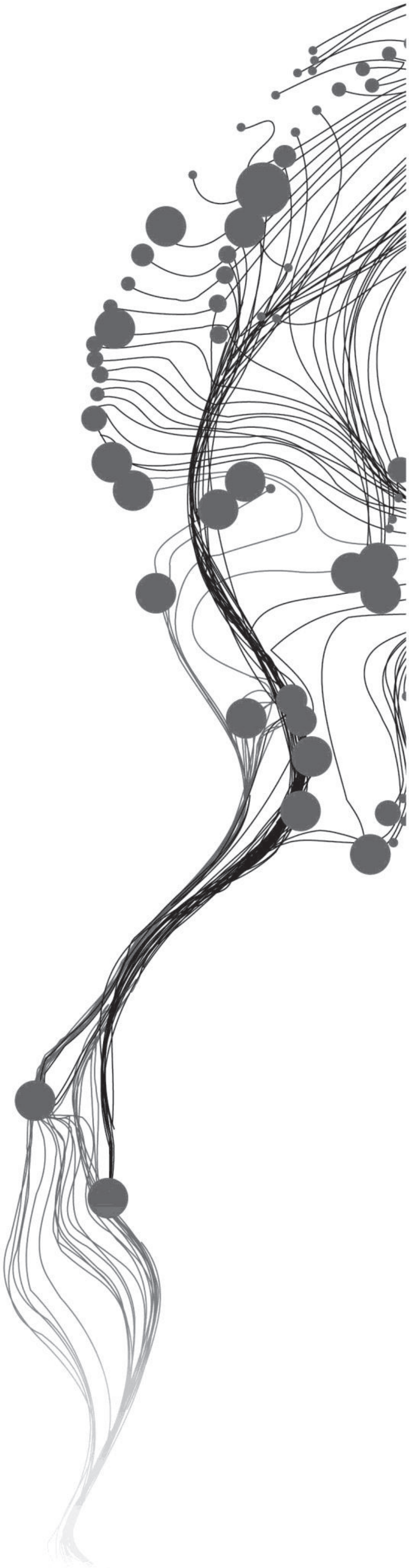
Modeling the Spatial Distribution and the Risk of Hunting Pressure of Three Co-occurring African Pangolins in Ghana

ATTA-KUSI ERIC
March, 2013

SUPERVISORS:
Dr. Tiejun Wang, ITC, Netherlands
Dr. A. Arko Adjei, KNUST, Ghana
Mr. L. Addae-Wireko, KNUST, Ghana



Modeling the Spatial Distribution and the Risk of Hunting Pressure of Three Co-occurring African Pangolins in Ghana

ATTA-KUSI ERIC
Enschede, The Netherlands, March, 2013

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente The Netherlands and Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology Ghana, in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

SUPERVISORS:
Dr. Tiejun Wang, ITC, The Netherlands
Dr. A. Arko Adjei, KNUST, Ghana
Mr. L. Addae-Wireko, KNUST, Ghana

THESIS ASSESSMENT BOARD:
Chairman: Prof. Dr. A.K. (Andrew) Skidmore, ITC
External Examiner: Dr. B. Kumi Boating, UMAT
Internal Examiner: Mr. John Ayer, KNUST

ABSTRACT

Knowledge on spatial distribution of species and hunting pressure is vital to conservation planning and management of threatened wildlife species. Species distribution models can be applied to map potentially suitable and priority areas, making them essential tools in conservation studies. These models are also used as a guide to the selection of areas for systematic ecological studies and wildlife management purposes. Not much is known about the current distribution pattern and hunting pressure on pangolin in Ghana and West Africa as a whole. To understand this, the study employed the MaxEnt model to map the probable distribution of three threatened African pangolins in Ghana. The study as well mapped the distribution of risk of hunting pressure using six important anthropogenic factors known to influence game hunting in West Africa. The MaxEnt model was run using presence only data of the three known pangolin species in Ghana. Eleven environmental variables suspected to influence pangolin distribution were used for the MaxEnt modelling of the three species at 1 by 1km resolution. The three models were evaluated using the area under the ROC curve (AUC) whilst the jackknife test was used in determining the importance of the variables used in the models. At probability threshold of 0.6 for distribution maps of all three species, model for the Giant pangolin (Manis gigantea) yielded the widest potential distribution with extent of 22,060km² (representing 9% of the study area) followed by the Tree pangolin *(Phataginus tricuspis)* 18,500 km² (7.5%). The Long-tailed pangolin (*Manis tetradactyle*) had the least distribution with total extent of 5,200 km² (2.1 %). South western part of Ghana dominated by semi-deciduous and high rain forest showed high probability of occurrence for all 3 pangolin species than other parts of the study area. The three models performed better than random with mean AUC (> 0.8). The most important predictor variable for both Long-tailed pangolin and Tree pangolin is dry-season NDVI. Maximum Temperature was the most important variable for predicting the distribution of the Giant pangolin (*Manis gigantea).* Aspect and mean annual temperature were of least importance to predicting distribution of *Manis tetradactyle* and *Manis gigantea.* To evaluate the level of threat on pangolins in Ghana with regards to hunting, risk of hunting pressure map was modelled using selected anthropogenic factors such as ; road density, distance to bushmeat markets, human population density, distance to game reserves, distance towns and ecological factors like cover type and species preference. The resultant risk map revealed that all three pangolin species in Ghana are potentially prone to high risk of hunting pressure. However, areas in and around game reserves showed low to moderate hunting pressure mainly due to lack of road accessibility and low human population density. Even though there are challenges to the applicability of species distribution models, comparing potential and known distributions can enhance the reliability of model outputs as well as offer resource managers with much confidence in strategizing for conservation programs. Lastly, the move towards identifying areas of potential risk of hunting pressures can be applied to effective planning of anti-poaching operations and evaluation of law enforcement programs to realize optimum results.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the Almighty God for His guidance and protection throughout my study both in Ghana and the Netherlands.

My profound gratitude goes to the Wildlife Division of the Forestry Commission for nominating me for the fellowship. I also express my sincere appreciation to NUFFIC for sponsoring my entire study.

Special appreciation also goes to my first supervisor Dr. Tiejun Wang of ITC, for his immense support, critical comments and encouragement during the entire period of my research. I am equally grateful to Mr. Louis Addae-Wireko and Dr. A. Arko-Adjei, my supervisors from KNUST for their advice and suggestions.

I also thank the entire staff of the NRM program both in Ghana and at ITC for their help throughout the course. I cannot proceed without recognizing the immense support of the Ghanaian community resident in Enschede, especially the Ghana Student Union of ITC, you really made me feel at home. God richly bless you.

I am also indebted to my colleague Wildlife Officers at the various parks in Ghana who were always ready to provide me with the needed field records during my research; space will not allow me to mention your names. I am really grateful.

My appreciation also goes to the NRM/GISNATUREM 2012 group, Alex, George and Lillian; I really enjoyed your company.

Finally, my heartfelt gratitude goes to my family for their continuous support and prayers. And to my dear wife and my daughter, "Little Abi" I say big 'Kudos' to you for always being there for me.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Acronyms

ASCII	American Standard Code for Information Interchange
AUC	Area Under the Curve
CREMA	Community Resource Management Area
DEM	Digital Elevation Model
ESRI	Environmental Sciences Research Institute
GIS	Geographic Information System
GSBAs	Globally Significant Biodiversity Area (s)
MaxEnt	Maximum Entropy
NDVI	Normalised Difference vegetation Index
PAs	Protected Areas
ROC	Receiver Operation Characteristic
USGS	United State Geological Survey
SDM	Species Distribution Model
UTM	Universal Traverse Mercator
VIF	Variance Inflation Factor
WD	Wildlife Division

1. General introduction

1.1. Background

Wildlife and wildlife products constitute a significant component of the natural resource needs of mankind. More than 60% of the people in the developing parts of the world rely on wildlife for their nutritional and medicinal needs (Pullan, 1981; Saha & Sundriyal, 2012). Many rural households globally rely on wildlife and other non-forest timber products as their subsistence and/ or main source of income (Saha & Sundriyal, 2012).

Habitat loss due to clearing, logging and other human-related activities is considered a serious threat to the survival of global wildlife fauna in recent times. One of the major consequences of environmental degradation resulting from ecosystem alteration is the loss of species diversity, which is happening at a very rapid rate than ever before (McNeely *et al.*, 1990; Oates *et al.*, 2000; Santos *et al.*, 2009; Scholes *et al.*, 2006; Sorace, 2001; Zahler, 2001) The major factors that contribute to biodiversity loss and for that matter, depletion of global wildlife resources are over-exploitation, habitat degradation and conversion of forest to other land use.

In Africa, some studies have suggested that many regions with high species richness are expected to experience substantial biodiversity losses in the next few decades (Hannah *et al.*, 2002; Midgley *et al.*, 2002). There is also general concern about the rapid decline in West Africa's faunal populations, once considered a major hotspot for wildlife population on the African continent (Fa & Brown, 2009). Significant among these are the small to medium-sized mammals which constitute a major component of the diet of most of the people (Abedi-Lartey, 2004; Alves *et al.*, 2010; Fa & Brown, 2009). For example, populations of four of the eight pangolin species in the world, found in this region are said to be threatened due to the rise in their exploitation as bush meat, medicinal, mythical and more, recently through illegal wildlife trade (Barnett & Prangley, 1997; Fa & Brown, 2009; Fynn & Bonyongo, 2011; Mbete *et al.*, 2011). In order to address the numerous challenges confronting conservationists and managers of wildlife resources in Africa, there is the need to provide adequate information of the current status and factors that threatens biodiversity in all parts of the continent. Although considerable amount of information can be found on the plant community of most regions in Africa, similar records are lacking on wildlife resources, mainly due to the high cost involved in conducting conventional field surveys on animals than on plants (Pullan, 1981). Spatial records are particularly limited on most threatened wildlife species, especially in the West Africa sub-region (Lehmann et al., 2007). The need to fill the wide information gap on the status, distribution and ecological requirements of wildlife resources in the West Africa sub-region and Africa in general is therefore, more crucial now than ever.

The advancement of geographic information science and remote sensing techniques have provided other cost-effective ways of mapping natural resources beyond the conventional field survey and image interpretation. These have further led to the development of several environmental- based models also capable of successfully mapping faunal distribution (Elith *et al.*, 2006; Pearson *et al.*, 2006; Wiens *et al.*, 2009). Studies into GIS and species distribution models to predict species distribution and abundance have been used to provide useful information in many regions with limited datasets, at relatively cheaper cost without compromising on quality of information (Aarts *et al.*, 2012; Heumann *et al.*, 2011; Jackson & Robertson, 2011; Loiselle *et al.*, 2003; Phillips *et al.*, 2006). In many instances, few historical presence only records on endangered and threatened species have proven very crucial in identifying priority areas for conservation purposes through the use of ecological models (Phillips*, et al.*, 2006). Recently, much interest has also been generated on the significance of biodiversity hotspots and how GIS and remote sensing techniques can be used to generate useful information in that field. Identifying biodiversity hotspots and prioritizing the management of such hotspots have been considered as very important for protecting threatened and endangered species in countries with limited budget for conservation programs. Ghana, like many other West African countries with huge data deficit and limited budget provides a perfect scenario for the adoption of GIS and remote sensing techniques that utilizes minimum datasets available to generate useful information for biodiversity conservation planning.

1.2. Problem statement

Pangolins have been a staple of traditional West Africans for centuries (Akpona *et al.*, 2008; Fa & Brown, 2009; Mbete*, et al.*, 2011; Oates*, et al.*, 2000; Pullan, 1981). Pangolin scales and blood are used in traditional medicine, the meat is a delicacy, and stuffed pangolins are sold as souvenirs (Akpona*, et al.*, 2008; Asibey, 1974; Fa & Brown, 2009). In Ghana, all three pangolin species found in the country are eaten by majority of the people (Asibey, 1974). However, due to growing human populations and loss of suitable habitat there has been increasing pressure on the species.

Figure 1: Typical bushmeat processing centres and selling joints in West Africa.

The high value put on pangolins in the West African Sub-region does not, however, commensurate with the available literature on the species. For example, in Ghana presence records on pangolins are only scattered and kept at the various parks and protected areas where these data are collected. Similar records are also available in recent faunal surveys conducted in 24 globally significant biodiversity areas in Ghana (Hillers *et al.*, 2009; Larsen, 2008; Oates*, et al.*, 2000; Ryan & Attuquayefio, 2000). There are however, no available records on the distribution, critical ecological requirements and impact of human activities (Fa *et al.*, 2000), on the three co-occurring pangolin species in Ghana. Even though conservationists have suggested that where there is insufficient data on a particular species one can use its presence only records as a means to assess its conservation status (Rodríguez *et al.*, 2007), no attempt has been made to generate useful information from the available presence data on the pangolin species in Ghana. Given that, there are concerns about the imminent extinction of pangolins if no conservation efforts are put in place, and the fact that Ghana is one of the few African countries where three of the four African pangolins co-exist makes the continue lack of information on their spatial distribution and uncertainty regarding their hunting pressure very serious.

In light of the current exploitation, threat to conservation and the information gap on pangolins the present study will examine the distribution patterns as well as potential risk of hunting pressure of the three co-occurring African pangolins in Ghana using GIS and remote sensing approaches in order to provide reliable information to enhance their sustainable management. The study will in addition, provide insight into how the available data can be used to improve our understanding of which areas require optimum attention for the conservation of pangolins.

1.3. Study objectives

1. To model the distribution of the three co-occurring African pangolins in Ghana.
2. To determine the environmental variable that is most important in predicting the distribution of each of the three species in Ghana.
3. To identify diversity hotspots of pangolins in Ghana.
4. To determine areas of potential risk of hunting pressure on pangolins in Ghana.

1.4. Research questions

The research would answer the following questions;

1. What are the distribution patterns of the three African pangolins in Ghana?
2. Which environmental variable is most important in explaining the distribution of each of the three pangolin species in Ghana?
3. Where are the diversity hotspots of pangolins in Ghana?
4. Which areas are potentially at risk to hunting pressures on pangolins in Ghana?

1.5. Hypothesis

- H_{0}: The selected environmental variables for the MaxEnt model do not predict pangolin distribution better than prediction by chance.

- H_{1}: The selected environmental variables for the MaxEnt model predict pangolin distribution better than prediction by chance.

1.6. Research approach

The research approach consists of two main parts; the first part is the modelling of the spatial distribution of three pangolin species and the second part is evaluation of potential hunting pressure (Figure 2).

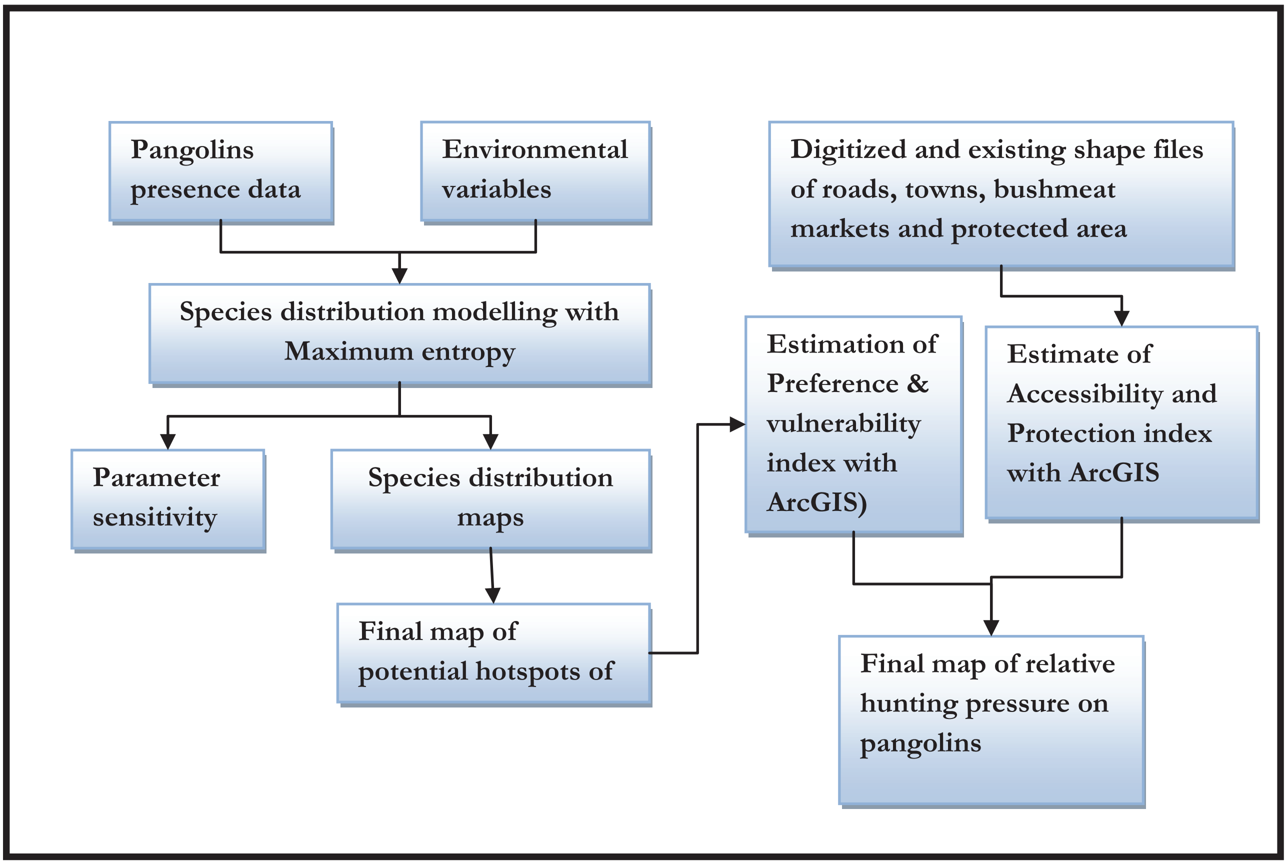


Figure 2: Framework of the research approach

2. Materials and methods

2.1. Study area

The study area is Ghana, formerly called the Gold Coast, and lies within latitude 4° 44´N and 11°11´N and 3°11´W and 1°11´E. Ghana shares boarder on the east with The Republic of Togo, Burkina Faso in the north and la Cote d'Ivoire on the western part (Figure 3). The Gulf of Guinea of the Atlantic Ocean is at the south of the country, which forms a coastline of 550 km long. With a total area of about 240,000 km^2, Ghana has a population of about 25,000,000 and average population density of 105/km^2 (Ghana Statistical Service, 2012). The climate of Ghana is the tropical type; with temperatures varying with season and elevation. The climate of Ghana ranges from a bimodal rainfall equatorial type in the southern sector to the tropical uni-modal monsoon type in the north. Mean annual temperature is 27 °C with absolute maxima approaching 40 °C, especially in the northern regions. The absolute minimum temperature goes down to about 15 °C. The coastal region which is influenced by the sea breeze has annual temperature range of between 5-6 °C with the interior having a range of about 7 °C to 9 °C (Oduro-Afriyie, 1996). The amount of rainfall generally decreases as one move from the south to the north. The wettest part of Ghana is the extreme southwest where the rainfall is in excess of 2,000 mm per annum. In most parts of the north, the annual rainfall is less than 1000 mm. Ghana's vegetation is part of the complex structure of West Africa, which stretches between the Sahara and Gulf of Guinea. As one of the biodiversity hotspots in Africa, there are rich resources of flora and fauna especially at the south-western part of the country. The main vegetation formations comprise of the Coastal Savannah, Guinea Savannah, Sudan Savannah , the Transition Zone, Semi Deciduous and High forest zone (Hall & Swaine, 1976). The Transition zone is an area expanding along the forest fringes where grassland is gradually replacing forest (Figure 3).

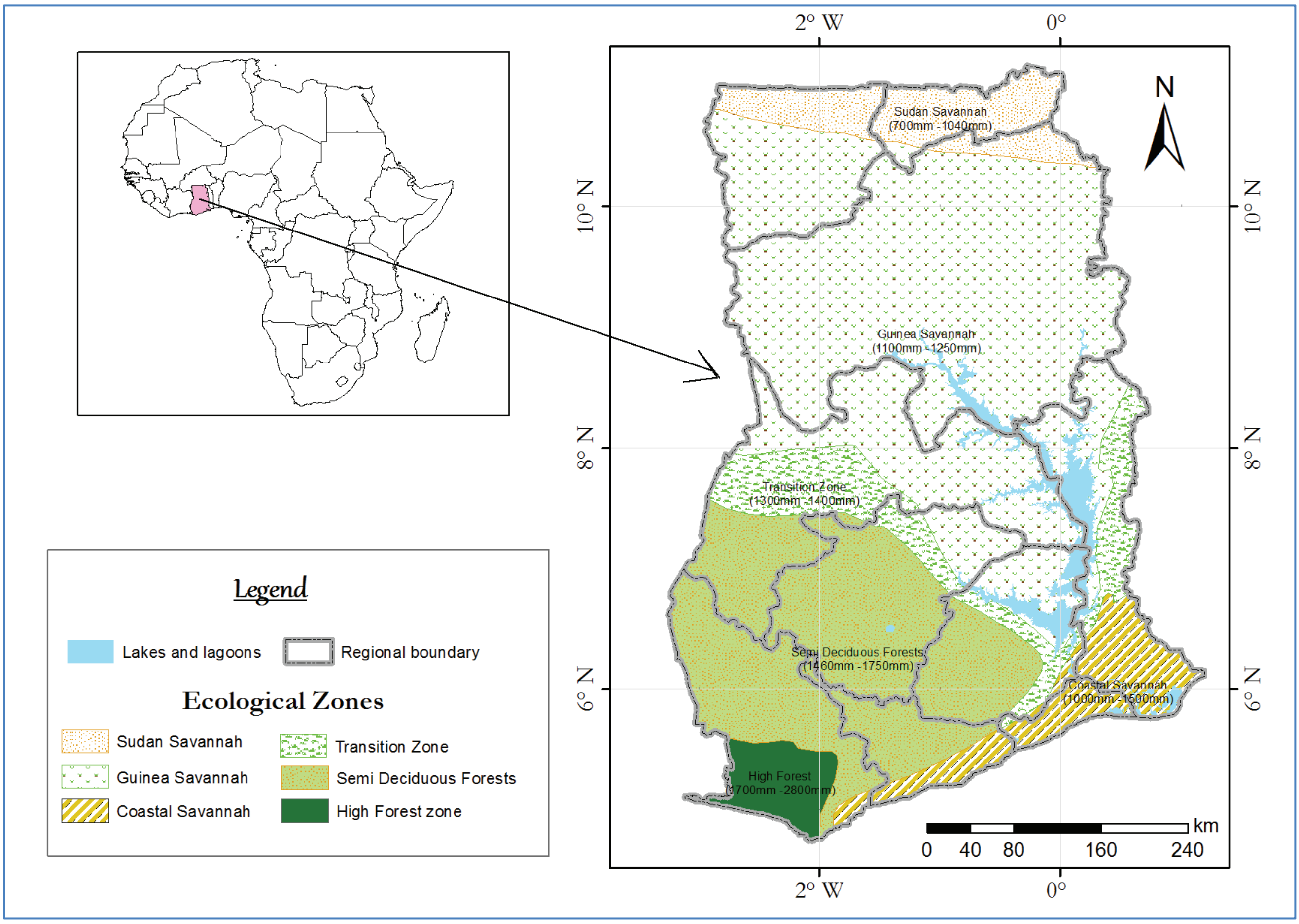
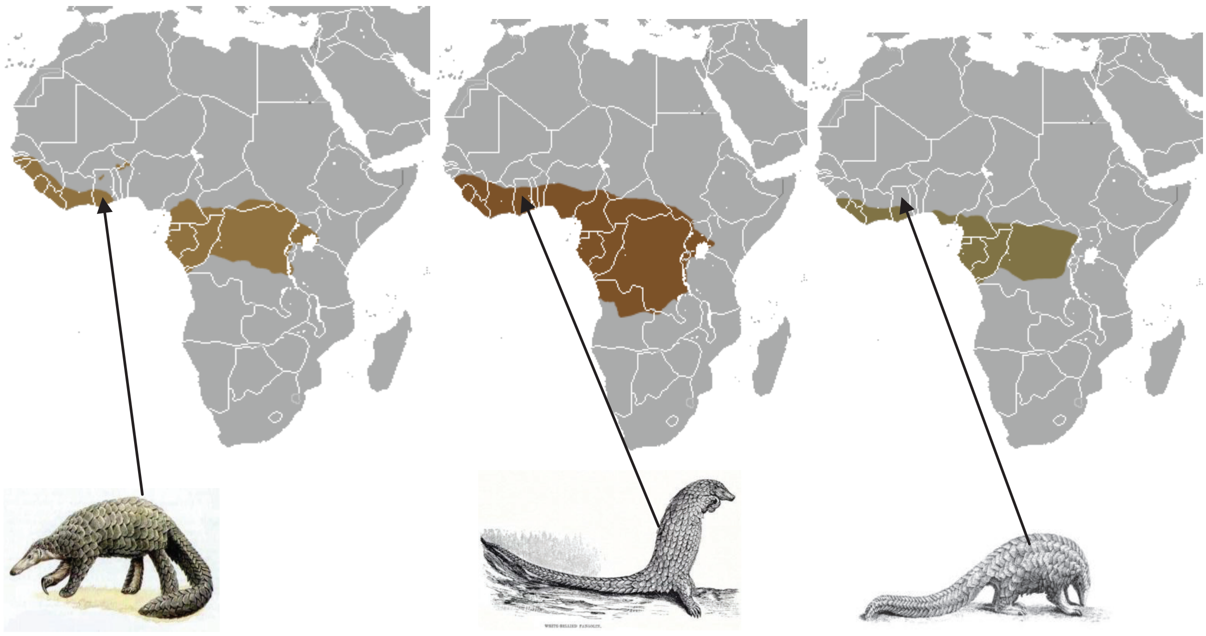


Figure 3 Map of study area (Ghana) showing the major ecological zones

Most of Ghana's soils are developed on thoroughly weathered parent materials, with alluvial soils and shallow soils (Leptosol) being common to all ecological zones. Soils found in the forest zones are classified under forest Oxysols and forest acid Gleysols. Soils that occur in the savannah zones originate from various igneous, metamorphic and sedimentary rocks, which determine the nature and properties of the soils. The terrain of Ghana comprise mainly of low lands with the Kwahu Plateau in the south-central area. Half of the country is bellow 152 m above sea level, whilst the highest peak is 883m. Ghana has four distinct geographical regions in terms of terrain description. The Low plains extend across the southern part of the country. The north has three regions--the Ashanti Uplands, the Akwapim-Togo Ranges, and the Volta Basin. The diverse flora and fauna composition of the country reflects its complex vegetation structure. The evergreen and semi-deciduous forests harbours several economic tree species like Sapele, tall-silk cottons, kolas, and various West African hardwoods such as Mahogany, Odum, and Ebony. The northern part is covered by savannah (tropical grassland with a scattering of shrubs and trees), featuring Shea trees, Acacias, and Baobabs. Large mammals such as elephants, tigers and lions that use to be found almost everywhere in the savannah regions are now rare and largely confined to nature reserves. The forest expanse provides habitat for several primates, reptiles, antelopes and pangolins. There are more than 725 bird species in Ghana.

2.2. Description of pangolin species

Pangolins are members of the genus *Manis* in the family Manidae, the only known family in the order Pholidota. Closest kith and kin are the armadillos, Xenarthrans-anteaters, and sloths. There are eight pangolin species worldwide. Four of the pangolin species are found in Asia. These are Chinese or Formosan pangolin, Malayan or Sunda pangolin, Palawan pangolin and Indian pangolin (Norman & Lim, 2007). The remaining four species are found on the Africa continent. There is the Cape or Ground pangolin, Tree pangolin, the Giant pangolin and the Long-tail pangolin. Pangolins are generally distinct by protective overlapping scales which cover most parts of their body. The four Asian pangolins are easily distinguished from the African species by the presence of bristles which emerge from between the scales. Pangolins can survive in a variety of habitats including tropical forests, thick brush, savannah grassland, and sometimes cleared and cultivated areas (Akpona*, et al.*, 2008). In general pangolins occur in areas with large numbers of ants and termites. African pangolins are particularly threatened by loss of suitable habitat due to expansion in agriculture, exploitation as food (in the form of "bush meat") and recently, through illegal wildlife trade (Fa & Brown, 2009). Pangolins create deep burrows for sleeping and nesting young ones. The Malayan pangolin can also sleep in the hollows and forks of trees and fallen trees. Pangolin scales offer good defensive mechanism against predators. The current study will focus on three of the four African pangolin species found in Ghana: namely, the Tree or African white-bellied pangolin (*Phataginus tricuspis*), the Giant pangolin (*Manis gigantea*), and the Long-tailed or black-bellied pangolin (*Manis tetradactyla*).



Giant pangolin **Tree pangolin** **Long-tailed pangolin**

Figure 4: Geographical distribution of the three pangolin species understudy on the African continent. Source: Wikipedia

2.2.1. Tree pangolin (*Phataginus tricuspis*)

Tree pangolin, also called three-cusped pangolin, happens to be the most widespread of the African forest pangolins. It is currently listed as Near Threatened due mainly to the impact of hunting for bushmeat (Fa & Brown, 2009). Habitat of the Tree pangolin stretches from Guinea through Sierra Leone and much of West Africa to Central Africa as far east as Kenya and north-western Tanzania. Its habitat further extends to Angola and as far as north-western Zambia. The Tree pangolin is able to move on all four legs or on its hind legs by using its tail for balance. It has a well-developed sense of smell, which compensates for its poor eyesight. It has no teeth and relies on its gizzard-like stomach to digest ingested food. It is able to swim across water through buoyancy by filling its stomach with air before entering into water. The Tree pangolin is subject to widespread exploitation for bushmeat, traditional medicine, and is by far the most common of the pangolins found in African bushmeat markets (Akpona*, et al.*, 2008). In Ghana, the Tree Pangolin can be found in Atewa and Apedwa forest reserves.

2.2.2. Giant pangolin *(Manis gigantea)*

Giant pangolins, *Manis gigantea* are found to inhabit areas stretching along the equator from West Africa to Uganda. This species is mainly found in the rain forest and sometimes the savannas, inhabiting areas with high termite populations and water. The Giant pangolin is known to select low lands over high elevation areas. It is the largest of all four pangolin species in Africa. On average, one Giant pangolin has been found to weigh 25 kg. The males are usually bigger than females, with males having average length of about 140 cm and females about 125 cm. The infants have soft scales that eventually harden as they grow and are born with their eyes already open (Wilson, 1994). Records on Giant pangolins have been reported in the forest and savannah regions of Ghana (Asibey, 1974).

2.2.3. Long-tailed pangolin *(Manis tetradactyle)*

The Long-tailed pangolin, *Manis tetradactyle*, popularly called black-bellied pangolin is a tree dwelling pangolin whose origin can be traced to the forests of sub-Saharan of Africa. The species derived its common name practically from its long tail which averages 60 cm. Notwithstanding its long tail the long-tailed pangolin is the smallest of the four species in Africa. This species is mostly found in the high forest regions of West and Central Africa, with its habitat spanning from Sierra Leone through south-eastern Guinea, Liberia, Côte d'Ivoire and Ghana. It is also found in Cameroon as well as the Congo Basin forest block. There is lack of quantitative data on the density or abundance of the long-tailed pangolin. This particular species is considered as the least recorded of all African pangolin and known to be very shy. The Long-tailed pangolin basically lives on trees, and mainly restricted to least-disturbed habitats.

2.3. Data requirements for species distribution model

2.3.1. Species Presence data

Presence only points of the three African pangolins in the study area were used. Occurrence records on the three African pangolins found in Ghana were collated from existing independent field points on the target species taken by wildlife field officers in and around protected areas where any of the species have been located. It consists of X, Y coordinates where pangolins have been observed by either direct observation or signs (spoor, footprint, scales) of its presence. Additional presence points were extracted from independent data sources from fauna surveys in 24 Globally Significant Biodiversity Areas (GSBAs) in Ghana. The period of records spans between 2003 and 2010. Few extra field points were collected during the study from areas where pangolins have been observed but their GPS locations were not available. This extra data was used to augment the existing ones and were used to validate the distribution model. All species occurrence points were converted to a comma delimited value (.csv) format as required by MaxEnt. The final (.csv) file contained the species name, latitude (Y) and longitude (X) in the required projection system.

Table 1: Pangolin presence only data

Species	Training points	Testing points	Total
Tree pangolin	153	51	*204*
Giant pangolin	73	25	*98*
Long-tailed pangolin	85	29	*114*

2.4. Selection and pre-processing of environmental variables for species distribution modelling

Species are normally distributed within certain temporal and spatial scale due to prevailing environmental conditions (Pearson*, et al.*, 2006). Selection of environmental variables greatly influence the outcome of species distribution models, thus careful selection of variables is important step in species modelling. Pangolin habitat consists of natural and physical environment, and the quality of pangolin habitat is limited by many environmental factors. Suitability of the habitat depends on both biotic and abiotic conditions; abiotic environmental factors include slope, elevation and aspect, and biotic factors include vegetation cover and food and shelter requirements of the species.

Eleven environmental variables were selected for this study on their potential relevance based on expert knowledge and from other studies on ecological requirements of pangolin species. The environmental variables used for this study are elevation, slope, aspect, annual mean temperature, mean temperature for driest months, mean temperature for wettest months, precipitation for dry season, precipitation wet season, normalized difference vegetation index (NDVI) for the wet and dry seasons.

Although records of direct relationship between African pangolins and topographical variables like slope, elevation and aspect have not been reported on, the current study included them to observe their contribution to the model since these categories of environmental variables might interacts with climate and vegetation to influence pangolin distribution. Slope and elevation are two important biophysical factors which influence the distribution of both fauna and flora. For instance the Giant pangolin has been observed to avoid high-altitude areas as it requires higher energy expenditure to access areas with variability in terrain. The terrain variables used for the study were obtained from the USGS Digital Elevation Model (DEM) data files which consist of range of elevations of a number of ground points at regular space and intervals. These digital geographic data files are produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program. The DEM used for this study had spatial resolution of 90m by 90m which was resample to 1km by 1km to ensure integration with other data sources.

Despite the generally lack of information on the role of climatic variables in predicting the distribution of pangolins, other studies using species distribution models have reported that there might be casual relationship between climatic variables and fauna distribution (Jackson & Robertson, 2011; Miller & Franklin, 2010; Phillips & Dudík, 2008). Climate data for this study was obtained from Worldclim bioclimatic database (http://www.worldclim.org/), which has 19 climatic variables for the period 1950 – 2000. The climatic layers were generated by interpolation of average monthly data from weather stations using thin plate smoothing. The variables were extracted from the monthly temperature and precipitation values which were in ESRI Grid Format at 1km² (30 arc seconds) resolution.

All environmental layers for the modelling were standardized to the same projected coordinate system (WGS 1984 UTM Zone 30N). The datasets were subjected to further manipulations such that all environmental layers have consistent grid size and spatial extent. Layers that were not in raster format were also converted to raster format using ArcGIS, ArcToolbox-Conversion Tools. The datasets were then converted to ASCII format so that it could be run in Maxent.

2.5. Modelling the distribution of three pangolin species using MaxEnt

Species distribution model (SDM) is currently one of the most reliable tools employed by ecologists in their quest to understand global biodiversity patterns and their relationship with environmental parameters. The study employed Maximum Entropy (Phillips*, et al.*, 2006; Phillips & Dudík, 2008; Skilling, 1991; Townsend *et al.*, 2007) to estimate spatial distribution of three African pangolin species in Ghana. MaxEnt estimates the ecological niche of a species by determining the distribution of maximum entropy, subject to the constraint that the expected value of each environmental variable under this estimated distribution matches its empirical average (Phillips*, et al.*, 2006). MaxEnt was chosen for the current study because it requires only presence data, it has also been shown to perform well with small sample sizes (Aarts*, et al.*, 2012; Jackson & Robertson, 2011; Phillips*, et al.*, 2006), and has performed very well when compared with alternative approaches (Elith *et al.*, 2011). The distribution models generated from the study were validated using the jackknife approach developed by (Phillips*, et al.*, 2006). For model validation, receiver operating characteristic (ROC) analysis was followed to evaluate the performance of the model. The ROC analysis is a threshold-dependent procedure that has been applied in the evaluation of species distribution models over the years (Elith*, et al.*, 2011; Kerr & Ostrovsky, 2003; Phillips*, et al.*, 2006). ROC curve is a plot of the sensitivity (proportion of true positives) of the model against the measure of its specificity (proportion of false positives), at a given threshold. The area under the ROC curve (AUC) provides a single measure of model performance, which is comparable between different model scenarios. AUC value of 1 is an indication of a perfect model, while a value of 0.5 indicates a random model.

2.5.1. Multi-collinearity analysis of environmental variables

Multi-collinearity analysis is used to describe the presence of linear relationship among explanatory variables. The presence of multi-collinearity often results in the overlap or sharing of predictive power among the affected variables(Phillips & Dudík, 2008), resulting in a situation whereby the regression model fits the data well, but none of the predictors has a significant influence in predicting the dependent variable (Elith*, et al.*, 2011). The reason is that when predictor variables are highly correlated, they contribute basically the same information. In combination, they may explain a great deal of dependent variable, but may not individually contribute significantly to the model. One method of checking for multi-collinearity problem is the calculation of (VIF) Variance Inflation Factor (Phillips & Dudík, 2008), as stated in the equation bellow;

$VIF_{i} = 1/(1- R^{2}i)$ .... Equation (1)

Where R^2 is the coefficient of determination obtained after regressing the ith variable on the reminder predictors.

The VIF measures the degree to which collinearity among the predictors degrades the precision of an estimate. Generally, a VIF of greater than 10 is considered problematic and quite often excluded from the model unless there is special need for the inclusion of the affected variable.

Multicolinearity analysis was conducted on the preselected environmental variables using the "R" Studio. Since all the pre-selected variables had VIF values less than 10 after the initial run of the collinearity analysis they were all included in the model.

2.5.2. Model evaluation and validation

Evaluating the predictive power of a model is very important, both for practical and theoretical point of view. Model evaluation is described as the testing process required to justify the acceptability of a model for its intended purpose (Pearson *et al.*, 2007). Several indices have been used in the assessment of species distribution models performance. This study used both the threshold dependent (Binomial test) and threshold independent (Area Under the Curve) methods.

The threshold dependent binomial test is based on omission rates and predicted area values. MaxEnt automatically generate the statistical significance of the prediction using test omission rates and fractional predicted area and provide the corresponding *p*- values, which can be used to directly evaluate the model performance. For this study, a one tailed binomial test was used to establish whether the models predicted the test localities significantly better than random at the; cumulative thresholds of 1, 5 and 10, following (Ficetola *et al.*, 2007; Pearson*, et al.*, 2007; Phillips*, et al.*, 2006). The binomial test requires the setting of threshold in order to convert predicted areas into barriers indicating suitable and unsuitable places for the target species.

The Area Under the Curve of the Receiver Operating Characteristic (ROC) measure the quality of ranking of sites (Elith*, et al.*, 2006). Practically, there are challenges in evaluating predictions from presence only data. A common method is to use background points or pseudo absences. Pseudo-absences are sites randomly selected across the geographical area of interests where no species presence was recorded and for which species occurrence is set as absent (Elith*, et al.*, 2011). The Area Under the Curve (AUC) is the probability that a randomly selected presence site will be ranked above a random background site. The ROC AUC is calculated by plotting sensitivity on the y-axis against specificity on the x-axis for all possible thresholds. It makes predictions using values between 0 and 1. Sensitivity describes how well the data correctly predicts true presence, whereas specificity shows a measure of correctly predicted absences (Phillips & Dudík, 2008). The advantage of ROC is that it provides a single measure of model performance, independent of any particular threshold. An AUC value close to 0.5 indicates a fit no better than expected by random, while a value of 1 indicates a perfect model. An AUC >0.9 denotes very good model, from 0.7 – 0.9 is good and < 0.7 is considered as uninformative (Phillips*, et al.*, 2006).

2.5.3. Determination of relative contribution of environmental variables

Jackknife test (Phillips, *et al.*, 2006) was used to evaluate the relative importance of each environmental variable in explaining the distribution of pangolins. The contribution of individual predictor variable is tracked at each step of the training process as the MaxEnt model is being trained. MaxEnt assigns the increase in the gain of the model to the variable that the feature depends on. Three different gains are estimated; one with all the predictor variables, another with only the predictor variable in isolation and one excluding one predictor variable. This attribute of jackknife makes it more reliable in explaining the strength of each predictor variable. The variable that has the highest gain when used in isolation have the greatest influence on the species being modelled. The variable that reduces the gain most when excluded from the model is considered to have the most information that is not present in the other variables and therefore, likely to be highly influential. Variable importance in this study was determined using both Jackknife test and the percentage contribution values from MaxEnt.

2.5.4. Species distribution maps

A general practice in species distribution modelling is to choose the best performing model which could be used to map the distribution of a target species in the study area from a set of random combinations. This is based on selecting the best of the separate models in all the combinations based on some predefined criteria (Pearson, *et al.*, 2006). In this study, continues suitability maps were used to represent the potential geographic distribution of the three pangolin species in order to show a whole gradient in habitat suitability instead of choosing a threshold which is much subjective. The output maps were also analysed visually to see how they fit with presence records and existing conservation areas.

2.6. Mapping pangolins diversity "hotspots"

Maps for pangolin "hotspots" were generated based on the probability maps produced from modelling the three co-occurring pangolin species. This was done by overlaying the maps generated for the three species using Spatial Analyst Toolbox in ArcMap. A threshold was selected to differentiate the distribution probability for each species between 1 (presence) and 0 (absence). The three probability maps generated from MaxEnt were then combined to yield 4 hotspots classes (from 0 to 3 with 0 indicating where none of the models predict a grid as presence; 1 indicating where at least 1 model predicting a grid as presence and so forth). Areas where all three models indicated a grid as presence was assigned the highest "hotspot" class of 3. The protection status of the pangolin "hotspots" were further evaluated by overlying the boundaries of existing wildlife protected areas. In instances where the word hotspot is put in quotation marks, it is not different from where there was no quotation mark but only indicates that the usage of word is limited to the definition given in this study.

2.7. Modelling the risk of hunting pressure on pangolins

Understanding the spatial distribution pattern of hunting pressure and its consequences on wildlife populations is very fundamental to assessing their sustainability. Equally important is the knowledge required on the distribution and magnitude of anthropogenic factors that poses threat to the persistence of wildlife. Studies from other regions suggest that hunting pressure can be estimated from points of human access such as towns/villages, ranch settlements, roads and forest cover type (Czetwertynski *et al.*, 2007; Fa & Brown, 2009). Human population density and species preference have also been suggested as other important factors in estimating impact of hunting pressure on vertebrates in West Africa (Fa & Brown, 2009).

2.7.1. Selection and pre-processing of anthropogenic variables for hunting pressure modelling

Data compilation and preparation for the hunting pressure modelling was done using ArcGIS 10.0. Data on human settlements (towns and villages), roads, human population density and location of bush meat trading markets known to be associated with wildlife mortality from hunting pressure were also generated (Fa, *et al.*, 2000) based on Google Earth and BingMaps satellite and aerial imagery covering the study area. Extra datasets (roads, towns/ villages and bushmeat markets) were manually edited or digitized using ArcMap editing toolbar. All data layers were standardized to the same projection system and then converted to raster formats using ArcGIS, Arc Toolbox-Conversion Tools to enhance further geo-processing steps. Inputs variables required for the modelling were defined with relative weights assigned to each threat factor according to their estimated importance to other factors.

Final map showing areas of different scale of hunting pressures were generated by combining individual risk maps based on index of ; Accessibility (distance to road, distance to bushmeat market, and distance to towns and villages), Vulnerability (human population density and species preference) and protection index (distance to protected area), through overlay processes in ArcGIS 10.0. Figure 5 below shows the flowchart of the hunting pressure model for estimating our hunting pressure map. For the purpose of this study, parameters used to estimate potential hunting pressure on pangolins were grouped under four indices of probability measurements. Anthropogenic environmental factors such as distance to roads, human population, towns/villages and bushmeat markets were considered under accessibility index.

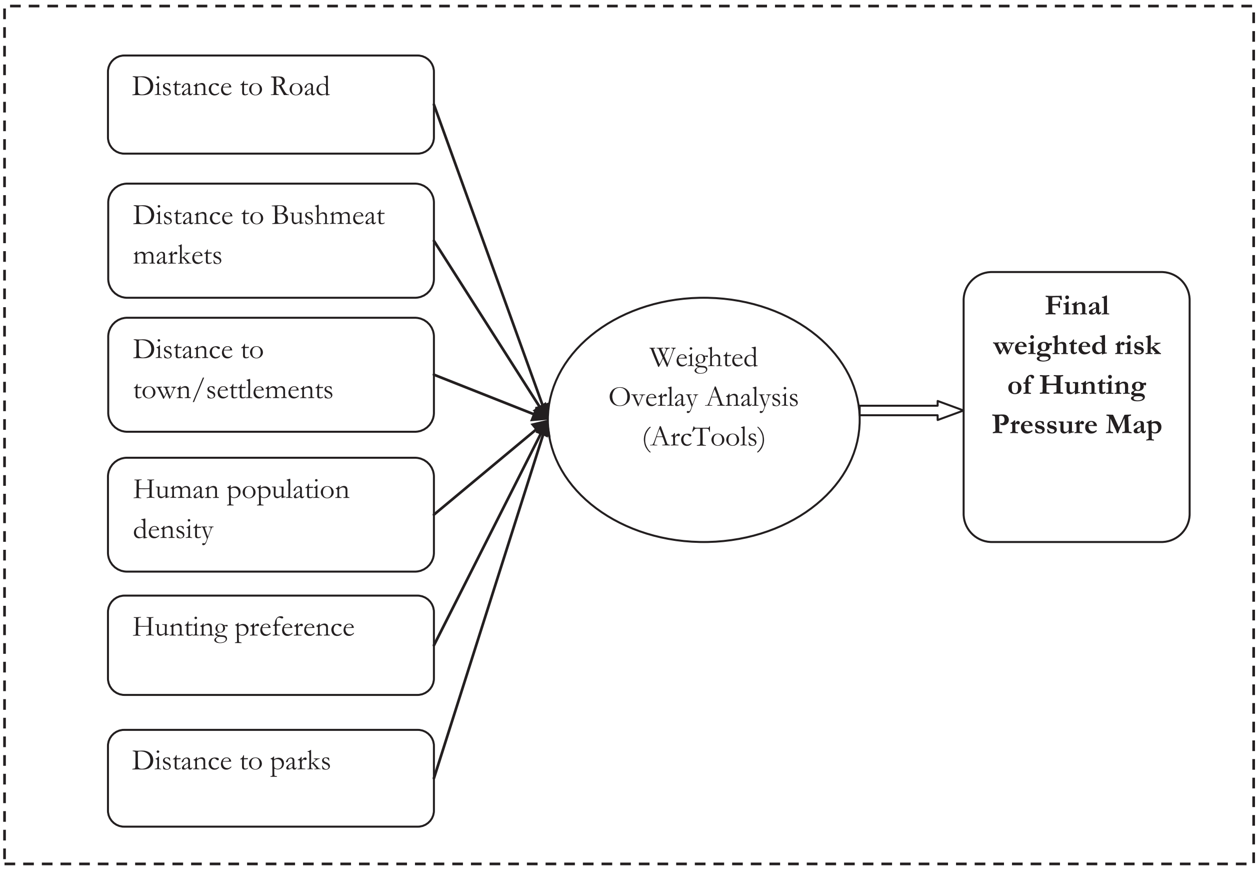


Figure 5: Relationship among variables used in model for determining risk of hunting pressure

2.7.1.1. Distance to road

Road networks substantially influence hunting pressure by increasing access to game whilst facilitating transport to market. Given that roads are key access points for hunters looking for game, road conditions and relative of use can be a good indicator of the risk mammals face from hunting pressure.

2.7.1.2. Distance to bushmeat markets

Another important factor in determining risk from hunting pressure in Africa is proximity of bushmeat markets (Fa*, et al.*, 2000). Logically, easy access to reliable sale points will motivate hunters in their operations, hence relatively higher risk. Bushmeat is usually transported from forest areas where the hunting mainly takes place to markets within local communities or urban centres for ready markets. Interview with hunters during the study revealed that ready market is enough incentive to hunt more. Out of about 25 hunters interviewed, only three were willing to travel as far as 20 kilometres to sell their meat. On average, the hunters interviewed would travel up to 10 km to trade their catch.

2.7.1.3. Species preference

All the three pangolin species are eaten in Ghana, however, there is the likelihood that hunters may put in different hunting effort due to market value and demand for each of the three species. In order to consider this as a factor in modelling hunting pressure, 50 hunters and bushmeat traders were interview. Extracting information from hunters in Ghana requires a lot of skills and tact because of the fear that owning up will lead to their arrest by officials from Wildlife Division and moreover, the study period coincided with annual ban on hunting for bushmeat which is popularly known in Ghana as "Close season". Since the main aim for this interview was to just ascertain whether hunters put different values on the three pangolin species, the interview was structured to last for at most ten minutes. Respondents were simply asked to assign values; 1, 2 and 3, to each of the species with value three being the highest effort they will invest in order to obtain a particular species. Based on results from the traders/hunters interviewed (No=50), the Giant pangolin was assign the highest value since it was the most preferred and requested of the three species, followed by the Tree pangolin and Long-tailed pangolin in that order.

2.7.1.4. Role of Protected areas (PA's)

The fourth measure is the protection index which indicates whether an area is inside or outside protected area. In Ghana, the Wildlife Division (WD) of the Forestry Commission is responsible for the protection and management of wildlife resources through its protected area networks. Ghana currently has 13 wildlife protected areas consisting of five National Parks, five Game production Reserves, one Strict Nature Reserve and two Wildlife Sanctuaries distributed across the major vegetation zones in the country. Hunting for bushmeat in these protected areas is strictly prohibited by law. The enforcement of this law is achieved through regular patrols by field guards of the wildlife division. Animals found inside wildlife protected areas are thus, relatively more secured compared to their counterparts outside protected areas (Jachmann, 2008). Effective management of conservation area is therefore a fundamental step toward continued availability of wildlife.

The protected area boundary file was manipulated using raster calculator (ArcToolbox, Spatial Analyst, Map Algebra, and Raster Calculator) to assign relative weight to wildlife protected areas (PAs) and areas outside wildlife protected areas. For this study, areas within PAs were assigned risk value of (1), with areas outside been assigned risk of (3). Also, areas within 2 km radius of protected area boundaries were assign risk value of two due to spilt-over impact from conservation education and regular presence of wildlife law enforcement officers in the localities.

Human population density was chosen as another important factor for the hunting pressure model due to its influence on rate of off-take of wildlife resources from an area. Since most of mans activities such as farming and clearing of forest for other land use purposes influence pangolins distribution (Fa & Brown, 2009), its inclusion in the model is of significant importance. For this study, human population density was divided into 6 levels, from 1 to 6 representing the density from the lowest (0), where there is hardly human presence, to the highest, where the density reaches as high as 7000 persons/km².

2.7.2. Development of formula for calculating hunting pressure

Table 4 bellow shows a mathematical formula was used to generate the potential risk map of hunting pressure on the three pangolins in Ghana.

Table 2: Formula for estimating risk of hunting pressure

Risk of hunting pressure formula	**Threat factor**	**Weight**	**Impact radius (km)**
Equations; HP(1) = ((Rmax-R)/Rmax)*W)* (d/v))............ (1) HP(t) = $\sum_{i=1}^{n}$((Rmax-R)/Rmax)*W)* (d/v)) ..... (2) **Where;** HP(1)= hunting pressure of individual threat factor HP(t) = estimate for overall hunting pressure R = risk value Rmax =maximum risk value W = weight d =distance from threat where impact is felt v =variance	Bushmeat market Town Roads Population density Vegetation cover Park boundary Species preference	8 7 6 5 4 3 3	20 10 10 - - 2 -
Total		36	

3. RESULTS

3.1. Spatial distribution of three pangolin species in Ghana

Output maps of the probability distribution of the three co-occurring pangolins in Ghana are shown in Figures 6, 7 and 8. Predictive maps from MaxEnt uses colours to show the range of probability that conditions are favourable for a species. Warmer colours (red) shows high probability of favourable conditions the species whiles green is an indication of low probability. All the models showed relatively lower probability distribution in the northern sector and higher probability values towards the south-western Ghana. The predicted potential distribution maps (Figures 6, 7& 8), indicate that Giant pangolin (*M gigantea*) could thrive in much wider area in Ghana as compared to the two remaining species. Suitable areas for all three pangolin species are widely distributed throughout the south-western part of Ghana (Figure 6 & 7).

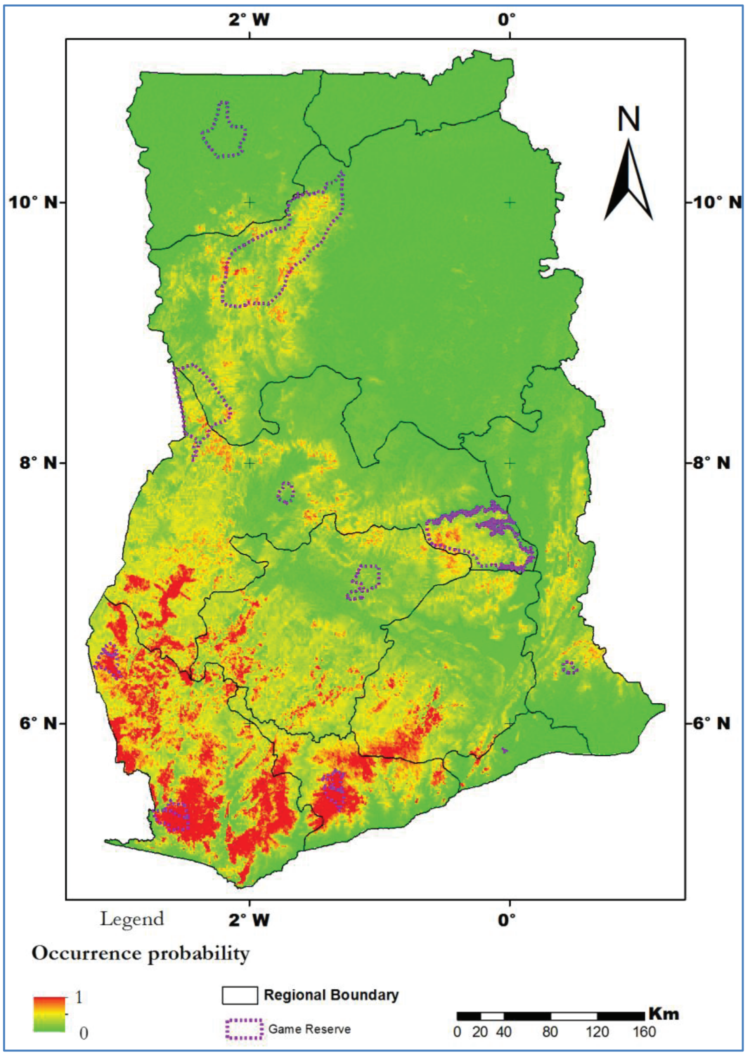


Figure 6: Probability of occurrence map for Tree pangolin (*Phataginus tricuspis)* in Ghana

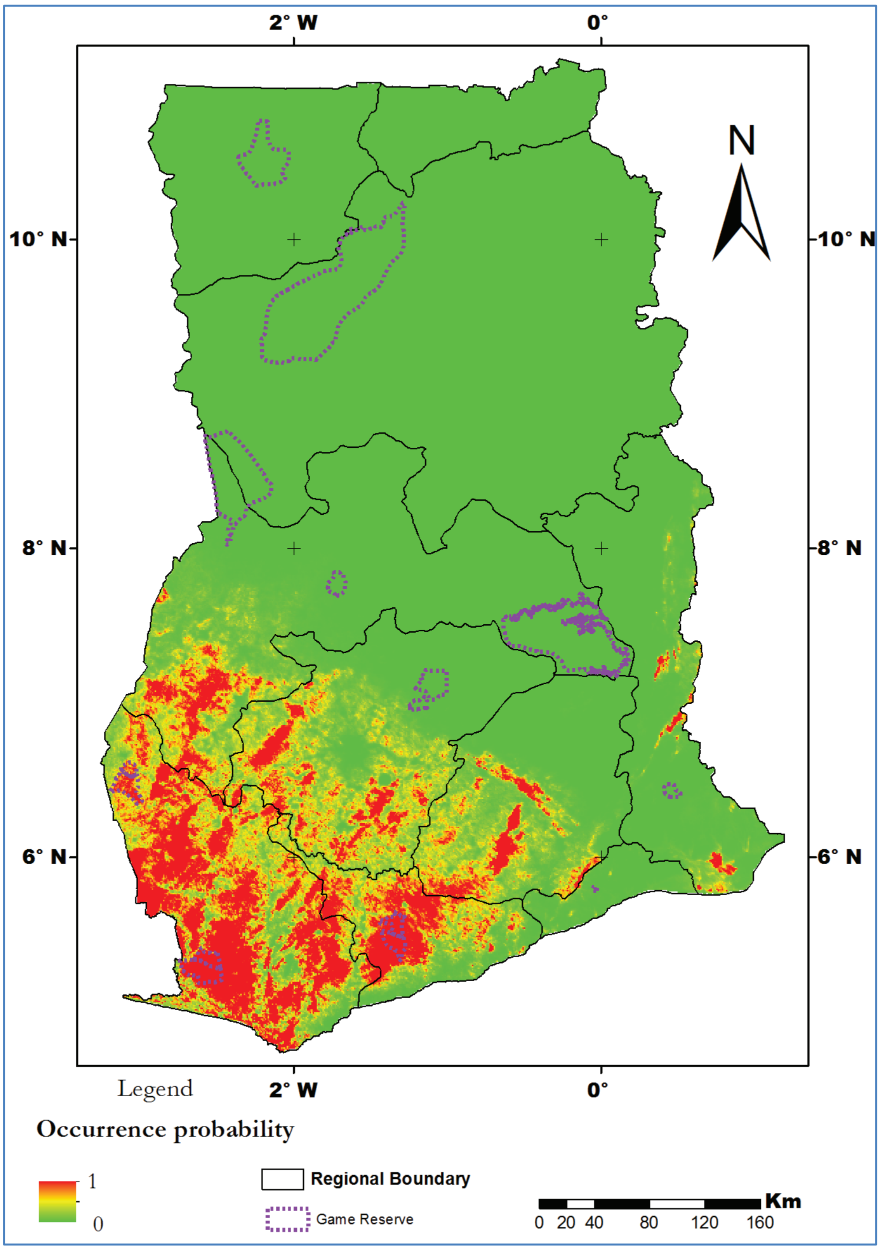


Figure 7: Occurrence probability map for Long-tailed pangolin species (*Manis tetradactyle*) in Ghana

Model outputs for Tree pangolin (*P. tricuspis)* and Long-tailed pangolin *(M. tetradactyle*) look very similar by visual comparison, except that the later is limited in distribution at the central and north-western part (figures The sharp contrast in the spatial distributions of Long-tailed pangolin between the north and the south corresponds with the presence of relative intact forests in the region which is crucial for that particular species. Long-tailed pangolin is known to thrive in high forest areas with minimal disturbances. The areas predicted as presence also corresponds well with known Long-tailed pangolin presence locations on the ground. The probability distribution maps for Giant pangolin and Tree pangolin (Figure 6

& 8) indicates much wider areas as suitable as opposed to Long-tailed pangolin. Model for Giant pangolin also identified few areas at the north as having moderately high probabilities of occurrence. The Giant pangolin model showed more continues distribution pattern at the western part of the study area. The probability distribution maps for Giant pangolin (*M gigantea)* and Tree pangolin (*P. tricuspis)* (Figure 6 & 8) indicates much wider areas as suitable as opposed to Long-tailed pangolin (Figure 7*)*. Model for M. gigantea also identified few areas at the north as having moderately high probabilities of occurrence. *M. gigantea* model showed more continues distribution pattern at the western part of the study area.

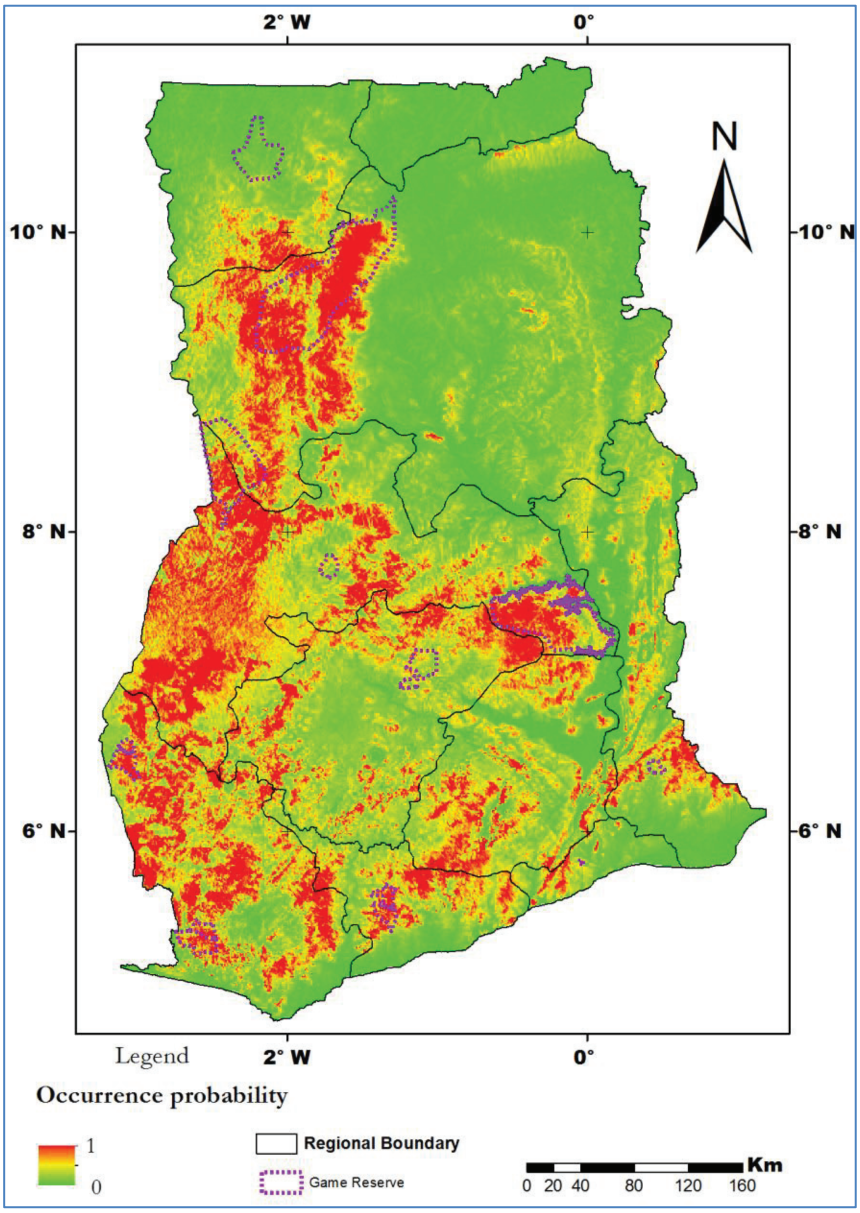


Figure 8: Occurrence probability map for Giant pangolin species (*Manis gigantea*) in Ghana

Another important step in assessing model performance in MaxEnt is to determine whether the model predicted the test locations better than random. . Figures 9, 10 & 11 show the ROC curves for models for Giant pangolin, Tree pangolin and Long-tailed pangolin respectively. An AUC value closer to 1.0 indicate better model performance whiles an AUC of 0.5 means the performance of the model was no better than random (Pearson*, et al.*, 2006). The predictive performance of the models for the three pangolin species is summarized in Table 3. For the AUC, model built for Long-tailed pangolin had the highest predictive performance in terms of test and training gains (Table 3). The results represent mean values of random partitions (n=5) using all presence locations. The accuracy of the modelled distributions based on training, test and mean AUC were significantly better than random for all three models.

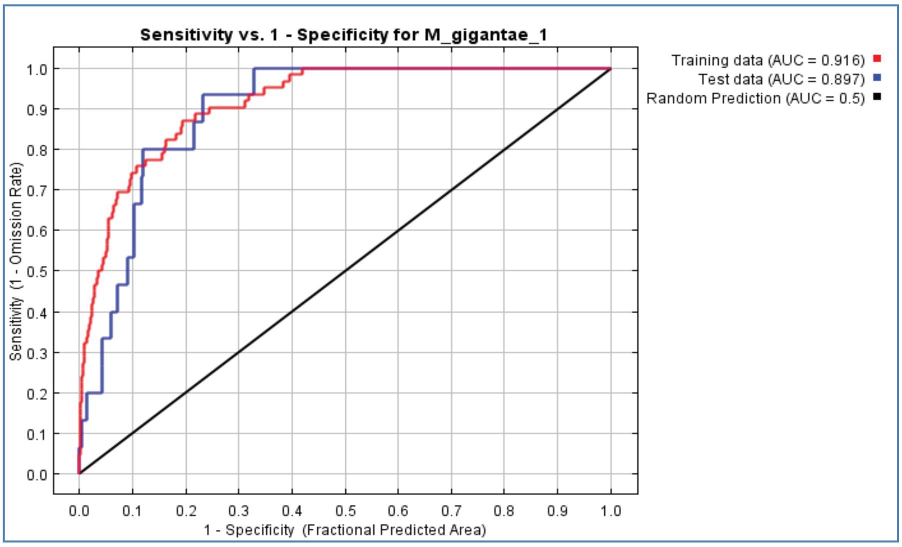


Figure 9: ROC curve of Specificity versus Sensitivity for Giant pangolin (*M. gigantea*)

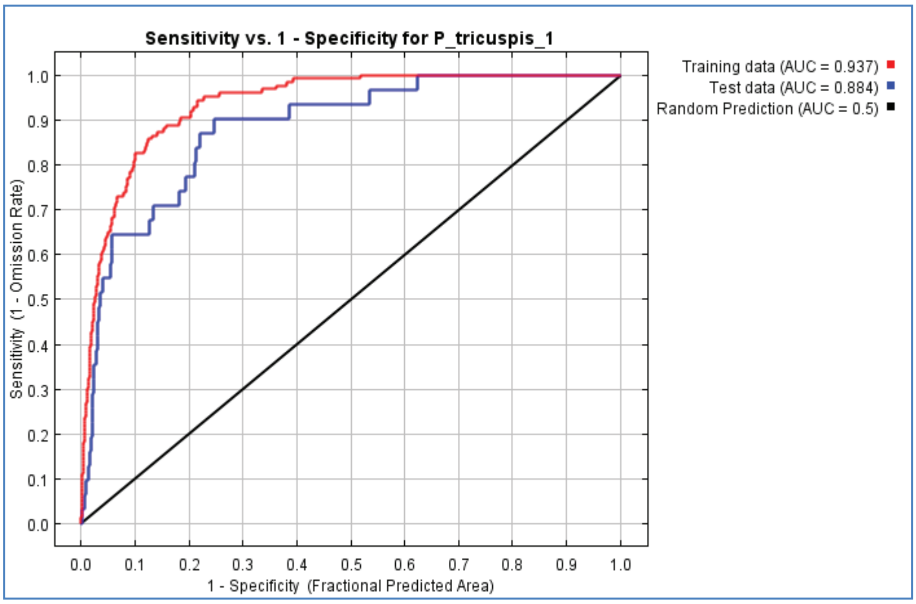


Figure 10: ROC curve of Sensitivity versus Specificity for Tree pangolin (*P. tricuspis*)

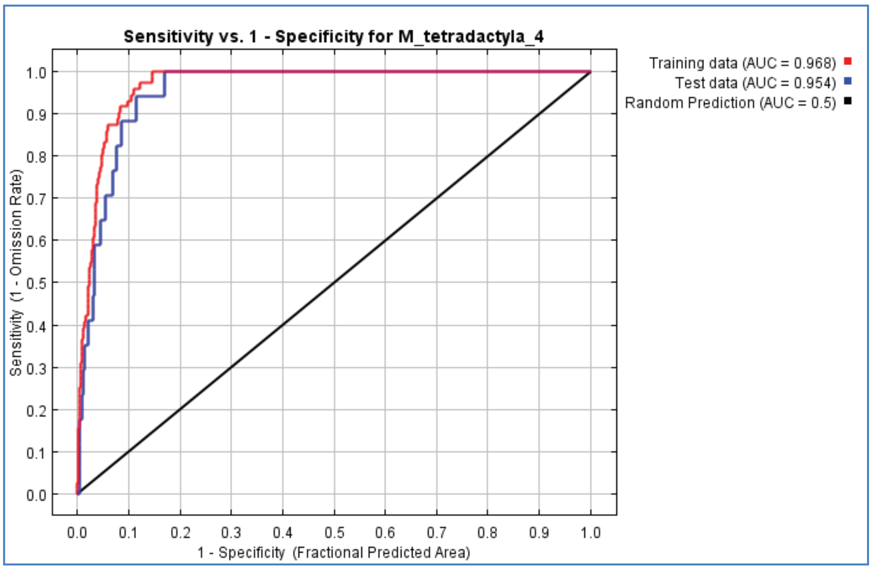


Figure 11: ROC curve of Sensitivity versus Specificity for Long-tailed pangolin (M. tetradactyle)

Table 3: Species distribution- model summary Statistics for the three pangolin species in Ghana

Variable	Tree pangolin	Giant pangolin	Long-tailed pangolin
Training AUC	0.93	0.91	0.96
Test AUC	0.93	0.89	0.94
Mean AUC	0.93	0.90	0.95

Table4: Fractional predicted areas and corresponding P-values at 10 Percentile thresholds for the three distribution models

Species	Fractional Predicted area	Training Omission rate	Test Omission rate	P-value
Tree pangolin	0.169	0.096	0.161	1.256E-23
Giant pangolin	0.244	0.097	0.067	3.082E-8
Long-tailed pang.	0.069	0.099	0.235	1.501E-12

All three models yielded very low p-values indicating that our models performed significantly better than random. At 10 percentile threshold, Giant pangolin yielded the highest fractional predicted area (0.244), followed by Tree pangolin (0.166) with Long-tailed pangolin (0.069) having the least.

3.2. Relative contribution of environmental variables on pangolin distribution modelling

Table 5 shows the percentage contribution of environmental variables used for mapping the distribution of the three pangolin species. It gives the estimate of relative contributions of individual environmental variables to the Maxent models for the three pangolin species. In the models for Tree pangolin (*P tricuspis*) and Long-tailed pangolin (*M tetradactyle)*, the normalized difference vegetation index (NDVI) for dry season came up as the most important variable with contributions of 38% and 68.5%, respectively. In the model for Giant pangolin, maximum temperature (tem_max2) was the most important variable in terms of its contribution to the prediction of spatial distribution of the species. Variables of least importance to the prediction model for Giant pangolin were annual mean temperature and annual minimum temperature with contributions of 0.5 and 1.1% respectively. Aspect (0.1 %) and rain season NDVI (1.5%) were found to be variables with the least contribution to the prediction models for Long-tailed pangolin and Tree pangolin respectively.

Table **5**: Percentage contributions of variables to Maxent models for three pangolin species in Ghana.

Variable	**Percentage contribution**		
	P. tricuspis	*M. tetradactyle*	*M. gigantea*
1. dry_ndvi	**38**	**68.7**	**23.9**
2. prec_dryseason	**14.7**	**8.7**	7.2
3. temp_max2	10.3	7.9	**29**
4. mean_ndvi3	9	3.6	8.5
5. ghana_slope	7.4	0.3	7.7
6. Elevation	5.5	2.4	5.4
7. temp_min_annual	5.4	2.2	(1.1)
8. prec_wet1	3.6	4.6	5.1
9. temp_mean2	2.9	(0)	(0.5)
10. aspect	(1.8)	(0.1)	4.9
11. rain_ndvi	(1.5)	1.3	6.7

The results shown are averages over replicate runs (n=5). Just as with jackknife, variable contributions should be interpreted with caution especially when the predictor variables are correlated. Variables with highest contributions are in bold and those with least in parenthesis.

Figure 12 (a, b & c) shows the output of jackknife test of variable importance in MaxEnt model for the three species. For *M. tetradactyle*, (Figure 12 a), the variable that gave the highest training gain when used alone was NDVI for dry season (dry_ndvi) which seems to have the most useful information by itself. This was followed by dry season precipitation and maximum temperature in that order. The variable that decreases the gain the most when it is omitted is still dry_ndvi, which therefore appears to have the most information that is not present in the other variables. The jackknife tests for both training and test gains still showed the dry season vegetation index as most useful variable. Similarly, the result of the jackknife test of variable importance for modelling *P. tricuspis* (Figure 12 b) indicates that the variable with highest gain as well as the variable that decreases the gain the most when omitted is the dry season vegetation index (dry_ndvi). This variable appears to have the most information that is not present in the other variables.

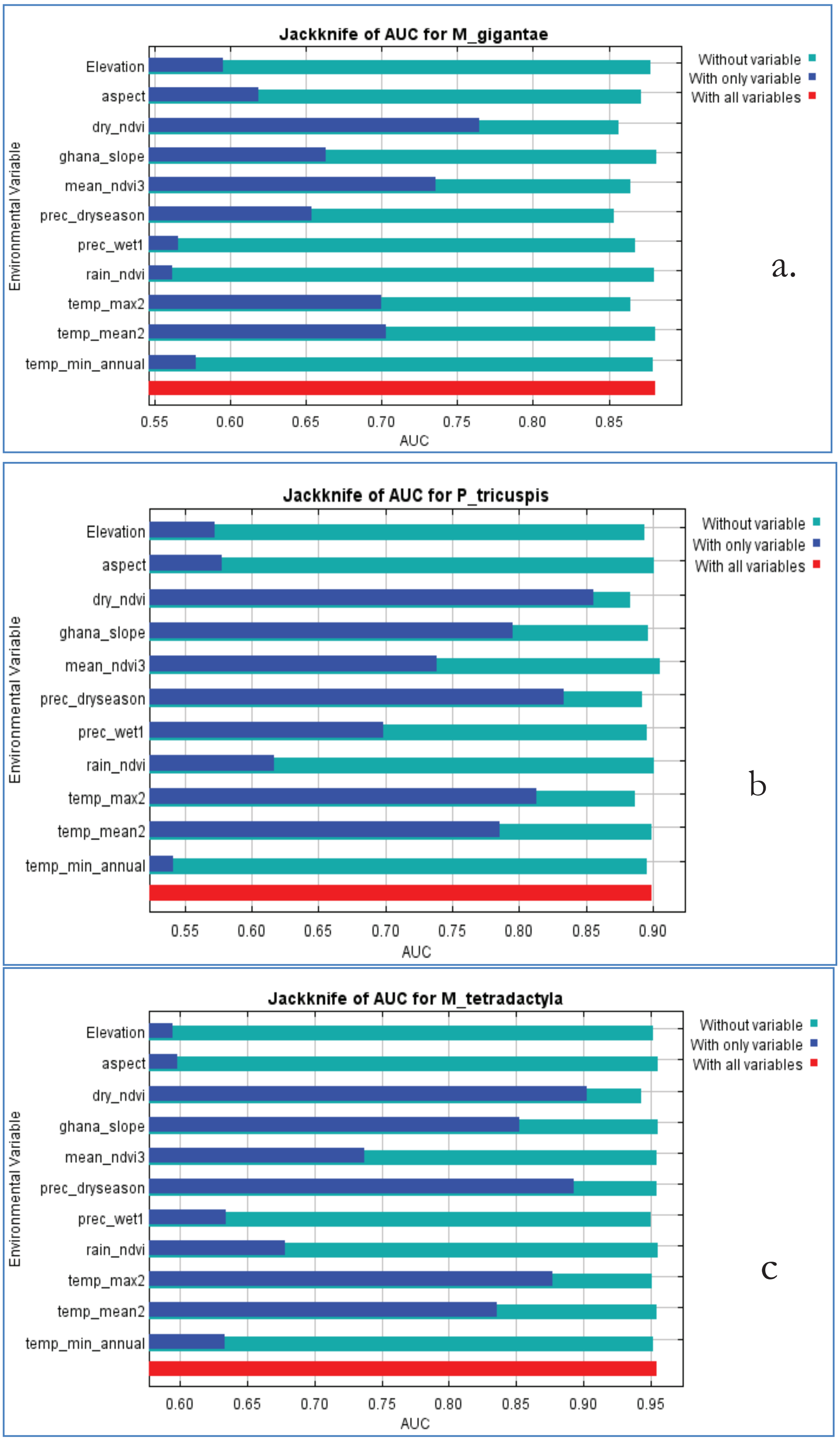


Figure 12: Jackknife test of AUC for variable importance in MaxEnt models for *M gigantea* (a), *P tricuspis* (b) and *M tetradactyle* (c)

3.3. Pangolin diversity "hotspots" in Ghana

The predicted hotspots map generated by combining the three probability distribution maps for the target species (Figure 13) shows that the predicted diversity hotspots were mostly found at the south western part of Ghana. Four classes were identified: Class(0) means no hotspot was predicted; class (1) means only 1 species was predicted for the area; class(2) means two species were predicted; and class(3) represent areas predicted as presence by all three species distribution models. The "hotspot" map generated showed very large portion of the study area as not suitable for any of the three pangolin species. The cut-off probability threshold selected to determine the hotspots was 0.6. The results also revealed that there are few areas, mostly in the moist and Upland evergreen forest areas, where suitable habitats for the three pangolin species overlap.

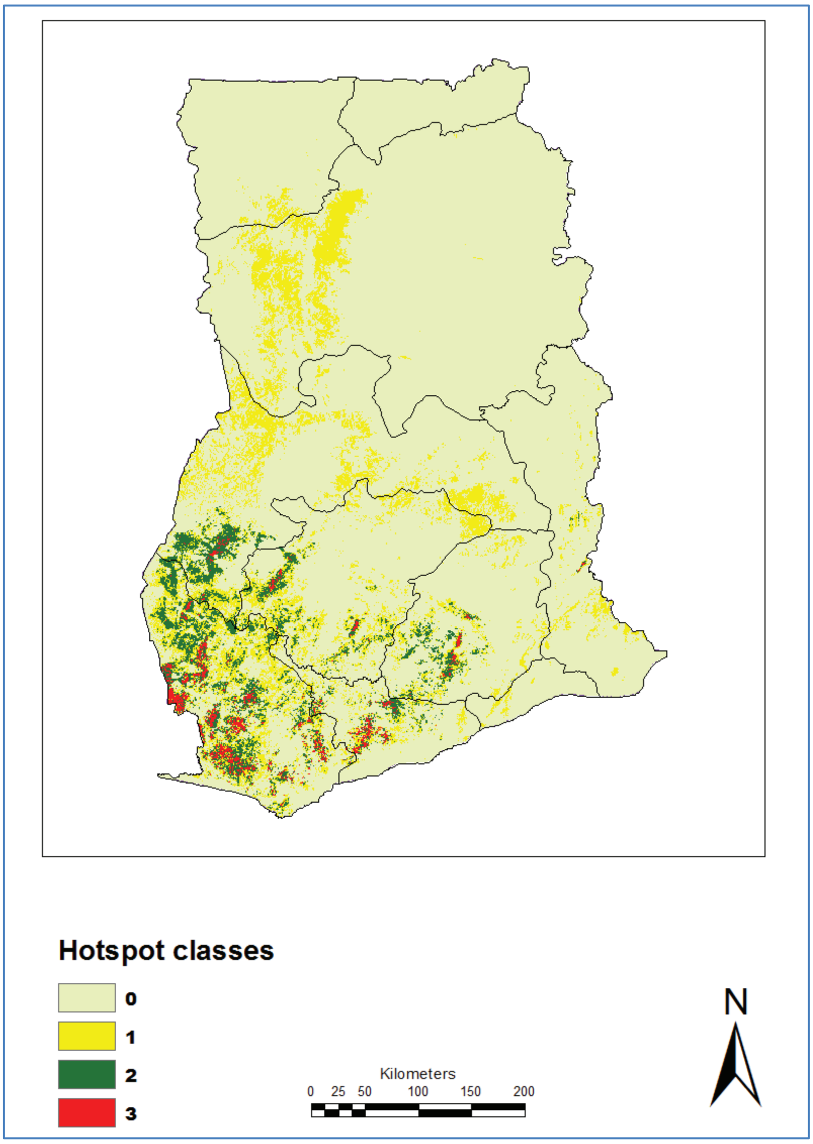


Figure 13: Pangolin diversity "hotspot" map showing places where suitable habitats of the three pangolins overlap

The extent of areas predicted as "hotspots" per classes were; (0) or no prediction (183,750 sq km or 75%), areas suitable for only one of the species (class-1) (44,100 sq km or 18%), areas suitable for two of the species (class-2) predicted (13,700 sq km or 5.6%), and hotspot class-3 which represent suitable areas where all three species could co-exist, predicted (3400 sq km or 1.4%).

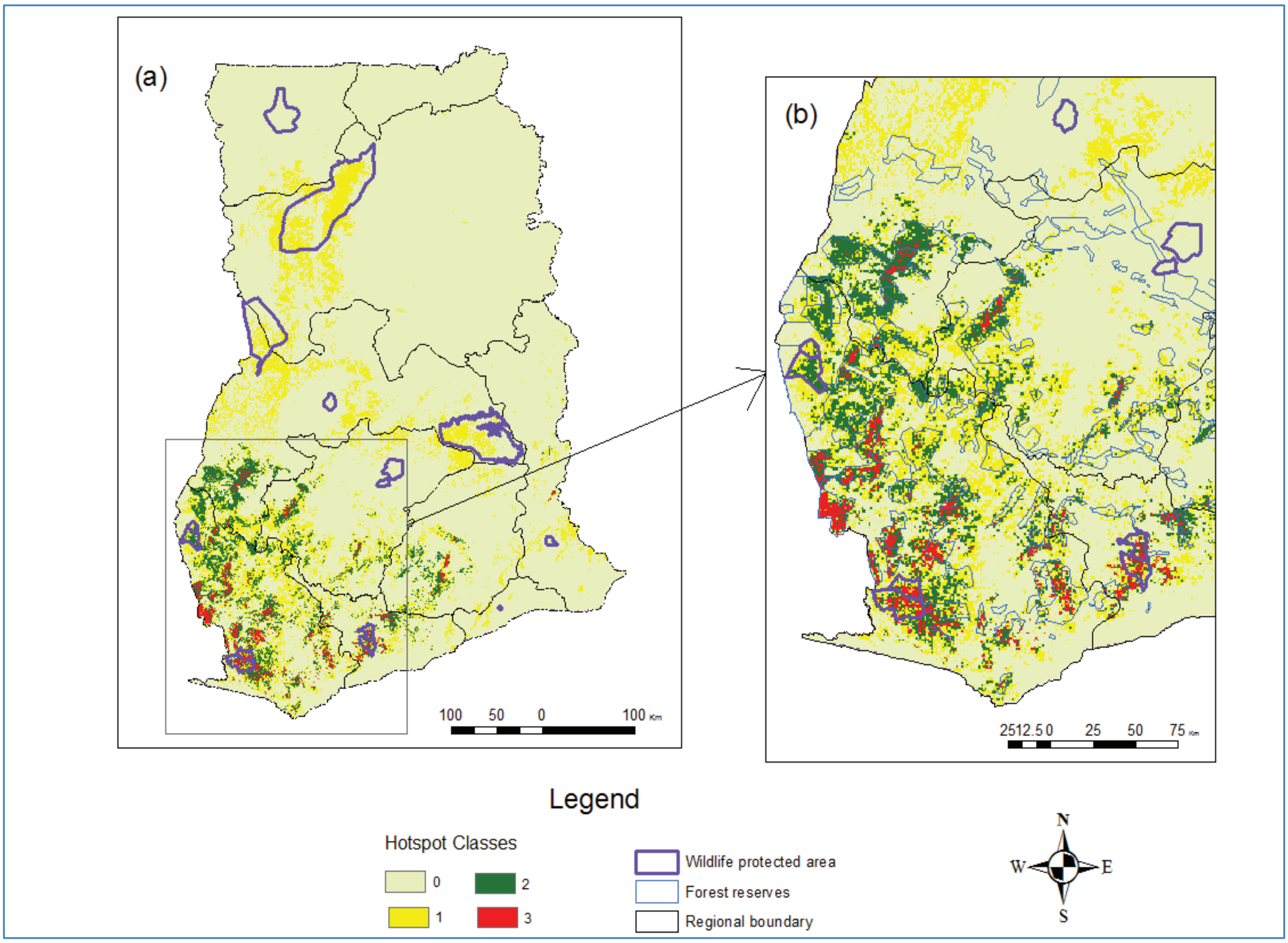


Figure 14: Pangolin "hotspot" maps; (a) overlaid with wildlife protected areas and (b) zoomed to south-western Ghana with gazetted forest reserve boundaries

Ironically, most areas predicted as presence for all three species were also in locations other than legally acquired wildlife protected areas (Figure 14 a & b). In figure 14b, it could be observed that many of the "hotspot" areas found outside wildlife PAs overlapped with forest reserve boundaries. From analysis of our "hotspots" map, only 25% of areas predicted for all three species are currently under protection of game reserves in Ghana. None of the predicted hotspots for two or more species were located in the three largest parks which happen to be located in the Guinea Savannah and forest-savannah transition zones.

3.4. The rsik of hunting pressure on pangolins in Ghana

The final risk map of hunting pressure distribution is shown in (Figure 15). A visual analysis of the risk of hunting pressure map indicates that majority of the study area generally falls within moderate to moderately low risk areas. Areas modelled as low risk zones were found towards the northern portion of Ghana, which incidentally had low probability of occurrence for all the three pangolin species modelled.

Our hunting pressure risk distribution map overlaid with the existing wildlife protected areas (Figure 15.b), revealed that majority of the wildlife protected areas were located in areas with relatively low or no risk values.

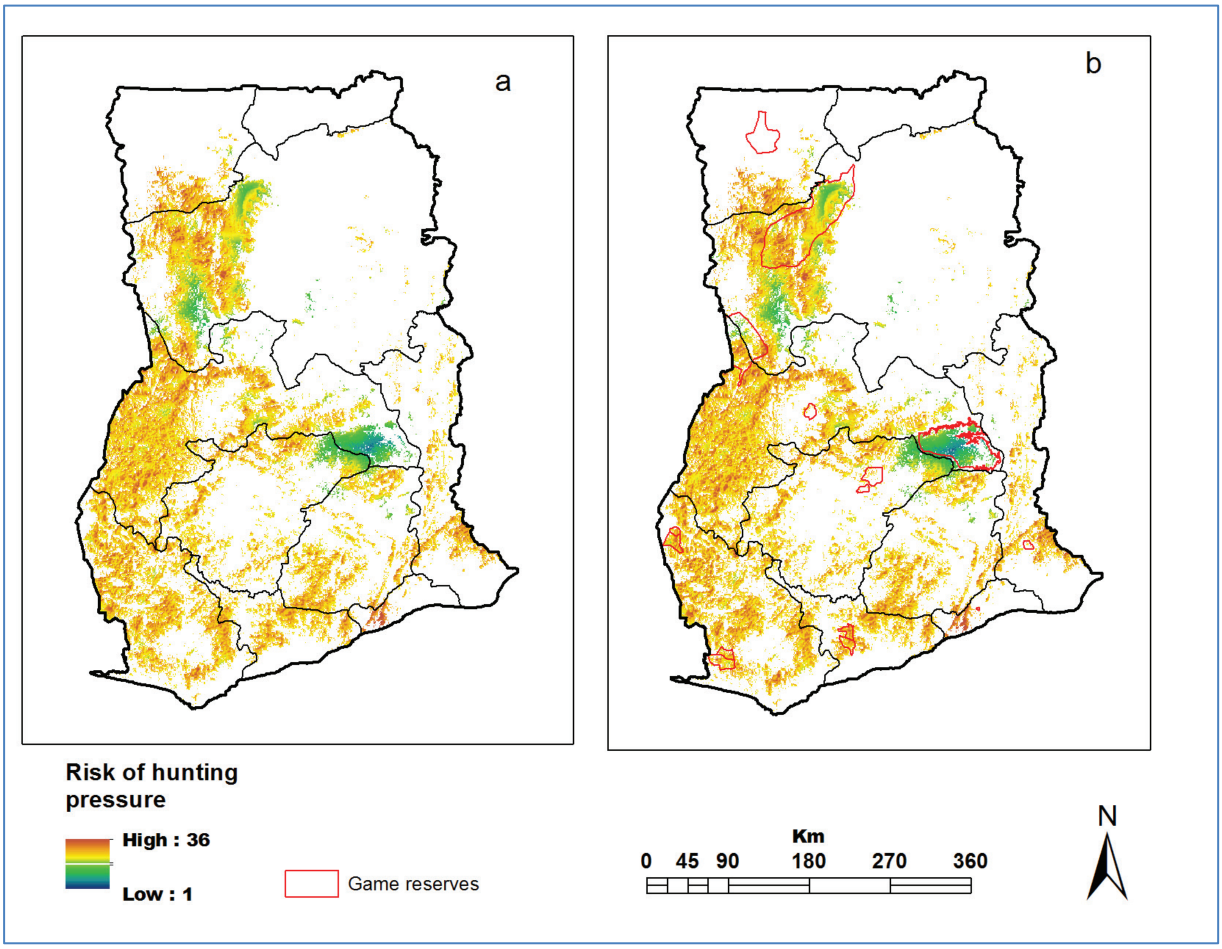


Figure 15: Map showing risk of hunting pressure as function of anthropogenic and ecological factors (15a), and risk map overlaid by wildlife protected areas (15 .b)

Low risk values were observed around some wildlife protected areas or Game reserve that are located in the remotest parts of Ghana (Figure 15), example is Digya National Park (at mid-east section), where there is limited access to roads and other infrastructure. The presence of law enforcement staff of the wildlife division of Ghana manning these parks could also serve as disincentive to hunters. On the other hand the protected areas in south western part with highest hotspots (Figure 15 b) overlap with locations predicted as high risk of hunting pressure.

4. DISCUSSION

4.1. Pangolins distribution pattern in Ghana

This section highlights on the probable spatial distribution of the three co-occurring pangolins in Ghana, namely; the Tree pangolin *(Phataginus tricuspis*), the Long-tailed pangolin (*Manis tetradactyle*) and the Giant pangolin (*Manis gigantea*), it also provide insight into the environmental variables with most influence in the determination of these distribution.

The result as shown in (Figure 7) indicates that *Manis tetradactyle* has much restricted range of habitat, and mostly limited to the high forest and semi-deciduous forest zones at south western part of Ghana. Low probability areas predicted for *Manis tetradactyle* in the northern and eastern sections of Ghana (Figure 7) could be due to the characteristics grassland dominated nature of those areas (Refer to study area map in figure 3) as opposed to the forest dominated south- western regions where much of the ecological needs of the species are met. The results also corresponds with the assertion by Akpona*, et al.* (2008) that of the four African pangolins, the *Manis tetradactyle* is the most elusive and more restricted to less disturbed forest habitats.

The results as could be seen in (Figures 6, 7 & 8) revealed that *Manis gigantea* and *Phataginus tricuspis* showed similar spatial distribution patterns with both species occupying relatively wider areas as compared to *Manis tetradactyle*. In both models the probability of finding a species decreased as one move towards the savannah grassland areas of Ghana. This results gives some credence to the expectation that overlap in resource requirement and competition are greatest among closely related species. The model for *Manis gigantea* (Table 3) had the lowest mean AUC value (0.90), but was still very informative (Pearson*, et al.*, 2006). The low AUC value for the Giant pangolin could be explained by its widespread in the study area relative to the other two species. Generally, models for species that have restricted habitats yield high AUC values than generalists.

Intensive logging and converting forests to other land-use have been major contributors to the declining pangolin populations worldwide (Wilson, 1994; Wu *et al.*, 2003; Zahler, 2001). However, contrary to our expectations, majority of the areas predicted as hotspots particularly in the central and northern part (Figure. 12) were located outside wildlife protected areas. This could be due to the dominance of grassland vegetation across most parts of the northern Ghana where most of these protected areas are found and the fact that two of the pangolin species are typical forest dwellers. Another explanation to high pangolin distribution outside game reserves is due to the presence of forest reserves especially in south-western part, remnant patches of intact or less disturbed sacred forests, areas of low logging intensity and riparian vegetation along streams in the study area which equally provide suitable conditions for the pangolin species. The Overlap of identified pangolin "hotspot" with some forest reserves at the south-western part of the study area (Figure 14. b), agree with other studies (Danquah *et al.*, 2010; Decher & Fahr, 2007; Larsen, 2008; Oates*, et al.*, 2000) that have suggested that special priority be given to these forest reserves, some of which already classified as Globally significant biodiversity areas (GSBAs), in view of their richness in terms of threatened wildlife and plant species.

4.2. Factors determining distribution of pangolins

The study demonstrated that normalized difference vegetation index (NDVI) for the dry season was the most significant variable in the prediction models for all the three pangolin species in Ghana. Vegetation indices are known to play very important role in predictive models involving wildlife species. It is however, worth nothing that whiles dry-season NDVI demonstrated to be very critical in the prediction models, rain season NDVI performed poorly as predictor variable. This could be linked to the saturation effect of NDVI. Since areas with vegetation other than forests may have equally high NDVI like that of forested areas during rainy season, high NDVI values cannot distinguish one vegetation type from the other due to saturation (Pettorelli *et al.*, 2005). On the other hand, during the dry season, areas in the wet evergreen or high forest zones will still have plush green vegetation, whilst areas in the moist semi-deciduous zone still showing somehow lower NDVI values that could easily be distinguished from the evergreen. The grassland and savannahs which turns brown with dried vegetation during the dry months shows lesser values in terms of NDVI. From this study, the dynamics of vegetation change and its effects on wildlife distribution which is gaining much popularity among ecologists (Pettorelli*, et al.*, 2005), appeared to be very important factor for pangolin distribution in Ghana. However, the probability of occurrence of the three pangolins generally, did not show much variation in response to topographic variables such slope, aspect and elevation which were used in this study. Of the three topographical variables used in the three models (Figure 12 a, b & c), it is only slope which performed above average in terms of contribution to the overall performance of the three predictive models. The two other physical variables aspects and elevation, performed poorly to the prediction of all the three pangolin species. It will be misleading, however, to conclude that these three topographic variables; slope, aspect and elevation are of less relevance to pangolins distribution in general in the sense that variations in these physical parameters are not that marked across Ghana, as compared to other parts of the continent like east Africa, hence the poor performance.

The response curves generated by MaxEnt (Appendix 2) also indicates that distribution of the three pangolins studied generally correlate positively to normalized difference vegetation index values, particularly values ranging between 0.6 to 0.8. This result agree with the study conducted in Lama forest in

Benin (Akpona*, et al.*, 2008) which reported that pangolins were more abundant in closed natural forests (usually associated with high NDVI values) than in areas with spares tress.

4.3. Risk of hunting pressure

Existing information indicates that if hunting pressure is too heavy, even large tracts of forests are not enough to replenish hunted areas (Fa & Brown, 2009; Grenyer *et al.*, 2006). Possible compensatory response of pangolins to hunting pressure in Ghana and other Afro-tropical forests requires further attention because of the threatened status of these species. In Ghana with the exception of the few wildlife protected areas, very few forest reserves enjoy some amount of protection from hunting pressure from the resident human populations of fringed communities.

The results of this study revealed relatively high levels of hunting pressure across most areas predicted as possible habitats with presence of pangolins. Generally, some species are more tolerant to hunting pressure than other species that have lower reproductive rates or high harvest sensitivity (Di Bitetti *et al.*, 2008). Pangolins have been found to give birth to only one offspring in a year (Wilson, 1994), and for that matter will require relatively long duration to recover from impact of over exploitation. Among the three pangolin species in Ghana, the giant pangolin is much exposed to hunting pressure compared to the other two species mainly due to its higher market demand which is linked to its bigger size. Interaction with pangolin hunters during the study revealed that hunting for pangolins requires less sophisticated implements such as machete, sticks, and wire-snares and in some cases bare-hands. The above, coupled with the fact that pangolins are slow moving creatures and harmless, might highly expose them to much danger than other wildlife species exploited for bushmeat.

The hunting pressure distribution map presented in this study considered variability among the three pangolin species only in terms of hunter's preference rather than the ecology of individual species and inherent characteristics. From visual analysis of our hunting pressure map, all three pangolin species in Ghana are potentially exposed to high risk of hunting pressure. However, the existence of M tetradactyle is most threatened considering the fact that its distribution coincides with high hunting risk areas. The pressures on wildlife resources of West Africa are enormous. Considering the fact that bushmeat harvesting is not regulated and at unsustainable levels, particularly outside game reserves (Fa & Brown, 2009), and results from this study suggesting most potential pangolin diversity "hotspots" to be outside protected areas should be of great concern to pangolin conservation in Ghana. If the persistence of the three co-occurring African pangolins in Ghana is valued by stakeholders in conservation, then it is only imperative that emphasis should be geared towards community involvement in wildlife conservation outside game reserves. This call for a holistic approach to the adoption of the community resource management area (CREMA) concept currently been pursued by the Ghana Wildlife Division which seeks to promote conservation through sustainable management and utilization of wildlife resources by local communities. Since from our results some of the areas identified as "hotspots" for pangolins overlapped with areas with relatively higher risk of hunting pressure, there is the need to prioritize these areas for pangolin conservation programs through the CREMA concept.

Although the current estimation of hunting pressure may have some limitations due to tropical landscape heterogeneity and other related factors that were not considered in the current study due to time constraint, it still provide fundamental and useful information for effective planning and implementation of law enforcement programs. The general idea from our findings can also be applied to other threatened wildlife species by varying the factors and conditions to suit the selected species.

5. CONCLUSION

The research was carried out to map the potential distribution of the three co-occurring African pangolins in Ghana as well as identifying their diversity hotspots for effective conservation planning and management programs. It was also to evaluate the spatial distribution of risk of hunting pressure in the study area using six identified anthropogenic factors.

The main conclusions made are as follows:

- Performance of distribution models for the three pangolin species namely; *Manis gigantea, Phataginus tricuspis, Manis tetradactyle* were better than random (0.5), with mean AUC values of 0.80, 0.93 and 0.95 respectively. This finding thus, affirms the null hypothesis that "predictive models for all the three pangolin species in Ghana perform better than prediction by random. Even though the predictive performance were generally high for models of all the species, the performance can still be improved by using more recent species presence data, as areas where a species was located might have been converted to different land use.
-
- Using probability threshold (>0.6) to determine pangolins presence for the three models, the following deductions could be made;
  - *Manis gigantea* (giant pangolin) has the widest spatial distribution with potential presence area 22,060km² or 9 % of Ghana's land mass which constituted the study area.
  - *Phataginus tricuspis* (tree pangolin) has the second highest potential distribution with predicted presence area of 18,500 km² constituting about 8.1% of area studied.
  - *Manis tetradactyle* (long-tailed pangolin) has the least spatial distribution with potential presence area of 5,200 km² which constitute 2.1% of the study area.
- Analysis of predictor variable importance using both binomial and threshold dependent methods show that;
  - Normalised difference vegetation index (NDVI) for dry months (Dec. – March) was the most important variable for predicting the distribution of Giant pangolin (*Mani*s *gigantea*) and Long-tailed pangolin (*Manis tetradactyle*). NDVI for dry months was however the second most important factor determining the distribution for Phataginus tricuspis which had maximum temperature as the most important predictor variable.
- The diversity hotspot map generated from combining distribution maps for the three pangolins revealed that;

  - 29700km² representing about 12% of the study area is suitable for only one of the three pangolin species in Ghana.
  - 9100km² representing about 3.7% of the study area are places where suitable habitats of at least two of the three pangolins in Ghana overlap. More than 60% of areas under this category fall outside existing wildlife protected areas.
  - 2100km², representing less than 1% of the study area are spots identified as potentially suitable for the co-existence of all the three pangolin species. Areas in this category are predominant in the semi deciduous and high forest zones in south western Ghana. Less than 20% of these critical areas which require special attention are located inside existing Game reserves/ wildlife protected areas.
- Risk of hunting pressure maps modelled based on selected extrinsic factors shows that all three pangolin species in Ghana are potentially prone to high off-take.
- Hunting pressure was found to be generally low in and around wildlife protected areas where human population density and road accessibility is low.
- Visual examination of the hunting pressure map reveals that majority of the areas with high occurrence probability for *Manis tetradactyle* coincided with high hunting risk areas.
- The intensity of hunting pressure on pangolins minimises as one move towards the northern part of Ghana.

Even though lack of empirical data on actual trend of pangolin harvest in the study area to validate whether our estimated potential hunting pressure reflect reality is a major limitation, findings from the current study still offer managers and planners of conservation useful information in strategising for effective law enforcement programs.

REFERENCES

Aarts, G., Fieberg, J., & Matthiopoulos, J. (2012). Comparative interpretation of count, presence-absence and point methods for species distribution models. [Article]. *Methods in Ecology and Evolution, 3*(1), 177-187.

Abedi-Lartey, M. (2004). *Bushmeat hunters do better : indigenous vs scientific habitat evaluation.* ITC, Enschede.

Akpona, H. A., Djagoun, C., & Sinsin, B. (2008). Ecology and ethnozoology of the three-cusped pangolin Manis tricuspis (Mammalia, Pholidota) in the Lama forest reserve, Benin. [Article; Proceedings Paper]. *Mammalia, 72*(3), 198-202.

Alves, R. R. N., Souto, W. M. S., & Barboza, R. R. D. (2010). Primates in traditional folk medicine: a world overview. [Review]. *Mammal Review, 40*(2), 155-180.

Asibey, E. O. A. (1974). Wildlife as a source of protein in Africa South of the Sahara. *Biological Conservation, 6*(1), 32-39.

Barnett, A. A., & Prangley, M. L. (1997). Mammalogy in the Republic of Guinea: an overview of research from 1946 to 1996, a preliminary check-list and a summary of research recommendations for the future. *Mammal Review, 27*(3), 115-164.

Czetwertynski, S. M., Boyce, M. S., & Schmiegelow, F. K. (2007). Effects of hunting on demographic parameters of American black bears. *Ursus, 18*(1), 1-18.

Danquah, E., Oppong, S. K., Akom, E., & Sam, K. M. (2010). Preliminary survey of Chimpanzees and threatened monkeys in the Bia-Goaso forest Block in south-western Ghana. *Ecology 4*, 46-58.

Decher, J., & Fahr, J. (2007). A conservation assessment of bats (Chiroptera) of Draw River, Boi-Tano, and Krokosua Hills Forest Reserves in the Western Region of Ghana. *Myotis, 43*, 5-30.

Di Bitetti, M., Paviolo, A., Ferrari, C., Di Angelo, C., & Di Blanco, Y. (2008). Differential responses to hunting in two sympatric species of brocker deer. *Biotropica, 40*, 636-645.

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F.*, et al.* (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography, 29*(2), 129-151.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions, 17*(1), 43-57.

Fa, J. E., & Brown, D. (2009). Impacts of hunting on mammals in African tropical moist forests: a review and synthesis. *Mammal Review, 39*(4), 231-264.

Fa, J. E., Yuste, J. E. G., & Castelo, R. (2000). Bushmeat Markets on Bioko Island as a Measure of Hunting Pressure

Mercados de Carne Silvestre en la Isla Bioko como Medida de la Presión por Caza. *Conservation Biology, 14*(6), 1602-1613.

Ficetola, G. F., Thuiller, W., & Miaud, C. (2007). Prediction and validation of the potential global distribution of a problematic alien invasive species — the American bullfrog. *Diversity and Distributions, 13*(4), 476-485.

Fynn, R. W. S., & Bonyongo, M. C. (2011). Functional conservation areas and the future of Africa's wildlife. *African Journal of Ecology, 49*(2), 175-188.

Ghana Statistical Service. (2012). National Data Archive (NADA).

Grenyer, R., Orme, C. D. L., Jackson, S. F., Thomas, G. H., Davies, R. G., Davies, T. J., Jones, K. E., Olson, V. A.*, et al.* (2006). Global distribution and conservation of rare and threatened vertebrates. [10.1038/nature05237]. *Nature, 444*(7115), 93-96.

Hall, J. B., & Swaine, M. D. (1976). Classification and Ecology of Closed-Canopy Forest in Ghana. *Journal of Ecology, 64*(3), 913-951.

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*(1), 264-268.

Heumann, B. W., Walsh, S. J., & McDaniel, P. M. (2011). Assessing the application of a geographic presence-only model for land suitability mapping. *Ecological Informatics, 6*(5), 257-269.

Hillers, A., Boateng, C. O., Segniagbeto, G. H., Agyei, A. C., & Rödel, M.-O. (2009). Assessment of the amphibians in the forests of southern Ghana and western Togo. *Zoosystematics and Evolution, 85*(1), 127-141.

Jachmann, H. (2008). Monitoring law-enforcement performance in nine protected areas in Ghana. *Biological Conservation, 141*(1), 89-99.

Jackson, C. R., & Robertson, M. P. (2011). Predicting the potential distribution of an endangered cryptic subterranean mammal from few occurrence records. *Journal for Nature Conservation, 19*(2), 87-94.

Kerr, J. T., & Ostrovsky, M. (2003). From space to species: ecological applications for remote sensing. *Trends in Ecology & Evolution, 18*(6), 299-305.

Larsen, T. (2008). Forest butterflies in West Africa have resisted extinction… so far (Lepidoptera: Papilionoidea and Hesperioidea). *Biodiversity and Conservation, 17*(12), 2833-2847.

Loiselle, B. A., Howell, C. A., Graham, C. H., Goerck, J. M., Brooks, T., Smith, K. G., & Williams, P. H. (2003). Avoiding Pitfalls of Using Species Distribution Models in Conservation Planning. *Conservation Biology, 17*(6), 1591-1600.

Mbete, R. A., Banga-Mboko, H., Racey, P., Mfoukou-Ntsakala, A., Nganga, I., Vermeulen, C., Doucet, J. L., Hornick, J. L., & Leroy, P. (2011). Household bushmeat consumption in Brazzaville, the Republic of the Congo. *Tropical Conservation Science, 4*(2), 187-202.

McNeely, J. A., International Union for Conservation of, N., Natural, R., World Resources, I., Conservation, I., World Wildlife, F., & World, B. (1990). *Conserving the world's biological diversity*. Gland, Switzerland; Washington, D.C.: IUCN ; WRI : CI : WWF-US : World Bank.

Midgley, G. F., Hannah, L., Millar, D., Rutherford, M. C., & Powrie, L. W. (2002). Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography, 11*(6), 445-451.

Miller, J. A., & Franklin, J. (2010). *Mapping species distributions: spatial inference and prediction*. GB: Cambridge University Press.

Norman, T. L., & Lim, P. K. L. (2007). Home range, activity cycle and natal den usage of a female Sunda pangolin Manis javanic(Mammalia:Pholidota) in Singapore. *Endang Species Res., 3*, 8pp.

Oates, J. F., Abedi-Lartey, M., McGraw, W. S., Struhsaker, T. T., & Whitesides, G. H. (2000). Extinction of a West African Red Colobus Monkey. *Conservation Biology, 14*(5), 1526-1532.

Oduro-Afriyie, K. (1996). Rainfall erosivity map for Ghana. *Geoderma, 74*(1–2), 161-166.

Pearson, R. G., Raxworthy, C. J., Nakamura, M., & Townsend, P. A. (2007). ORIGINAL ARTICLE: Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography, 34*(1), 102-117.

Pearson, R. G., Thuiller, W., Araújo, M. B., Martinez-Meyer, E., Brotons, L., McClean, C., Miles, L., Segurado, P*., et al.* (2006). Model-based uncertainty in species range prediction. *Journal of Biogeography, 33*(10), 1704-1711.

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution, 20*(9), 503-510.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling, 190*(3–4), 231-259.

Phillips, S. J., & Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography, 31*(2), 161-175.

Pullan, R. A. (1981). THE UTILIZATION OF WILDLIFE FOR FOOD IN AFRICA - THE ZAMBIAN EXPERIENCE. [Article]. *Singapore Journal of Tropical Geography, 2*(2), 101-113.

Rodríguez, J. P., Brotons, L., Bustamante, J., & Seoane, J. (2007). The application of predictive modelling of species distribution to biodiversity conservation. *Diversity and Distributions, 13*(3), 243-251.

Ryan, J. M., & Attuquayefio, D. (2000). Mammal fauna of the Muni-Pomadze Ramsar site, Ghana. *Biodiversity and Conservation, 9*(4), 541-560.

Saha, D., & Sundriyal, R. C. (2012). Utilization of non-timber forest products in humid tropics: Implications for management and livelihood. [Article]. *Forest Policy and Economics, 14*(1), 28-40.

Santos, X., Brito, J. C., Caro, J., Abril, A. J., Lorenzo, M., Sillero, N., & Pleguezuelos, J. M. (2009). Habitat suitability, threats and conservation of isolated populations of the smooth snake (Coronella austriaca) in the southern Iberian Peninsula. *Biological Conservation, 142*(2), 344-352.

Scholes, R. J., Kuper, W., & Biggs, R. (2006). Biodiversity. from http://hdl.handle.net/10204/1179

Skilling, J. (1991). Maximum Entropy and Bayesian Methods On Parameter Estimation and Quantification. In W. T. Grandy & L. H. Schick (Eds.), (Vol. 43, pp. 267-273): Springer Netherlands.

Sorace, A. (2001). Value to Wildlife of Urban-Agricultural Parks: A Case Study from Rome Urban Area. *Environmental Management, 28*(4), 547-560.

Townsend, P. A., Papeş, M., & Eaton, M. (2007). Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. *Ecography, 30*(4), 550-560.

Wiens, J. A., Stralberg, D., Jongsomjit, D., Howell, C. A., & Snyder, M. A. (2009). Niches, models, and climate change: Assessing the assumptions and uncertainties. *Proceedings of the National Academy of Sciences, 106*(Supplement 2), 19729-19736.

Wilson, A. E. (1994). Husbandry of pangolins Manis spp. *International Zoo Yearbook, 33*(1), 248-251.

Wu, S., Liu, N., Ma, G., Xu, Z., & Chen, H. (2003). Studies on habitat selection by Chinese pangolin (Manis pentadac-tyla) in winter in Dawuling Natural Reserve. *Acta Ecologica Sinica, 23*(6), 1079-1086.

Zahler, P. (2001). Endangered Mammals. In A. L. Editor-in-Chief: Simon (Ed.), *Encyclopedia of Biodiversity* (pp. 441-454). New York: Elsevier.

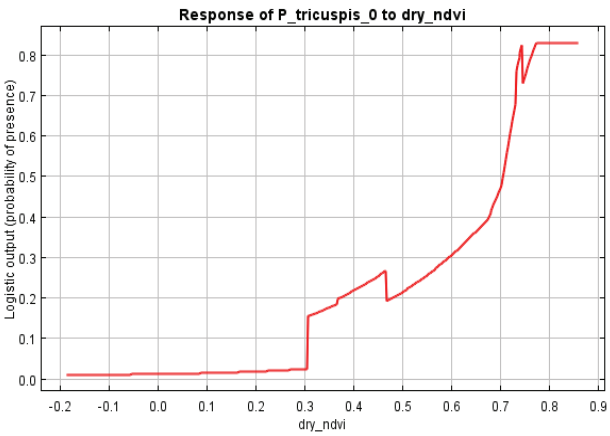
APPENDICES

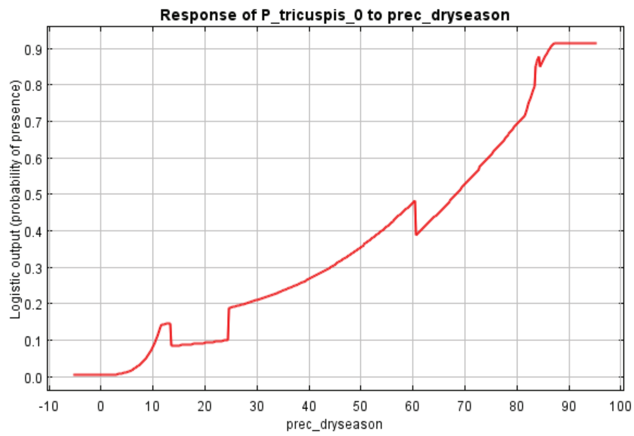
Apendix A: Explanation of Environmental variables

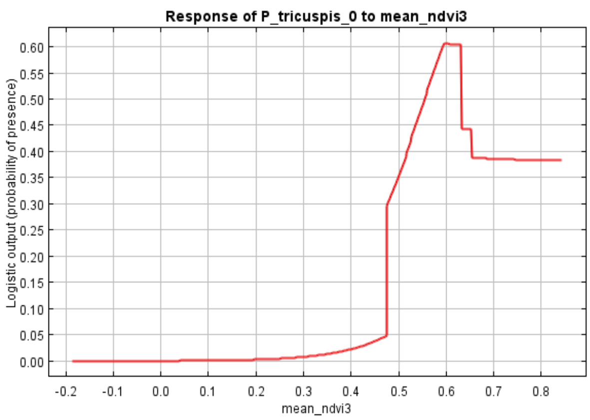
Variable	Explanation
1. dry_ndvi	Normalized difference vegetation index for driest months
2. prec_dryseason	Precipitation for driest months (Dec. – March)
3. temp_max2	Maximum temperature
4. mean_ndvi3	Normalized difference vegetation index (annual mean)
5. ghana_slope	Slope
6. Elevation	Elevation
7. temp_min_annual	Annual minimum temperature
8. prec_wet1	Mean precipitation for the wettest months (April-July)
9. temp_mean2	Annual mean temperature
10. aspect	Aspect
11. rain_ndvi	Normalized difference vegetation index for wettest months

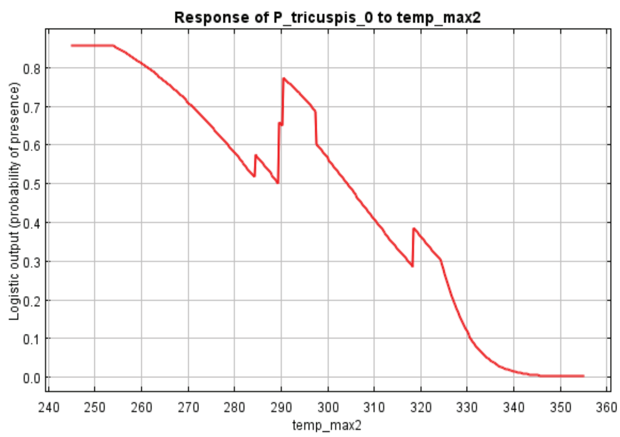
Appendix B: Response Curves for four top variables

1. ***Phantaginus tricuspids*** **(Tree Pangolin)**

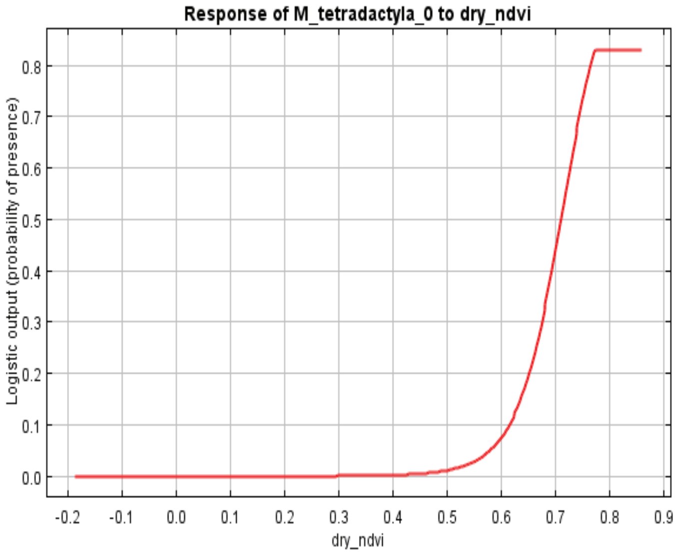


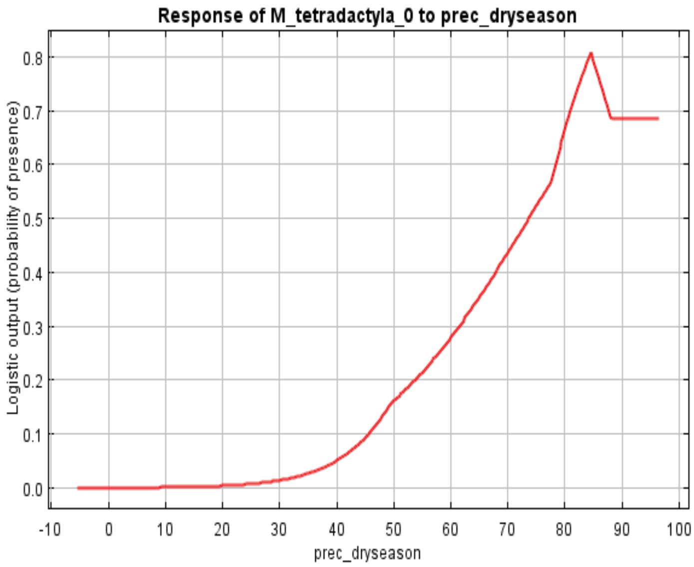


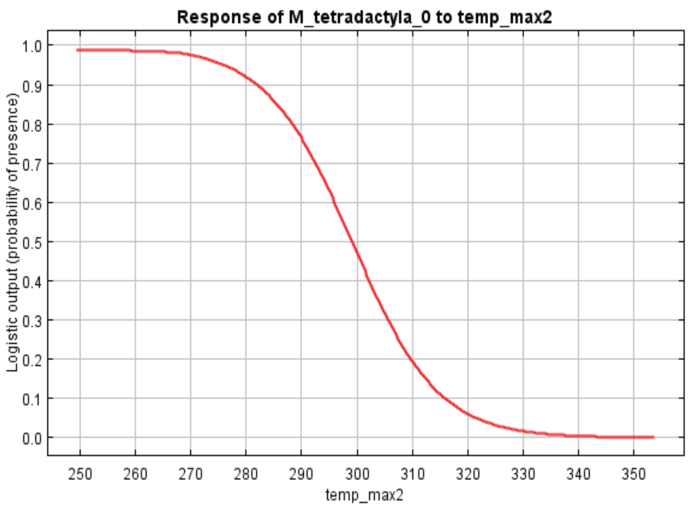


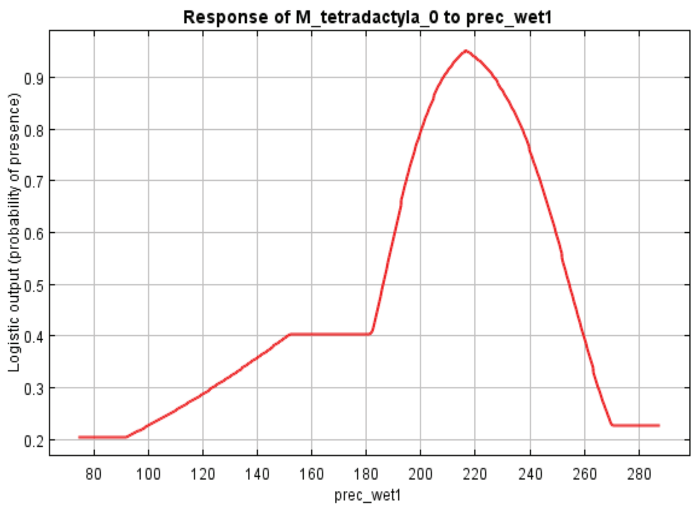


2. ***Manis tetradactyle* (Long -tailed Pangolin)**









3. ***Manis gigantea* (Giant pangolin)**