CONNECTING HABITATS: MODELLING LANDSCAPE CONNECTIVITY FOR LARGE MAMMALS IN OMO-SHASHA-OLUWA FOREST RESERVES, SOUTH-WEST NIGERIA

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ABSTRACT

Preserving landscape connectivity in the Omo-Shasha-Oluwa Forest Reserves is crucial due to human-induced fragmentation, shrinking habitats, and disrupted migration routes for wildlife. From 2014 to 2016, we conducted surveys to gather large mammal presence data, mapping their distribution using the MaxEnt algorithm. Employing Circuitscape software and circuit theory concepts, we predicted connectivity patterns for six large mammal species. Our results consistently showed robust predictive performance, with Area Under the Curve (AUC) values exceeding 0.75 for species distribution models. Notably, we identified suitable habitat patches for seven key species, spanning 1760 km² for *C. civetta*, 1515 km² for *T. Scriptus*, 729 km² for *L. cyclotis*, 1693 km² for *P. porcus*, 1350 km² for *C. mona*, 1406 km² for *P. maxwellii*, and 1379 km² for *C. torquatus*. Our analysis highlighted distance to human settlements as the most significant predictor for habitat models concerning *T. Scriptus*, *C. civetta*, *P. maxwellii*, *C. torquatus*, *P. porcus*, and *C. mona*, whereas land use type emerged as a critical factor for *L. cyclotis*. Furthermore, examination of maximum current flow patterns revealed varying degrees of connectivity among habitat patches, indicating potential bottlenecks to species movement, particularly across major rivers and in areas affected by human activities. These findings offer crucial insights for conservation efforts, guiding strategies to preserve wildlife metapopulation dynamics in the Omo-Shasha-Oluwa Forest Reserves landscape

Keywords: Large mammals, Landscape connectivity, Forest Conservation, Habitat suitability

INTRODUCTION

Human activities are significantly transforming forested landscapes, leading to changes in habitat composition and configuration (Ellis *et al.*, 2010; Mengist *et al.*, 2021). Anthropogenic activities, such as logging and hunting, have resulted in the loss and fragmentation of forest habitat, which is a major driver of the decline in regional forest wildlife diversity (Gökyer, 2013; Liu *et al.*, 2014; Haddad *et al.*, 2016; Fetene *et al.*, 2019;

Lindenmayer, 2023). Fragmentation of large forests into smaller blocks also increases accessibility to forest interiors for poachers and bush meat traders, contributing to the depletion of wildlife populations and the phenomenon known as 'empty forest syndrome' (Redford, 1992; Wilkie *et al*., 2011; Bogon *et al.*, 2022).

Intensive hunting, timber extraction, and poor farming practices further exacerbate forest loss and fragmentation (Graham *et al*., 2009; Ndah *et al.*, 2012; Bodo *et al*., 2021). Infrastructure development, particularly roads for timber and mineral extraction, facilitates access to remote forest areas, intensifying hunting pressure (Wright et al., 2007; Greengrass, 2009; Fotang *et al*., 2021; Tudge *et al*., 2022). Advancements in hunting technology, such as motorized transportation and battery-powered lights, increase hunting efficiency and further impact wildlife abundance and distribution.

Large mammals play vital ecological roles in forests as seed dispersers, predators, and habitat engineers (Wright *et al*., 2007; Lacher *et al*., 2019). They regulate plant population dynamics by dispersing seeds and controlling plant growth, influencing forest structure and function (Terborgh *et al*., 2008; Corlett & Hughes, 2015). Understanding how large mammals persist in human-dominated landscapes is crucial for landscape conservation, but accommodating their movement poses challenges due to habitat requirements and human activities (Fasona *et al*., 2018). Landscape connectivity, which facilitates movement, is essential for wide-ranging species and adaptation to climate change (Thorne *et al.*, 2006; Wang *et al.*, 2023).

Forest fragmentation threatens wildlife population viability and landscape integrity (Fahrig, 2003; 2020). Conservation strategies aim to mitigate fragmentation effects by establishing corridors or stepping stones to increase landscape connectivity (Bennet, 2005; Beier *et al*., 2008; Gregory & Beier, 2015). Landscape connectivity is crucial for species to move across landscapes, especially in the face of barriers like roads, development, and habitat conversion, which impede movement and increase mortality (Riley *et al*., 2006; Meese *et al*., 2009).

Fine-scale wildlife landscape connectivity analysis integrates species' habitat requirements, dispersal abilities, and landscape barriers to identify high-quality habitat and linkage areas (Noss, 1991; MacDonald, 2003). To model the probability of large mammal presence, the Maximum Entropy algorithm (MaxEnt) is utilized, identifying core habitat areas (Phillips *et al*., 2006; Elith *et al*., 2011). Core areas serve as focal regions for landscape connectivity analysis, predicting movement patterns, and identifying crucial connective elements for wildlife conservation.

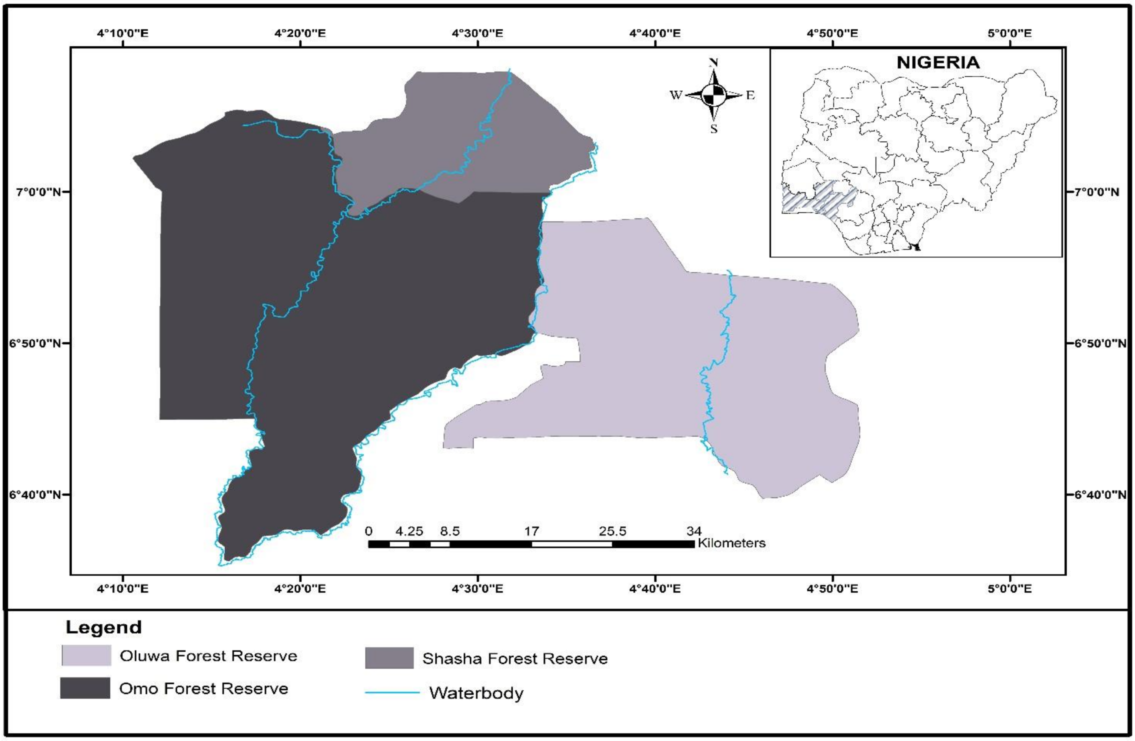
In conclusion, human activities significantly impact forested landscapes, leading to habitat loss, fragmentation, and wildlife depletion. Conservation efforts focus on mitigating these impacts through strategies such as landscape connectivity enhancement and habitat preservation, informed by advanced modelling techniques like MaxEnt and landscape connectivity analysis. Understanding the complex interactions between human activities, wildlife populations, and landscape dynamics is essential for effective conservation planning and management in forested ecosystems.

MATERIALS AND METHODS

Study Area

We evaluated attributes associated with large mammal use of space at the Omo-Omo-Shasha-Oluwa Forest Reserve landscape in South-West Nigeria (Figure 1). The largest of the three reserve clusters is Omo (1,325 km^2), followed by Oluwa (827 km^2) and Shasha (310 km^2). The Reserves are located between 6˚30' to 7˚21'E Longitude and 4o10' to 4˚57'N Latitude (Adedeji & Adeofun, 2014). Until 1925 the reserves were part of a single large Shasha Forest Reserve until it was split into Omo, Oluwa, and Shasha Forest Reserves (Isichel, 1995). The natural vegetation is that of a tropical forest. Annual temperatures range from 21.4°C to 32.2°C degree (Adebisi *et al*., 2004). There are two dominant seasons, the wet season which lasts from March to November, and the dry season which lasts from December to February. Average annual precipitation is between 1,700 mm and 2,200 mm (Ogunjemite & Olaniyi, 2012). The major rivers flowing through, and draining, the reserves include the Shasha River (or Omo), which forms part of the boundary between the Omo and Shasha Reserves; Owena River which flows through the Shasha reserve and joins the Omo River at the south-western axis of Shasha reserve; the Oni River which is a natural boundary between Omo and Oluwa Reserves, joins Omo River just before it flows into the Lagos Lagoon; the Oluwa River which flows through the center of Oluwa reserve; Ominla River which is the eastern boundary of Oluwa Reserve.

Fig.1: Omo-Shasha-Oluwa Forest Reserve Landscape



Occurrence Data

A 5 km grid was placed over the study area and 52 sampling locations were randomly selected. Species occurrence data were collected from transects obtained from the randomly selected areas. The length of the transects ranged between 500 m-1 km within the Omo-shasha-Oluwa Forest Reserves landscape. Direct and indirect diurnal sightings of large mammals between 7:00 am to 12:00 noon and 4:00 pm to 6:00 pm; during the wet and dry seasons were carried out from March 2021 to February 2023.

Habitat Suitability Modelling

Five natural environmental variables were considered for this study. The environmental variables include aspect, slope, and elevation from the Digital Environmental Model (DEM), land cover type, and nearness to water (Table 1). These variables have been notified from literature as important parameters affecting species habitat suitability and movement (Lecours, *et al*., 2016). Only one anthropogenic variable was included in the model and this was nearness to settlement. This was chosen as a proxy for poaching pressure, based on the assumption that poaching will be higher in areas more accessible to hunters. For all the large mammal presence data 75 % of the locations were used for model training and 25 % were used for testing.

We created a species distribution model using the presence-only occurrence data for each of the seven large mammal species detected above using the machine learning algorithm implemented in Program MaxEnt (Philips *et al*., 2006). MaxEnt merges species occurrence data with environmental information to create spatially explicit estimates of the likelihood of a species occurrence at a particular location (Phillips & Dudik, 2008). When MaxEnt is applied in species distribution modelling each grid cell of the study area presents a probability species distribution, which may be interpreted as an index of habitat suitabilityfor the species. The area under the curve (AUC), ranges from 0-1 and provides an estimate of the model fit: the probability that a presence location will be chosen before an absence location at random. Here, 0.50 indicates a model no better than random and a higher AUC indicates a better model fit (Phillips & Dudik, 2008).

We used the SDM from MaxEnt for each species to identify species habitat core areas (HCA's). We define HCA's as any region that has a probability of species occurrence >50 % likelihood of occurrence. This value was chosen because it projects a more realistic distribution of the species in the study area. From the species prediction output associated with the MaxEnt SDM, we plotted the likelihood of the area being within an HCA as a function of the range of observed values for each included land cover attribute (Hijman *et al*., 2012). We next characterized land cover attributes within each HCA using Arc Map info to calculate summary statistics and composition of each species HCA.

Landscape Connectivity Modelling

To predict landscape connectivity among HCA's calculated on the landscape we used Program Circuitscape (McRay *et al.,* 2008). Circuitscape uses electrical circuit theory to identify the regions of lowest resistance to movement among HCA's. The circuit theory model uses resistance values parameterized from the land cover attribute data to create a resistance surface (Spears *et al*., 2010). To generate current maps, circuitscape was operated in the pairwise mode using the core areas and conductance layers created from previous habitat modelling on maxEnt. Circuitscape may be better used in situations such as identifying dispersal rates.

RESULTS

Habitat suitability model

Only seven large mammals with sufficient data for habitat suitability modelling were used for the study. These included Red-capped mangabey (*Cercocebus torquatus*), Mona monkey (*Cercopithecus mona*), Maxwell's duiker (*Philantomba maxwellii*), Bushbuck (*Tragelaphus scriptus*), Red river hog (*Potamochoerus porcus*), African forest elephants (*Loxodonta cyclotis*) and African civet (*Civettictis civetta*). For the landscape connectivity modelling, African forest elephants (*Loxodonta cyclotis*) were excluded because occurrence data could only be obtained for one location within the landscape.

The AUC for the training data for *T. Scriptus* was 0.846 while the test data was 0.751, for *C. cietta* AUC training data was 0.836, and the test data was 0.834, for *P. maxwellii* AUC training data was 0.854 and test data was 0.820, for *L. cyclotis* AUC training data was 0.951 and test data was 0.968, for *C. mona* AUC training data was 0.867and test data was0.742, lastly for *C. torquatus* AUC training data was 0.885 and test data was 0.965. The AUC for training data for *P. porcus* was 0.852 and the test data was 0.712.

Distance to settlement had the most contribution to the model for *T. scriptus* (77.3 %), *C. cietta* (63.3 %), *P. maxwellii* (55.9 %), *C. mona* (82.6 %), *P.porcus* (86.3 %) and *C. torquatus* (58.2 %). For the *L.cyclotis* the major contributor to the model land covers type (54.9%) (Table 1).

The model identified 1760 km^2 suitable habitat patches for *C.cietta*, 1515 km^2 for *T. scriptus*, 729 km^2 for *L. cyclotis*, 1693 km^2 for *P. porcus*, 1350 km^2 for *C. mona*, 1406 km^2 for *P. maxwellii*, 1379 km^2 for *C. torquatus*.

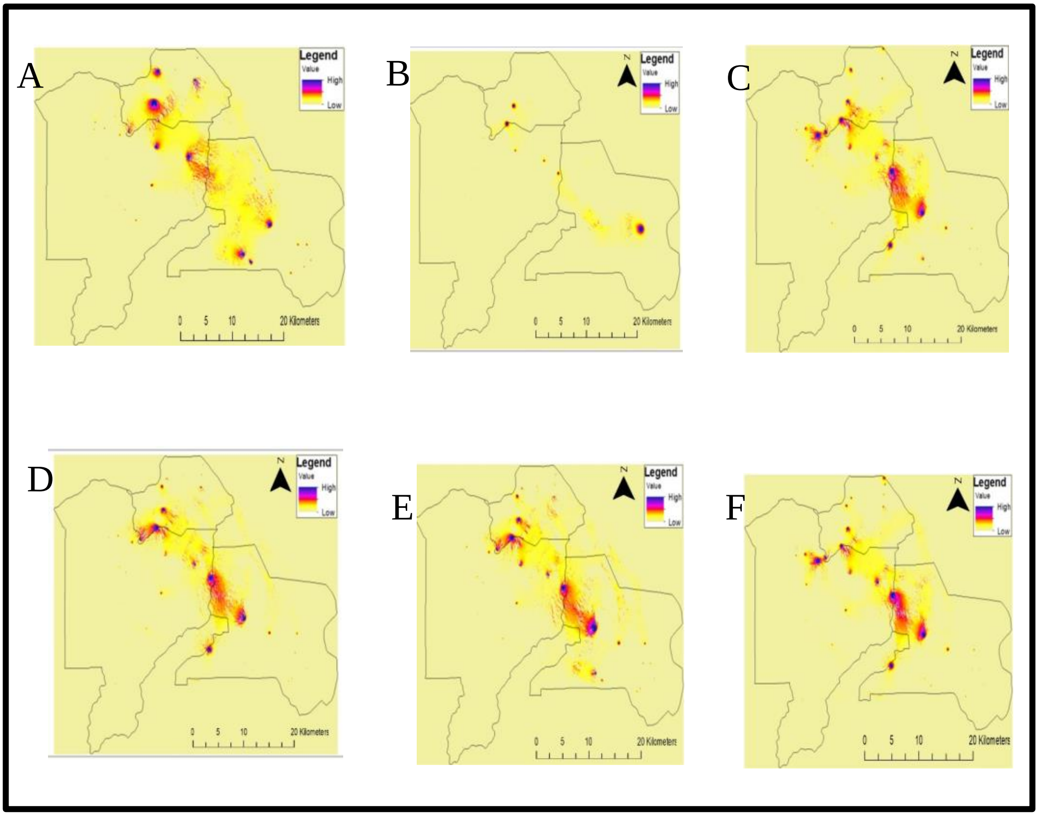
Table 1: Relative contributions of Maxent model of large mammals' suitable habitat in Omo-Shasha-Oluwa Forest Reserves Landscape

	Bushbuck	Civet cat	Maxwell's duiker	Forest elephant	Mona monkey	Red river hog	Red-capped mangabey
Aspect	5.2	3.2	5.6	0.7	3.1	13.6	0
Elevation	1.8	11.3	6.7	0	3.3	8.6	0
Land cover	10.1	11.4	18.5	54.9	1.4	16.1	9.4
Distance to River	2.3	2.4	3.5	0	2	2.7	4.2
Distance to settlement	77.3	63.3	55.9	44.4	82.6	58.2	86.3
Slope	3.3	8.4	9.9	0	7.6	0.9	0.1

Landscape connectivity

For the modelling of landscape connectivity only six species were included, *L. cyclotis* was excluded from the model because the presence record could only be obtained at the north-eastern part of the Omo reserve. Overall for the six species landscape connectivity seems to be stronger from the north-western part of Omo reserves to the southern part of Shasha reserve down to the western part of Oluwa. Although there is landscape connectivity for *T. scriptus* there seems to be low landscape connectivity between the north-eastern part of the Omo reserve and the southern part of the Shasha reserve; southern Shasha and eastern part of the Oluwa reserve (Figure 2). There also seems to be low landscape connectivity between core areas for *C.torquatus* and *C.mona* (Figure 2)

Fig. 2: Potential landscape connectivity maps for (A) Red river hog (*Potamochoerus porcus*)) (B) Red capped mangabey (*Cercocebus torquatus*) (C) Mona monkey (*Cercopithecus mona*) (D) Maxwell's duiker (*Philantomba maxwellii*) (E) Bushbuck (*Tragelaphus scriptus* (F) Civet cat (*Civettictis civetta*) within Omo-Shasha-Oluwa Reserves



DISCUSSION

The assessment of habitat suitability has unveiled concerning trends regarding *L. cyclotis*, as only 729 km^2 (0.29 %) has been identified as suitable habitat. This limitation can be starkly attributed to the direct loss of natural forest and increased fragmentation within the Omo-Shasha-Oluwa Forest Reserves (OSOFR), as underscored by the research of Adedeji & Adeofun (2014). Consequently, sightings of *L.cyclotis* have predominantly occurred in the north-western portion of the Omo Forest Reserve, as documented by studies conducted by Amusa *et al*. (2017) and Akala *et al*. (2023). In contrast, other species such as *C. civetta* and *P. porcus* exhibit broader ranges of suitable habitat, although compromised functional landscape connectivity due to human disturbances remains an issue.

The importance of maintaining landscape connectivity for viable populations, particularly for endangered species like *L. cyclotis* and *C. torquatus*, cannot be overstated. Advocacy for this cause has been championed by researchers such as Green *et al*. (2017), Imong *et al*. (2014), and Torres *et al*. (2022). Strategic corridors identified from landscape connectivity modeling, spanning from the north-western Omo Reserve to the southern Shasha Reserve and the western Oluwa Reserve, offer crucial pathways for species movement and gene flow.

Understanding the influence of land use on large mammal distribution is paramount due to its profound impact on habitat quality and species persistence. Studies by Blom *et al*. (2005), Wang *et al.* (2015), Smith *et al*. (2018), and Shanee *et al.* (2023) have highlighted the correlation between land use changes and the decline in forest patches, exacerbated by direct anthropogenic pressures like hunting, which poses imminent threats to forest dynamics and biodiversity, as emphasized by Rovero *et al*. (2014), Rich *et al*. (2016), and Mancini *et al.* (2023).

Furthermore, the coexistence of large mammals in both forest reserves and commercial plantations underscores the need for comprehensive occupancy assessments to accurately delineate priority conservation areas. Species like *T. scriptus* and *P. maxwellii* exhibit adaptable behavior to disturbed habitats, yet robust management strategies are still required to mitigate escalating human pressures, as noted by Coates & Downs (2007) and Bayih & Yihune (2018).

In light of these challenges, collaborative efforts involving local communities and forest managers are indispensable. Engagement of stakeholders in wildlife monitoring and conservation initiatives can raise awareness and facilitate the implementation of proactive measures to safeguard the long-term viability of large mammal populations.

In conclusion, the integration of habitat suitability and landscape connectivity modeling offers invaluable insights into the conservation status of large mammals within the OSOFR The study addressed a critical knowledge gap by identifying suitable connecting habitats for large mammals within the fragmented landscape of the OSOFR. While certain species exhibit promising habitat suitability and landscape connectivity, concerted efforts are imperative to address identified gaps, particularly concerning *L. cyclotis*. Prioritizing structural landscape connectivity and restoration efforts, alongside adaptive management strategies, can enable the Omo-Shasha-Oluwa Forest Reserves to fulfill their dual role as crucial biodiversity hotspots and essential research stations, ensuring the preservation of invaluable ecosystems for future generations.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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