Sahara Desert towards the West Africa, the temperatures increase during the dry season with a peak which can reach 40^o C in April.

Normalised temperatures showed an inter-annual variation with an increasing trend for both stations which present a rising temperature (Fig. 8). Although, their general trend is rising from 1960 to 1978 Kedougou recorded the highest temperature while from 1979 to 2014 the reverse was observed.

1.2.2.3. Ombrothermic Diagram

Although rainfall is recorded slightly in May, the wet season for both regions starts in June and ends in October (Fig. 9). During this period temperatures decrease as compared to the temperatures of the dry season. The peak of rainfall is recorded in August with 318.47 mm and 218.34 mm for Kedougou and Tambacounda, respectively. This reflects the difference of rainfall aforementioned between the north and the south of the park.

1.2.2.4. Relative humidity

Relative humidity or water's saturation of the atmosphere is the ratio of the quantity of water vapour in the air at a specific temperature to the maximum quantity that the air may contain at that temperature, expressed as a percentage. Linked to temperature, the relative humidity is subjected to two major variations during the year. From November to April a low relative humidity is observed followed by a period of high humidity from May to October due to the monsoon wind (Fig. 10). Soil humidity is up to 80% during the rainy season and moderately high for the rest of the year which generates a microclimate mostly perceptible in the riparian forest.

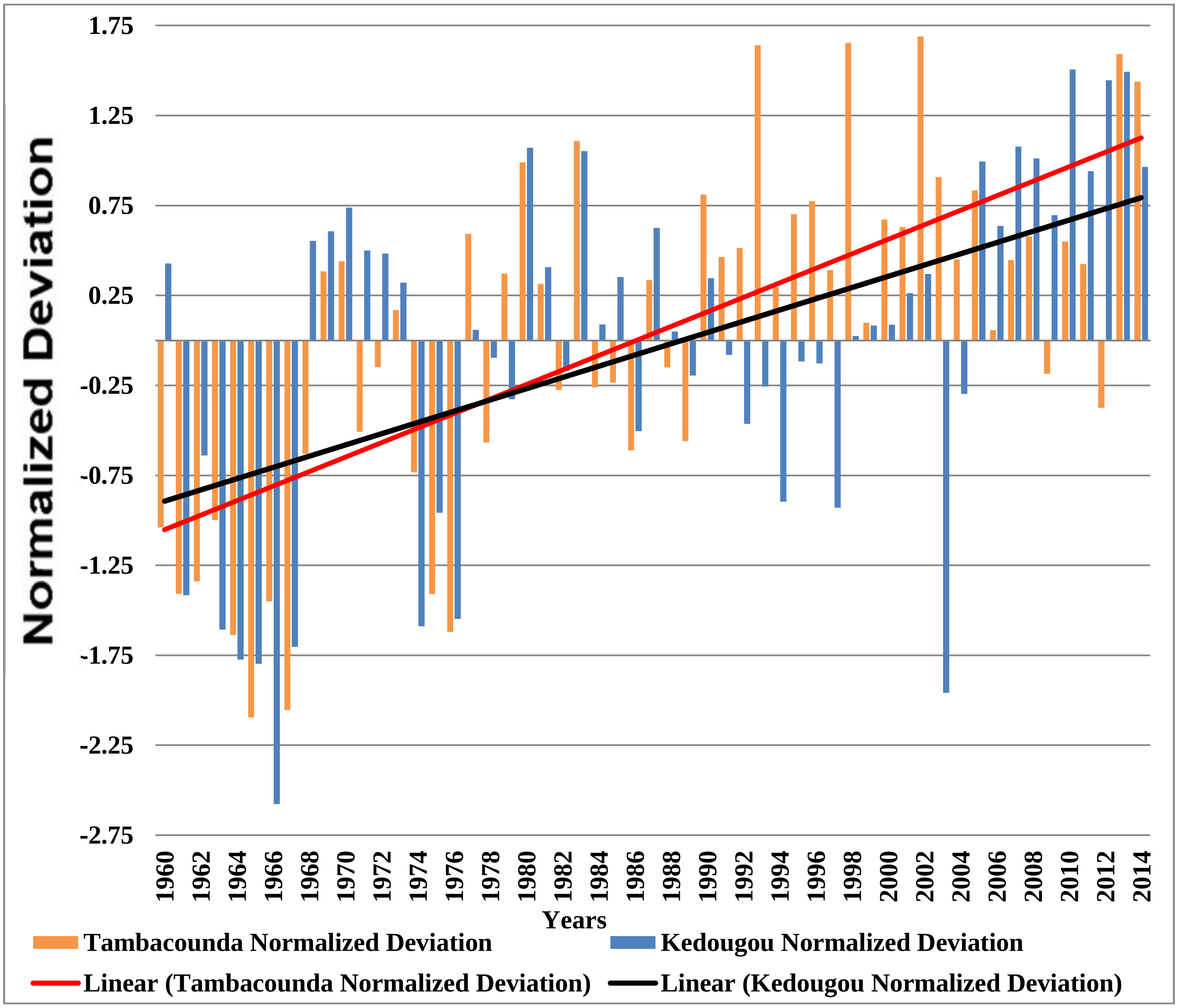
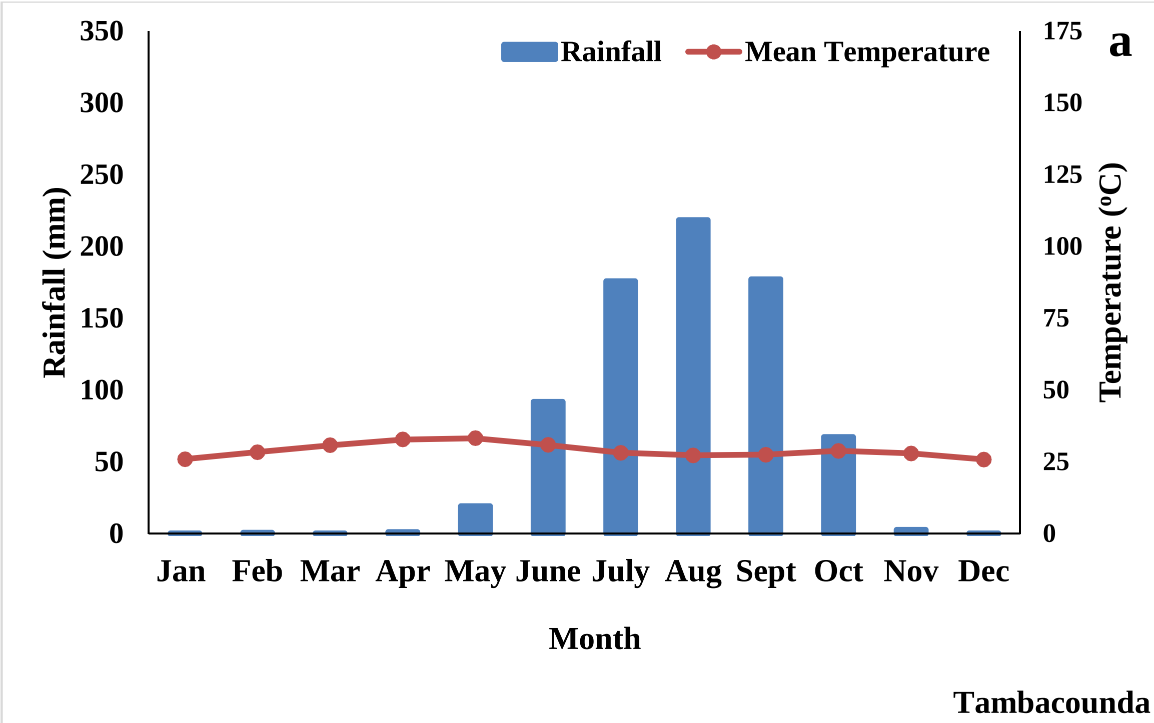


Figure 8: Normalized deviation of the annual mean of temperature recorded in the meteorological stations of Tambacounda and Kedougou from 1960 to 2014 (Source: ANACIM, 2015)



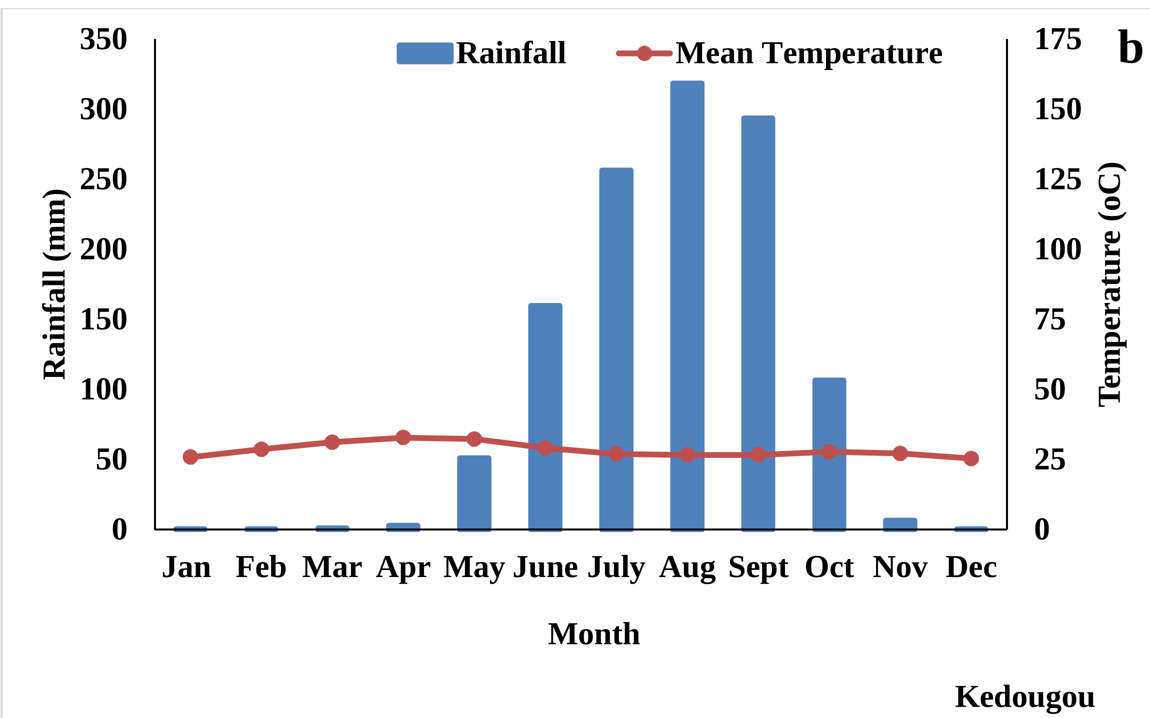
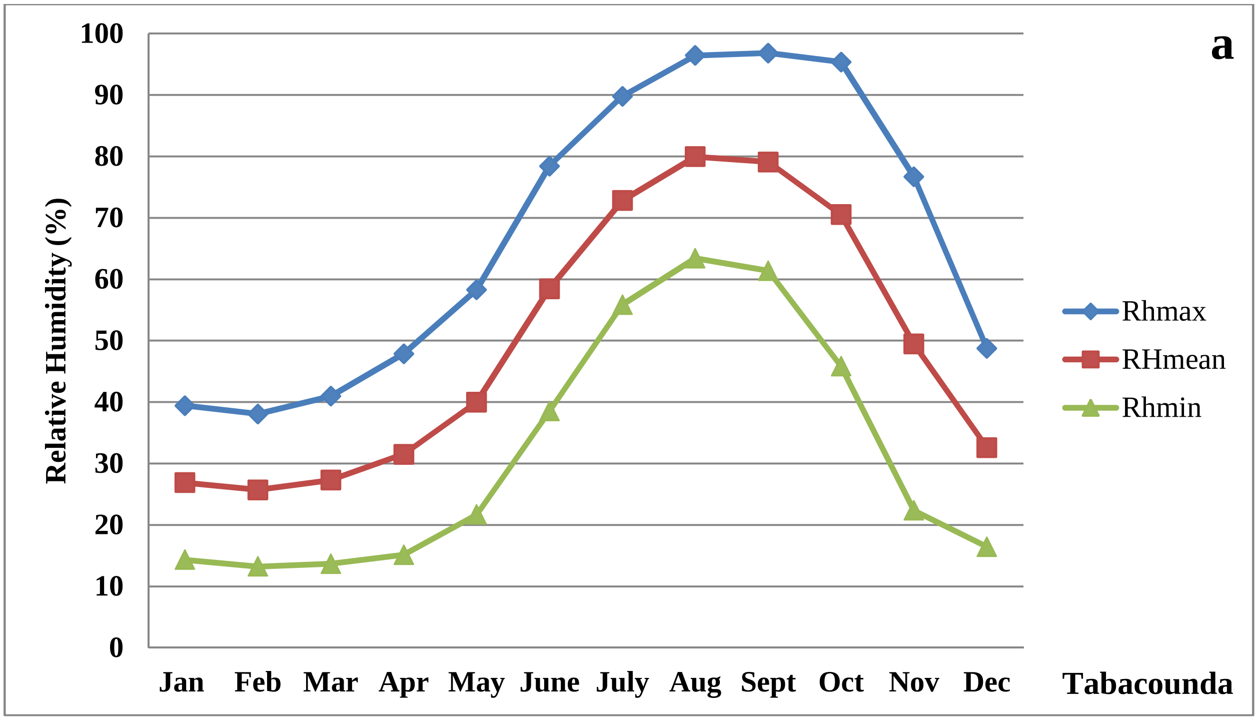


Figure 9: Ombrothermic Diagrams from data of the meteorological stations of Tambacounda (a) and Kedougou (b) from 1960 to 2014 (Source: ANACIM, 2015)



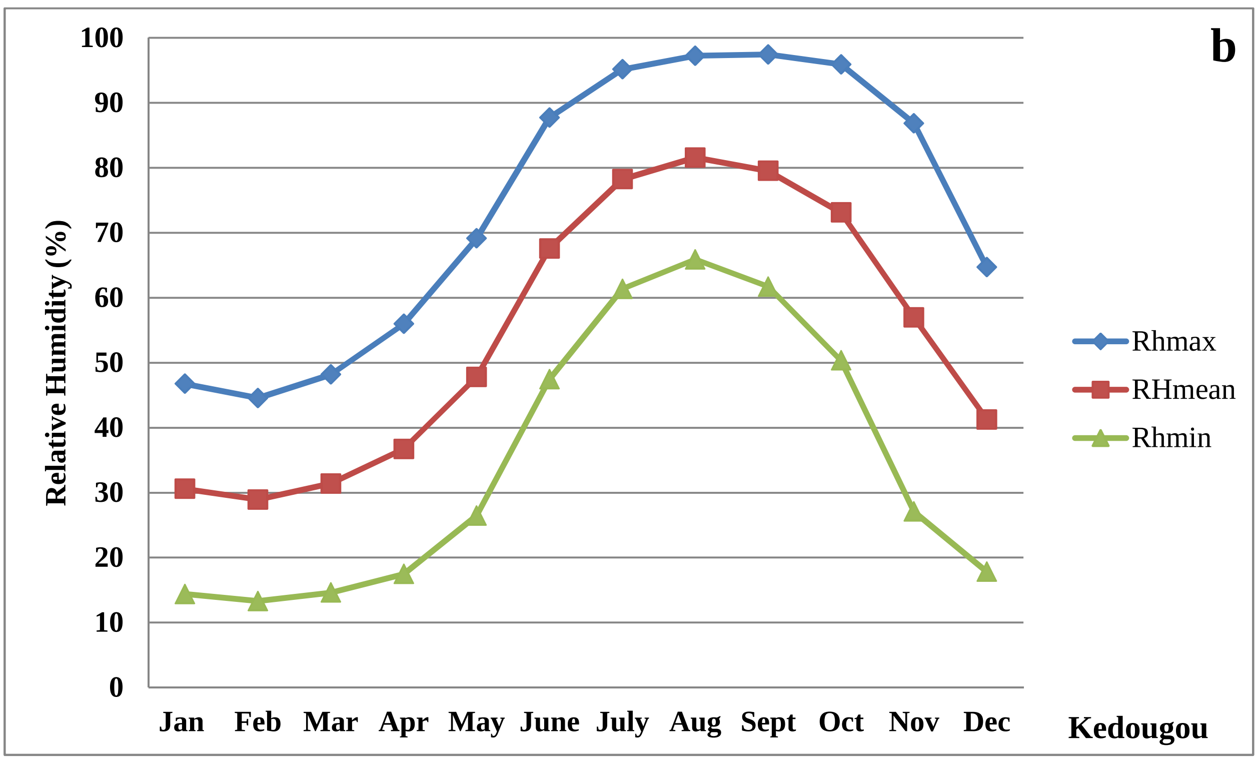


Figure 10: Variataion of the monthly relative humidity recorded in the meteorological stations of Tambacounda (a) and Kedougou (b) between 1960 and 2014 (Source: ANACIM, 2015)

1.2.3. Geomorphology and pedology

1.2.3.1. Geomorphology

The topography of NKNP is relatively flat except the southern part which constitutes the foothill of the nearby Guinean Fouta Djalon Mountains. The height above sea level is 100-150 m and the peak of the table-top mountain Assirik at 311 m (Fig. 11).

1.2.3.2. Pedology

The soil of NKNP is mainly dominated by tropical red iron poor developed soils. While, some areas because of a great content of iron are transformed into hard armour of ferro-lateritic crusts either entirely exposed or with a thin layer of grey silt. NKNP contains some parts with a sandy-clay substrate (Fig. 12). The soil of NKNP is divided in five typical morphologic types (Table II which are associated with particular kinds of soil. This classification of that soil is based on the nomenclature of **Vieillefon (1971).** The structure of the morphology of the park may explain the seasonal movement observed for some large mammals like the WED towards the plate during the rainy season in order to escape the flooding of marshy and clayey lands.

1.2.3.3. Hydrology

The park is crossed by the Gambia River on roughly 200 km oriented East-West and South-North and its two major tributaries the Niokolo Koba and the Koulountou oriented East-West and North-South, respectively. The hydrologic system of NKNP (Fig. 13) is a tropical system with a maximum water flow during the rainy season in September and the lower water flow in March. Thus the quantity of water flown in these three rivers is different in term of power (Table III). This hydrological system plays an important role for maintaining the vegetation cover and for its protection notably in riparian forests against the fire outbreak because of the high humidity at the bordering sides of the river. Consequently, it safeguards a good food supply for herbivores. Further to the dense hydrological system, around 200 temporary and permanents ponds are well distributed within the park (Fig. 13). This distribution helps a lot for the faunal distribution as well as reduces the competition among animals for water resource.

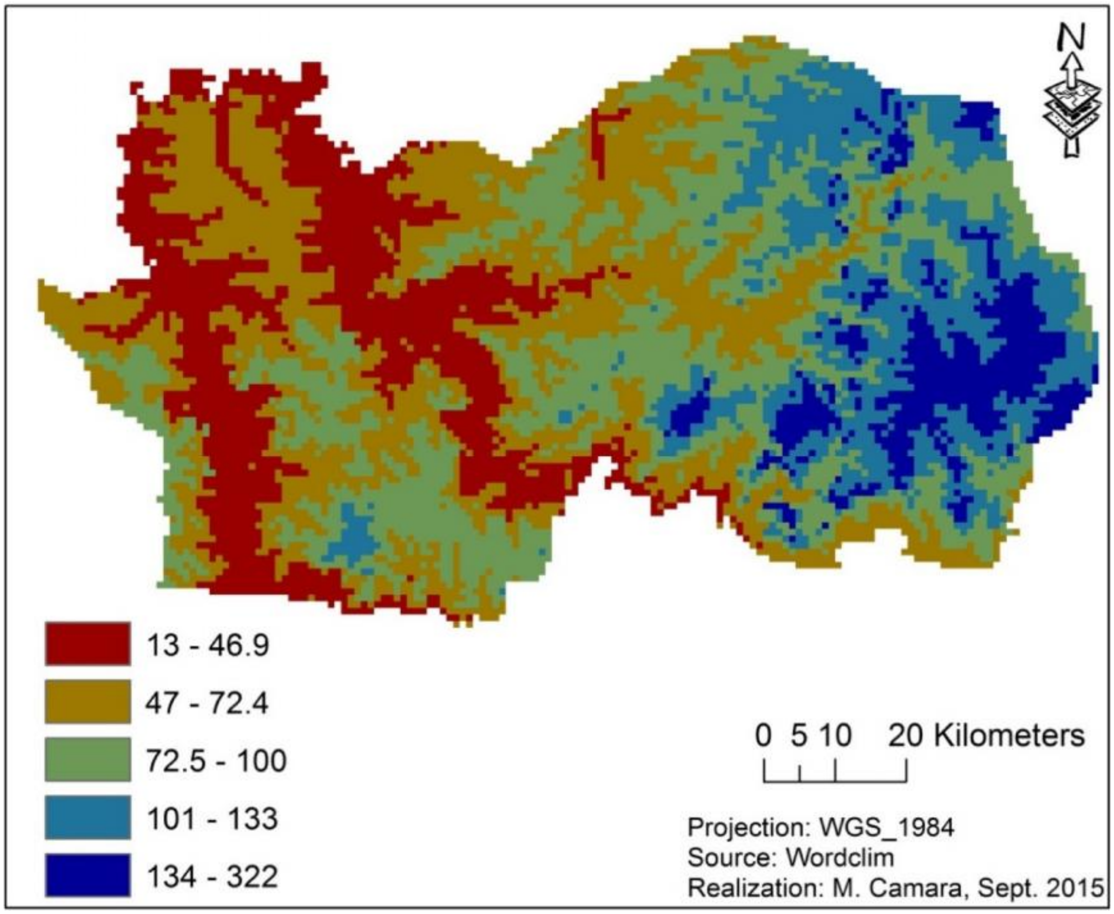


Figure 11: Map of the geomorphology of the park

Table II: Description of soil types in the study area according to Vieillefon (1971)

Designation	Soil type	Description
SL	Sandy loam	Little developed sandy deposits in alluvial zones and on bounds of plateaus
LG	Lateritic soil with gravel	Type of regosol with fine gravel, associated with fragments of ferric soils
FM	Ferralitic soil with medium stone	Complex of lithosols associated with gravel, hydromorphic and ferric soils with fairy stones
GO	Granite outcrop	Granite massive orientated southeast–northwest, outcrops constituted by big granite boulders on hills
PH	Plinthitic hardpan	Type of lithosol with ferrolateritic concretions

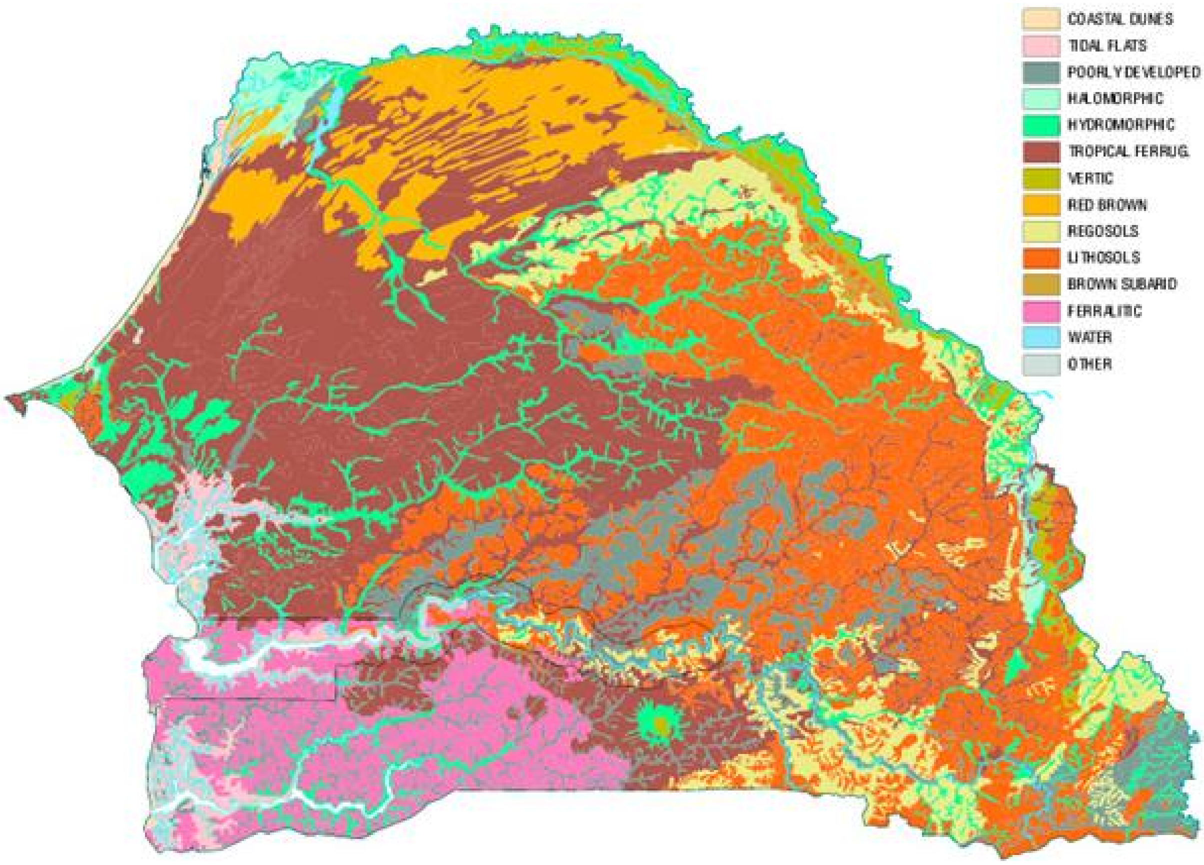


Figure 12: Soil map of Senegal (Source [U.S. Geological Survey](), 2013)

1.2.4. Vegetation and flora

NKNP stretches in the transitional phytogeographical zone of the Sudanese and Sudano-guinean savannas **(White, 1983)**. It harbours a very high plant biodiversity of which 1500 species were assessed **(Madsen *et al*., 1996)** and more than 1100 taxa were stored in the Herbarium of the Cheikh Anta Diop University in Dakar **(Ba *et al*., 1997)**. These species belong to 120 families among which the Poaceae (13.6 %), Fabaceae (12.7 %), Cyperaceae (7.2 %) and Rubiaceae (5.5 %) are the most represented. The main vegetation types in NKNP are represented by wooded savanna, shrub savanna and grass savanna (Fig. 14, 15 and 16). Most of the time shrub savanna and grass savanna stretch on the ferro-lateritic crusts almost without soil with some dotted bare land (Fig. 16b). The riversides are covered by gallery forests with their special microclimate. During the last few decades, invasive species such as *Mimosa pigra* L. developed on marshes become a concern on forage and water availability. This is a serious problem and a very limiting factor for the animals mostly during the peak of the dry period when fodder and water become rare.

Climatic conditions were defined as the most important factors determining the vegetation in NKNP **(Trochain, 1940; Lawesson, 1995)** but recent studies showed fire outbreak as a factor influencing the vegetation in NKNP **(Mbow, 2000)**.

Fire outbreak gradually changes vegetation in favour of pyrophytic taxa such as the genus *Combretum* Loefl. which can be unsuitable for herbivores' forage. However, despite their negative impacts on the vegetation, the regeneration and the adult trees (Fig. 17) early fires are used since the establishment of the park as management tools in order to avoid severe consequences in late dry season when the savanna is arid **(Menaut *et al.*, 1991; Bellefontaine, 1997)** and they likewise, help by reducing predatory pressure and by increasing the animals' visibility and the touristic attraction (e.g. safari photo).

Table III: Flow of the rivers of NKNP (Source: Mbow, 1995)

Rivers	Flow (km^3/an)
Gambie	2 259 805 600
Koulountou	913 140 490
Niokolo-koba	148 317 900

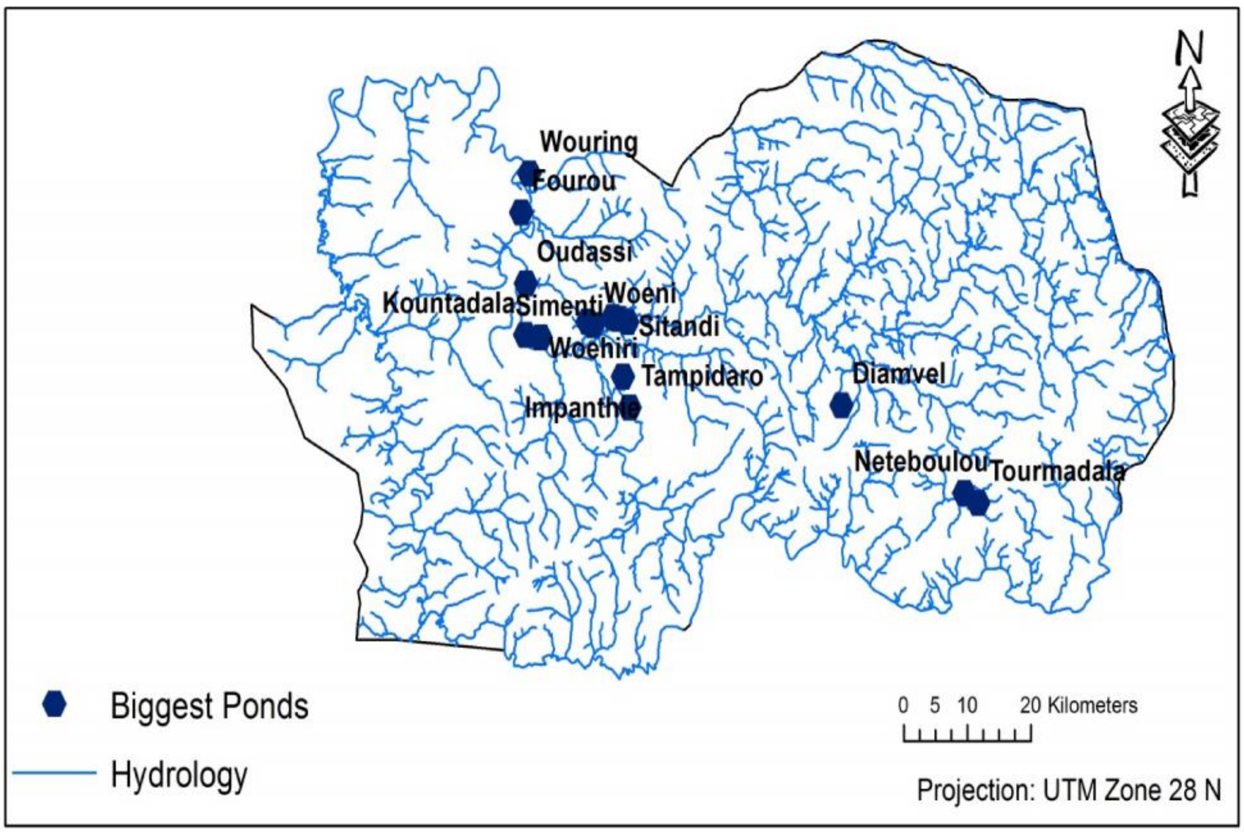


Figure 13: Biggest ponds and hydrologic system of the NKNP

Figure 14: Woodland savanna in Niokolo Koba National Park (Camara, 2014)

Figure 15: Shrub Savanna in Niokolo Koba National Park (Camara, 2014)

Figure 16: Grass land savanna in Niokolo Koba National Park on bowe (a) and on ferro-lateritic crust substrate of bowe (b) (Camara, 2014)

Figure 17: Marks of fire outbreak in Niokolo Koba National Park (Camara, 2014)

1.2.5. Fauna

The NKNP is the main area where the most abundant and diversified wild fauna is living in Senegal due to the diversity of biotopes it harbours **(Dupuy & Verschuren, 1982; Galat *et al*., 1992)**. It presents an extensive protected ecosystem in West Africa which probably exceeds those of the neighbouring countries of Senegal. Therefore, it constitutes the last refuge for large animals in this area and has a huge faunal diversity **(Neierkove *et al*., 2004).**

Arthropods are the most important taxa in the invertebrates' phylum, particularly with a high diversity inside the insects' class. The molluscs with 19 species assessed are among the well-known animal groups in NKNP. Twelve of them are aquatic and seven terrestrial **(Traoré, 1997)**.

In the vertebrate phylum fishes are also diversified with 61 known species identified. Amphibians represent up to 20 species and reptiles' species are about 34. Birds are the most diversified vertebrate taxa with 327 species recorded in NKNP **(Traoré, 1997)**.

Among the herbivores, species like the damalisc (*Damaliscus lunatus korrigum* Ogilby, 1837) disappeared in 1920 and the last giraffe (*Giraffa camelopardalis peralta* Thomas, 1898) have been killed by a poacher from the village of Sibikilling in 1950 **(Dupuy, 1971)**.

However, since NKNP received the status of national park in 1954, no disappearance was noticed in NKNP but a high decrease of the population of the western chimpanzee (*Pan troglodytes* Blumenbach, 1776), the elephant (*Loxodonta africana* Blumenbach, 1797), the Bohor reedbuck (*Redunca redunca* Pallas, 1767), the African wild dog (*Lycaon pictus* Temminck, 1820) and the lion (*Panthera leo* Linnaeus, 1758) were noticed **(Neierkove *et al*., 2004).** The decrease of population of these animals set them on list of endangered species living in the NKNP. Among them, the case of the WDE may be the most remarked. Indeed, because of the high decrease of its population the WDE is recorded on threatened species IUCN red list since 1976.

Other remarkable animals like the Orycterope (*Orycteropus afer* Pallas, 1766), the giant ant pangolin (*Smutsia gigantea* Illiger, 1815), the civet (*Civettictis civetta* Schreber, 1776), the Daman of rocks (*Procavia capensis* Pallas, 1766) and the leopard (*Panthera pardus* Linnaeus, 1758) are found in NKNP.

1.2.6. Human context

The NKNP is surrounded by villages belonging to different ethnic groups. The Bedik, the Bassari, the Koniagui and the Peuhls are at the South, the Diankhanke mixed with the Peuhls and the Mandings at East and at the North and mainly the Peuhls at the West part **(Roure, 1956)**. The main activities are agriculture and breeding sometime accompanied by commerce and fishing. Because of the successive extensions of the boundaries of NKNP, local populations were evicted from their native lands to the border of the park. The decision of the eviction was taken in 1969 and executed in 1972 but the last villages left in 1976-1977. Traces of these villages remain at their location with the presence of occupancies' vestiges, fallows and some anthropogenic indicator plant species such as baobab *Adansonia digitate* L., silk-cotton or kapok tree *Ceiba pentadra* (L.) Gaertn., mango *Mangifera indica* L., Senegal mahogany *Khaya sengalensensis* (Desr.) A. Juss., never die *Moringa oleifera* Lam. and Foetid Cassia *Cassia occidentalis* Linn. (**Traoré, 1997).** Nervertheless, they consider the park as their property and still use its natural resources (poaching, honey harvest, logging, livestock grazing, fruit picking . . .) as usual. Hence, the relations between the NKNP managers, park's rangers and the local inhabitants are extremely strained.

Poaching has a negative impact on the park's fauna and it is a big problem for the administrators of the park. In front of illegal activities, the park's directorate first used a persuasive approach in order to raise the awareness of the villagers and dissuade them from taking products from the park. Moreover, they are trying to improve their relation with local communities by attempting to promote them alternative livelihoods by involving them in the tourism activities, as guides or hostels' keepers, the exploitation of the buffer zone for wood, fruits collection and animal grazing and by funding them for the development of socio-economic activities (poultry and livestock farming, gardening, agriculture, carbon market...). For instance, the funding of some projects such as banana plantations in Madina Kouta and Wassadou at the northern border of the NKNP provides a good example.

Though, friendly solutions are used by the directorate to conciliate the neighbourhood, illegal activities are still repressed and severe penalties are applied by the law court to discourage the recidivist villagers.

Chapter 2:
METHODOLOGY

2.1. Identification of the confinement area of the Western Derby Eland in Niokolo Koba National Park

2.1.1. Data collection

Recent observations of researchers and park rangers showed a shrinking of the zones of occurrence of the WED in NKNP. The confinement area of the WED was determined based on on collection of the location of the WDE within the park. This was done using data of occurrence from the available literature, interviews, camera traps recorded and field records. The available literature is the compilation of past ecological surveys of NKNP and data from research teams on WED in NKNP.

Individual semi-structured interviews were carried out with 59 respondents. These include 32 active, four elder and four retired park agents, 10 resource persons at the Directorate of the National Parks (DNP), three former poachers and the six evicted villagers living in the surrounding areas of the park. Before each interview, the scientific concept and scope were explained and their consent obtained. Respondents were selected on the basis that they have seen the WDE at least once in NKNP. In addition to the previous condition, only villagers who were at least 18 years old at the time of eviction were interviewed. The selection of resource persons and the active, elder and retired park agents as well as the former poacher was facilitated by the DNP. The evicted villagers were interviewed with the authorization of the chief of the village after explaining him the purpose of the work. Their interviews took place at their respective home. To confirm their knowledge about the WDE we brought pictures of all large mammals of NKNP. We asked them first to describe the WDE and then to show the picture of the WDE among the others. An interpreter aided for the translation of two local languages “Mandingue” and “Pular”. The questionnaire was administrated in French but for the evicted villagers and former poacher it was translated into the respondents’ native language for better understanding. Questionnaire details are in appendix 1.

The field records were collected along random pedestrian transect. Before, dungs and foot-prints of the WDE were collected in Bandia and Fathala reserves in order to gather good references. Furthermore, we joined the census campaign of the big fauna organised by the DNP in 2014, in order to benefit from the human and technical support as they covered the all park concomitantly. That census focused only on visual contacts. The geographic coordinates of known places (e. g. Niokolo, Linguekoto, Massafara) were recorded from the data base of GIS office of NKNP in order to harmonise the location with previous works.

The sites of location of the WDE quoted by informants were weighted with a coefficient ranging from 1 to 6 according to their reliability (Table IV).

2.1.2. Data analysis

We built a matrix of informants in column and site of occurrence of the WDE in row in Microsoft Excel sheet (2010). Then, a matrix of relative frequency of informants for each of site of occurrence of the WDE was made. A Principal Component Analysis (PCA) was performed with that matrix of relative frequency of informants and sites of occurrence of the WDE in a bid to assess the concordance of the informants on zones of occurrence of the WDE. Then the matrix of sites of occurrence of the WDE was submitted to a K-means cluster analysis in order to group sites and zones of occurrence of the WDE within the NKNP. Analyses were executed in R software version 3.1.2 **(R Core Team, 2016)** package FactoMineR **(Le *et al.*, 2008)**.

Using their geographic coordinates, sites totalled ≥ 10 points were mapped in order to show their distribution within the park. Then, each site was surrounded by circle of 12 km radius defined from the home range of the Eastern Derby Eland (*Taurotragus derbianus gigas* Heuglin, 1863) (**Graziani & d'Alessio, 2004**). This radius was used for the WDE because of lack of data on it in NKNP. These authors using GPS collars found that the radius of home range was 5 km and 12 km for females and males, respectively. In this study we took the greatest radius (12 Km). The shape of the confinement area of the WDE inside NKNP was demarcated by merging overlapping circles around sites. The mapping was performed in ArcGis version 10.2.1.

Table IV: Coefficient attributed to informants on the location of the Western Derby Eland in Niokolo Koba National Park.

Informants	Weighed coefficient
A	6
B	5
C	4
D	3
Interview with the current park agents	3
Interview with the retired park agents	3
Office of Ecological survey PIKO	3
E	2
Interview with the former poachers	2
Interview with the evicted villagers of NKNP	1

Informants are composed by synthetized literature (A-E) and by respondents. Synthetized literature abbreviations: (A) Czech researchers' unpublished and published data collected from 2004 to 2007, (B) Kane (2015) using camera trap for its data collection in 2014 geo-localized the WDE within NKNP, (C) Renaud *et al.* (2006) using aerials and pedestrian means for their data collection in 2006, (D) Niang (2005) gave site of location of the WDE within NKNP during his data collection in 2005, (E) Thiam *et al.* (2004) produced location of the WDE within NKNP in their final report for UNESCO on WDE Monitoring Program in 2004.

2.2. Dynamics of the vegetation in the confinement area of the Western Derby Eland in relation with climatic parameters

Woodward (1987) argued that the distribution of terrestrial ecosystems is determined primarily by climatic factors particularly temperature and rainfall. As NKNP is a strictly controlled park **(Roure, 1956),** it has been assumed that the climate factors especially rainfall variation (drought and recovery) influences the vegetation dynamics.

2.2.1. Data collection

2.2.1.1. Satellite images

Initially scheduled for 10 years of intervals from 1973 to 2013, a time series of Landsat images was acquired for 1973, 1984, 1990, 2003 and 2013 (Table V) from the United State Geological Survey (USGS, http://glovis.usgs.gov/), due to some technical issues. According to their availability from USGS, the closest dates of the targeted images were downloaded. Images were selected during the dry season in order to minimize the effect of the herbaceous and cloud cover **(Bobée *et al*., 2012; Sambou *et al*., 2014).** This period has also the advantage to have the highest density records of woody species. But, due to the aforementioned constraints images of 1984 were available for September. Fortunately, the cloud cover did not affect the study area. The study site falls on two scenes; therefore for each year the two scenes were downloaded.

2.2.1.2. Climatic Data

Monthly rainfall was collected for the station of Simenti located inside the park from *the Agence Nationale de l'Aviation Civile et de la Météorologie* (ANACIM) from 1968 to 2014.

2.2.2. Data analysis

2.2.2.1. Vegetation dynamic

2.2.2.1.1. Images treatment

Images already georeferenced underwent a calibration as they are multi-date **(Richter, 1997)**. To avoid a geographic deviation between images due to differences in sensor when superimposing them for change detection analysis, the images from 1973, 1984, 1990 to 2003 were registered to the image of 2013 which is the reference. A Principle Component Analysis (PCA) was performed **(Moisan *et al*., 1999)**. The combination of bands 3-4-5 displayed respectively in red, green and blue (RGB) highly advised by **Girard & Girard (1999)** for woody studies was not used because the contrast obtained did not facilitate the identification of the Regions of Interest (ROIs). A combination of bands 5-4-3 displayed in RGB was used because the colours displayed were close to the natural tint which facilitates the observation and identification (Fig. 18). For the images of 1973 and 2013 respectively composition 6-4-7 and 6-5-4 displayed in RGB were used. After the colour composition a mosaic followed by a subset to extract the study area were done for each image.

Then an unsupervised classification was performed. This classification of the images into different vegetation cover classes facilitated the choice of classes **(Boakye *et al*., 2008)**. The choice of this method is justified by the heterogeneity of the land cover and the high probability of confusion amidst components **(Sambou *et al*., 2014)**. The final numbers of classes were defined by a supervised classification combined with the ground truth verification done in April-May 2014.

The ground truth verification consisted of visiting the different spectral signatures through the field. Based on a minimum of five points for each spectral signature, 167 points were visited. The preliminary map, for the ground truth verification, was gridded at 250 m x 250 m, for each spectral signature only pure pixels (grid falls on unique signal) were selected and verified. Pixels distributed on the entire park were randomly chosen using Forest survey tool http://www.jecreemonsite.net/javascript/nbaleat.php. Visited pixels points were located with their geographic coordinates using Global Positioning System (GPS) Garmin map 62s and map 60C5x with a margin error of 2-5 m. In the field, the vegetation and morphological presentation of each grid were described. Details on the distribution of the visited pixels within the park are on Fig. 19.

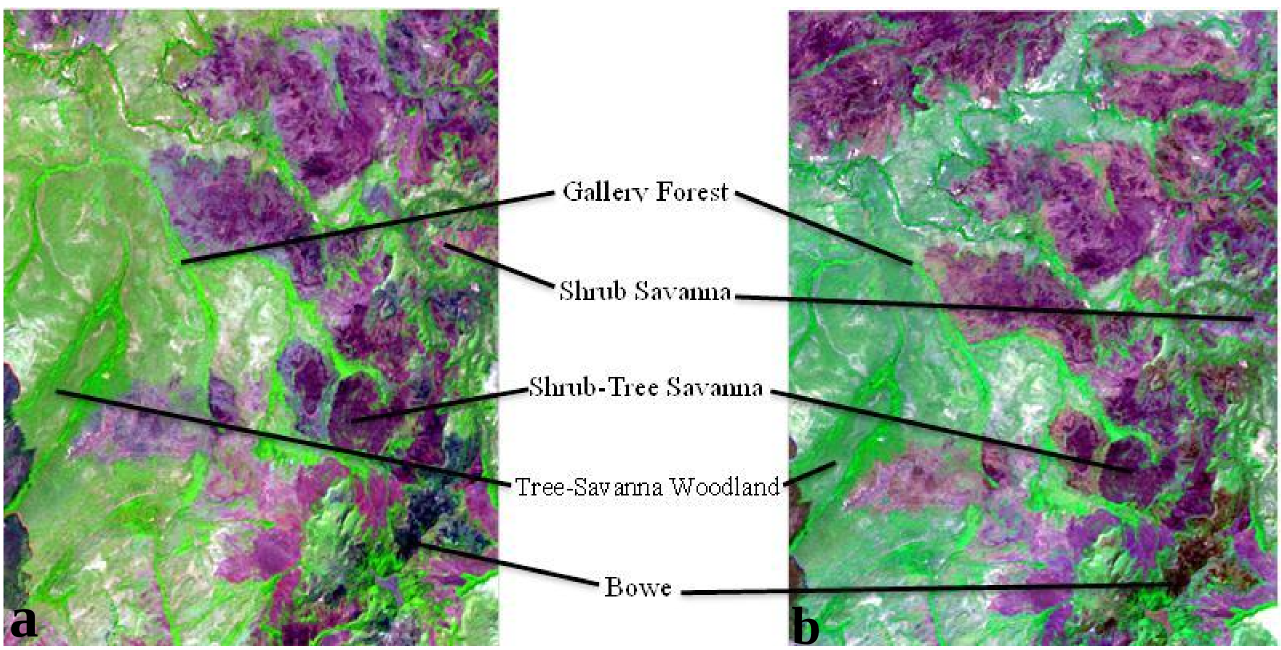
Back to the field the preliminary map was improved with data from the ground truth verification, and the administrative maps. Then, based on supervised classification by maximum likelihood the images were homogenized at filter of 3 x 3 pixels of the majority/minority analysis. Finally, the images were vectorised and exported to the ArcGIS software where the completion of the cartographic process to produce maps of the land cover of each considered years was done.

Land cover changes were defined by cross-pairing land cover maps. Three types of changes, modification, conversion and stability, were used. Modifications were changes perceived within the same category of land use such as a shrub savanna moving to a dense vegetation type like shrub-tree savanna or *vice versa* between the two periods. Conversion was the transition from one category to another for example: River to gallery forest or *vice versa* between the two periods. If there was no change in vegetation covers between the two periods the change pattern was called stability trend **(Lambin *et al*., 2003; Sambou *et al.*, 2014)**. Matrices of changes and their legend were built following the scale of **Lagabrielle *et al*. (2007).**

The different steps of the methodology process (Fig. 20) started by the pre-treatment of images (steps 1 and 2) followed by the visual enhancement (steps 3, 4 and 5). Steps 6 to 13 concern the pseudo-supervised classification and land cover maps' production while the step 14 was the study of changes.

Table V: Images used to characterize the land cover dynamics in the confinement area of Western Derby Eland

Images	Sensors	Paths	Row	Date of acquisition
Landsat 1	Multispectral Scanner (MSS)	217 & 218	51	1973
Landsat 4	Thematic Mapper (TM)	203 & 202	51	1984
Landsat 5	Thematic Mapper (TM)	203 & 202	51	1990
Landsat 7	Enhanced Thematic Mapper (ETM+)	203 & 202	51	2003
Landsat 8	Operational Land Imager (OLI)	203 & 202	51	2013



Colour Composite 5-4-3 **Colour Composite 3-4-5**

Figure 18: Colour Composite scene 203/51 Landsat image with band combinations 5-4-3 (a) and 3-4-5 (b) displayed in Red Green Blue (RGB) of Landsat image 2002

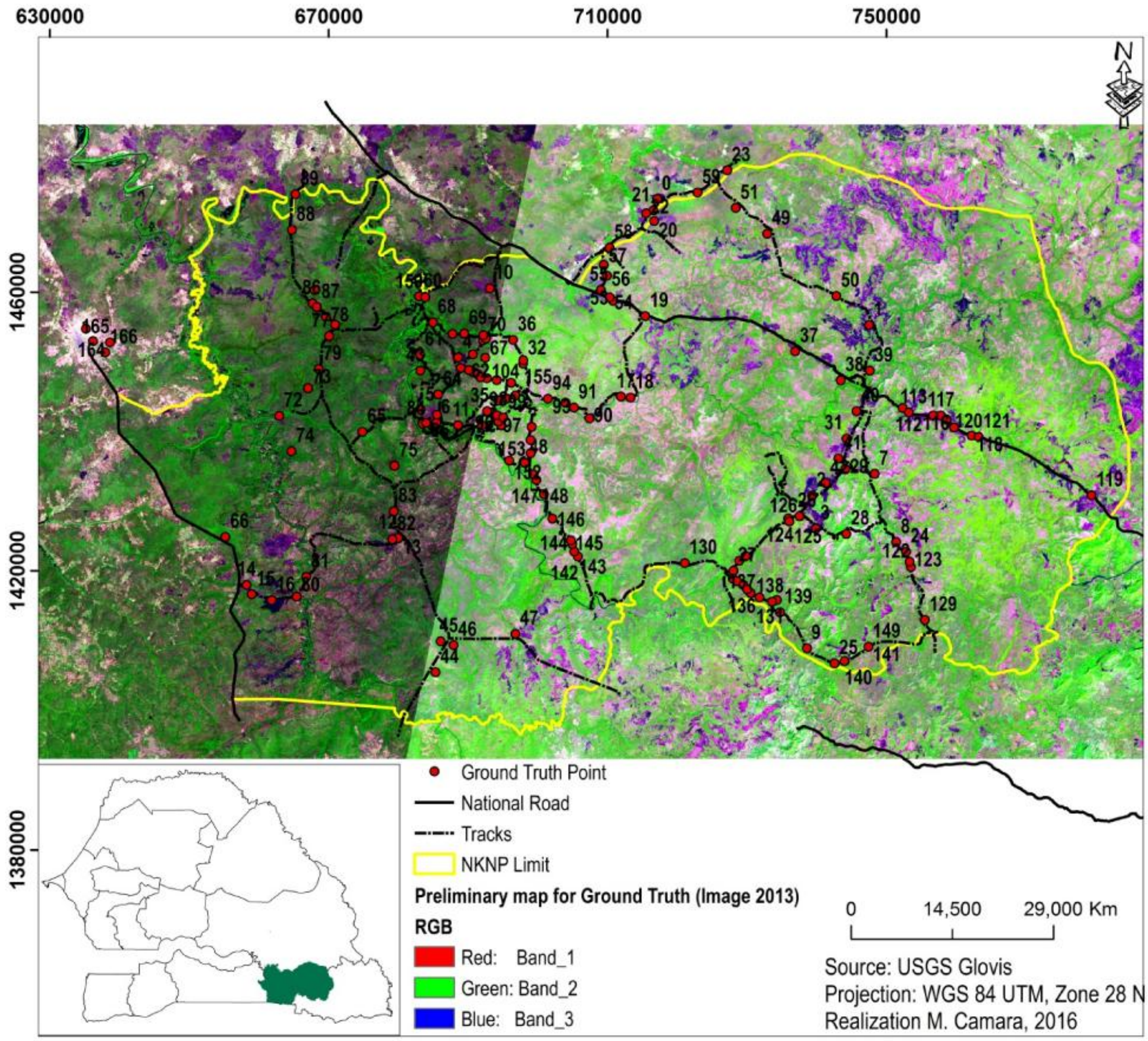


Figure 19: Preliminary map of the ground truth verification based on the Image 2013 and distribution of the points visited on the field

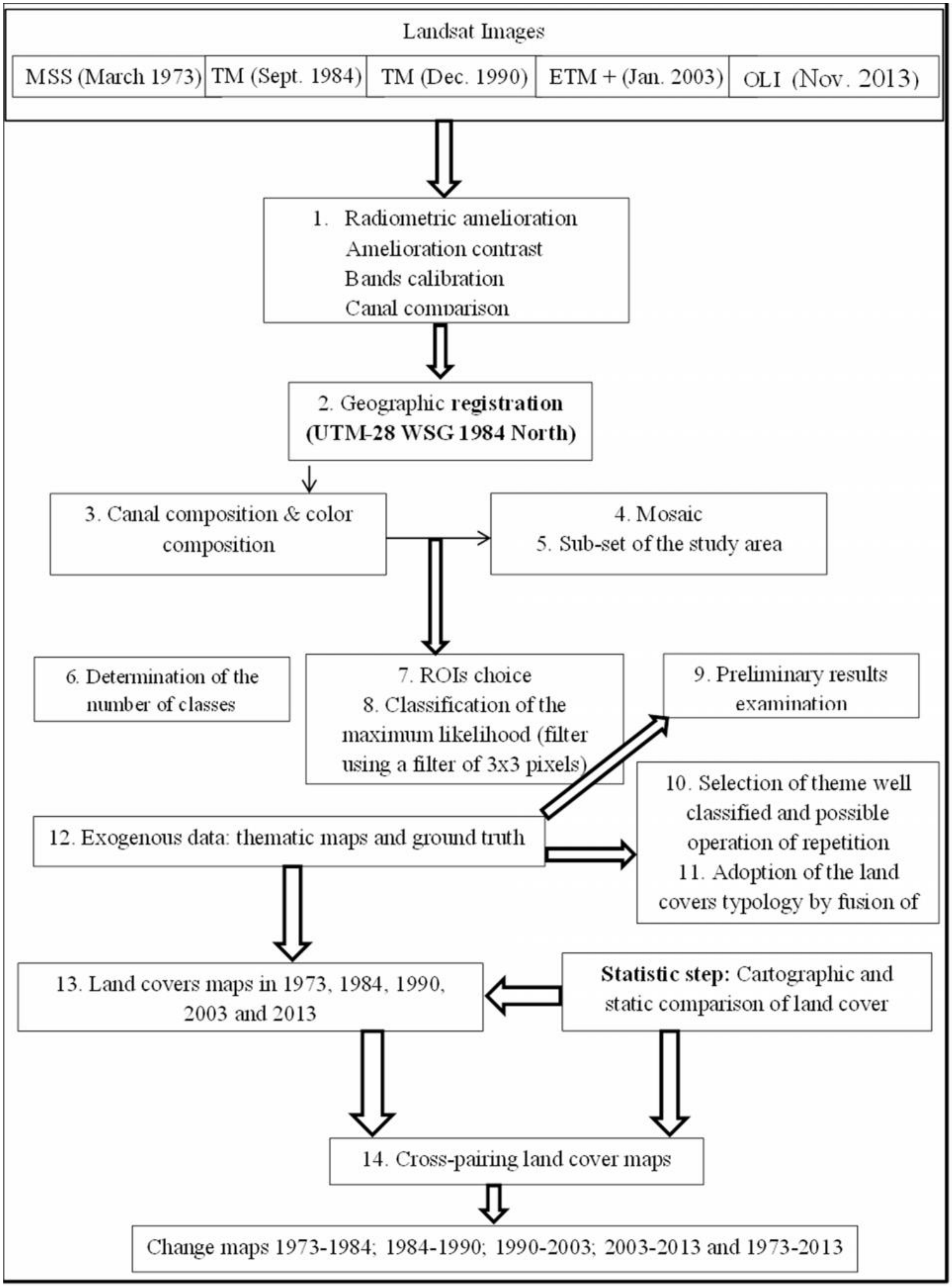


Figure 20: The steps of the images processing

2.2.2.1.2. Validation of the supervised classification

The Validation of the results obtained by the supervised classification was performed with determination of the kappa coefficient and its accuracy. This allowed to assess the quality of the results and to evaluate the potential risk for possible confusion and the ability to better differentiate the occupation of classes **(Girad & Girad, 1999)**. The classification quality was assessed using the scale proposed by **Blum *et al*. (1995)** in which the kappa index arranged to 1-0.81; 0.80-0.61; 60-41; 0.40-0.21; 0.20-0.00 and < 0 corresponds respectively to excellent, good, medium, low, fairly bad and bad.

Legend of the classified types of vegetation was based on the nomenclature of **Yamgambi (1956), Aubreville (1957), Trochain (1957)** and **Adam (1962).**

Images processing was performed in ENVI 4.1 software and cartographic analyses were run in ArcGIS software 10.

2.2.2.2. Relation between vegetation dynamic and climatic factors

The relation between the land cover evolution and rainfall variation was defined by analysing the evolution of standard normalized deviation and the extreme events at 10 and 90 percentile of rainfall from 1968 to 2014 and the dynamics of the land cover obtained.

2.3. Characterization of the vegetation of the confinement area of the Western Derby Eland

2.3.1. Sampling and data collection

2.3.1.1. Sampling

2.3.1.1.1. Mapping

An inventory was made using a stratified random scheme at two levels. Stratification was based on a preliminary identification of homogenous covers corresponding to vegetation types. Homogeneous ranges of vegetation cover were mapped on the basis of a Landsat-8/ Operational Land Imager (OLI) scenes (Fig. 21).

2.3.1.1.2. Sampling size

The sample size N was computed with a margin error of 9 % using the formula of **Dagnelie (1998):**

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

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

N = 156 plots have been shared into the confinement area of the WDE proportionally to the surface occupied by each land cover type.

2.3.1.1.3. Form and size of plots

Circular plots mostly recommended for vegetation studies were replaced by square plots of 20 m x 20 m (400 m^2). The form and size of plots were justified by the fact that they were easier to establish and were also used successfully during previous studies **(Hejcmanova-Nezerkova & Hejcman, 2006; Sambou *et al*., 2008; Niemet-Gampika, 2013; Mbow *et al*., 2013)**.

2.3.1.1.4. Sample design

The sampling design was adapted from **Sambou (2004).** Squares plots (grid) of 250 m x 250 m were set randomly on a net grid map of the study area. Within each selected square plot, four sub-plots of 20 m x 20 m (400 m^2) were established using a random distance in the four compass directions (0, 90, 180 and 270^o) (Fig. 22). Sub-plots were set at random distance from the centre of the grid at the right **(Mbow, 2000; Sambou, 2004)**. Before pulling the distance of the sub-plot from the centre of the grid, a margin distance of 10 m was taken away in order to avoid overlapping of the sub-plots **(Niemet Gampika, 2013)**. Forestry survey http://www.jecreemonsite.net/javascript/nbaleat.php was used for the choice of the location of the plots and the distance of sub-plots from the centre of the plots of 250 m x 250 m.

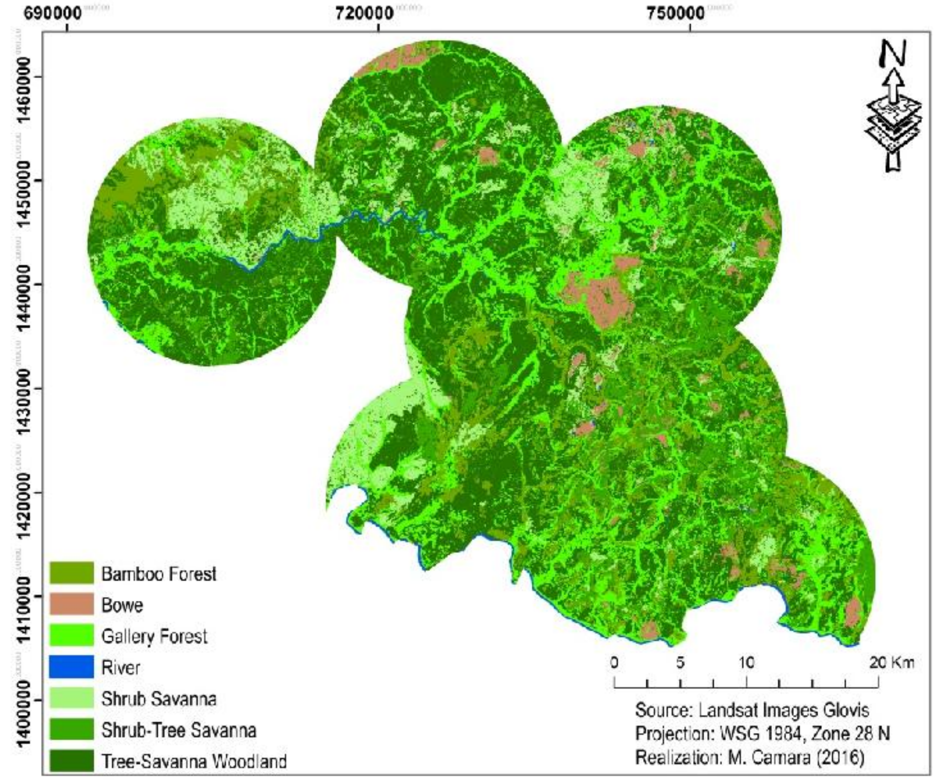


Figure 21: Vegetation cover of the confinement area of the Western Derby Eland

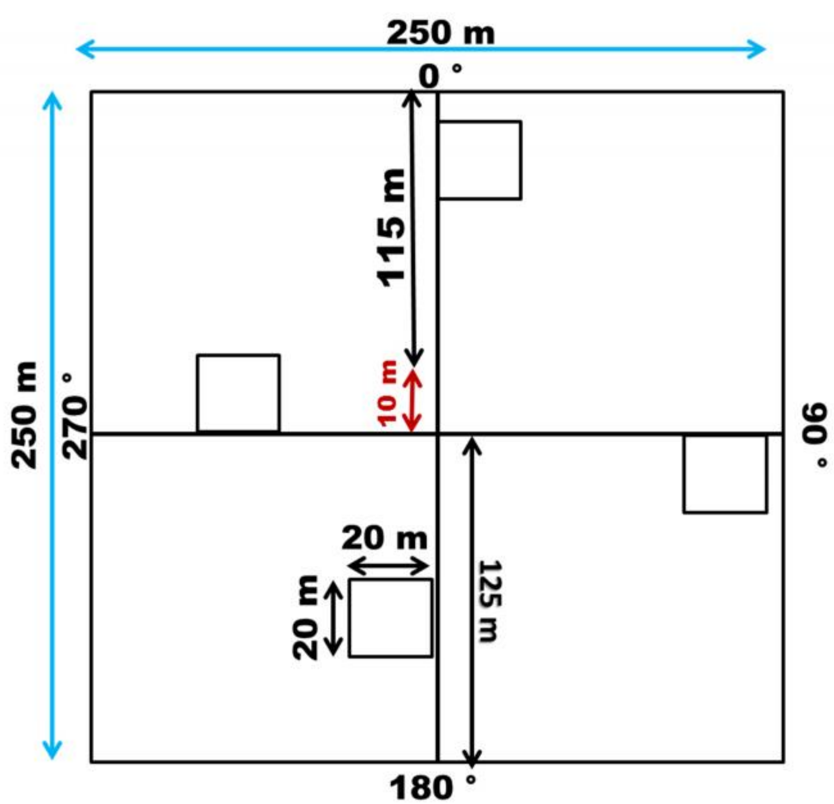


Figure 22: Sampling design used for the plant inventory (adapted from Sambou, 2004)

2.3.1.2. Data collection

After pulling, GPS coordinates of the centre of sub-plots and grids' centres were recorded and saved in a GPS for their location in field. Data were collected inside the square sub-plots of 20 m x 20 m.

2.3.1.2.1. Environmental data

Environmental parameters like soil type, percentage of vegetation cover, altitude and fire outbreak were noted. Soil type was determined using the Munsell soil colour book (Fig. 23). Soil hardness at 4 cm depth was also measured using a penetrometer **(Li *et al*., 2006)** (Fig. 24).

2.3.1.2.2. Vegetation data

Vegetation data focused on woody plant species because the diet of the WED in NKNP is constituted at more than 95% of woody plants species **(Hejecmanova *et al*., 2010)**. Data were collected at two levels.

Individuals with diameter at breast height (dbh) ≥ 5cm were considered as adults **(Madsen *et al.*, 1996; Mbow, 2000; Sambou, 2004**). List of all adult tree species met in the plots was elaborated and the numbers of their individuals were recorded. Further, their height (H) and their diameter at breast height (DBH) were recorded **(Madsen *et al*., 1996; Mbow, 2000; Sambou, 2004)**.

Regeneration data were collected for individuals of trees with a DBH < 5 cm **(Madsen *et al*., 1996).** This regeneration was classified in two groups **(Mbow, 2000; Sambou, 2004)**:

- Individuals belonging to C1 (seedling) with dhh < 5cm and height < 1.30 m
- Individuals belonging to C2 (sapling) with dbh < 5 cm and height ≥ 1.30 m.

For both groups lists of species were noted and the number of individuals of each species was recorded in each plot. The binominal nomenclature of each tree species was recorded following **Berhaut (1967)** and **Lebrun & Stork (1991-1997)** and the author' names were confirmed using **IPNI (2015)**.

Figure 23: Munsell soil color book (a) and determination of soil type (b) (Camara, 2015)

Figure 24: Photos of the penetrometer front view (a) and back view (b) (Camara, 2014)

2.3.2. Data analysis

2.3.2.1. Floristic composition

To test the discrimination of plots according to zones or sites of occurrence of the WDE the matrix of species abundance per plot were submitted to a non-metric multidimensional scaling (NMDS). NMDS is an indirect gradient analysis approach which produces an ordination based on Bray-Curtis dissimilarity. The matrix of abundance was built in column list of species recorded and in row plots inventoried. Confidence ellipses were built for each group of plots based on the above a priori categorization at 95%. To run the NMDS sixteen plots were cancelled from the sample size (Table VI) because they were empty (P1, P2, P39, P 96, P 107, P 125 and P 132) or redundant as they had the same species and the same number of individuals (P 95, P 106, P 113, P 114, P114, P 120, P 122, P 131 and P 144). For redundant plots, one plot was kept and the rest with the same information was cleared of the final matrix. To test the reliability and validity of proportion of variance of the scaled data which were accounted for by the NMDS procedure, the r^2 and stress value were computed. A r^2 of 0.9 and below and a stress ranged from 0.7 and 0.15 indicate a very good ordination.

Th Importance Value Index (IVI) was computed for the overall plant species recorded in order to define the most ecological important species (**Cottam & Curtis, 1956**). The IVI was computed using this following equation:

$$IVI = R_D + R_{Do} + R_F \quad \textbf{(2)}$$

with R_D represents the relative dominance (basal area), R_{DO} represents the relative density and R_F represents the relative frequency.

A species in a given habitat is considered to be ecologically important in that habitat when its IVI is greater than 10 **(Houéhanou *et al.*, 2013)**.

Species indicator value analysis based on species combinations **(De Cáceres *et al.*, 2012)** were used to identify indicator species of each group of plots. Only the first five most significant species or species combinations were reported. This analysis was run with a matrix comprising species in column and plots of the different groups identified in row.

Finally to assess the impacts of environmental factors (soil type, altitude, hardness, fire outbreak and vegetation cover) on the floristic composition of plots, a Canonical Correspondence Analysis (CCA) was implemented with two matrices. The first matrix has environmental factors in columns and plots of vegetation type in rows. The second matrix has species in columns and plots of the vegetation type in rows.

Analyses were performed with R 3.1.2 **(R Core Team, 2016).** The NMDS and the CCA were implemented in packages vegan (**Oksanen *et al*., 2013**) and MASS **(Venables & Ripley, 2002)** while the indicator species analysis was executed in *Indicspecies* packages **(De Cáceres & Legendre, 2013)**.

The lists of floristic and dendrometric parameters were estimated following some schemes of computations (Table VII). Average values and coefficient of variation (cv) of the dendrometric parameters were calculated for the whole stand, and for each zone and site. Student *t-test* and one-way Anova were performed to compare these parameters across zones and sites of WDE occurrence, respectively.

Table VI: Number of plots used per zone and per site for the statistical analysis

Zones	Sites	Number of plots	Percentage
Medium occurence of the WDE	Kossi Kossi	13	9.29
High occurence of the WDE	Linguekountou	59	42.14
	Mansafara	14	10.00
	Niokolo	54	38.57
	Total	127	90.71

Table VII: Calculated floristic and dendrometric parameters

Parameter	Equation	Components
Species richness	S = counted number	S: the total number of observed species recorded in the class or the site.
Shannon index	$H' = -\sum_{i=1}^{s} p_i \mathrm{Log}_2 p_i$ with $p(i) = ri/R$	ri is the mean number of individuals of the species i R is the total number of individuals of all species.
Evenness coefficient or **Pielou's evenness**	$Eq = \frac{H'}{H_{max}}$ *with* $H_{max} = \mathrm{Log}_2 S$	*H'*: Shannon-Wiener's diversity index H_{max} : maximum value of the diversity index S: Specific Richness is the number of species recorded in the considered vegetation type.
Tree density	$N = \frac{n_i}{s}$	ni = number of individuals of a given species S = area
Basal area	$G = \frac{\pi}{40000\ s} \sum_{i=1}^{n} d_i^2$	d = diameter of individual i S = area (S = 0.04 ha)
Mean diameter of the trees	$D_g = \sqrt{\frac{1}{n} \sum_{i=1}^{n} d_i^2}$	n = total number of individual d = diameter of individual i.
Lorey's mean height	$H_L = \frac{\sum_{i=1}^{n} g_i\ h_i}{\sum_{i=1}^{n} g_i}$ *with* $g_i = \frac{\pi}{4} d_i^2$,	di = diameter of specie i hi = height of species i.

2.3.2.2. Diameter class structure

To establish the trees diameter size class distribution (SCD) all tree species individuals with DBH ≥ 5cm were grouped into 5 cm DBH classes in order to obtain enough classes **(Bonou *et al.*, 2009)**. Diameter size class distribution was adjusted to the 3-parameters Weibull theoretical distribution. Tree densities were assessed for diameter classes. For each group, diameters of trees were used to estimate the parameters b (scale) and c (shape) based on the maximum likelihood method **(Johnson & Kotz, 1970; Bonou *et al*., 2009; Houéhanou *et al*., 2013)**. The threshold (a) value for the diameter was 5 cm. These analyses were performed in Minitab 14.

The log-linear analysis model was performed in SAS **(SAS Inc., 2013)** for each SCD to test the adequacy of the Weibull distribution to the observed structure. The hypothesis of adequacy between results was accepted if the probability value of the test was higher than 0.05. The model described is as follow **(Caswell, 2001):**

$$\text{Log Frequency} = F + F_{Class} + F_{adjustment} + \varepsilon \quad \textbf{(3)}$$

Where F = mean frequency of the classes, F_{Class} = non-randomly gap linked to the differences in frequency between classes, $F_{adjustment}$ = non-randomly gap linked to differences between observed and theoretical frequencies and ε = is the error of the model.

2.4. Prediction of distribution of plant species consumed by the Western Derby Eland under climate change within Niokolo Koba National Park

The prediction of the distribution of plant species consumed by the WDE was extended to the park because of the fact that we were dealing with an animal able to move within the park seeking for suitable area. Furthermore, we were predicted the suitable areas by the end of this century. Hence, it would be better to look for all the possible suitable habitats for the WDE during this period in order to enhance its conservation. We recognise that a suitable habitat is composed by several objects. But, vegetation plays a key role in herbivores survival by providing habitat, cover, protection from natural enemies and forage (**Pienaar, 1974**). In this section we focused on the feeding plants such as *Boscia angustifolia* A.Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. and *Ziziphus mauritiana* Lam. described as part of the diet of the WDE using faeces analyses **(Hejcmanová *et al.*, 2010).** Without a doubt, the quantity and quality of vegetation (forage) provide essential information that must be taken in consideration in the habitat management of large herbivores **(Kamler & Homolka, 2011).**

2.4.1. Data collection

2.4.1.1. Presence records

Geographic coordinates (longitude and latitude) of CPS were collected at random sets from the fieldwork and then completed from the herbarium of the Department of Plant Biology of Cheikh Anta Diop University in Dakar (Table VIII).

Duplicate records in a grid were removed in order to reduce the sampling bias in favour of some sites where sampling was highly concentrated **(Da, 2010; Elith *et al*., 2011)**.

2.4.1.2. Environmental data set

Environmental variables used were current and future climate data (temperature and precipitation) (Table IX). Climatic data were downloaded from Worldclim database (http://www.worldclim.org/download) that provides a set of global climate layers generated through interpolation of climate data from weather stations at an original spatial resolution of 30 arc-second (0.00833°, approximately 1 km^2). The current data covers monthly means of each climate variable for the period from 1950 to 2000. Future climatic data have been simulated using different General Circulation Models (GCMs) and Representative Concentration Pathways (RCPs) based on different IPCC climate-change scenarios from the IPCC 5th Assessment **(IPCC, 2013)**. Future climatic data cover two time periods which are 2050 (monthly mean from 2041 to 2060) and 2070 (monthly mean from 2061 to 2080). We used three climate models (Fig. 25; Table X) GFDL-ESM, HadGEM2-ES and MPI-ESM-LR and two climate RCPs (scenarios 4.5 and 8.5) to predict the potential distribution and shift of the plant species consumed in NKNP by the end of this century. GFDL-ESM, MPI-ESM, and HadGEM-ES are respectively assigned for forecasting, dry, neutral and wet over Sahel by the end of this century (Fig. 25) **(Park *et al.*, 2015)**.

Table VIII: Number of occurrence points of plant species consumed by the Western Derby Eland recorded for each species from the field and the herbarium

Species	Number of occurrences	
	Field work	Herbarium
Boscia angustufolia A. Rich.	26	6
Grewia bicolor Juss.	6	2
Hymenocardia acida Tul.	99	9
Strychnos spinosa Lam.	419	1
Ziziphus mauritiana Lam.	16	2

Table IX: List of climatic factors used for projections of Western Derby Eland consumed species distribution

Abbreviation	Variables description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Sources Worldclim, original resolution = 1 km

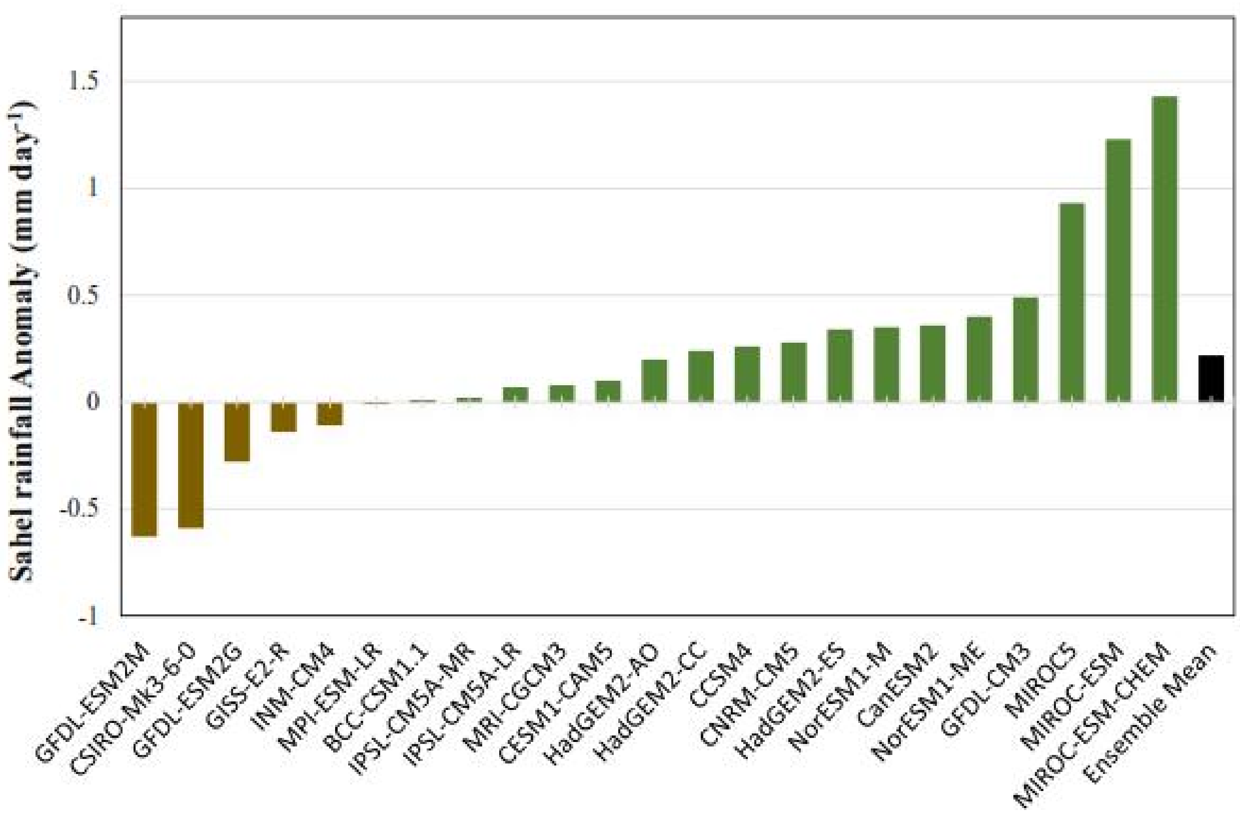


Figure 25: Future Sahel rainfall projections (source: Park, 2015)

Table X: Representative concentration pathways (RCPs) in years 2100 (source: IPCC, 2013)

Scenarios	Nominal radiative forcing (W/m)	CO2 equivalent concentration (ppm)	Rate of change in radiative forcing	Projected increase in global mean temperature for 2100 (^{o} C)	Closest SRES equivalent
RCP 8.5	8.5	1350	Rising	2.6 - 4.8	SRES A1F1
RCP 4.5	4.5	650	Stabilizing	1.0 - 2.6	SRES B1

SRES: Special Report on Emissions Scenarios (4th IPCC Report)
RCP: Representative Concentration Pathways (5th IPCC Report)

In absence of regional models for Africa, we used the Global Circulations Models (GCMs) which are considered the most reliable climate models currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations **(Hannah *et al.*, 2002)**.

2.4.2. Data analysis

Assuming that climate is the most important factor determining the distribution range of species, we modelled individual species niches from observation points and projected these models into the future using different future climate scenarios **(Phillips *et al*., 2006)**. Only presence data and climate envelope modelling (CEM) program implemented in MaxEnt (The Maximum Entropy approach) were used to determine the current distribution of plant species consumed (here referred to as today) and then to predict their distribution and shift under climate change. We projected the GFDL-ESM, MPI-ESM and HadGEM-ES models at the horizon 2050 under RCP 4.5 and at the horizon 2070 under RCPs 4.5 and 8.5 (IPCC, 2013). The Choice of RCPs was guided by the fact that they have a quite similar evolution through the first half of the century. Then after the middle of this century, they diverged with a rapid rising temperature for RCP 8.5 and a levelling off for RCP 4.5 (Fig. 26) **(Harris *et al.*, 2014; Sagna *et al.*, 2015)**. Thus, choosing the higher RCP 8.5 and the lower RCP 4.5 emission scenarios for the second part of the century is the best approach of apprehending emission range of changes **(Matthews & Solomon, 2013)**.

A Jackknife procedure was performed on the climatic factors (Table IX) to determine those contributing mostly to the model prediction. Models predictive power and goodness of fit were assessed using the True Skill Statistic (TSS) and the area under curve (AUC) of the receiver operating characteristic (ROC) curve of the cross-validations. The AUC gives the probability that the predictive power of a model is better than random prediction. The ROC curve describes the relationship between the proportion of observed presences correctly predicted (sensitivity) and the proportion of observed absences incorrectly predicted (1– specificity). Specificity is measured here with the background pixels chosen uniformly at random since there was no absence point in the model **(Phillips *et al*., 2006).** The TSS is a measure of the capacity of the model to accurately detect true presences (sensitivity) and true absences (specificity). The scale suggested by **Araújo *et al.* (2005)** was used to appreciate the model predictive ability. The model goodness of fit is excellent if AUC > 0.90, good at 0.80>AUC≤0.90, acceptable when 0.70>AUC≤0.80, bad with 0.60 >AUC≤ 0.70 and invalid if 0.50>AUC≤0.60. A TSS ≤ 0 indicates a random prediction while when TSS > 0.5 the predictive power is good **(Allouche *et al.*, 2006).**

The potential distributions of species were given in form of probabilities for the presence of each species. At each time period and for each model and RCPs, the suitable habitats generated with MaxEnt were transformed into a presence/absence matrix using the logistic probability distributions values ranging from 0 to 1. The habitats are suitable for species when the value of their occurrence probability is above the value of the logistic threshold at the 10 percentile training presence and unsuitable when the value of their occurrence probability below of the value of the threshold **(Da, 2010; Scheldeman & van Zonneveld, 2010).**

The potential current habitats and future suitable distributions of species generated with MaxEnt were mapped. Then the possible potential gain and loss in species distribution per grid cell habitat under current and future climate models was estimated by calculating difference between present and future values of each specie distribution using spatial analyst tool in ArcGIS.

Analyses were run using seventeen bioclimatic variables (Table IX) because two variables Bio14 and Bio17 with notable outliers within the park were removed. The modelling was performed using the latest available version of MaxEnt 3.3.3k and all geographic information system (GIS) analyses were performed in ArcGIS 9.2 and 10.

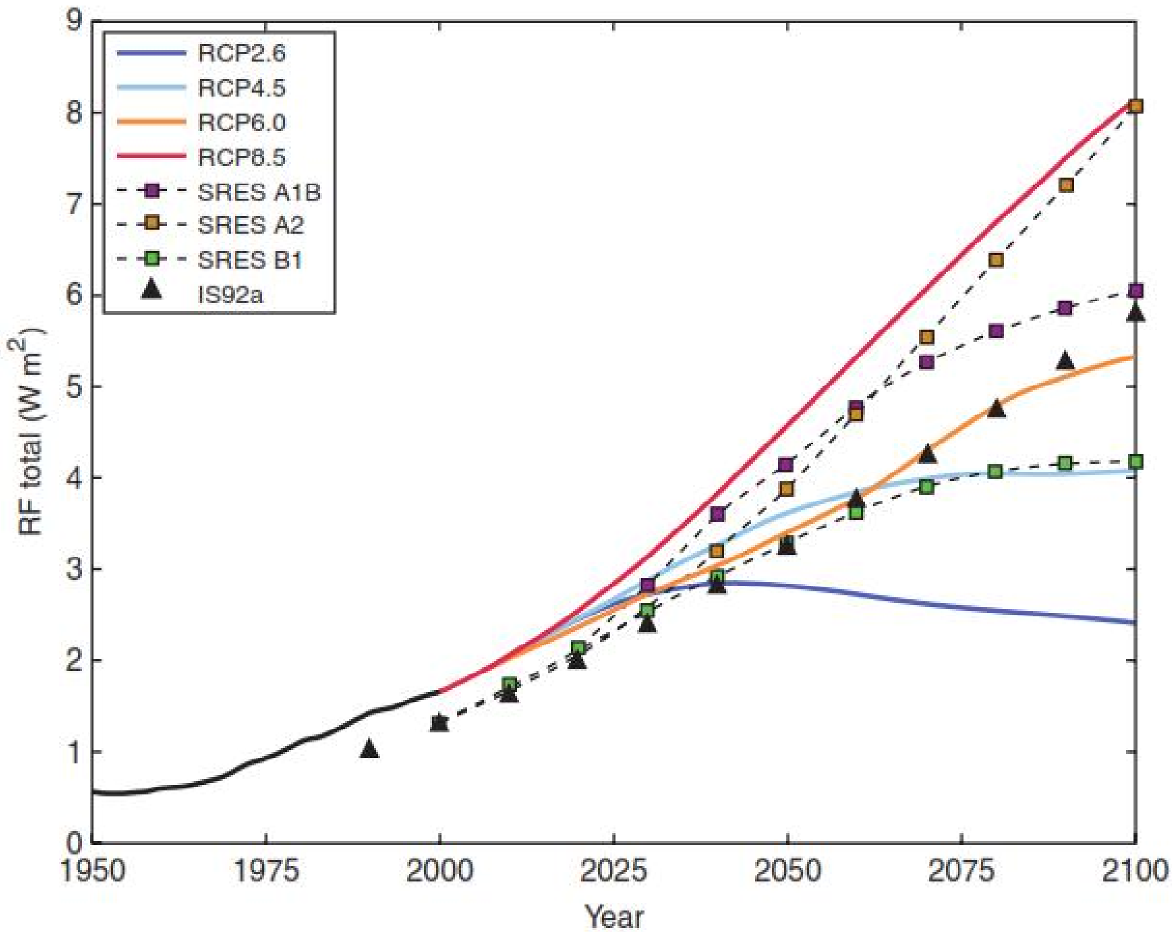


Figure 26: **Historical and expected total anthropogenic radiative forcing for Special Report on Emission Scenarios (SRES) and Representative Concentration Pathways (RCPs) between 1950 and 2100 (source: Harris *et al*., 2014)**

IS92a refers to a Second Assessment.

Chapter 3:

RESULTS

3.1. Identification of the confinement area of the Western Derby Eland in Niokolo Koba National Park

3.1.1. Concordance of informants on the occurrence zones of the Western Derby Eland in Niokolo Koba National Park

The first three axes of the principal component analysis (PCA) explained 64.75 % of variation of occurrence zones according to informants. The correlation between sites and PCA axes (Fig. 27; Appendix 2) showed that axis (dimension) 1 was negatively correlated to Niokolo and Assirik and positively to Malapa, Camp du Lion, Badi, Linguekoto, Simenti, Passage Koba, Mbolor 1, Mbolor 2 and Tambanoumia while axis (dimension) 2 was negatively correlated to Damantan, Oubadji, Kenoyo and positively correlated to Linguekountou, Niakassi, Niokolo, Wouroly and Banghare (Fig. 27a; Appendix 2). Axis (dimension) 3 was negatively correlated to Patte d'oie and positively correlated to Grande Faune, Badoye, Dalaba and Antenne de Sane (Fig. 27c; Appendix 2).

The projection of the sources of information into the systems of plans 1-2 and 1-3 (Figs. 27b-d) indicated that on axis 1 the researchers, former poachers, literature, active and retired agents were concordant about the presence of the WDE in Niokolo and Assirik while elder agents, and evicted villagers were concordant about the occurrence of the WDE in Simenti, Malapa, Mbolor 1 and 2, Tambanoumia, Linguekoto, Camp du Lion Passage Koba and Badi. On axis 2, resource persons, active and retired agents were concordant on the presence of the WDE in Niokolo, Banghare, Niakassi, Wouroly and Linguekountou while evicted villagers were concordant about the presence of the WDE in Damamtan, Oubadji and Kenoyo. On axis 3, former poachers, retired agents and resource persons were concordant on the sight of the WDE in Patte d'oie. However literature and evicted villagers were concordant about the presence of the WDE in Dalaba, Badoye, Grande Faune and Antenne Sane vicinity.

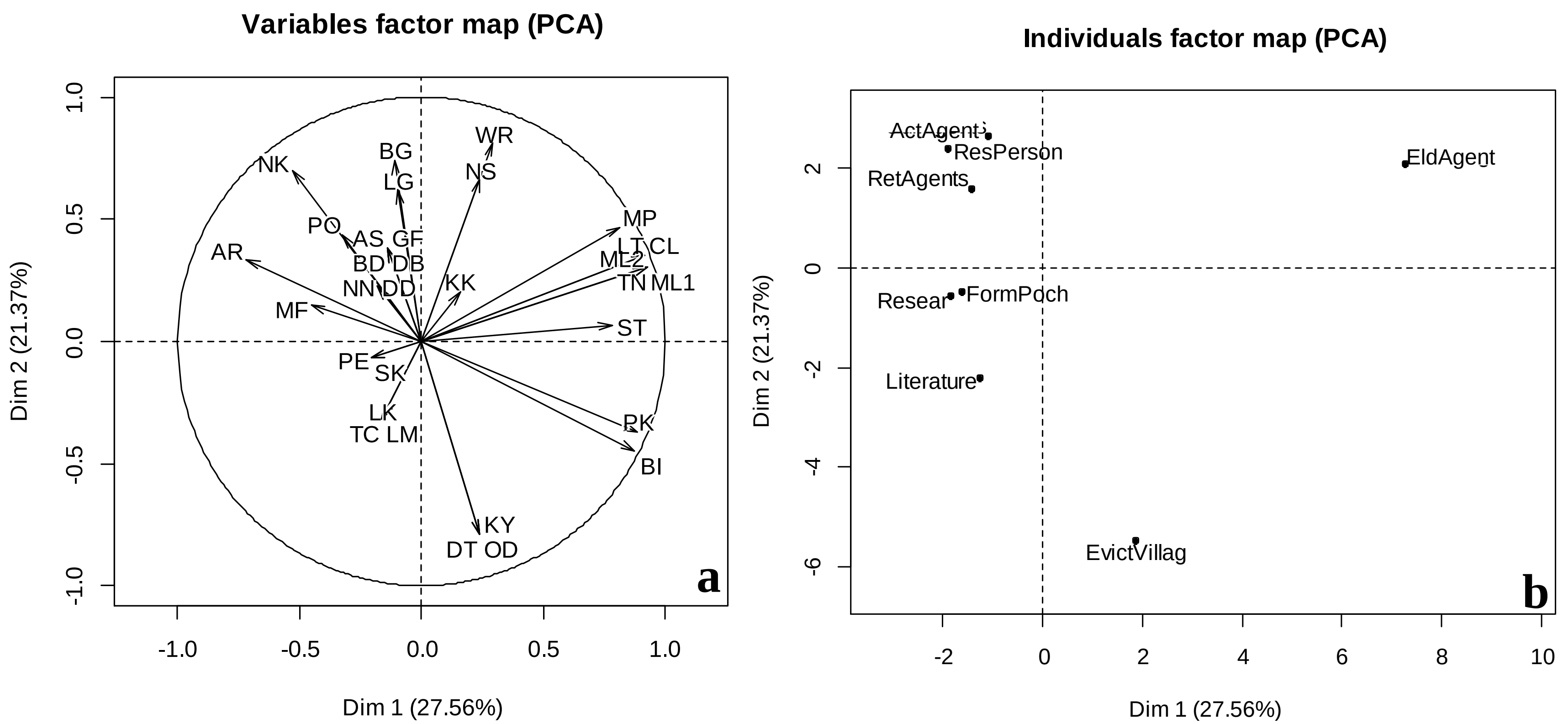


Figure 27a: Principal component analysis on the sites of occurrence of the Western Derby Eland in Niokolo Koba National Park. The first principal component axis explains 27.56% of data variation; the second principal component axis explains 21.37% of data variation while the third principal component axis explains 15.82 % of data variation. (a) Circle of correlation of the WDE occurrence in plan 1 and 2, (b) projection of informants into plan 1 and 2. Sites of occurrence of the WDE abbreviations; (LG) Linguekountou, (NK) Niokolo, (WR) Wouroly, (MP) Malapa, (CL) Camp du Lion, (GF) Grande Faune, (MF) Mansafara, (LT) Linguekoto, (NS) Niakassi, (BG) Banghare, (BD) Badoye, (AR) Assirik, (DB) Dalaba, (AS) Antene Sane, (TC) Timbicotodala, (LK) Louma Koba, (BI) Badi, (LM) Lekemere, (ST) Simenti, (PK) Passage Koba, (ML1) Mbolor1, (ML2) Mbolor2, (TN) Tambanounia, (PO) Patte d'Oie, (DD) Dienoudiala, (NN) Niannikoye, (KK) Kossi Kossi, (PE) Pharmacie des Elephants, (SK) Sayinki, (DT) Damantan, (OD) Oubadji, (KY) Kenoyo.

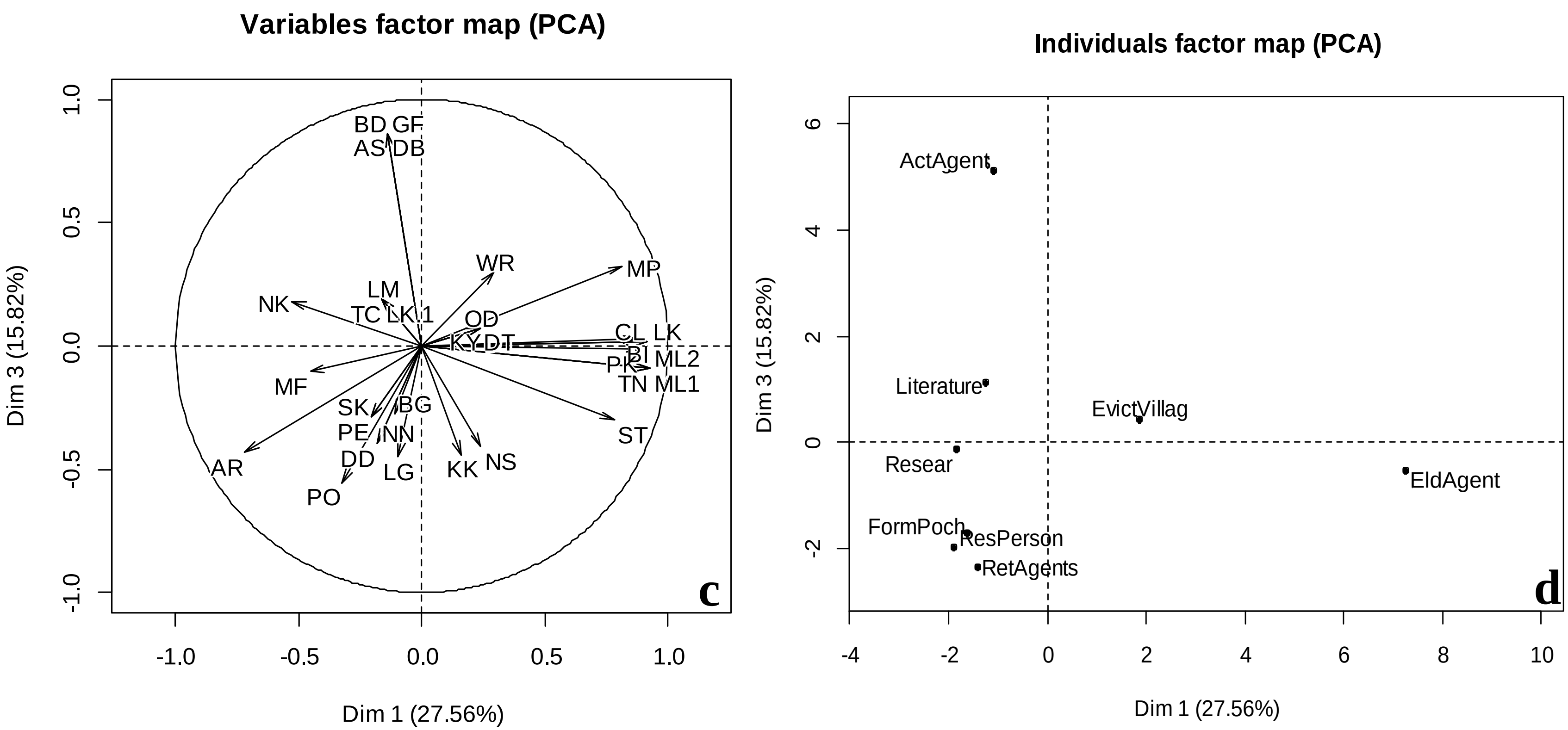


Figure 26b: Principal component analysis on the sites of occurrence of the Western Derby Eland in Niokolo Koba National Park. The first principal component axis explains 27.56% of data variation; the second principal component axis explains 21.37% of data variation while the third principal component axis explains 15.82 % of data variation. (c) Circle of correlation of the WDE occurrence in plan 1 and 3, and (d) projection of informants into plan 1 and 3. Sites of occurrence of the WDE abbreviations; (LG) Linguekountou, (NK) Niokolo, (WR) Wouroly, (MP) Malapa, (CL) Camp du Lion, (GF) Grande Faune, (MF) Mansafara, (LT) Linguekoto, (NS) Niakassi, (BG) Banghare, (BD) Badoye, (AR) Assirik, (DB) Dalaba, (AS) Antene Sane, (TC) Timbicotodala, (LK) Louma Koba, (BI) Badi, (LM) Lekemere, (ST) Simenti, (PK) Passage Koba, (ML1) Mbolor1, (ML2) Mbolor2, (TN) Tambanounia, (PO) Patte d'Oie, (DD) Dienoudiala, (NN) Niannikoye, (KK) Kossi Kossi, (PE) Pharmacie des Elephants, (SK) Sayinki, (DT) Damantan, (OD) Oubadji, (KY) Kenoyo.

3.1.2. Location of the confinement area of the Western Derby Eland in Niokolo Koba National Park

K-means analysis clustered zones of occurrence of the WDE in three classes. Class A was the zone of low probability of occurrence of the WDE (ZLPOE) with scores ranging from 1 to 8. Class B was the zone of medium probability of occurrence of the WDE (ZMPOE) with scores ranging from 10 to 18 and the class C was the zone of high probability of occurrence of the WDE (ZHPOE) with scores ranging from 38 to 107 (Fig. 28).

Subsequently to k-means analysis, the sites belonging to ZMPOE and ZHPOE scored ≥ 10 points were mapped (Fig. 29). The shape and location of the confinement area of the WDE within NKNP is shown on Fig. 30. The confinement area of the WDE in NKNP covers around 250298.19 ha representing 27.41 % of the total surface of the park.

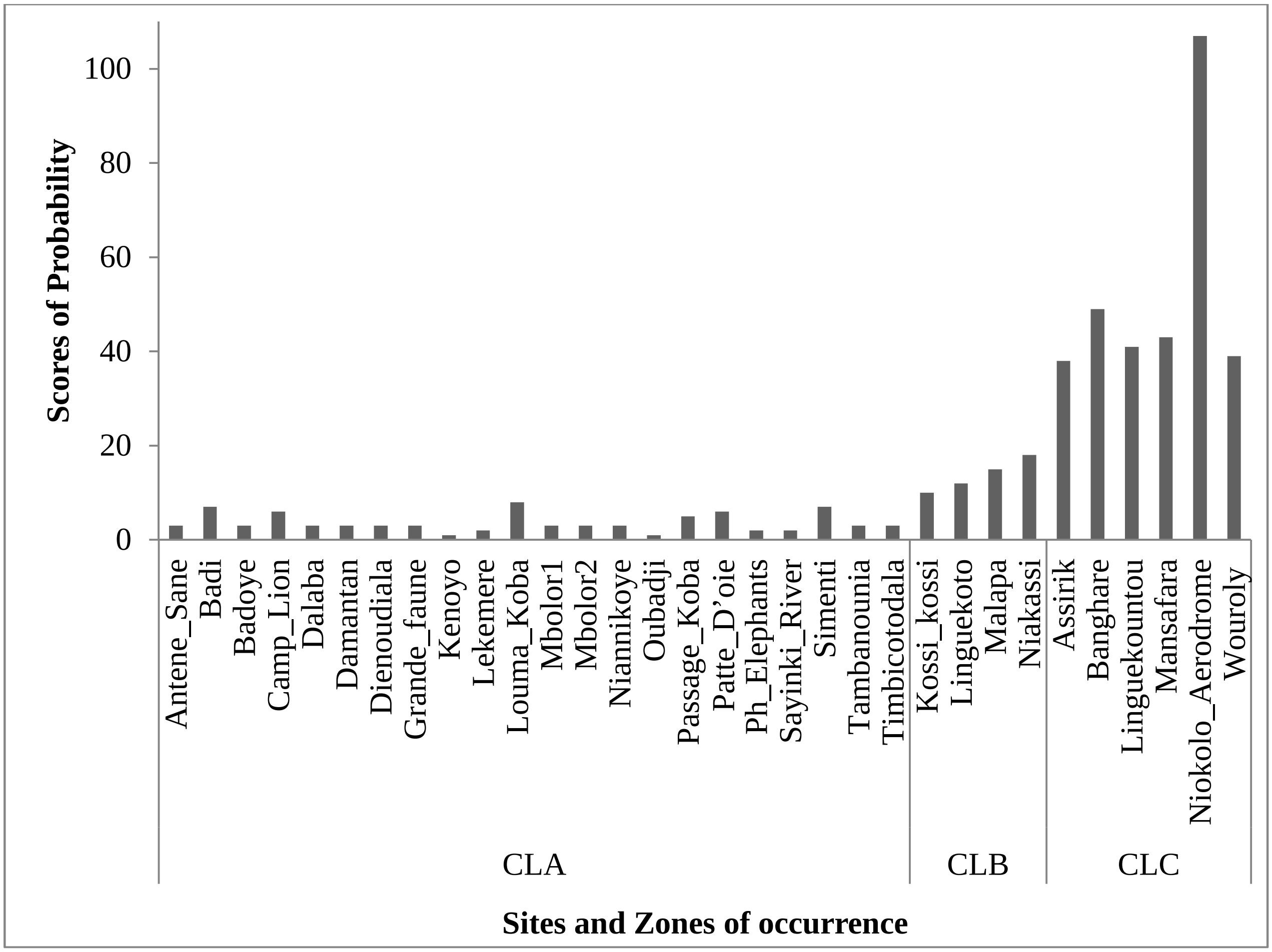


Figure 28: Classification of the zones and the sites of occurrence of the Western Derby Eland

CLA: zones of low probability of the occurrence of the WDE, CLB: zones of average probability of the occurrence of the WDE and CLC: zones of high probability of the occurrence of the WDE.

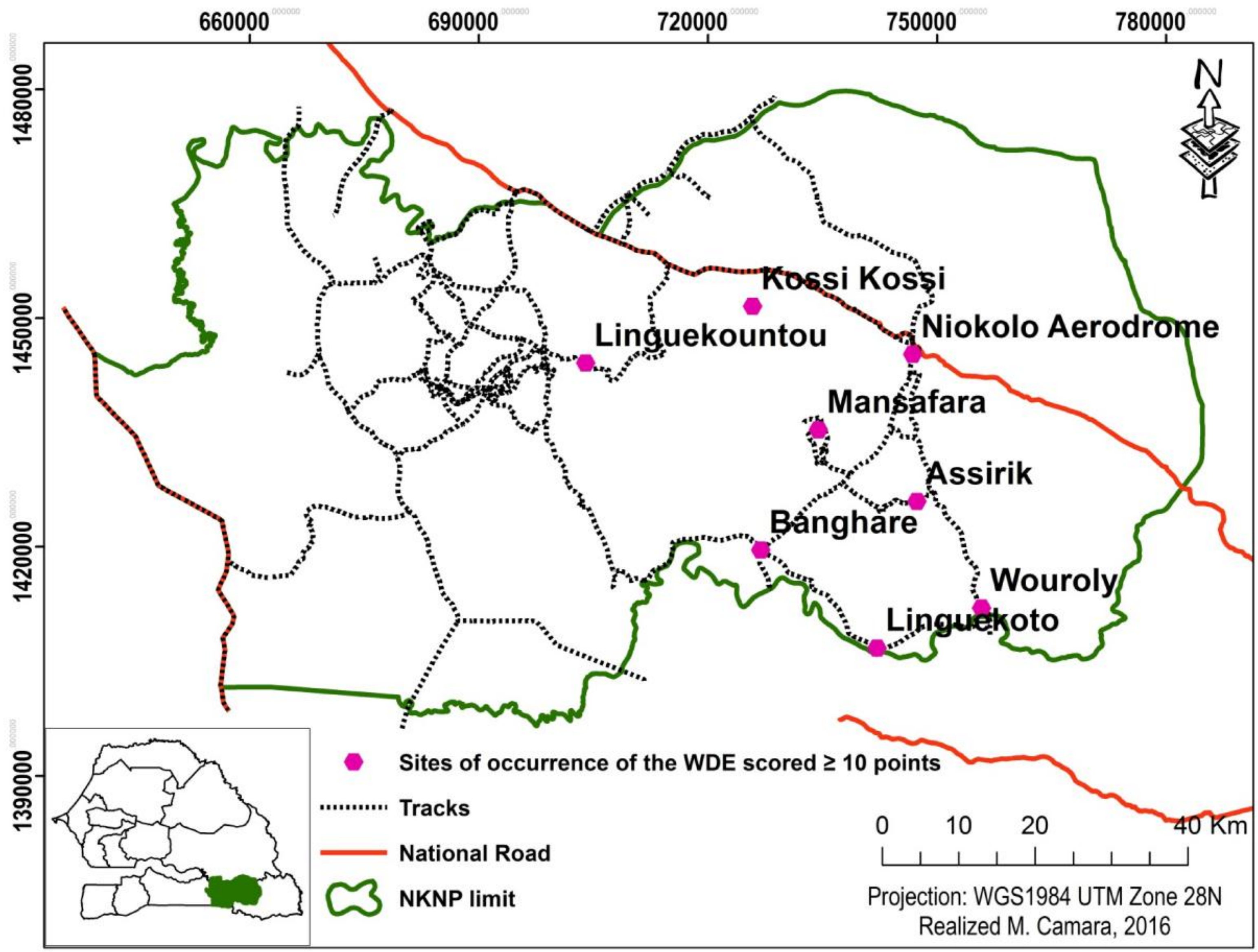


Figure 29: Location of the sites of occurrence of the Western Derby Eland in Niokolo Koba National Park with scores ≥ 10 pts

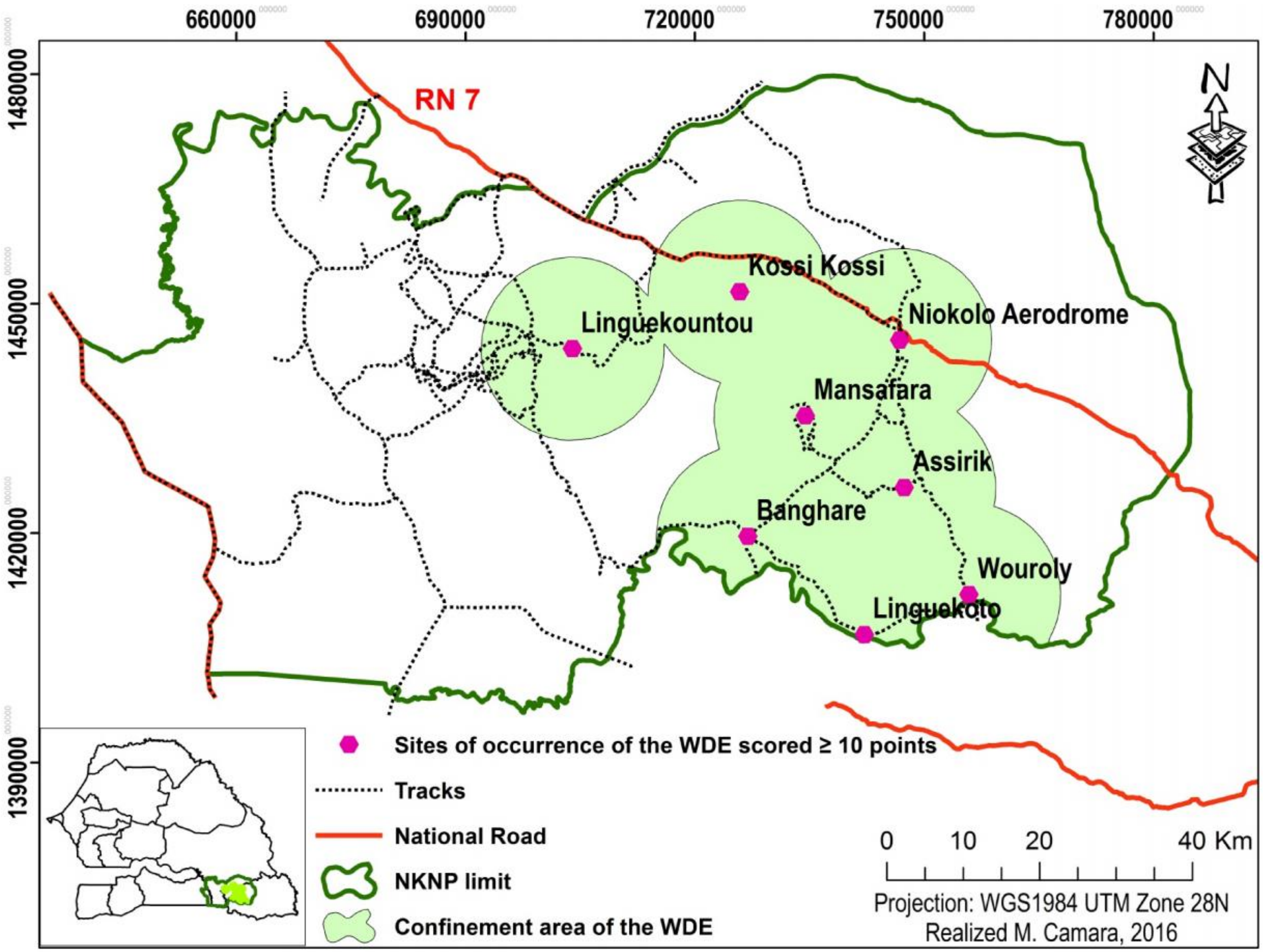


Figure 30: Map of the confinement area of the Western Derby Eland in Niokolo Koba National Park

3.2. Dynamics of the vegetation in the confinement area of the Western Derby Eland in relation with climatic parameters

3.2.1. Rainfall evolution

Analysis of the extreme events at 10 percentile revealed 1977, 1990, 2011 and 2014 were the driest years. While, the analysis of the extreme events at 90 percentile indicated 1978, 1999 and 2003 were the rainiest years (Fig. 31). The normalised deviation of rainfall from 1968 to 2014 showed an inter-annual variation with alternation of dry and wet years. The overall trend of the rainfall showed a slight recovery (Fig. 32). From 1968 to 1998, NKNP experienced a rainfall deficit illustrated by drier years (20) than wet years (10). While since 1999, the reverse was observed with rainier years (9) than dry years (7). Furthermore, rainfall of 1972, 1983 and 2002 were dry years compared to the mean of the serial whereas 1989 and 2012 were wet years.

3.2.2. Land cover of the confinement area of the Western Derby Eland

Results of the confusion matrices gave a good to excellent differentiation of classes with accuracy higher than 84 % and kappa coefficient ranging from 0.79 to 0.90 (Table XI). This expressed significant statistical discrimination between land cover units.

Seven land covers units were identified in the confinement area of the WDE. They were composed of bamboo forest, gallery forest, bowe, shrub savanna, shrub-tree savanna, tree-savanna woodland and rivers. The dynamics of the vegetation from 1973 to 2013 showed variation of the land cover units (Table XII). However, the savanna units (shrub savanna, shrub-tree savanna and tree-savanna woodland) predominated (Fig. 33).

In 1973, the land cover was dominated at 87.41 % by the savanna with a predominance of shrub savanna which occupied 42.98 % of the land cover (Table XII; Fig. 34) while the tree-savanna woodland occupied 30.92 % (Fig. 33).

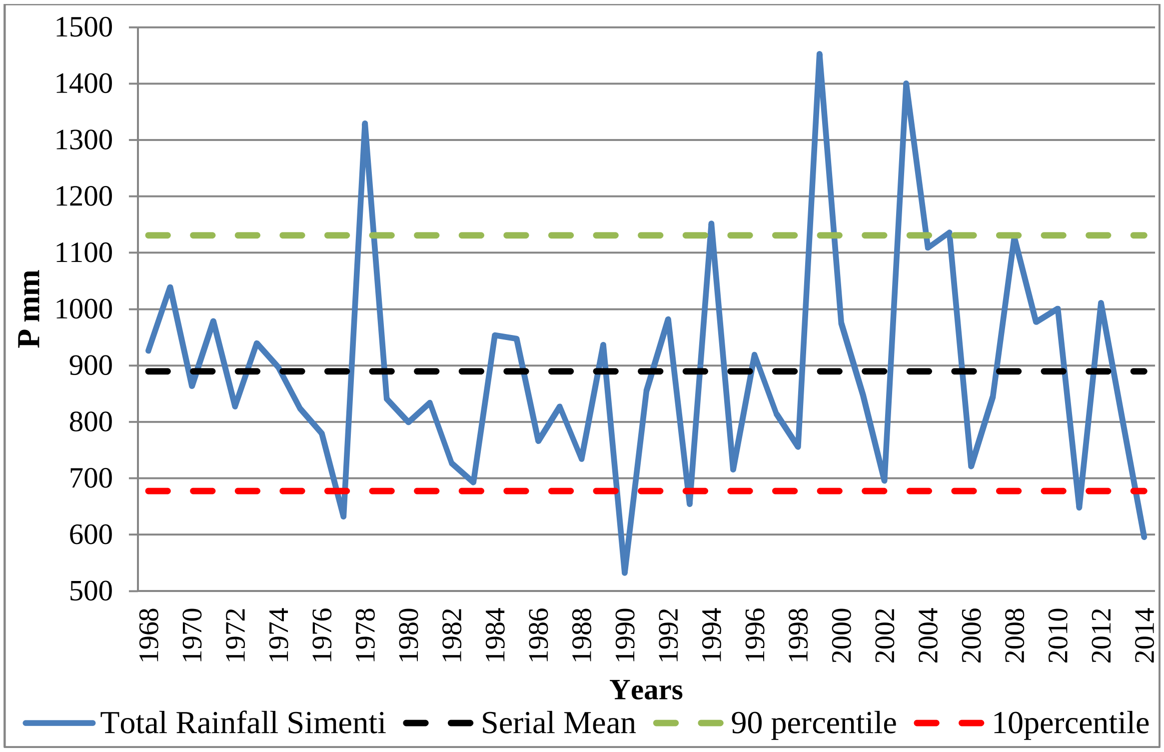


Figure 31: Extreme events of rainfall in Niokolo Koba National Park from 1968 to 2014 at 10 and 90 percentile (Source: ANACIM, 2015)

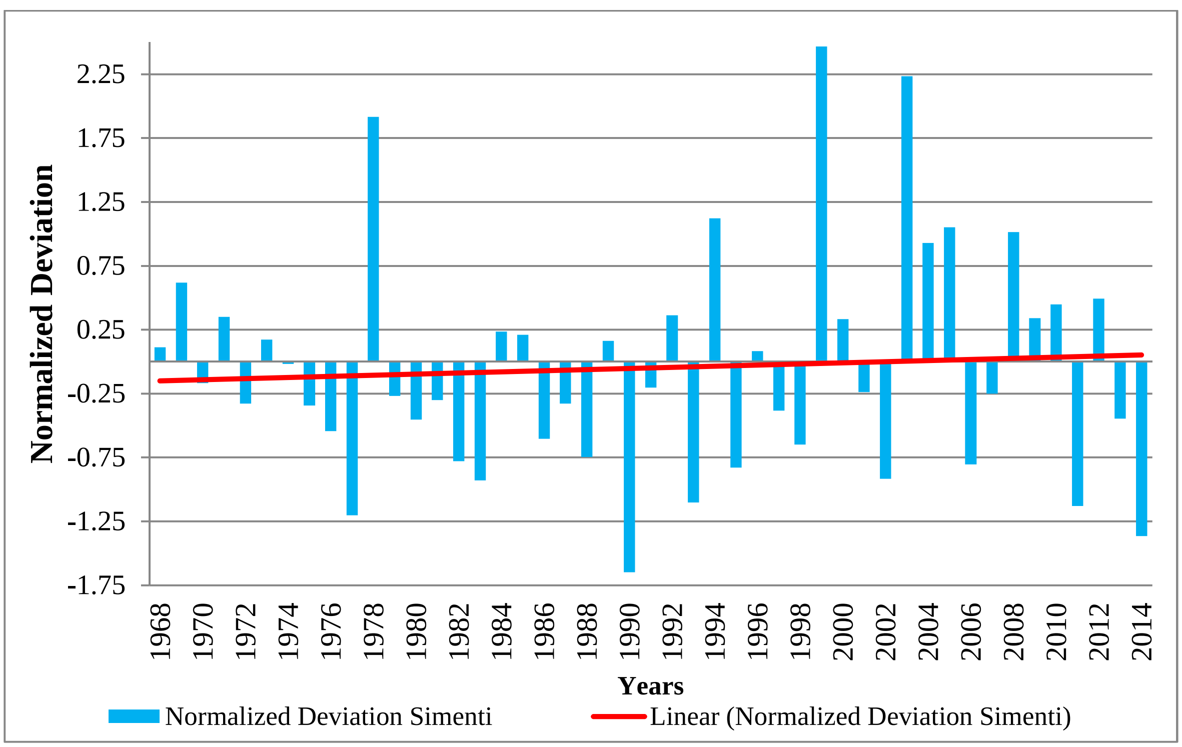


Figure 32: Normalized deviation of the rainfall of Niokolo Koba National Park from 1968 to 2014 (Source: ANACIM, 2015)

Table XI: Results of the confusion matrices of Landsat images from 1973 to 2013

Years	1973		1984		1990		2003		2013	
	Kappa	Accuracy	Kappa	Accuracy	Kappa	Accuracy	Kappa	Accuracy	Kappa	Accuracy
	0.82	84.89 %	0.80	86.29 %	0.84	88.64 %	0.79	84.13 %	0.90	94.20%

Table XII: Dynamics of the vegetation cover in the WDE confinement area from 1973 to 2013

Land type	Area (ha) occupied per land cover for each year				
	1973	1984	1990	2003	2013
Bamboo forest	0.00	9549.90	32126.99	37529.11	33451.15
Bowe	6831.25	8599.11	21187.97	17058.38	8138.70
Gallery forest	23126.79	14460.43	14601.15	18222.63	53910.69
Rivers	1553.30	1107.66	1066.61	1173.93	690.76
Shrub savanna	107570.22	55876.06	60330.18	68653.36	22247.71
Shrub-tree savanna	33820.48	22022.85	26049.35	26835.75	26043.09
Tree-savanna woodland	77396.15	138891.63	94935.93	80825.06	105816.10
Total	**250298.19**	**250507.63**	**250298.19**	**250298.22**	**250298.19**

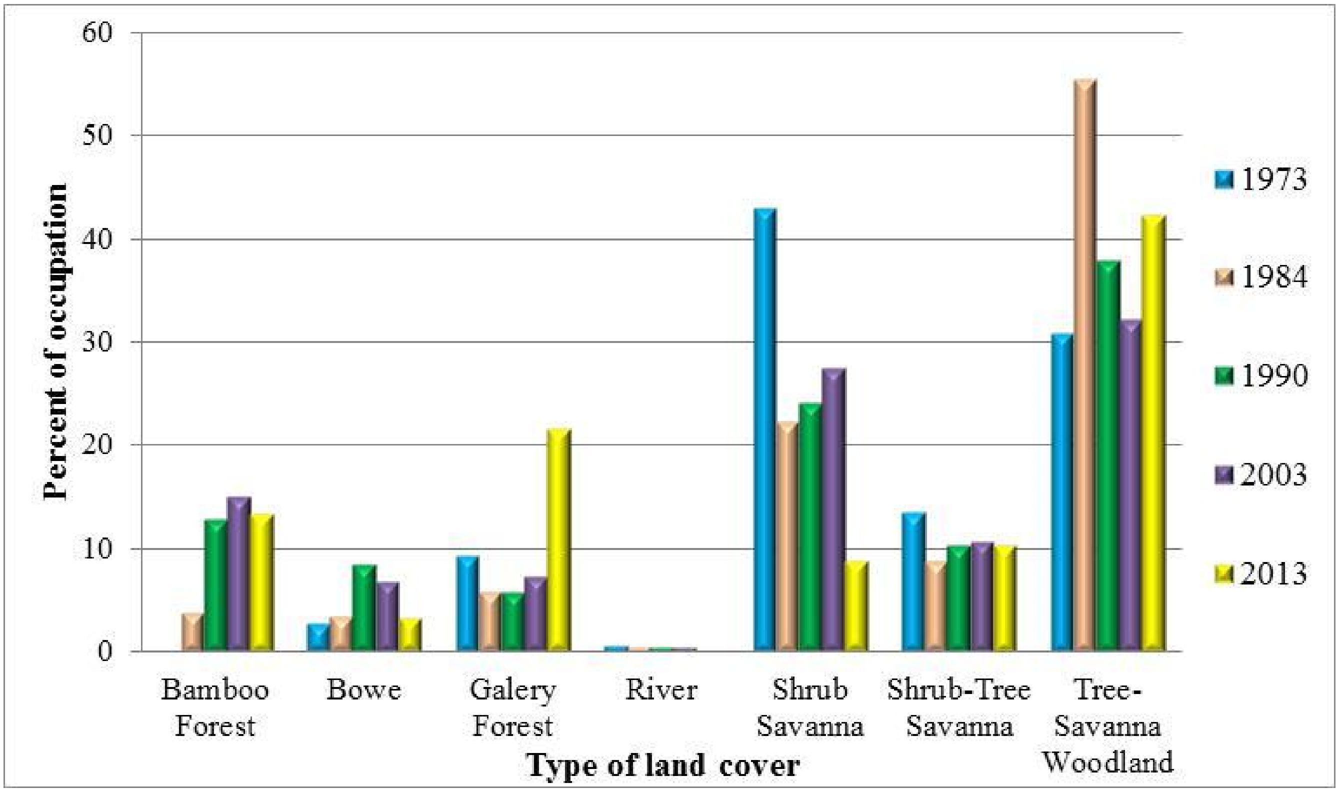


Figure 33: Percentage of evolution of the land-cover in the Western Derby Eland confinement area from 1973 to 2013

In 1984, all savannas represented 86.54 % of the vegetation cover with 22.31 % of shrub savanna, 8.79 % of shrub-tree savanna and 55.44 % of tree savanna woodland, respectively. The tree-savanna woodland increased by 61495.47 ha compared to the previous decade (Figs. 33 & 35). The bamboo forest covered 3.81 % of the total surface (Table XII; Figs. 33 & 35).

In 1990, the land cover units of bamboo forest and bowe increased to 12.84 % and 8.47 %, respectively. The surface of savannas still dominated the land cover with 72.44 % of the total surface. The surface of tree-savanna woodland decreased to 37.93 % whereas those of shrub savanna and shrub-tree savanna increased by 24.10 % and 10.41 %, respectively (Table XII; Figs. 32 & 36).

In 2003, the land cover units of bamboo forest and gallery forest increased to 14.99 % and 7.28 %, respectively. Though, the savanna vegetation still dominated the land cover, it decreased to 70.44 %. This decrease was more perceptible for the tree-savanna woodland which occupied 32.29 % of the land cover while the shrub savanna increased slightly at 27.43 % (Table XII; Figs. 33 & 37). The different land cover units seemed quite similar to the ones of 1990.

In 2013, the surface of the three savannas decreased and covered 61.57 % of the land cover of the confinement area. The shrub savanna and shrub-tree savanna decreased to 8.89 % and 10.40 %, respectively while the tree savanna woodland increased to 42.28 % (Table XII; Figs. 33 & 38). The gallery forest increased also to 21.54 %.

Generally, from 1973 to 2013 the surfaces of bamboo forest, bowe, gallery forest and tree savanna woodland increased to 13.36 %, 0.52 % and 11.35 %, respectively while the surfaces of shrub savanna and shrub-tree savanna decreased to 34.09 % and 3.11%, respectively (Fig. 39). The important changes from 1973 to 1984 were the decrease of the shrub savanna to 20.67 % and the increase of the tree savanna woodland to 24.52 %. From 1984 to 1990 the bamboo forest increased to 9.02 % while the tree savanna woodland decreased to 17.51%. From 1990 to 2003, changes showed an increase of the shrub savanna to 3.33 % and a decrease of the tree savanna woodland to 5.64 %. From 2003 to 2013, the surface of the gallery forest increased by 14.26 % whereas the surface of the shrub savanna decreased by 18.54 % (Fig. 39).

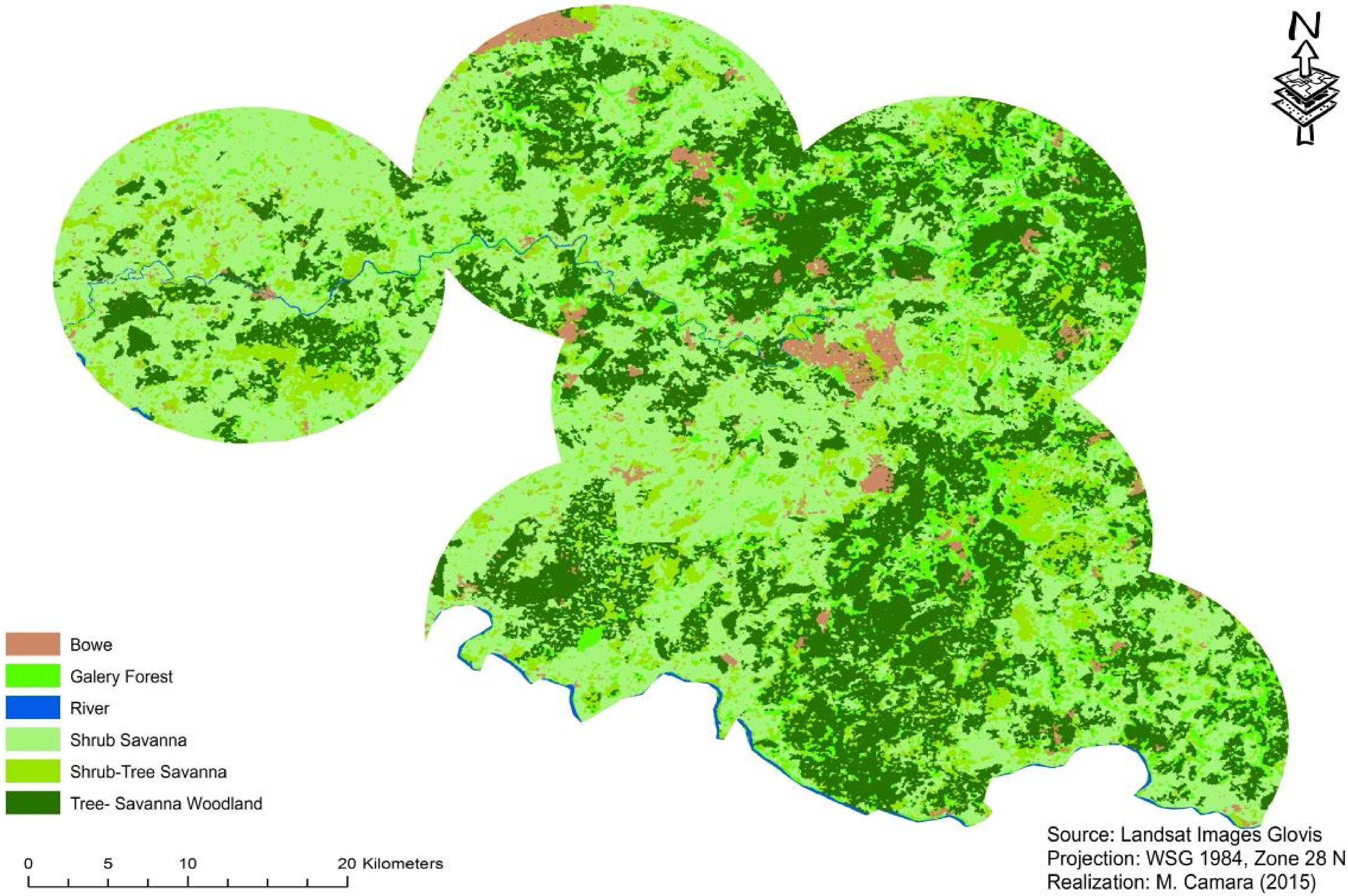


Figure 34: Land cover of the confinement area of the Western Derby Eland in 1973

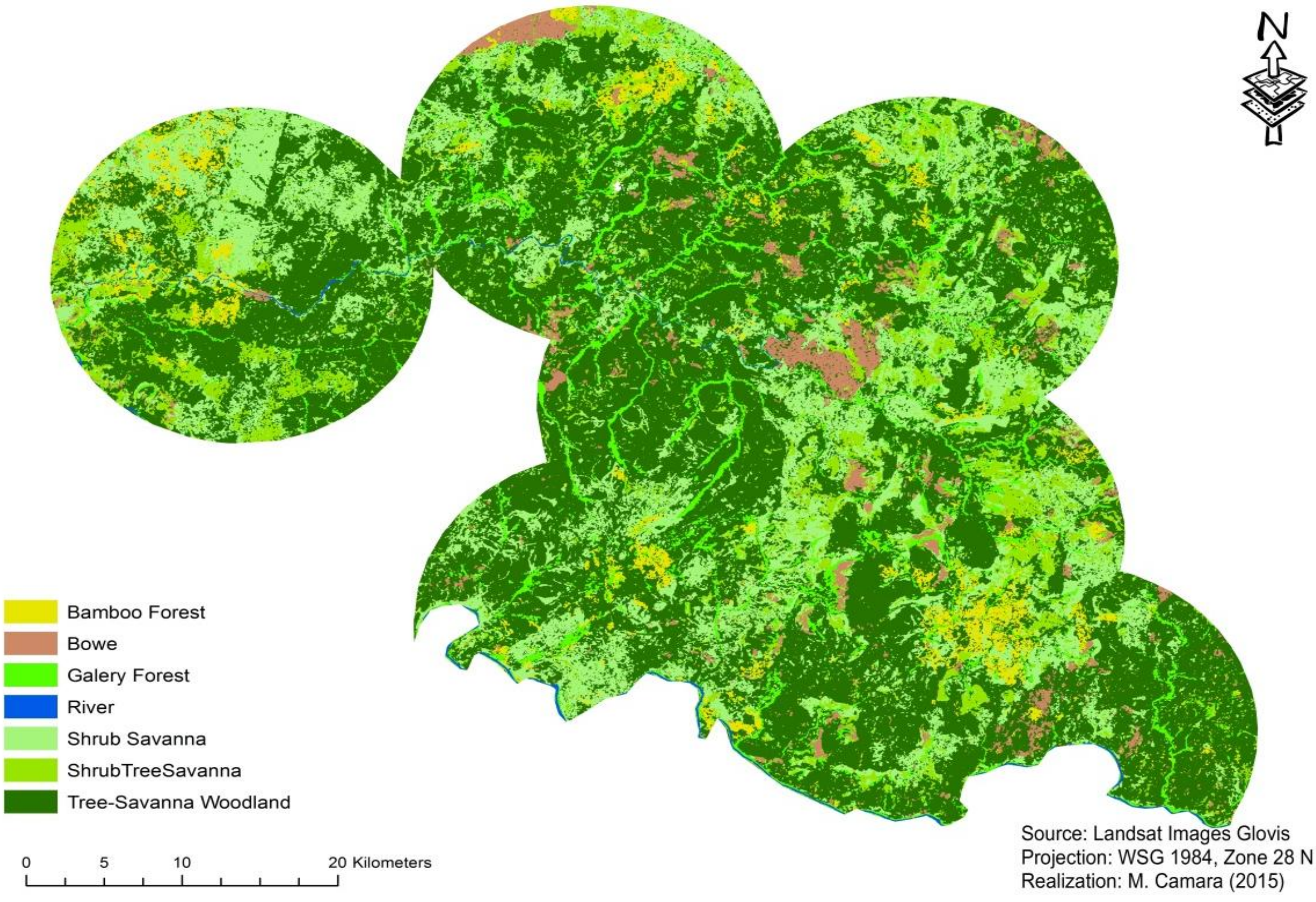


Figure 35: Land cover of the confinement area of the Western Derby Eland in 1984

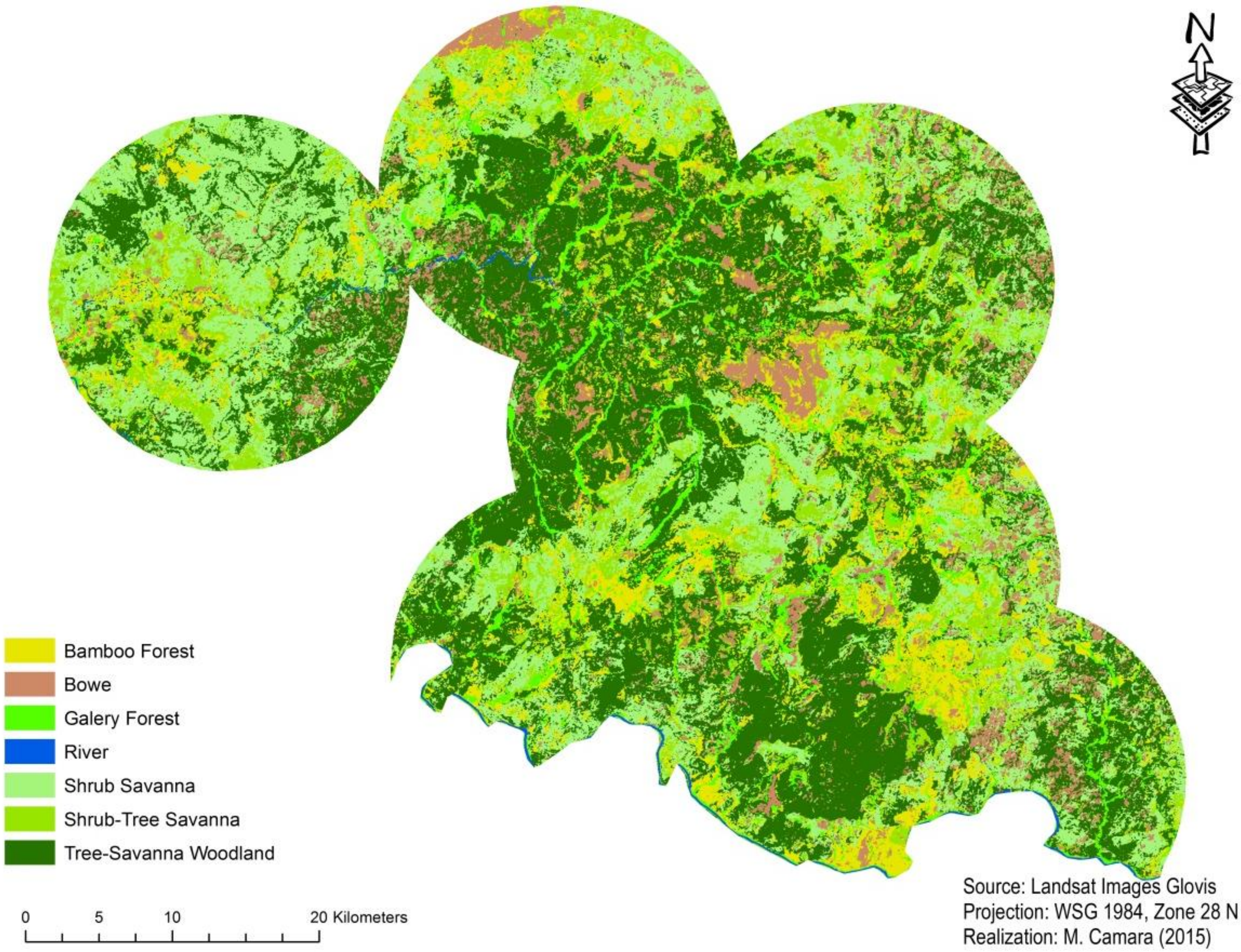


Figure 36: Land cover of the confinement area of the Western Derby Eland in 1990

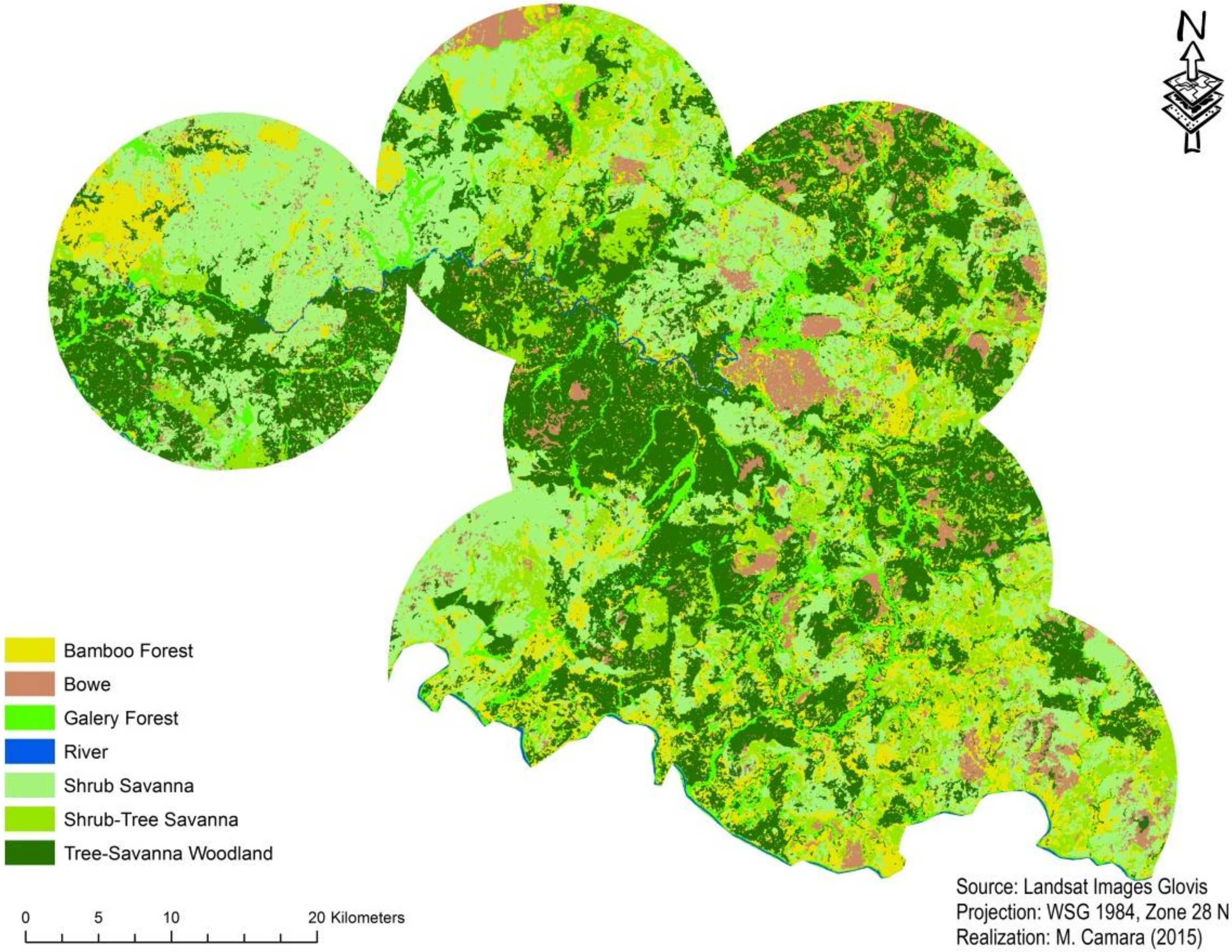


Figure 37: Land cover of the confinement area of the Western Derby Eland in 2003

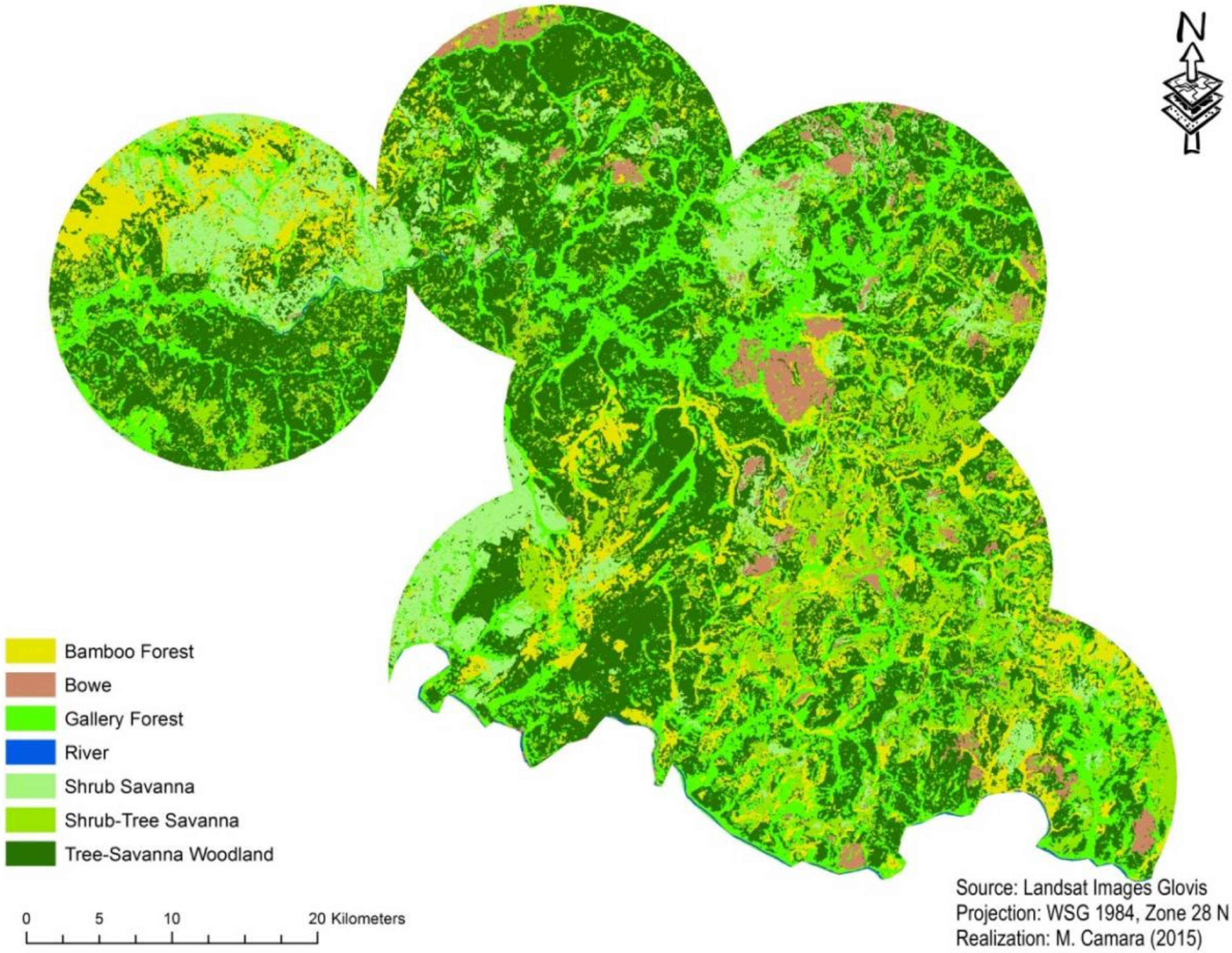


Figure 38: Land cover of the confinement area of the Western Derby Eland in 2013

3.2.3. Spatial and temporal changes of the Land cover of the confinement area of the Western Derby Eland

Global changes showed that conversion was very low ≤ 0.30% within the confinement area of the WDE from 1973 to 2013. Modification recorded presented the highest changes with values ranging from 50.74 % for 1984-1990 to 73.95 % for 1973-2013 (Figs. 40 & 41). The values of stability varied from 25.68 % in 1973-2013 to 49 % in 1984-1990. This revealed that land cover changes in the confinement area of the WDE from 1973 to 2013 were mostly dominated by modification and stability which represented 185089.78 ha and 64267.02 ha, respectively corresponding to 73.95 % and 25.68 %, respectively of the surface of this area (Figs. 40 & 41).

Between 1973 and 1984, modifications were observed for all vegetation types but medium to high modifications were recorded for the shrub savanna and tree-woodland savanna. The conversion observed was at 24.03 % from river to gallery forest (Table XIII).

The land-cover change matrix (Table XIV) from 1984 to 1990 showed a medium conversion of the river into bamboo forest and the tree-woodland savanna at 10.37 % and 14.96 %, respectively. The shrub savanna underwent a medium to high modification and gained from bamboo forest, bowe, shrub-tree savanna and tree-woodland savanna 18.45 %, 12.45 %, 37.52 % and 20.16 %, respectively. While tree-woodland savanna extended 22.54 %, 22.25 % and 24.60 % from bamboo forest, bowe and shrub savanna.

From 1990 to 2003, the modification covered 60.67 % whereas stability covered 38.98 % of the confinement area of the WDE corresponding to 151849.76 ha and 97577.19 ha, respectively (Table XV). Compared to the period 1984-1990, the modification increased by 10 % while stability decreased by 10 %. High modifications were found mainly for the shrub savanna and the tree-woodland savanna while the shrub-tree savanna recorded a medium modification. The conversion was medium from the river to the gallery forest (17.1 %).

Between 2003 and 2013, land-cover changes were relatively stable. Conversion, modification and stability covered 783.73 ha, 150 110.02 ha and 99 404.19 ha, respectively (Table XVI) corresponding to 0.31 %, 59.97 % and 39.71 %, respectively of the surface of the confinement area of the WDE. Conversion from river to gallery forest was estimated at 32.81 %. Bowe was transformed at 19.8 % into shrub-tree savanna and at 28.28 % into tree-woodland savanna. The shrub savanna was transformed at 10.84 % and 43.2 % into shrub-tree savanna and tree-woodland savanna. The bamboo forest and shrub-tree savanna were highly transformed at 37.48 % and 42.22 %, respectively into a tree-woodland savanna.

The overall changes were 0.38 % of conversion, 73.95 % of modification and 25.68 % of stability in confinement area of the WDE (Table XVII). A tendency towards close vegetation was observed with an increase of the surface of bamboo forest, gallery forest, and tree-woodland savanna.

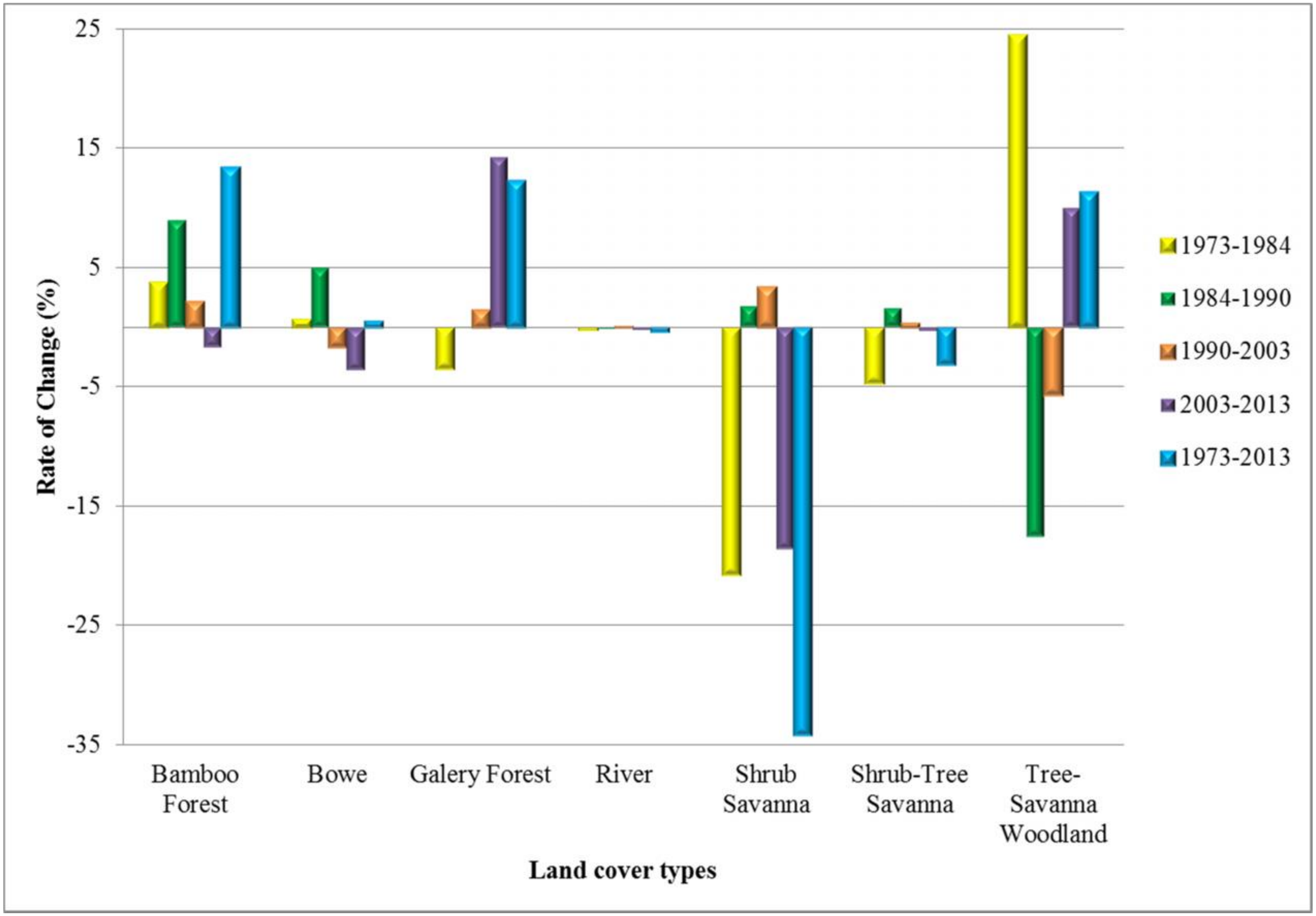


Figure 39: Rate of the land cover changes in the confinement area of the Western Derby Eland

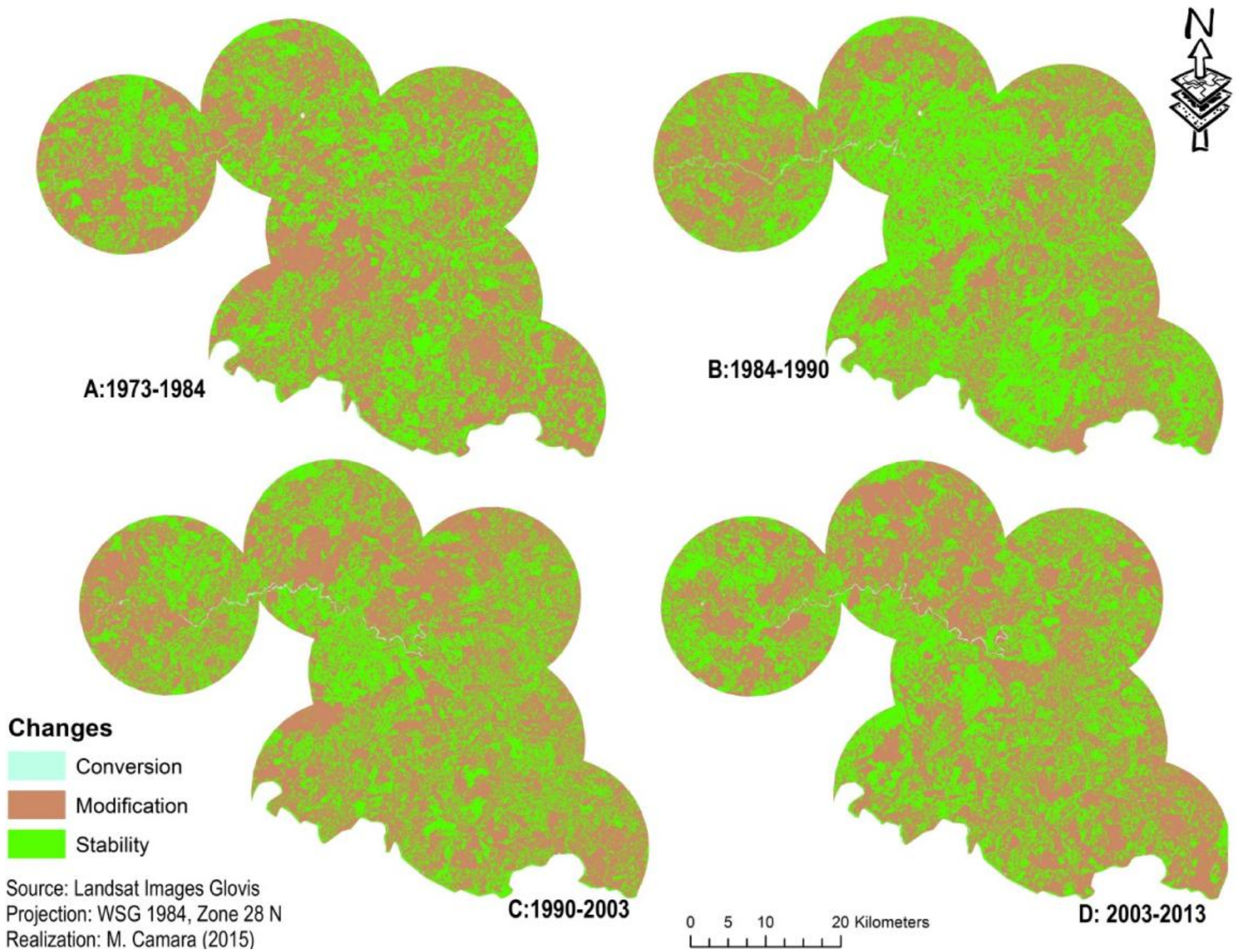


Figure 40: Land-cover spatial and temporal changes in the confinement area of the Western Derby Eland from 1973 to 2013 (A) 1973-1984, (B) 1984-1990, (C) 1990-2003 and (D) 2003-2013

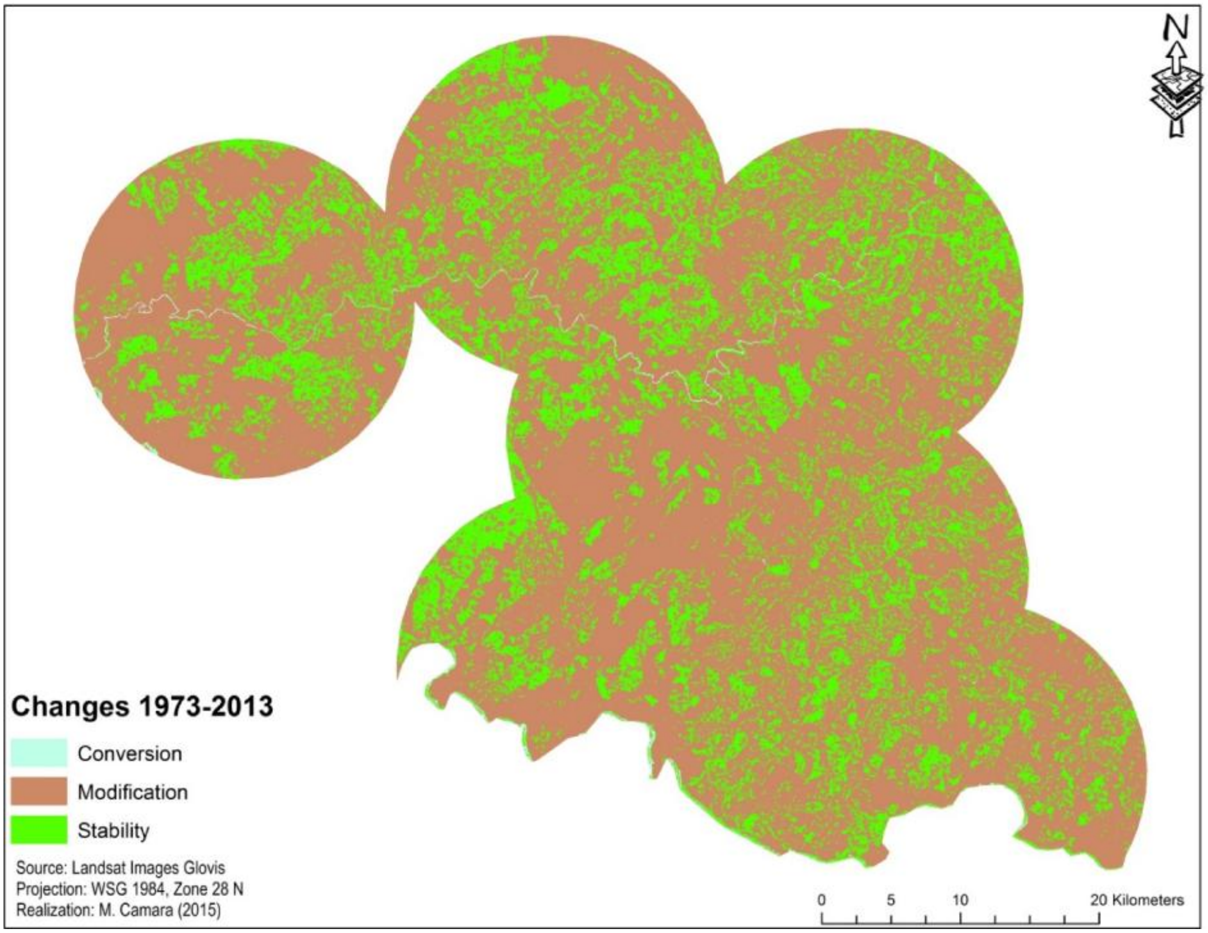


Figure 41: Spatial and temporal changes of land-cover in the confinement area of the Western Derby Eland from 1973 to 2013

Table XIII: Matrix of the land-cover change from 1973 to 1984 in the confinement area of the Western Derby Eland

Land cover type	Bowe	Gallery Forest	River	Shrub Savanna	Shrub-Tree Savanna	Tree-Woodland Savanna
Bamboo Forest	2.31	4.48	0.54	4.08	4.74	3.05
Bowe	**49.30**	1.99	0.2	1.58	2.33	2.95
Gallery Forest	1.26	**19.90**	24.03	4.44	4.76	3.8
River	0	0.04	**70.29**	0	0	0
Shrub Savanna	15.18	16.08	1.08	**28.90**	22.43	16.06
Shrub-Tree Savanna	7.6	4.37	0.4	7.57	**19.63**	7.37
Tree-Woodland Savanna	24.35	53.14	3.46	53.43	46.11	**66.77**
Total	100.00	100.00	100.00	100.00	100.00	100.00
Stability	Low Conversion 0-10 %	Medium Conversion 10-20 %	High Conversion > 20 %	Low Modification 0-10 %	Medium Modification 10-20 %	High Modification > 20 %

Table XIV: Matrix of the land-cover change from 1984 to 1990 in the confinement area of the Western Derby Eland

Land cover type	Bamboo Forest	Bowe	Gallery Forest	River	Shrub Savanna	Shrub-Tree Savanna	Tree-Woodland Savanna
Bamboo Forest	**43.46**	9.73	1.17	10.37	10.65	6.64	13.89
Bowe	4.28	**45.84**	0.1	0.54	9.02	16.28	6.05
Gallery Forest	0.13	0.15	**96.87**	0	0.19	0.05	0.33
River	0.1	0.13	0.32	**69.46**	0.13	0.08	0.1
Shrub Savanna	18.45	12.45	0.24	1.94	**39.14**	37.52	20.16
Shrub-Tree Savanna	11.04	9.45	0.12	2.73	16.27	**23.33**	7.46
Tree-Woodland Savanna	22.54	22.25	1.18	14.96	24.60	16.1	**52.01**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Legend	**Stability**	Low Conversion 0-10 %	Medium Conversion 10-20 %	Low Modification 0-10 %		Medium Modification 10-20 %	High Modification > 20 %

Table XV: Matrix of the land-cover change from 1990 to 2003 in the confinement area of the Western Derby Eland

Land cover type	Bamboo Forest	Bowe	Gallery Forest	River	Shrub Savanna	Shrub-Tree Savanna	Tree-Woodland Savanna
Bamboo Forest	**25.55**	7.45	10.72	6.2	12.18	12.32	16.38
Bowe	3.2	**28.5**	0.44	1.17	7.76	6.09	3.84
Gallery Forest	10.27	1.21	**56.27**	17.1	1.13	1.11	5.58
River	0.19	0.05	1.36	**64.22**	0.03	0.06	0.19
Shrub Savanna	16.68	23.46	5.24	4.04	**42.22**	24.3	27.09
Shrub-Tree Savanna	3.94	18.19	1.05	0.56	13.87	**33.8**	4.62
Tree-Woodland Savanna	40.17	21.14	24.92	6.71	22.81	22.32	**42.3**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Legend	**Stability**	Low Conversion 0-10 %	Medium Conversion 10-20 %	Low Modification 0-10 %	Medium Modification 10-20 %		High Modification > 20 %

Table XVI: Matrix of the land-cover change from 2003 to 2013 in the confinement area of the Western Derby Eland

Land cover type	Bamboo Forest	Bowe	Gallery Forest	River	Shrub Savanna	Shrub-Tree Savanna	Tree-Woodland Savanna
Bamboo Forest	**27.27**	4.6	15.59	3.54	10.75	2.55	14.21
Bowe	0.87	**31.47**	0.4	10.58	1.47	2.68	0.64
Gallery Forest	28.48	6.17	**71.24**	32.81	11.27	3.02	25.06
River	0.08	0.07	0.22	**46.06**	0.06	0.01	0.03
Shrub Savanna	2.47	9.61	1.43	0.4	**22.41**	8.88	2.04
Shrub-Tree Savanna	3.35	19.8	0.83	0.5	10.84	**40.64**	3.59
Tree-Woodland Savanna	37.48	28.28	10.29	6.11	43.2	42.22	**54.43**
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Legend	**Stability**	Low Conversion 0-10 %	Medium Conversion 10-20 %	High Conversion > 20 %	Low Modification 0-10 %	Medium Modification 10-20 %	High Modification > 20 %

Table XVII: Matrix of the land-cover overall change from 1973 to 2013 in the confinement area of the Western Derby Eland

Land cover type	Bowe	Gallery Forest	River	Shrub Savanna	Shrub-Tree Savanna	Tree-Woodland Savanna
Bamboo Forest	8.79	13.92	2.25	15.55	12.84	11.02
Bowe	**29.59**	1.49	8.56	1.56	4.39	3.2
Gallery Forest	11.82	**41.40**	39.25	20.26	18.65	19.15
River	0.02	0.03	**41.93**	0.01	0.03	0.01
Shrub Savanna	6.21	3.48	0.08	**10.92**	9.54	7.81
Shrub-Tree Savanna	16.45	5.71	0.58	8.36	**13.83**	12.82
Tree-Woodland Savanna	27.12	33.97	7.35	43.34	40.73	**46.00**
Total	100.00	100.00	100.00	100.00	100.00	100.00
Stability	Low Conversion 0-10 %	Medium Conversion 10-20 %	High Conversion > 20 %	Low Modification 0-10 %	Medium Modification 10-20 %	High Modification > 20 %

3.3. Characterization of the vegetation of the confinement area of the Western Derby Eland

3.3.1. Floristic and structural composition

50 trees species belonging to 40 genera and 29 families were recorded (Appendix 2) of which 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 (r^2 = 0.943) and a stress value of 0.122 (Fig. 42). However no discrimination of the plots (Fig. 43) was observed suggesting that floristic composition is quite similar among sites and zones of occurrence of the WDE.

The species richness and Shannon-Wiener diversity index (Table XVIII) were higher (S = 50 and H'= 3.99) in the ZHPOE than in the ZMPEO (S=18 and H'=3.20) whereas Pielou's index was higher in the ZMPEO (Eq= 0.77) than in the ZHPEO (Eq= 0.71). This meant that the ZHPOE had a higher number of species recorded than the ZMPOE and it had more heterogeneity in species abundance than the ZMPOE. At site level, Niokolo showed the highest species richness while Linguekountou presented the highest Shannon diversity index value. Mansafara revealed the highest Pielou's index value (Table XVIII). This meant that at site level, Niokolo had the highest species richness followed by Linguekountou, Kossi kossi and Mansafara while the abundance of species decreased in heterogeneity from Niokolo, Linguekountou, Kossi kossi to Mansafara.

The comparison of the structural parameters in the ZMPOE and the ZHOPE through the Student *T-test* revealed that only density varied significantly ($P < 0.05$) between zones of medium to high occurrence (Table XIX) and the higher density was found in the ZMPEO with N = 392 trees/ha versus N = 280 trees/ha in ZHPEO. The comparison of the other dendrometric parameters showed similar schemes in both zones (Table XIX). At site level, the comparison showed significant difference ($P < 0.05$) across sites at 95 % confidence interval except for the trees density (Table XX). Kossi Kossi in medium zone of occurrence of the WDE was characterized by the highest density, basal area and the Lorey mean height of adult trees whereas the lowest density was recorded at Mansafara, the lowest basal area and the Lorey mean height at Niokolo in high WDE occurrence zone (Table XX). In the high zone of occurrence of the WDE, Linguekountou showed the highest mean DBH whereas Niokolo experienced the lowest DBH (Table XX). For the density of the regeneration, Linguekountou presented the highest C1 density whereas Kossi kossi showed the highest C2 density (Table XX).

With an Importance Value Index (IVI) greater than 10 *Combretum glutinosum* Perr. ex DC., *Pterocarpus erinaceus* Poir., *Lannea acida* A. Rich., *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth., *Bombax costatum* Pellegr. & Vuillet, *Strychnos spinosa* Lam. and *Terminalia macroptera* Guill. & Perr. were the most ecologically important species in the confinement area of the WDE (Table XXI, Appendix 3). No indicator species was found in the ZHPOE while the most indicator species or species combinations found in the ZMPOE were respectively *Combretum glutinosum* Perr. ex DC.+ *Crosssopteryx febrifuga* (Afzel. ex G. Don) Benth., *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth., *Combretum glutinosum* Perr. ex DC + *Pterocarpus erinaceus* Poir., *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.+ *Pterocarpus erinaceus Poir.*and *Combretum collimum* Fresen. + *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. (Table XXII).

The results of the CCA indicated that the first three axes accounted for 69.46 % of the total variation captured by the CA with 29.39 % for the first axis (CCA1), 21.45 % for the second axis (CCA2) and 18.61 % for the third axis (CCA3), respectively. CCA1 was negatively correlated to altitude. CCA2 was positively correlated to fire outbreak and tree cover. CCA3 was positively correlated to soil type and herbaceous cover and negatively to fire outbreak and hardness (Table XXIII).

The projection of environmental variables into the three CCA axes with the plots (Fig. 44) showed that plots of the ZMPOE were located in areas with low tree cover and altitude, less fire outbreak and on short (sandy) to compact clay soils (less hard) whereas plots of the ZHPEO showed a correlation with high tree cover and altitude, more fire outbreak and hard substrate (granite outcrop).

At sites level, Linguekountou's plots were discriminated from plots of other sites in area with low altitude, high tree cover, average fire outbreak, less herbaceous cover and on short clay to medium fine sand. Some of Niokolo and plots of Mansafara were characterized by high altitude, less herbaceous cover, less tree cover, high fire outbreak and on solid sand to lateritic breastplate (Fig. 45).

3.3.2. Distribution of diameter size classes

A good adjustment of the observed distribution to the Weibull theoretical distribution was observed for zones of occurrence ($P > 0.05$). The observed diameter structures showed an inverse ''J'' shape, with c-value of the Weibull distribution smaller than 1, indicating a natural multispecies populations with a heterogeneity in the DBH classes' distribution (Fig. 46 and 47). Diameters were ranged from 5.09 cm to 105.73 cm.

Diameters classes in the ZMPOE fluctuated from 5.09 cm to 65.28 cm and species recorded at the two extremes were *Acacia macrostachya* (Reichnb. Ex DC), *Combretum collinum* (Fresen.), *Combretum glutinosum* (Perr. Ex DC), *Crossopteryx febrifuga* (G. Don.) Benth, *Hexalobus monopetalus* (A. Rich.) Engl. & Diels., *Strychnos spinosa* Lam., and *Ximenia americana* L. and *Pterocarpus erinaceus* Poir. respectively. Diameter classes between 5 and 12.5 cm in this zone had the highest number of individuals and were mostly represented by species like *Acacia macrostachya* (Reichnb. Ex DC), *Combretum collinum* (Fresen.), *Combretum glutinosum* (Perr. Ex DC), *Bombax costatum* Pellegr. & Vuill., *Ximenia americana* L., *Xeroderris sthulmanii* (Taub.) Mendonça & E.P. Sousa and *Strichnos spinosa* Lam. Species with diameter higher than 40 cm were sporadic.

The distribution of DBH classes in the ZHPEO had their majority of trees between 5 - 15 cm of DBH and the maximum diameter was recorded for an individual of *Sterculia setigera* Del. at 105.73 cm. The most encountered species with DBH less than 15 cm were *Combretum glutinosum* (Perr. Ex DC), *Combretum collinum* (Fresen.), *Strichnos spinona* Lam., *Acacia macrostachya* (Reichnb. Ex DC), *Grewia lasiodiscus* K. Schum. Diameters up to 40 cm were recorded mostly for species like *Pterocarpus erinaceus* Poir. , *Sterculia setigera* Del., *Khaya senegalensis* (Desr.) A. Juss., *Terminalia macroptera* (Guill. & Perr.), *Bombax costatum* Pellegr. & Vuill. and *Cordyla pinnata* (Lepr. Ex A. Rich.) Milne-Redh. Trees with big diameters (DBH > 50 cm) were scarce (Fig. 46).

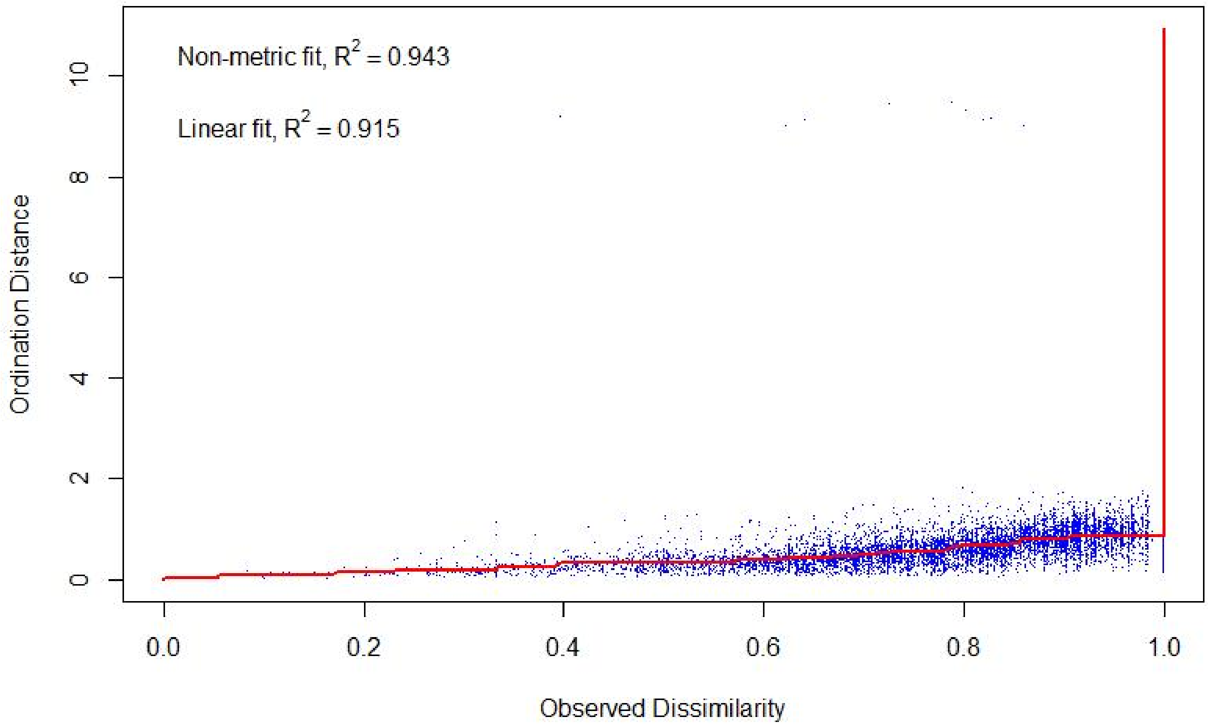


Figure 42: Statistic of goodness of fit of the Non-Metric Multidimensional Scaling

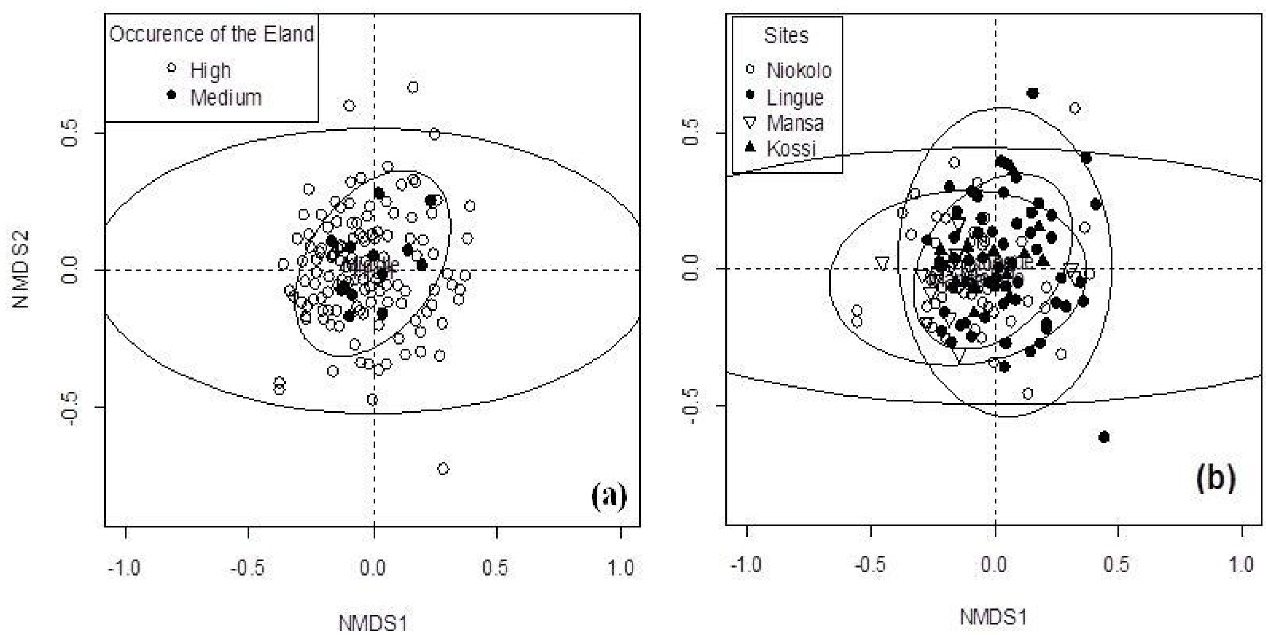


Figure 43: Non-Metric Multidimensional Scaling of plots from zones of high and medium occurrence of Western Derby Eland (a) and Sites (b).

High: plots of the ZHPOE, Medium: plots of ZMPOE, Niokolo, Lingue, Mansa and Kossi: plots belonging to site of Niokolo, Linguekountou, Mansfara and Kossi kossi.

Each plots' zone or site were circled by a confident ellipse at 5%.

Table XVIII: Floristic indexes between the sites and zones of medium and high occurrence of the Western Derby Eland

Level of occurrence	**Medium** (n = 13)	**High** (n = 127)				**Global** (n = 140)
Sites	Kossi kossi (n=13)	Linguekountou (n=59)	Mansafara (n=13)	Niokolo (n=54)	Total	
Species richness	18	35	15	40	50	50
Shannon index	3.20	3.84	3.11	3.81	3.99	3.92
Pielou's evenness	0.77	0.75	0.80	0.72	0.71	0.69

Table XIX: Structural parameters between the zones of medium and high occurrence of the Western Derby Eland

Level of occurrence	**Medium** (n = 13)		**High** (n = 127)		**Global** (n = 140)		**P value**
Parameters	**m**	**Cv (%)**	**m**	**Cv (%)**	**m**	**Cv (%)**	
Density (ind./ha)	392.31	48.98	280.32	67.04	290.71	65.50	0.046
Mean DBH (cm)	15.72	30.03	15.02	53.03	15.09	51.12	0.359
Basal area (m^2/ha)	7.56	60.84	5.20	93.11	5.42	89.55	0.057
Lorey mean high (m)	9.94	31.70	8.35	44.42	8.50	43.31	0.098
Density C1 (ind./ha)	2215.38	56.48	2694	61.28	2649.0	61.15	0.331
Density C2 (ind./ha)	415.40	83.23	562.40	117.23	548.80	116.14	0.451

n is the total number of plots in each zone; C 1: individuals with DBH < 5cm and height < 1.30 m; C 2: individuals with DBH < 5 cm and height ≥ 1.30 m. Read mean for m and variation for Cv.

Table XX: Structural parameters between the sites of occurrence of the Western Derby Eland

Sites of occurrence / Parameter	Kossi kossi (n=13)		Linguekountou (n=59)		Mansafara (n=13)		Niokolo (n=54)		P value
	m	Cv (%)	m	Cv (%)	m	Cv (%)	m	Cv (%)	
Density (ind./ha)	392.31	48.97	300.42	63.02	230.35	41.31	271.30	74.91	0.120
Mean DBH (cm)	15.72	30.03	18.05	53.41	13.24	35.23	12.17	40.64	0.000
Basal area (m^2/ha)	7.56	60.84	6.89	78.04	3.65	72.46	3.74	107.80	0.000
Lorey Mean Height (m)	9.94	31.70	9.46	42.31	8.10	35.66	7.19	44.70	0.002
Density C1 (ind./ha)	2215.38	56.48	3148.0	54.92	2291.0	40.63	2301.0	69.58	0.011
Density C2 (ind./ha)	415.40	83.23	894.00	91.46	310.70	84.07	265.30	88.94	0.000

n is the total number of plots in each site; C 1: individuals with DBH < 5cm and height < 1.30 m, C 2: individuals belong with DBH < 5 cm and height ≥ 1.30 m. Read mean for m and variation for Cv.

Table XXI: Importance Value Index (IVI) of the top seven ecologically important species in the confinement area of the Western Derby Eland in descending order

Species	Relative Density	Relative Frequency	Relative Dominance	IVI
Combretum glutinosum Perr. ex DC.	28.81	17.97	13.32	60.10
Pterocarpus erinaceus Poir.	12.42	11.88	29.59	53.90
Lannea acida A. Rich.	5.12	8.12	6.53	19.76
Crossopteryx febrifuga (Afzel. ex G. Don) Benth.	7.31	6.67	4.11	18.08
Bombax costatum Pellegr. & Vuillet	2.74	4.06	8.68	15.48
Strychnos spinosa Lam.	7.19	5.80	1.90	14.89
Terminalia macroptera Guill. & Perr.	3.29	3.62	6.12	13.04

Table XXII: Indicator species of zones and sites in the Western Derby Eland's confinement area

Level of analysis	Modalities	Species combinations	A	B	IndVal	P value
Zones of Occurrence of WDE	Medium	*Combretum glutinosum + Crossopteryx febrifuga*	0.817	0.692	0.752	0.002
		Crossopteryx febrifuga	0.787	0.692	0.738	0.002
		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	-	-	-	-	-
Sites of Occurrence of WDE	Kossi kossi	*Combretum glutinosum + Crossopteryx febrifuga*	0.545	0.692	0.614	0.001
		Crossopteryx febrifuga	0.500	0.692	0.588	0.004
		Combretum collimum+ Crossopteryx febrifuga	0.853	0.385	0.573	0.001
		Combretum glutinosum + Pterocarpus erinaceus	0.501	0.615	0.555	0.022
		Pterocarpus erinaceus	0.445	0.692	0.555	0.039
	Linguekountou	*Terminalia macroptera*	0.846	0.339	0.536	0.005
		Cordyla pinnata	1.000	0.220	0.469	0.011
		Combretum nigricans	0.744	0.271	0.449	0.033
		Lannea acida + Terminalia macroptera	1.000	0.153	0.391	0.024
		Lannea acida + Terminalia macroptera	1.000	0.153	0.391	0.037
	Mansafara	*Pericopsis laxiflora*	0.982	0.500	0.701	0.001
		Combretum glutinosum +Pericopsis laxiflora	0.979	0.429	0.648	0.001
		Crossopteryx febrifuga +P. laxiflora	0.969	0.357	0.588	0.001
		Pericopsis laxiflora + Pterocarpus erinaceus	0.959	0.357	0.585	0.001
		Lannea acida + Pericopsis laxiflora	0.921	0.214	0.444	0.007
	Niokolo	*Acacia dudgeoni +P.erinaceus*	1.000	0.111	0.333	0.037

Component 'A' is the probability that the surveyed site belongs to the target site group given the fact that the species has been found. This conditional probability is called the specicity or positive predictive value of the species as indicator of the site group.
Component 'B' is the probability of finding the species in sites belonging to the site group. This second conditional probability is called the delity or sensitivity of the species as indicator of the target site group.
IndVal = Indicator Value Index (De Cáceres, 2013)

Table XXIII: Correlation of environmental variables with ordination axes of CCA.

Environmental variable	Axes		
	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

Only Values ≥ 0.5 in bold contribute substantially to the CCA axes

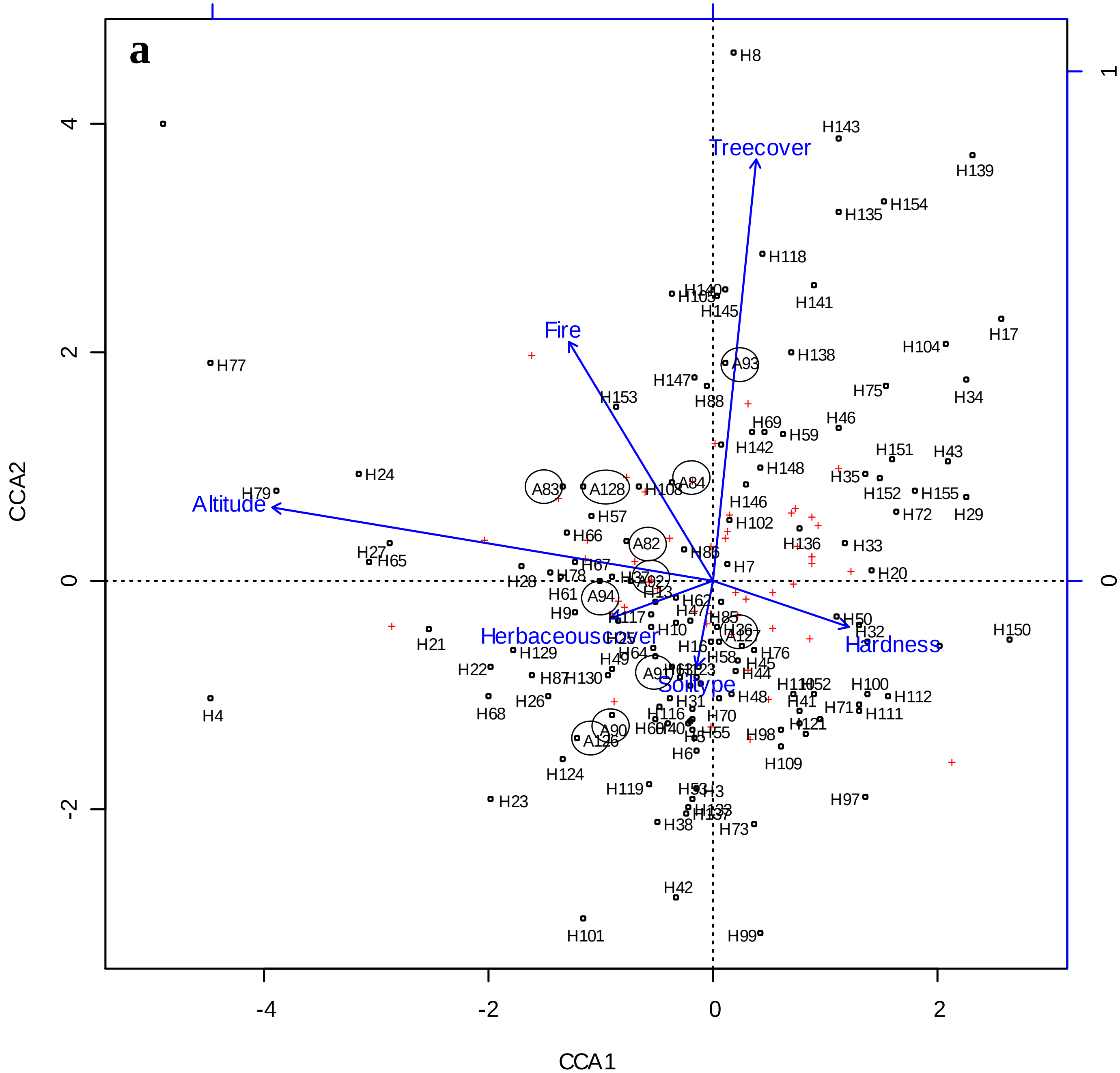


Figure 44a: Distribution of environmental variables and plots based on the zones of medium and high occurrence of the Western Derby Eland into CCA plan 1-2

A with black circle for plots in medium Western Derby Eland occurrence zone and H for plots in high Western Derby Eland occurrence zone

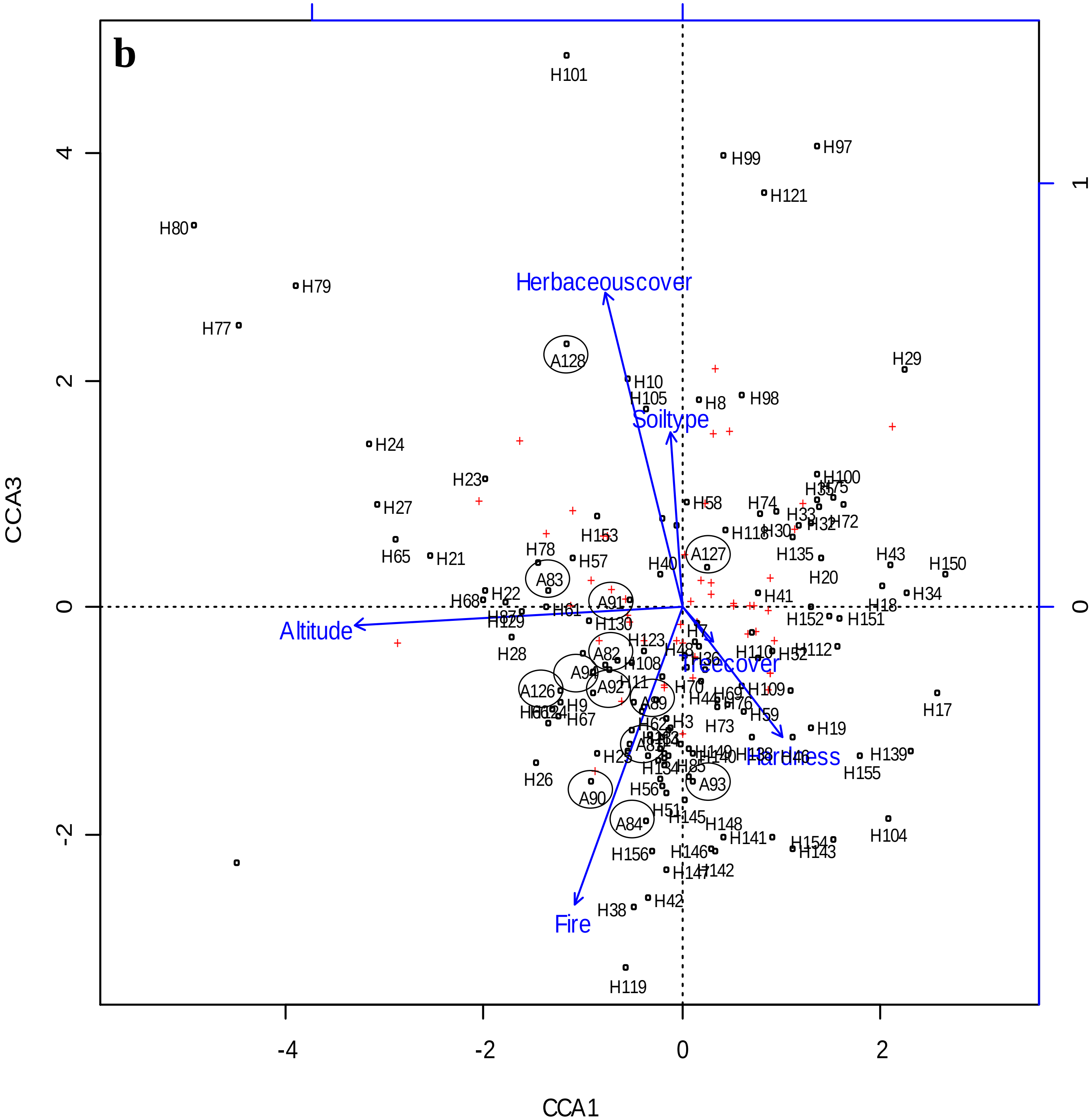


Figure 44b: Distribution of environmental variables and plots based on the zones of medium and high occurrence of the Western Derby Eland into CCA plan 1-3

A with black circle for plots in medium Western Derby Eland occurrence zone and H for plots in high Western Derby Eland occurrence zone

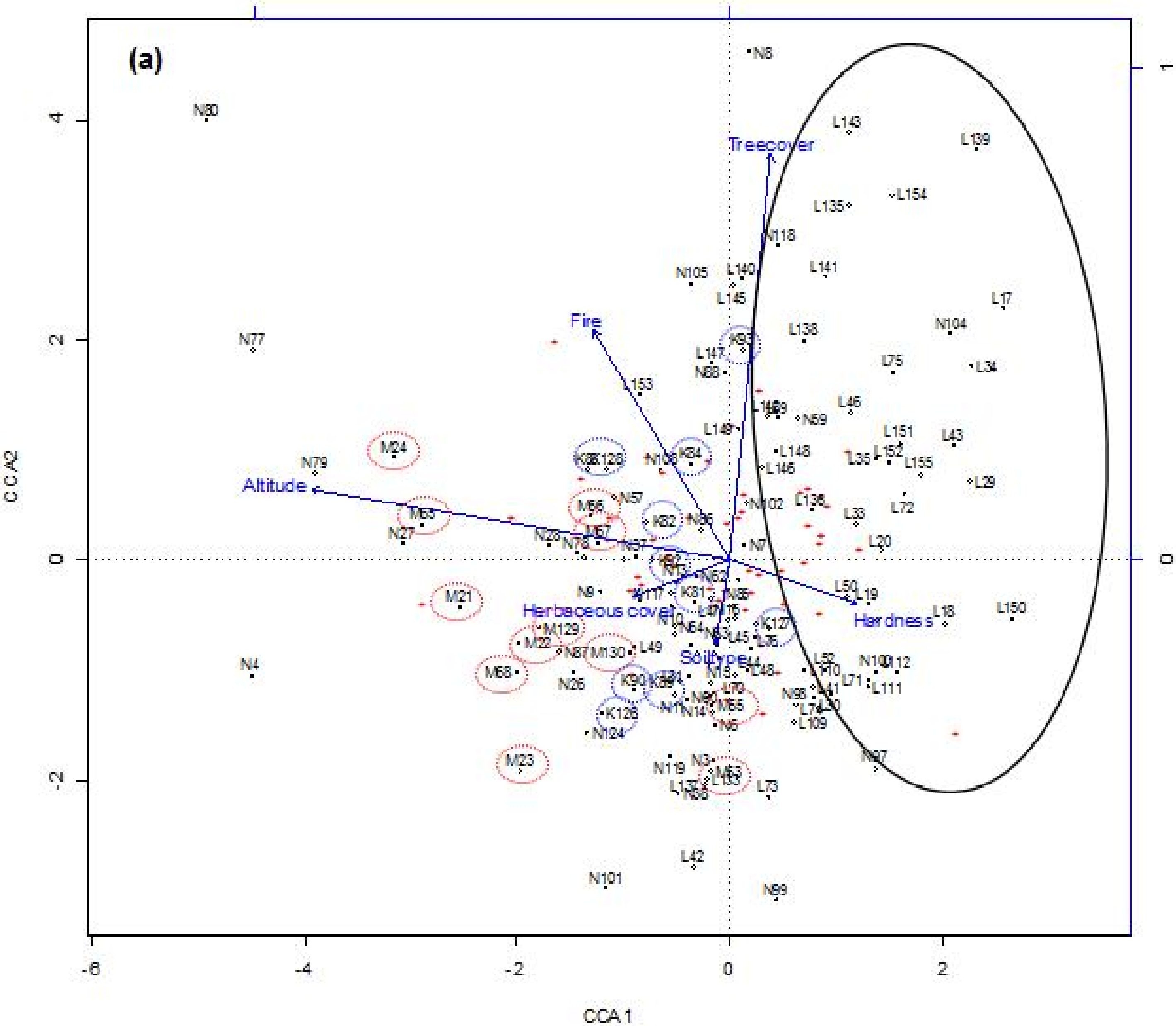


Figure 45a: Distribution of environmental variables and plots based on the sites occurrence of the Western Derby Eland into the CCA plan 1-2

K for Kossi Kossi, L for Linguekountou, M for Mansafara and N for Niokolo

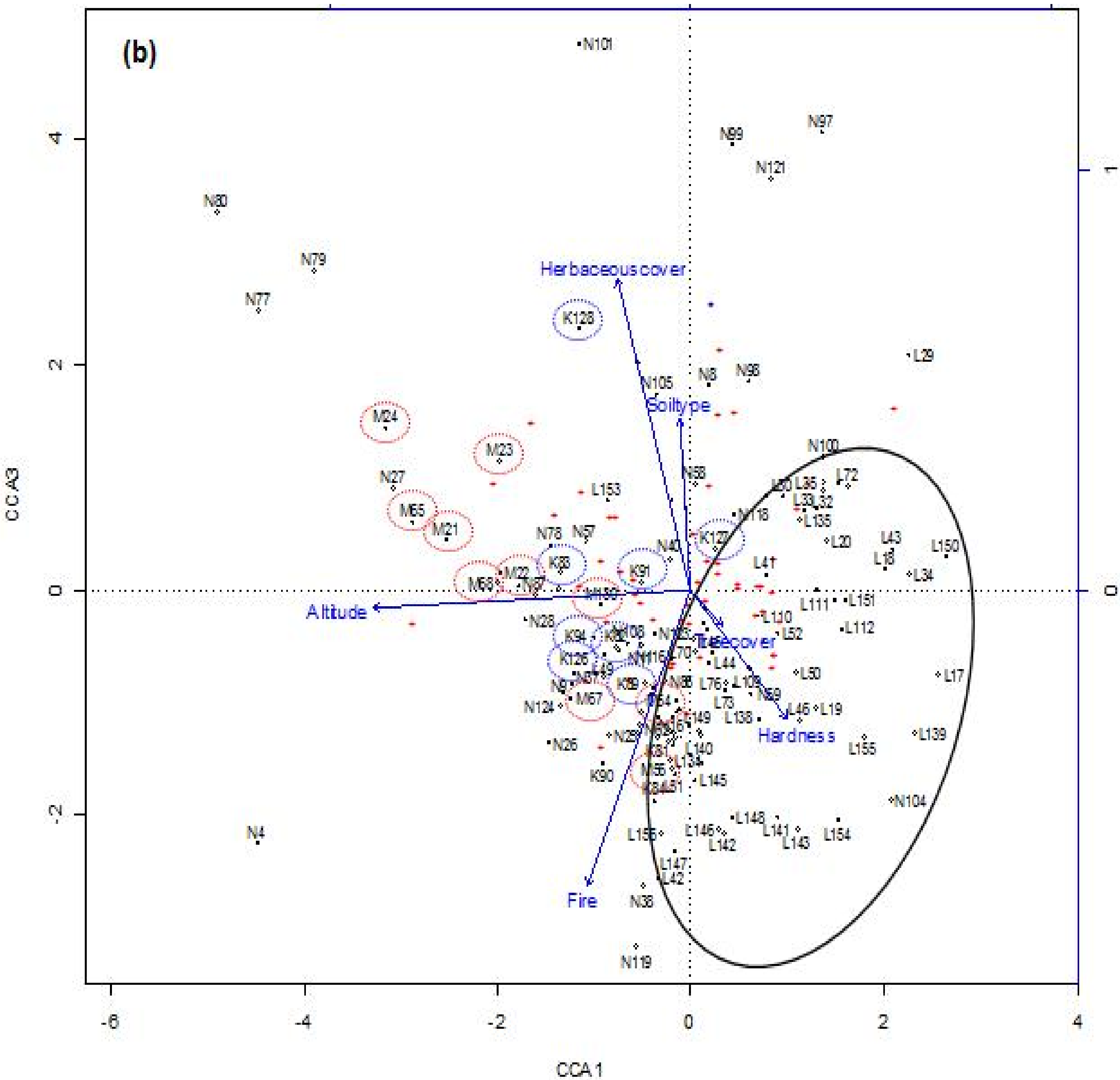


Figure 45b: Distribution of environmental variables and plots based on the sites occurrence of the Western Derby Eland into the CCA plan 1-3

K for Kossi Kossi, L for Linguekountou, M for Mansafara and N for Niokolo.

At site level, diameter classes within 5 - 15 cm were well represented and the trees species frequently met were *Combretum collinum* (Fresen.), *Combretum glutinosum* (Perr. Ex DC), *Strichnos spinosa* Lam., *Acacia macrostachya* (Reichnb. Ex DC) and *Annona senegalensis* Pers. Individuals with DBH more than 40 cm were occasional and species like *Pterocarpus erinaceus* Poir. , *Bombax costatum* Pellegr. & Vuill, *Sterculia setigera* Del., *Cordyla pinnata* (Lepr. Ex A. Rich.) Milne-Redh., *Terminalia macroptera* (Guill. & Perr.), *Pericopsis laxiflora* (Benth.) Van Meeuwen, and *Khaya senegalensis* A. Juss. were recorded in these DBH classes (Fig. 47).

For the consumed plants, the distribution of DBH classes was not done for *Hymenocardia acida* Tul. and *Boscia senegalensis* (Pers.) Lam. ex Poir. for which two and one individuals were respectively recorded. DBH classes' distribution of *Grewia bicolor* A. Juss. showed an inverse ''J'' shape suggesting a high potential of regeneration of this species with c-value of the Weibull distribution smaller than 1 while those of *Strychnos spinona* Lam. and *Ziziphus mauritiana* Lam. showed a positive dissymmetric distribution with ($1 < c < 3.6$) expressing a predominance of individuals with small DBH (Fig. 47). Individuals with diameters ranging from 5 to 10 cm were the most represented with the majority of trees (86.821 %) whereas individuals with DBH more than 15 cm were scarce (2.33 %) for all consumed species considered. A good adjustment ($P > 0.05$) of the observed distribution to the Weibull theoretical distribution for these species was noticed (Fig. 48).

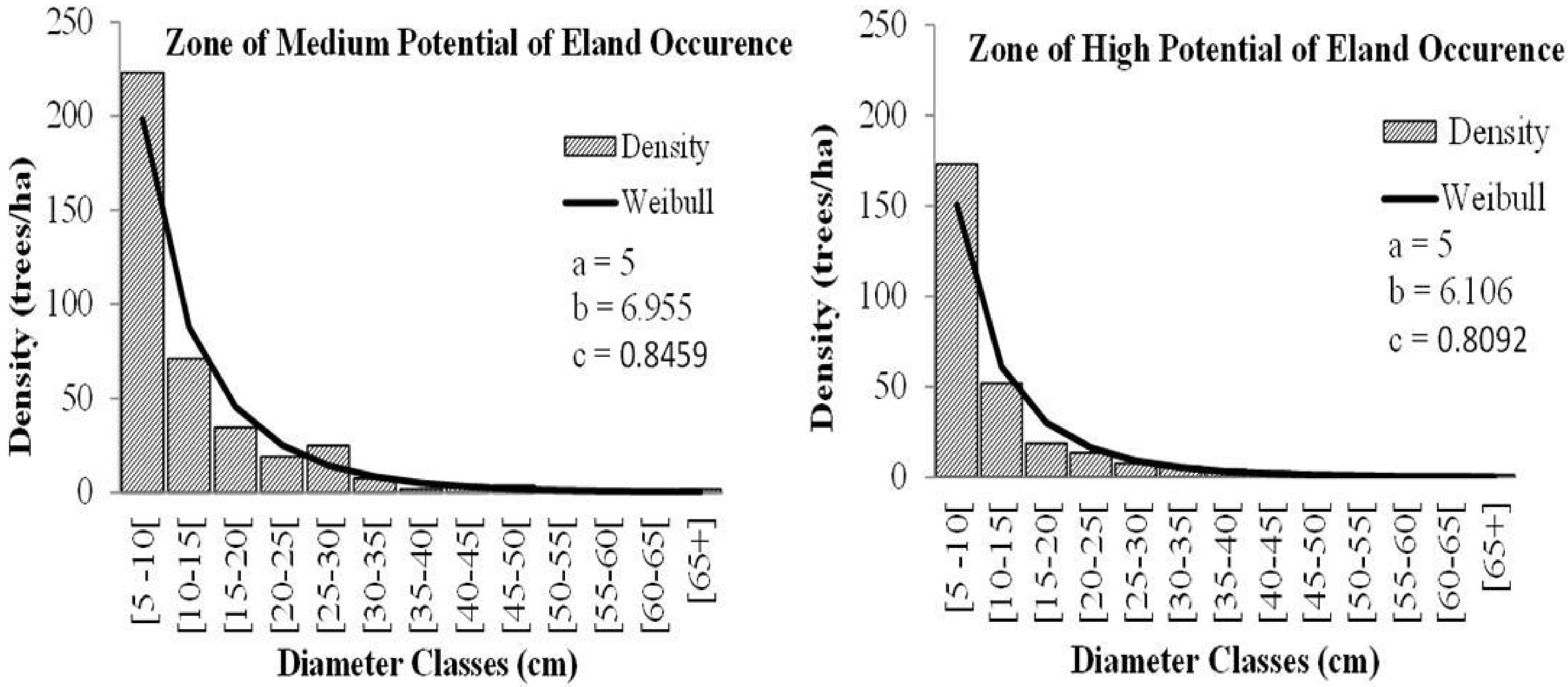


Figure 46: Distribution of DBH classes of the trees inside the zones of medium and high potential of occurrence of the Western Derby Eland

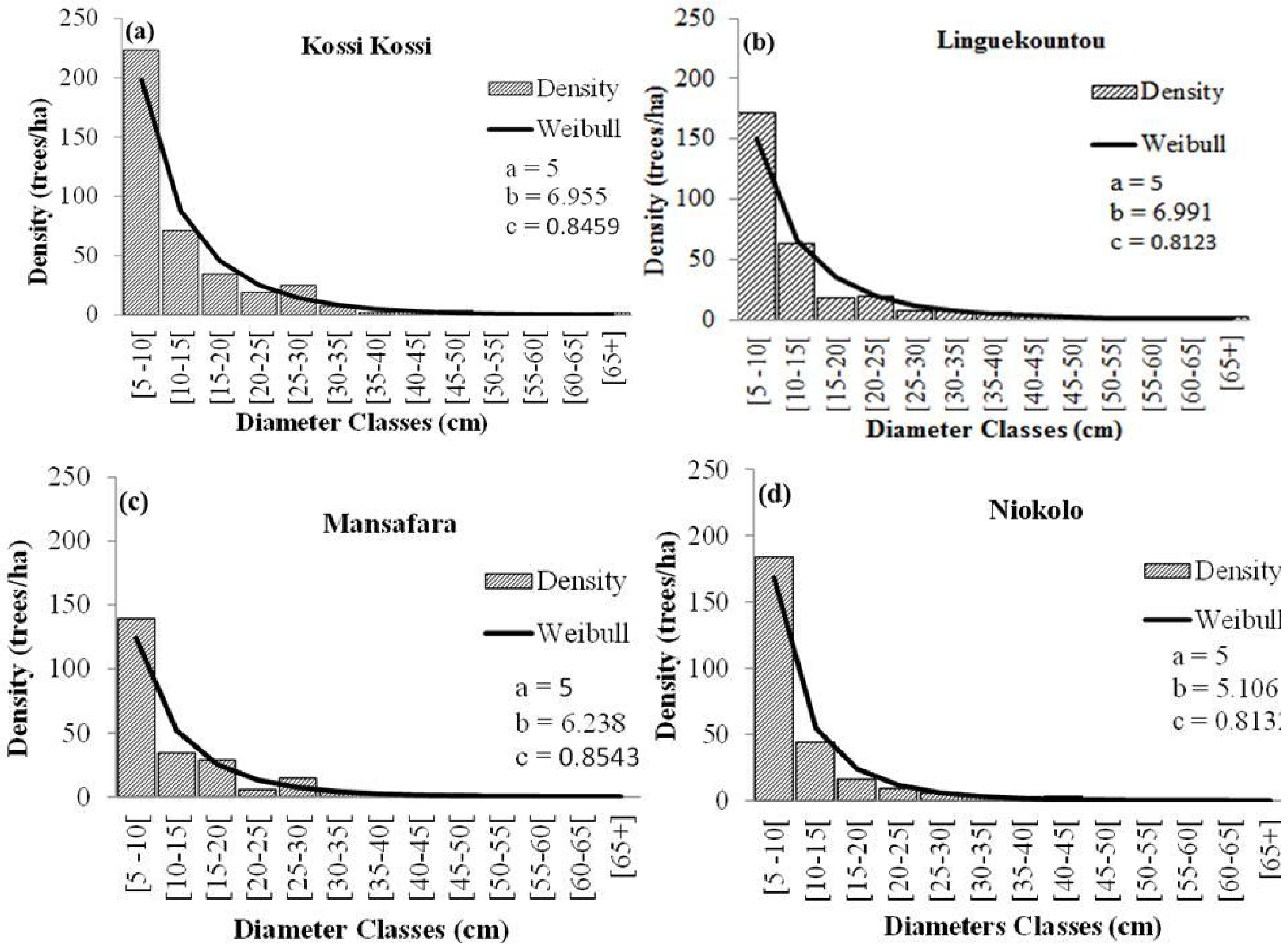


Figure 47: Distribution of DBH classes of the trees per site of occurrence of the Western Derby Eland within its confinement area

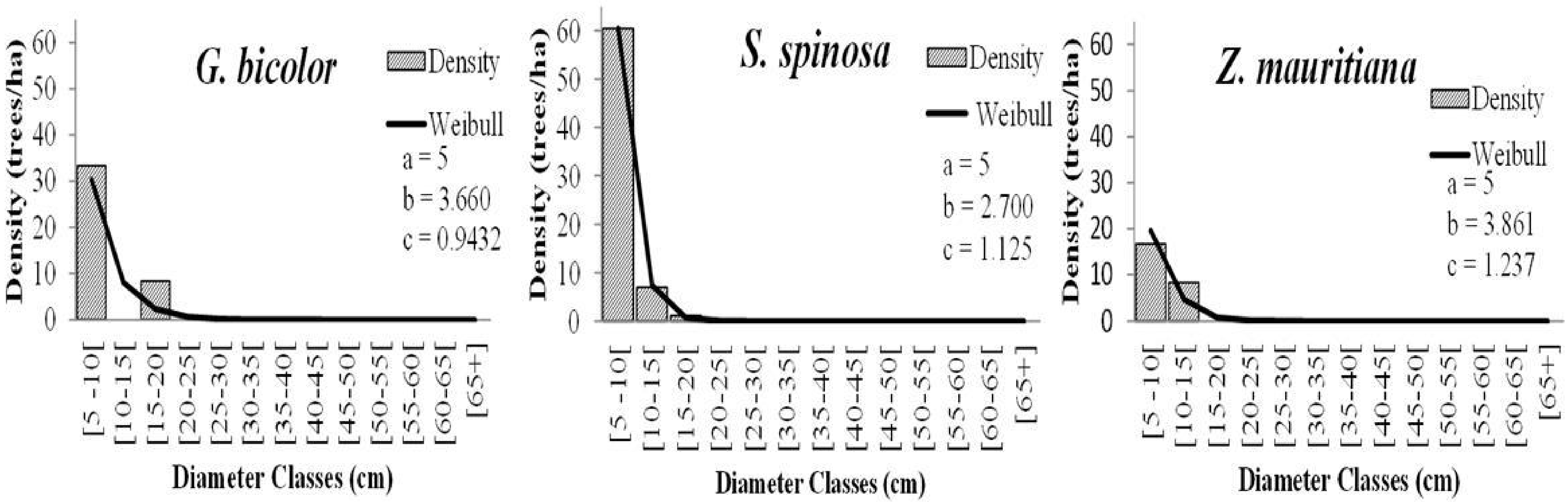


Figure 48: Distribution of DBH classes of the trees of consumed plants species by the Western Derby Eland within its confinement area

3.4. Prediction of distribution of plant species consumed by the Western Derby Eland under climate change within Niokolo Koba National Park

3.4.1. Models validation

Model utility is influenced by the evaluation of its performance which is an essential tool of model building. Hence, the goodness of fit or accuracy of the model should be tested to determine the relevance of the model. Thus, the Models' goodness of fit and the predictive power were assessed for all consumed plant species. They showed a good predictive ability with the area under curve (AUC) ranging from 0.80 to 0.89 and the true skill statistic (TSS) value ranging from 0.49 to 0.54. Whereas, *G. bicolor* Juss. had a fairly predictive power with AUC's value of 0.76 and TSS's value of 0.47. Values of the logistic threshold at 10 percentile training which discriminated the suitable and unsuitable habitat of each species were ranged between 0.314 and 0.457 (Table XXIV). Analyses of the contribution of climatic factors and Jackknife test revealed that the model prediction of *B. angustifolia* A. Rich. was more influenced by temperature factors while those of other plant species consumed by the WDE were more influenced by precipitation factors (Table XXV; Appendices 5-6).

3.4.2. Current distribution of plant species consumed by the Western Derby Eland within Niokolo Koba National Park

Globalely, 30.26 %, 54.75%, 24.56 %, 25.55 % and 43.69 % of the surface of the park were suitable habitats for *B. angustifolia* A. Rich., *G. bicolor* Juss., *H. acida* Tul., *S. spinosa* Lam. and *Z. mauritiana* Lam. respectively (Fig. 49).The potential distribution of the consumed plants species according to their logistic probability distributions showed a probability of their distribution constrained between 0 and 1(Fig. 50). The closer the number got to 1, the most probable to find the species at that location was. The binary distribution, suitable vs unsuitable habitat, for each plant species consumed according to their respective value of the logistic threshold at 10 percentile training presence was presented in Fig. 51. *B. angustifolia* A. Rich., *H. acida* Tul. and *G. bicolor* Juss. had their high suitable area located at the eastern part of the park with some islands of suitability in the western part for the two first species cited. *S. spinosa* Lam.

and *Z. mauritiana* Lam. had their high suitable area located at the centre with a stretching along the rivers for *Z. mauritiana* Lam. in the eastern part of the park (Fig. 51).

Overlay of the distributions of all plant species consumed showed that they were well distributed through the park. The highest possibilities to find them together at the same place were located in the Centre toward the Eastern part of the park (Fig. 52).

3.4.3. Prediction of distribution of plants species consumed by the Western Derby Eland within Niokolo Koba National Park

3.4.3.1. Prediction of distribution of plant species consumed by the Western Derby Eland within Niokolo Koba National Park under year 2050

The prediction of distribution and shift of suitable habitat of plant species consumed by the WDE under year 2050 using GFDL-ESM, MPI-ESM and HadGEM-ES and RCP 4.5 (Figs. 53, 54 & 55, Table XXVI) showed that *B. angustifolia* A. Rich. was predicted to have a reduction of 93.107 % of its suitable habitat with GFDL-ESM model while it is expected to be extinct for MPI-ESM and HadGEM-ES models. Under the three models, *G. bicolor* Juss. showed a good trend with a suitability extending to the whole park whereas *H. acida Tul.* and *S. spinosa* Lam. had a negative tendency with a prediction of their potential extinction. *Z. mauritiana* Lam. had an increase of 126.88 %, 40.20 % and 124.72 % of its suitable area whithin the park for GFDL-ESM, MPI-ESM and HadGEM-ES models, respectively.

Overlay of display of plant species consumed distribution showed a distribution of suitable area located at the border of the park for GFDL-ESM, at the centre toward the north for MPI-ESM and at almost the entire park for HadGEM-ES (Figs. 56, 57, & 58).

3.4.3.2. Prediction of distribution of plant species consumed by the Western Derby Eland within Niokolo Koba National Park under year 2070

The prediction of shift of suitable habitat of consumed plants by the WDE under year 2070 was performed using GFDL-ESM, MPI-ESM and HadGEM-ES models and RCPs 4.5 and 8.5 (Table XXVII, Figs. 59 - 68). However for the RCP 8.5, because of the lack of data for the GFDL-ESM model predictions were performed with the MPI-ESM and HadGEM-ES models only.

Table XXIV: Values of the models' predictive ability for assessing theirs validation

Species	AUC	TSS	Logistic threshold at 10 percentile training presence
B. angustifolia A. Rich.	0.86	0.59	0.314
G. bicolor Juss.	0.76	0.47	0.407
H. acida Tul.	0.89	0.64	0.457
S. spinosa Lam.	0.88	0.64	0.407
Z. mauritiana Lam.	0.80	0.49	0.371

Table XXV: Contribution of the top five climatic factors influencing the models of each plant species consumed by the Western Derby Eland in Niokolo Koba Natiational Park in descending order

Species	Variable	Percent contribution
B. angustifolia A. Rich.	bio_07: Temperature Annual Range	28.0
	bio_15: Precipitation Seasonality	23.5
	bio_09: Mean Temperature of Driest Quarter	14.1
	bio_02: Mean Diurnal Temperature Range	13.7
	bio_08: Mean Temperature of Wettest Quarter	10.8
G. bicolor Juss.	bio_01: Annual Mean Temperature	99.5
	bio_08: Mean Temperature of Wettest Quarter	0.5
	bio_16: Precipitation of Wettest Quarter	0.0
	bio_15: Precipitation Seasonality	0.0
	bio_13: Precipitation of Wettest Month	0.0
H. acida Tul.	bio_06: Min Temperature of Coldest Month	22.5
	bio_12: Annual Precipitation	13.7
	bio_18: Precipitation of Warmest Quarter	13.4
	bio_07: Temperature Annual Range	11.6
	bio_19: Precipitation of Coldest Quarter	7.5
S. spinosa Lam.	bio_09: Mean Temperature of Driest Quarter	20.1
	bio_12: Annual Precipitation	20.1
	bio_15: Precipitation Seasonality	13.5
	bio_04: Temperature Seasonality	10.4
	bio_18: Precipitation of Warmest Quarter	8.2
Z. mauritiana Lam.	bio_01: Annual Mean Temperature	55.5
	bio_18: Precipitation of Warmest Quarter	19.9
	bio_13: Precipitation of Wettest Month	12.6
	bio_15: Precipitation Seasonality	9.4
	bio_10: Mean Temperature of Warmest Quarter	2.2

The jackknife test performed determined the bioclimatic variables that contributed to the model prediction. Here we have the top five of the most influencing bioclimatic variables of models of each species in descending order, details are in appendices 5 and 6.

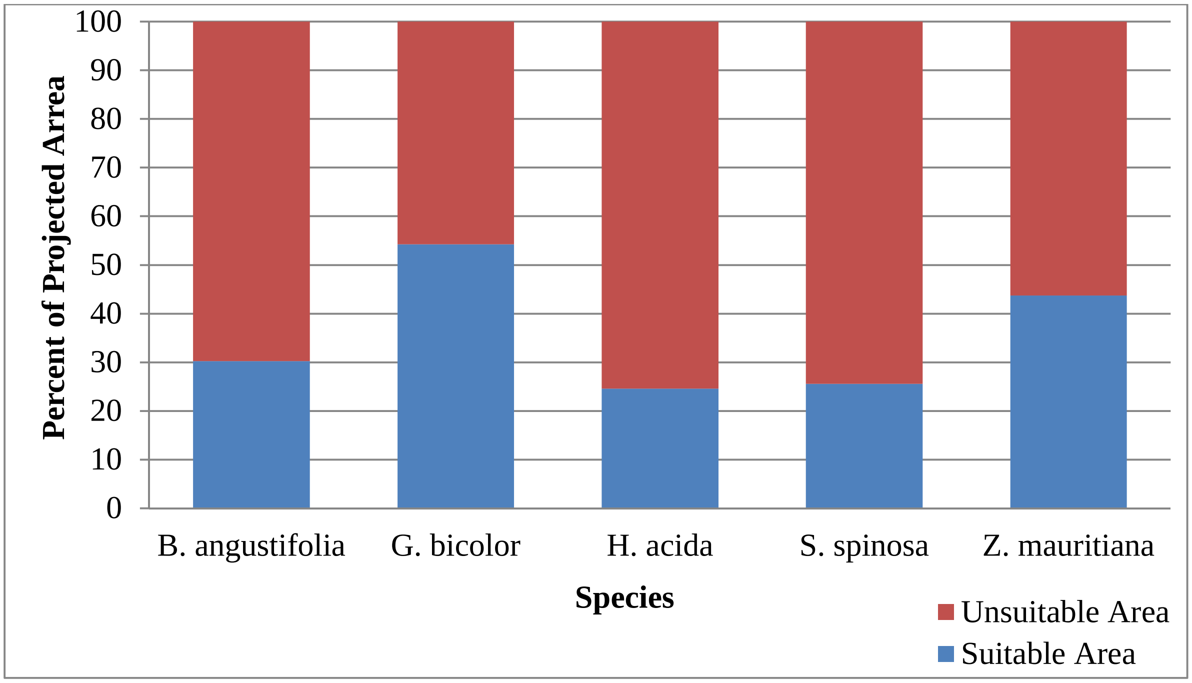


Figure 49: Current potential percent of suitable and unsuitable habitat of plant species consumed by Western Derby Eland in Niokolo Koba National Park

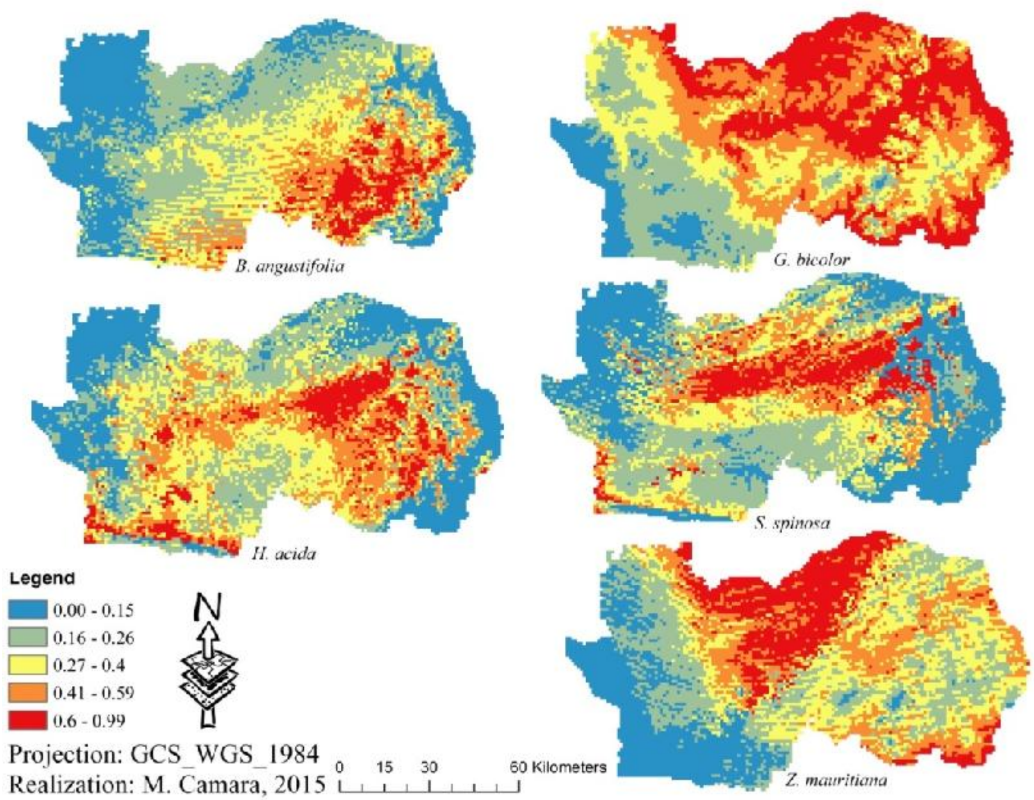


Figure 50: Current potential distribution of plant species consumed by Western Derby Eland in Niokolo Koba National Park

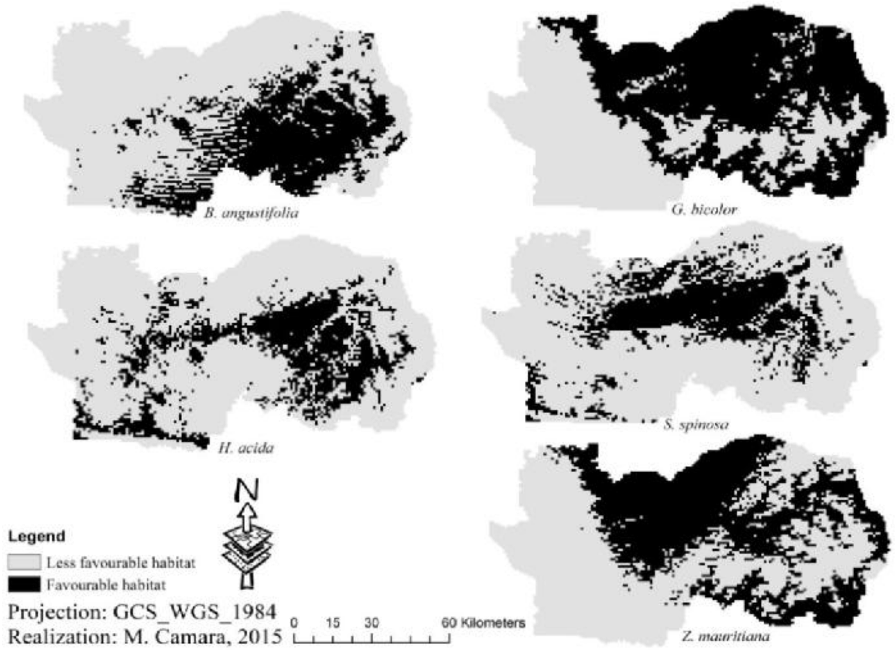


Figure 51: Current potential distribution of each plant species consumed by the Western Derby Eland in Niokolo Koba National Park using treir respective logistic threshold value at 10 percentile

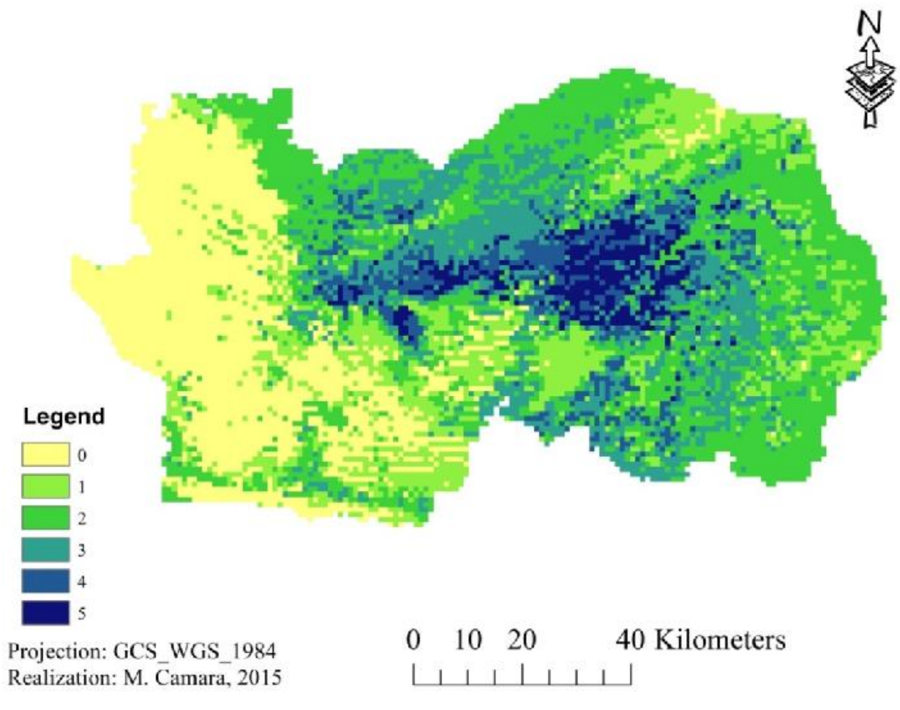


Figure 52: Superimposing current distribution of consumed plants species by the Western Derby Eland in Niokolo Koba National Park using their logistic threshold at 10 percentile

1, 2 3, 4 and 5: correspond to the number of species to find on that location
Only precipitation and temperature were used as prediction variables.

Table XXVI: Prediction of habitat suitability of plant species consumed by the Western Derby Eland in Niokolo Koba National Park under current and year 2050 for representative concentration pathway (RCP) 4.5

Current Habitat Surface (km^2)		
Species	Suitable	Less favourable
B. angustifolia A. Rich.	3118	7186
G. bicolor Juss.	5590	4714
H. acida Tul.	2531	7773
S. spinosa Lam.	2633	7671
Z. mauritiana Lam.	4502	5802

Year 2050 RCP 4.5												
Models	GFDL-ESM2G				MPI-ESM-LR				HadGEM2-ES			
Habitat	Suitable		Less suitable		Suitable		Less suitable		Suitable		Less suitable	
Species	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)
B. angustifolia A. Rich.	215	-93.10	10089	40.40	0	**-100**	10304	43.39	0	**-100**	10304	43.39
G. bicolor Juss.	10304	84.33	0	**-100**	10304	84.33	0	**-100**	10304	84.33	0	**-100**
H. acida Tul.	0	**-100**	10304	32.56	0	**-100**	10304	32.56	0	**-100**	10304	32.56
S. spinosa Lam.	0	**-100**	10304	-34.32	0	**-100**	10304	-34.32	0	**-100**	10304	34.32
Z. mauritiana Lam.	10214	126.88	90	-98.45	6312	40.20	3992	-31.2	10117	124.72	187	-96.78

(+): gain in suitable area, (-): lost in suitable area; **-100**: (**black bold:** decrease of suitable area even close extinction, bad trend; **bold red:** increase suitable area good trend)

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 **(IPCC, 2013)**

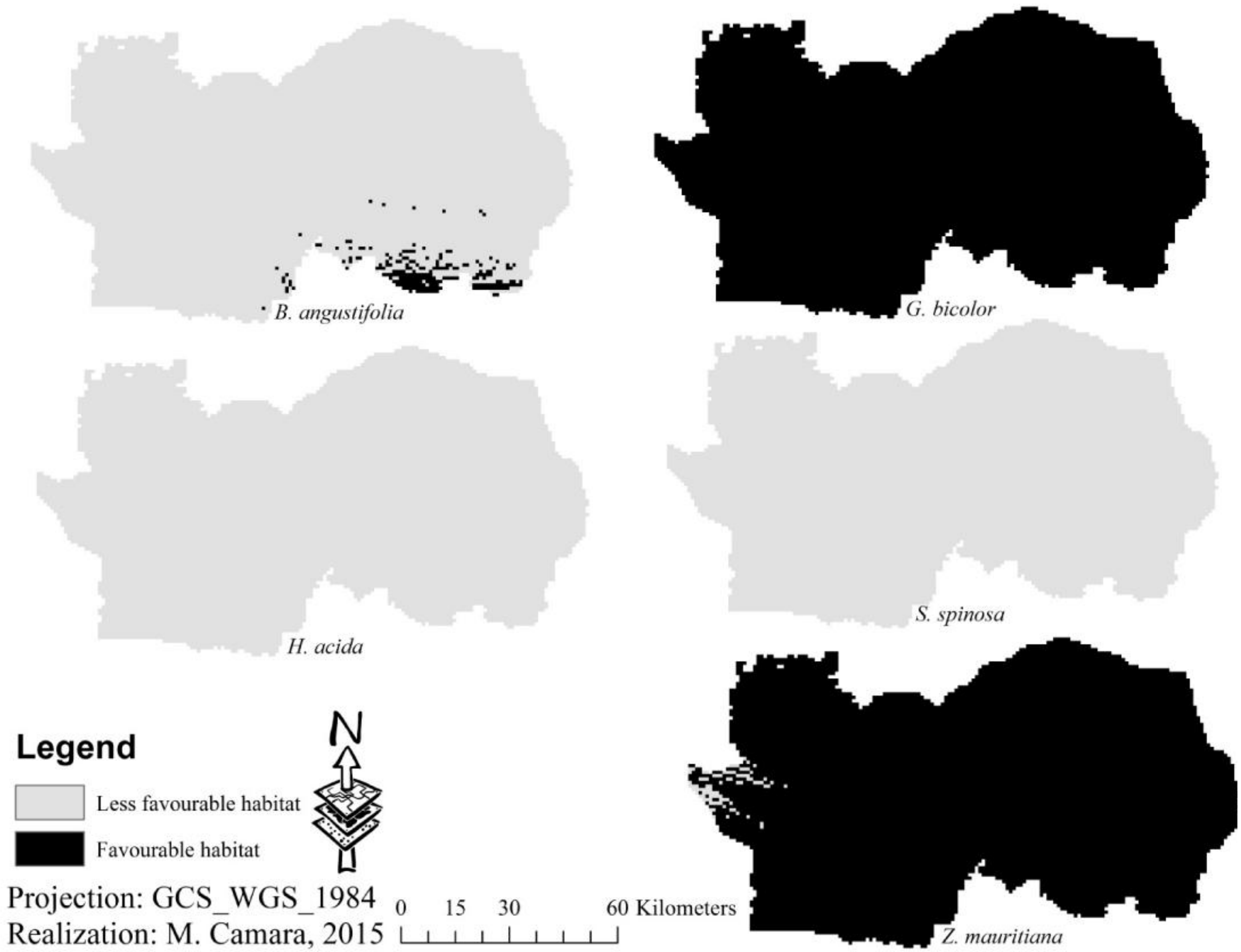


Figure 53: Potential distribution of plant species consumed from the GFDL-ESM2G model with the representative concentration pathway (RCP) 4.5 under year 2050

An average increase of temperature of + 1–2.6 °C is expected for RCP 4.5 (**IPCC, 2013)**

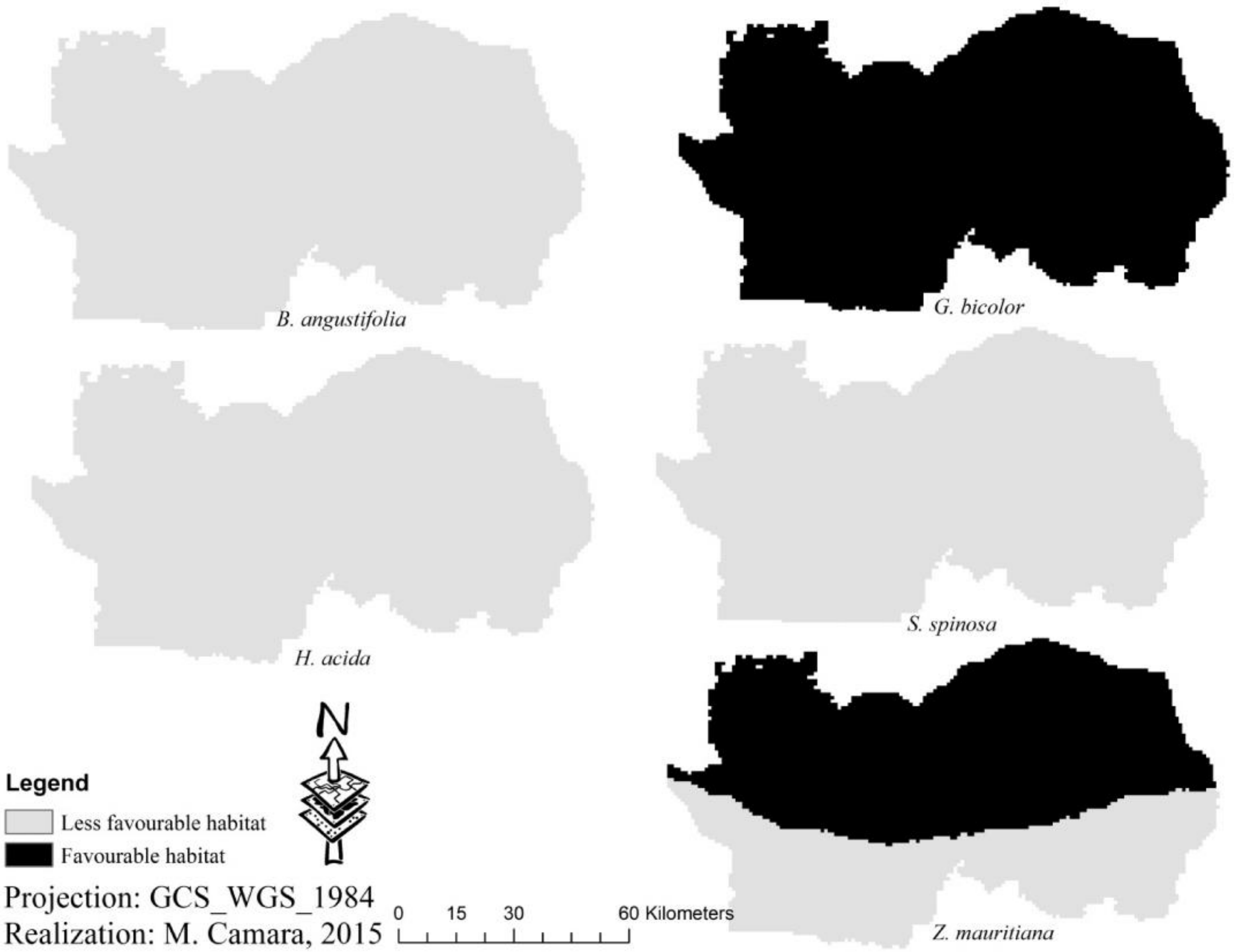


Figure 54: Potential Distribution of plant species consumed from the MPI-ESM-LR model with the representative concentration pathway (RCP) 4.5 under year 2050

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 **(IPCC, 2013)**

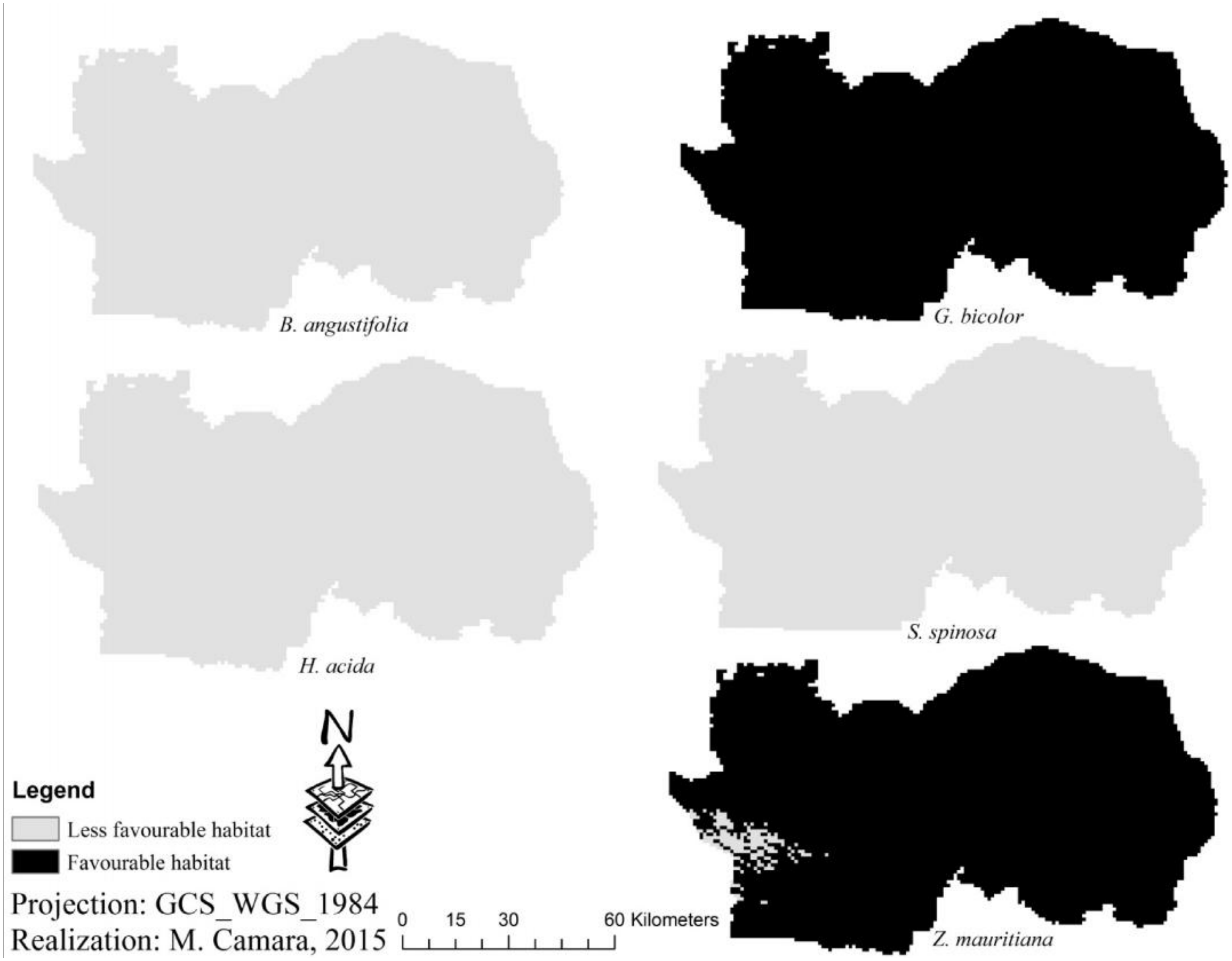


Figure 55: Potential Distribution of plant species consumed from the HadGEM2-ES model with the representative concentration pathway (RCP) 4.5 under year 2050

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 **(IPCC, 2013)**

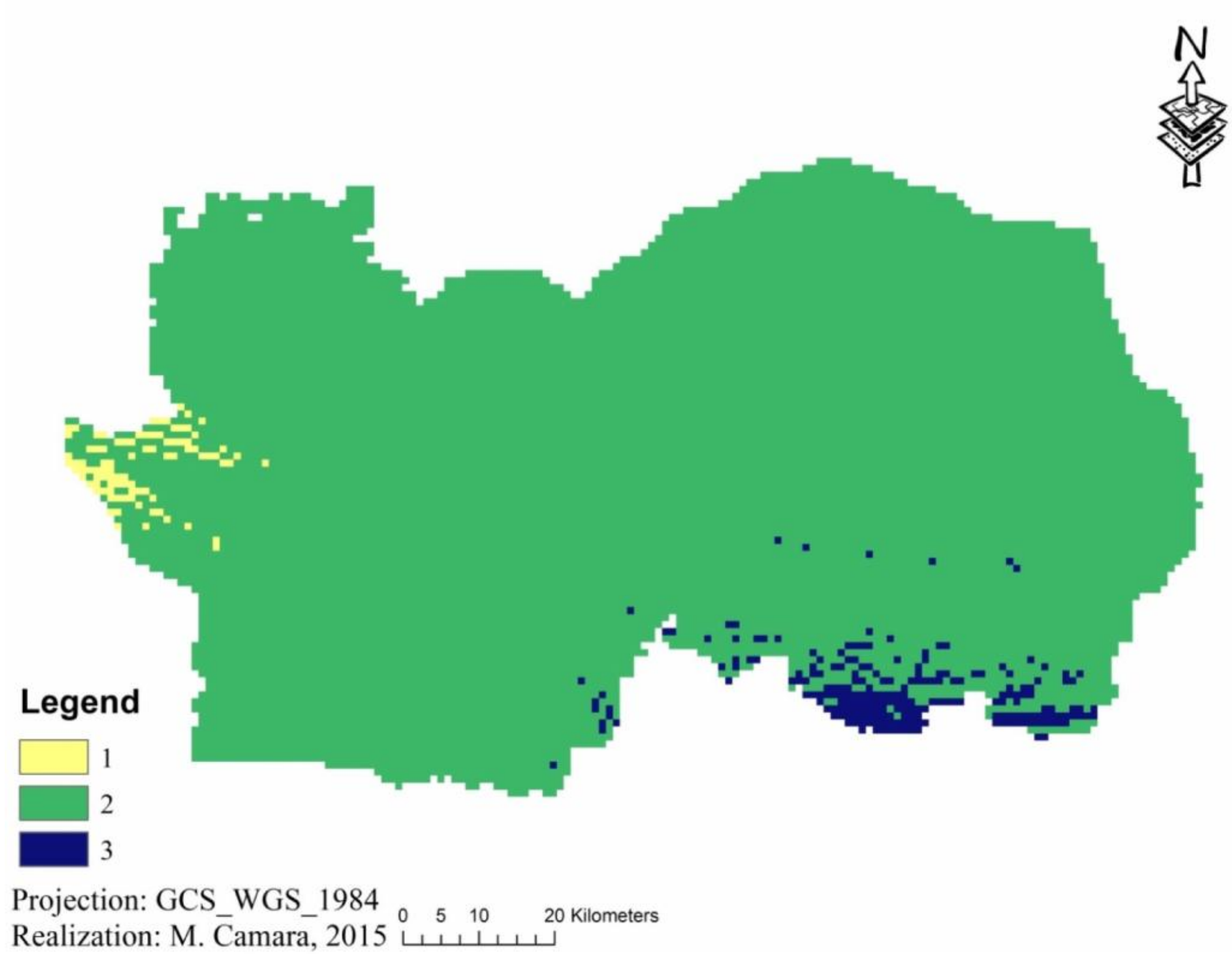


Figure 56: Superimposing of the potential distribution of plant species consumed from the GFDL-ESM2G model with the representative concentration pathway (RCP) 4.5 under year 2050

1, 2 and 3: correspond to the number of species to find on that location.
An average increase of temperature of + 1–2.6 °C is expected for RCP 4.5 **(IPCC, 2013)**

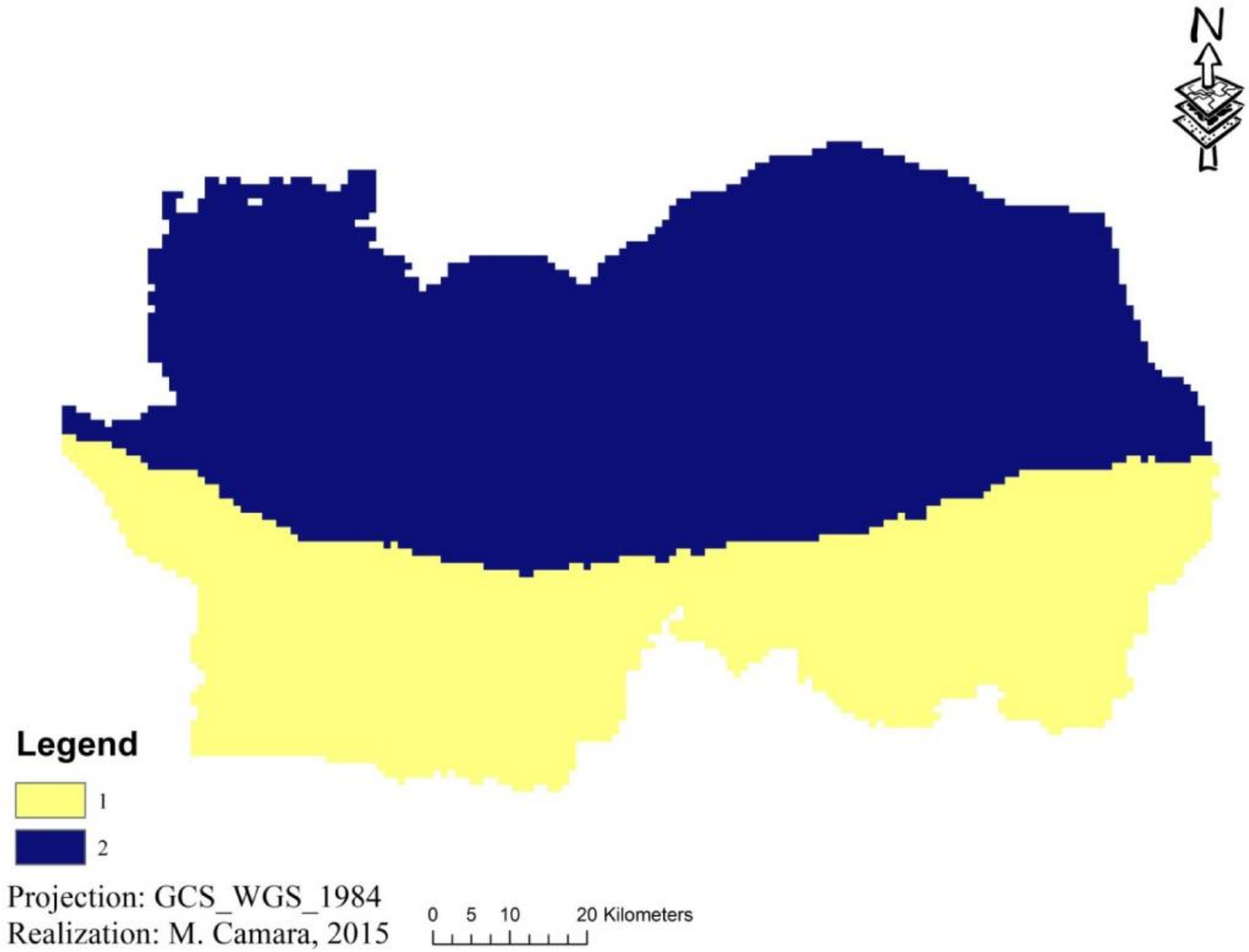


Figure 57: Superimposing of the potential distribution of plant species consumed from MPI-ESM-LR model with the representative concentration pathway (RCP) 4.5 under year 2050

1and 2: correspond to the number of species to find on that location.

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 **(IPCC, 2013)**

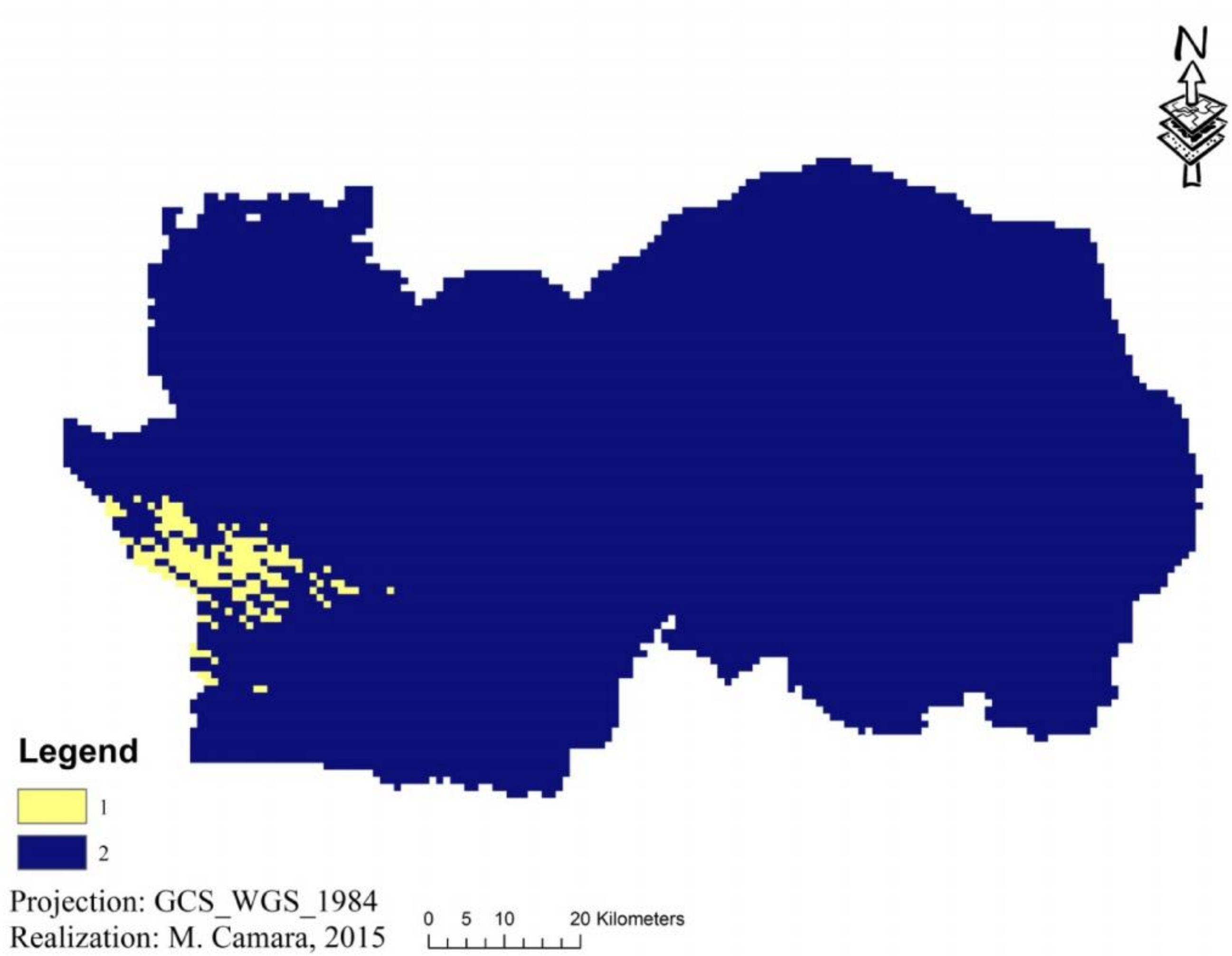


Figure 58: Overlay of potential distribution of plant species consumed from the HadGEM2-ES Model with the representative concentration pathway 4.5 under year 2050

1 and 2: correspond to the number of species to find on that location.
An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 (**IPCC, 2013)**

3.4.3.2.1. Prediction of distribution of plant species consumed by the Western Derby Eland within Niokolo Koba National Park under year 2070 and Representative concentration pathway 4.5

The prediction of the three models under year 2070 and RCP 4.5 showed that *B. angustifolia* A. Rich. had the same predictive tendency that under year 2050 for the RCP 4.5 (Figs. 59- 64). For this species, a decrease of 76.75 % of its habitat suitability was noticed for the GFDL-ESM model whereas an increase of its unsuitable habitat was extended to the entire park for the MPI-ESM and HadGEM-ES models, respectively. *G. bicolor* Juss. had a potential distribution of its habitat suitability extended to the whole park for the three models. *H. acida* Tul. and *S. spinosa* Lam. had a decrease of 87.40 % and of 83.74 % of their suitable habitat for the GFDL-ESM model, respectively. Whereas, they recorded an increase of their unsuitable habitat to the entire park for the MPI-ESM and HadGEM-ES models (Table XXVII, Figs. 59, 60 & 61). *Z. mauritiana* Lam. had an increase of 120.92 %, 29.16 % and 106.82 % of its suitable habitat for the GFDL-ESM, MPI-ESM and HadGEM-ES models (Table XXVII, Figs. 59, 60 & 61), respectively.

3.4.3.2.2. Prediction of distribution plant species consumed by the Western Derby Eland within Niokolo Koba National Park under year 2070 and Representative concentration pathway 8.5

B. angustifolia A. Rich., *G. bocolor* Juss., *H. acida* Tul. and *S.pinosa* Lam. showed the same tendency under year 2070 and RCP 8.5 like under year 2050 and RCP 4.5 for the three models (Table XXVII, Figs. 65 & 66). *Z. mauritiana* Lam. showed an increase of its habitat suitability of 89.54 % and 128.88 % for MPI-ESM and HadGEM-ES models, respectively (Table XXVII, Figs. 65 & 66). Under horizon 2070, temperature did not seem to significantly impact the plant species consumed while based on climatic models characteristics precipiation appeared to affect the prediction under this horizon.

The overlay display of plant species consumed distribution showed more and less the same tendency under year 2070 and RCPs 4.5 and 8.5 (Figs. 62-64 and 67 & 68) than models' under year 2050 (Figs. 56-58). The distribution of the suitable area was located at the border south west toward the south east of the park for GFDL-ESM model, at the centre towards the north for MPI-

ESM model and at almost the whole park for HadGEM-ES model under RCP 4.5 while it covered all park under RCP 8.5 (Figs. 62-64 and 67 & 68).

Generally, the three models showed negative impacts on the occurrence and the distribution of the plant species consumed by the WDE. GFDL-ESM model even though it predicted dryness in the Sahel, it presented less harmful impacts of climate change on the occurrence and the distribution of the plant species consumed by the WDE. Indeed, this model predicted only a reduction of the suitable area of distribution for *B. angustifolia* A. Rich., *H. acida* Tul. and *S. spinosa* Lam. Whereas, MPI-ESM and HadGEM-ES models, which forecasted neutral and wet climate on the Sahel, predicted 100 % of unsuitable habitat committed to an extinction for these plant species consumed by the end of this century for RCP 4.5 as well as RCP 8.5. Furthemeore, the prediction of GFDL-ESM model on the occurrence and the distribution of the plant species consumed by the WDE for 2050 was tougher than those for 2070 with the RCP 4.5. *G. bicolor* A. Rich. showed a habitat suitability extended to all park with all models and RCPs by the end of this century. *Z. mauritiana* Lam. showed an increase to more favourable surface of distribution than the potential current one. Thererfore, by the end of this century *G.bicolor* Juss. and *Z. mauritiana* Lam. were expected less harmful impacts of climate change through models and RCPs than *B. angustifolia* A. Rich., *H. acida* Tul. and *S. spinosa* Lam..

Table XXVII: Prediction of habitat suitability for plant species consumed by Western Derby Eland in Niokolo Koba National Park under current and 2070 climatic conditions for representative concentration pathway (RCPs) 4.5 and 8.5.

Current Habitat Surface (km2)		
Species	Suitable	Less favourable
B. angustifolia A. Rich.	3118	7186
G. bicolor Juss.	5590	4714
H. acida Tul.	2531	7773
S. spinosa Lam.	2633	7671
Z. mauritiana Lam.	4502	5802

Year 2070

RCP 4.5

	GFDL-ESM2G				**MPI-ESM-LR**				**HadGEM2-ES**			
Habitat	Suitable		Less favourable		Suitable		Less favourable		Suitable		Less favourable	
Species	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)
B. angustifolia A. Rich.	725	-76.75	9579	33.30	0	**-100**	10304	43.39	0	**-100**	10304	43.39
G. bicolor Juss.	10304	84.33	0	**-100**	10304	84.33	0	**-100**	10304	84.33	0	**-100**
H. acida Tul.	319	-87.40	9985	28.46	0	**-100**	10304	32.56	0	**-100**	10304	32.56
S. spinosa Lam.	428	-83.74	9876	28.74	0	**-100**	10304	34.32	0	**-100**	10304	34.32
Z. mauritiana Lam.	9946	120.92	358	-93.83	5815	29.16	4489	-22.63	9311	106.82	993	-82.89

RCP 8.5

	GFDL-ESM2G				**MPI-ESM-LR**				**HadGEM2-ES**			
Habitat	Suitable		Less favourable		Suitable		Less favourable		Suitable		Less favourable	
Species	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)	Surface (km^2)	Trend (%)
B. angustifolia A. Rich.		ND		ND	0	**-100**	10304	43.39	0	**-100**	10304	43.39
G. bicolor Juss.		ND		ND	10304	84.33	0	**-100**	10304	84.33	0	**-100**
H. acida Tul.		ND		ND	0	**-100**	10304	32.56	0	**-100**	10304	32.56
S. spinosa Lam.		ND		ND	0	**-100**	10304	34.32	0	**-100**	10304	34.32
Z. mauritiana Lam.		ND		ND	8533	89.54	1771	-69.48	10304	128.88	0	**-100**

ND: no data, (+): gain in surface, (-): lost in surface, **-100:** decrease of area (**bold black:** decrease of suitable area even close extinction, bad trend; **bold red:** increase of suitable area good trend).
Average increases of temperature of + 1–2.6 °C for RCP 4.5 and +2.6–4.8 °C for RCP 8.5 are expected **(IPCC, 2013).**

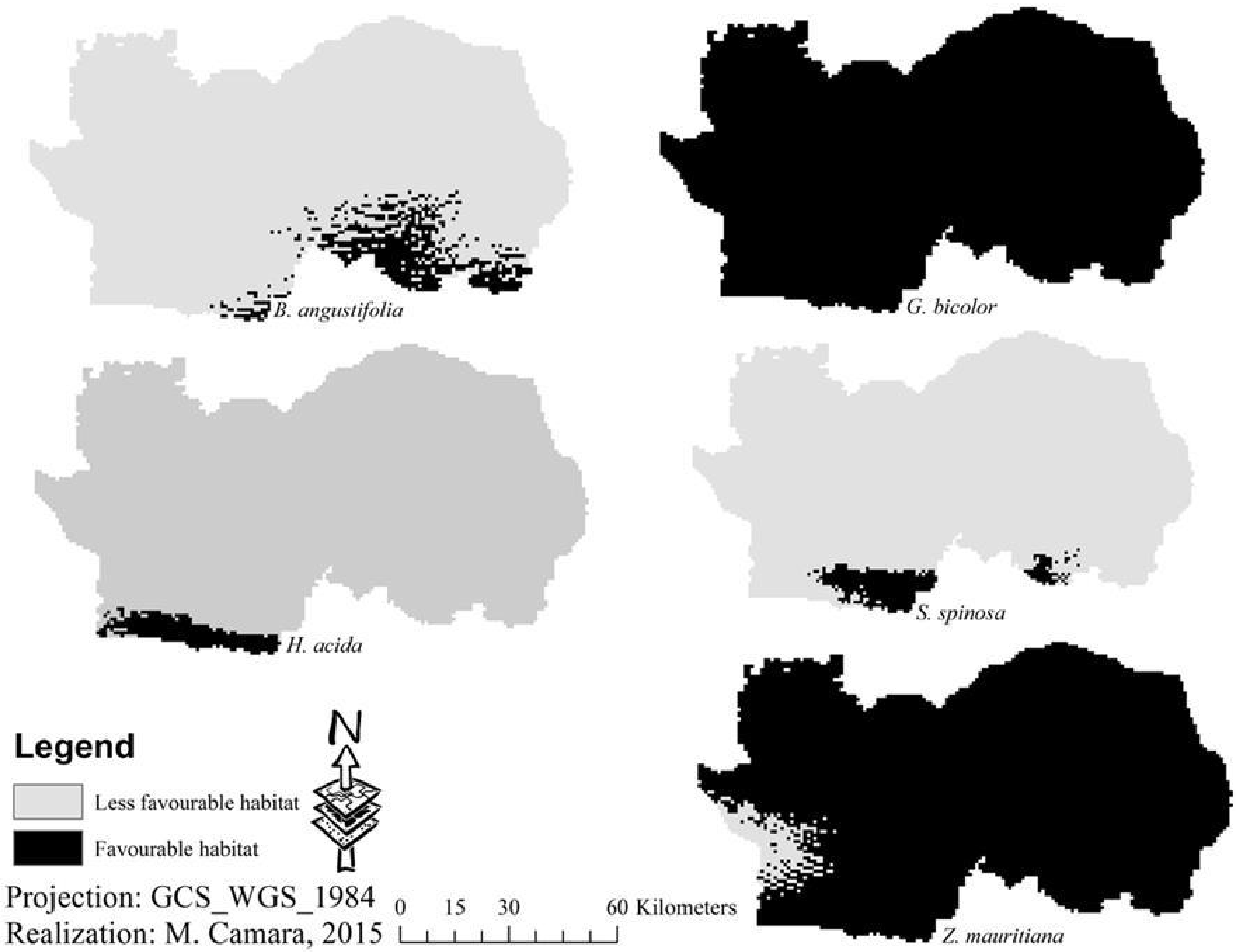


Figure 59: Potential Distribution of plant species consumed from the GFDL-ESM2G model with the representative concentration pathway (RCP) 4.5 under year 2070

An average increase of temperature of + 1–2.6 °C is expected for RCP 4.5 **(IPCC, 2013)**

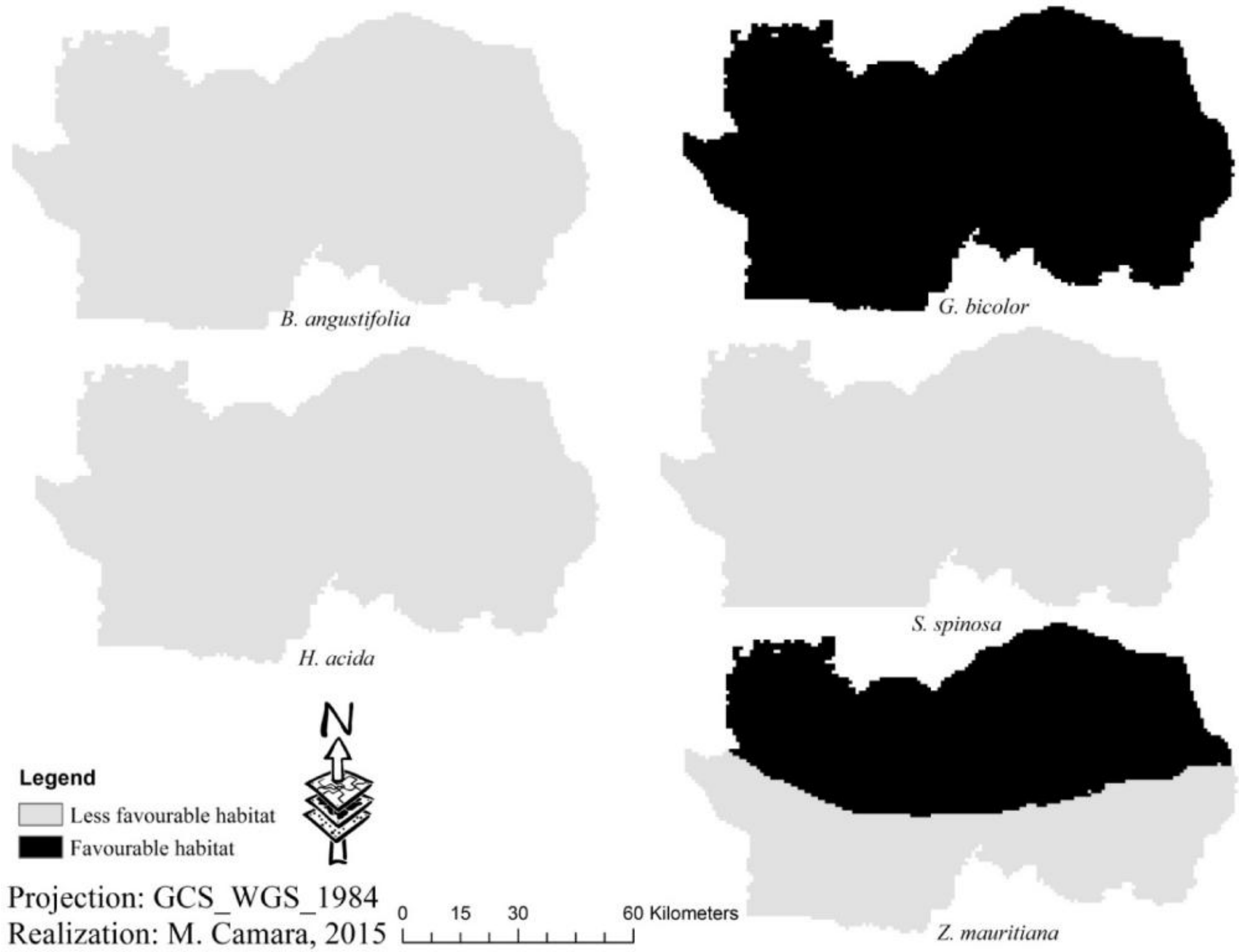


Figure 60: Potential Distribution of plant species consumed from the MPI-ESM-LR model with the representative concentration pathway (RCP) 4.5 under year 2070

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 (**IPCC, 2013)**

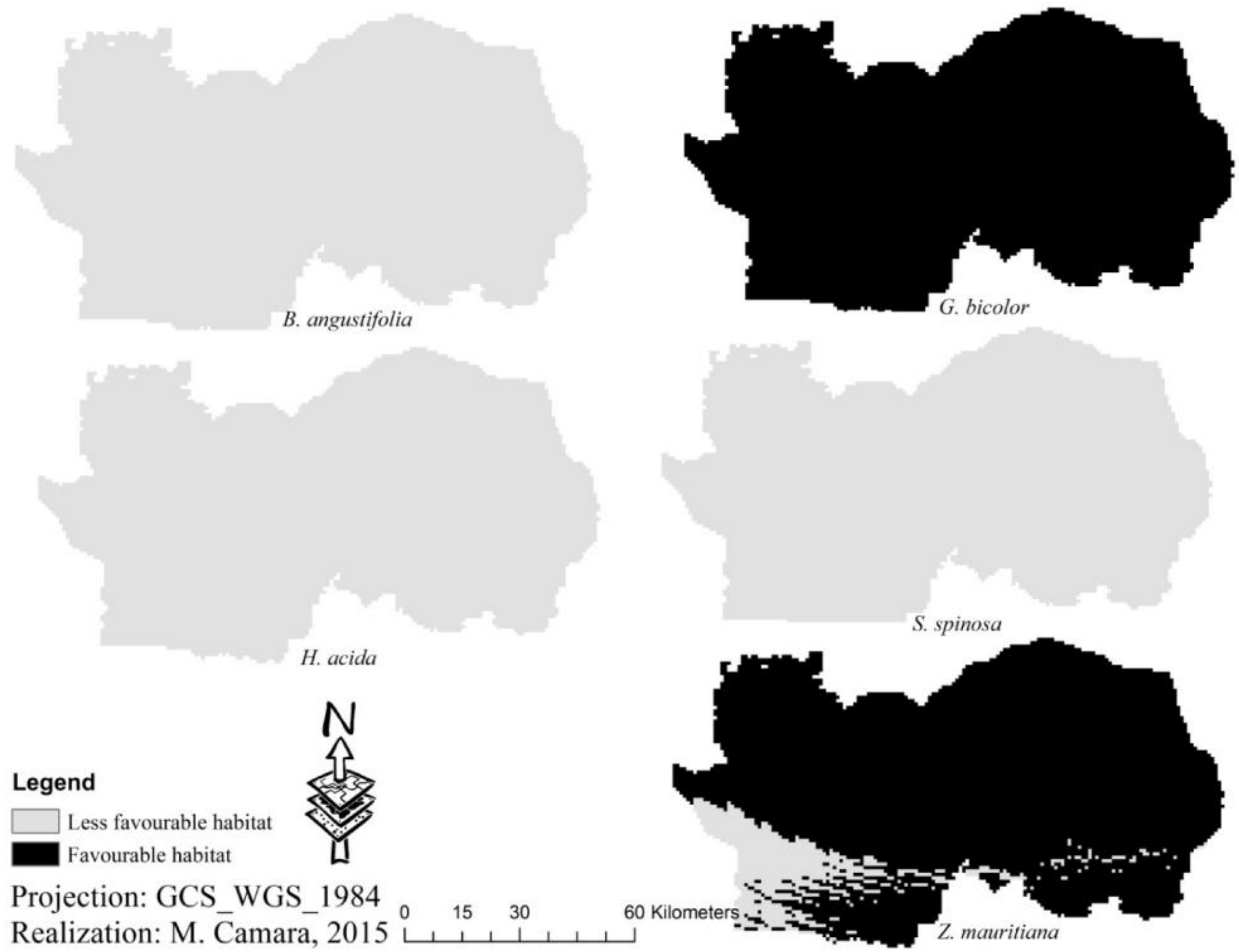


Figure 61: Potential Distribution of plant species consumed from the HadGEM2-ES model with the representative concentration pathway (RCP) 4.5 under year 2070

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 **(IPCC, 2013)**

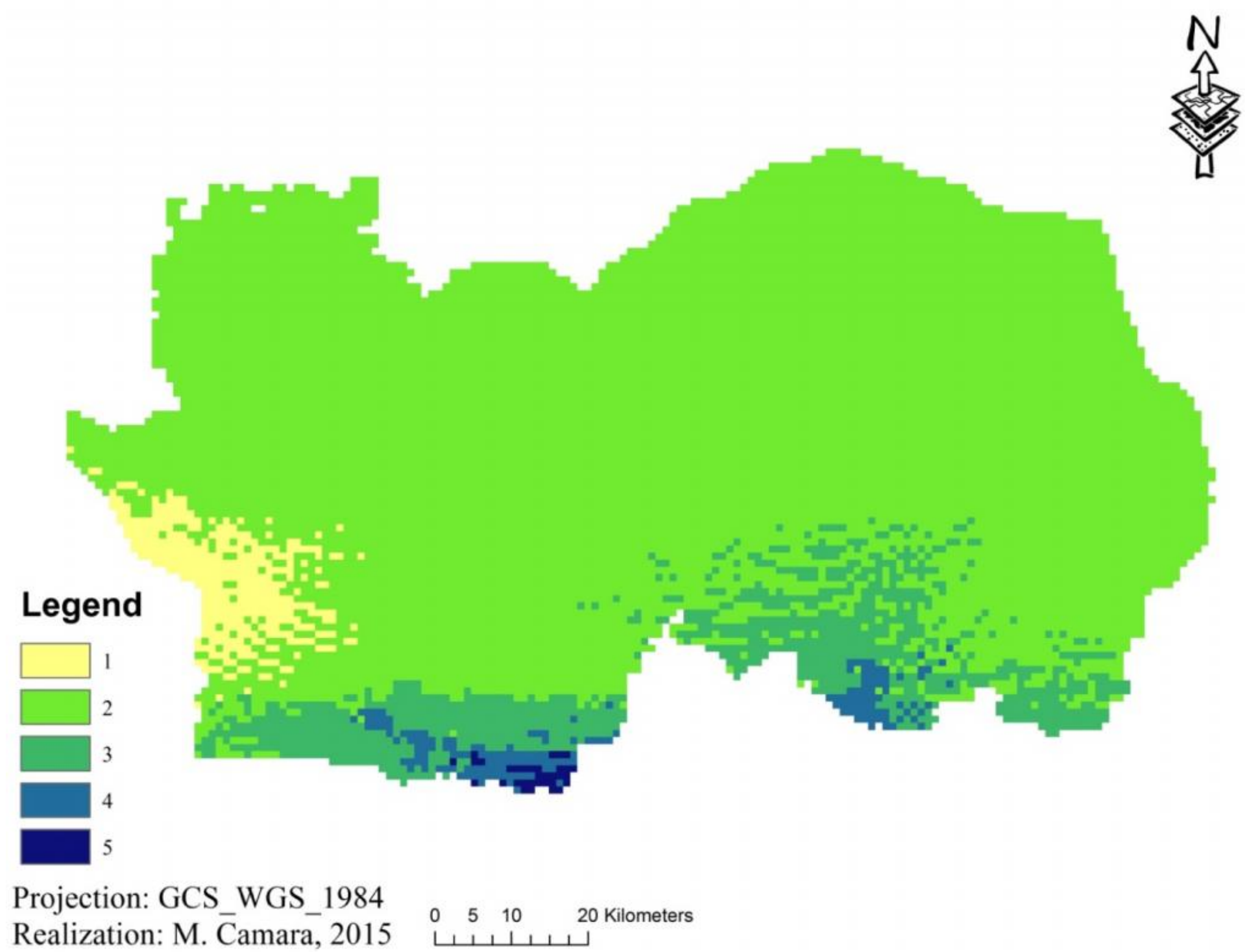


Figure 62: Overlay of Potential Distribution of plant species consumed from the GFDL-ESM2G model with the representative concentration pathway (RCP) 4.5 under year 2070

1, 2, 3, 4 and 5: correspond to the number of species to find on that location.

An average increase of temperature of + 1–2.6 °C is expected for RCP 4.5 **(IPCC, 2013)**

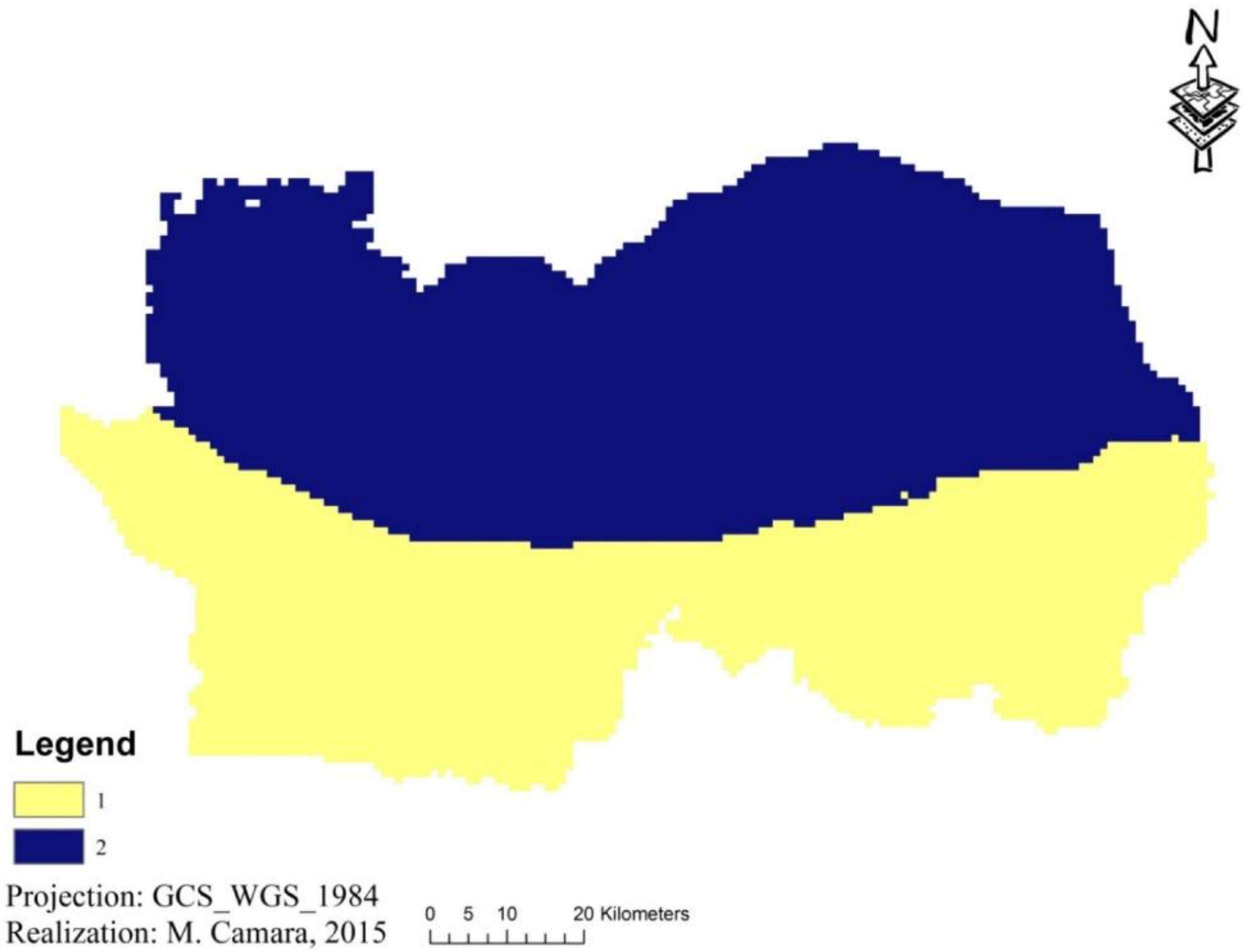


Figure 63: Overlay of Potential Distribution of plant species consumed from the MPI-ESM-LR model with the representative concentration pathway (RCP) 4.5 under year 2070

1 and 2: correspond to the number of species to find on that location.

An average increase of temperature of + 1–2.6 ^{o}C is expected for RCP 4.5 (**IPCC, 2013)**

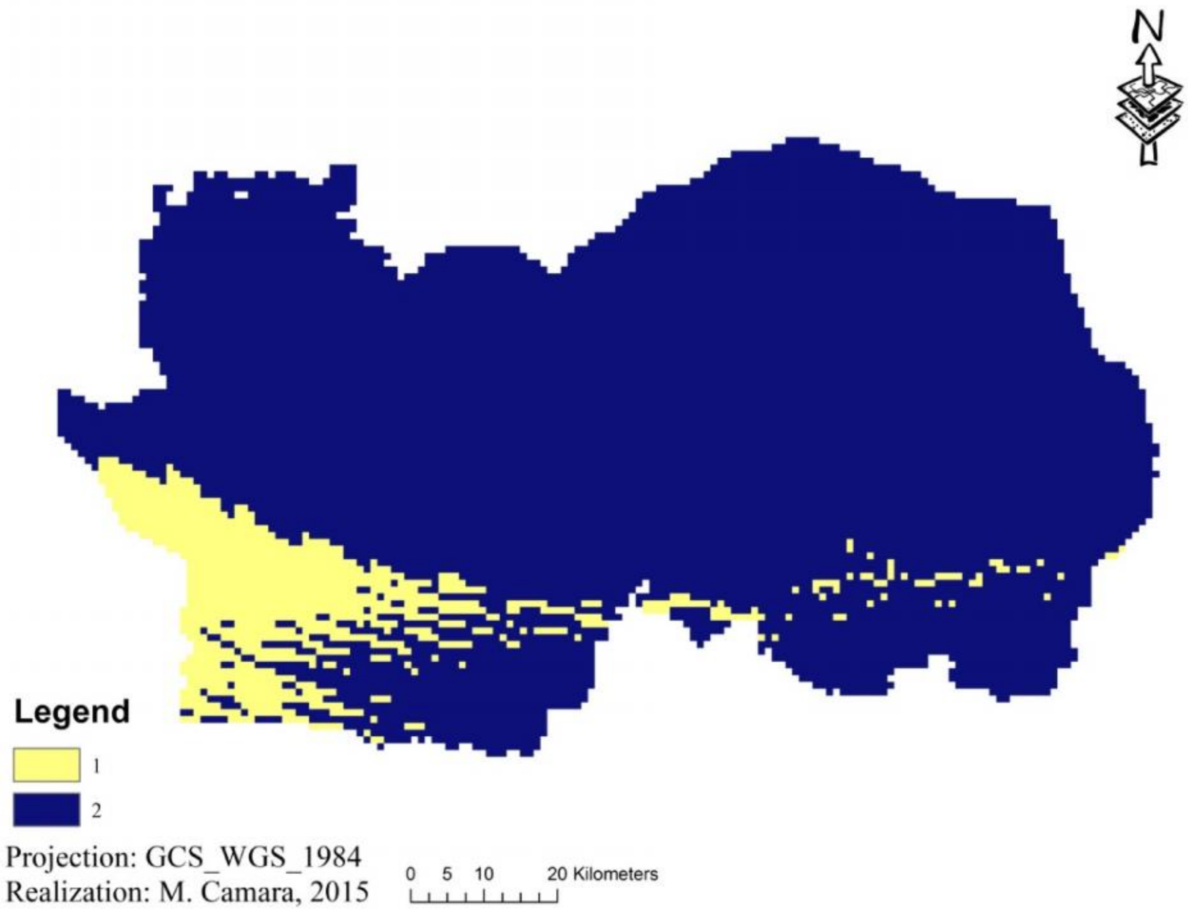


Figure 64: Overlay of Potential Distribution of plant species consumed from the HadGEM2-ES model with the representative concentration pathway (RCP) 4.5 under year 2070

1 and 2: correspond to the number of species to find on that location.

An average increase of temperature of + 1–2.6 °C is expected for RCP 4.5 (**IPCC, 2013)**

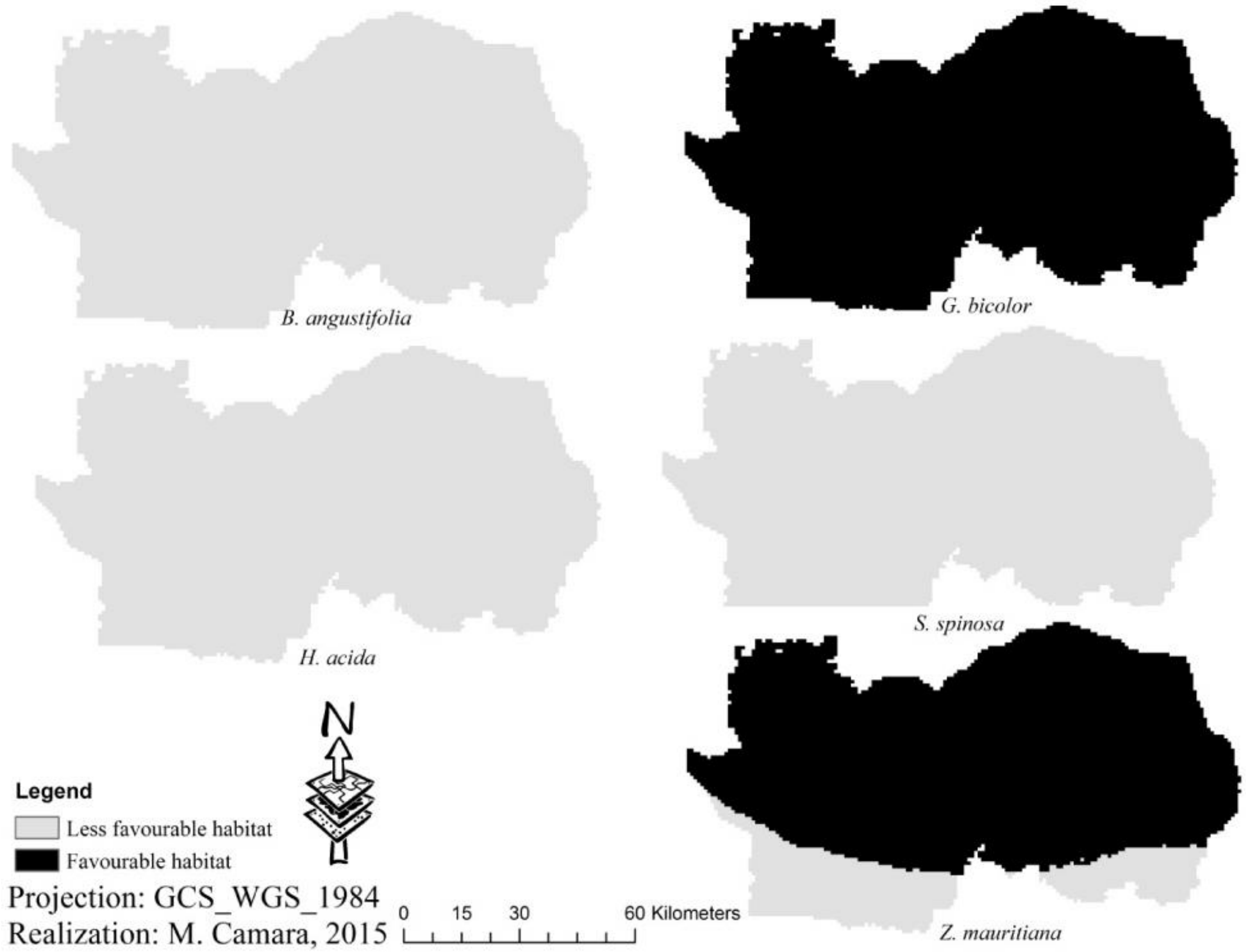


Figure 65: Potential Distribution of plant species consumed from the MPI-ESM-LR model with the representative concentration pathway (RCP) 8.5 under year 2070

An average increase of temperature of +2.6–4.8 ^{o}C is expected for RCP 8.5 **(IPCC, 2013)**

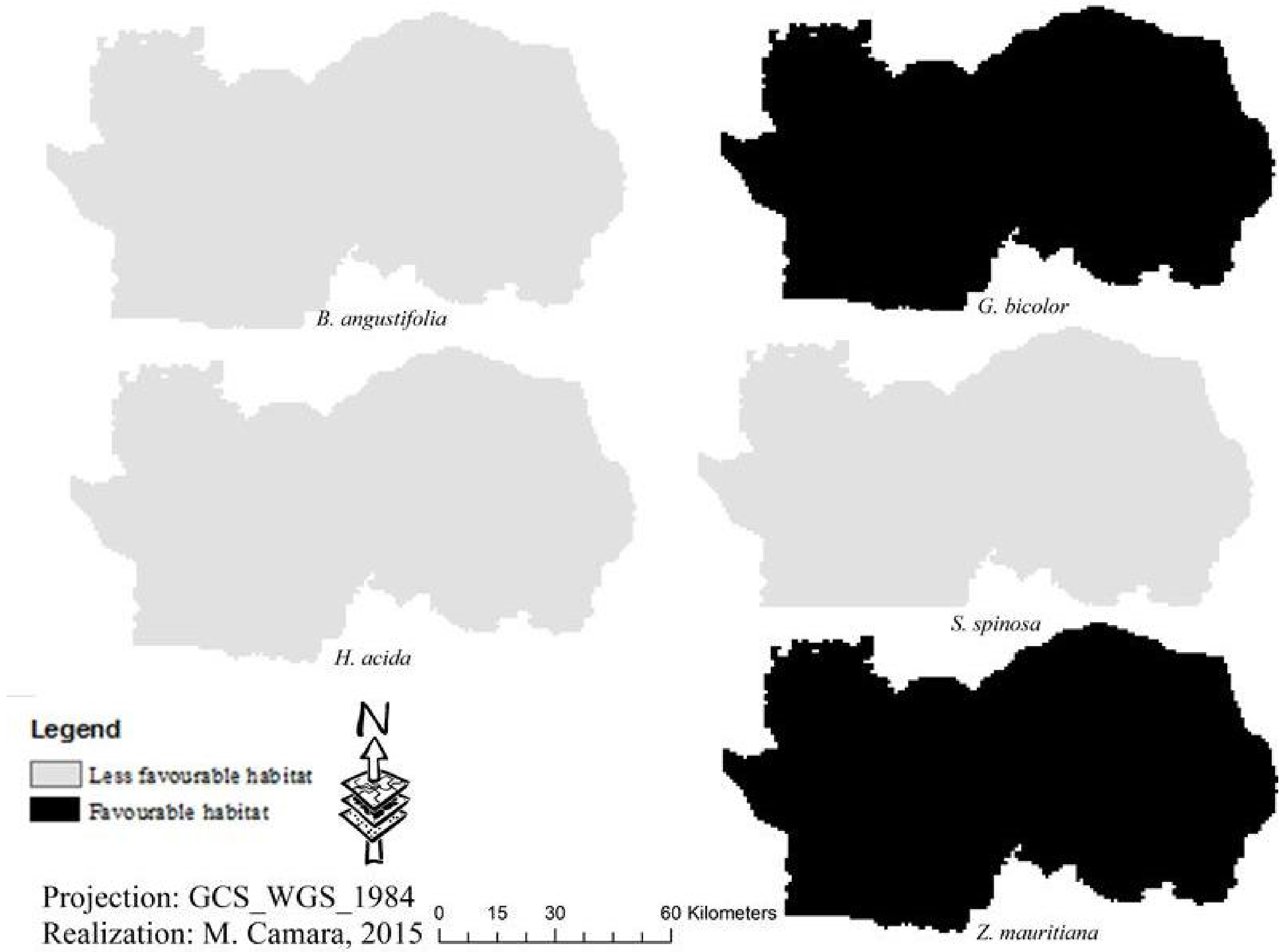


Figure 66: Potential Distribution of plant species consumed from the HadGEM2-ES model with the Representative concentration pathway (RCP) 8.5 under year 2070

An average increase of temperature of +2.6–4.8 °C for is expected for RCP 8.5 **(IPCC, 2013)**

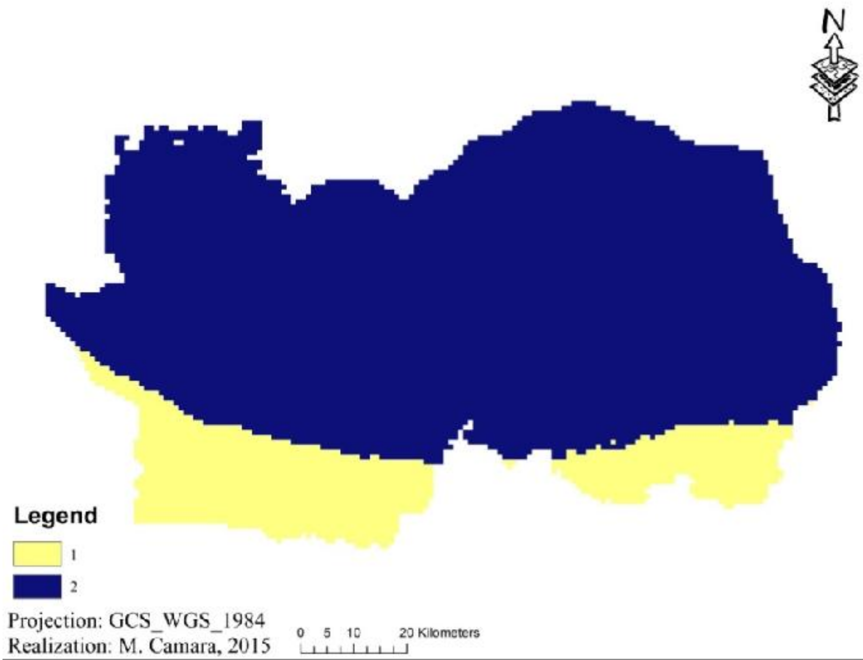


Figure 67: Overlay of Potential Distribution of plant species consumed from the MPI-ESM-LR model with the representative concentration pathway (RCP) 8.5 under year 2070

1 and 2: correspond to the number of species to find on that location.

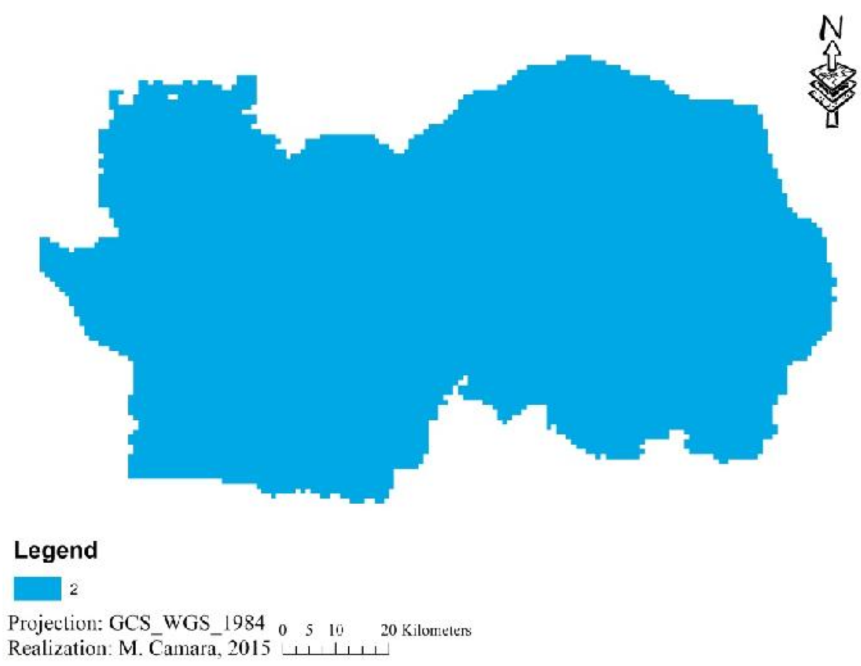


Figure 68: Overlay of Potential Distribution of plant species consumed from the HadGEM2-ES model with the representative concentration pathway (RCP) 8.5 under year 2070

2: correspond to the number of species to find on that location.

An average increase of temperature of +2.6–4.8 ^{o}C for is expected for RCP 8.5 **(IPCC, 2013)**

Chapter 4: DISCUSSION

4.1. Identification of the confinement area of the Western Derby Eland in Niokolo Koba National Park

The PCA analysis revealed some discordance between informants who currently frequent the park, researchers, former poachers, literature, active and retired agents, and those who used to frequent the park in the past, elder agents and evicted villagers. This could be explained by the fact the elder agents were relieved from office work and had not gone in the park for years and the evicted villagers corollary to their eviction have not had access to the park. Without a doubt, created in 1954 the national park was successively extended from 22700 ha to its current size 913000 ha in 1969. These successive extensions were followed in 1970 by the eviction of villages out of the new boundaries. Consequently, only the elders from these villages saw the WDE within the park when they lived inside. Therefore, the sites cited by these persons might be considered as sites frequented by the WDE in the past or less frequented nowadays. In contrast, sites indicated by researchers, literature, resource persons of the DNP, retired and active agents might be the most probable sites of occurrence of the WDE currently in NKNP because all informants of this group are frequent in the park. These sites of occurrence of the WDE, belonging to the ZMPOE and ZHPOE, are in accordance with findings of **Thiam *et al.* (2004)** and **Niang (2005)**. **Renaud *et al.* (2006)** reported the biggest herd of the WDE (69 individuals) seen during these last decades on Niokolo's plate during their aerial census. **Hejcmanová *et al.* (2010)** reinforced our findings with records of presence and dungs of WDE at Linguekountou, Mansafara, and Assirik. More recently, **Kane (2014)** using camera traps captured WDE's pictures and movies with GPS coordinates at Mansafara, Niokolo and in the vicinity of Assirik. However, all informants and personal observations during the data collection agreed that it is hard to find and to get prolonged visual contacts of the WDE in the park. Most of the visual contacts are unexpected and casual. This is due to the behaviour of the WDE in the wild. It is a very suspicious and vigilent antelope always alert of its surrounding environment thanks to its excellent visual, auditory and olfactory senses (**Spinage, 1986; Bro-Jorgensen, 1997)**. This may explain the low number of respondents obtained during the data collection, because only respondents who saw the WDE at least once in the park were interviewed.

The cluster of areas frequented by the WDE in NKNP presented three zones of occurrence including the ZMPOE and the ZHPOE where the WDE has high probability to be observed. The cluster analysis was based on a new approach by combining information collected from informants, which then were *weighted* according to their reliability. In contrast, the location and the habitat of the Eastern Derby Eland have been defined by scholars using GPS tracking **(Bro-Jorgensen, 1997)** and GPS collards **(Graziani & d'Alessio, 2004)**. Sites of these zones are recognized by the ecological department of the park, researchers, active agents and casual visitors (tourists) to record the highest visual contacts and traces of the WDE **(Thiam *et al.*, 2004; Niang, 2005; Hejcmanová *et al.*, 2010; pers. Comm; park ranger's observation)**. Sites such as Niokolo, Assirik, Mansafara, Wouroly, Linguekoto and Banghare located in the high and hilly part of the park are hard to access. The location and topography of these sites are in line with the description of the habitat of its relative *T. d. gigas* Heuglin, 1863 (**Kingdon, 1997; Bro-Jorgensen, 1997; East, 1998)**. Linguekountou and Kossi kossi, sprinkled with lick soils, increase the importance for WDE feeding and health needs **(Graziani & d'Alessio, 2004; Ayotte *et al.*, 2008)**.

The confinement area of the WDE in NKNP stretches on vegetation type dominated by savanna similar to the habitat of the *T. d. gigas* Heuglin, 1863 **(Kingdon, 1997; East, 1998; Graziani & d'Alessio, 2004)**. Additionally, its morphological structure lies on the hilliest and rockiest parts of the park and encompasses almost all the plates (bowe) of the park and some saline outcrops. This is in concordance with habitat described to allow the WDE to feed and hide themselves and their offspring. On these bowe (big glade), large antelopes such as the WDE, the roan antelope and the hartebeest were met several times during the data collection notably on Niokolo Bowal **(park rangers and personal observations)**. Such areas play a key role in the habitat of large antelope especially in anti-predatory strategies **(Jarman, 1974; Sinclair, 1977)**. Furthermore, the confinement area is located at the centre-eastern part of NKNP and fits perfectly inside the polygon of distribution for big mammals in NKNP (**Renauld *et al.*, 2006**). This central position of the confinement area in addition to its conformity with WDE behaviour may be explained by additional external factors. Indeed, the park is belted in its immediate neighbourhood by several disturbing activities, such as basalt quarry exploitation by WATIC, CSE and AZESKI at the North, livestock grazing at the West, Guinean poaching at the South and gold prospection by the insdustrial mining society (permit granted since 2009) and gold traditional exploitation "Dioura" at the East, which in synergy could explain the confinement of the WDE at the centre of NKNP. Indeed, the WDE is running away from anthropogenic activities at the border as reported by

IUCN (2015). Furthermore, gold mining activities at the eastern border of the park should be pointed out because they use mercury upstream of the River Gambia which flows and supplies the hydrological network of the park. **Niane (2014)** showed the consequence of chemical transformation of mercury into methylmercury, the most dangerous form even in low quantities in water, due to its bioaccumulation and bio-amplification along the food chain. Consequently, gold mining practices may induce a possible water pollution which in short to mid term might impact the health and the survival of herbivores including the WDE**.** Moreover, the national road RN7 crossing NKNP on 100 km and the confinement area requires attention because it fragmented the habitat suitability of the WDE inside its confinement area. If left unchecked, this could increase the factors threatening the WDE in NKNP. Indeed **Riitters *et al.* (1997)** argued that fragmentation reduces individual species across habitats. **Verboom *et al.* (1991)** and **Short & Turner (1994)** emphasized that fragmentation results in the increased probability of extinction and the loss of species over time. In addition, **IUCN (2015)** reported the danger of this road for the survival of herbivores including the WDE by showing the numerous animals killed by accident. Indeed, this road is an important international corridor of the Economic Community of West African States (ECOWAS) highly used all day and that connects Senegal to Mali and Guinea and also Tambacounda to Kédougou. **Bro-Jorgensen (1997)** reported that heavy poaching was among the anthropogenic factors threatening the Eastern Derby Eland. However, although poaching activities were recorded during the field work, it is believed that they do not affect directly the WDE in NKNP. Indeed on one hand, elder villagers pointed out some traditional beliefs around the WDE. According to them only experienced and mystic hunters can kill the WDE. Yet, very few of these poachers are still alive and are old and their know-how is not transmitted because of the repressive anti-poaching measures engaged by the park rangers. On the other hand, the park rangers never collected carcasses of the WDE while they used to collect lot of carcasses of the other antelopes across the park. These unwritten and orally transmitted traditional beliefs are a good asset for conservation of the WDE within NKNP as reported by **Anthwal *et al.* (2010)**.

4.2. Dynamics of the vegetation in the confinement area of the Western Derby Eland in relation with climatic parameters

The value of the kappa coefficient confusion 0.82, 0.80, 0.84, 0.79 and 0.90 for 1973, 1984, 1990, 2003 and 2013, respectively revealed that our classification was good to excellent according to the scale of **Blum *et al.* (1995)**. The analysis of the confusion matrices of land cover classes shows some confusion among the land cover classes of the five images. This may be explained by three reasons amidst others: (i) the choice of classes based on radiometric values and the choice of training plots, (ii) the field data and knowledge of the study area which facilitated the analysis and visual interpretation of images and (iii) the qualities of images **(Guiro *et al.*, 2012; Sambou *et al.*, 2014)**. Indeed, **Kadeba *et al.* (2015)** argued the resolution of Landsat images (60-30 m) is a limit for the spatial analysis which may influence the accuracy of classification of small surface, transitional zones between classes and spectral similarities between certain classes in the confinement area of the WDE. Furthermore, **Akpo (1997)** reported that in Sahelian countries like Senegal, woody and herbaceous vegetation are hard to differentiate from the Landsat image signal, as their seasonal lush cycles are very similar in this region. This might explain the confusion and rate of modification observed between bowe and shrub tree and tree woodland savannas and between bamboo forest and tree woodland savanna because images were recorded in the early dry season when the whole vegetation cover were luxuriant. Likwise, the confusion between bowe and River might be explained by their spectral similarities. Indeed, bowe are grass land savanna containing outcrops of granite dotted with impermeable bare lands that retain water during the rainy and early dry season.

The rainfall history over the 40 years considered in this study (1973 to 2013) indicated that from 1973 to 1998 the rainfall of the confinement area of the WDE was deficient. In contrast, from 1999 to 2013 a slight recover of the rainfall was observed. It is believed that the inter-annual variations of rainfall might be the main driver of the vegetation dynamics tendency particularly the savannas tendency **(Fensham *et al.*, 2005)**. In 1984, the increase of tree-woodland savanna observed might be explained by either the period of acquisition of images or the recolonization of the natural vegetation after the eviction of the local population. The emergence of the bamboo forest in 1984 might be explained by its lifespan. Indeed, the bamboo forest has a lifetime estimated between 14 to 50 years. Moreover, bamboo flowers towards the end of its lifetime and then dies soon after **(Embaye, 2000).** Thus, it has been assumed that 1973 coincided with the period of the end of lifecycle of the bamboo forest within the confinement area of the WDE.

The analysis of changes showed that the rate of conversion was very low (less 1 %). This supports the argument of **Mbow (2000)** who said that NKNP is a well protected area less affected by anthropogenic pressure such as agricultural land conversion. Indeed, protected areas in West Africa usually undergo many conversions such as logging, charcoal production, livestock grazing, agricultural land progression as noticed by **Houessou *et al.* (2013)** around the "W" Biosphere Reserve, Benin and by **Inoussa *et al.* (2011)** at "W" Biosphere Reserve, Niger. However, conversion in the confinement area of the WDE was natural and fluctuated between vegetation to river and vice versa mainly between gallery forest and River. This could also be explained by the fact that after rainfall and the subsequent flooding of the river, vegetation was luxuriant with a good development of the canopies which could influence the of the image images when they are recorded.

Besides the conversion, the main land cover changes in the confinement area of the WDE were modifications illustrated by the fluctuation of gain and loss in vegetation cover. Seven land cover units dominated by savanna (shrub savanna, shrub-tree savanna and tree-savanna woodland) were identified through the time series 1973-2013. Generally, savanna cover decreased from 86.75 to 61, 57 % while the size of gallery forest increased from 9.24 to 21.54 % between 1973 and 2013. Bowe increased from 2.73% in 1973 to 8.47 % in 1990 and decreased to 3.25 % in 2013. For the WDE, bowe and savanna are preferred habitats. Bowe are open places with low densities of trees which provide the greatest visibility and help to avoid predatory attacks **(Sinclair, 1977)**, while savannas particularly shrub and shrub-tree savannas provide forage and shelter **(Bro-Jorgensen, 1997; East 1998; Grazian & d'AlessiSilvio, 2004)**. The modification of the land cover of the habitat of the WDE is more perceptible trough fluctuation of savannas surface. Furthermore, through the shrub savanna and shrub-tree savanna which lost 34.09 % and 3.11 % of their surface in favour of a close vegetation (bamboo frest, gallery forest and tree-savanna woodland), respectively. Analyses of matrices of land cover changes show the same tendency to close woody vegetation. The decrease of shrub savanna and shrub-tree savanna in favour of close woody vegetation may be explained by the fluctuation and the recovery of rainfall observed (Figs. 29 and 30) after the drought of the 1970s and the 1980s (**Salack *et al.*,**

2011). This rainfall recovery may be linked to recent results on the re-greenery of the Sahel which is a slight recovery of vegetation over the Sahel **(Herrmann *et al.,* 2005)**. Beside the general tendency, 1984 recorded the highest surface of shrub-tree savanna and tree-savanna woodland with 555876.06 ha and 138891.63 ha, respectively. This may be explained either by the natural recolonization of vegetation after the eviction of villages or by the impact of the rainy season on the vegetation cover as the images of 1984 were available in September. The tendency toward close vegetation may induce threatening impacts on the survival of the WDE in the mid to long term whitin its last wild refuge. Without a doubt, if this trend continues we may have a forest colonisation whereas WDE is dwelling in savanna and open spaces such as bowe because of its large size. **Grazian & d'Alessio (2004)** reported that in close habitats such as forest large browser mammals like the WDE will move hardly. Consequently, this may reduce its ability to feed and hide itself. Futhermore, in Tanzania **Nyamasyo & Kihima (2014)** reported **t**he decline of ungulates related to land cover variation towards woody vegetation.

4.3. Characterization of the vegetation of the confinement area of the Western Derby Eland

To date, very little information is available on the habitat of the WDE especially on the floristic and dendrometric characteristics. Predominant families comprising the Combretaceae, the Leguminosae-Mimosoideae, the Leguminosae-Caesalpinioideae, the Leguminosae-Papilinoideae, the Rubiaceae and the Tilliaceae found in the confinement area of the WDE are in accordance with the ones established by **Hejcmanová *et al.* (2010)** when they studied the diet constituents of the WDE in NKNP. The species richness of 50 woody species assessed on 6.24 ha is quite similar from the 59 species of trees and shrubs recorded on an area of 500 ha by **Hejcmanovā-Nežerková & Hejcman (2006)**. But, it is lower than the 106 woody species recorded on an area of 22800 ha reported by **Traoré (1997)** in NKNP. This diversity is an important asset for herbivorous browsers such as the WDE which find variate fodder within their habitat. However, this woody plant richness is low compared to the one found in the Eastern Derby Eland's habitat. Indeed **Grazian & d'AlessiSilvio (2004)** recorded 212 species and **Bro-Jorgensen (1997)** noted less than 10 common species in the habitat of the Eastern Derby Eland in Central African Republic. That difference may be attributed to data collection methods, geographic location and local climatic conditions. The habitats of the Western and the Eastern

Derby Eland are also different in terms of species composition **(Spinage, 1986; Bro-Jorgensen, 1997; Kingdon, 1997)**. Indeed, the Eastern Derby Eland is found in *Isoberlinia doka* Craib & Stapf savanna while this plant species is not recorded in the Senegalese flora **(Berhaut, 1967; Ba *et al.*, 1997)**. Its absence from the Senegalese flora is explained by its endemism to the Guinea - Cameroon corridor (**Arbonnier, 2004**).

The NMDS analysis revealed that the vegetation of the confinement area of the WDE in NKNP harbours almost the same woody species. This finding supports the hypothesis that the WDE frequents habitat with a quite similar floristic composition **(Kruskal, 1964).** This floristic similarity is witnessed by the results of species indicator analysis. Indeed, even though some species or combinations of species present specificity, no fidelity of species was recorded in the WDE habitat **(Dufrene & Legendre, 1997; De Cáceres & Legendre, 2009; De Cáceres *et al.*, 2012).** The ZHPOE without species or combination of species indicator reveals that no species recorded a p-value higher than the significance reference ($p \leq 0.05$) as suggested **De Cáceres *et al.* (2012)**. Species like *Combretum glutinosum* Perr. ex DC., *Pterocarpus erinaceus* Poir., *Lannea acida* A. Rich., *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. and *Bombax costatum* Pellegr. & Vuillet were the most ecologically important on the overall stand. **Reitsma (1988); Houéhanou *et al.* (2013)** stated that a plant species is ecologically important to an area when its IVI is > 10. Among the fifty adult tree species recorded, *Strychnos spinosa* Lam., *Ziziphus mauritiana* Lam., *Grewia bicolor* Juss., *Hymenocardia acida* Tul. and *Boscia angustifolia* A. Rich. described as part of the wild WDE diet have 7.27 %, 0.37 %, 0.31%, 0.12% and 0.06% of abundance respectively. Among them, *S. spinosa* Lam. is ecologically important to this area with IVI = 14.89. *C. glutinosum* Perr. ex DC., because of its resistance to fire outbreak **(Dayamba *et al.*, 2008)**, its density of 72.55 ind/ha and its abundance of 28.08 %, requires attention in future studies of WDE's diet in NKNP. Without a doubt, **Bro-Jorgensen (1997)** identified this plant species as a well selected one by Eastern Derby Eland during the dry season in Cameroon. Therefore, it might play an unknown role in the WDE's feeding in the late dry when forage is very scarce.

The CCA analysis reveals that fire outbreak, soil type, altitude and tree cover are the most important environmental factors influencing vegetation distribution. Overall, shrubs and small trees are found in the ZMPOE whereas big trees are found in the ZHPOE. **Traoré (1997);**

Hejcmanovā-Nežerková and Hejcman (2006) identified soil type and topography as factors impacting the species composition in NKNP. Topography was also described as a key factor determining the Derby Eland habitat **(East, 1998)** and this is witnessed by park rangers' observations. Indeed, during the rainy season the WDE migrates from the low altitude and marshy areas to the high altitude and hilly rocky areas (park rangers' observations). **Mbow (2000)** identified fire outbreak as factor controlling the species composition in NKNP too. Indeed, early fires are used every year by park rangers as management tool to prevent damages from late fires occurring in the late dry with drastic consequences. These early fires are supposed to improve the regrowth of some herbaceous species participating to herbivores' feeding, to increase visibility for tourism and to reduce predation pressure for herbivores. In NKNP, apart from reducing predation and preventing the consequences of late fires, these early fires do not seem to really impact the survival of the WDE in NKNP. Indeed, **Hejcmanová *et al.* (2010)** reported that the diet of the WDE contains less than 5% grass. In contrast, **Bro-Jorgensen (1997)** admitted that the Eastern Derby Eland never feeds on grass while **Hillman & Fryxell (1998)** showed that the Eastern Derby 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 in NKNP.

Tree density varies significantly among zones and the mean density of the ZMPOE is N = 392 trees/ha versus N = 280 trees/ha for the ZHPOE. The relatively low values of density observed for the global stand as well as for zones of occurrence are in concordance with **Riginos & Grace (2008)** findings'. This presents the confinement area of the WDE as a good habitat for the WDE, because these authors found that wild herbivores are more present in areas with low tree density. Certainly, such open places may offer high visibility to them against the predatory attacks. The mean diameter for the global stand was estimated to 15.09 cm. A larger value was reported elsewhere (24.4 cm) for woodlands in drier areas of the Sudanian-Guinean transition zone like NKNP **(Glèlè Kakaï & Sinsin, 2009)**.

The diameter structures of trees showed a good adjustment of the observed distribution to the Weibull theoretical distribution and an inverse "J" shape for the zones of occurrence as well as for the consumed species suggesting that the confinement area of the WDE in NKNP has stable natural vegetation dynamics with relatively younger plant species than large plant species. Thus, the potential of feeding plant species seems well supplied. Indeed, the majority of trees have DBH recorded between 5 and 10 cm and the plant species consumed with DBH > 15cm were rare. The distribution of diameter classes is often reported in the literature to be of great interest for forest management than the height structures because they are used as indicators of stand structure and dynamics **(Van Laar & Akça, 2007)**.

According to the density of seedlings $N_{1,}$ the confinement area of the WDE presents a very good regeneration potential with value ranging from 3148.0 to 2215.38 trees/ha amidst sites and a global stand of 2649.0 trees/ha. This confirms the important presence of young plant species in the vegetation structure. The high value of density of seedlings may be explained by ungulate grazing which reduce competition with herbaceous by removing the litter and the herbaceous cover as reported by **Bullock *et al.* (1995)**. However, the decrease of density from seedlings, sapling to adults trees (N_1= 2649 trees/ha, N_2= 548.80 trees/ha and N= 290.71 trees/ha) shows a good natural tendency of the vegetation structure as reported by **Fisaha *et al.* (2013)** with a good potential of regeneration. Though, it reveals that trees encounter some influencing factors while growing. As NKNP is well protected from the anthropogenic factors, the early fire's management and the climatic conditions appear to be the potential factors affecting plant species from their young stage to their adult age **(Mbow, 2000; Sonko, 2000; personal observation)**. Hence, if they continue influencing the vegetation in the confinement area of the WDE, these factors may decrease the plant species consumed presence (forage availability) by the WDE. Consequently, this may affect the survival of the WDE within NKNP **(Antoninova *et al.*, 2004; Baskaran *et al.*, 2011)**. Nevertheless, caution is recommended in the analysis of the dynamics tendency of vegetation from the diameter structure of trees because some debates are still opened. Indeed, **Feeley *et al.* (2007), Fandohan *et al.* (2011) and Houéto et *al.* (2013)** advised to interpret outputs of Weibull with care because the shape parameter of the three-parameter Weibull distribution (c) is not necessarily a good predictor of stand dynamics.

4.4. Prediction of the distribution of plant species consumed by the Western Derby Eland under climate change within Niokolo Koba National Park

This is the first attempt to investigate prediction of species–climate envelope models, using observed range occurrence of the five known plants species consumed by the WDE in NKNP under climate change by the end of this century.

In modelling approach, the performance of the model depends on the evaluation of its goodness of fit or its accuracy. Therefore, it reinforces the model's predictive power. Thus, the accuracy of the models was assessed using UAC and TSS. The predictive power was good for *B. angustifolia* A. Rich., *H. acida* Tul., *S. spinosa* Lam. and *Z. mauritiana* Lam. while, it was fair for *G. bicolor* Juss. **(Araùjo *et al.*, 2005; Allouche *et al.*, 2006; Fandohan *et al.*, 2015)**. For *G. bicolor* Juss., this may be explained by its low number of occurrence recorded. Indeed, **Van Proosdij *et al.* (2015)** reported that for good assessment of the accuracy of a model, a minimum record of occurrence for species should be ranged from 14 to 25 for Africa, when only eight presence records were obtained for *G. bicolor* Juss. Its low record may be related either to a low effective population in NKNP or to the random sampling used for the data collection which might fall in areas where it does not occur.

The current potential distribution of plants species consumed by the WDE showed a good distribution of these plant species through the park and particularly in the confinement area which fit in the polygon of big Mammals' occurrence in NKNP (**Renauld *et al.*, 2006)**. This combined to the aforementioned tendency of the vegetation structure of the plant species consumed revealed that feeding plants seem currently well supplied and distributed for the WDE. This means that in the nearest future without unexpected changes, the WDE has a good forage supply. This is a good contribution to its sustainable presence in NKNP **(Kamler & Homolka, 2011)**. Further, the availabilities and distribution of plant species consumed are a good advantage in reducing feeding time investment as compared to the activities such as mating, resting or avoiding predators as mentioned by **Shipley *et al.* (1994)**. Moreover, the forage availability will be followed by their intake which is a good implement in maintaining the sustainability of ecosystems such as protected areas by increasing the biodiversity of plant species and the structural diversity in savanna stability (**Sankara *et al.*, 2005**).

HadGEM2-ES and MPI-ESM-LR models under horizon 2050 as well as under horizon 2070 showed drastic reduction on the habitat of *B. angustifolia* A. Rich., *H. acida* Tul. and *S. spinosa* Lam. even committed to extinction. In contrast, the models predicted an increase of the suitable area at the mid and the end of this century for *Z. mauritiana* Lam. and 100 % of suitability for *G. bicolor* Juss. GFDL-ESM2G, projecting the Sahel under dryness in this century, predicted an increase of the suitable areas for *G. bicolor* Juss. and *Z. mauritiana* Lam. like the previous models and a decrease of suitable area for *B. angustifolia* A. Rich. under horizons 2050. It projected also a reduction of the suitable area even a potential extinction for *H. acida* Tul. and *S. spinosa* Lam. under 2050. Even though, *G. bicolor* Juss. is predicted to have 100 % of suitability by the end of this century regardless the considered models or the RCPs. Its case should be analysed with caution. Indeed, on one hand, its records of occurrence were low and did not reach the minimum of occurrence point advised **(van Proosdij *et al.*, 2015)** and on the other hand its prediction is a bit contradictory to its ecology and biophysical limits. Although, it is very much drought resistant, it is described to occur in areas with mean annual rainfall ranging from 200 to 900 mm **(Arbonnier, 2004; Orwa *et al.*, 2009)** while the southern part of the park may have an annual rainfall more than 1000 mm. Subsequently, unless the park undergoes huge human pressures, by the end of this century which in the long run, facilitate the huge variation of climatic variables, it will be difficult to expect that the whole park is going to be suitable for *G. bicolor* Juss. However, the positive and increasing tendency of *Z. mauritiana* Lam. through RCPs and models could be explained by its remarkable plasticity in term of climatic entails needs. According to **Orwa *et al.* (2009)** *Z. mauritiana* Lam. occurs in area with mean annual temperatures ranging from 10 ^{o} to 48^{o} C and mean annual rainfall between 120 and 2200 mm. But, it is more widespread in areas with an annual rainfall between 300 and 500 mm. These requirements may explain the increase of the suitable area for *Z. mauritiana* Lam. Indeed, the highest prediction of the increase of suitable area for *Z. mauritiana* Lam. was recorded by GFDL-ESM2G which projected a decrease of the rainfall in the Sahel by the end of this century. Moreover, *Z. mauritiana* Lam. is currently exposed to temperatures between 20 and 36^{o} C in the park. Thus, despite the prediction of increase of 1.0 ^{o} – 2.6° C and 2.6 ^{o} – 4.8^{o} C for RCPs 4.5 and

8.5, respectively, this species will stay in its ecological comfort. This may further explain the increase of its suitable habitat within NKNP with the different models and RCPs.

Generally, the three models showed negative impacts on the consumed plant by the WDE. Three plant species of the five plant species consumed would expect a drastic decrease of their suitable areas. Even though, RCPs 4.5 and 8.5 projected an increase of mean temperatures about 1.0 ^{o} – 2.6° C and 2.6 ^{o} – 4.8 ^{o} C, respectively. These differences appear not to influence the prediction of species distribution because models showed the same tendency under both RCPs. In contrast, precipitation mainly rainfall seems to affect the prediction of species under periods. Indeed, only GFDL-ESM model, predicting dryness in the Sahel by the end of this century, presents harmless impacts on the future presence of plant species consumed by the WDE compared to the HadGEM2-ES and MPI-ESM-LR models which predicted heavy negative impacts on the plant species consumed under periods 2050 and 2070 and RCPs 4.5 and 8.5. These results are supported by model contributing factors in which precipitation factors contributed more than temperature factors.

Consequently, this might in turn induce negative impacts on the survival of the WDE in NKNP. WDE find shelter and forage in the natural vegetation. Any disruption on these plant species consumed would affect the WDE because of the thin relation between herbivore mammals' presence and the abundance and quality of the habitat notably, the food availability. Indeed, the availability of plant species determines its consumption, which in turn controls the herbivore population dynamics as argued by **Barlow (1987)**. Moreover, as *B. angustifolia* A. Rich., *H. acida* Tul. and *S. spinosa* Lam. would expect huge decrease of their suitable area. It is believed that subsequently the forage for the WDE will also decrease. If this happens, the WDE may initiate migrating movements for forage seeking outside of the borders of the park as reported **Astrom *et al.* (1990)**. This would increase the vulnerability of the WDE towards the livestock's proximity promoting the transmission of diseases affecting wildlife or the hunting and poaching actions **(Carrillo *et al.*, 2000; Kock, 2005)**. Concerning the two plant species with positive impacts of climate change, their distributions are sometimes questionable for the survival of the WDE. Indeed, their suitable areas located at the border of the park are not appropriate for the WDE's survival because of threats at the periphery of the park. On one hand there is human pressure through logging and poaching and on the other hand grazing competition and potential diseases' contamination (e.g. rinderpest) with livestock of the surrounding population **(Kock, 2005; Renauld *et al.*, 2006).**

Species distribution models are currently gaining interest in predicting the suitable spatial distribution for a target species **(Pearce & Boyce, 2006; Evangelista *et al.*, 2008)**. They help in understanding niche requirements for species and in predicting their potential distributions. Their utility has been highlighted in supporting conservation planning such as endangered species management, in the designation of protected areas and in the assessement of the ecological impacts of various factors including climate change **(Guisan & Thuiller, 2005)**. However, despite its recognised usefulness, results of prediction have to be interpreted with vigilance as they serve for future management and decision making. Indeed, models are run with a certain number of uncertainties. Uncertainties can be induced by the selected climate variables used to predict the potential distribution of species. Here, we used only environmental variables related to temperature and precipitation while the importance of factors like biotic interactions (e.g. intra and inter-specific competition) and abiotic interactions (e.g. pedology, geology, altitude, fire outbreak, land use and cover) are recognised to considerably shape the distribution range of many species in their natural environment.

Uncertainties may be caused also by the use of climate models as input for SDMs because climate models could be influenced by the future emission scenarios and the evolution of the natural variability of the climate system **(Hawkins & Sutton, 2009)**.

Uncertainties are also triggered by the GCMs. GCMs commonly represent climate at resolutions of several hundred kilometres, but ecological applications often require climate data at much finer-scale resolution which are now easily accessible. However, these climate data are derived in different ways and represent varying degrees of sophistication **(Harris *et al.*, 2014)**. Moreover, the reliability of projections derived from the GCMs is higher for some variables (e.g. temperature) than for others (e.g. precipitation) and it is higher for larger spatial scales and longer time averaging periods **(IPCC, 2007)**. Likewise, the models validation and the choice of the threshold may generate uncertainties on the SDMs results **(Liu *et al.*, 2009)**.

Thus as explained earlier, projections into the future with climatic conditions outside the current range might be influenced by some over or underestimations (e.g. to species distribution, potential shifts, extinctions and colonisations). According to **Thuiller (2004)** predictions of future species distributions cannot be reliably discussed unless the methodological uncertainty is quantified explicitly.

CONCLUSION

AND

RECOMMENDATIONS

This study examines the characterization of the habitat of the Western Derby Eland in relation to climate change within Niokolo Koba National Park (Senegal), its last wild refuge.

Our results show that the WDE is found at the centre-eastern part of the park. This current location is different from where it used to be found some years ago according to informants. This confinement area of the WDE is quite similar to the habitat described for its relative the Eastern Derby Eland. It stretches at high altitude on a hilly rocky substrate with some outcrops of granite and at low altitude on sandy-clayey substrate with saline outcrops. It covers 2502.98 km^2 representing 27.41 % of the surface of the NKNP.

The floristic composition of the confinement area of the WDE is diverse. The vegetation structure has a good tendency with a good potential of recruitment of young plant species. The regeneration status is good. Altitude, fire outbreak and vegetation cover were the most important environmental factors influencing the distribution of species, but they seem not to have negative impacts on the floristic composition and the vegetation structure.

The land cover of the WDE's zones of occurrence is composed by seven land overs units: bamboo forest, bowe, gallery forest, shrub savanna, shrub-tree savanna and tree-savanna woodland of which savanna units dominated. Overall, changes of the land cover dynamics of the confinement area of the WDE recorded from 1973 to 2013 showed 0.38% of conversion, 73.95 % of modification and 25.65 % of stability. This confirms the relative stability and the least influence of anthropogenic activities. The modification recorded has a tendency towards woody vegetation. It is believed that this tendency to woody vegetation is related to rainfall recovery and might be correlated to the regreenery observing over the Sahel. However, this tendency is in contrast with the WDE habitat requirement because the WDE dwells in savanna not in close vegetation where its size is constrained.

The current highest possibility of occurrence of the plant species consumed is located within the confinement area of the WDE. This shows the importance of this confinement area for the conservation of the WDE. However, among the five plants species consumed known for now, *B. angustifolia* A. Rich., *H. acida* Tul. and *S. spinosa* Lam. are expected severe reduction of their suitable area according to the three models used GFDL-ESM, HadGEM2-ES and MPI-ESM-LR. Among them, GFDL-ESM predicted the least drastic consequences on the plants species consumed by the WDE. This suggests that precipitation principally rainfall seems the influencing factor of the species prediction rather than temperature. However, although *G. bicolor* A. Rich. and *Z. mauritiana* Lam. are expected an increase of their suitable areas, their distribution near the border of the park is negative for the WDE's survival. Certainly, the border exposes the WDE to livestock disease contamination and poaching pressure. Consequently, these harmful predictions on the overall occurrences of the plant species consumed might undesirably affect the survival of the WDE by the end this century in NKNP.

Thus, it appears that the combined effects of anthropogenic and climate factors influence the WDE and its confinement area. However, poaching, reported to affect the Eastern Derby Eland, is likely a least threatening factor to the WDE within NKNP. Indeed, the traditional beliefs around the WDE are an asset for its conservation. In addition, the repressive anti-poaching measures of the park managers discourage the youth to the poaching practices.

Based on the current knowledge, to improve a sustainable management and conservation of the WDE in NKNP, we highly recommend the establishement of an *in-situ* enclosure within the confinement area. This might be performed considering the management experience of Bandia and Fathala reserves where the WDE responded well to the *in-situ* condition.

Future researches might identify the home range of the WDE in NKNP using telemetric tools such as radio-collars, camera traps and drones. In addition, the most recent information on the population size was provided by **Renauld *et al.* (2006)**, therefore, study on the population (size, density, structure and herd conformation) and the ethology of the WDE within the NKNP are highly recommended.

It is also important to investigate the dynamics and viability of the WDE population within the park. Study on genetic diversity on the semi-captive population in Bandia reserve **(Zemanová *et al.*, 2015)** might be extended to the population in Fathala reserve and NKNP and results might be compared in order to assess the potential genetic modification across locations (wild vs semi-captivity). The results from the aforementioned studies will contribute for implementing effective management plans, facilitating conservation strategies and formulating policy.

Study of the vegetation dynamics might be implemented using high resolution satellite images. This will provide a better-quality of spectral signatures which will highly improve the accuracy of classification of small and similar areas and refine the land cover units' extent and their transitional zones.

Studies on fire management might be also initiated in order to outline efficient planning for the execution of early fire and to circumscribe their consequencies.

Further reseach is also needed to determine the list of plant species consumed by the WDE in NKNP. In addition, research on models predictions of the plant species consumed by the WDE might, further to temperature and precipitation, consider others environemental factors (e.g. pedology, geology, altitude, fire outbreak, land cover) that are known to significantly contribute to the distribution range of hervbivore as well as their plant species consumed. Moreover, the modelling the distribution of the WDE with GAP analysis might be done in order to assess the appropriate areas for *ex-situ* conservation within the national protected areas network in Senegal.

In addition, to research perspectives we recommend the park managers to:

- Identify the corridors used by animals crossing the national road RN 7 and increase their surveillance with camera traps. This will help to reduce the number of animals by car-accidents;
- Reinforce efforts against poaching using drones in order to support the park rangers who encounter some issues during their patrols (e. g. flooding, high temperature, long walking distance, lack of technical means, and inaccessibility of some places). Although, it seems that poaching is not directly affecting the WDE, the existence of poaching activities within the park might affect the presence and the distribution of the WDE within NKNP;
- Motivate the park rangers who spend more time in the park than with their families, because they are a good backing for data collection for the NKNP ecological office, as well as for researchers;
- Reform gold mining licence acquisition policies as well as the artisanal mining practices because in long run mining activities might (i) induce water chemical pollution and methylmercury accumulation and amplification along the food chain and (ii) increase the poaching within the "Dioura".

REFERENCES

Adam J.G. 1962. Contribution à l'étude de la flore de la végétation de l'Afrique Occidentale la Basse Casamance: deuxième partie - Bull. IFAN, *sér. 1 – 25*: 116–167.

Akpo L. E. 1997. Phenological interactions between tree and understory herbaceous vegetation of a sahelian semi-arid savanna. *Plant Ecology*, **131**: 241–248**.**

Allouche O., Tsoar A. & Kadmon R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and true skill statistic (TSS). *Journal of Applied Ecology*, **43**: 1223–1232.

Anthwal A., Gupta N., Sharmac A., Anthwal S. & Kim K. 2010. Conserving biodiversity through traditional beliefs in sacred groves in Uttarakhand Himalaya, India. *Resources, Conservation and Recycling* **54:** 962–971.

Antoninova M., Nežerková P., Vincke X. & Al-Ogoumrabe N. 2004. Herd Structure of Giant Eland in Bandia Reserve. *AgriculturaTropica and Subtropica*, **37(1):** 5 p.

AOF 1926. Arrêté n° 127 promulguant le décret du 10-03-1925 réglementant la chasse et instituant les Parcs de refuge pour les espèces animales sauvages en AOF Dakar, *Journal officiel*: 364-365**.**

AOF 1936. Arrêté du 17/09/1936 créant la Réserve spéciale de chasse de Niokolo Koba AOF Dakar, *Journal officiel*: 972-976.

AOF 1936. Arrêté nº 2716 promulguant en AOF le décret du 13/10/1996 portant réglementation de la chasse dans les principaux territoires africains relevant du Ministère des colonies. Dakar, *Journal officiel*: 972.

AOF 1950. Arrêté nº 4032 du 18107/1950 créant la Réserve totale de chasse de Niokolo Koba AOF idem Dakar, *Journal officiel*: 1207 p.

AOF 1953. Arrêté du 15 1011 1953 augmentant la superficie de la Réserve spéciale de chasse de Niokolo Koba. Dakar, *Journal officiel:* 1285 p.

AOF 1954. Arrêté du 04/08/1954 créant le Parc National-de Niokolo Koba. Dakar, *Journal officiel*: 1305p.

Araùjo MB, Pearson RG, Thuiller W. & Erhard M. 2005. Validation of species-climate impact models under climate change. *Global Change Biology*, **11:** 1504–1513.

Arbonnier M. 2004. Trees, Shrubs and Lianas of West African Dry Zones. *CIRAD*, Paris (France), 541 p**.**

Astrom M. Lundberg P. & Danell K. 1990. Partial prey consunption by browser: trees as patches. *Journal of Animal Ecology*, **59**: 287–300.

Aubreville A., 1957. Accord à Yamgambi sur la nomenclature des types africains de végétation. *Bois et Forêts des Tropiques*, **(51):** 23–27.

Ayotte J. B., Parker K. L., Arocena J. M. & Gillingham, M. P. 2008. Chemical Composition of Lick Soils: Functions of Soil Ingestion by Four Ungulate Species, *Journal of Mammalogy*, **89(4):** 1041–1050. doi: http://dx.doi.org/10.1644/07-MAMM-A-345.1

Ba A. T., Sambou B., Ervick F., Goudiaby A., Camara C. & Diallo D. 1997. Végétation et flore du parc transfrontalier du Niokolo-Badiar. G.H.M. Messana, I. Diop & M.B. Sow Eds. Aarhus. Union Européenne, 157p.

Baillie J. E. M., Groommbridge B., Gardebfors U. & Statterfield A. J. 1996. IUCN List of Threatened Animals. IUCN, Gland Switzerland.

Baskaran N., Kannan V., Thiyagesan K. & Desai A. A. 2011. Behavioural Ecology of four horned antelope (*Tetracerus quadricornis* de Blainville, 1816) in the tropical forests of southern India. *Mammalian Biology*, **76(6):** 741–747, doi:10.1016/j.mambio.2011.06.010

Barlow N. D. 1987. Pasture, prey and productivity: simple grazing models with two herbivores. *New Zealand Journal of ecology*, **10:** 43–55.

Bellefontaine R. A., Gaston A. & Petrucci Y. 1997. Aménagement des forêts naturelles des zones tropicales sèches, Rome, FAO, 321p.

Berhaut J. 1967. Flore du Sénégal. *Claireafrique*, Dakar (Senegal), 485p.

Blancou L. 1960. Destruction and protection of the fauna of French Equatorial and French West Africa. Pt. 2: The large animals. *Afr Wildl* **14:** 101-108.

Blum A., Feldmann L., Bresler F., Jounny P., Briançon S. & Régent D. 1995. Intérêt du calcul du coefficient kappa dans l'évaluation d'une méthode d'imagerie. [Measuring agreement as an evaluation of a diagnostic imaging method]. *European Journal of Radiology*, **76(7):** 441– 443.

Boakye E., Odai S. N., Adjei K. A. & Annor F. O. 2008. Landsat Images for Assessment of the Impact of Land Use and Land Cover Changes on the Barekese Catchment in Ghana. *European Journal of Scientific Research*, **22 (2):** 269–278

Bobée C., de Noblet-Ducoudré N., Ottlé C., Maugis P., Maignan F., Lézine A. M. & Ndiaye M. 2012. Monitoring vegetation dynamics in highly anthropized Sahelian environments using MODIS LAI. Application to agricultural systems of northwest Senegal. *J. Arid Environ.***84**: 38–50.

Bonou W., Glèlè Kakaï R. L., Assogbadjo A. E., Fonton H. N. & Sinsin B. 2009. Characterization of *Afzelia africana* sm. Habitat in the Lama Forest Reserve of Benin. *Forest Ecology and Management*, **258:** 1084–1092.

Boyd J. & Banzhaf S. 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, **63(2-3):** 616–626. doi:10.1016/j.ecolecon.2007.01.002

Brandlová K., Hejcmanová P., Haberová T., Junková Vymyslická P., Žácková M., Ndiaye S. & Mallon D. 2013. Western Derby Eland (*Taurotragus derbianus derbianus*) Conservation Workshop, An Overview of Species Conservation Strategic Planning, 20 p.

Bro-Jorgensen J. 1997. The ecology and behaviour of the Giant Eland (*Tragelaphus derbianus*, Gray 1847) in the wild. Master‘s thesis, University of Copenhagen, 106 p.

Bullock S. H., Mooney H. A. & Medina E. 1995. Seasonally dry tropical forests. 1st ed, Cambridge University Press, New York (USA).

Burt W. H. 1943. Territoriality and home range concepts as applied to mammals**.** *J. Mamm.*, **24:** 346–352.

Carrillo E., Wong G. & Cuarón A. D. 2000. Monitoring mammal populations in Costa Rican protected areas under different hunting restrictions. *Conservation Biology*, **14 (6):** 1580–1591. DOI: 10.1111/j.1523-1739.2000.99103.x

Caswell H. 2001. Matrix Population Models: Construction Analysis and Interpretation. 2nd ed. *Sinauer Associates*, Sunderland, USA.

Cottam G. & Curtis J. T. 1956: The use of distance measurements in phytosociological sampling. *Ecology*, **37:** 451– 460.

Da S. S. 2010. Spatial patterns of West-African plant diversity along a climatic gradient from coast to Sahel. Thesis Dissertation, Bonn University, 1–131 p.

Dacosta H. & Albergel J. 1991. Les Écoulements non pérennes sur les petits bassins du Sénégal. Revue hydrographique, géoscience et outil pour le développement O.R.S.T.O.M. : 120–135.

Dacosta H., Konate Y. K. & Malou R. 2002. La Variabilité Spatio-temporelle des

Précipitations au Sénégal depuis un Siècle. In: Regional Hydrology: Bridging the Gap between Research and Practice. Proceedings of the Fourth International FRIEND Conference held at Cape Town, (South Africa), IAHS Publ. no. 274.2002. p 499–506.

Dai A., Lamb P. J., Trenberth K. E., Hulme M., Jones P. D. & Xie P. 2004. The Recent Sahel Drought is real. *Int J Climatol*, **24**: 1323–1331.

Dagnelie P., 1998. Statistique théorique et appliquée. Tome 2 : Inférence statistique à une et à deux dimensions. *Université De Boeck & Larcier*, Bruxelles (Belgique), 659 p.

Dayamba S. D., Tigabu M., Sawadogo L. & Oden P. C. 2008. Seed germination of herbaceous and woody species of the Sudanian savanna-woodland in response to heat shock and smoke. *Forest Ecology and Management*, **256:** 462–470.

De Cáceres M. 2013. How to use the indicspecies package (ver. 1.7.1). Catalonia, Spain, 29p.

De Cáceres M. & Legendre P. 2009. Associations between species and groups of sites: indices and statistical inference. *Ecology*, **90(12):** 3566–3574, DOI: 10.1890/08-1823.1

De Cáceres M., Legendre P., Wiser S. K. & Brotons L. 2012. Using species combinations in indicator value analyses. *Methods in Ecology and Evolution*, **3:** 973–982. doi: 10.1111/j.2041-210X.2012.00246.x

De Cáceres M. & Legendre P. 2013. Dissimilarity measurements and the size structure of ecological communities. *Methods in Ecology and Evolution*, **4(12):** 1167–1177 http://dx.doi.org/10.1111/2041-210X.12116.

De Maeyer P., De Temmerman L., Bogaert P., Vansteenvoort L., Goossens R. & Binard M. 2004. The benefits of remote sensing for conservation and monitoring World Heritage Sites. Remote Sensing in Transition (ed.) 2004. *Milpress*, Rotterdam (Netherlands), p 381–385.

Dorst J. & Dandelot P. 1970. A field guide to the larger mammals of Africa. *Collins*, London (United Kindom), 287 p.

Dufrene M. & Legendre P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, **67(3):** 345–366.

Dupuy A. R. 1971. Le recensement aérien de la faune d'avril 1971 au Parc National du Niokolo Koba.-Notes Africaines, *IFAN Dakar* **N^{o} 131:** 67–70.

Dupuy A. R. & Verschuren J. C. 1982. Note d'introduction biologique sur le Parc National du Niokolo Koba (Senegal).- Notes Africaines, *IFAN* **N^{o} 124:** 118–123.

East R. 1998. African Antelope Data Base. Ed Gland, Switzerland: The IUCN Species Survival Commission, 1999. p 355–383.

East R. 1999. African Antelope database. IUCN/SSC Antelope Specialist Group Report, IUCN, Gland, Switzerland and Cambridge, (United Kingdom), 545 p.

Elith J., Philips S. J., Hastie T., Dudik M., En Chee Y. & Yates C. J. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distribution*, **17:** 43–57.

Embaye K. 2000. The indigenous bamboo forests of Ethiopia: an overview. *AMBIO: A Journal of the Human Environment*, **29(8):** 518–521.

Evangelista P. H., Norman III J., Berhanu L., Kumar S. & Alley N., 2008. Predicting habitat suitability for the endemic mountain nyala (*Tragelaphus buxtoni*) in Ethiopia. *Wildl. Res.* **35**: 409–416.

Fandohan B., Assogbadjo A. E., Glèlè Kakaï R. L. & Sinsin B. 2011. Effectiveness of a protected areas network in the conservation of Tamarindus indica (Leguminosea–Caesalpinioideae) in Benin. *African Journal of Ecology*, **49:** 40–50.

Fandohan A. B., Oduor A. M. O., Sodé A. I., Liang W., Cuni-Sanchez A., Assédé E. & Gouwakinnou G. N. 2015. Modeling vulnerability of protected areas to invasion by Chromolaena odorata under current and future climates. *Ecosystem Health and Sustainability*, **1(6): 1**–20. http://dx.doi.org/10.1890/EHS15-0003.1

Feeley J. K., Davies S. J., Nur Supardi Noor M. D., Davies S. J., Kassim A. R. & Tan S. 2007. Do current stem size distributions predict future population changes? An empirical test of intraspecific patterns in tropical trees at two spatial scales. *Journal of Tropical Ecology*, **23:** 191–198.

Fensham R. J., Fairfax R. J. & Archer S. R. 2005. Rainfall, land use and woody vegetation cover change in semi-arid Australian savanna. *Journal of Ecology*, **93(3):** 596–606.

Fisaha G., Hundera K. & Dalle G. 2013. Woody plants' diversity, structural analysis and regeneration status of Wof Washa natural forest, North-east Ethiopia. *Afr. J. Ecol.*, **51**: 599–608. doi:10.1111/aje.12071

Galat G., Benoit M., Chevillotte H., Diop A., Duplantier J. M., Galat-Luong A. & Pichon G. 1992. Denombrement de la Grande Faune du Parc National du Niokolo-Koba, Sénégal, 1990-1991. 57 p.

Galat G., Galat-Luong A. & Nizinski J. J. 2011. Diet preferences of a Western giant’s (Lord

Derby’s) eland group in a Sahelian dry habitat. *Animal Biology,* **61:** 485–492.

Gentry A. W. 1971. Order Artiodactyla. In: Mammals of Africa Meester. J., Setzer H. W. (eds.). (1971) Smithsonian Institute Press, Washington DC (unated States), p 1–93.

Girard M. C. & Girard C. 1999. Traitement de données de télédétection. Edition Dunod, Paris, 529 p.

Glèlè Kakaï R. L. & Sinsin B. 2009. Structural description of two Isoberlinia dominated vegetation types in the WariMaro Forest Reserve (Benin). *South African Journal of Botany*, **75:** 43–51.

Gonzalez P. 1997. Dynamics of biodiversity and human carrying capacity in the Senegal Sahel. Ph-D dissertation, University of California, Berkeley 427p.

Gonzalez P. 2001: Desertification and a shift of forest species in the West African Sahel. *Climate Research,* **17:** 217-228.

Guisan A. & Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecol. Lett.,* **8**: 993–1009.

Goudiaby A., Sambou B., & Bâ A. T. 2004. La structure de la forêt galerie de la vallée de la cascade de Dindéféllo, Sud-est du Sénégal, *SEREIN N° 19,* **0(0) :** 203–223.

Graziani P. & d’Alessio S. G. 2004. Monitorage radiotélémetrique de l’Eland de Derby (*Tragelaphus derbyanus gigas*) dans le Nord de la République Centrafricaine ECOFAC-ZCV PROJET, I.E.A. (Instituto di EcologiaApplicata)- ROMA, 77 p.

Groves C. P. & Grubb P. 2011. Ungulate Taxanomy. The John Hopkins University Press, Baltimore (USA), 336 p.

Guiro I., Mbow C., Baret F. & Diaw A. T. 2012. Dynamique de l’occupation du sol de la forêt classée de Patako et de sa périphérie de 1972 à 2002. *Revue de Géographie du Laboratoire Leïdi,* **10:** 213–230.

Hájek I. & Verne P.H. 2000: Aerial Census of Big Game in Niokolo-National Park and Falemé Regionin Eastern Senegal. Proceed. 3rd All Africa Conference on Animal Production, Alexandria, 5-9 November 2000.

Hannah L., Midgley G. F., Lovejoy T., Bond W. J., Bush M., Lovett J.C., Scott D. & Woodward F.I. 2002. Conservation of biodiversity in a changing climate. *Conservation Biology,* **16:** 264–268.

Harris Rebecca Mary B., Grose Michael R., Lee Greg, Bindoff Nathaniel L., Porfirio

Luciana L. & FoxHughes P. 2014. Climate projections for ecologists. *WIREs Clim Change,* **5:** 621–637. doi: 10.1002/wcc.291

Hawkins E. & Sutton R. 2009. The potential to narrow uncertainty in regional climate predictions. *Bull Am Meteorol Soc.* **90:** 1095–1107.

Herrmann S.M., Anyamba A. & Tucker C.J. 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, **15:** 394–404.

Hejcmanová P., Homolka M., Antonínová M., Hejcman M. & Podhájecká V. 2010. Diet composition of Western Derby Eland (*Tauratragus derbianus derbianus*) in the dry season in a natural and managed habitat in Senegal using fecal analyses. *South African Journal of Wildlife Research,* **40(1):** 27–34.

Hejcmanovā-Nežerková, P. & Hejcman M. 2006. A Canonical Correspondence Analysis (CCA) of the Vegetation-Environment Relationships in Sudanese Savanna, Senegal. *South African Journal of Botany*, **72(2):** 256–262. Doi:10.1016/j.sajb.2005.09.002

Hillman J. C. & Fryxell J. M. 1988. Sudan. In: Antelopes: Global survey and regional action plans, East, R. ed. Part 1: East and Northeast Africa. Gland: IUCN, p 5–16.

Houéhanou T. D., Assogbadjo A. E., Glèlè Kakaï R. L., Kyndt T., Houinato M. & Sinsin B. (2013) How far a protected area contributes to conserve habitat species composition and population structure of endangered African tree species (Benin, West Africa). *Ecological Complexity*, **13**: 60–68.

Houessou L. G., Teka1 O., Imorou1 I. T., Lykke A. M. & Sinsin B. 2013. Land Use and Land-Cover Change at "W" Biosphere Reserve and Its Surroundings Areas in Benin Republic (West Africa). *Environment and Natural Resources Research,* **3(2):** 87–101.

Houéto G., Fandohan B., Ouédraogo A., Ago E.E., Salako V. K., Assogbadjo A. E., Glèlè Kakaï R. L. & Sinsin B. 2013. Floristic and dendrometric analysis of woodlands in the Sudano-Guinean zone: a case study of Belléfoungou forest reserve in Benin. *Acta Botanica Gallica,* **159(4):** 387–394.

Howard P., Wangari E. & Rakotorisoa N. 2007. Mission de suivi réactif conjointe UNESCO/UICN au Parc national du Niokolo-Koba, Sénégal, Rapport de mission, UICN, UNESCO, 18 p. + annexes.

Hulme M., Doherty R., Ngara T., New M. & Lister D. 2001. African climate change: 1900-

2100. *Climate research,* **17(2)**: 145–168.

Inoussa M. M., Mahamane A., Mbow C., Saadou M. & Bachmann Y. 2011. Dynamique spatio-temporelle des forêt dans le Parc national du W du Niger (Afrique de l'Ouest). *Sècheresse*, **22:** 108–116.

IPCC 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press, New York (United States of America), 987 p.

IPCC 2013. Climate change 2013: The physical science basis. IPCC Working Group I Contribution to the IPCC Fifth Assessment Report. Cambridge University Press, New York, New York, USA.

IUCN 2008. *Tragelaphus derbianus ssp. derbianus*. **T**he IUCN Red List of Threatened Species2008: e.T22056A9354316, SSC Antelope Specialist Group (eds). http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T22056A9354316.en, Version 2015.2.

IUCN 2015. Rapport de la mission au Parc National du Niokolo Koba, Sénégal du 10 au 17 mai, 2015, 52 p.

Jarman P. J. 1974. The social organisation of antelope in relation to their ecology. *Behaviou*r, **48:** 215–268.

Johnson N. L. & Kotz S. 1970. Distributions in Statistics: Continuous Univariate Distributions. John Wiley & Sons, New York (United States of America), 719 p.

Justice C., Scholes R. & Frost P. 1994. African Savannas and the Global Atmosphere: Research Agenda. IGBP (Report No. 31), Stockholm (Sweden), 51 p.

Kadeba A., Nacoulma B. M. I., Ouedraogo A., Bachmann Y., Thiombiano A., Schmidt M. & Boussim J. I. 2015. Land cover change and plants diversity in the Sahel: A case study from northern Burkina Faso. *Ann. For. Res.* **58(1):** 109–123.

Kamler J. & Homolka M. 2011. Needles in faeces: an index of quality of wild ungulate winter diet. *Folia Zool.,* **60 (1):** 63–69.

Kane M. D. 2014. Estimating population size, density, and occupancy of lions (*Panthera leo*), leopards (*P. pardus*) and servals (*Leptailurus serval*) using camera traps in the Niokolo Koba National Park in Senegal, West Africa. Master Thesis, University of Virginia Tech, Blacksburg, USA, 135 p.

Kingdon J. 1997. The Kingdon Field Guide to African Mammals. *Academic Press*, London and

New York: Natural World.

Kock R.A. 2005. 'What is the infamous wildlife/livestock disease interface? A review of current knowledge', Southern and East African Experts Panel on Designing Successful Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock, and Human Health. AHEAD Animal Health for the Environment And Development Forum. IUCN/SSC Veterinary Specialist Group, Southern Africa Sustainable Use Specialist Group et al., IUCN, Gland, Switzerland and Cambridge, UK, 14-15 September 2003.

Kolackova K., Hejcmanova P., Antonınova M. & Brandl P. 2011. Population management as a tool in the recovery of the critically endangered Western Derby eland *Taurotragus derbianus* in Senegal, Africa. *In Wildl. Biol*., **17:** 299–310 DOI: 10.2981/10-019.

Kruskal J. B. 1964. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika,* **29:** 1–27.

Lambin E. F., Geist H. J. & Leper E. 2003. Dynamics of land-use and land-cover change in tropical regions. *Annu. Rev. Environ. Resour.*, **28:** 205–241. doi: 10.1146/annurev.energy.28.050302.105459.

Lagabrielle E., Metzger P., Martignac C. Lortic B. & Durieux L. 2007. Les dynamiques d'occupation du sol à la Reunion (19889-2002). *M@ppemonde***, 86(2)**: 1–23.

Lawesson J. E. 1995. Study of woody flora and vegetation in Senegal. *Opera Botanica,* **125:** 1-172.

Le S., Josse J. & Husson F. 2008. FactoMineR: An R Package for Multivariate Analysis. Journal of Statistical Software, 25(1): 1–18. 10.18637/jss.v025.i01

Lebel T. & Ali A. 2009. Recent Trends in the Central and Western Sahel Rainfall Regime (1990–2007). *J Hydrol.,* **375 (1):** 52–64, Doi:10.1016/j.jhydrol.2008.11.030

Leborgne J. 1988. La Pluviométrie au Sénégal et en Gambie. Paris: Ministère de la Coopération Française; O.R.S.T.O.M., 94 p.

Lebrun J. P. & Stork A. L. 1991–1997. Énumération des plantes à fleurs d'Afrique tropicale. Tome 1- 4. Geneva: Conservatoire et Jardin Botanique de la ville de Genève.

Li S. G., Tsujimura M., Sugimoto A., Davaa G. & Sugita M. 2006. Natural recovery of steppe vegetation on vehicle tracks in central Mongolia *J. Biosci*., **31:** 85–93.

Liu C., White M. & Newell G. 2009. Measuring the accuracy of species distribution models: a review. World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009 http://mssanz.org.au/modsim09, 4241– 4247.

Madsen J. E., Dione D., Traoré A. S. & Sambou B. 1996. Flora and Vegetation of Nikolo Koba National Park, Senegal. In: The Biodiversity of African plants. L. J. G. vander Maesen et al. (eds), Kluwer Academic Publishers, Dordrecht (Netherlands), p 214 – 219.

Matthews H. & Solomon S. 2013. Irrversible does not mean unavoidable. *Science,* **340:** 438 – 439.

Menaut J.C., Abbadie L., Loudjani P. & Podaire A. 1991. Biomass Burning in West Africa Savannas, In: Global Biomass Burning. Atmospheric, Climatic, and Biospheric Implications. Levine S.J. (Ed.), The MIT Press, Cambridge, Massachusetts, London, England, p 133–142.

Mertz O., Mbow C., Østergaard Nielsen J., Maiga A., Diallo D., Reenberg A., Diouf A., Barbier B., Bouzou Moussa I., Zorom M., Ouattara I. & Dabi D. 2010. Climate factors play a limited role for past adaptation strategies in West Africa. *Ecology and Society*, **15(4):** 25. URL: http://www.ecologyandsociety.org/vol15/iss4/art25/

Mbow C. 1995. Identification et gestion des ressources naturelles dans le Parc National du Niokolo Koba. Mémoire de Maîtrise. Département de Géographie. UCAD (Sénégal) 130p.

Mbow C. 2000. Étude des caractéristiques spatio-temporelles des feux de brousse et de leur relation avec la végétation dans le Parc National du Niokolo-Koba (Sud-Est du Sénégal). Thesis Dissertation ISE/FST, University Cheikh Anta Diop, 121 p.

Mbow C., Chhin S., Sambou B. & Skole D. 2013. Potential of dendrochronology to assess annual rates of biomass productivity in savanna trees of West Africa. *Dendrochronologia*, **31(1):** 41–51, http://dx.doi.org/10.1016/j.dendro.2012.06.001.

Moisan Y., Bernier, M. & Dubois J. M. M., 1999. « Détection des changements dans une série d'images ERS-1 multidates à l'aide de l'analyse en composantes principales ». *International Journal of Remote Sensing*, **20 (6)** : 1149–1167.

Niane B. 2014. Impacts environnementaux liés à l'utilisation du mercure dans l'exploitation artisanale de l'or dans la région de Kédougou (Sénégal Oriental). Thesis dissertation University of Geneva. 121 p.

Niang C. 2005. Evaluation of the situation Of the Derby Eland (*Taurotragus derbianus derbianus* Gray, 1847) in NiokoloKoba National Park, Training Report of School of Fauna of Garoua (Cameroon), 35 p.

Neierkove P., Verner P. H. & Antonimove M. 2004. The conservation programm of Western giant eland (*Taurotragus derbianus derbianus*). Gazella 31, 2004 Zoo, Praha, 96p.

Nicholson S. E. 1989. Long-term Changes in African Rainfall. *Weather*, **44 (2):** 46–56.

Nicholson S. E. 2000. Land Surface Processes and Sahel Climate. *Rev Geophys*, **38:** 117–139.

Nicholson S.E., 2005. On the question of the "recovery" of the rains in the West African Sahel. *Journal of Arid Environments*, **63:** 615-641, doi:10.1016/j.jaridenv.2005.03.004

Niemet Gampika D. 2013. Contribution à l'étude de la dynamique de l'occupation du sol et de la diversité des espèces végétales ligneuses dans la Réserve Naturelle, la Forêt Classée et la Zone de Terroir de Popenguine au Sénégal. Master Thesis ISE/FST University Cheikh Anta Diop de Dakar (Senegal), 88 p.

Nowak R. M., and Paradiso J. L. 1983. Walker's Mammals of the World. *Johns Hopkins University Press*. Baltimore (USA)

Nyamasyo S. K. & Kihima B. O. 2014. Changing Land Use Patterns and Their Impacts on Wild Ungulates in Kimana Wetland Ecosystem, Kenya. *International Journal of Biodiversity*, **2014:** 10 p. doi.org/10.1155/2014/486727

Oksanen J., Blanchet F. G., Kindt R., Legendre P., Minchin P. R., O'Hara R. B., Simpson L. G., Solymos P., Stevens M. H. H. & Wagner H. 2013. Vegan: Community Ecology Package. R package version 2.0-10. http://CRAN.R-project.org/package=vegan

Olff H. & Ritchie M. E. 1998. Effects of herbivores on grassland plant diversity. *TREE*, **13(7):** 261–165.

Orwa C., Mutua A., Kindt R., Jamnadass R. & Anthony S. 2009. Agroforestree Database: a tree reference and selection guide version 4.0.pdf.

Pappas L. A. 2002. *Taurotragus oryx*. *Mammalian Species*, **689:** 1–5. Doi: http://dx.doi.org/10.1644/1545-1410(2002)689<0001:TO>2.0.CO;2

Park J-Y., Jurgen B. & Daniela M. 2015. Northern-hemispheric differential warming is the key to understanding the discrepancies in the projected Sahel rainfall. *Nature*, **6:** 1–13, DOI: 10.1038/ncomms6985.

Pearce J. L. & Boyce M. S. 2006. Modelling distribution and abundance with presence-only data. *J. Appl. Ecol.*, **43:** 405–412.

Pienaar U. DE V. 1974. Habitat Preference in South African antelope species and its significance in natural and artificial landdistribition patterns, *Koedoe*, **17:** 185–195.

Planton H. P. & Michaux I. G. 2013. *Tragelaphus derbianus* Giant Eland (Lord derby's Eland) In: Mammals of Africa. Vol 6, Bloomsbury Publishing. London (United Kingdom), p 186–190.

Phillips S. J., Anderson R. P. & Schapire R. E. 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, **190:** 231–259

Poupon H. 1980: Structure et Dynamique de la Strate Ligneuse d'une Steppe Sahélienne au Nord du Sénégal. Paris: O.R.S.T.O.M., 256 p.

Prince P. & Fisher J. 1970. Wildlife Crisis. *Cowles*, New York (USA), 256 p.

R Core Team 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rafferty J. P. 2010. Grazers. 1st ed. New York, NY: Britannica Educational Pub. 399 p.

Reitsma J. M. 1988. Forest Vegetation in Gabon. Tropenbos Technical Series 1.Tropenbos Foundation, The Netherlands, p. 142.

Renaud P. C., Gueye M. B., Hejcmanová P., Antoninova M. & Samb M. 2006. Inventaire aérien et terrestre de la faune et relevé des pressions au Parc National du Niokolo Koba African Park Conservation/Ministere de l'Environnement et de la Pretection de la Nature, 44 p.

Richter R., 1997. Correction of atmospheric and topographic effects for high spatial resolution satellite imagery. *International Journal of Remote Sensing.* Academic Press Inc., New York (Uniated States), 245 p.

Riggio J., Jacobson A., Dollar L., Bauer H., Becker M., Dickman A., Funston P., Groom R., Henschel P., de Iongh H., Lichtenfeld L. & Pimm S. 2013. The size of savanna Africa: a lion's (*Panthera leo*) view. *Biodiversity & Conservation*, **22**: 17–35

Riginos C. & Grace J. B. 2008. Savanna tree density, herbivores, and the herbaceous community: bottom-up vs. top-down effects. *Ecology*, **89(8):** 2228–2238. DOI: 10.1890/07-1250.1.

Riitters K.H., O''Neill R.V. & Jones K.B. 1997. Assessing Habitat Suitability at Multiple

Scales: A Landscape-Level Approach. *Biological Conservation* **81:** 191–202

Rubes J., Kubickova S., Pagackova E., Cernohoska H., Di Berardino D., Antoninova M., Vahala J. & Robinson T. J. 2008. Phylogenic study of spiral-horned antelope by cross-species chromosome painting. *Chromosome Research*, **16:** 935–947.

Ruggiero R. 1990. Lord Derby's eland Swara, East African Wildlife *Soc*, **13:** 10–13.

Roure G. 1956. La Haute Gambie et le Parc National du Niokolo Koba. Dakar : GIA 191p.

Sagna P., Ndiaye O., Diop C., Diongue N. A., Sambou P. C. 2015. Les variations récentes du climat constatées au Sénégal sont-elles en phase avec les descriptions données par les scénarios du GIEC ? [Are recent climate variations observed in Senegal in conformity with the descriptions given by the IPCC scenarios?]. *Pollution Atmosphérique*, **227:** 1–17.

Salack S, Muller B. & Gaye A.T. 2011. Rain-based Factors of High Agricultural impacts over Senegal. Part I. Integration of local to sub-regional trends and variability. *Theoretical and Applied Climatology*, **106:** 1– 22, doi : 10.1007/s00704-011-0414-z.

Sambou B. 2004. Évaluation de l'état, de la dynamique et des tendances évolutives de la flore et de la végétation ligneuses dans les domaines soudanien et sub-guinéen au Sénégal. Thesis Dissertation, ISE/FST University Cheikh Anta Diop de Dakar (Senegal), 241p.

Sambou B., Ba A. T., Mbow C. & Goudiaby A. 2008. Studies of the woody vegetation of the Welor forest reserve (Senegal) for sustainable use. *West Afr J Appl Ecol*, **13**: 67–76. DOI: 10.4314/wajae.v13i1.40577

Sambou H., Sambou B., Diaw A. T., Mbow C. & Traoré V. B. 2014. Remote sensing mapping of the rice field and vegetal cover and the impacts of soil factors on herbaceous in the sub-watershed of Boutolate (lower Casamance, Senegal). *American Journal of Environmental Protection*, **3(2):** 73–82, doi: 10.11648/j.ajep.20140302.16

Sankaran M., Hanan N. P., Scholes R. J., Ratnam J., Augustine D. J., Cade B. S., Gignoux J., Higgins S. I., Le Roux X., Ludwig F., Ardo J., Banykwa F., Bronn A., Bucini G., Caylor K. K., Coughenour M. B., Diouf A., Ekaya W., Freal C.J., February E. C., Frost P. G. H., Hiernaux P., Hrabar H., Metzeger K. L., Prins H. H. T., Ringrose S., Sea W., Tews J., Worden J. & Zambatis N. 2005. Determinants of woody cover in African savannas. *Nature* **438:** 846–849

SAS Institute Inc. 2003. SAS OnlineDoc® Version 9.1. Cary (NC): SAS Institute Inc.

Scheldeman X. & van Zonneveld M. 2010. Training manual on spatial analysis of plant diversity and distribution. Biodiversity International, Rome (Italy), 179 p.

Shipley L. A., Gross J. E., Spalinger D. E., Hobbs N. T. & Wunder B. A. 1994. The Scaling of Intake Rate in Mammalian Herbivores. *The American Naturalist*, **143 (6):** 1055–1082.

Short J. & Turner B. 1994. A test of the vegetation mosaic hypothesis: a hypothesis to explain the decline and extinction of Australian mammals. *Conserv. Bioi.,* **8:** 439–449.

Sinclair A. R. E. 1977. The African Buffalo. University of Chicago Press, Chicago.

Sonko I. 2000. Étude des effets des régimes de feux dits précoces et de feux tardifs sur la flore et la végétation ligneuses des plateaux du Parc National du Niokolo-Koba, Sud-Est du Sénégal. Dissertation University Cheikh Anta Diop, ISE/FST, 124 p.

Spinage C. A. 1986. The Natural History of Antelopes. *Croom Helm* (Eds.), London (United Kingdom), 310 p.

Sournia G. & Dupuy A. 1990. Senegal.- In: EAST, R.: Antilopes. Global survey and regional action plans, Pt 3: West and Central Africa, IUCN Gland.

Thiam N. S., Ndiaye B. & Sidibe M. 2004. Program of natural survey of the Eland (*Taurotragus derbianus derbianus*, Gray, 1847) in NiokoloKoba National Park September 2003-August 2004. Directorate of National Parks and United Nation Organisation for Health and Education UNESCO, 50 p

Thuiller W. 2004. Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology*, **10:** 2020–2027. doi:10.1111/j.1365-2486.2004.00859.x

Traoré A. S. 1997. Analyse de la flore ligneuse et de la végétation de la zone de Simenti (parc National du Niokolo Koba), Sénégal Oriental. These Departement Biologie Vegetale/ FST, Universite Cheikh Anta Diop Dakar (Senegal), 147 p.

Trochain J. L. 1940. Contribution à l'Etude de la Vegetation du Senegal. Memoire IFAN, Larose, Paris (France), **2:** 434 p.

Van Laar A. & Akça A. 2007. Forest mensuration. *Springer*, Dordrecht (Netherlands), 383 p.

Van Proosdij A. S. J., Sosef M. S. M., Wieringa J. J. & Niels R. 2015. Minimum required number of specimen records to develop accurate species distribution models *Ecography*, **38**: 001–011. doi: 10.1111/ecog.01509

Venables W. N. & Ripley B. D. 2002. Modern Applied Statistics with S. Fourth Edition.

Springer, New York. ISBN 0-387-95457-0

Verboom J., Schotman A., Opdam P. & Metz J. A. J. 991. European nuthatch metapopulations in a fragmented agricultural landscape. *Oikos,* **61:** 149–156.

Vieillefon J., 1971: Le milieu physique.-Sols. Le Niokolo Koba le premier grand Parc national de la République du Sénégal. G.I.A., Dakar**.**

Watkinson A. R. & Ormerod S. J. 2001. Grasslands, grazing and biodiversity: editors' introduction. *J. Appl. Ecol.,* **38:** 233–237.

White F. 1983. The vegetation of Africa. A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map. Natural Resources research XX. UNESCO, Paris (France), 355 p.

Woodward F. I. 1987. Climate and plant distribution. Cambridge University Press, New York (USA), 147p.

Yangambi 1956. Conference on Phyto-Geography, 28th July – 8th August. Scientific Council for Africa South of The Sahara, **22:** 75 p**.**

Zemanová H., Bolfíková C. B., Brandlová K., Hejcmanováa P. & Huva P. 2015. Conservation genetics of the Western Derby Eland (Taurotragus derbianus derbianus) in Senegal: integration of pedigree and microsatellite data. *Mammalian Biology* **80**: 328–332

WEBOGRAPHY

Forestry survey 2010. **http://www.jecreemonsite.net/javascript/nbaleat.php** Consulted on **5th June 2015.**

Harper D., 2008. "Antelope" Online Etymology Dictionary. Consulted **20th April 2015**

Huffman B., 2007. Uncovering Ungulate Taxonomy http://www.ultimateungulate.com/familytree.html, Consulted 1**0th March 2015.**

International Plant Names Index (IPNI) 2015. Database http://www.ipni.org/ Consulted on **5th November 2015.**

IUCN 2008. ***Tragelaphus derbianus ssp. derbianus*****. The IUCN Red List of Threatened** Species 2008: e.T22056A9354316. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T22056A9354316.en. Consulted on **31st January 2016.**

Johannesburg Zoo 2011. http://www.zoochat.com/1356/giant-lord-derby-eland-taurotragus-derbianus-238541/ Consulted on **10th February 2016**

U.S. Geological Survey 2013. http://lca.usgs.gov/lca/biodiversity_senegal/mapgallery.php Page Last Modified: March 26, 2013, Page Contact Information: rowland@usgs.gov consulted on **1st April 2016**.

World Agroforestry Centre 2009. Agroforestree Database: a tree reference and selection guide version 4.0 http://www.worldagroforestry.org/treedb/ consulted on **20th December 2015.**

APPENDICES

Appendix 1: Interview support

REPUBLIQUE DE COTE D'IVOIRE

Union-Discipline-Travail

Ministère de l'Enseignement Supérieur

et de la Recherche Scientifique

UNIVERSITE FELIX HOUPHOUET BOIGNY

UFR Biosciences

WASCAL

West African Science Service Center on Climate Change and Adapted Land Use

Center for Development Research

University Bonn

Graduate Research Program Climate Change and Biodiversity

Ph-D Research Project

CHARACTERIZATION OF THE HABITAT OF THE DERBY ELAND (*Taurotragus derbianus derbianus* GRAY, 1847) IN RELATION TO CLIMATE CHANGE WITHIN NIOKOLO KOBA NATIONAL PARK (SENEGAL) ITS LAST WILD REFUGE

This interview is used for academic issue and strictly confidential no of the information delivered will be used against you.

Date:………………………… Date of retirement: ………………………….

Name: ……………………… Family name: …………………………

Function: …………………... Grade: ………… Zone: ……………..

How long are you working in the park?

…………………………………………………………………………………………………

Do you know the derby eland?

……………………………………………………………………………………………….

How can you describe it?

…………………………………………………………………………………………………

Do you make survey in the park?

……………………………………………………………………………………………………..

What is the frequency of the survey?

……………………………………………………………………………………………………

Do you see the derby eland or its traces during your survey or around your post?

……………………………………………………………………………………………………

How many times do you observe the eland or its traces during a survey or around post?

……………………………………………………………………………………………………

Do you remember the derby eland's sight frequency per month? And during this last 3 months?

……………………………………………………………………………………………………

In case of direct observation: Is the eland observed solitary or in herd?

……………………………………………………………………………………………………

If in herd, what is usually the herd size?

……………………………………………………………………………………………………

How is the herd structure habitually? (Number if possible)

	Adult	Sub-adult	Young
Male's number			
Female's number			
Total			

If the previous question is not available, how many caves did you see in the herds? (If possible)

……………………………………………………………………………………………………

Which kind of activities do you see them doing usually?

……………………………………………………………………………………………………

How do they react when they see you?

……………………………………………………………………………………………………

At what distance are you from them?

……………………………………………………………………………………………………

Which plants do you see them consuming?

……………………………………………………………………………………………………

Are the traces observed fresh? (In case of traces)

…………………………………………………………………………………………………

Which kind of traces (nature) do you observed frequently?

…………………………………………………………………………………………………

Is it easy to find the eland or its traces?

…………………………………………………………………………………………………

In which zones, do you observe the eland or its traces are observed frequently?

…………………………………………………………………………………………………

What is the favourable time to see them?

…………………………………………………………………………………………………

When and where did you see the eland for the first time?

…………………………………………………………………………………………………

In which type of habitat did you find it?

…………………………………………………………………………………………………

When and where did you see the eland for the last time?

…………………………………………………………………………………………………

In which type of habitat did you find it?

…………………………………………………………………………………………………

Do you have an idea on the number of eland in the park?

…………………………………………………………………………………………………

Do you know natural predators of the derby eland?

…………………………………………………………………………………………………

If yes, which one?

…………………………………………………………………………………………………

What are the natural competitors of the derby eland?

…………………………………………………………………………………………………

Where will you guide us to find the eland or its traces in the park?

…………………………………………………………………………………………………

Do you have any idea on the poaching level in your zone?

…………………………………………………………………………………………………

Do you notice traces of poaching where eland and its trace are found?

…………………………………………………………………………………………………

Which kind of trace are they?

……

How is the pressure of poaching on the eland?

…….

Where can we find poachers or poaching’s traces in and around the park?

……

Among the bordering villages where can we find the most redoubtable poachers?

………………………………………………………………………………………………………

Which village can you advice for a social study on the eland?

……

Why?

……

What is your appreciation of the eland in your zone?

………………………………………………………………………………………………………

Appendix 2: Correlation values of the sites on the three first axes.

Bold numbers denote significant correlations with axes; Stars indicate p values for correlation comparisons: '***' ($P \leq 0.001$) very high correlation; '**' ($0.001 < P \leq 0.01$) high correlation and '*' ($0.01 < P \leq 0.05$) fair correlation.

Sites	PC1	PC2	PC3
Antene Sane	-0.14	0.38	**-0.86****
Assirik	**-0.72***	0.34	0.43
Badi	**0.87*****	-0.45	-0.03
Badoye	-0.14	0.38	**-0.86****
Banghare	-0.11	**0.74**	0.27
Camp du Lion	**0.92*****	0.35	-0.02
Dalaba	-0.14	0.38	**-0.86****
Damantan	0.24	**-0.79****	-0.07
Dienoudiala	-0.188	0.23	0.39
Grande Faune	-0.14	0.38	**-0.86****
Kenoyo	0.24	**-0.79****	-0.07
Kossi Kossi	0.16	0.2	0.44
Lekemere	-0.16	-0.32	-0.19
Linguekounto	-0.1	**0.62**	0.45
Linguekoto	**0.92*****	0.35	-0.02
Louma Koba	-0.16	-0.32	-0.19
Malapa	**0.81****	0.47	-0.32
Mansafara	-0.45	0.15	0.1
Mbolor1	**0.92*****	0.3	0.09
Mbolor2	**0.92*****	0.3	0.09
Niakassi	0.24	**0.66**	0.41
Niannikoye	-0.18	0.23	0.39
Niokolo Aerodrome	**-0.53**	0.7	-0.18
Oubadji	0.24	**-0.79****	-0.07
Passage Koba	**0.89*****	-0.37	0.01
Patte D'oie	-0.32***	0.44	0.55
Pharmacie des Elephants	-0.21	-0.07	0.29
Sayinki	-0.21	-0.07	0.29
Simenti	**0.78**	0.07	0.3
Tambanounia	**0.92***	0.3	0.09
Timbicotodala	-0.16	-0.32	-0.19
Wouroly	0.29	**0.81****	-0.3

Appendice 3: List of species and families of zone of Medium and High occurrence of the Western Derby Eland (reference IPNI, 2015)

Probability of Derby Eland occurrence	Species	Families
Medium	*Acacia macrostachya* Reichenb. ex DC.	Leguminosae - Mimosaceae
Medium	*Annona senegalensis* Pers.	Annonaceae
Medium	*Bombax costatum* Pellegr. & Vuillet	Bombacaceae
Medium	*Combretum collinum* Fresen.	Combretaceae
Medium	*Combretum glutinosum* Perr. ex DC.	Combretaceae
Medium	*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Rubiaceae
Medium	*Ficus glumosa* Del.	Moraceae
Medium	*Hexalobus monopetalus* (A. Rich.) Engl. & Diels	Annonaceae
Medium	*Lannea acida* A. Rich.	Anacardiaceae
Medium	*Lannea microcarpa* Engl. & K. Krause	Anacardiaceae
Medium	*Lannea velutina* A. Rich	Anacardiaceae
Medium	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Leguminosae - Caesalpiniaceae
Medium	*Pterocarpus lucens* Guill. & Perr.	Leguminosae - Papilionaceae
Medium	*Strychnos spinosa* Lam.	Loganiaceae
Medium	*Terminalia macroptera* Guill. & Perr.	Combretaceae
Medium	*Vitex madiensis* Oliv.	Verbenaceae
Medium	*Xeroderris stuhlmannii* (Taub.) Mendonça & E.P. Sousa	Leguminosae - Papilionaceae
Medium	*Ximenia americana* L.	Olacaceae
High	*Acacia dudgeoni* Craib ex Hall.	Leguminosae - Mimosaceae
High	*Acacia macrostachya* Reichenb. ex DC.	Leguminosae - Mimosaceae
High	*Allophylus africanus* P. Beauv.	Sapindaceae
High	*Annona senegalensis* Pers.	Annonaceae
High	*Anogeissus leiocarpa* (DC.) Guill. & Perr.	Combretaceae
High	*Bombax costatum* Pellegr. & Vuillet	Bombacaceae
High	*Boscia angustifolia* A. Rich.	Capparaceae
High	*Burkea africana* Hook. f.	Leguminosae - Caesalpiniaceae
High	*Combretum collinum* Fresen.	Combretaceae
High	*Combretum glutinosum* Perr. ex DC.	Combretaceae
High	*Combretum molle* R. Br. ex G. Don	Combretaceae

High	*Combretum nigricans* Lepr. ex Guill. et Perr.	Combretaceae
High	*Cordyla pinnata* (Lepr. ex A. Rich.) Milne-Redhead	Leguminosae - Caesalpiniaceae
High	*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Rubiaceae
High	*Detarium microcarpum* Guill. & Perr.	Leguminosae - Caesalpiniaceae
High	*Diospyros mespiliformis* Hochst. ex A. Rich.	Ebenaceae
High	*Dombeya quinqueseta var. senegalensis* (Planch.) Keay	Sterculiaceae
High	*Entada africana* Guill. & Perr.	Leguminosae - Mimosaceae
High	*Erythrina senegalensis* DC.	Leguminosae - Papilionaceae
High	*Erythrophleum africanum* Afzel.	Leguminosae - Caesalpiniaceae
High	*Ficus glumosa* Del.	Moraceae
High	*Gardenia ternifolia* Schumach. & Thonn.	Rubiaceae
High	*Grewia bicolor* Juss.	Tilliaceae
High	*Grewia lasiodiscus* K. Schum.	Tilliaceae
High	*Hexalobus monopetalus* (A. Rich.) Engl. & Diels	Annonaceae
High	*Hymenocardia acida* Tul.	Hymenocardiaceae
High	*Khaya senegalensis* (Desr.) A. Juss.	Meliaceae
High	*Lannea acida* A. Rich.	Anacardiaceae
High	*Lannea microcarpa* Engl. & K. Krause	Anacardiaceae
High	*Lannea velutina* A. Rich	Anacardiaceae
High	*Lonchocarpus laxiflorus* Guill. & Perr.	Leguminosae - Papilionaceae
High	*Maytenus senegalensis* (Lam.) Exell	Celastraceae
High	*Mitragyna inermis* (Willd.) Kuntze	Rubiaceae
High	*Pericopsis laxiflora* (Benth.) van Meeuwen	Leguminosae - Papilionaceae
High	*Piliostigma reticulatum* (DC.) Hochst.	Leguminosae - Caesalpiniaceae
High	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Leguminosae - Caesalpiniaceae
High	*Pteleopsis suberosa* Engl. & Diels	Combretaceae
High	*Pterocarpus erinaceus* Poir.	Leguminosae - Papilionaceae
High	*Pterocarpus lucens* Guill. & Perr.	Leguminosae - Papilionaceae
High	*Sterculia setigera* Del.	Sterculiaceae
High	*Stereospermum kunthianum* Cham.	Bignoniaceae

High	*Strychnos spinosa* Lam.	Loganiaceae
High	*Tamarindus indica* L.	Leguminosae - Caesalpiniaceae
High	*Terminalia avicennioides* Guill. & Perr.	Combretaceae
High	*Terminalia macroptera* Guill. & Perr.	Combretaceae
High	*Trichilia emetica* Vahl	Meliaceae
High	*Vitex madiensis* Oliv.	Verbenaceae
High	*Xeroderris stuhlmannii* (Taub.) Mendonça & E.P. Sousa	Leguminosae - Papilionaceae
High	*Ximenia americana* L.	Olacaceae
High	*Ziziphus mauritiana* Lam.	Rhamnaceae

Appendix 4: Importance Value Index (IVI) of especies

Species	Relative Density	Relative Frequency	Relative Dominance	IVI
Combretum glutinosum Perr. ex DC.	28.81	17.97	13.32	60.10
Pterocarpus erinaceus Poir.	12.42	11.88	29.59	53.90
Lannea acida A. Rich.	5.12	8.12	6.53	19.76
Crossopteryx febrifuga (Afzel. ex G. Don) Benth.	7.31	6.67	4.11	18.08
Bombax costatum Pellegr. & Vuillet	2.74	4.06	8.68	15.48
Strychnos spinose Lam.	7.19	5.80	1.90	14.89
Terminalia macroptera Guill. & Perr.	3.29	3.62	6.12	13.04
Hexalobus monopetalus (A. Rich.) Engl. & Diels	0.12	5.36	4.06	9.54
Xeroderris stuhlmannii (Taub.) Mendonça & E.P. Sousa	2.98	3.19	2.06	8.23
Grewia lasiodiscus K. Schum.	7.06	0.58	0.20	7.84
Cordyla pinnata (Lepr. ex A. Rich.) Milne-Redhead	1.40	1.88	4.17	7.45
Combretum nigricans Lepr. ex Guill. et Perr.	2.80	3.33	0.98	7.12
Combretum collinum Fresen.	2.07	3.62	1.19	6.88
Lannea velutina A. Rich	1.89	3.48	1.11	6.48
Sterculia setigera Del.	0.49	1.16	4.05	5.70
Vitex madiensis Oliv.	1.64	2.75	0.30	4.69
Lannea microcarpa Engl. & K. Krause	0.85	1.45	1.61	3.91
Acacia dudgeoni Craib ex Hall.	1.71	1.30	0.76	3.77
Acacia macrostachya Reichenb. ex DC.	1.77	1.30	0.51	3.58
Pericopsis laxiflora (Benth.) van Meeuwen	0.91	1.16	1.44	3.51
Anogeissus leiocarpa (DC.) Guill. & Perr.	0.49	0.58	1.85	2.92
Terminalia avicennioides Guill. & Perr.	0.91	1.01	0.75	2.68
Burkea Africana Hook. f.	0.30	0.72	0.88	1.90
Piliostigma thonningii (Schumach.) Milne-Redh.	0.55	0.87	0.40	1.82

Ximenia Americana L.	0.49	0.87	0.18	1.54
Detarium microcarpum Guill. & Perr.	0.43	0.43	0.51	1.37
Ziziphus mauritiana Lam.	0.37	0.87	0.12	1.36
Gardenia ternifolia Schumach. & Thonn.	0.30	0.58	0.24	1.12
Grewia bicolor Juss.	0.49	0.43	0.13	1.06
Stereospermum kunthianum Cham.	0.24	0.58	0.23	1.05
Hymenocardia acida Tul.	0.73	0.29	0.03	1.05
Piliostigma reticulatum (DC.) Hochst.	0.24	0.58	0.07	0.89
Ficus glumosa Del.	0.30	0.29	0.27	0.86
Entada Africana Guill. & Perr.	0.06	0.43	0.33	0.83
Khaya senegalensis (Desr.) A. Juss.	0.06	0.14	0.56	0.77
Pteleopsis suberosa Engl. & Diels	0.37	0.29	0.11	0.77
Erythrophleum africanum DC.	0.12	0.14	0.21	0.48
Lonchocarpus laxiflorus Guill. & Perr.	0.12	0.29	0.02	0.43
Annona senegalensis Pers.	0.12	0.29	0.02	0.43
Maytenus senegalensis (Lam.) Exell	0.18	0.14	0.07	0.40
Boscia angustifolia A. Rich.	0.06	0.14	0.11	0.32
Mitragyna inermis (Willd.) Kuntze	0.06	0.14	0.09	0.29
Pterocarpus lucens Guill. & Perr.	0.06	0.14	0.06	0.27
Combretum molle R. Br. ex G. Don	0.06	0.14	0.01	0.22
Dombeya quinqueseta (Planch.) Keay	0.06	0.14	0.01	0.22
Erythrina senegalensis DC.	0.06	0.14	0.01	0.22
Tamarindus indica L.	0.06	0.14	0.01	0.21
Allophylus africanus Hochst. ex A. Rich.	0.06	0.14	0.01	0.21
Diospyros mespiliformis	0.06	0.14	0.01	0.21
Trichilia emetica Vahl	0.06	0.14	0.01	0.21
TOTAL	100.00	100.00	100.00	300.00

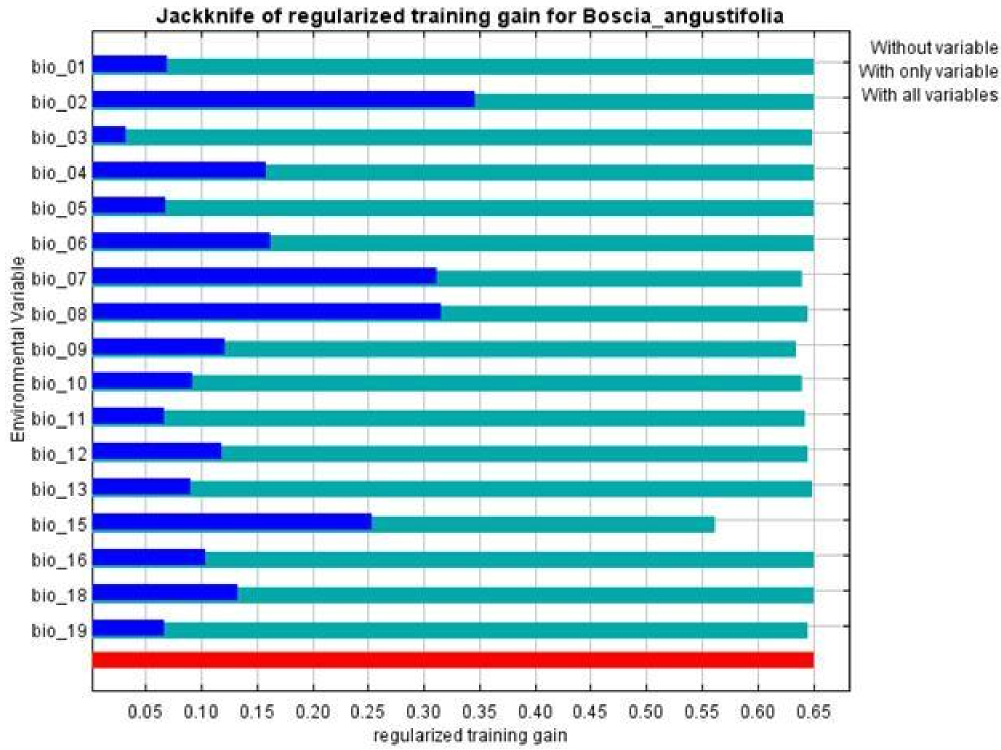
Appendix 5: Contribution of climatic factors influencing the models of each plant species consumed by the Western Derby Eland

Species	Variable	Percent contribution
B. angustifolia A. Rich.	bio_07	28
	bio_15	23.5
	bio_09	14.1
	bio_02	13.7
	bio_08	10.8
	bio_12	6
	bio_19	1.6
	bio_10	0.9
	bio_11	0.6
	bio_18	0.5
	bio_03	0.2
	bio_13	0.1
	bio_16	0
	bio_06	0
	bio_05	0
	bio_04	0
	bio_01	0
G. bicolor Juss.	bio_01	99.5
	bio_08	0.5
	bio_16	0
	bio_15	0
	bio_13	0
	bio_12	0
	bio_11	0
	bio_10	0
	bio_09	0
	bio_07	0
	bio_06	0
	bio_05	0
	bio_04	0
	bio_03	0
	bio_02	0
	bio_19	0
	bio_18	0

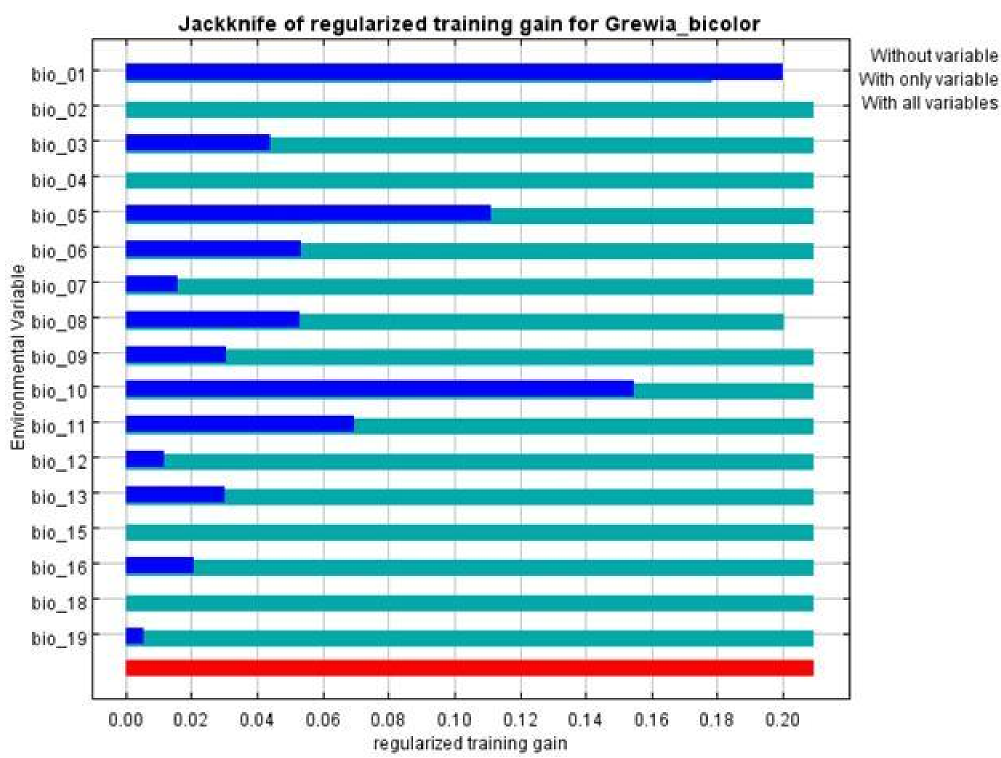
H. acida Tul.	bio_06	22.5
	bio_12	13.7
	bio_18	13.4
	bio_07	11.6
	bio_19	7.5
	bio_02	7.1
	bio_11	6.1
	bio_09	5.5
	bio_03	4.6
	bio_08	3.3
	bio_16	2.7
	bio_05	0.9
	bio_10	0.5
	bio_04	0.3
	bio_15	0.1
	bio_01	0
	bio_13	0
S. spinosa Lam.	bio_09	20.1
	bio_12	20.1
	bio_15	13.5
	bio_04	10.4
	bio_18	8.2
	bio_19	7.8
	bio_10	6.1
	bio_01	3.9
	bio_08	3.5
	bio_13	2.2
	bio_11	1.3
	bio_16	0.9
	bio_07	0.8
	bio_06	0.5
	bio_03	0.4
	bio_02	0.3
	bio_05	0

	bio_01	55.5
	bio_18	19.9
	bio_13	12.6
	bio_15	9.4
	bio_10	2.2
	bio_08	0.4
	bio_06	0
	bio_05	0
Z. mauritiana Lam.	bio_04	0
	bio_03	0
	bio_02	0
	bio_19	0
	bio_16	0
	bio_12	0
	bio_11	0
	bio_09	0
	bio_07	0

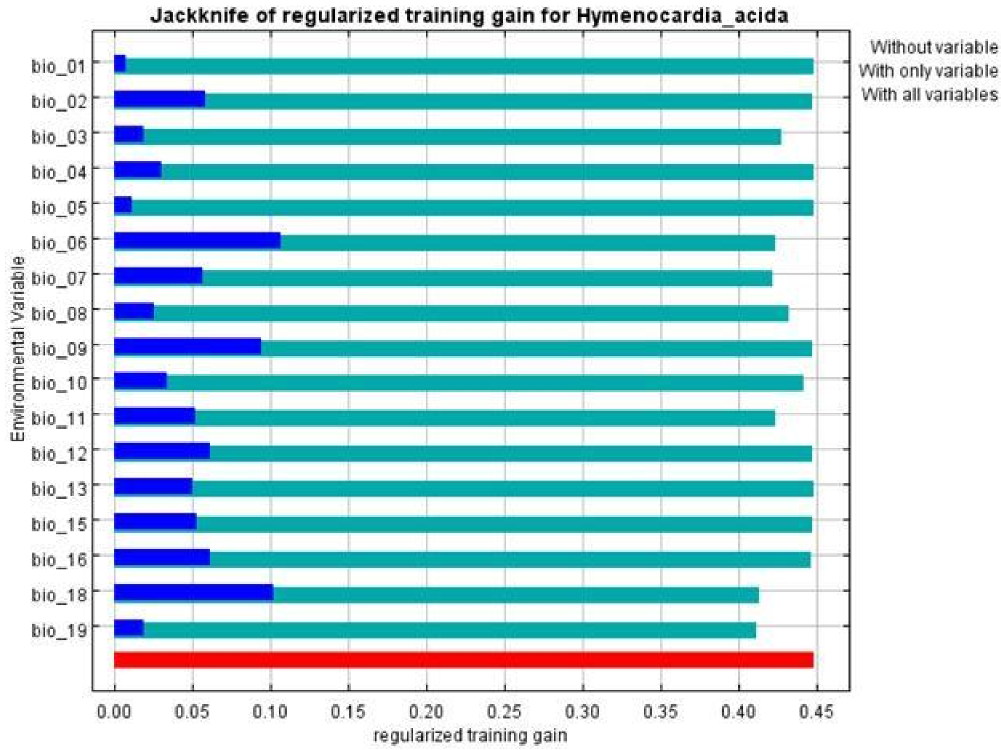
Appendix 6: Results of a Jackknife test for regularized training gain for consumed plants species



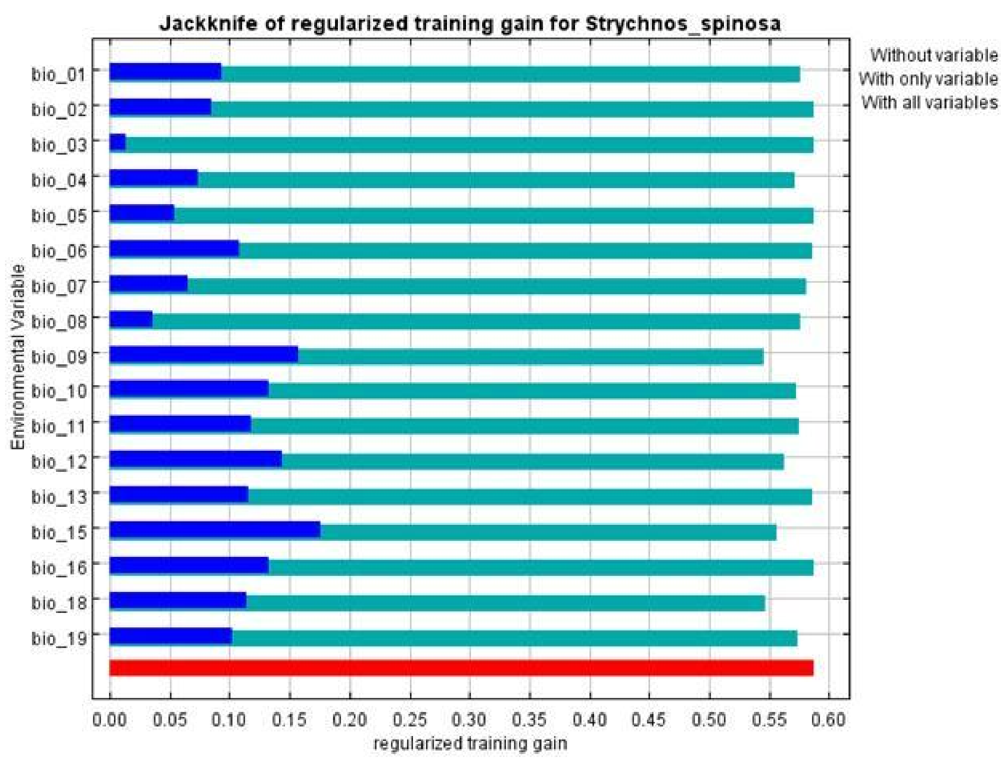
Results of a Jackknife test for regularized training gain for *Boscia angustifolia* A. Rich**.**



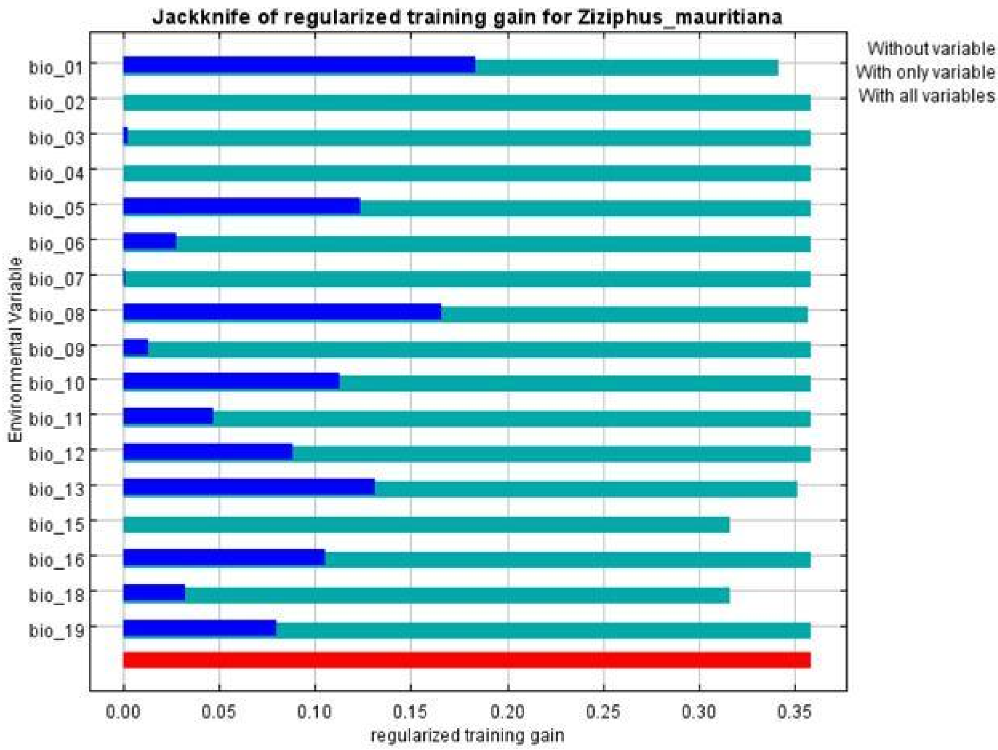
Results of a Jackknife test for regularized training gain for *Grewia bicolor* Juss.



Results of a Jackknife test for regularized training gain for *Hymenocardia acida* Tul.



Results of a Jackknife test for regularized training gain for *Strychnos spinose* Lam.



Results of a Jackknife test for regularized training gain for *Ziziphus mauritiana* Lam.

Appendix 7: French summary of the Thesis

IntroduCtion

Depuis des millénaires, la plus grande diversité d'ongulés de la terre est englobée par la savane africaine qui s'étend du Sénégal à l'ouest jusqu'à l'Éthiopie à l'est. Ce biome comprend des écosystèmes tropicaux caractérisés par une couche d'herbe continue apparaissant conjointement avec des arbres sous un régime climatique différent (**Justice *et al.*, 1994**). Ces écosystèmes fournissent de nombreux services pour le bien-être des hommes **(Boyd & Banzhaf, 2007) ;** de meme que des abris et de la nourriture pour la faune. Cependant, au cours des dernières décennies, la recherche a montré que la savane est assujettie à des dégradation et fragmentation dues aux effets combinés des activités humaines et du changement climatique (**Riggio *et al.*, 2013**). Le changement climatique est défini par le Groupe intergouvernemental sur l'évolution du climat (**IPCC, 2007**) comme un changement dans l'état du climat qui peut être identifié par des changements dans la moyenne et / ou de la variabilité de ses propriétés et qui persiste pendant une période prolongée, généralement des décennies ou plus, soit par naturelle ou humaine. Face à ces changements, de nombreuses espèces sont très menacées voir en danger d'extinction. Il a été observé que les grands mammifères comme les ongulés sont les plus menacés (**Basrankan *et al.*, 2008**). En Afrique occidentale, notamment au Sénégal, l'Eland de Derby Occidental (EDO) *Taurotragus derbianus derbianus* Gray, 1847 est l'une des espèces de mammifères citée sur la liste rouge de l'Union Internationale pour la Conservation de la Nature (UICN) comme menacée et même proche de l'extinction (**UICN, 2008**). Son habitat naturel est aujourd'hui restreint au Parc National du Niokolo Koba (PNNK) où son nombre d'individus a drastiquement diminué de 1000 en 1990 à environ 150 en 2006 **(Sournia and Dupuy, 1990; Renauld *et al.*, 2006)**. En plus, son habitat est aussi suspectée diminuer dans le PNNK. En réponse ces menaces le premier troupeau semi-captif a été installé à Bandia dans l'espoir de sauver le pool génétique (**Antoninova *et al.*, 2004**).

Des études ont été initiées aussi bien en semi-captivité que dans le PNNK, mais ces dernières étaient limitées à des inventaires pédestres et aériens **(Galat *et al.*, 1992; Hájek and Verne, 2000; Renaud *et al.*, 2006)** et au régime alimentaire **(Hejcmanová *et al.*, 2010).** Jusqu'à une date récente, très peu d'informations sont disponibles sur l'habitat de l'EDO à l'état sauvage.

Ainsi, cette recherche vise à caractériser l'habitat sauvage de l’EDO dans son dernier refuge sauvage, le PNNK situé dans le sud-est Sénégal. Spécifiques les objectifs suivants ont été déclinés :

- Déterminer l’aire de confinement de l’EDO dans PNNK,
- Déterminer la dynamique de la végétation en relation avec les paramètres climatiques de 1973-2013 dans l’aire de confinement,
- Caractériser la composition floristique, la structure de la végétation et la capcité de régénération dans l’aire de confinement,
- Prédire l'impact du changement climatique sur la distribution des espèces végétales appétées par l’EDO dans le PNNK.

I. Méthodologie

1. Présentation de la zone d'étude

Approximativement à 650 km de Dakar, le PNNK couvre une superficie de 913 000 ha. Il est situé entre 12 ° 30' à 13 ° 20' de latitude Nord et de 12 ° 20' à 13 ° 35' de longitude Ouest. Créé avant l'indépendance en 1954, il a été agrandi successivement en 1962, 1965, 1968 et 1969 à sa taille actuelle. Catégorie II dans la classification de l'UICN, il est depuis 1981 une réserve de biosphères et patrimoine mondial de l'UNESCO. La topographie est relativement plate excepté la partie sud qui constitue le contrefort des Montagnes du Fouta Djallon de la Guinée. La hauteur au-dessus du niveau de la mer est de 100-150 m et le point culminant, le Mont Assirik, est à 311 m de haut. Le sol est tropical ferrugineux peu développé avec des affleurements de croûtes ferro-latéritiques parfois surmontées d’une mince couche de limon gris. Le PNNK est dans la zone de transition soudano-guinéenne, où deux saisons s’alternent une longue sèche et une courte pluvieuse dont la précipitation moyenne est estimée 831 mm (**Mbow *et al.,* 2013**). Il constitue le dernier refuge des grands animaux et offre une énorme diversité faunistique: 80 espèces de mammifères, 330 oiseaux, 38 reptiles, 2 espèces d'amphibiens et 60 espèces de poissons (**Neierkove *et al.,* 2004**). 1500 espèces de plantes ont été identifiées (**Madsen *et al.,* 1996**) et plus de 1 100 sont stockées à l'Herbier de l'Université Cheikh Anta Diop de Dakar (**Ba *et al.,* 1997**).

2. Identification de l’aire de confinement de l’Eland de Derby Occidental dans Parc National du Niokolo Koba

Une revue bibliographique couplée à des entretiens individuels semi-structurés et des collectes de données de terrain ont été effecté. Les questionnés étaient des agents du parc en fonction, retraite et âgés, des personnes ressources à la Direction des Parcs nationaux, des chercheurs, des anciens braconniers et des villageois déguerpis vivant dans autour du parc. Leur selection été base sur au moins une vue de l'EDO dans le park. Les données collectées visaient exclusivement la localisation de l’EDO dans le park. Les sites d'apparition cités par les informateurs ont été pondérés avec un coefficient variant 1-6 en fonction de la fiabilité de l’informateur.

Une Analyse en Composantes Principales (ACP) a été réalisée afin d'évaluer la concordance des informateurs sur les zones d'apparition de l’EDO. Ensuite, la matrice des scores des sites d'apparition a été soumise à une analyse typologique (K-means) en vue de grouper les sites d’apparition. Ces analyses ont été effectuées dans le logiciel R version 3.1.2 **(R Core Team, 2016)** avec le package FactoMineR **(Le *et al.*, 2008)**. Utilisant de ArcGIS 10.2.1, les sites d'apparition dont les scores ≥ 10 points après le K-means ont été entourés par des cercles de 12 km de rayon qui correspondent au domaine vital de l’Eland de Derby Oriental (EDOr) (**Graziani et d'AlessiSilvio, 2004**). Les cercles chevauchant ont été fusionnés et la forme obtenue définissant l’aire de confinement de l’EDO dans le PNNK a été extraite du *shape* du parc.

3. Dynamique de la végétation dans l’aire de confinement de l’Eland de Derby Occidental

Les séries chronologiques des précipitations 1968-2014 enregistrées auprès de l'Agence nationale de l'aviation civile (ANACIM) et des images Landsat de 1973, 1984, 1990, 2003 et 2013 obtenues de United State Geological Survey (USGS, http://glovis.usgs.gov/) ont été utilisées. Les images ont été sélectionnées pendant la saison sèche afin de minimiser l'effet de la couverture herbacée et nuageuse (**Mbow et Thiaw, 2003; Bobee *et al.*, 2013**).

Les images ont été soumises à un prétraitement (enregistrement, composition des couleurs, de la mosaïque, extraction...). Ensuite, une classification non-supervisée suivi d’une classification supervisée ont été exécutées. Après, une vérification de terrain a été fait entre Avril-Mai 2014 (**Girard et Girard, 1999**). Les changements d’occupation des terres ont été définis par le croisement deux à deux images (**Lambin *et al.*, 2003**). Les matrices de changements et de leur légende ont été construites suivant l'échelle de **Lagabrielle et al. (2007).** La légende des classes de la végétation a été basée sur la nomenclature de **Yamgambi (1956); Aubréville (1957) et Adam (1962).** La validation des résultats de la classification supervisée a été appreciée à partir du coefficient de kappa et sa précision de chaque image (**Blum *et al*., 1995)**.

4. **Caractérisation de l'aire de confinement de L'Eland de Derby Occidental**

Sur la base de la stratification aléatoire à 2 niveaux, 156 placettes de 20 m x 20 m ont été installées suivant les directions cardinales à l'intérieur des parcelles de 250 mx 250 m à raison de 4 placettes par parcelles (**Sambou *et al.*, 2008; Mbow *et al.*, 2013**). À l'intérieur de chaque placette la liste de toutes les espèces de plantes adultes avec DBH ≥ 5cm a été établie, leur hauteur et leur DBH ont été mesurés. Les données de régénération ont été recueillies pour les individus de plantes avec DBH < 5cm. Les données environnementales (type de sol, pourcentage de couverture végétale, l'altitude, le passege des feux et de la dureté du sol) ont été aussi mesurées.

La matrice d'abondance des espèces par placette a été soumise à une analyse non-métrique multidimensionnelle scaling (NMDS). Des ellipses de confiance à 95% ont été construites pour chaque groupe de placettes. L'indice de la valeur d'importance (IVI) a été calculé pour la liste des espèces végétales inventoriées. L'analyse des espèces indicatrices a été exécutée pour identifier les espèces ou combinaisons d'espèces indicatrices de l'aire de confinement de l'EDO (**De Caceres *et al.*, 2012**). L'effet des paramètres environnementaux sur la composition floristique des groupes placettes a été défini à partir de l'Analyse Canonicale par Correspondance (ACC). Les listes des paramètres floristiques et dendrométriques (N, DBH, Ba et H_L) ont été estimés. Les valeurs moyennes et les coefficients de variation (CV) des paramètres dendrométriques ont été calculés pour l'ensemble et pour chaque groupe. Student-t tests a été réalisée pour comparer ces paramètres entre les zones. Ces analyses ont été effectuées dans le logiciel R version 3.1.2 **(R Core Team, 2016)**. Le NMDS et l'ACC ont été exécutés dans les packages vegan (**Oksanen *et al.*, 2013**) et MASS (**Venables et Ripley, 2002**) alors que l'analyse des espèces indicatrices a été faite dans le package Indicspecies (**De Caceres et Legendre, 2013**). Les structures des DBH des zones d'apparition ainsi que celles des espèces végétales appétées ont été établies et ajustée à la distribution théorique de Weibull aux 3-paramètres dans

Minitab 14. Le modèle d'analyse log-linéaire a été réalisée dans SAS (**SAS Inc., 2013**) pour chaque structure afin de tester l'adéquation de la distribution de Weibull à la structure observée. L'hypothèse de l'adéquation est acceptée si la valeur de probabilité est supérieure à 0,05 (**Caswell, 2001**).

5. **Prédire l'impact du changement climatique sur la distribution des espèces végétales appetées**

Les points de présence des espèces végétale appetées, *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. et *Ziziphus mauritiana* Lam. décrites comme faisant partie du régime alimentaire de l'EDO (**Hejcmanová *et al.*, 2010**), ont été collectés sur le terrain et completés par la collection de l'herbier de FTS/UCAD. Ces derniers ont été couplés avec trois modèles climatiques, GFDL-ESM, HadGEM2-ES et MPI-ESM-LR et deux scénarios climatiques (4.5 et 8.5) téléchargés à partir de WorldClim (http://www.worldclim.org/download) (IPCC, 2013).

Les données de présence et les variables climatiques ont été soumis au programme MaxEnt pour prédire la distribution des espèces végétale appetées face aux changements climatiques à l'horizon 2050 avec le scenario 4.5 et à l'horizon 2070 avec les scénarios 4.5 et 8.5 (**Harris *et al.*, 2014**). Les données de présence ont été maillées à 1 km^2. Les doublons ont été retirés des grilles afin de réduire le biais d'échantillonnage en faveur des sites où l'échantillonnage a été très concentrée (**Elith *et al.*, 2011**). Une analyse de Jack-knife a été réalisée sur les variables environnementales pour déterminer ceux qui contribuent plus à la prédiction des modèles. La qualité et la puissance prédictive des modèles ont été évaluées avec l'AUC « *area under curve* » du ROC « *receiver operating characteristic* » et le TSS « True Skill Statistic ». Les distributions potentielles d'espèces données sous forme de probabilités (0 à 1), ont été transformées en une matrice de présence / absence en utilisant la valeur seuil du 10 percentile présence logistique (**Da, 2010**). Les habitats potentiels favorables actuels et futurs des espèces générées par MaxEnt ont été cartographiés. Puis la répartition de leurs gains et leurs pertes ont été estimés en calculant la différence entre les valeurs actuelles et futures de distribution de chaque espèce en utilisant l'outil d'analyse spatiale dans ArcGIS. La modélisation a été réalisée en utilisant la dernière version disponible de MaxEnt 3.3.3k et toutes les analyses SIG ont été réalisées dans ArcGIS 9.2 et 10.2.1.

II. Résultats et discussion

1. Identification de l'aire de confinement de l'EDO

L'ACP a révélé que les trois premiers axes expliquent 64,75% de la variation des zones d'apparition en fonction des informateurs. Une dichotomie a été observée entre les informateurs fréquentant le parc et ceux qui ne le fréquentent plus (agents âgés et villageois déguerpis). L'analyse K-means a établie trois classes d'occurrence de l'EDO : la zone de faible probabilité d' apparition de l'EDO (ZFPAE) avec des scores variant de 1 à 8, la zone de moyenne probabilité d' apparition de l'EDO (ZMPAE) avec des scores allant de 10 à 18 et la zone de forte probabilité d' apparition l'EDO (ZFPAE) avec le score variant de 38 à 107. Les sites appartenant à ZPMAE et ZPFAE sont Assirik, Banghare, Kossi kossi, Mansafara, Niokolo, Linguekountou et Wouroly. Ces sites définissent l'aire de confinement de l'EDO dans le PNNK qui couvre 250298.19 ha soit 27.41 % de la surface totale du parc avec une longueur et une largeur moyenne respective de 51 et 49 km. Cet aire situé au centre-est du parc s'insère bien dans le polygone des grands mammifères dans PNNK et dans les zones où l'EDO a été dernièrement observé (**Renauld *et al.*, 2006; Kane, 2014).** Cette aire ressemble à l'habitat décrit pour l'EDOr (**Bro-Jorgensen**, **1997; Graziani et d'AlessiSilvio, 2004)**. Sa situation géographique pourrait être expliquée par les pressions anthropiques entourant le parc. En effet, le parc esr ceinturé par les carrières de basalte au Nord, l'Orpaillage et exploration aurifère à l'Est, le braconnage au Sud et la divagation du bétail à l'Ouest (**UICN, 2015**). L'usage du mercure par les orpailleurs et la route nationale RN7 constituent aussi des menaces supplémentaires à la survie des herbivores notamment de l'EDO avec la pollution des cours d'eau (**Niane, 2014)** et les innombrables accidents mortels d'animaux qui s'ajoutent à la fragmentation de l'aire de confinement **(Verboom *et al.*, 1991 ; Short et Turner, 1994; Riitters *et al.*, 1997**)

2. Dynamique de la végétation dans l'aire de confinement de l'EDO

Les matrices de confusion ont révélé une bonne à excellente différenciation des types de végétation avec une précision supérieure à 84% et les coefficients de kappa variant 0,79 - 0,90 (**Blum *et al.*, 1995**). Sept unités d'occupation de sol ont été identifiées : forêt bambou, bowé, forêt galerie, savane arbustive, savane arbustive-arborée, savane arborée-boisée et fleuve. Une prédominance d'occupation de la savane (savane arbustive, savane arbustive-arborée et savane arborée-boisée) a été remarquée.

De 1973-2013 la forêt Bambou, le bowé, la forêt Galerie, la savane arborée-boisée ont augmenté respectivement de 13,36%, 0,52%, 12,30% et 11,35%, tandis que la savane arbustive et la savane arbustive-arborée ont diminué de 34,09% et 3,11%. Dans les détails de 1973 à 1984 la savane arbustive a diminué de 20,67% alors que la savane arborée-boisée a augmenté de 24,52%. De 1984 à 1990 la forêt bambou a augmenté de 9,02% tandis que la savane arborée-boisée a diminué de 17,51%. De 1990-2003, la savane arbustive a augmenté de 3,33% et la savane arborée-boisée a diminué de 5,64%. De 2003 à 2013 la forêt galerie a augmentée de 14,26%, tandis que la savane arbustive a diminué de 18,54%. Ces fluctuations de l'occupation pourraient être reliées aux fluctuations observées sur l'évolution pluviométrique du parc durant cette période. Les taux de changements de conversion, de modification et de stabilité ont été respectivement de 0,38%, 73,95% et 25,68%. Le faible taux de conversion a montré que le parc est bien protégé des pressions anthropiques (**Mbow, 2000**) comparé à certaines aires protégées de l'Afrique de l'Ouest soumises à l'avancée des terres agricoles comme le parc du W (**Inoussa *et al.*, 2011 ; Houessou *et al.*, 2013**). Les modifications ont révélé une tendance à la densification de la végétation. Ce constat pourrait être corrélé à la reprise pluviométrique des années 2000 et aussi à la tendance de la re-verdure du Sahel notée par certains chercheurs dont **Herrmann et al. (2005).** Néanmoins, cette densification de la végétation pourrait induire des impacts négatifs à la survie de l'EDO qui à cause sa taille importante. En effet, l'EDO habite la savane arbustive, la savane arbustive-arborée et les zone ouverte comme bowé (**Bro-Jorgensen, 1997; Grazian et d'AlessiSilvio, 2004**) qui lui offre plus de mobilité et de possibilités anti-prédatrices.

3. Caractérisation de l'aire de confinement de L'EDO

Cinquante espèces de plantes appartenant à 40 genres et 29 familles ont été enregistrées. Les familles les plus représentées étaient Combretaceae (13,92%), Légumineuses-Mimosoideae (12.66%), Légumineuses-Caesalpinioideae (11,39%), Légumineuses-Papilionoideae (7,59%), Rubiaceae (7,59%) et Tiliaceae (6,33%). Les espèces les plus abondantes étaient *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%) et *Hexalobus* *monopetalus* (A. Rich.) Engl. & Diels (7,06%). Cette richesse spécifique est très proche des résultats de **Hejcmanovā-Nežerková et Hejcman (2006)** dans le PNNK, mais différent de celles observées dans l'habitat de l'EDOr (**Bro-Jorgensen, 1997; Grazian et d'AlessiSilvio, 2004**). Cette différence pourrait être attribuée à la différence climatique entre les habitats des deux élands de derby ou aux méthodes de collecte de données utilisées.

Le NMDS a révélé une très bonne ordination toutefois la discrimination des placettes n'était pas claire. Ce qui suggère que la composition floristique est assez similaire dans la zone de confinement de l'EDO confirmant l'hypothèse que l'EDO fréquente les zones avec composition floristique similaire **(Kruskal, 1964)**. La richesse des espèces et l'indice de diversité Shannon-Wiener sont plus élevés (S = 50 et H' = 3,99) dans la ZFPAE que dans ZMPAE (S = 18 et H' = 3,20), tandis que l'indice de Pielou est plus élevé dans ZPMAE (Eq = 0,77) que dans ZFPAE (Eq = 0,71). Les paramètres dendrométriques ont illustré que seule la densité variait de manière significative (P <0,05) entre les zones d'apparition. Pour les densités de la régénération, la C 1 (individus avec dbh < 5cm and hauteur < 1.30 m) était plus élevée dans ZMPAE (N1 = 2215.38 arbres / ha) que dans ZFPAE (N1 = 2694 arbres / ha), tandis que l'inverse était observée la C2 (individus avec dbh < 5 cm and hauteur ≥ 1.30 m) (N2 = 415,4 arbres / ha pour la ZFPAE versus N2 = 562,4 arbres / ha pour la ZMPAE). Pour chaque zone la densité des adultes < C 2 < C1 ceci témoigne d'une bonne tendence évolutive (**Fisaha *et al.*, 2013)**. Cette tendance correspond à celle déclinée par **Riginos et Grace (2008)** qui atteste que les herbivores comme l'EDO fréquente les zones moins dense avec une grande visibilité leur permettant d'être aux aguets des prédateurs.

Les trois premiers axes ont représenté 69,46% (29,39% pour le premier, 21,45% pour le deuxième et 18,61% pour le troisième axe) de la variation totale capturée par l'ACC. Altitude, le passage des feux, la couverture végétale et le type de sol ont été les paramètres environnementaux qui agissent la répartition de la végétation. Ces paramètres ont déjà été identifiés comme des facteurs influençant la végétation du PNNK **(Traoré, 1997; Mbow, 2000; Hejcmanovā-Nežerková et Hejcman, 2006**). Altitude, la couverture végétale et le type de sol ont été définis comme des facteurs importants dans l'habitat de l'eland de derby (**Bro-Jorgensen, 1997 ; East, 1997)** et le passage des feux aide à augmenter la visibilité en réduisant la prédation (**Riginos et Grace, 2008)**.

Les structures de DBH ont montré une forme en "J" inversé et la valeur du paramètre c de la distribution de Weibull inférieure à 1 indique une végétation multi-spécifique. Ceci illustre que la végétation est stable avec plus jeunes arbres. Pour les espèces végétales appetées, les structures n'ont pas été faites pour *Hymenocardia acida* et *Boscia angustifolia* en raison du faible nombre d'individus obtenu. La structure de diamètre pour *G. bicolor* a montré une forme en "J" inversé avec la valeur du c de la distribution de Weibull inférieure à 1 caractéristique d'un fort potentiel de régénération. Les structures de DBH pour *S. spinona* et *Z. mauritiana* ont montré une distribution dissymétrique positive (1< c < 3.6) signifiant une prédominance des individus avec un petit diamètre (DBH). Toutes ces structures combinées à l'évolution des densités témoignent d'une végétation stable avec un bon pouvoir de recrutement cependant l'interprétation des résultats du Weibull doivent se faire avec précaution car la valeur du paramètre c n'est pas toujours un bon indicateur de la dynamique d'une végétation d'après **Feeley *et al.* (2007).**

4. Prédire l'impact du changement climatique sur la distribution des espèces végétales appetées

Les modèles ont montré un bon pouvoir prédictif pour les espèces végétale appetées (**Araujo *et al.*, 2005; Allouche *et al.*, 2006**). Cependant, *G. bicolor* avait un pouvoir prédictif moyen qui pourrait être expliqué par son faible nombre de points de présence enregistrés (**Van Proosdij *et al.*, 2015).** Les résultats de la distribution potentielle actuelle ont montré que 30,26%, 54,75%, 24,56%, 25,55% et 43,69% de la surface du parc sont respectivement favorable à *B. angustifolia, G. bicolor, H. acida, S. spinosa* et *Z. mauritiana*. La distribution superposée des espèces végétale appetées se localise au centre-est du parc confortant la zone de confinement antérieurement définie. Ceci est en conformité avec le polygone des grands mammifères du PNNK défini par **Renauld *et al.* (2006**).

Sur les cinq espèces végétales appetées, les trois sont prédits à subir des impacts négatifs allant des réductions drastiques de leur surface favorable aussi bien sous l'horizon 2050 qu'à l'horizon 2070 et ce pour tous les deux scénarios considérés. Les trois modèles prédisent des impacts négatifs sur les espèces végétales appetées. Cependant, GFDL-ESM a montré l'impact négatif le moins prononcé avec seulement une réduction de la surface favorable pour *B. angustifolia, H. acida* et *S. spinosa* alors que les autres ont prédits une diminution drastique voir leur possible extinction (100 % de surface non favorable) quelque soit l'horizon considéré. Ceci pourrait laisser croire que les facteurs climatiques notamment la disponibilité en eau serait le facteur contrôlant les espèces végétale appetées dans le parc car GFDL-ESM, HadGEM2-ES et MPI-ESM-LR respectivement ont prédit une sècheresse, une neutralite et une humidité sur le Sahel (**Park *et al.*, 2015**).

Globalement, si trois des cinq espèces végétales appetées sont menacées, l'EDO serait consécutivement menacè. En effet, **Barlow (1987)** a montrè la relation contiguë entre la disponibilité de fourrage et la survie des herbivores. Ces menaces pourraient induire des mouvements de migration à la recherche de pâturage ce qui augmenterait la vulnérabilités de l'EDO face au braconnage, à la compétition avec le cheptel et infection sanitaire **(Astrom *et al.*, 1990 ; Carrillo *et al.*, 2000; Kock, 2005).**

Toutefois, bien que l'utilité des modèles de distribution des espèces a été illustrée (**Evangelista *et al.*, 2008),** leur résultats doivent néanmoins être utilisés avec précaution car ces modèles sont basés sur un certains nombres d'incertitudes (**IPCC, 2007 ; Hawkins et Sutton, 2009 ; Liu *et al.*, 2009 ; Harris *et al.*, 2014 ;**)

Conclusion et recommandations

Cette étude porte sur la caractérisation de l'habitat de l'EO dans son dernier refuge naturel le PNNK. Nos résultats ont montrés que l'aire de confinement de l'EDO se trouve dans la partie centre-est avec une topographie variée. Les parties hautes reposent sur substrat rocheux accidenté et les parties basses renferment des affleurements de saline. L'altitude, le passage des feux, la couverture végétale et le type de sol ont été les identifiés comme les paramètres environnementaux influençant la répartition de la végétation. La composition floristique est diversifée. La structurale de la végétation révéle une bonne structure et un bon potentiel de recrutement des jeunes individus aussi bien la végétation génénrale que pour les espèces végétales appétées. Ce qui suggère un bon approvisionnement en fourrage pour l'EDO à court voir moyen terme sauf émanation de perturbations majeures inattendues. Cependant, les résultats de la dynamique de la végétation et la prédiction des impacts du changement climatique sur les espèces végétales appetées prédisent des difficultés à la survie de l'EDO dans PNNK d'ici la fin du siècle. D'une part la dynamique d'occupation sol montre une densification de la végétation.

D’autre part, les trois modèles utilisés prédisent des réductions sévères de la surface favorable voir une possible extinction pour *B. angustifolia, H. acida* et *S. spinosa* sur les cinq espèces végétales appetées connues pour le moment. La précipitation semble être le facteur contrôlant la distribution future des espèces végétales appetées. Car des trois modéles climatique utilisés GFDL-ESM, prédisant une secheresse sur le Sahel d’ici 2100, présente les moins sévère predictions sur les espèces végétales appetées.

Sur la base de ces connaissances, pour une meilleure conservation de l’EDO dans PNNK, il est fortement recommandé d’installer un site de conservation *in-situ* dans l’aire de confinement.

Des recherches sur l’identification précise du domaine vitale ainsi que la structure population (taille, densité, dynamique et conformation des troupeaux) et de l’éthologie de l’EDO sont souhaités afin d’assoir des fondements solides à la déclinaison des plans de gestion durable pour les décideurs et les acteurs de la conservation de la biodiversité. Ces études pourraient s’appuyer sur l’utilisant des drones, des colliers télémétriques et des caméras piège

Des études supplémentaires sur la dynamique du couvert végétal utilisant des images satellitaires à haute résolution sont aussi suggérées. Cela offrira une meilleure qualité des signatures spectrales qui significativement permettront d’améliorer la classification des petites surfaces et de différentier les unités du cover végétal ainsi que les zones de transition.

Une collaboration avec les universitaires pour déterminer une meilleure compréhension des conséquences des feux précoces serait aussi désirable, afin de proposer de meilleurs plannings de leur exécution.

Il est aussi conseillé de determiner la liste des plantes appétées par l’EDO dans le PNNK. En plus, des recherches sur les prédictions de la distribution ces espéces appétées tenant en compte les paramétres environnementaux tels que pédologies, géologie, altitude, fire occurrence, coverture végétale sont aussi recommendées. Également, la modélisation de la distribution de l’EDO utilisant le « gap analysis » est recommendée car il permettra d’évaluer les sites de conservation *ex-situ* dans le réseau des aires protégées du Sénégal.

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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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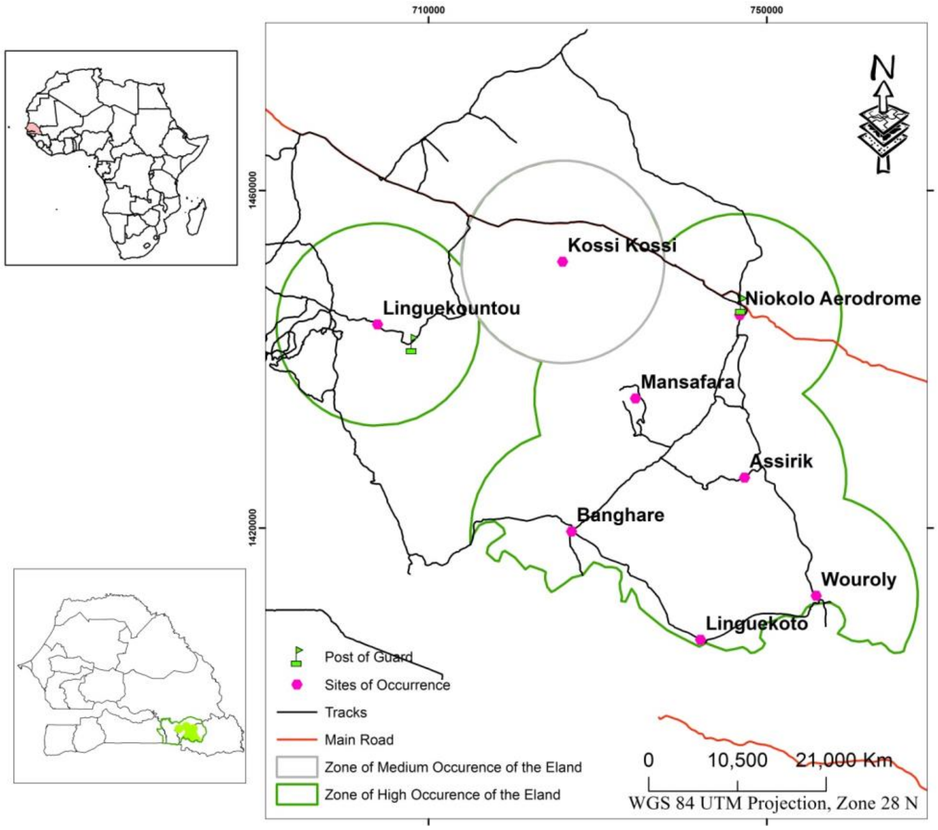

Figure 1. Location of the study sites.

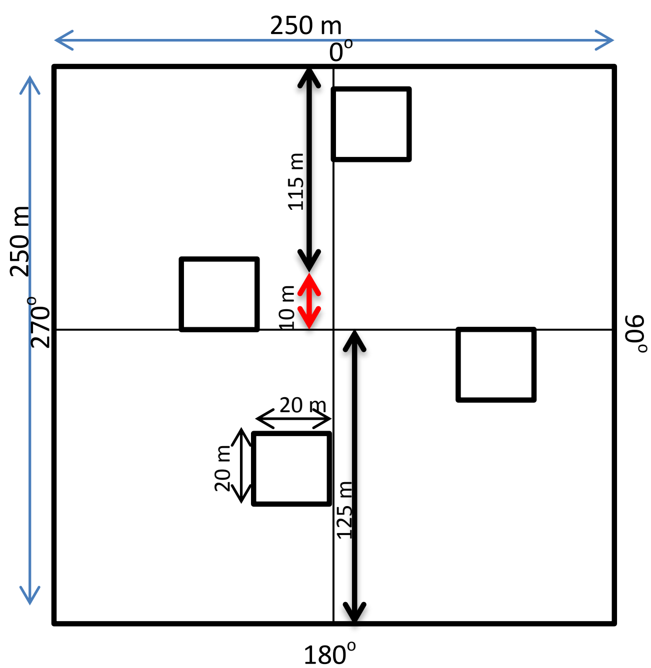

Figure 2. Sampling design.

(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 I*ndex* (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

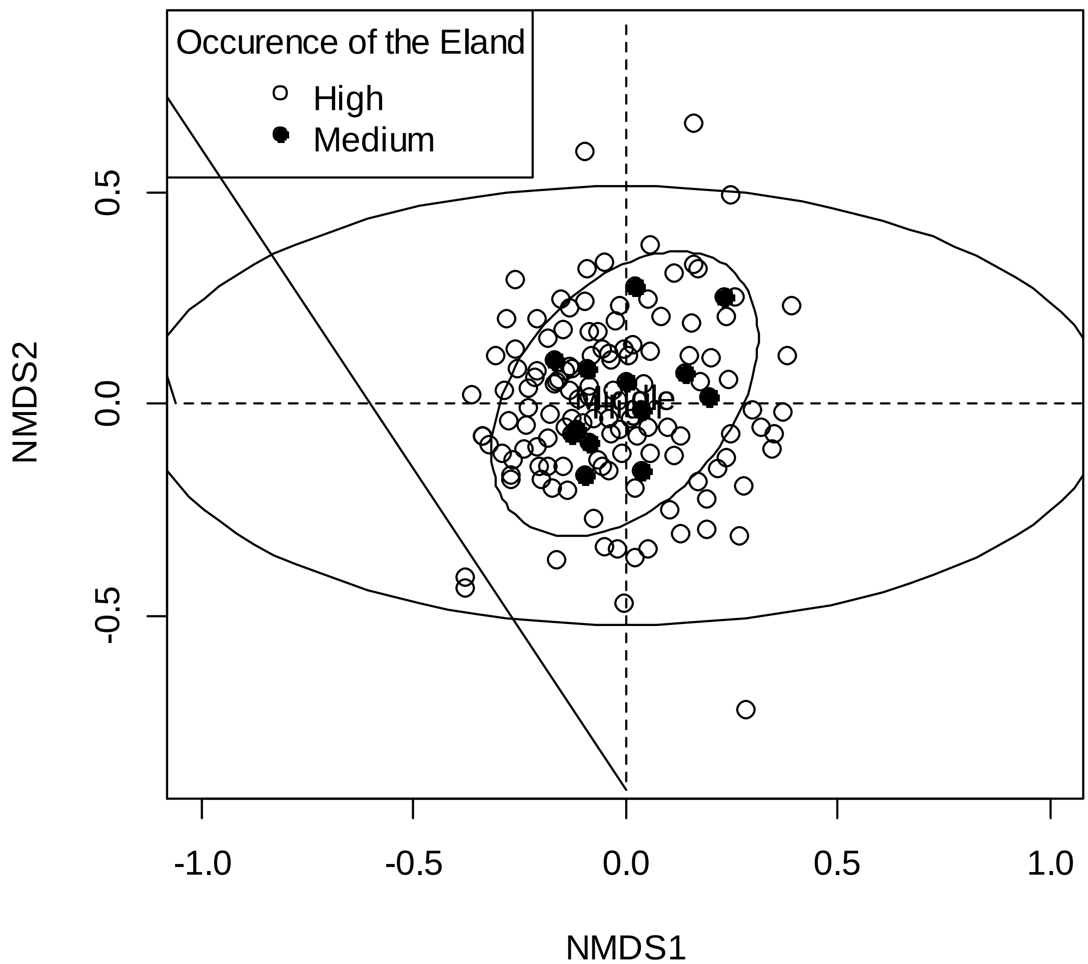

Figure 3. Non-metric multidimensional scaling of plots from zone of medium and high occurrence of Derby-Eland.

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-

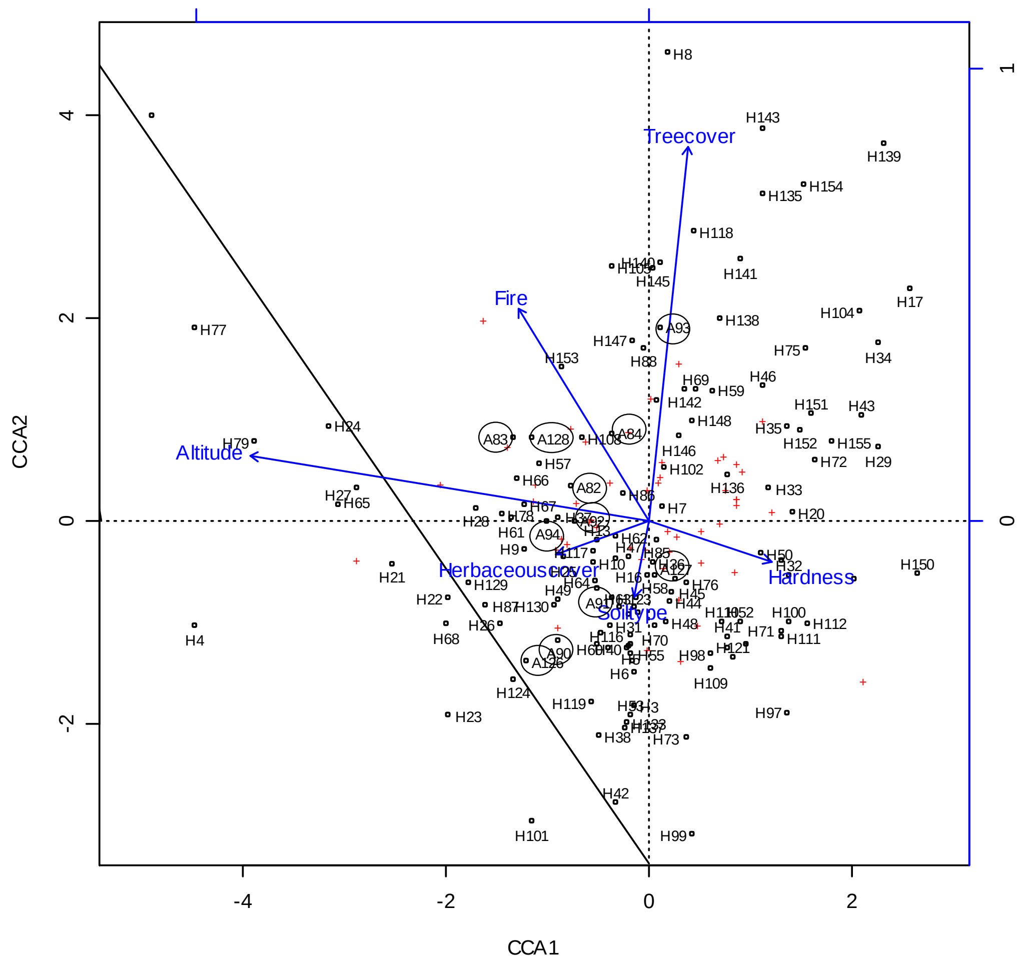

Figure 4a. Influence of environmental variables on the floristic composition in the (a) axes 1 and 2, (b) axes 1 and 3; Loading of sample units from zones of medium (A, black circle) and high (H) occurrence of Derby-Eland.

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

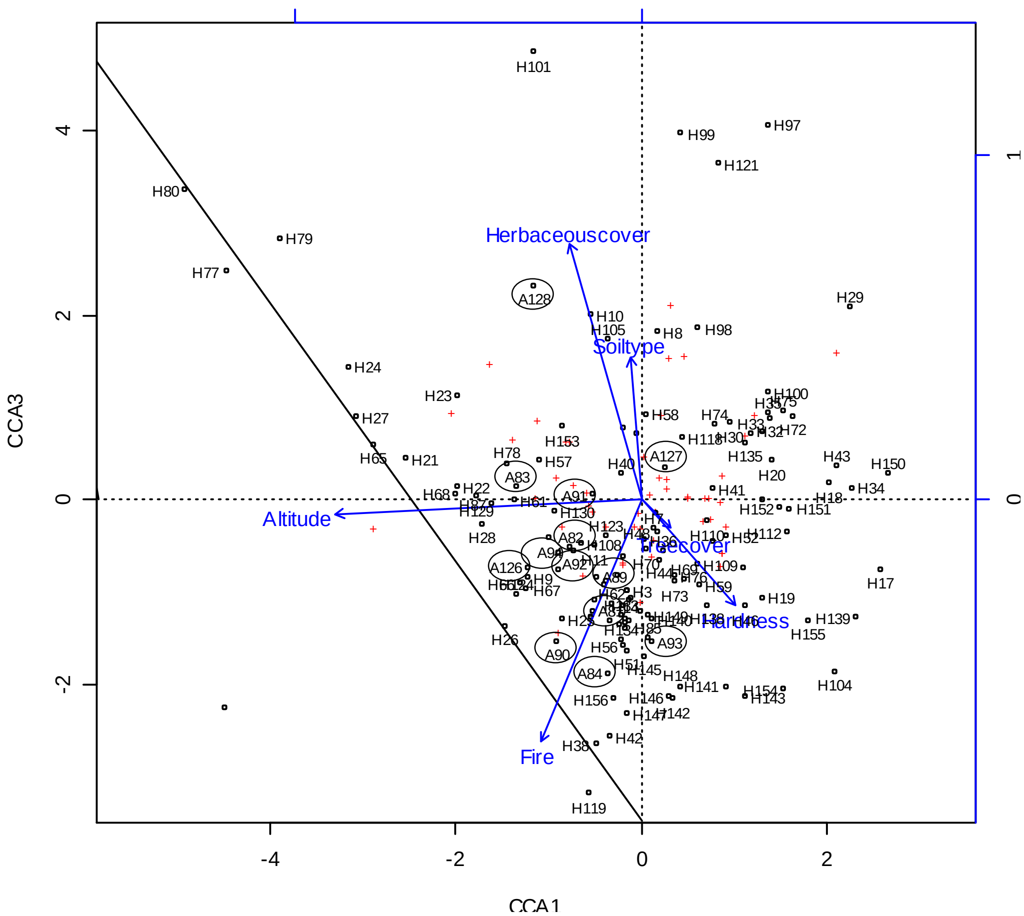

Figure 4b. Influence of environmental variables on the floristic composition in the (a) axes 1 and 2, (b) axes 1 and 3; Loading of sample units from zones of medium (A, black circle) and high (H) occurrence of Derby-Eland.

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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REFERENCES

Antoninova M, Nežerková P, Vincke X, Al-Ogoumrabe N (2004). Herd Structure of Giant Eland in Bandia Reserve. Agric. Trop. Subtropica. 37(1):1-5.

Ba AT, Sambou B, Ervick F, Goudiaby A, Camara C, Diallo D (1997). Vegetation and flora of the cross-bordering Niokolo-Badiar. G.H.M. Messana, I. Diop and M.B. Sow (Eds.). European Union, Aarhus.

Baskaran N, Kannan V, Thiyagesan K, Desai AA (2011). Behavioural Ecology of four horned antelope (*Tetracerusquadricornis* de Blainville, 1816) in the tropical forests of southern India. Mammal. Biol. 76:741-747.

Berhaut J (1967). Flora of Senegal. (2nded.). Claire Afrique, Dakar, 1–485.

Bro-Jorgensen J (1997). The ecology and behaviour of the Giant Eland (*Tragelaphus derbianus*, Gray 1847) in the wild. Master's thesis, University of Copenhagen. pp. 1-106.

Dagnelie P (1998). Applied and theorical statistic, vol. 2. De Boeck and Larcier, Belgique, Paris.

East R (1998). African Antelope Data Base. Ed Gland, Switzerland: The IUCN Species Survival Commission, Compiler 1999:355-383.

De Cáceres M, Legendre P (2009). Associations between species and groups of sites: Indices and statistical inference. Ecology. 90(12):3566-3574.

De Cáceres M, Legendre P, Wiser SK, Brotons L (2012). Using species combinations in indicator value analyses. Methods in Ecology and Evolution. 3:973-982.

De Cáceres M, Legendre P (2013). Dissimilarity measurements and the size structure of ecological communities. Methods Ecol. Evol. 4(12):1167-1177.

Dorst J, Dandelot P (1970). A field guide to the larger mammals of Africa. Collins, London, pp. 1-287.

Dufrene M, Legendre P (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67(3):345-366.

Galat G, Mauvais B, Chevillotte H, Diop A, Duplantier JM, Galat-Luong A, Pichon G (1992). Cenus of the big fauna of Niokolo Koba National Park, Senegal. 1990-1991:1-57.

Grazian P, d'AlessiSilvio G (2004). Radio-telemetric monitoring of Derby Eland (*Tragelaphus derbyanus gigas*) in north Centre Africa. Project ECOFAC-ZCV, I.E.A. (Instituto di EcologiaApplicata) – ROMA. pp. 1-77.

Hejcmanovā-Nežerková P, Hejcman M (2006). A Canonical Correspondence Analysis (CCA) of the Vegetation-Environment Relationships in Sudanese Savannah, Senegal. South Afr. J. Bot. 72(2):256-262.

Hejcmanová P, Homolka M, Antonínová M, Hejcman M, Podhájecká V (2010). Diet Composition Of Western Derby Eland (*Tauratragus derbianus derbianus*) In Dry Season In A Natural And Managed Habitat In Senegal Using Fecal Analyses. South Afr. J. Wildlife Res. 40(1):27-34.

Hájek I, Verne PH (2000). Aerial Census of Big Game in Niokolo-National Park and Falemé Region in Eastern Senegal. Proceed. All Africa Conference on Animal Production, Alexandria. 3:5-9.

Hillman JC, Fryxell JM (1988). Sudan. 5-16. In: East, R. ed. Antelopes: Global survey and regional action plans, Part 1: East and Northeast Africa. Gland: IUCN.

IUCN SSC Antelope Specialist Group (2008). Tragelaphus derbianus ssp. derbianus. The IUCN Red List of Threatened Species. Version 2015.2. <www.iucnredlist.org>. Downloaded on 10 July 2015.

Justice C, Scholes R, Frost P (1994). African Savannahs and the Global Atmosphere: Research Agenda. IGBP (Report N°. 31), Stockholm.

Kingdon J (1997). The Kingdon Field Guide to African Mammals. Academic Press, London and New York: Natural World.

Kruskal JB (1964a). Nonmetric multidimensional scaling: A numerical method. Psychometrika. 29:115-129.

Kruskal JB (1964b). Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika: 29:1-27.

Kruskal JB, Wish M (1978). Multidimensional Scaling, Sage University Paper series on Quantitative Applications in the Social Sciences. 07–011, Beverly Hills and London: Sage Publications.

Lawesson JE (1995). Study of woody flora and vegetation in Senegal. Opera Botanica. 125:1-172.

Lebrun JP, Stork AL (1991-1997). Enumeration of flower plants of Tropical Africa. 4 volumes. Geneva: Conservatory and Botanic Garden, Geneva.

Madsen J, Dione D, Traore SA, Sambou B (1996). Flora and vegetation of NiokoloKoba National Park, Senegal. In: van der Maesen, J et al., (Eds.), The Biodiversity of African Plants. Kluwer Academic Publishers, Dordrecht. pp. 214-219.

Magurran AE (2004). Measuring biological diversity. Blackwell Science Ltd.

Mbow C (2000). Study of the spatio-temporal characteristic of bush fire and their relation with the vegetation in Niokolo-Koba National Park (South-East Senegal). Thesis Dissertation University Cheikh Anta Diop, ISE/FST. 1–121.

Mbow C, Chhin S, Sambou B, Skole D (2013). Potential of dendrochronology to assess annual rates of biomass productivity in savannah trees of West Africa in Dendrochronologia (2012). Dendrochronologia. 31(1):41-51.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson LG, Solymos P, VenablesWN, Ripley BD (2002). Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

Renaud PC, Gueye MB, Hejcmanová P, Antoninova M, Samb M (2006). Aerial and pedestrian census of the fauna and records of the pressures in Niokolo Koba National Park. African Park Conservation/Ministry of environment and of the protection of nature. pp. 1-44.

Riggio J, Jacobson A, Dollar L, Bauer H, Becker M, Dickman A, Funston P, Groom R, Henschel P, de Iongh H, Lichtenfeld L, Pimm S (2013). The size of savannah Africa: a lion's (Pantheraleo) view. Biodiv. Conserv. 22:17-35.

Sambou B, Bâ AT, Goudiaby A, Sonko I, Mbow C (2007). Étude de la flore et de la végétation ligneuse pour la détermination des types d'usages compatibles avec une gestion durable de la forêt classée de Patako (Sénégal), Webbia: J. Plant Taxono Geograp. 62(1):85-96.

Sambou B, Ba AT, Mbow C, Goudiaby A (2008). Studies of the woody vegetation of the Welor forest reserve (Senegal) for sustainable use. West Afr. J. Appl. Ecol. 13:67-76.

Spinage CA (1986). The Natural History of Antelopes. Croom Helm (Eds.), London. pp. 1-310.

Sonko I (2000). Study of effect of early and late fire on the flora and ligneous vegetation of plates of Niokolo-Koba National Park, South-East Senegal. Thesis Dissertation University Cheikh Anta Diop of Dakar, ISE/FST. pp. 1-124.

Sournia G, Dupuy A (1990). Senegal. In: EAST, R.: Antilopes. Global survey and regional action plans, Pt 3: West and Central Africa, IUCN Gland.

Traore SA (1997). Analysis of ligneous flora and vegetation in Simenti zone (Niokolo Koba National Park), Eastern Senegal. Thesis Dissertation, University Cheikh Anta Diop of Dakar, ISE/FST. pp. 1-136.

ter Braak CJF (1986). Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecol. 67:1167-1179.

terBraak CJF (1987). The analysis of vegetation-environment relations by canonical correspondence analysis. Veg. 69:69-77.

Trochain JL (1940). Contribution to the study of vegetation of Senegal. Memory IFAN, Larose, Paris, 2:1-434.

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Présentée par Mariama CAMARA

Theme : **Caractérisation de l'Habitat de l'Eland de Derby Occidental (*Taurotragus derbianus derbianus* Gray, 1847) en Relation avec le Changement Climatique au sein du Parc National du Niokolo Koba (Sénégal), son Dernier Refuge Naturel**

Vu et approuvé
Abidjan le 09/01/2017

Directeur GRP WASCAL
Coordonnateur CEA-CCBAD

Professeur KONE Daouda

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Félix HOUPHOUËT-BOIGNY

Professeur AFFIAN Kouadio

Abstract

Endemic to West Africa, the Western Derby Eland (WDE) (*Taurotragus derbianus derbianus* Gray, 1847) the biggest antelope worldwide is critically endangered and close to extinction. This study aims to characterize the habitat of the WDE in its last wild refuge the Niokolo Koba National Park (NKNP), Senegal. This research was based on semi-structured interviews, remote sensing, woody plants inventory and modelling the distribution of the plants species consumed (PSC). Interviews revealed that the confinement area of the WDE is at the Centre-Eastern part of the NKNP where 50 trees species belonging to 40 genera and 29 families were recorded. Analysis of time series Landsat images showed that savanna vegetation dominated the land cover of the confinement area of the WDE. From 1973-2013 tree-savanna, gallery forest and bamboo forest increased by 11.35 %, 12.30 % and 13.36% respectively while shrub savanna and shrub-tree savanna decreased by 34.09% and 3.11 %, respectively. The current potential distribution of PSC showed that 30.26 %, 54.75%, 24.56 %, 25.55 % and 43.69 % of the park's extent are suitable habitats for *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. and *Zyzyphus mauritiana* Lam., respectively. However, GFDL-ESM, HadGEM2-ES and MPI-ESM-LR models predicted that on the five PSC *B. angustifolia* A. Rich., *H. acida* Juss. and *S. spinosa* Lam. would encounter an increase of their unsuitable areas or even extinction by the end of this century. This combined with the increase of woody vegetation could in turn impact negatively the survival of the WDE. Therefore, we highly recommend setting *in-situ* enclosures for its conservation. In addition, future research, using telemetric tools, should identify the full and home range, the total population and the ethology of the WDE in NKNP.

Key words: Critically Endangered, confinement area**,** land cover dynamics, plant inventory, modelling, conservation.

Résumé

Endémique à l'Afrique Occidentale, l'Eland de Derby Occidental (EDO), la plus grande antilope du monde est en danger critique et proche de l'extinction. Cette étude vise à caractériser l'habitat de l'EDO dans son dernier refuge sauvage, le Parc national du Niokolo Koba (PNNK), Sénégal. Elle est basée sur des entretiens semi-structurés, la télédétection, l'inventaire floristique des plantes ligneuses et la modélisation de la distribution des espèces appétées. Les interviews ont révélé que l'EDO demeure dans le centre-est du parc où 50 espèces d'arbres appartenant à 40 genres et 29 familles ont été recensées. L'analyse diachronique des images Landsat a montré que la savane domine la végétation de la zone d'occurrence de l'EDO. De 1973 à 2013, la Savane arborée, la forêt galerie et la forêt de bambou ont augmenté respectivement de 11,35%, 12,30% et 13,36%, tandis que la savane arbustive et la savane arbustive à arborée ont diminué respectivement de 34,09% et 3,11%. Les résultats de la distribution potentielle actuelle des espèces appétées ont montré que 30,26%, 54,75%, 24,56%, 25,55% et 43,69% de la surface du parc sont, respectivement, des habitats favorables pour *Boscia angustifolia* A. Rich., *Grewia bicolor* Juss., *Hymenocardia acida* Tul., *Strychnos spinosa* Lam. et *Zyzyphus mauritiana* Lam. Cependant, les modèles GFDL-ESM, HadGEM2-ES and MPI-ESM-LR prédisent que sur les cinq espèces appétées *B. angustifolia* A. Rich., *H. acida* Tul. et *S. spinosa* Lam. subiraient une diminution drastique de leur surfaces favorables, voire une extinction d'ici la fin du siècle. Ces potentielles disparitions des espèces appétées combinées à la densification de la végétation pourraient influencer négativement la survie de l'EDO. Ainsi, nous recommandons fortement la création de sites de conservation *in-situ* pour sa conservation. En plus, les futures recherches en s'appuyant sur la télémétrie, doivent identifier l'aire d'occurrence, le domaine vital et la population de l'EDO de même que son éthologie dans le PNNK.

Mots clés: En danger critique, aire de confinement, dynamique d'occupation du sol, inventaire floristique, modélisation, conservation.