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Suitable habitat of wild Asian elephant in Western Terai of Nepal

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Abstract

Background: There is currently very little available research on the habitat suitability, the influence of infrastructure on distribution, and the extent and connectivity of habitat available to the wild Asian elephant (Elephas maximus). Information related to the habitat is crucial for conservation of this species.

Methods: In this study, we identified suitable habitat for wild Asian elephants in the Western Terai region of Nepal using Maximum Entropy (MaxEnt) software.

Results: Of 9,207 km², we identified 3194.82 km² as suitable habitat for wild Asian elephants in the study area. Approximately 40% of identified habitat occurs in existing protected areas. Most of these habitat patches are smaller than previous estimations of the species home range, and this may reduce the probability of the species continued survival in the study area. Proximity to roads was identified as the most important factor defining habitat suitability, with elephants preferring habitats far from roads.

Conclusions: We conclude that further habitat fragmentation in the study area can be reduced by avoiding the construction of new roads and connectivity between areas of existing suitable habitat can be increased through the identification and management of wildlife corridors between habitat patches.

Keywords
Anthropogenic threats, habitat fragmentation, low land, variables, wildlife corridor

1 | INTRODUCTION

Wild Asian elephants (Elephas maximus) are endangered megafauna of the tropical and subtropical regions of Asia. It is native to 13 Asian countries including Nepal and is listed as “Endangered” in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Choudhury et al., 2008) and appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2017). This animal is also protected by the Nepalese Government National Parks and Wildlife Conservation Act 1973 (GoN, 1973).

Intact rainforest fragments, riparian vegetation, and grasslands are the preferred habitats of the wild Asian elephant in India (Kumar, Mudappa, & Raman, 2010; Sukumar, 1989). In the Shivalik range of India, Kamala trees (Mallatus philippinensis) are indicator of the presence of this species during the dry season (Bi et al., 2016). In Nepal, Pradhan and Wegge (2007) described riverine forest and tall grassland as preferred habitats with Spatholobus parviflorus.
Population of wild Asian elephant within Nepal has been estimated to be between 109 and 142 individuals (DNPCWC, 2012; Pradhan, Williams, & Dhakal, 2011) with distribution concentrated in protected areas of the Terai (low land) region, in the central and eastern parts of the country, with relatively low numbers in the west (Koirala et al., 2015).

Habitat loss, conflict with human, electrocution, and poaching are threats to elephants (Cordingley, 2008; Hoare, 1999; Kalam, Kumar Baishya, & Smith, 2018; Sampson et al., 2018; Sukumar, Ramakrishnan, & Santosh, 1998). The main threats to the survival of the wild Asian elephant are changes in the habitat and reduction in its suitable habitat, and these are caused by increased human activities (Zhang & Wang, 2003). Human expansion transforms natural habitats of wildlife into human settlements and agricultural lands (Cordingley, 2008; Hoare, 1999). Forests outside the protected areas have suffered extensive exploitation, due to the demands of human populations living along the fringe of the forest (Pradhan et al., 2011). This exploitation resulted habitat fragmentation and reduction and human–elephant conflict are frequent as elephants commonly raid crops, destroy property, and cause human injuries and fatalities (Acharya, Paudel, Neupane, & Kohl, 2016; DNPCWC, 2015; Koirala, Ji, Aryal, Rothman, & Raubenheimer, 2015; Pant, Dhakal, Pradhan, Leverington, & Hockings, 2016).

This study explored on how these threats are likely to impact current populations of elephants and the extent and connectivity of suitable habitat both inside and outside protected areas. Research into these factors is therefore crucial to ensuring the species continued survival within the country. The study identified the important habitat parameters and environmental variables within topographic, vegetation related, and anthropogenic category that determine suitable wild Asian elephant habitat in the Western Terai region of Nepal.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was conducted in the Banke, Bardia, Kailali, and Kanchapur districts of western Nepal, with a total area of 9,207 km² (Figure 1). Protected areas within the study site are Banke National Park and its Buffer Zone, Bardia National Park and its Buffer Zone, Shuklaphanta National Park and its Buffer Zone and Krishnasar Conservation Area (DNPCWC, 2017). National parks belong to II and conservation area and buffer zone belong to VI according to Protected Area Categories System of International Union for Conservation of Nature (iucn.org). Entry without permission of park authority is prohibited in national parks, but reasonable entry is accepted for local people for their daily activities in buffer zones and conservation area. The lowland Terai of Nepal is an area of high biodiversity and significant conservation value. Dominant tree species in the region are sal (Shorea robusta), asna (Terminalia tomentosa), botdhamero (Lagstroemia parviflora), and sindure (Mallatus philippinensis) (DFRS, 2015), and major fauna species include wild Asian elephant (E. maximus), spotted deer (Axis axis), gaur (Bos gaurus), swamp deer (Cervus duvaucelii), tiger (Panthera tigris), common leopard (P. pardus), python (Python molurus), rhino (Rhinoceros unicornis), sambar deer (Rusa unicolor), wild boar (Sus scrofa) four-horned antelope (Tetracerus quadricornis), and giant hornbill (Buceros bicornis) (DNPCWC, 2016; Oli et al., 2018).

2.2 | Data collection

2.2.1 | Elephant occurrence points

Occurrence points of wild Asian elephant were collected between September 2017 and March 2018. We first held discussions with officials responsible for protected areas in the region to identify...
potential habitat of elephants and visited identified areas from these
discussions to record evidence of elephant presence. Elephant pres-
ence was collected through direct observation of individuals, as
well as indirect observation of tracks and droppings. We also used
secondary sources of elephant occurrence records, previously re-
corded observations (GPS points) by park authorities, in each of the
protected area site offices. We collected a total of 76 records (GPS
points) of elephant presence during data collection.

2.2.2 | Environmental variables

Topographical variables
Digital elevation model (DEM) data of 30 m resolution were down-
loaded from the United States Geological Survey website (https://
earthexplorer.usgs.gov/), and the slope was computed from the DEM
using ArcGIS software (ESRI, 2017). Shapefiles of water sources
were downloaded from Geofabrik website (https://www.geofabrik.
de/data/shapefiles.html) and converted to distance raster file using
ArcGIS (ESRI, 2017). Elevation was used as a proxy of temperature
due to the unavailability of high-resolution climatic variables.

Vegetation-related variables
Herbivores are depended on vegetation-related variables (Andersen
et al., 2000). The elephant is a mega herbivore, so the inclusion of
vegetation-related variables to predict suitable habitat for this spe-
cies is a prerequisite for robust habitat modeling.

For the variable “forest cover,” we used data prepared by
Hansen et al. (2013) which were downloaded from the Global
Forest Change (GFC) website. This study used Enhanced
Vegetation Index (EVI) time series data for 2015, 2016, and
2017, from images obtained by Moderate Resolution Imaging
Spectroradiometer (MODIS) (https://earthexplorer.usgs.gov/). The
data were then smoothed using an adaptive Savitzky-Golay filter
in the TIMESAT program (Jönsson & Eklundh, 2004), to reduce
cloud cover in Environment for Visualizing Images, a software of
image analysis, and the EVI values were averaged over all the indi-
ces in order to obtain the final EVI index.

Anthropogenic variables
Human activities have been identified as a threat to wild Asian
elephants and influence the species distribution (Choudhury
et al., 2008; DNPWC, 2012). We, therefore, incorporated anthro-
pogenic variables into our model. Anthropogenic variables were
the distance to human paths (used by human and animal) and roads
(used by vehicle), distance to settlements, and land use. Location
of paths and roads was obtained from shapefiles available on the
Geofabrik website (https://www.geofabrik.de/data/shapefiles.
html). Settlement locations were obtained from the Department
of Survey, Nepal. Distance raster files of paths, roads, and settle-
ments were created using ArcGIS (ESRI, 2017). Land cover and land
use (LULC) data were downloaded from the International Centre for
Integrated Mountain Development website (ICIMOD; http://www.
icimod.org) (Uddin et al., 2015) and incorporated into the model.

2.3 | Prediction of distribution of the wild
Asian elephant

MaxEnt is a software package used to model species distributions
using geo-referenced occurrence data and environmental vari-
ables to predict suitable habitat for a species (Phillips, Anderson,
& Schapire, 2006). This software extracts a sample of background
locations that it contrasts against the presence locations and esti-
mate the density of presences across the landscape (Merow, Smith,
& Silander, 2013; Phillips et al., 2006). We incorporated the variables
listed in Table 1 into MaxEnt (version 3.4.1) along with our occur-
rence data to determine habitat suitability for wild Asian elephants
within our study area. The MaxEnt program is widely used to map
wildlife habitat and identify the influence of environmental variables
on species occurrence in similar study areas (Aryal et al., 2016; Bista,
Panthi, & Weiskopf, 2018; KC et al., 2019; Panthi, 2018; Panthi,

| TABLE 1 Environmental variables considered in the model |
|-----------|-------------|----------|---------|
| Category   | Source       | Variable | Type     | Unit   |
| Topographic| USGS         | Elevation| Continuous|m       |
|            |              | Slope    | Continuous| Degree |
|            | GEOFABRIK    | Distance to water | Continuous | m |
| Vegetation-related | MODIS | Mean EVI | Continuous | Dimensionless |
|            | GFC          | Standard deviation of EVI | Continuous | Dimensionless |
|            |              | Forest cover | Continuous | Dimensionless |
| Anthropogenic| GEOFABRIK  | Distance to settlement | Continuous | m |
|            |              | Distance to road | Continuous | m |
|            |              | Distance to path | Continuous | m |
|            | International Centre for Integrated Mountain Development | Land use land cover | Categorical | Dimensionless |

Abbreviation: EVI, Enhanced Vegetation Index.
Multicollinearity between environmental variables described in Table 1 is acceptable (|r| < .70) (Dormann et al., 2013), so we used all variables in the model. We maintained at least 1 km distances between species presence points to lessen spatial autocorrelation. We selected 1,000 maximum iterations and 10 replicates during modeling (Barbet-Massin, Jiguet, Albert, & Thuiller, 2012).

Accuracies of the model were accessed by two methods: threshold independent and threshold dependent. In the threshold independent method, the value of accuracy was directly obtained from the model, but in the threshold dependent method, we provided the threshold to maximize the sum of specificity and sensitivity. We used the area under the receiver–operator curve (AUC), which is automatically calculated during the modeling without using any threshold. An AUC < 0.7 denotes poor model performance, 0.7–0.9 denotes moderately useful model performance, and >0.9 denotes excellent model performance (Pearce & Ferrier, 2000). We chose true skill statistics (TSS) as the threshold dependent method. The TSS = Sensitivity + Specificity − 1 and ranges from −1 to 1, where values less than 0 indicate a performance no better than random and 1 indicates a perfect fit (Allouche, Tsoar, & Kadmon, 2006). We calculated TSS for all 10 model outputs in R software (R Core Team, 2018), and the final TSS was averaged from all ten replications (Bista et al., 2018; Jiang et al., 2014; Panthi, 2018). For species distribution models, presence-only data threshold to maximize the TSS is recommended (Liu, White, & Newell, 2013); so, we used this threshold to convert the continuous habitat suitability map to a suitable/unsuitable binary map.
3 | RESULTS

3.1 | The suitable habitat of the wild Asian elephant

We identified a total of 3,194.82 km² as suitable habitat for wild Asian elephant in the study area (Figure 2). About 39.11% (1,249.58 km²) of this habitat occurs in existing protected areas (Table 2). Bardia National Park and its Buffer Zone contain the largest proportion of suitable habitat (46.84%), with Krishnasar Conservation Area containing the smallest portion (0.16%). The largest area of suitable habitat outside protected areas was found in Kailali district (942.55 km²), following Banke, Bardia, and Kanchanpur districts containing 719.46 km², 798.67 km², and 734.14 km², respectively. Elephant habitat in the study area was highly fragmented, occurring as small, discrete patches. Connectivity between habitat patches was low in the southern and northern parts of the study area, but higher in the center (Figure 2).

3.2 | Important environmental variables

Of 10 variables used in the model, the distance to road, distance to water, elevation, and slope were found to be the most important variables determining habitat suitability. Distance to settlement, and mean EVI and LULC were identified as the least important variables (Figure 3).

In Figure 3, the regularized training gain of the model without distance to road was less than that of the model using without other single variables, so the distance to road is a more useful variable to the model. Similarly, the regularized training gain of the models without distance to water, elevation, and slope is less, indicating that these variables are useful predictors of habitat suitability for the species.

The model, therefore, indicates that elephants prefer habitat far from roads, near to water sources, with low elevation and gentle slope (Figure 4).

3.3 | Model accuracy

Accuracies of the model are relatively good. We obtained 0.813 ± 0.072 AUC and 0.528 ± 0.031 TSS (Table 3). We obtained 0.214 threshold to maximize the sum of sensitivity and specificity. We used this threshold to calculate the TSS and to covert the continuous habitat suitability map to binary suitable/unsuitable map.

4 | DISCUSSION

Our study has identified the suitable habitat of wild Asian elephant in Banke, Bardia, Kailali, and Kanchanpur district of Nepal. Previous studies already recorded the presence of this elephant in these

![Figure 4](image)

**TABLE 3** Thresholds and accuracies of different replications

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Replications</th>
<th>Average</th>
<th>Std</th>
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<tbody>
<tr>
<td></td>
<td>0 1 2 3 4 5 6 7 8 9</td>
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</tr>
<tr>
<td>1</td>
<td>Threshold</td>
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<td>0.22</td>
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<tr>
<td>3</td>
<td>TSS</td>
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There is large suitable habitat, the majority of suitable habitat occurs in small, discrete patches insufficient to accommodate the large resource requirements of the species. To increase connectivity between these patches, we recommend protecting existing habitat to provide corridors between Bardia National Park and Shuklaphanta National Park. The future road projects should consider the movement of wild Asian elephant and design accordingly.

5 | CONCLUSIONS

This study identified more than 3,000 km² of area as the suitable elephant habitat in the Western Terai region of Nepal. Around 40% of suitable habitat is covered by existing protected areas. Although