HABITAT SUITABILITY MODELLING OF WHITE-BELLIED PANGOLIN (*PHATAGINUS TRICUSPIS*) IN OLUWA FOREST RESERVE, ONDO STATE, NIGERIA

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Received: 25th May 2024, **Accepted:** 28th August 2024

ABSTRACT

Most endangered species face a significant threat from habitat loss. The destruction and degradation of natural tropical forest across West Africa has likely been the biggest threat to White-bellied Pangolin and has contributed to their decline as they depend on the habitat for different resources like food, water, and shelter. The current study investigated the habitat suitability of white-bellied pangolins in Oluwa Forest Reserve. The presence data of White-bellied pangolin was collected by taking the Global Positioning System (GPS) coordinates of the indirect signs observed. These data, along with the 19 bioclimatic variables, slopes, soil PH, soil texture, distance to rivers, distance to roads, and Normalized Difference Vegetation Index (NDVI), were used to generate habitat suitability maps using MaxEnt software. The MaxEnt analysis showed that out of 781 km^2 available for White bellied Pangolin during dry season, 338 km^2 was highly suitable, 209 km^2 was suitable, 126 km^2 was moderately suitable, 65 km^2 was less suitable and 44 km^2 was not suitable. During the wet season 235 km^2 was highly suitable, 225 km^2 was suitable, 164 km^2 was moderately suitable, 100 km^2 was less suitable and 57 km^2 was not suitable habitat. The jackknife test of variable contribution revealed that during the dry season, NDVI was the most important predictor variable as measured by the gain produced by a one-variable model, followed by aspects such as distance to the river, slope, distance to the road, and temperature seasonality. During the wet season, the jackknife-cross-validation test showed the highest gain when NDVI was used in isolation. Aspects were found to be the second most important predictor variable as measured by the gain produced by a one-variable model, followed by distance to the road, slope, elevation, and the mean temperature of the wettest quarter.

Keywords: White bellied Pangolin, Habitat Suitability, MaxEnt modelling, Habitat Suitability Model, Machine Learning

INTRODUCTION

Biodiversity is increasingly threatened by factors such as habitat loss, climate change, overexploitation, and pollution (IPBES, 2019; Pimm *et al*., 1995). Current extinction rates have surged to critical levels, with human activities causing extinction rates that are 8 to 100 times higher than natural levels, a phenomenon referred to as the "sixth extinction crisis" (Ceballos *et al*., 2015). These extinction rates and the impact of various factors on extinction risk differ by region, especially in relation to changes in land cover (Rodrigues *et al*., 2014). Some mammal species are especially at risk due to inherent characteristics like slow reproduction and sparse populations. These traits make them more vulnerable to human-induced threats such as overexploitation, habitat loss, and environmental degradation (Malakoutikhah *et al*., 2020; Sharma *et al*., 2014; Thomas *et al*., 2004). Understanding the geographic range, ecological, and biological attributes of species, as well as the factors that affect these aspects, is essential for successful conservation strategies and predicting future actions (Rushton *et al*., 2004). Additionally, this understanding is vital for advancing ecological restoration initiatives (Guisan & Thuiller, 2005; Martinez-Meyer *et al*., 2006).

Habitat suitability modeling (HSM) also known as Species distribution models (SDMs) are quantitative techniques that integrate data on a species' known occurrences with predictor variables, statistical models, and computer algorithms. These models serve two main purposes: 1) to calculate the values of each predictor variable and their effects on the species of interest at each known occurrence site, and 2) to identify suitable areas based on these predictor variables (Carpenter *et al*., 1993; Duan *et al*., 2014; Elith & Leathwick, 2009; Fielding & Bell, 1997a; Wisz *et al*., 2008). They can provide valuable information on the distribution and abundance of the species in the reserve, as well as identify potential areas for future conservation interventions. This modeling involves the use of ecological and environmental data to predict suitable habitats for the species based on its known biological and ecological requirements (Guisan & Zimmermann, 2000). The application of HSM as a tool for wildlife managers is becoming more important by the day, not only for efficient wildlife recovery but also for forecasting potential areas of high habitat quality for a given species to be conserved (Stevens & Conway, 2020). Recent advances in HSM, including the integration of machine learning techniques and remote sensing data, have enhanced the ability to accurately predict suitable habitats for threatened species (Elith *et al*., 2011; Merow *et al*., 2013). MaxEnt, a widely used modeling software, has been particularly effective in species distribution modeling due to its robust performance with presence-only data (Phillips *et al*., 2006).

Having a solid understanding of the potential distribution and suitable habitats for species with declining populations across their range is crucial for effective long-term conservation planning (Akrim *et al*., 2017). Pangolins is one of such specie. Pangolins are mammals of the order pholidata with eight recognized species distributed evenly between Africa and Asia (Maurice *et al*., 2019). Three species inhabit western African: White-bellied Pangolin (*Phataginus tricuspis*), the Black-bellied Pangolin (*Phataginus tetradactyla*) and Giant ground pangolin (*Simutsia gigantean*) (Challender & Waterman 2017). Nigerian pangolins inhabit natural forest; primary and secondary rain forest, moist tropical lowland and secondary growth forest, dense woodlands, especially along water courses or riverine and swamp forests dominated by palms, bamboo forest, forest-savanna- cultivation mosaic habitat (Challender & Waterman 2017; Odewumi & Ogunsina, 2018).

White Bellied Pangolin are known as anteaters as they feed mostly on ant and termites. They have no teeth and are scaly. Their scales are hardened and plate-like, it only covers their dorsal tail (Maurice *et al*., 2019). They occur predominantly in moist tropical lowland forests and secondary growth, but also occur in dense woodlands, especially along water courses

(Gaubert, 2011). *Phataginus tricuspis* are solitary and predominantly nocturnal (Kingdon *et al*., 2013). They inhabit a variety of habitats (Lagrada *et al*., 2014). They prefer trees with holes, dead wood, exiting holes or burrows (Maurice *et al*., 2019). They are found in high forest zones requiring the availability of large trees for shelter (Maurice *et al*. 2019).

The destruction and degradation of natural tropical forest across West Africa has likely been the biggest threat to White bellied Pangolin (Ofori *et al*., 2012; Megevand, 2013; Adeniji *et al*., 2023). They are overexploited for both local and international use mainly because of their meats and their scales (Heinrich *et al*., 2017). Various body parts of the pangolin are used in traditional medicine which drives its exploitation (Djagoun *et al*., 2013). The rampant population decline has led to some of its specie occurring in Nigeria as being listed as endangered in (International Union of Conservation of Nature (IUCN, 2019). It was also categorized in Appendix I (Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2017). The recent human population explosion in West Africa has exacerbated these threats (Kormos *et al*., 2003).

Research on the White-bellied Pangolin in Nigeria has primarily concentrated on its distribution and threats, using indirect signs and camera traps (Adeniji *et al*., 2023). However, no study has yet assessed habitat suitability and potential distribution of the White-bellied Pangolin using a Habitat Suitability Model (HSM) approach in Nigeria. To address this gap, the study posed two key research questions:

(1) What environmental variables influence the distribution of the White-bellied Pangolin, and how do these variables impact its distribution?

(2) What proportion of the habitat is suitable for the White-bellied Pangolin, and how is this suitable habitat distributed within the study area?

The hypothesis is that the distribution of the White-bellied Pangolin is influenced by elevation, vegetation types (Hoffmann *et al*., 2020; Waseem *et al*., 2020), and soil type, given that this species is a burrower. This study aims to enhance the understanding of White-bellied Pangolin ecology, which is essential for developing targeted conservation strategies for both the species and its habitat.

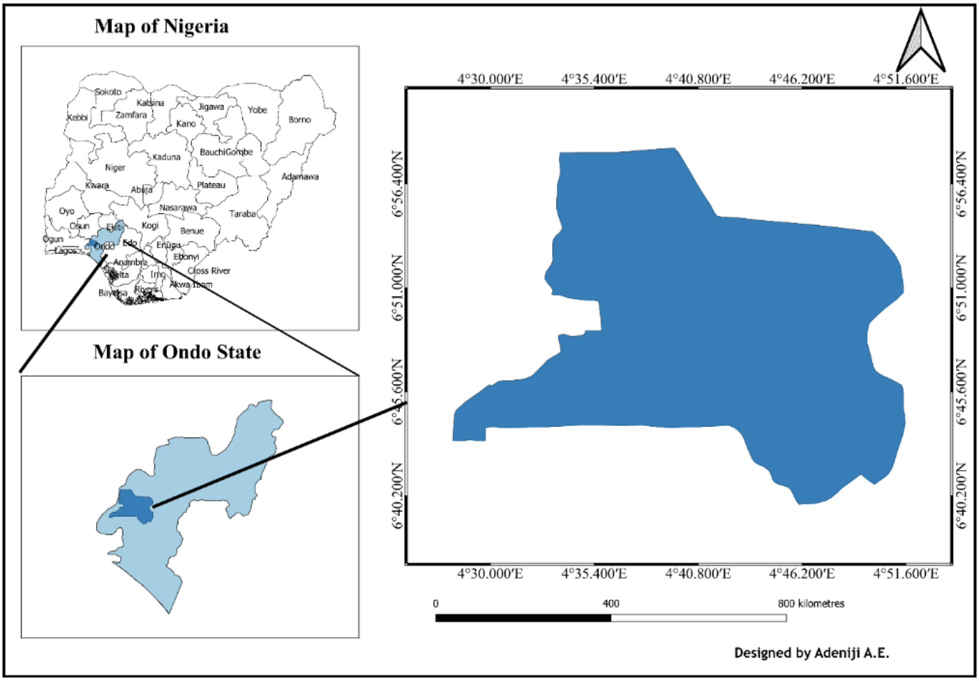
MATERIALS AND METHODS

Study Area

The research was conducted in Oluwa Forest Reserve, Ondo State, Nigeria. The reserve covers 678.06 km^2 with much of it lying approximately between 300 and 600 m above sea level (Ogunjemite *et al*., 2006). The reserve is situated along the Lagos-Benin expressway, with most of the reserve lying north of the road. Some of the land lies south of the road (about one-sixth of the overall area). Its eastern border is really close.to the Ondo-Ore Road, a major road that connects Ondo and Akure (Greengrass, 2006). Most of the rivers and streams that drain this area originate in the Oluwa forest's southern parts. Oni, Oluwa, and Ominla are three notable rivers. Natural forest exploitation was common in Oluwa Forest Reserve before to the development of large-scale plantations, and the remaining natural forest has not been exploited since the start of large-scale plantation establishment, even though it has been designated for planting (Onyekwelu *et al*., 2008). The rainy season lasts from March to November in the reserve, whereas the dry season lasts from December to February. The annual rainfall is between 1700 and 2200 mm. The average annual temperature in Oluwa is 26 ºC. Oluwa Forest Reserve has an average elevation of 100 meters (Onyekwelu *et al*., 2008). Soils has a mostly ferruginous tropical characteristic of the type found in heavily weathered places basement complex formations in the rainforest zone of south-western

Nigeria. The soils are well-drained and fertile, mature, red, stony and gravely in upper parts of the sequence. The texture of topsoil in the reserves is mainly sandy loam (Onyekwelu *et al*., 2008; Adeduntan, 2009).

Fig. 1: Location of Oluwa Forest Reserve in Ondo State, Nigeria



Data Collection and Preprocessing: The field survey was conducted within the two seasons of the forest reserve; wet and dry. The dry season survey was conducted between February and March while the wet season survey was conducted between April and May. The distinction between wet and dry seasons was based on the change in rainfall patterns. The survey was done with the participation of the local hunters to know more information about how the species are distributed within the forest and the potential areas where the animals can be found in the forest.

Four camera traps were secured on trees 3 to 5 m away from 6 randomly selected burrows to detect the animal occurrence. The camera was placed 30 to 50 cm above the ground to capture the burrows properly. Occurrence data was also collected by searching each transect for indirect signs (scats, trace of tail and footprint) and feature that can attract the species such as ant mounds, termitarium and, dead wood (Odewumi & Ogunsina, 2018). Global Positioning System (GPS) coordinates of each sighting (direct and indirect) was recorded. Major disturbances such as roads and settlements within the study area were noted with GPS coordinates. ArcGIS (ver. 10.7) and Maxent (ver. 3.3.4) were used to process data and develop habitat modeling.

Model Preparation and Environmental Variable: The presence data collected during the field surveys were analyzed using the average nearest neighbor technique for spatial autocorrelation in ArcGIS version 10.7. The aim of this analysis was to remove any data points that were spatially correlated and ensure that the data points were independent (Escobar *et al*., 2015; Kabir *et al*., 2017; and Zahoor *et al*., 2021). To model the suitable habitat of the White bellied Pangolin, a variety of variables were considered, including environmental variables, topography, and anthropogenic influences. The variables include Nineteen (19) bioclimatic variables, slopes, soil PH, Soil texture, distance to river, distance to roads, and Normalized Difference Vegetation Index (NDVI) (Table 1). Bioclimatic variables were obtained from the Worldclim database (WorldClim.org). To obtain distance-based variables (distances to river and distance to road), a shapefile of each feature type was created using ArcGIS version 10.3.1 and used to create raster files of Euclidian distance from the corresponding features. The Digital Elevation Model (DEM) was used to extract topographic variables which include slope, aspect, and terrain features of the study area. The primary source of data was 30 m resolution Shuttle Radar Topographic Mission (SRTM) which was be obtained from United States Geological Survey (USGS) archive https://earthexplorer.usgs.gov/. NDVI was calculated using Landsat satellite image (Landsat 8 OLI/TIRS) of the study area for the year 2021 with spatial resolution of 30 m and a cloud cover of less than 10 % which was obtained from United States Geological Survey (USGS) archive https://earthexplorer.usgs.gov/. The soil PH and texture layer were downloaded on the International Soil Reference and Information Centre database at 250 m spatial resolution (Hengl *et al*., 2017). All environmental data were masked to the full extent of the study area and all layers were resampled at a resolution of 30 × 30 m using ArcGIS.

Maxent Model

Maxent modeling approach was used to model the suitable habitat of White bellied Pangolin. We used 75 % of the available presence data to calibrate the model, and the remaining 25 % was used for model validation. To ensure the reliability of our results, we used a bootstrapping procedure with 20 replications and a maximum of 500 iterations. We assessed the accuracy of the model by calculating the Area Under the Curve (AUC) using Receiver Operating Characteristics (ROC) analysis, which is a common method for evaluating the performance of species distribution models (Hajian-Tilaki, 2013). The AUC is a measure of the predictive performance of a model, particularly for binary classification problems. A perfect model has an AUC of 1.0, while a model with a random guess has an AUC of 0.5. AUC values below 0.70 are suitable, values between 0.7 to 0.9 are good, and values above 0.9 denote excellent model performance (Valavi *et al*., 2022). The study used jackknife sensitivity analysis and response curves derived from univariate models to examine the influence of each environmental variable on the presence probability of the target species.

Table 1: Environmental variables used to develop habitat suitability model for White-bellied Pangolin.

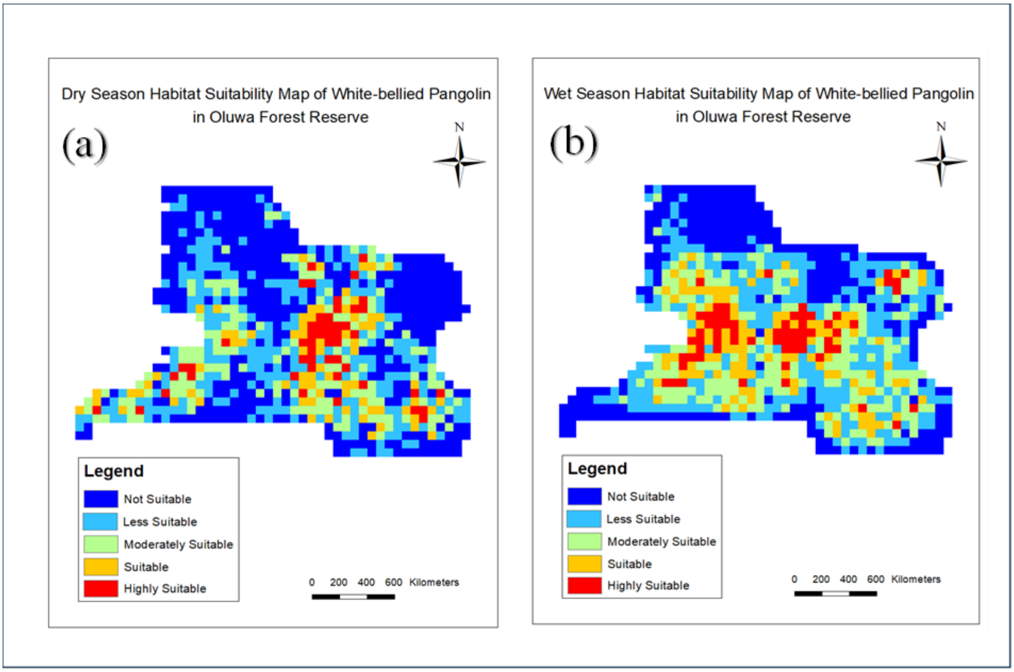
Environmental Variables	Codes	Data Source
Annual mean temperature	Bio1	www.worldclim.org
Mean diurnal range (mean of monthly (max temp - min temp)	Bio2	www.worldclim.org
Isothermality (BIO2/BIO7) (×100)	Bio3	www.worldclim.org
Temperature seasonality (standard deviation ×100)	Bio4	www.worldclim.org
Max temperature of warmest month	Bio5	www.worldclim.org
Min temperature of coldest month	Bio6	www.worldclim.org
Temperature annual range (BIO5-BIO6)	Bio7	www.worldclim.org
Mean temperature of wettest quarter	Bio8	www.worldclim.org
Mean temperature of driest quarter	Bio9	www.worldclim.org
Mean temperature of warmest quarter	Bio10	www.worldclim.org
Mean temperature of coldest quarter	Bio11	www.worldclim.org
Annual precipitation	Bio12	www.worldclim.org
Precipitation of wettest month	Bio13	www.worldclim.org
Precipitation of driest month	Bio14	www.worldclim.org
Precipitation seasonality (Coefficient of Variation)	Bio15	www.worldclim.org
Precipitation of wettest quarter	Bio16	www.worldclim.org
Precipitation of driest quarter	Bio17	www.worldclim.org
Precipitation of warmest quarter	Bio18	www.worldclim.org
Precipitation of coldest quarter	Bio19	www.worldclim.org
Euclidean distance to road (m)	dist_road	Calculated by using Euclidean distance tool in ArcGIS 10.4
Euclidean distance to rivers (m)	dist_river	Calculated by using Euclidean distance tool in ArcGIS 10.4
Soil PH	Soil PH	international Soil Reference and Information Centre database
Soil Texture	Soil Texture	international Soil Reference and Information Centre database
Slope of the area	Slope	Shuttle Radar Topographic Mission (SRTM) (https://earthexplorer.usgs.gov/)
Aspects	Aspects	Shuttle Radar Topographic Mission (SRTM) (https://earthexplorer.usgs.gov/)
Normalized difference vegetation index	NDVI	https://earthexplorer.usgs.gov/.

RESULTS

Habitat Suitability Model

Output maps of the habitat suitability model of the White-bellied Pangolin in Oluwa forest reserve during dry and rainy seasons are shown in Figures 2a and 2b respectively. In predictive maps generated by MaxEnt, a color scheme is used to represent the probability range of favorable conditions for a species. Warmer colors, such as red, indicate a high probability of favorable conditions for the species. Conversely, cooler colors, such as blue and green, indicate a moderate and low probability of favorable conditions respectively.

Fig. 2: Map showing habitat suitability of White-bellied pangolin (*Phataginus tricuspis*) in the study area during (a) dry season and (b) wet season



The MaxEnt analysis of dry season showed that out of 782 km^2 area available to White-bellied pangolin, 44.3 km^2 (5.7 %) area was “highly suitable” habitat, followed by 65.2 km^2 (8.3 %) area that was “suitable” habitat, 126 km^2 (16.1 %) area was “moderately suitable” habitat, 208.5 km^2 (26.7 %) area was “less suitable” habitat while another 338 km^2 (43.2 %) was found to be “not suitable” habitat (Table 2). Habitat suitability map of wet season showed that out of 782 km^2 area available to White-bellied pangolin, 57.3 km^2 (7.3 %) area was “highly suitable” habitat, followed by 99.9 km^2 (12.8 %) area that was “suitable” habitat, 164.2 km^2 (21 %) area was “moderately suitable” habitat, 225 km^2 (28.8 %) area was “less suitable” habitat while another 235.5 km^2 (30.1 %) was found to be “not suitable” habitat (Table 2). White-bellied pangolin have a larger area of highly suitable habitat in the wet season (57.3 km^2) than in the dry season (44.3 km^2).

The habitat suitability from the MaxEnt analysis was evaluated by counting the number of survey grids falling into each habitat category. A habitat was considered suitable if it provided optimal conditions for the thriving of the pangolin population, as indicated by the covariates used in the analysis. A less suitable habitat was characterized by the presence of the pangolin population, albeit with fewer field signs, as influenced by the covariates. On the other hand, an unsuitable habitat was identified as having a lower likelihood, as predicted by the MaxEnt analysis.

Table 2: Details of the habitat suitability area for White-bellied pangolin habitat estimated in both dry and wet season of the study area.

Season	Highly Suitable (Km^2)	Suitable (Km^2)	Moderately suitable (Km^2)	Less suitable (Km^2)	Not suitable (Km^2)	Total area of Study Area (Km^2)
Dry season	338	209	126	65	44	781
Wet season	235	225	164	100	57	781

The average test omission rate and predicted area were calculated for the cumulative threshold in the MAXENT model, considering both the wet and dry seasons. These calculations were based on ten replicate runs. It was observed that the receiver operating characteristic (ROC) curve, averaging over ten replicate runs, yielded higher area under the curve (AUC) values for the wet and dry seasons of elephants. The AUC values were determined to be 0.935 for the dry season (Fig. 3a) and 0.880 for the wet season (Fig. 3b). These values indicate that both the training and test data performed better than the random prediction line (0.5) in both seasons of the MAXENT model. This suggests a very good predictive ability in determining the habitat suitability of elephants in the study area.

The Maxent technique was employed to conduct a jackknife cross-validation test on both dry and rainy season data, as illustrated in Figures 4a and 4b, respectively. This approach was utilized to determine the relative contribution and permutation importance of each environmental variable in the White-Bellied Pangolin habitat suitability model within the Oluwa Forest Reserve.

During the dry season, the analysis revealed that NDVI had the highest gain when used in isolation, indicating its significant influence on habitat suitability (Figure 4a). Aspect was identified as the second most important predictor variable based on the gain produced by a one-variable model, followed by distance to river, slope, distance to road, and temperature seasonality (Bio 4).

In the wet season, NDVI again emerged as the most influential variable, with the highest gain in the jackknife cross-validation test (Figure 4b). Aspect remained the second most important predictor, followed by distance to road, slope, elevation, and the mean temperature of the wettest quarter (Bio 8)

Fig. 3: Analysis of omission/commission showing how well the model accurately predicted White bellied pangolin presence during (a) dry season and (b) wet season.

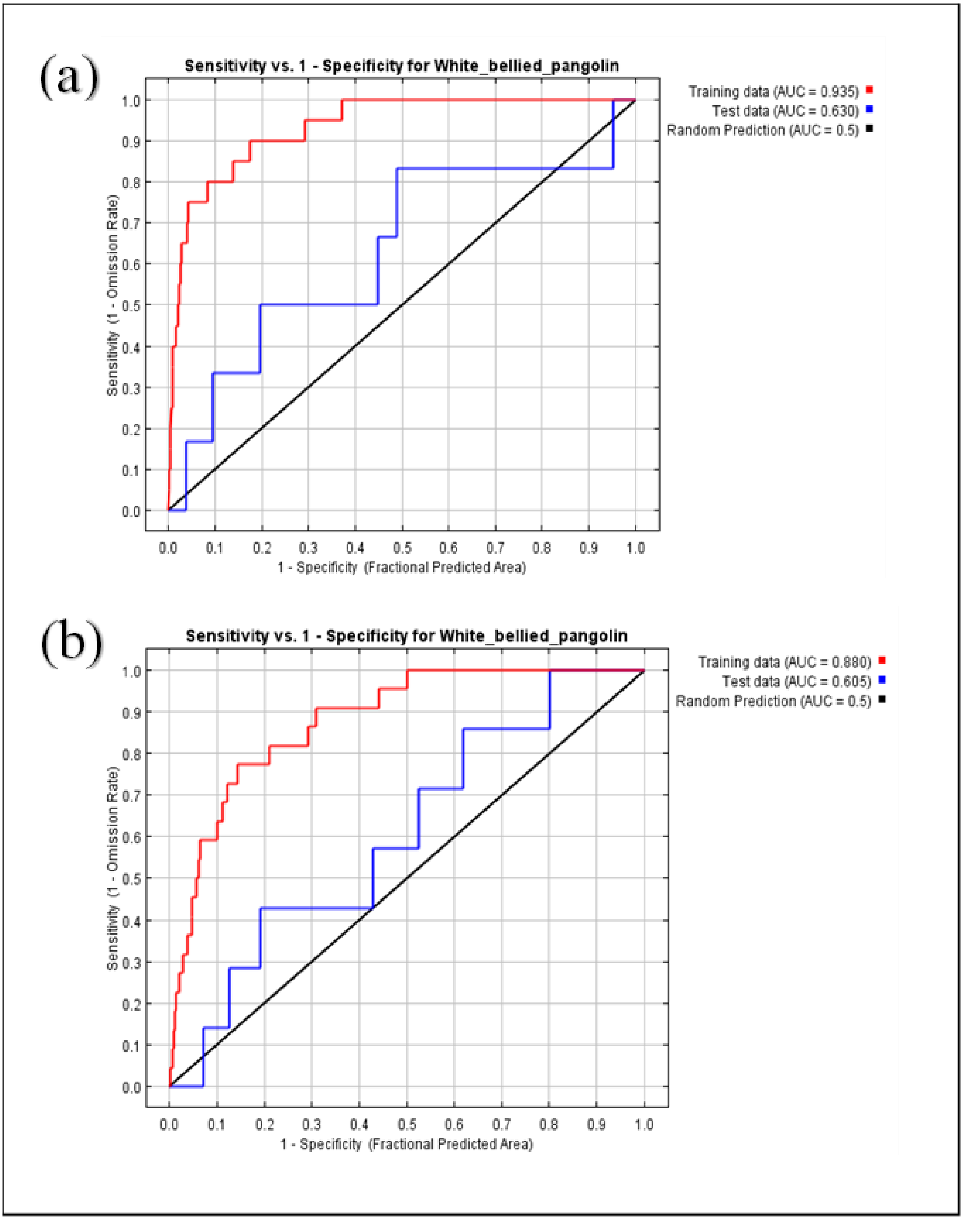


Fig. 4: Jackknife of AUC (area under the receiver operating curve) for White bellied Pangolin during (a) dry season and (b) wet season, showing average AUC gains for each variable (abbreviation of variables are in Table 1 above).

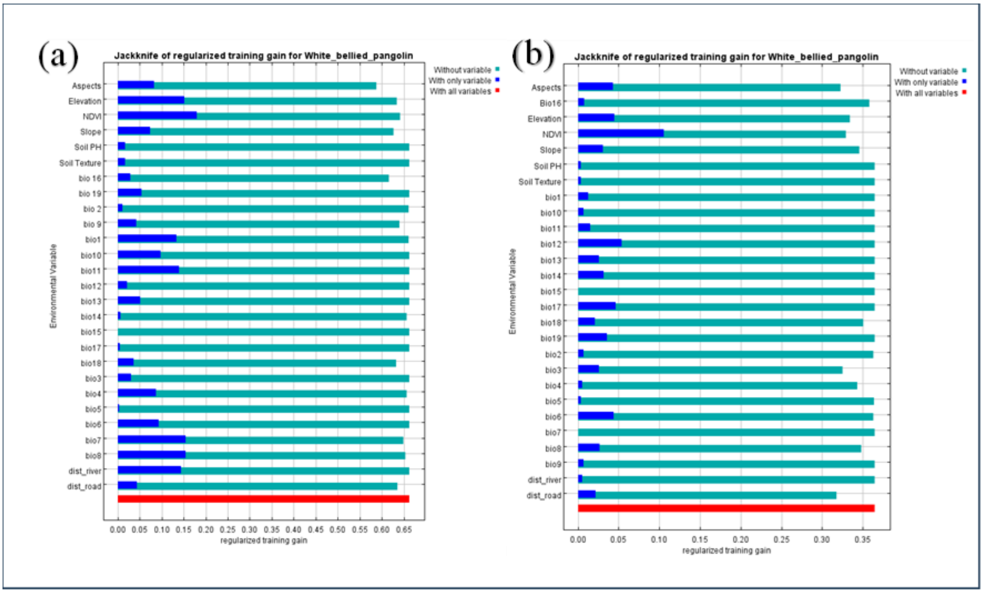


Table 3: Contribution and importance of predictor variables to the MAXENT model in the habitat of White-bellied Pangolin in both the wet and dry seasons.

Environmental Variables	Acronyms	Percent contribution	Permutation importance	Percent contribution	Permutation importance
		Dry Season		Wet Season	
Normalized difference vegetation index	NDVI	19.6	3.2	34.1	27.6
Aspects	Aspects	11.7	11	11.6	6.3
Euclidean distance to rivers (m)	dist_river	8.6	0	0.1	0.9
Slope of the area	Slope	8.6	4.2	9.3	8.1
Euclidean distance to road (m)	dist_road	8.6	26.3	9.5	6.3
Temperature seasonality (standard deviation ×100)	bio4	8.1	0.9	4.4	5.1
Precipitation of wettest quarter	bio 16	6.8	5.8	2	1.7
Temperature annual range (BIO5-BIO6)	bio7	6.1	6.1	0	0

Mean temperature of driest quarter	bio 9	4.2	0	0	0
Precipitation of coldest quarter	bio 19	3.5	0	0	0
Precipitation of warmest quarter	bio18	3.1	10.8	3.5	3.2
Min temperature of coldest month	bio6	2.9	0	0.3	0
Mean temperature of wettest quarter	bio8	2	2	8.3	17
Mean temperature of coldest quarter	bio11	1.8	0	0	0
Precipitation of driest month	bio14	1.3	0.3	0	0
Elevation	Elevation	1.2	18.5	8.9	16.5
Soil PH	Soil PH	0.9	0	0.3	0
Isothermality (BIO2/BIO7) (×100)	bio3	0.5	0	7.1	6.6
Mean diurnal range (mean of monthly (max temp - min temp)	bio 2	0.3	0	0.2	0.5
Annual mean temperature	bio1	0.3	10.7	0	0
Precipitation of driest quarter	bio17	0.1	0.3	0	0
Max temperature of warmest month	bio5	0	0	0.3	0.1
Precipitation seasonality (Coefficient of Variation)	bio15	0	0	0	0
Precipitation of wettest month	bio13	0	0	0	0
Annual precipitation	bio12	0	0	0	0
Mean temperature of warmest quarter	bio10	0	0	0	0

DISCUSSION

The primary and most significant threat to the White-bellied Pangolin in West Africa is the destruction and degradation of natural tropical forests (Ofori *et al*., 2012; Megevand, 2013). This habitat loss has had a detrimental impact on the population of White-bellied Pangolins. Additionally, they are subjected to overexploitation for both local and international markets, primarily driven by the demand for their meat and scales (Heinrich *et al*., 2017). These factors contribute to the decline in White-bellied Pangolin populations and pose a severe threat to their survival. In our study, we aimed to contribute to the understanding of the ecology of White-bellied pangolins by investigating the factors influencing their distribution and determining the suitability of their habitat in a forest reserve in Ondo state, Nigeria. Using a maximum entropy modeling approach (Phillips *et al*., 2006), we were able to gain insights into how environmental variables shape the distribution of white-bellied pangolins and influence their habitat suitability. Our findings suggest that modeling habitat suitability can be a valuable tool for conservationists and wildlife managers, particularly when it comes to identifying priority areas for conservation actions with limited resources.

Our findings revealed that the majority of the documented pangolin occurrences were in forested areas. It has been shown that forest is the most preferred habitat of White-bellied Pangolin (Panta *et al*., 2023). This preference for forest habitat could potentially be attributed to the abundant and diverse termite species found in these areas, as suggested by previous research (Okwakol, 2001). The presence of a high abundance and richness of termite species might create favorable conditions for pangolins, leading to their occurrence in forested habitats.

Among the environmental variables used for the habitat suitability model, Vegetation structure (here measured using NDVI) was the major predictor of habitat suitability of white-bellied pangolin in both wet and dry season. It has been recognized to affect species distributions and dynamics (Pettorelli *et al*., 2011). Predicted suitable habitats were obtained for NDVI values between 0.08 and 0.39, suggesting that white-bellied pangolin prefer habitat with low to moderate vegetation cover densities. Similar findings have been reported for Chinese and Indian pangolins, despite their ecological differences compared to white-bellied pangolins. Studies on Chinese and Indian pangolins have indicated that these species are predominantly found in areas characterized by low to moderate canopy cover (Acharya *et al*., 2021; Suwal *et al*., 2020). This suggests a common pattern among pangolin species, where they exhibit a preference for habitats with specific canopy cover conditions, regardless of their ecological distinctions. The White-bellied Pangolin is primarily found in moist tropical lowland forests and secondary forests (Akpona *et al*., 2008). However, it can also inhabit savanna-forest mosaics, dense woodlands, including miombo woodland, and riparian forests (Jenson *et al*., 2020).

Aspect was the second most important variable predicting the suitable habitat of White-bellied Pangolin. The same was also recorded for Chinese pangolin with aspect being a major variable affecting the specie presence (Dorji *et al*., 2020). According to Acharya *et al*. (2021), the pangolin demonstrates a preference for the west slope, possibly for the purpose of obtaining sunlight before foraging. However, Suwal (2011) reported a random distribution of burrows across different aspects. Thapa *et al*. (2014) observed a preference for the southwest aspect for burrow digging by pangolins. In contrast, a study by Dhital *et al*. (2020) conducted in the Nagarjun Forest of Shivapuri National Park revealed a preference for eastern aspects by pangolins. The openings of pangolin burrows often face the sun (eastward), which facilitates easier digging and helps regulate the burrow temperature during winter (Wu *et al*., 2004). The preference for specific aspects in certain locations may be influenced by local climatic conditions, food availability, water sources, and the extent of human disturbance (Dhakal, 2016).

Distance to river, slope of the area and distance to road were another factor that influenced the occurrence of White-bellied Pangolin during the dry season in the study area. The availability of water sources was found to have a positive influence on the presence of pangolins, according to a study conducted by Katuwal *et al.* in 2017. The distribution of burrows in relation to the distance from a water source was found to have a significant impact, as observed by Maurice *et al.* (2019) and Dorji (2016). Katuwal et al. (2013) recorded a higher number of burrows within 100 meters of the water source, with only one burrow observed at 700 meters. Similarly, Katuwal *et al.* (2017) noted a higher occurrence of pangolins within 200 meters of a water source, while Karawita *et al.* (2018) found that burrows were more frequent in areas located 100 to 200 meters away from water sources. The presence of burrows near water sources may serve as a strategy for avoiding predators and conserving energy, as pangolins require water for themselves and for attracting ants, termites, and other insects, which also prefer moist habitats (Bista *et al.*, 2017).

The burrows were majorly found on gentle and steep slopes. Our result is like the findings of Maurice *et al.* (2019) who observed a higher number of burrows in gentle and steep slopes, while very steep slopes had fewer burrows, which is contrary to the findings of Wu *et al.* (2004) and Suwal *et al.* (2020), who reported that pangolins prefer slopes of 30 to 60º and 30 to 50º, respectively, for constructing burrows.

The number of burrows and distribution of White-bellied Pangolin increased with the increase in distance from road. Our result is like the findings of Katuwal *et al.* (2017), where there was a higher occurrence of pangolins in areas characterized by minimal disturbance, particularly those located at distances greater than 1000 meters from human settlements and roads.

CONCLUSION

This study provides valuable insights into the habitat preferences and key environmental factors influencing White-Bellied Pangolins in Oluwa Forest Reserve, Ondo State, Nigeria. A major contribution of this research is the identification of NDVI and Aspect as consistently critical variables driving habitat suitability throughout both the dry and wet seasons, underscoring their role in shaping pangolin habitat use. Our findings reveal significant seasonal variations in habitat selection. During the dry season, factors such as distance to rivers, slope, and distance to roads were crucial, whereas in the wet season, distance to roads, slope, and elevation were more influential. This detailed seasonal analysis highlights the complexity of habitat use and the necessity for conservation strategies that are tailored to seasonal variations. The originality of our results is significant, offering a comprehensive case study in habitat suitability modeling with implications for similar ecological settings. This makes our findings pertinent to an international audience and provides a model that can be adapted to other regions with pangolin populations. To enhance conservation efforts of White-bellied Pangolin, it is vital to focus on preserving areas with high vegetation cover and important topographical features essential for pangolin survival. Protecting water resources during the dry season and mitigating human disturbances, such as road construction, are critical. Additionally, maintaining diverse topography, conducting seasonal monitoring, and engaging local communities in conservation initiatives will further support the long-term survival of the species.

ACKNOWLEDGEMENTS

This paper is based on my Master's thesis at Federal University of Technology Akure, Ondo State, Nigeria supervised by Prof. Bernadette N. Ejidike.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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