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Habitat suitability model for savanna large herbivores: identifying potential conservation area for Western Derby eland in the south-eastern Senegal

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Habitat suitability model for savanna large herbivores: identifying potential conservation area for Western Derby eland in the south-eastern Senegal" independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, the 14th May 2020

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Bc. Moussa Seydi

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Abstract

The population of the Western Derby eland (WDE) is low the wild, estimated at 150 - 200 individuals at the only site, i.e. in the Niokolo Koba national park in south-east Senegal. Therefore, the WDE is considered critically endangered subspecies of Derby elands at the IUCN Red List. This research aimed to predict a suitable habitat for Western Derby eland in his current range within the Niokolo Koba national park using Habitat Suitability Model (HSM) tool. This tool uses species occurrence data and environmental variables to estimate species-habitat relationships and predict potentially suitable habitat. We employed the maximum entropy model, MaxEnt, to predict suitable habitat for Western Derby eland with limited occurrence records, i.e. a total of 33 presence locations. Environmental variables included type of land cover, digital elevation model, distance to rivers, distance to ranger camps, distance to national road, and distance to villages. Model performance was measured by area under the Receiver Operating Characteristics (ROC) curve (AUC). The AUC of 0.91 indicated that the model performed substantially better than a random prediction. The national road crossing the park and the distance to villages around the protected area were relatively the most important variables affecting the model. The proximity to the road is not indicated as suitable for the WDE and suitability increases with distance, while it decreases again at certain point, having the peak of suitability around 2500 m from the road. Similar pattern occurred with the distance to villages indicating the peak of suitability at the distance 20000 m. The MaxEnt output confirmed the affinity of this species for the area in the core (central part) of the protected area, southern as well as northern side of the national road, avoiding the borders of park, the proximity of the road in the center of the park and a large sector south-western part the park, on the left side of the Gambia river in the direction to the Koulountou river. Beyond the protected area border on the north-east of the park, there were some few patches of suitability close to the northern border. This model can be used for informed, science-based and effective conservation decision-making. Further, this model could be enhanced with more occurrence positions and altered environmental variables to produce variations in predictions, allowing for more conclusive results.

Key words: Endangered antelope, Habitat Suitability Model, Maxent, Niokolo Koba national park, Senegal, *Taurotragus derbianus*, Western Derby eland, Wildlife conservation.

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List of the abbreviations used in the thesis

DPN	Direction des Parcs Nationaux du Sénégal
DTGC	Direction des Travaux Géographiques et Cartographiques
ENFA	Ecological-Niche Factor Analysis
GAM	Generalized Additive Model
GLM	Generalized Linear Model
IUCN	International Union for Conservation of Nature
MaxEnt	Maximum Entropy
NKNP	Niokolo-Koba National Park
SRMT	Shuttle Radar Topography Mission
WDE	Western Derby Eland

1. Introduction

The human population growth or rising levels of consumption tend to cause the scarcity of natural resources available to every person. Specifically, natural habitat fragmentation and loss of natural habitats form some of the greatest threats to faunal biodiversity and are primary contributors to species extinctions in many countries. The conservation and management of biodiversity is closely linked to the need of habitat quality estimation and prospect of wildlife spatial distribution.

The Western Derby eland (*Taurotragus derbianus derbianus* Gray, 1847) is a large antelope species that occurs throughout the eastern Senegal, namely in the Niokolo Koba National Park (NKNP) with limited population size of 120-150 individuals due to many reasons, in particular the habitat loss or poaching. The Western Derby eland, here after referred as WDE, has been documented in the NKNP covered by savanna woodland as the last site with confirmed presence in the last two decades (IUCN 2017). However, little is known about the WDEs habitat requirements.

The WDE is listed on the IUCN Red List of Threatened Species as Critically Endangered (IUCN SCC Antelope Specialist Group 2017). International and national agreements have supported the conservation strategy for WDE (see Brandlová et al. 2013) and the specific conservation activities for the WDE have been included in the recent management plan of the NKNP by the conservation authority in Senegal, the Directorate of National Parks of Senegal, hereafter referred as DPN (DPN 2018).

The NKNP in Senegal is one of the biggest parks in the West Africa with the area of 913000 hectares of protected ecosystem of Sudanian and Sudano-Guinean savanna. This park is home to many of the most characteristic species of Sudanian fauna and flora, remaining in the West Africa. We may mention lions as the flagship representative of large carnivores that are nowadays at extremely low population size and listed as critically endangered for the West Africa (Henschel et al. 2014 ; Dagorne et al. 2020); or flagship primate, the Western chimpanzees (*Pan troglodytes verus*) (Pruetz et al. 2012 ; McGrew et al. 2014), also listed as critically endangered (Humle et al. 2016); or the flagship large herbivores such as the Western Derby elands as one of the World's largest antelope, roan antelopes (*Hippotragus equinus*), Western hartebeest (*Alcelaphus buselaphus major*), or the West African savanna buffalo (*Syncerus caffer brachyceros*) (Renaud et al. 2006 ;

Rabeil et al. 2018). Other important large mammal species include elephant, leopard, African wild dog, and many others (DPN 2018). The flora of the park is also diverse with over 1,500 species of plants recorded (Renaud et al. 2006). The protected area was created to preserve large wildlife, certain habitat types and vegetation in 1920' and declared the national park in 1954. The NKNP was recognized as the Biosphere Reserve in 1981, registered on the World Heritage List, then listed as World Heritage in Danger in 2007 (Howard et al. 2007).

To perform conservation activities, i.e. conservation of a species together with its habitats respecting its complex ecological functions and environmental interactions, effectively, it is necessary to gain the knowledge and achieve a comprehensive understanding of the species in its specific geographical context. Last, but not least, it involves the anthropogenic context, i.e. the species interactions with local communities in both direct and indirect ways, which means, for instance harvesting (hunting) of the species by people or sharing the space and other resources. The current thesis focuses on the Western Derby eland in the NKNP in southeast Senegal in purpose to contribute to such complex decision making for the WDE conservation, taking into account the mentioned complexity and using the most recent available tools.

In the last decade, a very intensive and dynamic development of remote-sensing techniques and GIS enables to improve substantially the knowledge in its complexity and has a huge potential to support conservation decision-making. One of such tools is the modelling and predictions of species distribution and/or suitability of habitats for species. A wide variety of modelling techniques specially designed to model species distributions are currently available (Antoine Guisan & Thuiller 2005; Elith & Franklin 2013) and has been an attendant rise in the use of spatially explicit habitat models over the past two decades (Guisan & Zimmermann 2000). The GIS is an excellent tool for mapping the land cover and habitat factors required for habitat modelling. Due to rapid landscape changing and diminishing species populations, methods of accurately predicting suitable habitat are necessary to focus on and protect areas to support ecological functions and biodiversity.

The overall objective of this research is to build a model to identify the suitable habitat and potential distribution of the Western Derby eland through mapping and modelling in order to contribute to science-based interventions for population recovery and sustainable conservation of the critically endangered WDE in NKNP.

1.1. Habitat suitability modelling

Habitat Suitability Modelling, also known as environmental (or ecological) niche modelling (ENM), species distribution modelling (SDM), predictive habitat distribution modelling, and range mapping, belongs to Species Distribution Models (SDMs) that represent numerical tools that combine observations of species occurrence or abundance with environmental variables. They are used to gain ecological and evolutionary insights and to predict distributions across an area (Secondi 2014; Miller 2010). It is gaining more interest in biology conservation by assessing the habitat for a focal species within a study site (e.g. FitzGerald et al. 2018 ; Bleyhl et al. 2019). Habitat can be defined as an area which resources and/or conditions promote the existence of a species and allow the population to survive and reproduce. Habitat is characterized also by a description of environmental features necessary for the species (Grebner et al. 2013).

Habitat suitability is expressed by the quality of habitat from a species perspective based on a variety of resource attributes. It often quantifies a relative scale that ranges from 0 (unsuitable) to 1 (optimal habitat) (Schamberger & Krohn 1982).

Maps of distribution of animal species are useful to see the development of their distribution and know how they are carried out: if they are in phase of colonization or if they occupy already the whole territory. Potential area maps are useful not only as a database but also for managing endangered species (Miller 2010). In fact, from a potential area map and a map showing the sites where the species is present, we can identify which areas are favourable for the species that are not exploited and propose a management plan, allowing the species to colonize such places through the construction of wildlife corridors, for example. Less favourable areas can also be identified, and various arrangements made to improve them (Thuiller et al. 2015).

The various methods of analysis that lead to such maps are based on observation data and identify different ecogeographic variables, e.g. climatic parameters, topographical elements, vegetation units, hydrological conditions, land use or even presence of other animal (domestic and wild) species, that qualify the observation sites (Guisan & Thuiller

2005). Therefore, producing a habitat suitability map represents a complex process (see Figure 1).

1.2. Theoretical basis of species distribution models

There are two classic approaches to the modelling of species distribution: the mechanistic approach and the correlative approach (Peterson et al. 2015).

Mechanistic models are based on a mathematical approach, it means based on representation of the dynamics by differential equations solved in continuous or discrete time, or on computer science which points out an interaction between actors of the system and with the environment defined by semantic rules translated into algorithms and then into computer programs (Peterson et al. 2015). These models use the response that the species gives to environmental variables, considering certain demographic variables linked to the species (fertility, mortality, etc.) and their transitions or dynamics. This type of model requires a very good knowledge of the species studied (life traits and ecology).

The correlative models, for their part, estimate the optimal conditions for the establishment of a species by associating the presence and/ or absence data with the environmental variables which must then be well chosen in order to have an influence on the niche of the species. The correlative models thus make it possible to obtain a spatial prediction of the favourable zones to the conservation of the species studied. From an analytical point of view, this type of model draws their theoretical bases from the underlying statistical methods (supervised classifications, regressions, etc.).

Species distribution models are important decision support tools. It is in the field of species conservation, where the discipline emerged. Among the uses that can be made from this type of model we can cite:

- The conservation of endangered species;
- The discovery of new species;
- The impact of environmental variables and their variations on one or more species;
- Integrated pest management and eradication projects.

Among the differences between the models, one of the most important is the type of field data on species presence/absence that we use to build these models. This distinction leads to classification of these algorithms. In general, we distinguish:

1. Presence-only models;
2. Presence-absence models;
3. Presence-background models;
4. Presence-pseudoabsence models.

1.2.1. Presence-only models

These are approaches based solely on the use of presence data without other considerations on the available space. There are two approaches: an approach based on the construction of envelopes and a second approach based on the use of distances in ecological space. Envelope models are simple methods for estimating the niche of the species, we can cite for example the habitat algorithm which builds a convex envelope around presence data. Distance-based methods are a bit more complex in general. The principle is to calculate an index of dissimilarity between points in the ecological space.

1.2.2. Presence-absence models

When data on true absences are available, the estimation of the geographic distribution of a species is possible thanks to the use of more conventional statistical methods which make it possible to discriminate the presence and absences.

These approaches are often based on regression models such as generalized linear models (GLM), generalized additive models (GAM), etc. Another approach consists in using statistical learning algorithms such as decision trees, neural networks or even ensemble methods such as random forests.

In the case of GLMs (generalized linear models), the most common, the niche of the species is estimated on the assumption that there is a relationship between the average of the values of the variable to be explained and a linear combination of the explanatory variables. The adjustment of these models requires knowing beforehand the distribution laws of the explanatory variables. When the variable to be explained is binary (e.g. presence / absence), logistic regression is the most appropriate. Various adaptations of the GLMs have been made in order to respond to different situations encountered when handling ecological data. GAMs (generalized additive models), for example, are used when the relationships between variables are not linear and / or when the distribution laws of the explanatory variables are complex. Other approaches such as generalized dissimilarity models or adaptive multivariate regressions have also been developed but are less widely used. For (Thuiller et al. 2004), the information contained in absence data is very important and should be included in the models according to their availability.

1.2.3. Presence-background models

We speak of background data to describe the available environment on which the analysis is done. The methods that use this information in their analyses are different from those of presence-absence and presence-only, in that they compare the areas used by the species to those available in order to model the favorable conditions for the species. One of the most used presence-background methods is MaxEnt.

Maximum Entropy (MaxEnt)

MaxEnt is based on a fundamental principle of information theory, that of maximum entropy. The method was originally developed to make predictions or interpolations from incomplete information in different disciplines (Phillips et al. 2006). It has recently been adapted for modeling the distribution of species from presence data, and its use has spread rapidly. This approach is based on an algorithm that estimates the most likely distribution of the species based on the principle that the best estimation of an unknown distribution is the least constraining (with the maximum entropy) for the species. The "constraints" are defined by comparing the distribution of the values of the environmental variables at the observation points with their distribution for a large number of random points in the study area (absence or presence of the possible species) (Suárez-Seoane et al. 2008; Baldwin 2009).

An open access application has been developed to facilitate the use of the method (Phillips 2010). It includes a relatively accessible interface that allows to integrate different types of environmental variables (quantitative, qualitative ...), sets of observation points and / or test as well as to set the models. The implementation of the method results in several results including statistics and information that make it possible to judge the relevance of the predictions, as well as a spatialized representation of the results that can be exported in a GIS software for analysis.

The Maxent model allowed for species distribution predictions to be made with one presence-only biological dataset.

Other factorial methods such as the Ecological Niches Factor Analysis (ENFA) or the Factorial decomposition of Mahalanobis Distances (MADIFA) also belong to this type of algorithm. These factorial models look for directions in which the projection of the niche would be optimal. These are methods suitable for exploratory analysis of the niche of a species (Calenge & Basille 2008).

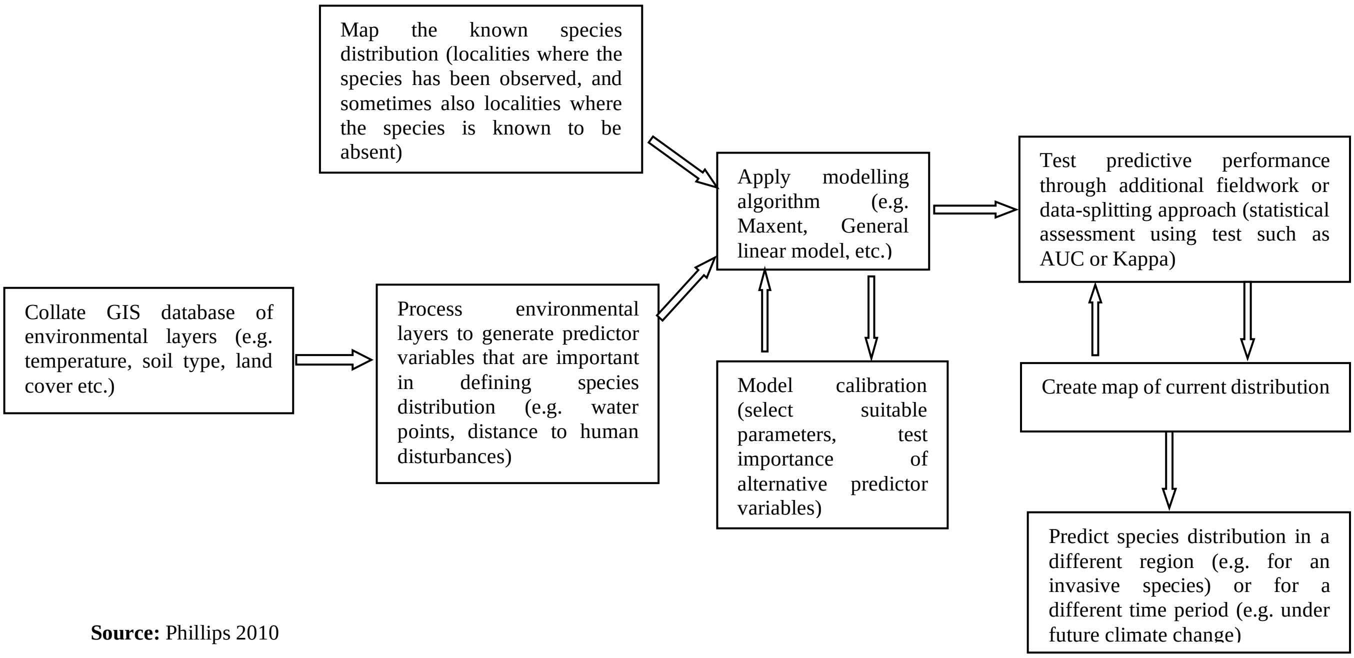
Ecological Niches Factor Analysis (ENFA)

The ENFA method uses the concept of ecological niche, further considering the ecological niche of a species as a multi-dimensional volume, corresponding to the environmental variables in which the species lives. This method compares the observed distribution of the species studied in the hyper-space formed by the set of variables over the entire study area (Hirzel et al. 2002). Potential habitats will be constructed based on their distance from observations in the hyper-volume, which is based on the assumption that a species has a non-random distribution and that the majority of individuals will globally occupy the same amplitudes of values of each eco-geographical variable. From point of presence only, the ENFA model calculates the relevance of each area based on the niche size of the species and will generate potential habitat maps (Davies et al. 2008; Hirzel et al. 2002).

At each point in the geographical area can be associated several environnemental measures (slope, type of vegetation, etc.). Each of these environmental variables defines a dimension in a multidimensional space called ecological space. The distribution of the species in this ecological space will make it possible to determine its needs; this hypervolume in which the species can maintain a viable population is called ecological niche of the species. Note that ENFA is more suited to determine the potential distribution of the species rather than its realized distribution (Valverde et al. 2008).

1.2.4. Presence-pseudoabsence models

When presence data are not available, one approach is to consider points in the available space where the species is not found as absences. This hypothesis then makes it possible to use conventional discrimination methods. The choice of these pseudo-absences are important for the success of the different models used (Chefaoui & Lobo 2008). It should however be noted that whatever the type of method used, precautions must be taken during the modelling phase.



Source: Phillips 2010

Figure 1: Habitat suitability modelling process – the flow diagram of the main steps required for building and validating a correlative species distribution model.

Table 1: Synthesis of the most commonly used approaches for spatialized modelling of the distribution of species with their main characteristics.

Most commonly published methods for species distribution modelling			
Method(s)	Model/ software	Species data type	References/ URL
Gower metric	DOMAIN	Presence-only	Carpenter et al., 1993 http://diva-gis.org/
Ecological Niche Factor Analysis (ENFA)	BIOMAPPER	Presence and background	Hirzel et al., 2002 http://www2.unil.ch/biomapper/
Maximum Entropy	MAXENT	Presence and background	Phillips et al., 2006 https://www.cs.princeton.edu/~schapire/maxent/
Genetic Algorithm (GA)	GARP	Pseudo-absence	Stockwell & Peters 1999
Artificial Neural Network (ANN)	SPECIES	Presence and absence (or pseudo-absence)	Pearson et al. 2002
Regression: Generalized Linear Model (GLM), Generalized additive model (GAM), Boosted Regeression Trees (BRT), Multivariate Adaptive Regression Splines (MARS)	Implemented in R	Presence and absence (or pseudo-absence)	Maggini et al. 2002 Hastie 2019 Leathwick et al. 2006 Elith et al. 2010
Multiple methods	BIOMOD	Presence and absence (or pseudo-absence)	Thuiller 2003
Multiple methods	OpenModeller	Depends on method implemented	http://openmodeller.sourceforge.net/

Source: Phillips 2010

1.3. The Western Derby eland – the flagship species for conservation in the West Africa

The Western Derby eland (*Taurotragus derbianus derbianus*) is a large, savanna-dwelling antelope of the West Africa. It is the western subspecies of Derby eland (*T. derbianus*, syn. *Tragelaphus derbianus*) listed as Critically Endangered in the category C2a (ii) (IUCN SSC Antelope Specialist Group 2017). The reason is that only estimated 150-200 animals remain in Senegal as confirmed population which is well below the threshold of 250 mature individuals. Over 90% these individuals are found in one sub-population in the NKNP in the southeast Senegal. There are few areas of neighbouring Mali and Guinea where some indices of presence were reported almost 20 years ago (East & ASG 1998 ; Darroze 2004), but the presence of this species has not been confirmed since then. The NKNP thus represents a key site for the WDE. Poaching and encroachment by livestock grazing within the park have been assumed as principal reasons of antelopes' low population numbers. However, the numbers of the WDEs had been estimated as very low in the long-term, even during the censuses organized in 1960's and 1970's, never exceeding several hundreds of individuals (see Table 2). Reasons can be associated to habitat loss, food resources change due to livestock or climate change, reproduction constraints related to deficiencies of essential minerals or to genetic bottleneck from the past. In reality, reasons have never been deeply investigated and understood. There is currently a semi-captive population in two nature reserves in Senegal, the Bandia and Fathala reserves. This population was established in 2000 by capture of 9 individuals from the NKNP, out of which 1 males and 5 females became founders (Nežerková et al. 2004). There were 118 living individuals divided into 6 herds in the two reserves in June 2019 (Brandlová et al. 2020).

Table 2: The overview of reports on the populations size, both observed and/or estimated, on the Western Derby elands in the Niokolo Koba national park in Senegal.

Year	Population size	Source
Till 1970	Just presence, no numbers reported	e.g. Dupuy 1969
1970	7 individuals spotted, 100 individuals estimated in the Niokolo Koba national park, 100 individuals expected outside park	Dupuy 1970
1971	3 individuals spotted	Dupuy 1971
1981	1000 individuals estimated	Dupuy and Verschuren 1982
1991/92	100 -150 individuals estimated	Galat et al. 1992, Benoit 1993
2000	120 individuals estimated	Hájek and Verner 2000
2001/02	200 individuals estimated	Geofroy Mauvais, pers. com.
2006	69 individuals spotted, 170 individuals estimated	Renaud et al. 2006

The Western Derby eland (Figure 2: **Adult male and female of the Western Derby eland in the Fathala reserve (Photo: P. Hejcmanová).** is a massive antelope with body that attains an average mass of 450-950 kg for the male and 440 kg for the female. The body length goes over 290 cm for the male, 220cm for the female and concerning its height at the withers, it goes between 150-176 cm for the male, 150 cm for the female. The overall body colour is chestnut, sometimes with a tint of bluish grey. This depends on the animal age and the climate period. It has roughly 9-14 white stripes on its flanks. The adults grow a knot of brown hairs on a forehead. From the chin to the chest there hangs an enormous black and white dewlap. Both sexes have horns. They curve in a spiral and can reach lengths of up 80-123cm (Livet 2012).

The Western Derby eland has been observed to consume predominantly leaves, flowers, and fruits of woody plants in the wild as well as in semi-captivity (Hejcmanová et al. 2010; Hejcmanová et al. 2013) and can be therefore classified as a browser with a certain level of selectivity for woody plant species, but particularly requiring a high diversity of woody plant species in its diet (Hejcmanová et al. 2019).

Figure 2: Adult male and female of the Western Derby eland in the Fathala reserve (Photo: P. Hejcmanová).

2. Aims of the Thesis

Conservation and management of endangered species require a comprehensive understanding of how species perceive and respond to their environments. Species distribution modelling (SDM) is an appropriate tool for identifying conservation areas of concern and importance.

The aim of the research was to build a habitat suitability model for the Western Derby eland (WDE) in the south-eastern Senegal within its current range of distribution in the Niokolo Koba national park (NKNP) with purpose to evaluate the potential of available habitats for the WDE spatial distribution and its ultimate conservation.

To achieve the aim, the following objectives were formulated:

- To provide a habitat suitability model for the WDE in the NKNP;
- To evaluate the criteria for potential spatial distribution of the WDE in the final habitat suitability model in terms of environmental and anthropogenic variables in the NKNP and to test specifically for the strength of the effects of each variable.

We formulated following predictions:

1. We assumed that the WDE would not show any specific preference to land cover within the protected area as the natural vegetation of undisturbed Sudanian and Sudano-Guinean savanna is heterogeneous and characterised by many transition zones between vegetation units (Lawesson 1995 ; Madsen and Sambou 1998 ; Duvall 2011) at small scale relative to the area of the national parks.
2. Then, we aimed to test the importance of the topography for the spatial distribution of the WDE in the NKNP, which was mentioned by Camara et al. (2016) as the key factor determining the “eland habitat”, based on (East 1999) and rangers’ observations and conclusions on the WDEs.
3. We do not assume the strong dependence on principal rivers and streams as they are all within the reach of estimated movements which are not known for the WDEs in the Niokolo, but reported on the Eastern Derby elands as daily distance walked ranging between 7 and 23 km in Cameroun (Bro-Jørgensen 1997) or between 5 and 7.6 km in Central African Republic (Graziani & D’Alessio 2004).
4. We assume that the WDEs avoid areas close to the border of the NKNP, specifically due to disturbance by human activities including the villages, related cattle grazing in

the proximity of villages, higher risk of poaching or timber logging (see the distribution of human-related activities in (Renaud et al. 2006).

5. The national road passes through the centre of the protected area which is the principal trade road between Senegal and Mali. We may expect that the animals will avoid the area close to the national road, similarly as in many other cases (reviewed by Fahrig & Rytwinski (2009), for reasons which may be related to the avoidance of collision, noice, or road surface (e.g. (Jaeger et al. 2005).

3. Material and Methods

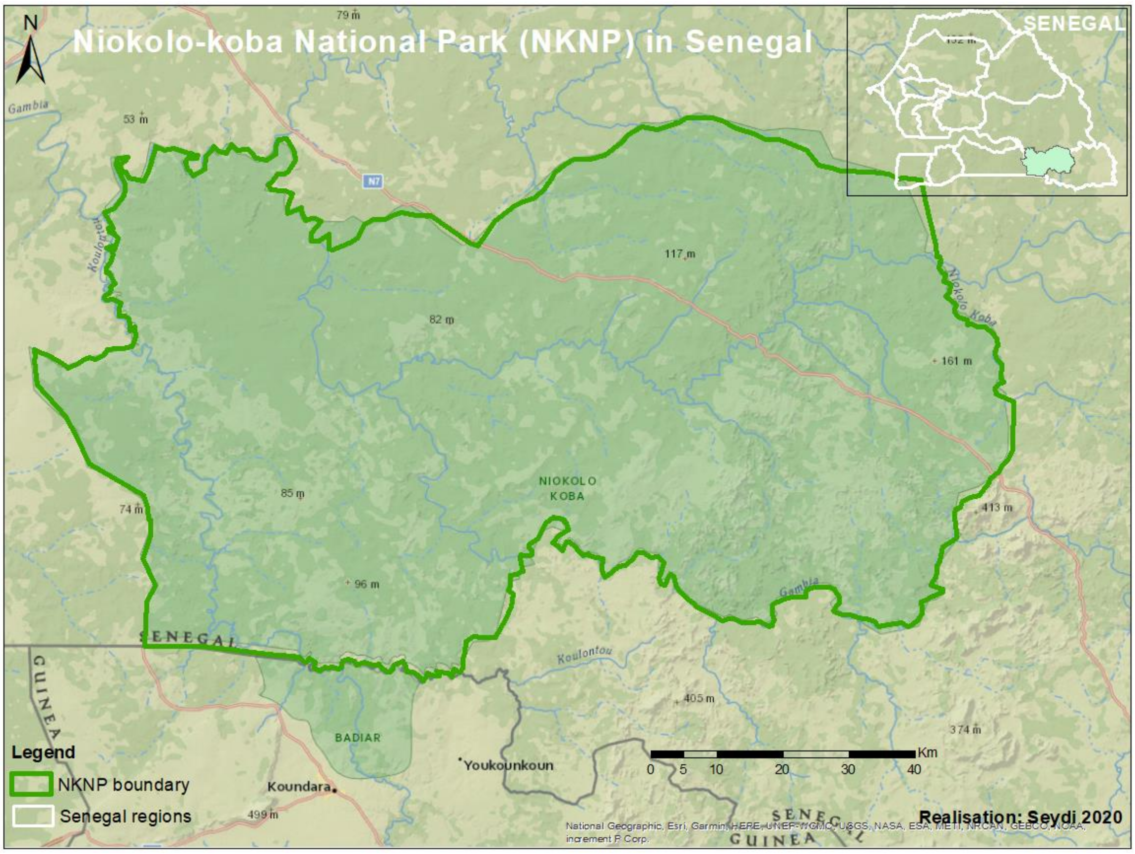
3.1. Study site

The Niokolo-Koba National Park (NKNP) is located in south-eastern Senegal (13° 04'N, 12° 43'W) (` Figure 3) and is the largest park in the country, with an area of 8 282 km² (9 130 km², counting the buffer zone). Although the national park is located mainly in the Tambacounda region, the entire western part of Koulountou is located in the Kolda region, the river constituting the administrative boundary.

The NKNP is a national park managed with purpose of biodiversity conservation, i.e. wildlife, plants as well as the whole ecosystem. Classified as a game reserve in 1926, the park changed its status from a classified forest in 1951 to a wildlife reserve in 1953, and finally a national park in 1954, with decrees in 1962, 1965, 1968 and 1969 amending and enlarging its area. The NKNP was accepted as a Biosphere Reserve and inscribed on the World Heritage List in 1981, then listed as World Heritage in Danger in 2007 (Howard et al. 2007).

According to Köppen climate classification (Kottek et al. 2006 ; Peel et al. 2007), the NKNP has a tropical savanna climate (900-1,200 mm of rain with a rainy season from June to October) The annual average temperature is 28.5 °C (in Tambacounda, period 1961-1990), ranging between 18.7 °C (January) and 38 °C (April/ May), according to season (DPN 2018). The relief is flat in the western part of the NKNP, while there are hills in the south east (hills of Mako, Baraboye, Ibel, Bandafassi massif). There are low tabular trays covered with a ferruginous or lateritic armour, sometimes outcropping granites, and loose formations of clay sands or gravel. The altitude ranges from 16 m to 311 m a.s.l. with Mount Assirick as the highest point of the park. Soils are predominantly ferric luvisols, lithosols on hardpans, regosols, alluvial and hydromorphic (DPN 2018).

The principal river is the Gambia river which runs through the park in the east – west, then south - north orientation and delimits part of the southern boundary of the park. Its two major tributaries are the Koulountou river in the west (facing south-north) and the Niokolo river in the middle eastern part of the park (flowing mainly from east to west). While Gambia and Koulountou have a quasi-permanent regime, the Niokolo river does not flow any more at the end of the dry season and permanent ponds only persist. More than 200 temporary or permanent marshes have been identified in the NKNP.



` **Figure 3:** Location of the Niokolo Koba National Park in south-east Senegal.

The park lies in the tropical region and has a range of diverse habitats and is home of numerous species of flora and fauna.

Flora and vegetation

The various botanical studies conducted in the NKNP have identified about 1,500 different plant species (Lawesson 1995 ; Madsen and Sambou 1998). The NKNP belongs to the West African savanna belt, specifically to the Sudanian and Sudano-Guinean savanna. The vegetation is dominated by a mosaic of woodland, grass and woody savannahs (Frederiksen and Lawesson 1992 ; Hejcmanová et al. 2006). The characteristic woody plant species are *Annona senegalensis, Combretum glutinosum, C. nigricans, Guiera senegalensis, Lannea microcarpa, Terminalia avicennoides,* and *Crossopteryx febrifuga*. The woody savanna is interspersed by grasses *Andropogon gayanus, Cymbopogon giganteus,* and *Diheteropogon amplectens.*

The short grass savanna of the plains is dominated by *Ctenium newtonii, Schizachyrium sanguineum,* sometimes associated with *Panicum anabaptistum*.

The dry forests are composed of Sudanian species such as *Piliostigma thonningii*, *Pterocarpus erinaceus*, *Pericopsis africana*, *Bombax costatum*, *Burkea africana*, *Prosopis africana*, *Sterculia setigera*, *Ficus ingens*, *Strychnos spinosa*, *Anogeissus leiocarpus*, *Hyparrhenia amaena*, *Vetiveria nigritana*, *Arundinella ecklonii*, *Eriochrysis brachypogon*, and *Hemarthria altissima*.

The species present in the gallery forests indicate a Guinean-type vegetation with an abundance of vines and *Raphia sudanica*, *Baissea multiflora*, *Nauclea latifolia*, *Dalbergia saxatilis*, *Landolphia dulcis*, *Saba senegalensis*, *Nauclea latifolia*, *Combretum tomentosum*, *Strophantus sarmentosus*, *Erythrophleum suaveoleus*, *Detarium senegalense*, *Syzygium guineense* and *Afzelia africana*, some species can easily exceed 30 meters in height (*Ceiba pentandra*, *Cola cordifolia*, *Khaya senegalensis*). Palms (*Borassus aethiopum* are present throughout the NKNP with remarkable concentrations along the Koulountou and Gambia.

Fauna

The NKNP is rich in fauna and represents an important refuge for West African wildlife. There is reported more than 80 mammal species, 330 bird species, 36 reptile species, 20 amphibian species and 60 fish species identified in the NKNP (DPN 2018). The large and medium-sized wildlife in the park is representative of savanna animals (Renaud et al. 2006).

Large herbivores are represented by the West African savanna buffalo (*Syncerus caffer brachyceros*), Western Derby eland (*Taurotragus derbianus derbianus*), roan antelope (*Hippotragus equinus*), hartebeest (*Alcelaphus buselaphus major*), bushbuck (*Tragelaphus scriptus*), kob (*Kobus kob kob*), waterbuck (*Kobus ellipsiprymnus defassa*), oribi (*Ourebia ourebi*), red-flanked duiker (*Cephalophus rufilatus*), and common duiker (*Sylvicapra grimmia*). The damalisque (*Damaliscus lunatus korrigum*) disappeared in 1920, and the last giraffe (*Giraffa camelopardalis peralta*) in 1950. The megaherbivores are only represented by the hippopotamus (*Hippopotamus amphibius*) and the elephant (*Loxodonta africana*).

With regard to carnivores, the NKNP hosts more than 15 different species, including for instance the lion (*Panthera leo*), leopard (*Panthera pardus*), African wild dog (*Lycaon pictus*), spotted hyena (*Crocuta crocuta*), jackal flanks striped (*Canis adustus*), serval

(*Felis serval*), and caracal (*Felis caracal*), civet (*Viverra civetta*), several mongoose species.

Finally, other remarkable mammals are present in the park, like the aardvark (*Orycteropus afer*), the giant pangolin (*Manis gigantea*) or the Rock hyrax (*Procavia capensis*) (DPN 2018), etc.

Bushfires

Bushfires represent an important aspect of park ecosystems and management. There are basically two types of bushfires in the NKNP depending on the period in which they occur (DPN 2018): 1) *Late fires* which are of anthropogenic origin, regularly run through the park in the advanced and late dry season (between January and June), when there is abundant dry fuels and favourable atmospheric conditions. These fires can result from the exploitation of the natural resources (e.g. poaching, clearing in the peripheral zone) or by accidents. These late bushfires are violent and constitute one of the most important factors of degradation and drastic reduction of the vegetation. 2) *Early fires* are set by the National Parks Administration each year as a management tool (to avoid destructive late fires and to boost the vegetation re-growth after the end of wet season) or by poachers (as a part of hunting strategy). More details of effects of fires on the environment, namely the vegetation, were reported by (Mbow et al. 2003).

3.2. Collection and processing species occurrence data

The data of occurrence of the Western Derby elands for the present study were compiled from various sources from a time period between 2001 and 2018. The data confirming the presence of Derby elands at a specific location were composed by positions of collected faeces within the frame of research of the foraging ecology performed by P. Hejcmanová between years 2001 and 2005, by positions of observations within the aerial and ground count of wildlife in the NKNP organised by the DPN and African Parks Foundation in 2006, and by positions of observations within the frame of monitoring activities of the NKNP Administration by camera traps (data from period 2010 – 2018, provided by NKNP, namely by Col. Mamadou Sidibé and Col. Mallé Gueye). It is necessary to acknowledge that the data come from a long-term period, are of diverse nature regarding the species presence records (include both direct and indirect presence, differing inherently in number of animals observed and repeated presence, specifically on stationary camera traps), and certainly do not represent a comprehensive evidence of Derby elands' distribution in the park. However, these data are the only available and represent thus a good basis for understanding the use of the NKNP's space.

The data were not evenly distributed throughout the study area and some positions overlapped or occurred in very close locations to one another. Further processing of data was therefore necessary. We executed a filtering method in R (R Core Team, Inc.) to reduce spatial autocorrelation (Castellanos et al. 2019). Filtering methods outperform unfiltered methods in correcting for sampling bias, which increases spatial autocorrelation and may lead to overfit models with falsely high-performance values (Boria et al. 2014). Therefore 33 points remained when filtering was complete. The overview of final occurrence data is given in the Table 3. Using the geographic coordinates, we converted the total presence location points to a shapefile map for use as a species presence map (Figure 4: **Positions of occurrences of Western Derby eland in the Niokolo Koba national park as input data for the MaxEnt model.**.

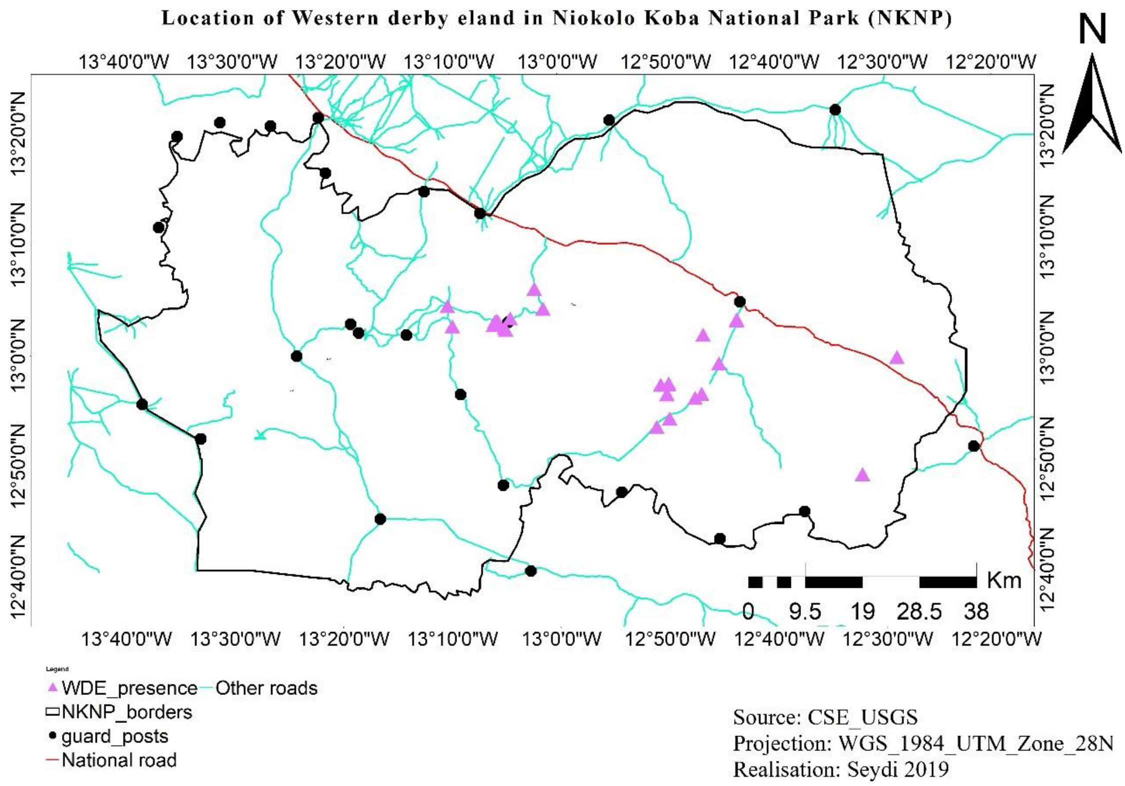


Figure 4: Positions of occurrences of Western Derby eland in the Niokolo Koba national park as input data for the MaxEnt model.

Table 3: The occurrence positions of Western Derby elands in the Niokolo Koba national park based on long-term data.

X	Y	Date	Site	Type of data	Provided by/ Note	Note
706244	1443131	24/05/2001	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
708801	1443703	20/06/2001	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
706756	1443196	5/6/2001	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
706399	1442610	14/11/2002	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
698362	1445725	24/06/2003	Badi x Patte d'Oie	Dung	P. Hejcmanová, pers.obs.	research
748243	1429451	14/06/2003	Tourmadala	Dung	P. Hejcmanová, pers.obs.	research
748486	1428989	14/06/2003	Tourmadala	Dung	P. Hejcmanová, pers.obs.	research
749429	1427189	14/06/2003	Assirick-Wouroli	Dung	P. Hejcmanová, pers.obs.	research
735093	1432958	14/06/2003	Mare Mansafara	Dung	P. Hejcmanová, pers.obs.	research
706401	1442555	22/06/2003	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
706686	1443163	22/06/2003	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
697322	1449862	24/06/2003	piste Bassari	Dung	P. Hejcmanová, pers.obs.	research
707864	1442123	2004	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
706553	1443297	2004	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
708063	1441803	2004	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
712818	1448623	2004	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
714277	1445296	25/04/2004; 04/04/2004; 06/05/2004	Lengué Kountou	Dung	P. Hejcmanová, pers.obs.	research
767494	1417777	23/05/2006	Mansa Fata north	Aerial count	Renaud et al. 2006, direct	monitoring
740938	1440995	28/05/2006	Banghare	Ground count	Renaud et al. 2006, indirect	monitoring
746537	1443542	04/01/2010; 28/01/2010; 23/01/2012; 07/05/2012		Camera traps	NKNP, Col. M. Sidibé	monitoring
773226	1437288	24/01/2012		Camera traps	NKNP, Col. M. Sidibé	monitoring
740705	1431137	12/12/2012		Camera traps	NKNP, Col. M. Sidibé	monitoring
743578	1436221	12/12/2012		Camera traps	NKNP, Col. M. Sidibé	monitoring
746522	1443335	23/01/2013		Camera traps	NKNP, Col. M. Sidibé	monitoring
734933	1431069	2017		Camera traps	NKNP, Col. M. Gueye	monitoring
735189	1432694	2017		Camera traps	NKNP, Col. M. Gueye	monitoring
733879	1432630	2017		Camera traps	NKNP, Col. M. Gueye	monitoring
733228	1425649	2017		Camera traps	NKNP, Col. M. Gueye	monitoring
734927	1431065	2018		Camera traps	NKNP, Col. M. Gueye	monitoring
735205	1432697	2018		Camera traps	NKNP, Col. M. Gueye	monitoring
735195	1432876	2018		Camera traps	NKNP, Col. M. Gueye	monitoring
699177	1442369	2016		Camera traps	NKNP, Col. M. Gueye	monitoring
735383	1427038	2017		Camera traps	NKNP, Col. M. Gueye	monitoring
739626	1430482	2018		Camera traps	NKNP, Col. M. Gueye	monitoring

3.3. Environmental variables

First, the basic layers regarding the official delimitation of borders of the NKNP, local roads within the NKNP, locations of active inhabited and ancient uninhabited rangers' camps, and villages around the NKNP were provided by the NKNP Administration. Then, we identified the following 6 variables that could affect the distribution of WDE in the NKNP and we used them as entry variables for habitat suitability modelling: type of land cover, digital elevation model (DEM), distance to rivers, distance to ranger camps, distance to national route, distance to villages. Environmental predictor variables were chosen based on the scientific literature and expert advice describing WDE dependencies on the environment (Table 4: **List of selected environmental and human-related variables as potential predictors of Wester Derby eland distribution in the Niokolo Koba national park.**).

The digital elevation model (DEM) with 30m resolution has been obtained from https://dwtkns.com/srtm30m/, then processed in ArcMap 10.7 (ESRI 2019).

Land cover data (Figure 5: **Land cover map in the Niokolo Koba National Park in Senegal.** was acquired from Mr. Gray Tappan from the USGS Earth Resources Observation and Science Center (see Appendix). The obtained shapefile contained 18 classes generalized to the level of vegetative structure, as well as the other parts of land use records. The data was cleaned of unclassified records and reclassified with Spatial Analyst tool in ArcMap 10.7 (ESRI 2019) to 9 classes existing in the study area (Table 5: **Classification of types of land use over the area of the Niokolo Koba national park and its surroundings. For reference of vegetation type (see GG Tappan - US Geological Survey 2012 or DPN 2018).**).

We measured human disturbances following these variables distance to rivers, distance to ranger camps, distance to national route, distance to villages. We calculated the distances variables using the Euclidean distances in Spatial Analyst tool in ArcMap 10.7 (ESRI 2019) (Figure 6).

Then, all the environmental variables have been converted 50m by 50m resolution using ArcMap 10.7 (ESRI 2019).

Table 4: List of selected environmental and human-related variables as potential predictors of Wester Derby eland distribution in the Niokolo Koba national park.

Predictor name	Abbreviation	Source of maps	Reason for inclusion
Type of land cover	LC	USGS - Earth Resources Observation and Science Center	Habitats form a primary living environment and niche for large herbivores which may exhibit a form of habitat selection, particularly in regard to their diet. WDEs as browsers (Hejcmanová et al. 2010) may potentially display a certain level of preference of habitat, despite we do not assume it.
Digital Elevation Model	DEM	Downloaded SRTM - https://dwtkns.com/srtm30m/	WDE was more frequently reported in the hilly area of the NKNP in comparison to flat parts of the park, therefore it may display a topographical preference, stated e.g. by Camara et al. 2016. It needs to be tested
Distance to river - water point	DR	Calculated from Eucledian distance tool in ArcMap from source data shapefile provided by DPN – NKNP, GIS unit.	The dependence to water sources needs to be tested in regards to distances of principal rivers in the park. WDEs in the semicaptive population in the Bandia reserve has been observed to come to water holes at daily basis (Brandlová et al. 2013).
Distance to the rangers' camps	DRC	Calculated from Eucledian distance tool in ArcMap from source data shapefile provided by DPN – NKNP, GIS unit.	Rangers' camps represent an anthropogenic feature in the natural habitat and functional camps can be noisy areas. Both, active and inactive camps may be for animals a source of disturbance.
Distance to national road	DR	Calculated from Eucledian distance tool in ArcMap from source data shapefile provided by DPN – NKNP, GIS unit.	Roads represent a linear anthropogenic feature which creates a source of disturbance for many wildlife species and represents a barrier causing the fragmentation of the living space. The importance for WDEs needs to be tested.
Distance to villages	DV	Calculated from Eucledian distance tool in ArcMap from source data shapefile provided by DPN – NKNP, GIS unit.	Villages are hub of human activities which substantially change the ecosystem, thus vegetation structure, are source of noise, represent a high risk of hunting/poaching, and create a high density of livestock (cattle, sheep, goat) encroaching the natural environment in the protected area.

Table 5: Classification of types of land use over the area of the Niokolo Koba national park and its surroundings. For reference of vegetation type (see GG Tappan - US Geological Survey 2012 or DPN 2018).

Class	**Land use (French)**	**Land use (English)**
Class 1 (Forest)	Forêt claire	Clear forest
	Forêt ripicole	Riparian forest
	Forêt dense	Dense forest
	Fourré	Thicket
	Forêt claire des vallées	Clear forest of the valleys
	Galerie forestière	Forest gallery
	Galerie claire ou dégradée	Clear or degraded gallery
Class 2 (Savannah)	Savane arbustive	Shrub savannah
	Savane boisée	Wooded savannah
	Savane herbeuse	Short grass savannah
Class 3 (Bowe)	Prairie herbeuse sur Bowe	Grass meadow on Bowe
	Arbustes et arbres sur Bowe	Shrubs and trees on ferralithic pans (bowe)
Class 4	Points d'eau	River
Class 5	Terrain rocheux	Rocky terrain
Class 6	Zone de culture	Crop fields
Class 7	Sols nus	Naked soils
Class 8	Carrière de latérite	Quarry of laterite

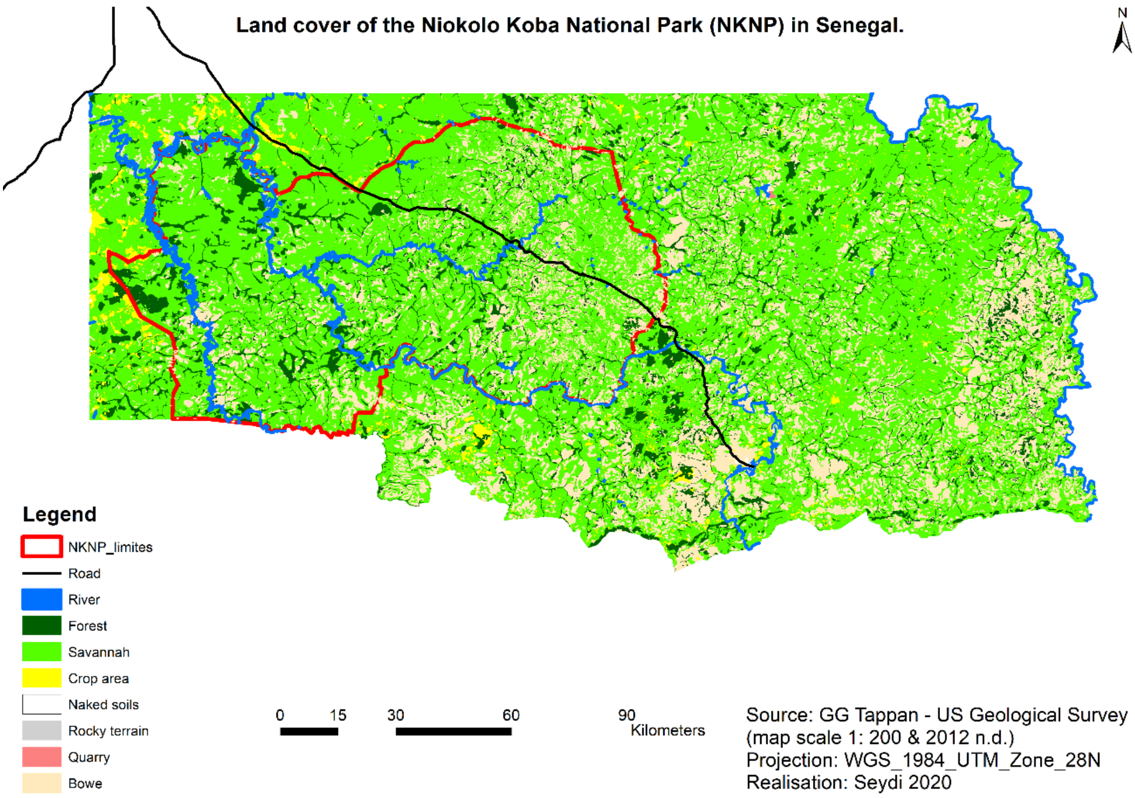


Figure 5: Land cover map in the Niokolo Koba National Park in Senegal.

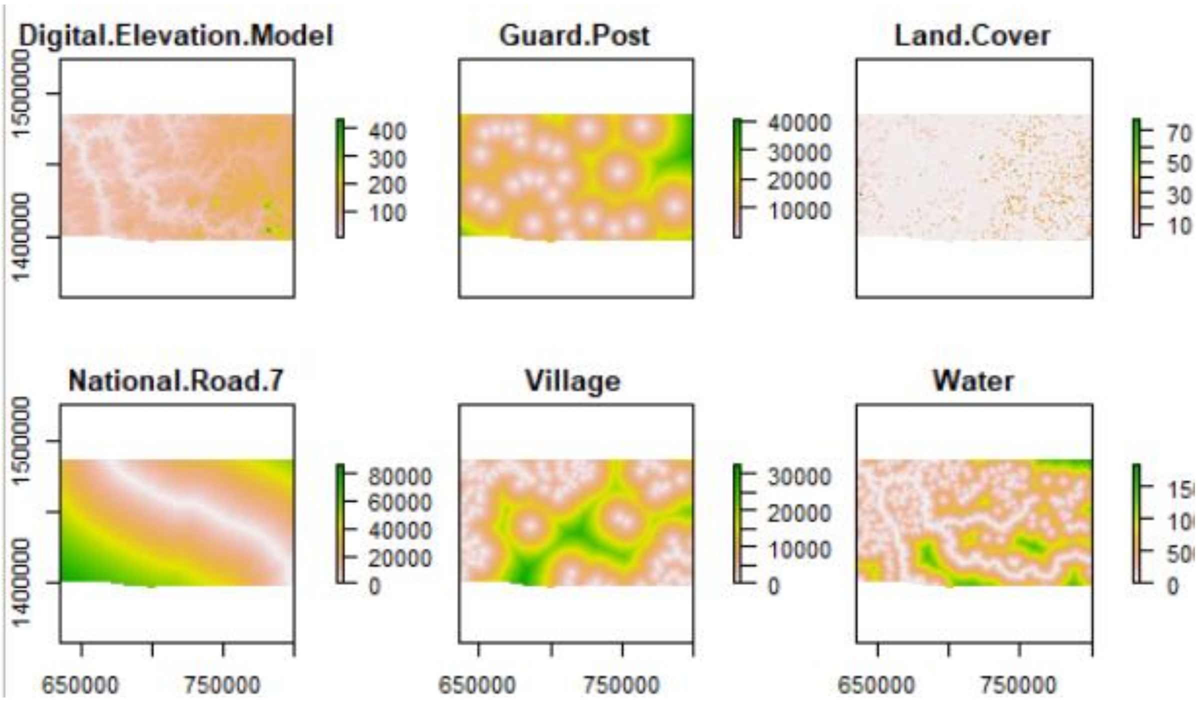


Figure 6: Environmental layers processed to become input variables in the model.

3.4. Modelling tool: MaxEnt

To map the suitable habitat for WDEs in the NKNP and analyse selected environmental and anthropogenic variables contributing to suitability, we used maximum entropy (MaxEnt) modelling approach (Phillips et al. 2006), a species distribution modelling algorithm that is well- suited for presence-background data and outperforms concurrent algorithms (Leathwick et al. 2006). It estimates relative probability of species presence given data on occurrence and user-selected variables. MaxEnt has been described as especially efficient to handle complex interactions between response and predictor variables (Hijmans et al. 2011; Ferrier et al. 2006) and to be little sensitive to small sample sizes (Wisz et al. 2008). Its ability to allow inferences from incomplete information or presence-only data (Phillips et al. 2006) makes it a powerful tool in case of studies with limited data.

This, as well as its extreme simplicity of use, has made MaxEnt the most widely used species distribution modelling (SDM) algorithm. MaxEnt modelling, and SDM in general, is now commonly implemented in conservation-oriented studies (Regan et al. 2013).

The method makes it possible to estimate the realized niche of the species by looking for the equilibrium state represented by the most frequent distribution statistically. This steady state corresponds to a maximum entropy value (Elith et al. 2011; Phillips et al. 2006).

MaxEnt analyses were performed using the dismo library (Elith & Franklin 2017; Hijmans et al. 2011) of R3.6.2 (R Core Team). The model results in a best-fit model classifying locations in the study area according to probability of presence in the range between 0 and 1, where 1 indicates the highest probability of presence.

We evaluated the model's predictive performance using the area under the receiver operating characteristic curve (AUC) (Swets 1988). AUC is a statistic measuring the area under the ROC (Receiver Operating Characteristic) curve. This curve is used to assess the performance of the models by analyzing the prediction value assigned to each of the pixels containing a presence. AUC measures the probability that a random presence point in the study area is ranked above background (or pseudo-absence) points (Phillips & Dudı 2008). The AUC was calculated for the model using the dismo library of R3.6.2. A model is generally considered to be efficient if its AUC value reaches at least 0.75, a random model has a value of 0.5 (Fosberg and Emeritus 1991) (Table 6: AUC classification). The ideal model has a value of 1, corresponding to 100% of true positives.

Table 6: AUC classification

AUC value	**Predictive value**
0.09 to 1.00	Excellent
0.80 to 0.90	Good
0.70 to 080	Fair
0.60 to 0.70	Poor
<0.6	Fail

Percent contribution, as a measure of the amount of explained variance each variable contributed to the model, was reported for each variable. The model was projected to the study area, which extends beyond the borders of the NKNP to assess the suitability of the area in the larger context than the protected area itself.

4. Results

4.1. Evaluation of the model

The fit of the final Western Derby eland habitat suitability model in the Niokolo Koba national park in Senegal using the six variables was 0.91 as indicated on the Figure 7 showing the values of the Area Under the Curve (AUC) for the implementation of the MaxEnt model and for its test. This indicates robustness of the modelling carried out and attests to the excellent performance of the MaxEnt algorithm in predicting the favourable area of the species studied.

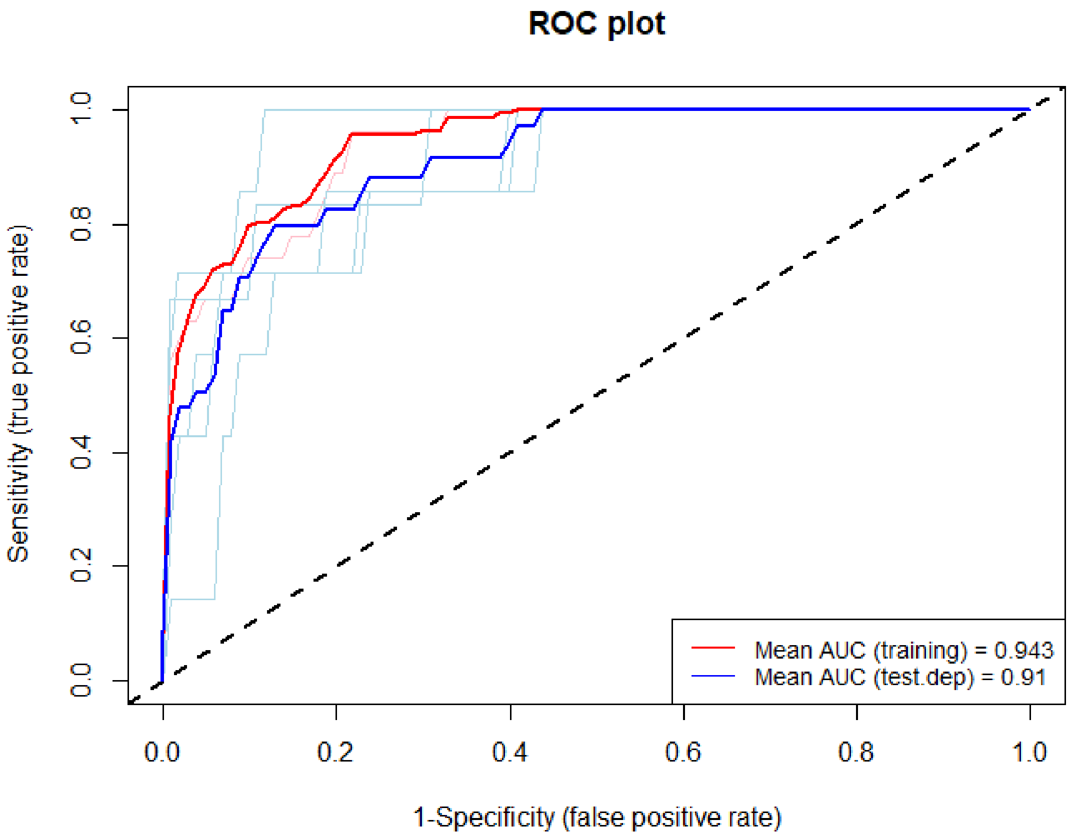


Figure 7: Output of the evaluation of the model using the area under the receiver operating characteristic curve (AUC).

4.2. Variable response curves and variable importance

The MaxEnt produced species response curves showing how each of six environmental and anthropogenic variables affected the final prediction of species distribution (Figure 8). The contribution, i.e. importance, of each variable to the final model is displayed in the Figure 9. Thereby the national road crossing the park and the distance to villages around the protected area were relatively the most important variables affecting the model. The distance to the national road plays important role showing that the proximity to the road is not indicated as suitable for the WDEs and suitability increases with distance, while it decreases again at certain point (the peak of suitability around 2.5 km from the road). Similar pattern occurred with the distance to villages indicating the peak of suitability at the distance approx. 20 km. The remaining variables were shown as less affecting the WDE distribution in the park in decreasing order as follows: distance to rangers' camps (guard), the elevation of the area, land cover, and distance to river (water) (Figure 9).

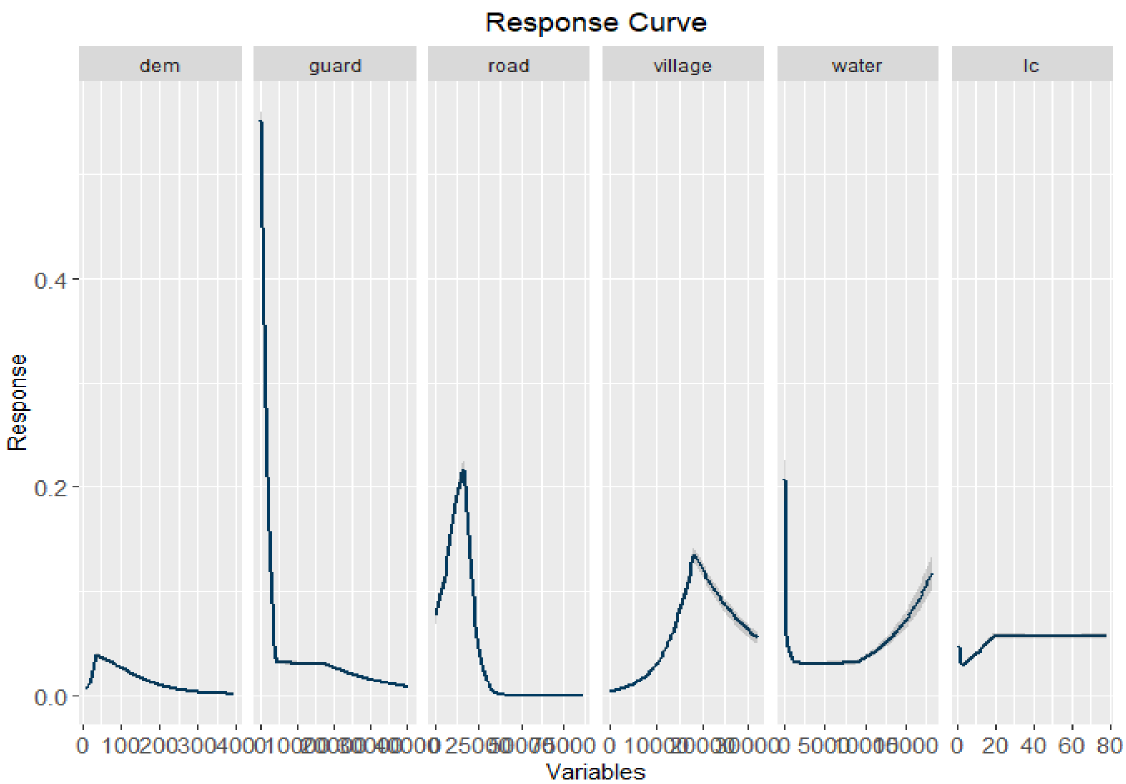


Figure 8: Response curve of the environmental variables in the model.

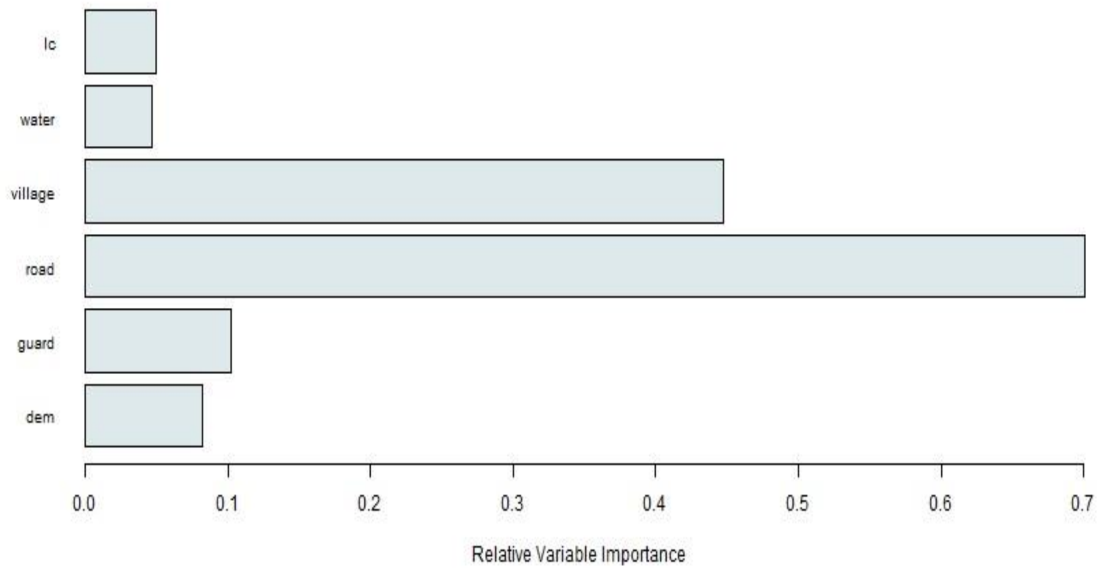


Figure 9: The importance (in %) of environmental variables in the final output model.

4.3. Habitat Suitability map using MaxEnt

The final output, i.e. the map of the model prediction of suitable and unsuitable habitat is shown at Figure 10. This predicted spatial distribution of the WDE confirmed the affinity of this species for the area in the core (central part) of the protected area, on both southern as well as northern side of the national road, avoiding the borders of park, the proximity of the road in the center of the park and a large sector south-western part the park, on the left side of the Gambia river in the direction to the Koulountou river. The predicted suitable area extended beyond the protected area border on the north-east of the park and there were some few patches on the northern border (Figure 10).

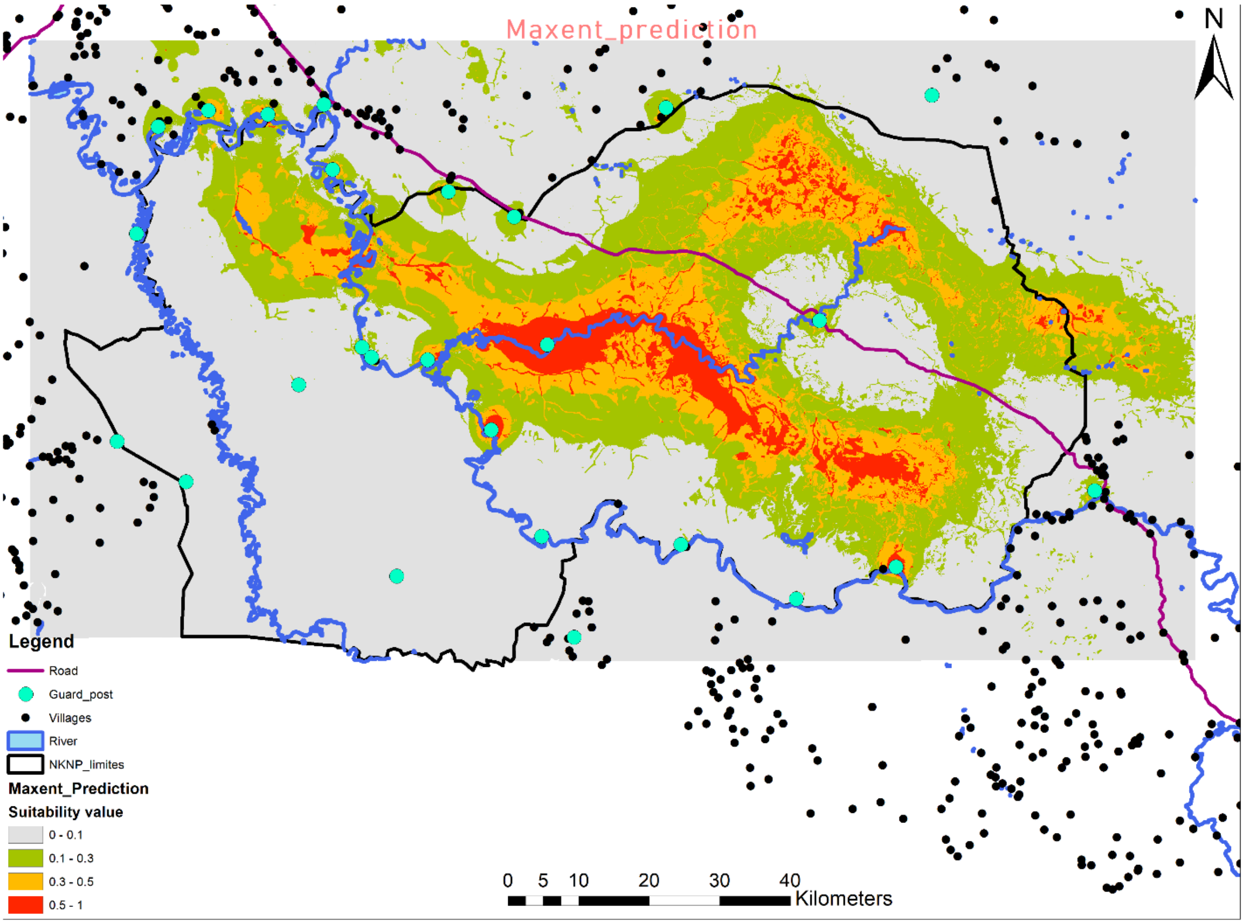


Figure 10: The map of the Habitat Suitability Model for the Western Derby eland in the Niokolo Koba National Park as the final output of the MaxEnt modelling tool.

5. Discussion

The final map of the habitat suitability model shows the highest probability of the WDE distribution in the central area of the NKNP, being the strongest in two core parts divided by the national road passing through the protected area.

The distance to the national road is the most affecting variable in the model, explaining up to 70% of the final output model. This national road between Tambacounda and Kedougou represents a very important commercial road with intensive freight transport of goods to/from neighbouring countries Mali and Guinea. It effectively slices the park in two parts. Inevitably the road creates a barrier for wildlife, thus WDEs movements across the landscape, contributing thereby to the fragmentation of the ecosystem and animal populations. Despite the traffic signs commanding drivers to the speed reduction, the heavy trucks pass exceeding the speed limits and increase the risks of wildlife collision. Wherever and whenever motorists and animals share the same space it is inevitable that some form of interaction will take place to the detriment of one or both parties (Eloff & van Niekerk 2008). The disturbance of this road to wildlife has been mentioned already by Verschuren (1983) when the transport was still at low frequency. Nowadays, however, the road is intensively used regarding the improved quality of the road, more intensive trade and rapid development of mining and related industry in the Kédougou region. At our knowledge, there is no published assessment of the real impact on the wildlife and frequency of collisions. The impact of the road on wildlife is not only because of the risk of collisions and fragmentation of habitats, but also increases the risks of intentional and/or unintentional fires started by drivers, easier access of illegal hunters, i.e. poachers, to the park, and changes (mostly degradation) of habitats by edge effects. There are, however, several patches of predicted distribution which cross the road. These parts would be worth of exploration directly in the field to reveal the real environmental value of these areas. For instance, one of these passes are directly at the ranger camp Niokolo where the road crosses the Niokolo River. The river forms there a permanent water point where many large ungulate species come. It is also at that site where the trucks have to stop for the formal control by rangers, thus the speed of the traffic is substantially low.

The next environmental factor with high importance for the WDE distribution model was the distance to villages. Further from the village, the more suitable habitat and higher probability of occurrence of WDE it was. It indicates that the animals prefer to avoid the area in the proximity of villages and that villages represent a significant human disturbance for these large antelopes. The human presence creates alterations in habitats, both food and water resources, and may be disturbing for simple reason of noise and lively rush. Last but not least, there is a higher risk of hunting close to the villages, as hunting, nowadays illegal (i.e. poaching) is a part of local culture at some parts of the NKNP periphery and source of subsistence. The avoided area related to villages, but already within the protected area correspond with the area occupied by grazing livestock, both cattle and sheep and goats, as recorded by aerial count in 2006 (Renaud et al. 2006). The presence of cattle, signs of overgrazing and strong erosion may appear in the areas most densely occupied by pastoralists, which raises fears of an advance of herds inside the NKNP in search of new pastures (Howard et al. 2007). This encroachment of livestock into the protected area for grazing generate a competition about the living space (niche) and food resources with the wildlife species. The spatial separation of wildlife species from grazing cattle invading into protected areas has been proved stronger for grazers such as hartebeest, Buffon's kob or buffaloes in the West Africa, probably due to direct competition for food, especially during the hot dry season in comparison to browsers (Hibert et al. 2010). Browsers such as WDE may be, however, affected not by the change of the vegetation in structure and woody plant species composition as reported by (Hahn-Hadjali et al. 2006 ; Nacoulma et al. 2011). The contact of wildlife with domestic animals represents also a high potential risk of disease infection. Disease can unfavourably affect animal population dynamics in the short and long term (IUCN Species Survival Commission n.d. 2005) and increases the risk of the extinction of rare species (Dahiye & Aman 2002).

Following the importance of the parameters, the next was the distance to ranger camps. The distance to ranger camps which are also representing a certain potential human disturbance was not already too strong predictor for WDE. We may find several complementary explanations. First, and the most important point is methodological. We used, in fact, the information about all ranger camps in the park, but there are some of them which are not already functional and were abandoned. This means that WDEs may occur there without any actual disturbance. It witnesses however the fact that locations of ranger camps in the NKNP, meaning the whole historical set of locations, were selected at sites with high importance to wildlife and have been fulfilling their mission of wildlife conservation. In addition, in terms of disturbance, the ranger camps are not comparable to villages, because of low number of people at one site at one time and because of overall nature and intensity of activities at the camps.

The topography, i.e. the digital elevation model, showed relatively low importance and does not therefore support an assumption mentioned by Camara et al. (2016) for a special preference regarding the altitude. There are no other data on the WDE spatial and habitat use in the NKNP to confirm any statement regarding the preference of hilly or flat areas and further research, for instance by more intensive camera trap or telemetric monitoring of WDEs in the NKNP would be beneficial to understand the specifics of the WDE ecology.

The least important variables in the model were land cover and distance to water resources, more precisely to principal rivers and marshes. Both variables are obviously affecting the distribution and spatial behaviour of many other species. Our findings therefore rise questions why land cover type and distance to water were not detected as important in the model. For the land cover type the reason could be that the ecosystem of Sudanian and Sudano-Guinean savanna in the NKNP is composed by a high variety of habitats, i.e. land cover types, and is structured in interspersed patches. It means that the vegetation cover in the NKNP is very mosaic and with many transition types of habitats. The difference in habitat types is not important from the distance perspective. The different types of habitat are close to each other at the scale of the park. As a result, animals move from one habitat to another easily, constantly and may thus occur in any of the present habitats. For instance, the Eastern subspecies of Derby elands move at daily distances up to 23 km (Graziani and D'Alessio 2004). If we assume similar behaviour in WDE in the NKNP, the animals would have to pass through the mosaic. It is very likely that at larger geographical scale encompassing large climatic and vegetation changes across landscape, the importance of land cover would increase. Similarly, we do not expect any specific effects of climatic parameters on the WDE distribution within the NKNP because of small geographical scale. The annual long-term temperatures and precipitation in the NKNP are stable and constant across the south-east of Senegal (Faye et al. 2019).

Similarly, as land cover types, the distance to rivers had low contribution to the model for very similar reasons. It means, that there are many water points in the NKNP besides those entered in the model. For instance, Renaud et al. (2006) documented that more than 200 temporary or permanent ponds have been identified in the NKNP, which are not mapped but do exist on the ground. Therefore, if the animals are water-dependent, there are many opportunities in water holes dispersed in the park and the animals will not display any specific relation to rivers. In addition, we may mention that the Gambia river is exploited also for the illegal fishing and illegal traditional gold mining which creates disturbance to animals and prevent them to come to rivers. In addition, like the common eland (Furstenburg 2012), the WDE may not be dependent on water and drink if it is available. However, such comparison would require more detailed ecological and behavioural study of the WDEs.

Besides the tested environmental variables and outcoming model, it is interesting to point out not only the areas predicted to be suitable to WDEs, but also the areas where the WDE have not been observed, neither modeled by the HSM. It is specifically the western part of the NKNP where a vast part of the protected area has not been identified as suitable for the WDE. The reason can be in human activities which were rather intensive last 20 years (Mauvais 2002 ; pers. comm.; Renaud et al. 2006), namely intensive livestock grazing and illegal logging of local palm *Borassus aethiopum*. However, the area may be also different in terms of topography or vegetation, but it was not detected by the model in terms of importance of these parameters. In any case, this gap in the use of space by WDEs is striking and would be worth of deeper study to get understanding where the constraint for the conservation potential in this part of the park is.

Similarly, an interesting part of the model is the potential suitability detected in the northern part of the NKNP. All WDE occurrence points entering in the model were located southward from the national road. The final model predicted, however, the area suitable for WDE northward from the national road. It indicates that there could be a suitable combination of environmental factors for the WDE and the area thus represents a big potential in terms of conservation. As it is not really clear what creates this suitability, it would be worth to investigate environmental conditions of this area in detail.

In addition to the interpretation of the final model it is necessary to point out some methodological aspects which obviously represent the limits of the present study. The main limitation of the study is very limited data on WDE occurrence in the park. Maxent have been shown to perform 90 % of maximum accuracy rate with only 50 sample points according to Stockwell & Peterson (2002), and more accurately than other modelling methods with as few as 5 to 25 sample points (Hernandez et al. 2006). Our AUC value of 0.91 suggested that the model fit was good, far closer to a perfect fit than a random one (Swets 1988). The main weakness does not lie therefore specifically in the low number of occurrence data, but in the sampling design of these data. Due to the lack of intensive and/or regular WDE monitoring, we had to use the data obtained throughout a long period between 2001 and 2018 and in an irregular nature. Moreover, some occurrence points were based on dung, while the other ones on camera trap records, but repeated records could not be used in the model, therefore the information about abundance of frequency of visits at certain locations are not accounted. To get more reliable results, a short-term intensive survey to get a snapshot of WDE presence in the park would be necessary.

The environmental variables provided good results, but the ecological relevance should be interpreted with caution. There are obviously more factors which play an important role for the distribution of the WDE in the park and contributes to the suitability of habitats which were not included in the model, mostly due to the lack of relevant data. Regarding environmental variables, we would recommend to use more detailed data on the water points available in the park landscape, together with actual, ground-verified map of habitats. The data on natural mineral licks are missing, despite they may be very important for wildlife, including Derby elands as reported from the Chinko protected area in the RCA (Švejcarová 2017). There also bushfires in the NKNP which may influence the spatial use of the protected area by large ungulates. However, the bushfires vary in time and space and creating a conceptually correct layer would require an independent study of the impact of fires on spatio-temporal movements of wildlife in savanna.

Regarding the anthropogenic factors, the principal missing data are data on cattle, sheep and goat distribution in the park, for instance the data from the aerial wildlife counts in 2006 and 2018 which would add a substantial explanatory strength. Then, the data on poaching, fishing, mining, and other human-related (illegal) activities in the park would contribute to understand the spatial distribution of the critically endangered WDE. Completing these missing layers coupled with correct design of occurrence data could result in performing better model and would contribute to the WDE conservation.

6. Conclusions

Using the MaxEnt tool, the habitat suitability model for critically endangered Western Derby elands in the Niokolo Koba national park in Senegal was built. The model was based on 33 locations of the WDE occurrence data and six environmental variables in order to estimate species – habitat relationships and to predict potentially suitable habitat. Regarding that the most important, explanatory variables were distance to the national road crossing the park and distance to villages, while other, mostly environmental variables (i.e. water, land cover, DEM) showed lower importance, we may conclude that the drivers and predictors of the WDE distribution in the NKNP are of anthropogenic origin, strongly related to human-induced disturbance which may be both, direct and indirect. In other words, the distribution of the WDE is most likely driven by avoidance of human activities.

We may conclude that the model identified the areas in central part of the protected area on both sides of the national road as suitable and can be therefore determined as critical conservation areas for targeted conservation actions. The model predicted also the areas with low probability of distribution of the WDE in the park, which are in the proximity to the borders of park, the proximity to the road in the center of the park, and a large sector in the south-western part the park, on the left side of the Gambia river in the direction to the Koulountou river. The reasons of avoidance are worth of deeper investigation.

This model can be used for informed, science-based and effective conservation decision-making, especially in the perspective that the WDE is critically endangered antelope and its population is very low and geographically very restricted. Further, this model could be enhanced with more occurrence positions and by including more environmental variables to produce variations in predictions, allowing for more conclusive results.

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Appendix

Figure AI. All land cover types in the original land cover layer showing the images and vegetation structure schema of individual types, i.e. habitats (Source: Tappan 2012).