Master Thesis

submitted within the UNIGIS MSc. programme at
the Department of Geoinformatics - Z_GIS
University of Salzburg, Austria
under the provisions of UNIGIS joint study programme with
Kathmandu Forestry College (KAFCOL), Kathmandu, Nepal

‘Assessing Habitat Overlap Among Spotted and Sambar Deer Using Geo-Spatial Approach: A case study of Chitwan National Park, Nepal’

by

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A thesis submitted in partial fulfilment of the requirements of
the degree of
Master of Science (Geographical Information Science & Systems) – MSc (GISc)

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Kathmandu, 23.04.2022

Science Pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

Usha Dahal

Kathmandu, 13.04.2022

Place and Date	Signature

Acknowledgements:

It’s my pleasure to acknowledge the contribution and support of various persons and organizations to complete this study. I would like to express my appreciation to Department of Geoinformatics - Z_GIS University of Salzburg for providing me the opportunity to write this thesis. I acknowledge the encouragement and support from my project supervisor Dr. Him Lal Shrestha UNIGIS program coordinator and co - supervisor Dr. Jhamak Bahadur Karki, Associate Professor at Kathmandu Forestry College. I am highly grateful and deeply indebted to them for their valuable and inspiring suggestion and kind cooperation. I would like to extent my thanks to the Assistant Forest Officer Mr. Saroj Panthi, Ministry of Forest Environment and Soil Conservation Gandaki Province Pokhara Nepal, who supported me on my study analysis part unconditionally. I would also like to thank Khumrose and Baghmara Buffer Zone Community Forest to provide me permission to carry my field work inside the forest area.

My special thanks go towards my friend Anubhav Dhital for his support in field study period. I am sincerely grateful to Mr. Mahesh Neupane, Assistant Conservation Officer, Chitwan National Park for providing me permission to collect data of pellet groups of ungulates. My cordial thanks go to Department of National Parks and Wildlife Conservation (DNPWC), and Chitwan National Park for permitting me to carry out my research work and most importantly National Trust for Nature Conservation (NTNC) for providing me secondary data. I am equally thankful to all teaching faculties and staff members of Kathmandu Forestry College. Finally am also grateful to all those who directly and indirectly contributed in completing this thesis work.

Abstract:

Identifying interspecies relationships between sympatric species living in a similar habitat is significant to direct conservation efforts so that multiple species can be benefited. There are very few studies exploring interspecies relationships in Nepal. This is the first study that explores habitat overlap between two major deer species i.e. Spotted deer (*Axis axis*) and Sambar deer (*Rusa unicolor*) along with their suitable habitat in Chitwan National Park (CNP), Nepal, using Maximum Entropy (MaxEnt) modelling. GPS points of species occurrence were collected from the field, and environmental variable were extracted from freely available sources. The result shows that the study area contained 264.14 km^2 of Spotted deer habitat and 457.25 km^2 of the Sambar deer habitat. 172.13 km^2 supported both species, which constituted 65% of the Spotted deer and 34% of the Sambar deer habitat. We recorded more presence data in Riverine forest, Sal forest and Mixed Sal forest for both the species. NDVI, LULC, forest cover, elevation and human settlement are the most effective environmental variable for predicting the distribution of the occurrence data of selected deer species. The study shows Spotted deer prefers shrub land and grassland whereas Sambar deer prefers dense forest area. The great portions of suitable habitat of both the species are also in buffer zone of national park therefore, conservation efforts for these sympatric species should be focused inside the buffer zone to reduce the community people's interference inside the buffer zone forest area for collecting forest products.

Key words: Habitat, Sympatric, Overlap, Maximum Entropy, Environmental Variables

Abbreviations and Acronyms

ASCII	American Standard Code for Information Interchange
AUC	Area under the Curve
CNP	Chitwan National Park
CSV	Comma Separated Value
DEM	Digital Elevation Model
DNPWC	Department of National Parks and Wildlife Conservation
ESRI	Earth System Resource Institute
GFC	Global Forest Change
GIS	Geographical Information System
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature and Natural Resource
MaxEnt	Maximum Entropy
NDVI	Normalized Difference Vegetation Index
NIR	Near-infrared
NPs	National Parks
OLI	Operational Land Imager
ROC	Receiver Operator Curve
SDMs	Species Distribution Models
TIRS	Thermal Infrared Sensor
USGS	United States Geological Survey
°C	Degree Celsius
%	Percentage

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Chapter-1: Introduction

1.1 Background

Studying resource use overlap is useful approach in understanding the interspecies interaction like competition and resource partitioning (Schoener, 1974). Competition within the members of same species is known as intraspecies competition, while the competition among individual of different species is known as interspecies competition. Species overlap on several niche dimension including, food, water, habitat and other resources results on interspecies competition between the species. Pianka (1981) stated competition is an interaction between species where the fitness of one is lowered by the presence of another. As per the competitive exclusion principle, species less cordial to compete for habitat resource are unable to coexist with other species population competing for same resources and sharing the same niche. Identifying species' habitat parameters are indispensible for effective conservation. It is always vital for species manger to understand the type and condition of the habitat where the species thrive. In Nepal, it still lacks the information regarding species habitat choices resulting inadequate conservation efforts in several landscape level. Several individual species-specific studies have been conducted in Nepal (Kandel et al., 2016), very few studies have conducted on multiple species relationships. The study focused on Sambar deer and Spotted deer living sympatrically in CNP. These populations have declined substantially due to severe hunting and anthropogenic exploitation of habitat. Wild ungulates are found across diversified habitats including forests, open grassland, cultivated land and agricultural landscapes (Sankaran and Ahrestani, 2016).

Spotted deer is a member of order Artiodactyla classified under the family cervidae (Mitchell, 1982). It is native to the tropical and sub-tropical forests of Bangladesh, Nepal, Srilanka and India. In Nepal, it is locally known as chital. According to International Union for Conservation of Nature (IUCN) Red List Category it is listed as least concern because it occurs over a very wide range with large populations (Duckworth et al. 2008). The spotted deer is a small cervid, often considered as the most beautiful among cervids due to presence of striking reddish brown coats marked by white spots (Schaller 1967). Spotted deer is a gregarious mammal, its social organization is variable with small groups of two to twenty individuals, but herds of more than hundreds animals can also be found.

Sambar is a large ungulate species distributed throughout South and Southeast Asia (Leslie, 2011). It is listed as vulnerable on the IUCN Red List because local populations are extinct because of extensive hunting and habitat loss (Timmins et al., 2015). In this deer species, the males live alone for much of the year, and the females live in small herds of up to 16 individuals. The sambar prefers the dense cover of deciduous shrubs and grasses (Geist, 1998), although the exact nature of this varies enormously with the environment because of its wide range.

Understanding relationships of wild ungulates with their habitat can help managers develop effective strategies for multiple species conservation and also the conservation of top predators like tiger that depend on these wild ungulates. Being similar habitat, distribution diet and threats, it is crucial to identify the spatial habitat overlap between these species and identify suitable habitats for sustainable species conservation.

1.2 Objectives

General Objective:

The general objective of the study is to study the interspecific interaction between major wild ungulates (i.e. Sambar deer and Spotted deer) using MaxEnt Distribution Modelling in eastern Buffer Zone and Core area of CNP, Nepal.

Specific Objective:

To achieve the general objective, following objectives are set;

- Identify suitable habitat of Spotted deer and Sambar deer in study site
- Mapping the area of overlapping habitat among the selected deer species

1.3 Rational of Study

Chitwan National Park supports remarkable number of wild herbivores and their predator like; Tiger. As per the latest tiger census of 2018, CNP and adjoining forests are home to the highest number of tigers. The most iconic and endangered carnivore species can be conserved only through proper management of its habitat and prey species (predominately wild ungulates). For this study only two deer species were selected i.e. spotted deer and sambar deer since, they were major deer species found in the study site. A study (Karanth and Sunquist, 1995) shows that among the medium to large sized ungulates, maximum bulk of the tiger's diet constitute of spotted deer and sambar deer. Therefore, these ungulates were found to be major prey species of tiger.

Significantly, identifying and understanding habitat suitability and competition assessment among these two ungulates are essential to sustain the long-term survival of the species. The overlapping in habitat, space and food between sympatric ungulates are more likely to compete for the limited resources, where less adaptable one is supressed by powerful one

(Pianka, 1981). Thus, it is necessary to assess the vulnerability of each species to the habitat loss and to assess the potential competition between the species. Assessing competition among these crucial ungulates herbivore allows the conservation partners and government of Nepal to protect the study area where all these ungulates species can survive sustainably.

1.4 Limitation

Following limitations were faced during the study period:

i) Year round habitat preference of the selected deer species could not be assessed due to shorter duration of research study for academic purpose.

ii) The estimation of suitable habitat of the species is only based on one time field visit i.e. dry season (Nov-Dec).

iii) Presence points were collected only from eastern sector due to time limitation and data accessibility.

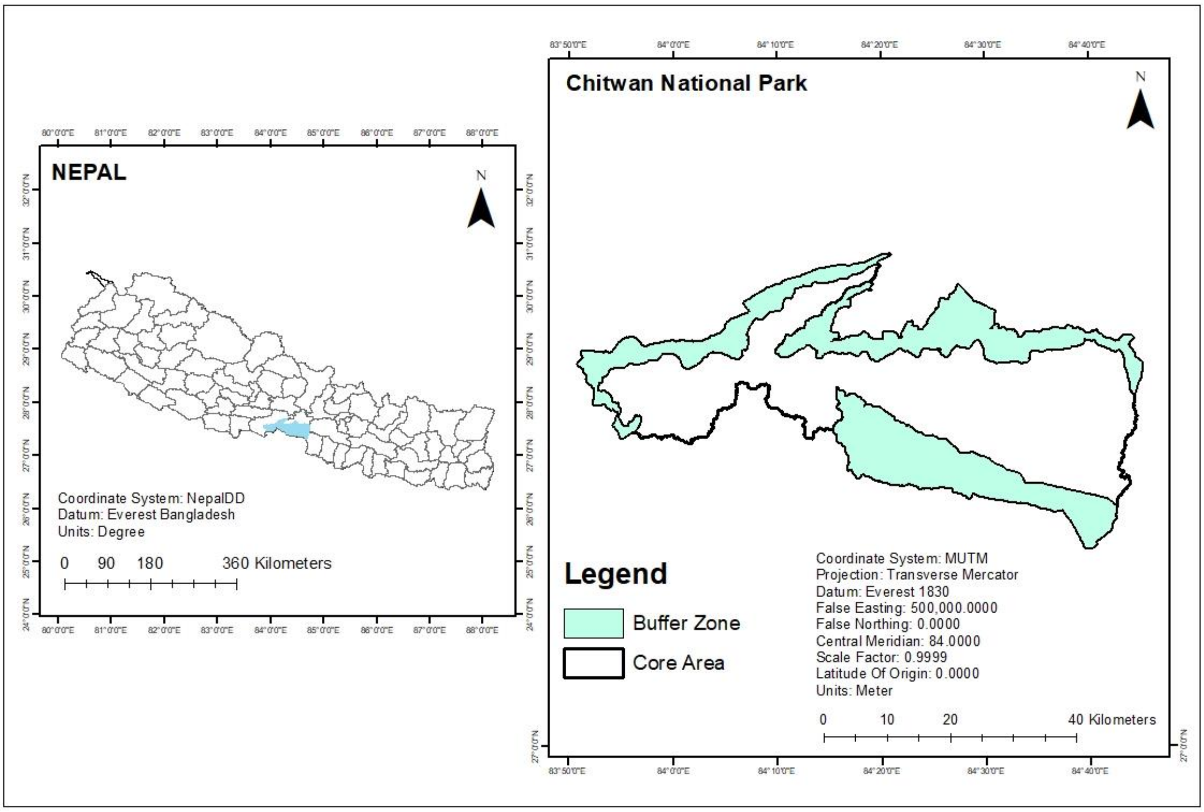
Chapter-2: Literature Review

The morphologically similar herbivores might have high level of niche overlap resulting in high competition when population density is high and resources are limited (Schoener, 1974). Jenkins & Wright, 1988 stated that the nature and range of competitive interaction between sympatric ungulates eventually determine the dynamics of their populations. Resource competition causes catastrophic effects on one or all sympatric ungulates species and results in reduced numbers, animal performance, or forage availability (Sinclair, 1976). The herbivores derive all the habitat components; food, cover, water and space from the areas they inhabit for their daily activities. The degree of habitat overlap between the species presents the interaction and the potential competition between the species. The species sharing the same space have the possibility to compete for resource as well as the risk of disease transmission. Conservation of these herbivores would be improved by evaluating the potential habitat overlap for cervid. Research study on several cervid species carried in north east of china showed similar behavioural characteristics, dietary habitats, and habitat preferences (Jiang, 2004; Li, 2005). However, limited information is available on the habitat preferences and patterns used by deer. Evaluating deer habitat use, mostly the habitat overlap between similar species, is essential for forming habitat protection approaches. Besides, better understanding the habitat preference of wild ungulates is significant for conservation and protection of top predator like tiger.

For conservation of any declining and threatened species, it requires the identification of those habitat resources that produces occupancy and support their survival and persistence (Hall et al., 1997). The biggest challenge conservationists face today is the biodiversity increasingly being endangered or threatened with extinction by manifold factors and difficulties to terminate this tide and maintain integrity and functionality of ecosystems (Millennium Ecosystem Assessment, 2005). Several conservation strategies, Geographic Position System (GPS) have been developed high extent in recent years in order to predict and evaluate the potential distribution of species on targeted areas (Fourcade et al., 2013; Vieilledent et al., 2013; Ward & Morgan, 2014). The species distribution models (SDMs) is one of the methods widely been developed to estimate, predict, and map species geographic ranges over time (Elith and Leathwick, 2009). SDMs establish the relationship between sites of known species occurrences and environmental factors that are presumed to affect their presence or absences. Among the SDMs, Maximum Entropy Modelling (Maxent) techniques requires presence-only records of the concerned species, is being widely used for estimation and prediction of a species geographical range (Phillips et al., 2006). Maxent is known to be an important tool to gain insights into current ranges and potential range-shifts with changes in several bio-climatic factors (Phillips et al., 2006). Maxent is a renowned and effective tool for studying habitat overlap among multiple species (Wu et al., 2016; Phillips et al., 2006; Brambilla et al., 2013). Identification of climatically suitable areas for the survival of the species could potentially aid in the existing and future conservation of the species.

Chapter-3: Research Methodology

3.1 Study Area



Map 1: Location Map of Chitwan National Park

Chitwan National Park was established in 1973; is the first national park in Nepal and also inherited as a World Heritage Site in 1984. It covers an area of approximately 952 square km and is located in the subtropical Inner terai lowlands of south-central Nepal covering three districts of Nawalpur, Parsa, Chitwan and Makwanpur. Further information of the study area such as geographic location, study area location, climate, geology, soils and flora and fauna are briefly described below.

3.2 Location

Chitwan National Park and its Buffer Zone is situated in southern part of Central Nepal which spreads over Chitwan, Nawalparasi, Parsa and Makawanpur districts. The park is between N 270 20' 19'' to 270 43' 16'' longitude and E 830 44' 50'' to 840 45' 03'' latitude geographical location whereas buffer zone is between N 270 28' 23'' and 270 70' 38'' longitude and E 830 83' 98'' and 840 77' 38'' latitude. It ranges in altitude from 100m in the river valley to 815 m in Churia Hills. Chitwan has a tropical monsoon climate with high humid all through the year. For the study, Sauraha sector and Kasara sector in core area, and Baghmara community forest and Khumrose community forest in buffer zone area of CNP were selected to collect the field sample data and study habitat suitability for whole CNP.

3.2.1 Climate

The park has diverse climatic seasons. The average temperature ranges from October to February of 25 ^{o}C, from March to June temperatures can reach up to 43^{o}C whereas the hot humid monsoon season lasts from late June to September. The high number of migratory birds joins the residential birds in September, November, February and April, which creates spectacular bird watching opportunities.

3.2.2 Geology & Soils

Chitwan valley lies within the Siwalik belt and consists of thick alluvial deposits. There are several geological formations in CNP which comprises late tertiary Siwalik formations in the south (Churia Management Plan for Chitwan National Park and It's Buffer Zone 2013-2017 - 3 - and Someshwor hills) and Rapti and Chitwan duns (inner valleys) to the north. Soil of the park is sandy and loamy mostly in valley whereas coarse bedded sandstone, crystalline rocks, clays and conglomerates are found in the south. The soil found in park and buffer zone is brown shallow soil, red soil, black soil, brown soil, wet well-drained soil, poorly drained brown soil and well sorted dry shallow soil.

3.2.3 Flora and Fauna

The park consists of tropical and subtropical forests. In CNP, Sal forests and Grasslands cover 70% and 20% of the park respectively. Several iconic mammal species, birds, amphibians and reptiles inhabits in the park. As per annual report 2076-77 of CNP; the park is the home for 93 tigers, 605 rhinos, 321 gaur and 166 garial likewise, 70 mammal species, 546 bird species, 47 reptile species 55 amphibian species and 120 fish species, resides in CNP. Bengal tiger (*Panthera tigris*), One-horned rhinoceros (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), Chines pangolin (*Manis pentadactyla*), Indian pangolin (*Manis crassicaudata*), Leopard cat (*Prionailurus bengalensis*), Clouded leopard (*Neofelis nebulosa*), Pygmy hog (*Porcula salvania*), Spotted lingsang (*Priondon pardicolor*), Striped hyaena (*Hyaena hyaena*), Hispid hare (*Caprolagus hispidus*), Ganges river dolphin (*Platanista gangetica*), Four-horned antelope (*Tetracerus quadricornis*), Gaur (*Bos gaurus*), Wild water buffalo (*Bubalus arnee*), Swamp deer (*Cervus duvaucelii*), Assam Macacue (*Macaca assamensis*) are the protected fauna found in CNP (NPWCA, 1973).

3.3 Methods

In order to develop modelling for Spotted deer and Sambar deer distribution and spatial overlap among the species alongside its habitat, several activities and processed – data as environmental layers need to be prepared beforehand. Basic needs for habitat as it has been initiated before (spatial area, land use, vegetation, forest cover, water, anthropogenic influence, etc.) become the main consideration in predicting the preference habitat for the selected species.

3.3.1 Maximum Entropy

As a machine learning method which requires presence only data in modelling, Maximum Entropy (MaxEnt) has high accuracy in predicting species geographic distribution (Phillips, 2005). Basically, according to (Philips et al., 2006) maximum entropy can be applied to solve the problem in any constraints. (Phillips et al., 2006) also clarified the process of prediction distribution of species by record 1 if the species is present and 0 for absent in every pixel over the study area. The value will be 0 or 1 for plants and range from 0 to 1 to animals which depicts the probability of species every pixel.

3.3.2 Presence Point

The presence point of the selected deer species were collected through informal interviews with local people and staff of the national park to identify potential habitats of the Sambar deer and Spotted deer within the park and its buffer zone. Then, the potential habitats of these two species were visited which were identified during the interviews. To collect occurrence points, accessible road inside the CNP core area located around Sauraha and Kasara sector, and buffer zone area of Khumrose and Baghmara community forest were selected for line transects. Along selected transact road presence of selected deer species were searched in every 500 meter distance through their evidence (direct/indirect) i.e. pellet groups, footprint and hair sites using GPS receiver. Moreover, presence points of these species were collected from secondary sources (published and unpublished reports). The combination of these kinds of data was applied in the modelling process by using MaxEnt Program.

3.3.3. Environmental Variable Used

3.3.3.1. Aspect/Slope/Elevation

Aspect, elevation and slope were used as topographic variables for habitat suitability criterion (Forsyth et al., 2009; Ghimire et al., 2019). For this, Digital Elevation Model (DEM) from Geological Survey (USGS) were downloaded and slope/aspect map were created using ArcMap 10.5.

3.3.3.2. Normalized Difference Vegetation Index (NDVI)

Vegetation is a major component for existence of any wildlife especially, for wild herbivores. Normalized Difference Vegetation Index (NDVI) can be used to quantify vegetation greenness and is the most popular one. NDVI was used as one of the major vegetation variables for habitat suitability criterion for deer species (Naithani et al., 2018). In this study Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) Level-1 data image of spectral bands 4 and 5 of the Red and Near Infrared bands ratio imagery with a spatial resolution of 10m having wavelengths of (0.64 – 0.67)µm and (0.85 – 0.88) µm respectively have been used for the generation of NDVI. This index is defined as:

NDVI = NIR – RED/NIR + RED,

Its calculation result has range value spread from (-1) to (+1) which indicate no green leaves (no vegetation) to high density of leaves, respectively. The low value of NDVI -0.19 to 0.26 considered as water body, moderate value range from 0.26 to 0.47 correspond to farmland and grassland, and the high value 0.47 to 0.99 indicates shrub land and dense vegetation. Normalized Difference Vegetation Index value on this study was derived from Landsat 8 Level 1 image downloaded from USGS earth explorer which has been processed in ArcMap 10.5 software.

3.3.3.3. Distance from Path/Settlement/Water/Forest/Land Use

Environmental variables viz. forest density, path, human settlement, water were important habitat suitability criterion for sambar deer habitat (Kushwaha et al., 2004). Shape file of path, human settlement, water and land use were extracted from Open Street Map (Geofabrik Download Server (https://www.geofabrik.de/data/shapefiles.html)).

In order to provide distance from settlement area, road and water as an environmental layer, image classification was calculated its distance by applying Euclidean distance in ArcMap 10.5. Similarly, Forest cover data was downloaded from Global Forest Change (GFC) website and processed on ArcMap.

3.3.4. Preparing Environmental Layers for MaxEnt

Maximum Entropy program needs environmental layers in ASCII raster grid format for its performance. Therefore, all processed variables converted in ASCII format in the exactly same cell, band, extent and coordinate system. The boundary of the study area was created by considering the extent which covers CNP landscape. The boundary was used as layer mask in environmental setting under Geo-processing tool in ArcGIS. Output coordinate was set in GCS_WGS_1984. For processing extent was set the same to layer mask (Top = 27.7217684852, Left = 83.8340584028, Right = 84.759203402, Bottom = 27.2644691363). Before executing the process, cell size under raster analysis menu was defined as Cell Size (X, Y) = (0.00029295282, 0.00029295282)

All the environment layers were multiplied by mask layer and the final products resulted in the same cell size and number (column 3158, rows 1561), cell alignment, projection system and extent as the mask. The last step is preparing the layers was converting all files into ASCII format and saving into an environmental layers folder.

3.3.5. Running MaxEnt Model

Samples and environmental layers were utmost for MaxEnt to proceed further. For species distribution modelling, a csv. file of both the selected deer species spotted deer and sambar deer were put as sample and environmental layers folder which contains all variables in ASCII format was employed in MaxEnt's environmental layers menu. After that, the data of all environment variables were changed to continuous except layer of land use and land cover, which was set to categorical. Do jack-knife to measure variable importance, create response curves, and make pictures of predictions have been ticked in MaxEnt menu. In order to determine random test percentage, basic setting of MaxEnt has been set into 30 in 10 replicates with max number of background points to 1000. On replicated run type menu, subsample was chosen and in advance setting, maximum iterations was set to 1000 while write background predictions was ticked in experimental setting to obtain pseudo background data.

3.3.6 Response Curve

Two sets of response curves for the environmental variables are created by MaxEnt. The first set of response curves are called marginal curves which demonstrates how the model prediction changes accordingly with each environmental variable while the rest of the variables remain at their average values. Similarly, the second set of response curves shows how the Maxent prediction reaches a peak and again decreases as the values rises for each environmental variable. Likewise Maxent uses two different methods to estimate variable importance. Maxent creates a table using data gathered during the training of the model that summarizes the environmental variable contribution to the model and the permutation importance, or stability, of the variable. The amount of increase or decrease of the model fit, called gain, is determined by the variable contribution, for each iteration of the Maxent algorithm. The permutation importance is calculated by randomly changing the value of an environmental variable among the model training points. Alternative method that MaxEnt uses to determine environmental variable importance is the jack-knife test. The variables that causes the largest decrease in the model's gain is calculated by removing each environmental variable by the jack-knife test in the model. This variable contains the most information not found in the other environmental variables. The second part of the jack-knife test is training the model using each environmental variable by itself where the environmental variable with the highest gain is known to have the most useful information within itself.

3.3.7. Model Performance

The AUC supports to define how well the model is able to predict presence and absence in Maxent modelling. The AUC created for Maxent models shows how well the model is able to distinguish presence from random (Merow et al., 2013).

The value for the AUC ranges from 0 to 1, the closer the value of the AUC is to 1 the better the fit of the model. An AUC value of 0.5 equals random prediction (Phillips & Dudík, 2008). A single-value measurement of model performance is indicated as the area under the ROC curve (AUC). AUC is equally reduced by both omission errors and commission errors that reduce sensitivity and specificity respectively. Likewise, the Receiver Operating Curve (ROC) is a threshold independent model widely used in evaluating species distribution models (Elith et al., 2011), and is a graphical plot of “Sensitivity” and “1- Specificity” for all possible thresholds. Sensitivity is a measure of proportion of the actual positive identified correctly while Specificity is a measure of the proportion of negatives which are correctly identified. In this case presence only data is used so the model is tested against a random model (Phillips et al., 2006). AUC gives a measures of overall for and ranges from 0.5 – 1, which values close to 0.5 indicate a fit no better than random, 1.0 indicates perfect fit (Araujo, 2007).

3.4 Methodological Flowchart

The resume of methodological sequence can be seen in (Figure 1).

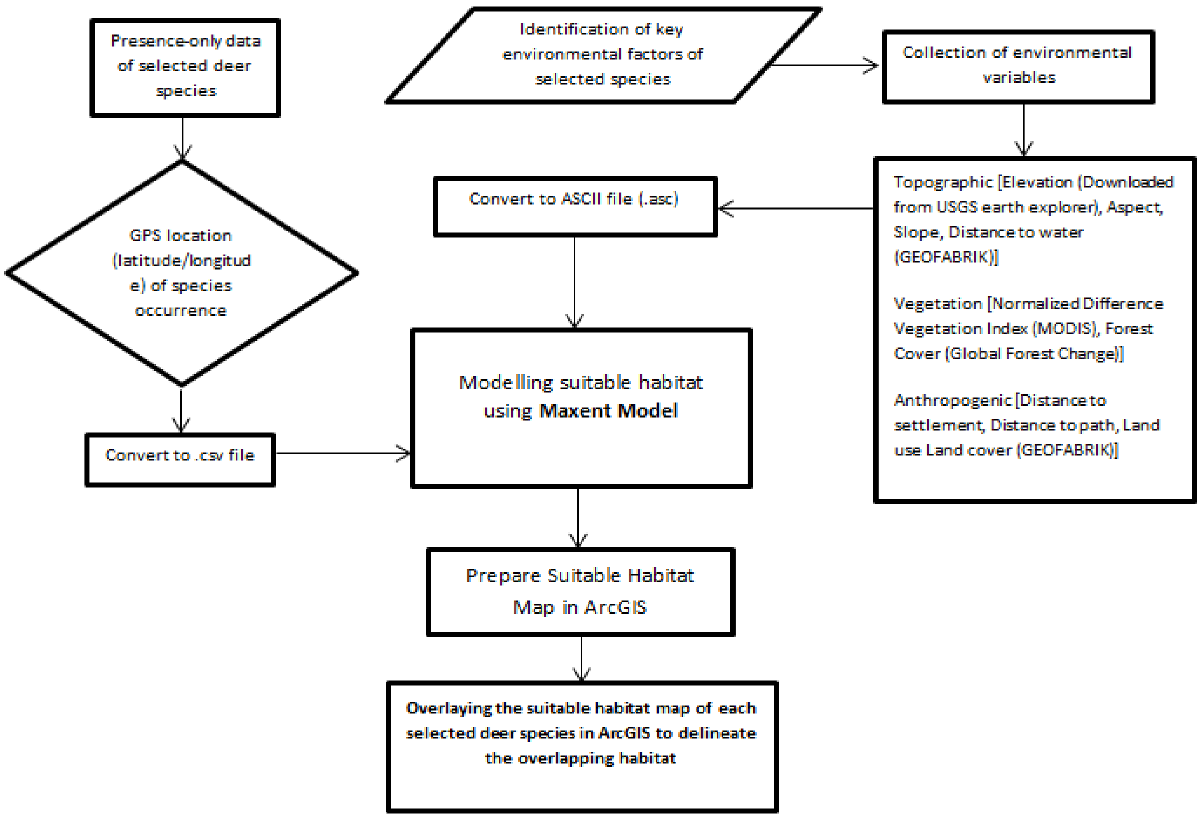


Figure 1: Methodological Flowchart

3.5 Raw Data

Below is the list of data materials used in this research:

Table 1: Data used in Research

Data	Description	Source
Base Map	Chitwan National Park	World imagery
Spotted deer and Sambar deer Presence Data	Presence Point	Fieldwork at CNP
Shape file	Road, Settlement, Water, Land use, Forest	Open Street Map
Landsat 8 level 1 Image	NDVI	USGS earth explorer

Chapter-4: Results

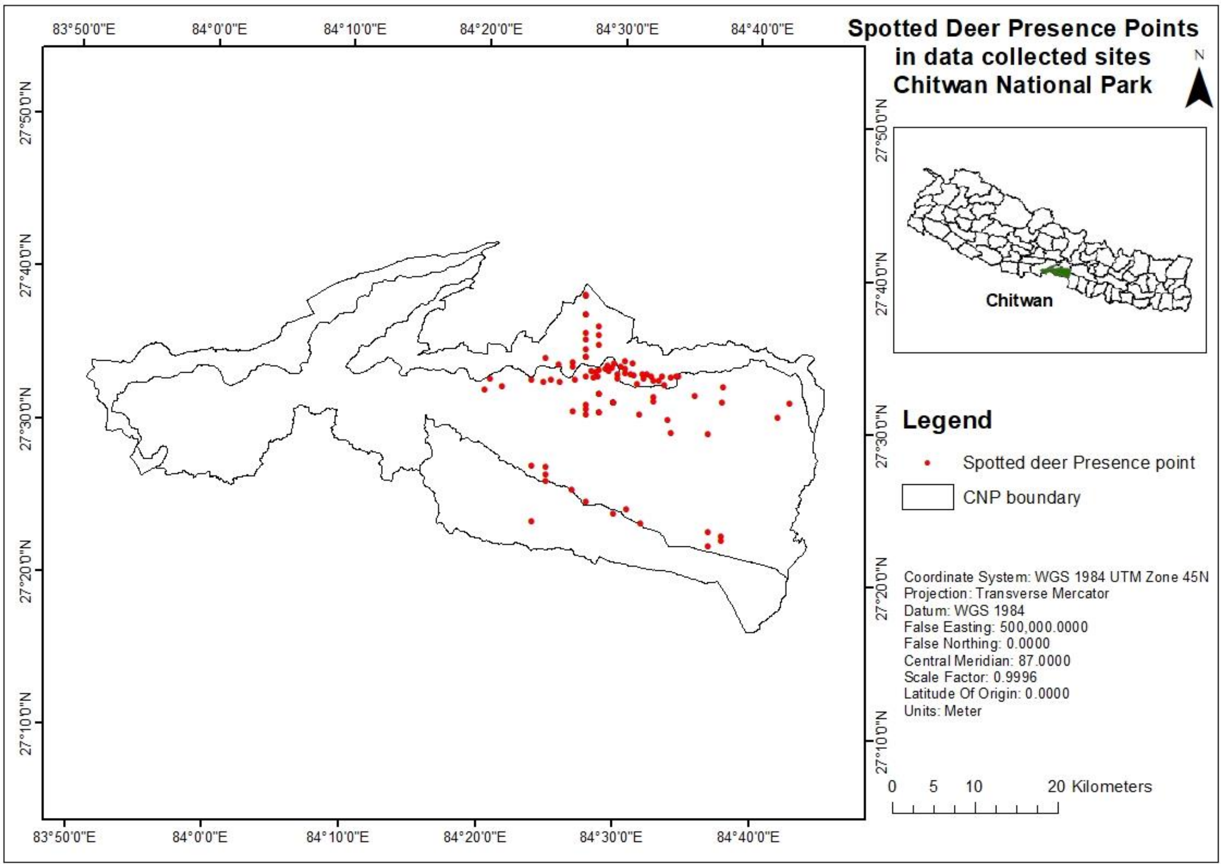
4.1 Deer Presence Point

Presence points data which have been collected from fieldwork activity and data from interviewing from villagers are displayed below.

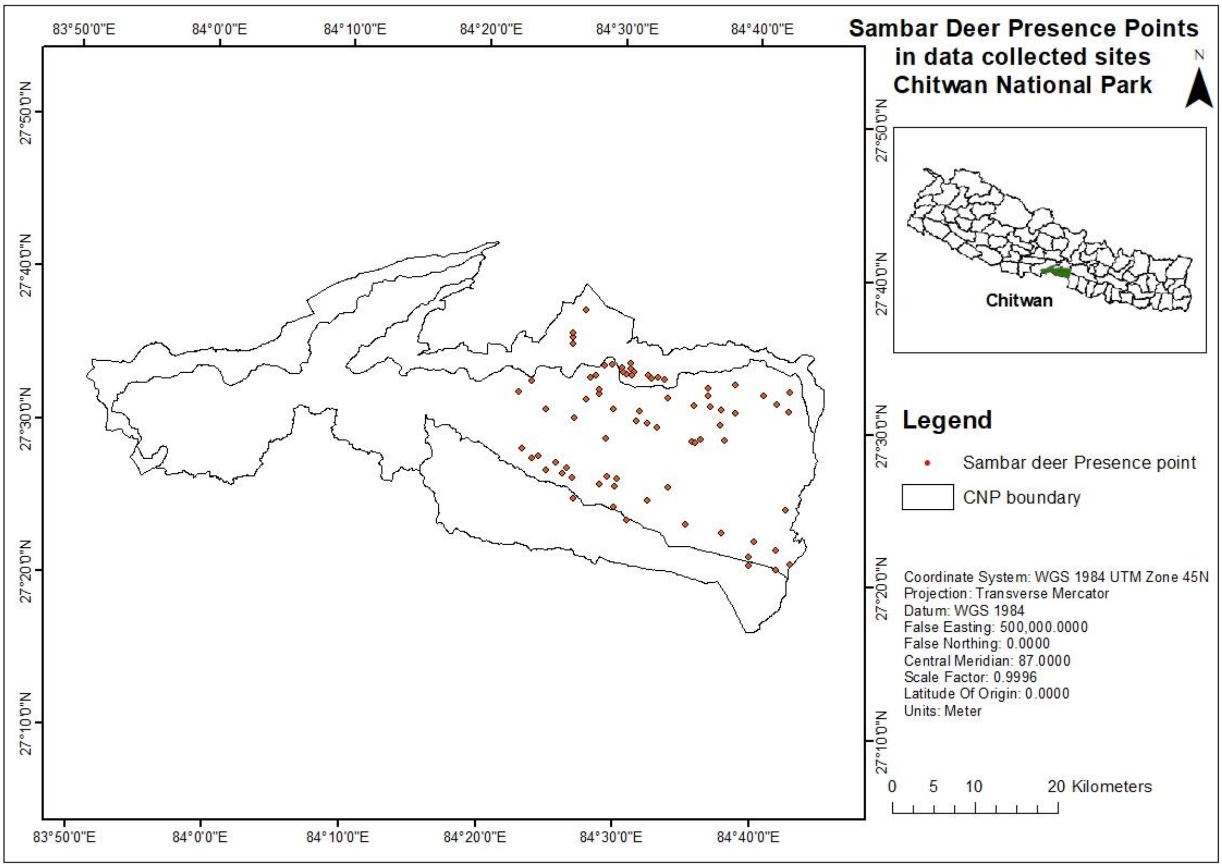
Table 2: Presence Point of Spotted and Sambar deer in CNP

Presence	Total
Spotted deer	93
Sambar deer	77

Total 170 presence points of both the deer species in CNP were used.



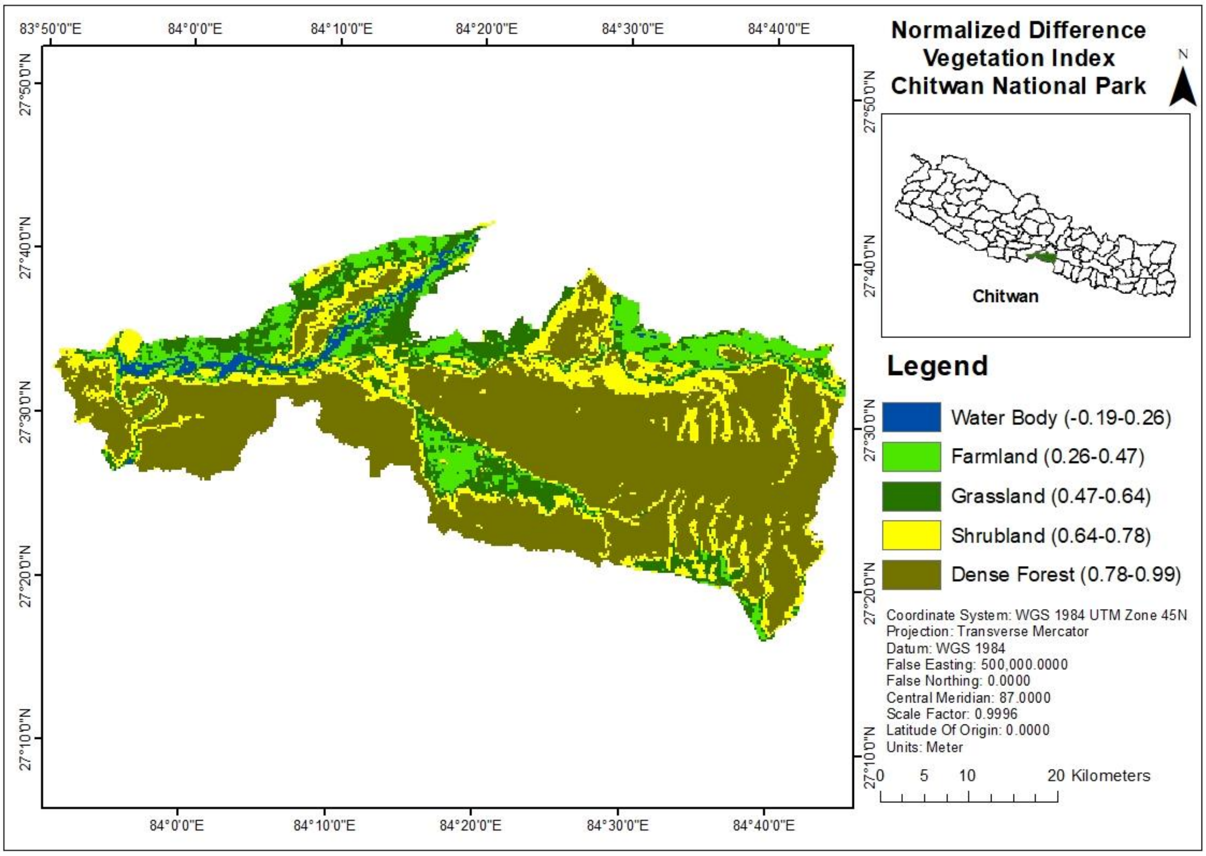
Map 2: Spotted deer Presence Points in data collected sites in CNP



Map 3: Sambar Deer Presence Points in data collected sites in CNP

4.2. Normalized Difference Vegetation Index (NDVI)

Meanwhile, the ranges of NDVI in the whole study area are -0.19 to 0.99 which indicates the greenness of a patch of land. The National Parks have the high value of NDVI (indicated by bright green color). CNP has high NDVI value which indicates that those areas are covered by vegetation in a peak growth phase. Based on the result, the landscape of the study area was dominated by shrub land and dense forest area.



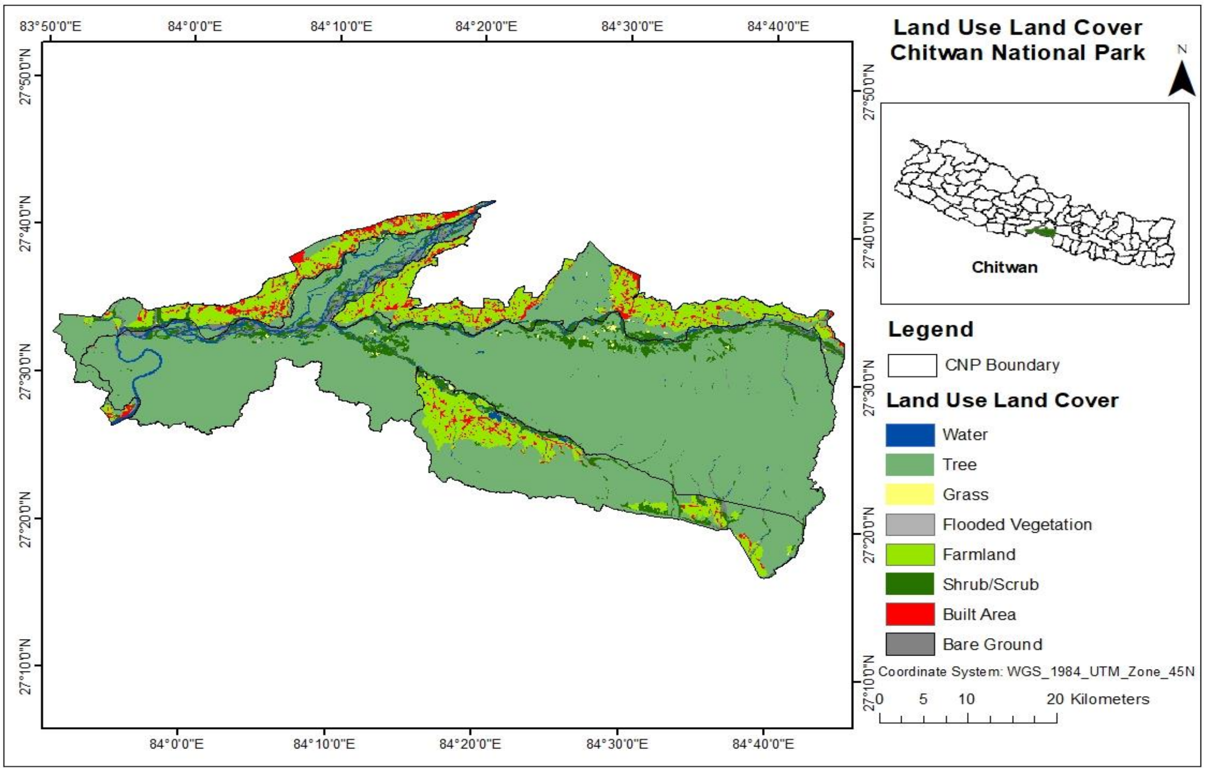
Map 4: Normalized Difference Vegetation Index in CNP

Table 3: NDVI Value

Land Cover	**Range of NDVI Value**
Water Body	0.19 – 0.26
Farm Land	0.26 – 0.47
Grassland	0.47 – 0.64
Shrubland	0.54 – 0.78
Dense Forest	0.78 – 0.99

4.3. Land Use and Land Cover (LULC)

LULC for this study was downloaded along with other anthropogenic environmental variables from Geofabrik Data Server. LULC was categorized into water, tree, grass, flooded vegetation, farmland, shrub, built area and bare ground (grounds with no green vegetation) which covers 58km^2, 1,403km^2 , 4km^2, 0.29km^2, 270km^2, 106 km^2, 65 km^2 and 39km^2 respectively (Table 4).



Map 5 Land Use and Land Cover of CNP

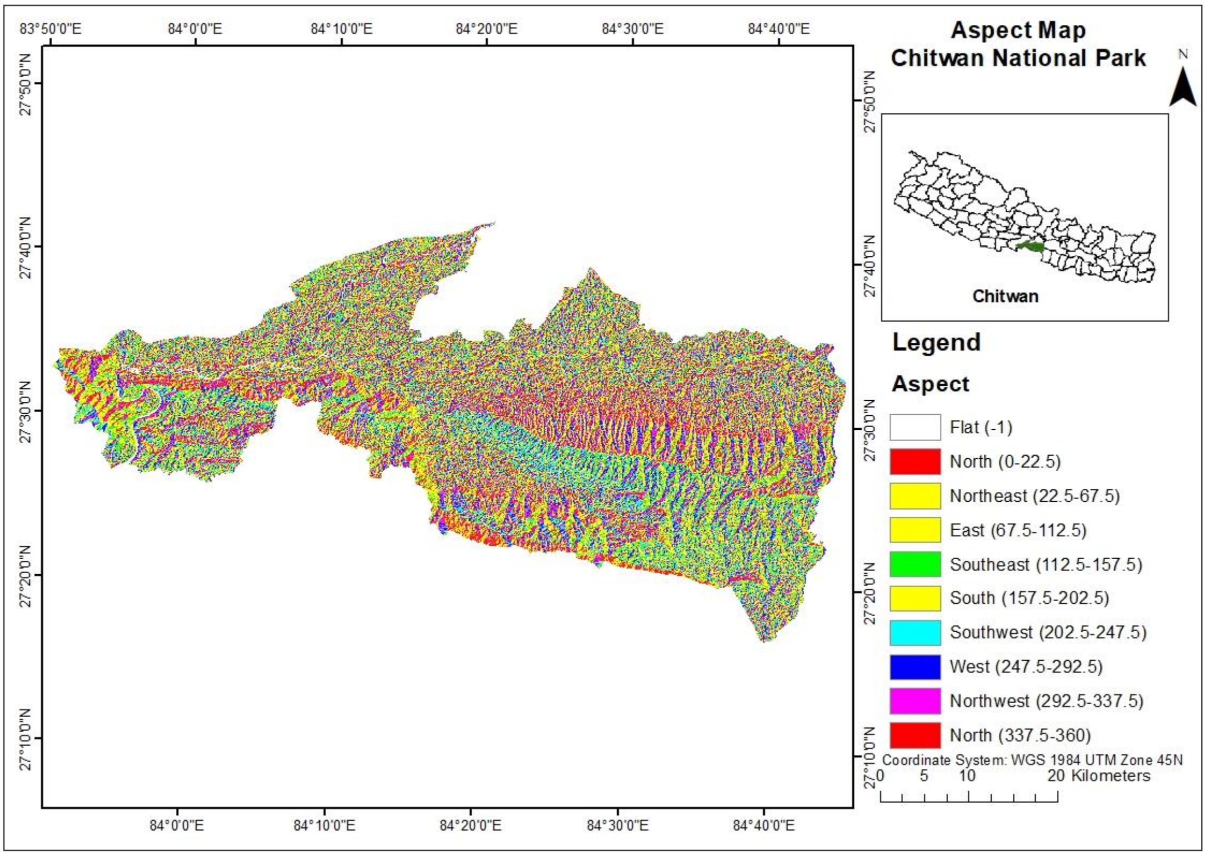
Table 4: Land use and Land Cover of CNP

Land Use and Land Cover	Area (km^2)
Water	57
Tree	1400
Grass	4
Flooded Vegetation	0.29
Farmland	270
Shrub/Scrub	106
Built Area	64
Bare Ground	39

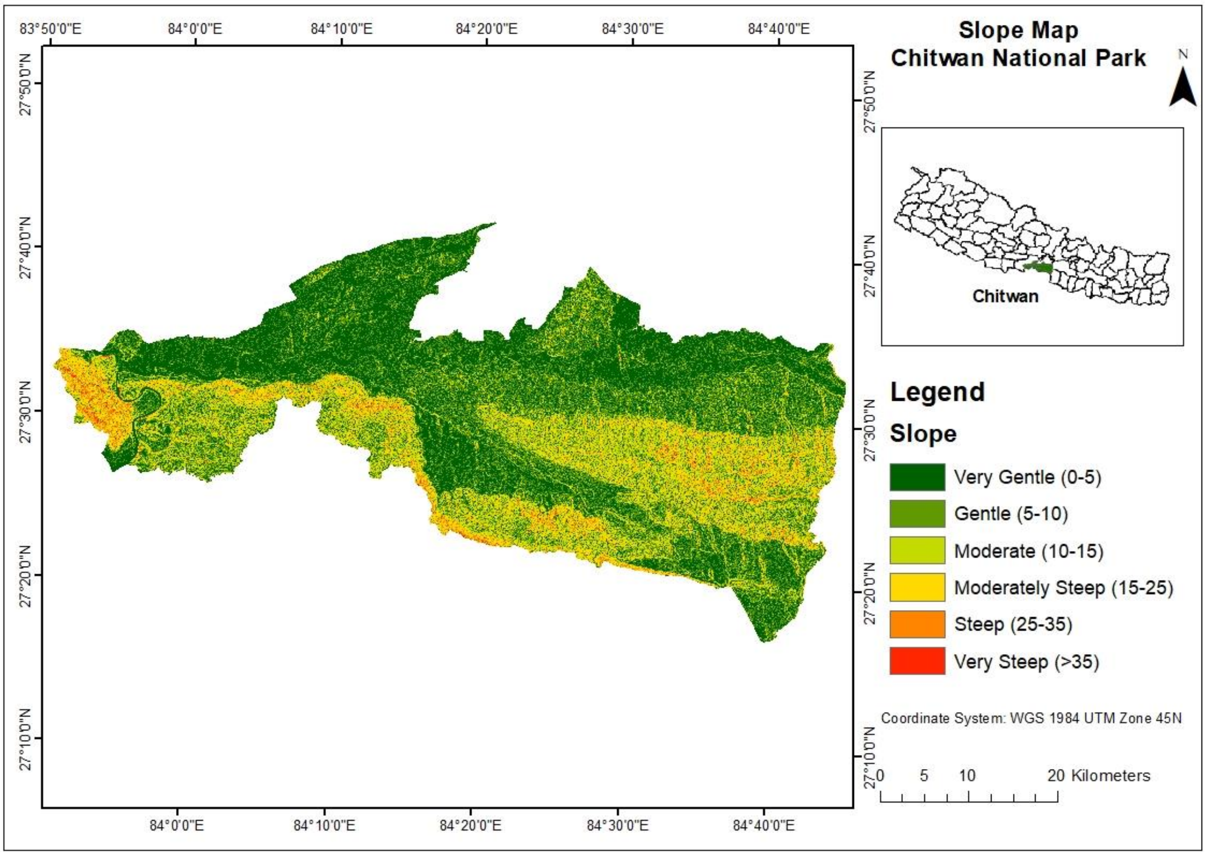
4.4. Aspect/Slope

Aspect and Slope were used as a topographic environmental variable created from Digital Elevation data downloaded from USGS earth explorer. DEM data was processed in Arc Map 10.5 to create aspect and slope map.

Here, Map 6 shows aspect map of CNP which was categorized into; flat, north, northeast, east, southeast, south, southwest, west and northwest. Similarly, Map 7 shows slope map of CNP which was categorized into; very gentle, gentle, moderate, moderately steep, steep and very steep.



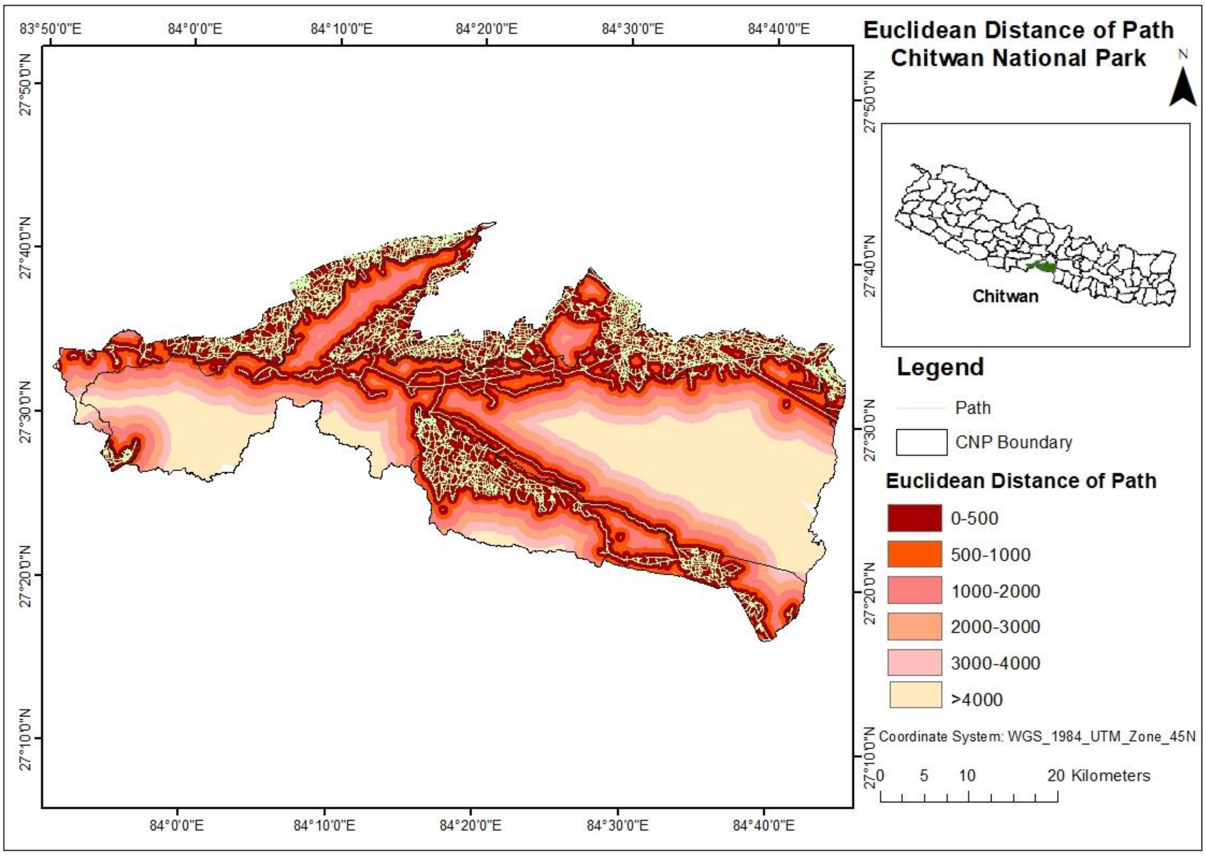
Map 6: Aspect Map of CNP



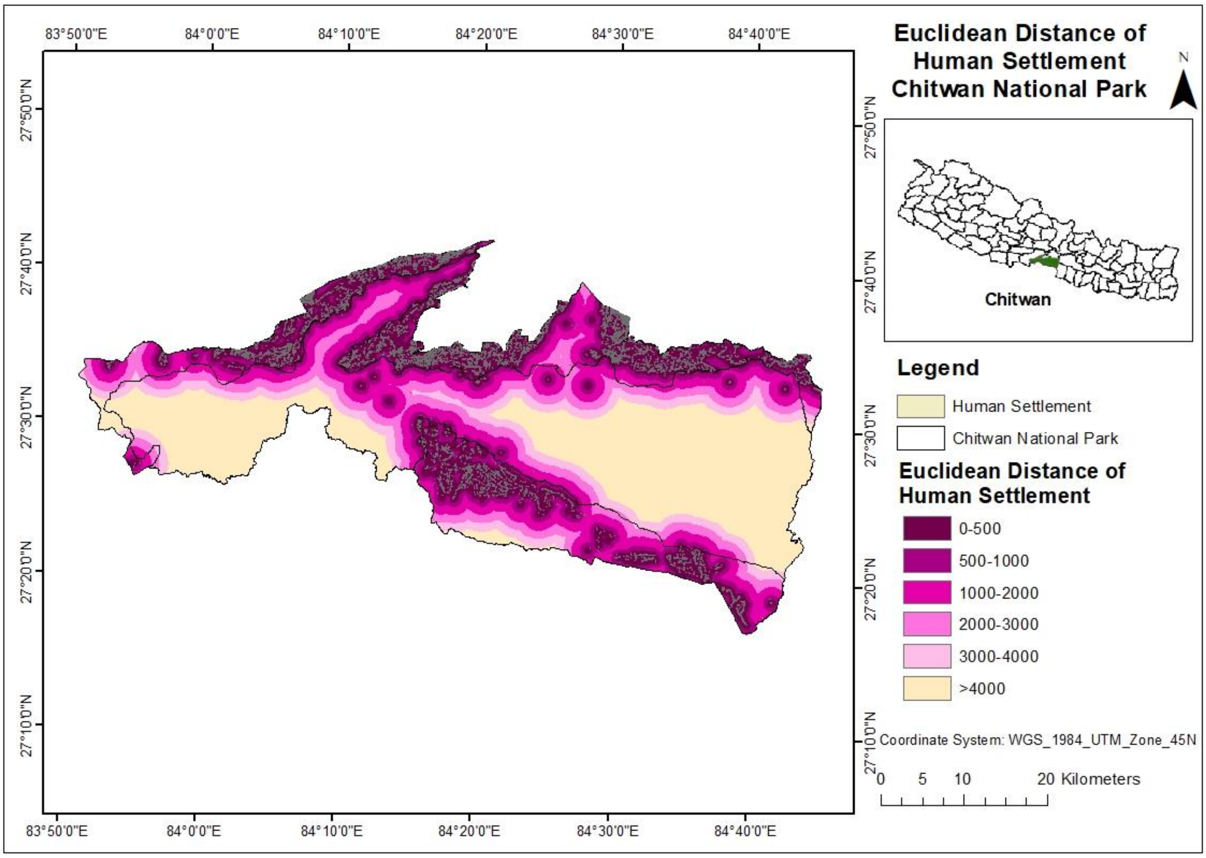
Map 7: Slope Map of CNP

4.5. Distance from Path/Settlement/Water

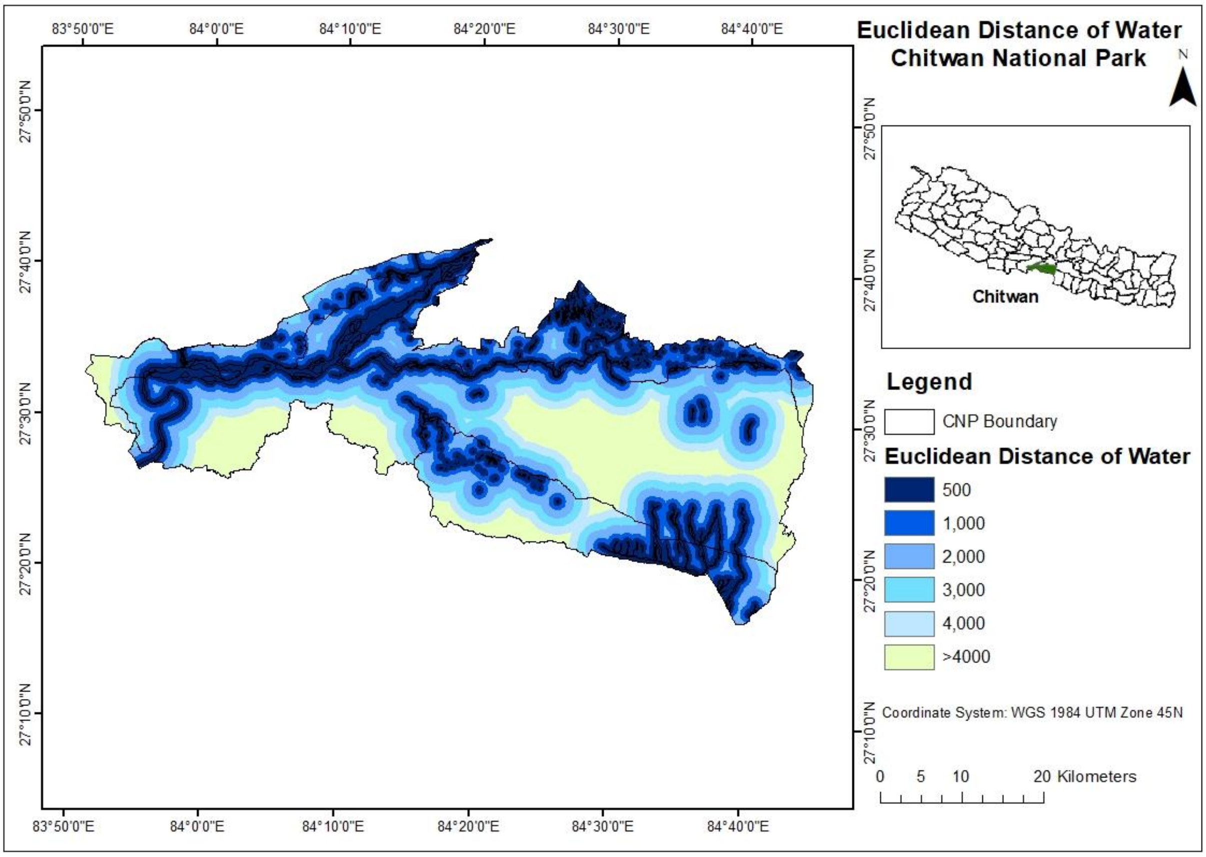
Distance from path, settlement and water were calculated by applying Euclidean distance in ArcMap 10.5 software. The distances for each variables were classified into five groups (0 – 500m, 500 – 1000m , 1000 – 2000m, 2000– 3000m, 3000m – 4000m and greater than 4000m).



Map 8: Euclidean Distance of Path in CNP



Map 9: Euclidean Distance of Human Settlement in CNP



Map 10: Euclidean Distance of Water in CNP

4.6. MaxEnt Output for Spotted deer

In Figure 2; X - Axis shows the cumulative threshold and Y– Axis shows the fractional value. Red line indicate mean area, blue area indicates mean area +/- one standard deviation, green line indicates mean omission on test data, whereas yellow area indicates mean omission +- one standard deviation and black line indicates predicted omission. The graph exhibit how testing and training omission and predicted area differ with the choice of cumulative threshold. According to the definition of the cumulative threshold the omission rate should be close to the predicted omission (Philips et al. 2006).

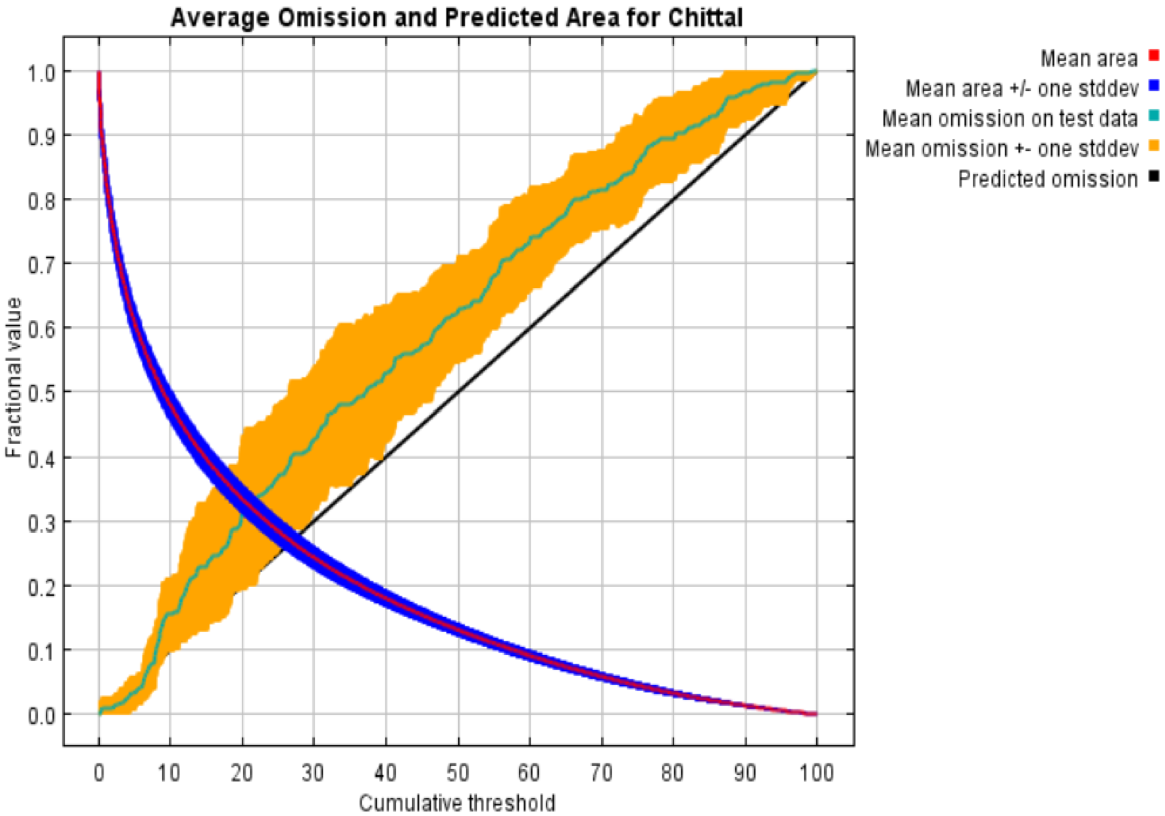


Figure 2: Omission rate and predicted area by using cumulative threshold for Spotted deer

Similarly, in figure 3; X – Axis shows the (1 – Specificity) which means “fractional predicted area” and Y – axis shows the Sensitivity which means “1 – omission rate”. The average test AUC for the replicate runs is 0.756, and the standard deviation is 0.031. The black line indicates random prediction.

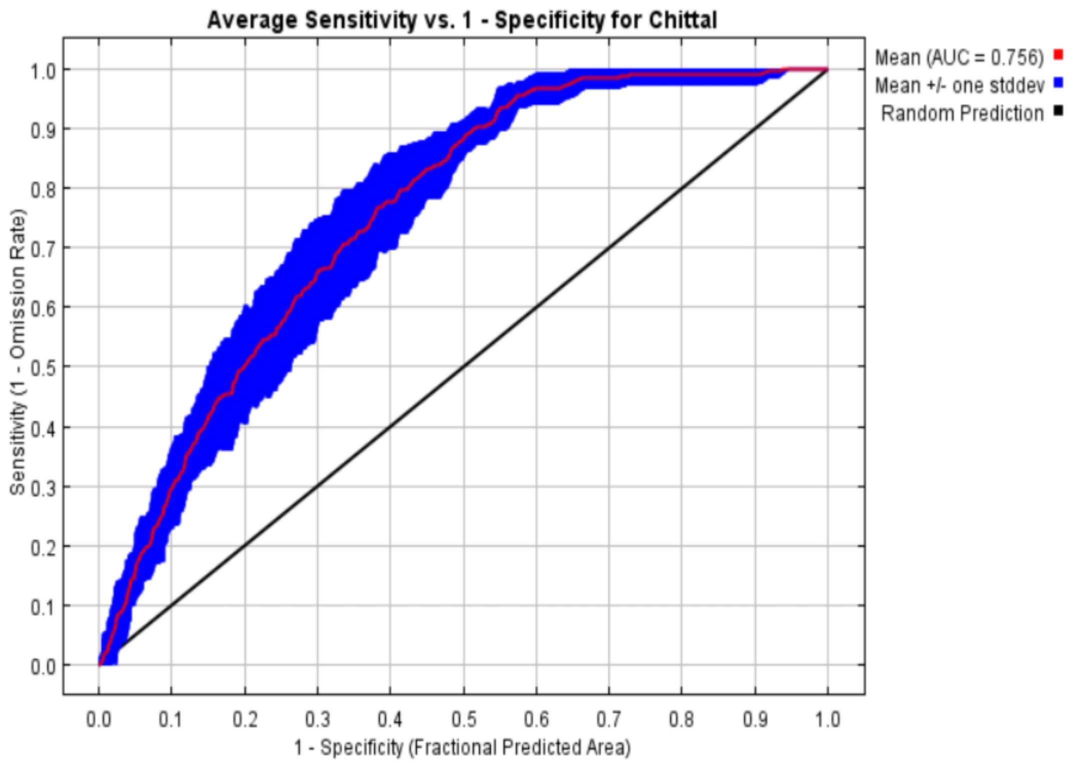


Figure 3: Receiver Operating Characteristics (Sensitivity Vs 1 - Specificity) on Spotted deer

The area under an Receiver Operating Characteristics (ROC) curve may be a measure of the usefulness of a test generally, where a greater area means a more useful test. ROC curve is used to compare the usefulness of tests. The AUC value of 0.5 indicates that the performance of the model is no better than random, while values closer to 1.0 indicate better model performance (Young et al., 2011). It allows us to compare the performance of one with another model which is most significant for evaluating multiple MaxEnt models.

The ROC curves in this model ROC curves shows high accuracy of the generated model with mean AUC 0.756. The red line in the figure shows the "fit" of the model to the training data. A higher AUC denotes higher model performance. An AUC <0.7 denotes poor model performance, 0.7–0.9 denotes moderately useful model performance, and >0.9 denotes excellent model performance (Phillips, 2006).

4.6.1. Analysis of variable contributions

Table 5; estimates the relative contributions of the environmental variables to the Maxent model. The model is re-evaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages. As with the variable jack-knife, variable contributions should be interpreted with caution when the predictor variables are correlated. The values shown on the table are averages over 10 replicate runs.

Table 5: Analysis of Variable Contribution for Spotted deer

Variable	**Percent Contribution**	**Permutation importance**
Path	37.6	31.1
LULC	24.6	16.9
Elevation	11.3	15.2
NDVI	9.6	18.8
Settlement	6.1	3
Forest Cover	3.5	2.2
Slope	3.4	5.7
Aspect	2	3.7
Water	1.9	3.4

4.6.2. Jack-knife Test

The following Figure 4; shows the results of the jack-knife test of variable importance. The environmental variable with highest gain when used in isolation is NDVI, which therefore appears to have the most useful information by itself. Values shown are averages over replicate runs. Jack-knife of regularized training gain for Spotted deer, it shows the result of Jack-knife variable test of variable importance. The environmental variable with highest gain when used in isolation is “NDVI” which therefore appears to have the most useful information through itself. Here X – axis show the regularized training gain and Y – axis shows the environmental variables whereas light blue colour shows the without variables and dark blue color shows only variable and red colour shows with all variables.

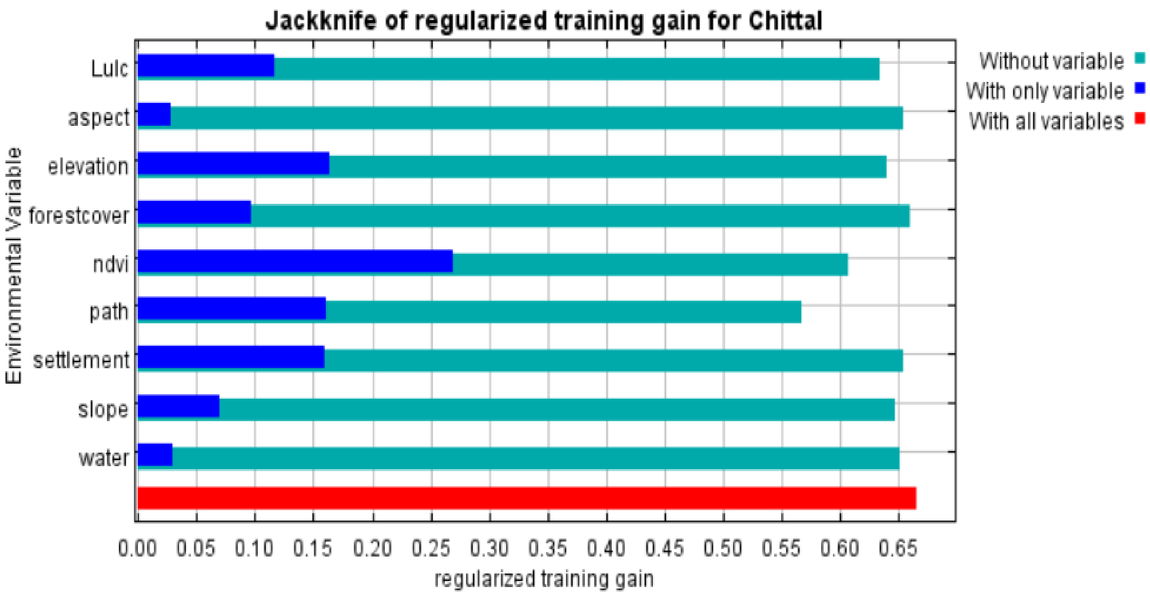


Figure 4: Jack-knife result of variable in regularized training gain for Spotted deer

Likewise, the jack-knife shows the training gain of each variable if the model was run in the isolation and compares it to the training gain all the variables. The spotted deer also provides a jack-knife for test gain of the species and AUC.

Again Figure 5; shows the same jack-knife test using AUC on test data. The AUC plot shows that NDVI, settlement, forest cover and elevation are the most effective variable for predicting the distribution of the occurrence data that was set aside for testing when predictive performance is measured using AUC.

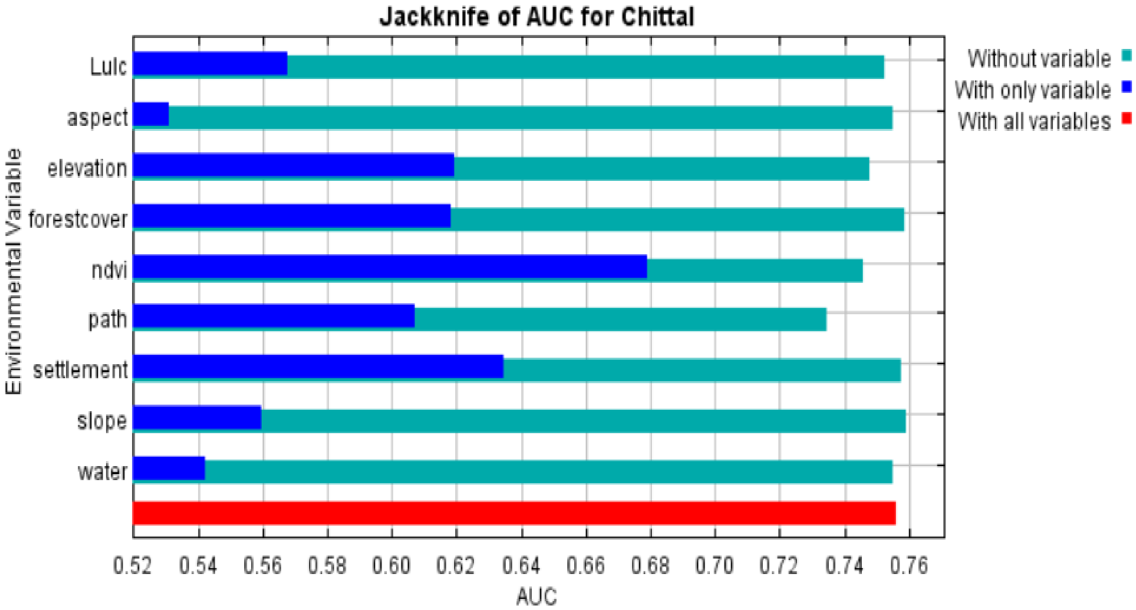


Figure 5: Jackknife result of variable in the AUC Spotted deer

The aspect shows opposite trend of environmental variable. That means it does not support jack-knife of test gain for spotted deer. It is remainder that conclusion about which variables are most important can change. So X – axis shows the test gain and Y – axis shows the environmental variables.

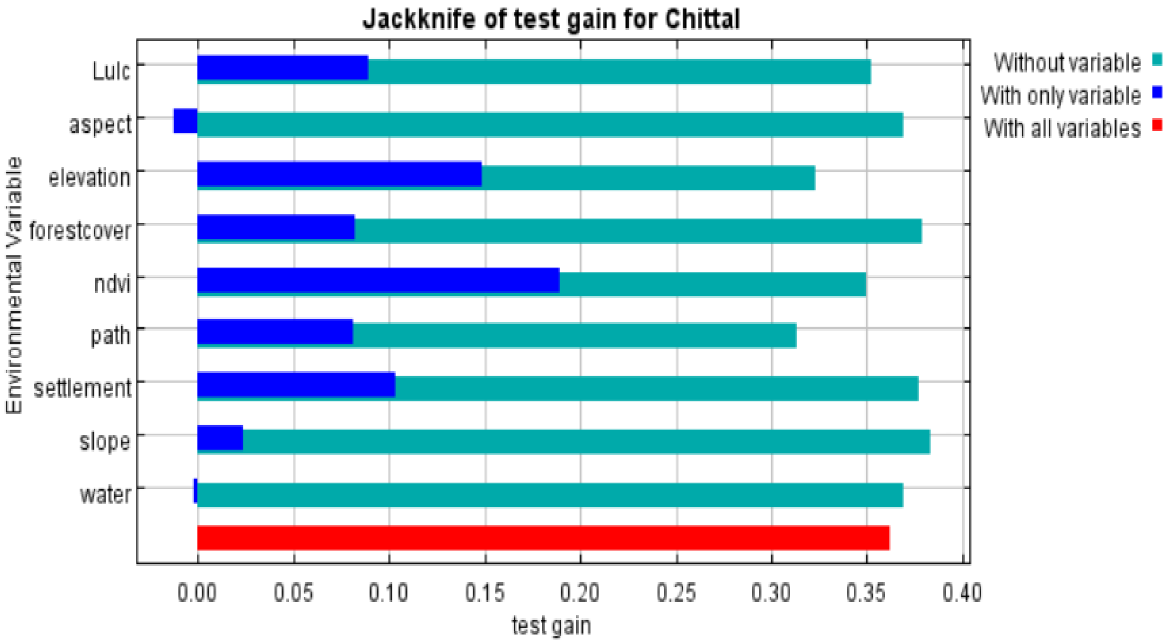


Figure 6: Jack-knife results of variable importance in the test gain for Spotted deer

Overall, jack-knife test shows the result of the test of environmental variable importance for this model. The environmental variable with highest training gain when used in isolation is NDVI which become most useful information through itself. This pattern is followed by elevation, forest cover, distance from path, distance from settlement, LULC, slope, distance from water and aspect have low gains when used in isolation. Hence resultant AUC has higher in the case of the variables NDVI, elevation, forest cover, distance from path, distance from settlement, LULC, slope, distance from water and aspect have significant gain.

4.6.3. Response Curve

The main function of response curves is to show how each environmental variable affects the Maxent prediction. When all other environmental variables are at their average sample value, the response curve shows how the logistic prediction changes as each environmental variable is varied.

Figure 7 shows response of spotted deer accordance to the LULC of the study area. Here, 1, 2, 3, 4, 5, 6, 7, 8 is categorized for water, tree or forest, grassland, flooded vegetation, farmland, shrub, built area and bare ground respectively. The probability of occurrence of the spotted deer in grassland is highest followed by forest area, water, shrub, bare ground, built area and farmland. Spotted deer preferred grassland for grazing but are found in all types of habitat (Wegge et al., 2009).

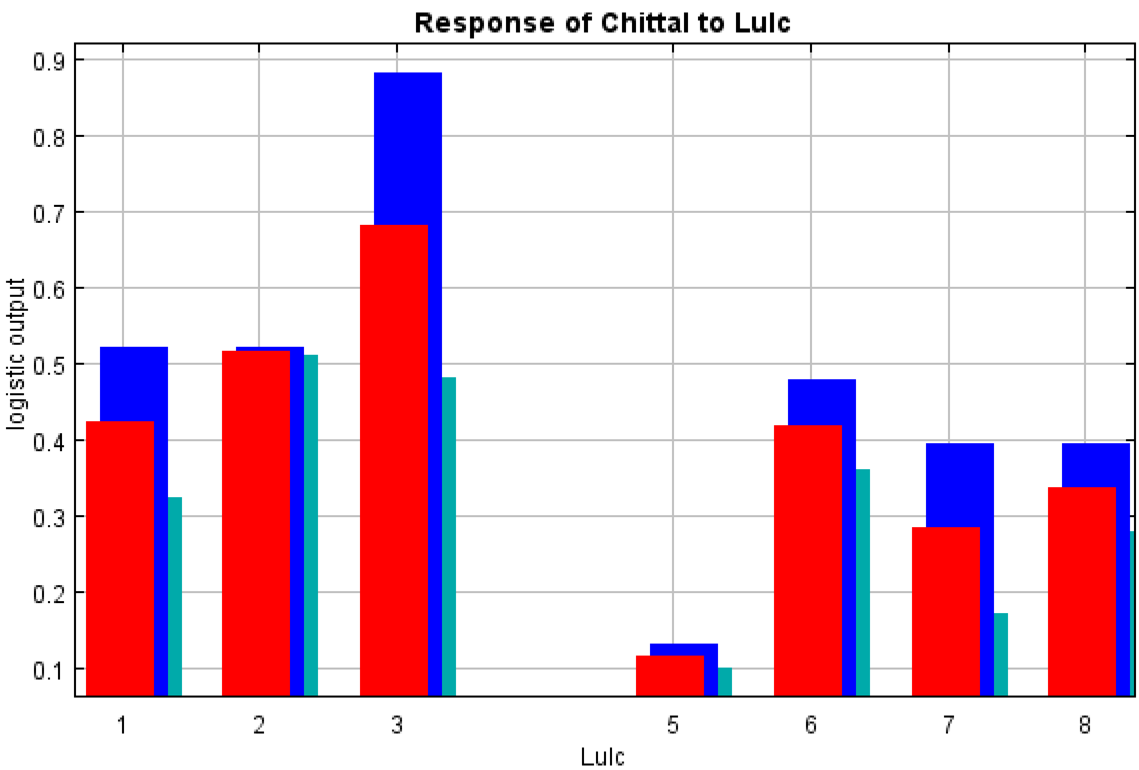


Figure 7: Response of Spotted deer presence to LULC

In figure 8; probability of occurrence of spotted deer in southeast/south aspect (112.5° - 202.5°) is the highest i.e. 5.5 and the lowest probability of occurrence of the deer is flat aspect (-1°).

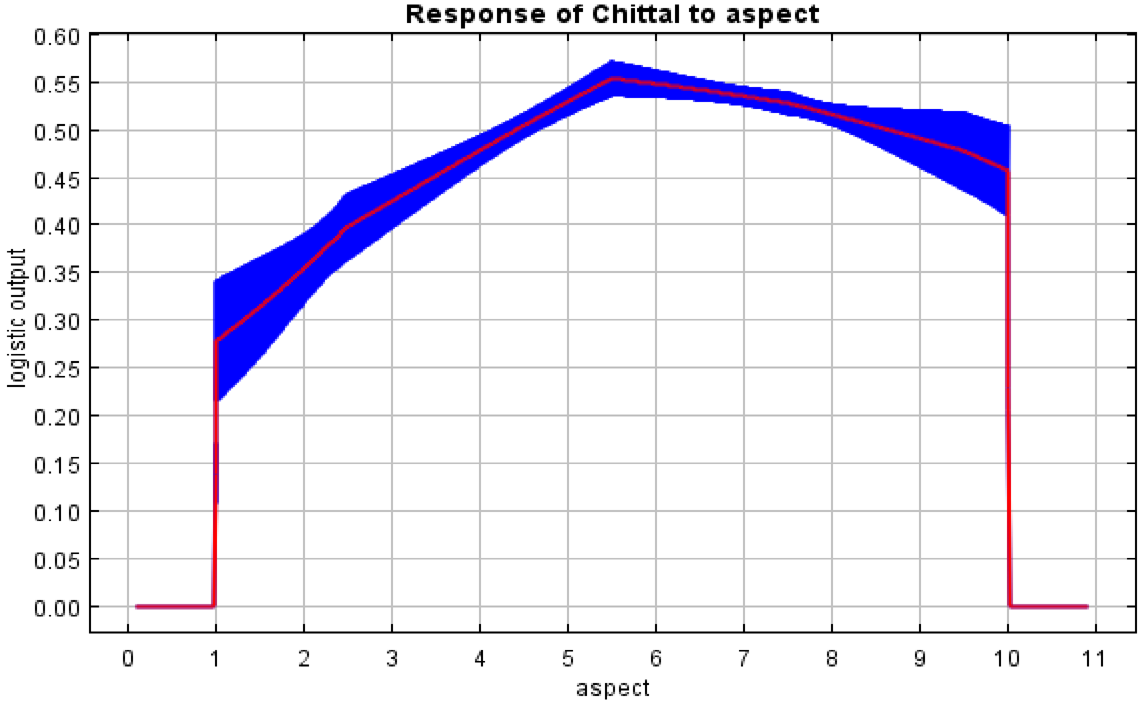


Figure 8: Response of Spotted deer presence to Aspect

In figure 9; the probability of spotted deer occurrence is higher around 250m and tends to decrease continuously in higher elevation. They are rarely found above an altitude of 1000m and are found at lower elevation below ~915m (Albes, 1977).

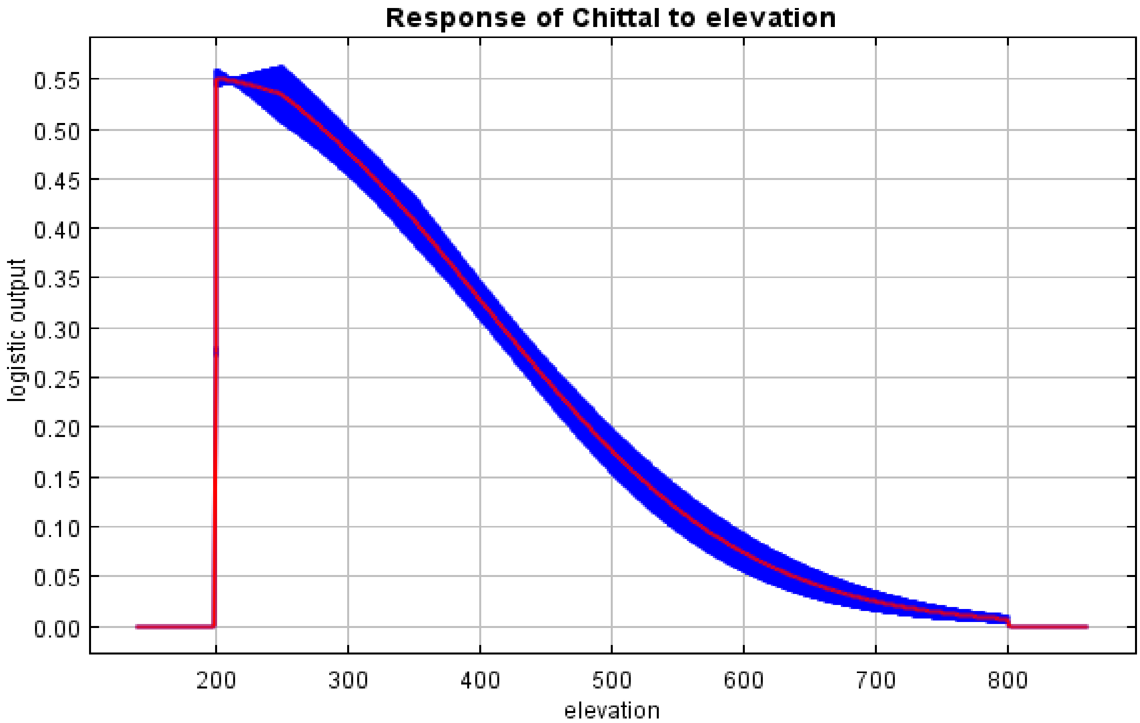


Figure 9: Response of Spotted deer presence to Elevation

In figure 10; the probability of spotted deer occurrence in forest cover where it starts increase from 0.33 and gradually increase up to 0.65 and then tends to decrease continuously up to 0.37. The curve shows occurrence of the species is minimum in dense forest in comparison to sparse vegetation. Spotted deer normally prefer ecotonal region between the grass patch and the forest (Mitra, 1990).

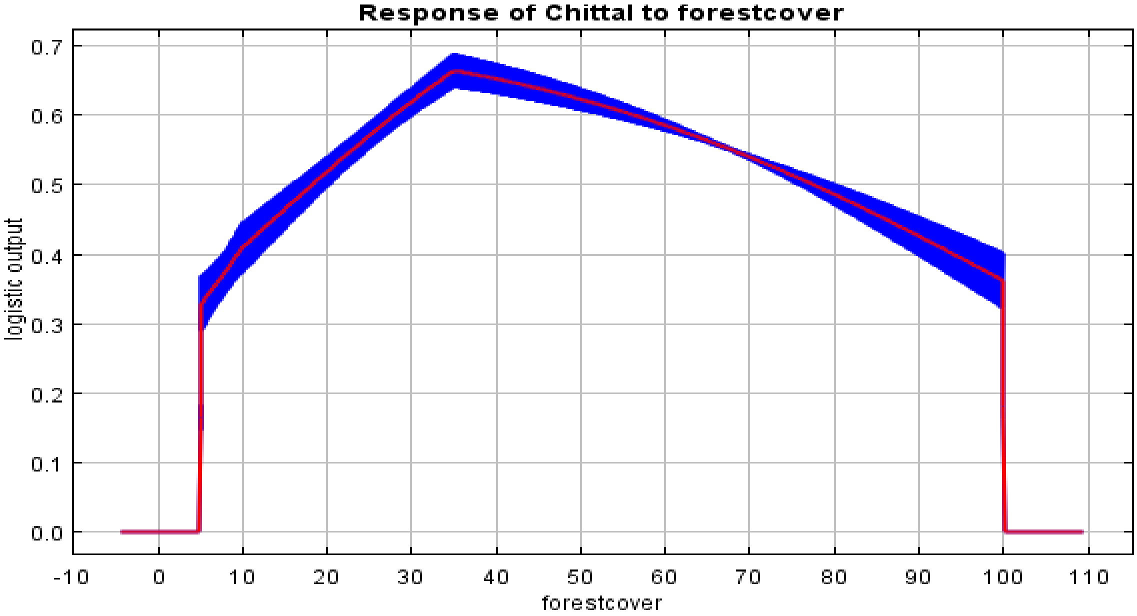


Figure 10: Response of Spotted deer presence to Forest cover

In figure 11; the probability of spotted deer occurrence is the highest (0.61) in NDVI with dense forest (0.8).

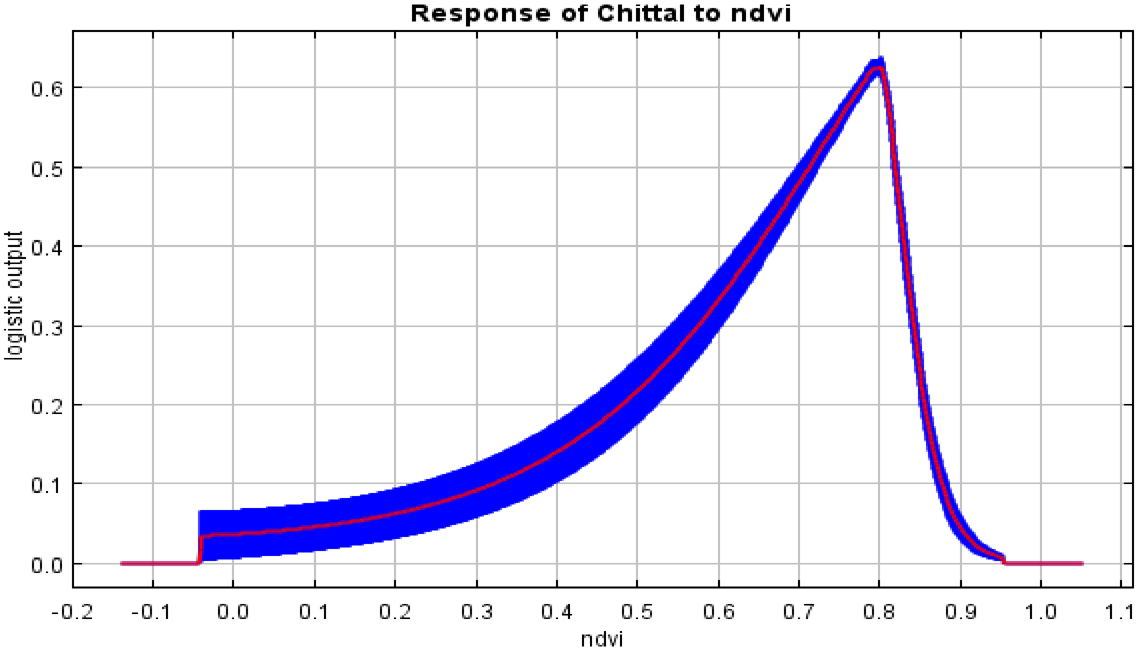


Figure 11: Response of Spotted deer presence to NDVI

In figure 12; the probability of spotted deer occurrence in “Distance from Path” where the deer occurrence gradually decreased from 0.52 up to 0.21. The occurrence of spotted deer is higher around 200m in compared to greater distance from the path, this might be due to no presence points of the species faraway from data collected trails.

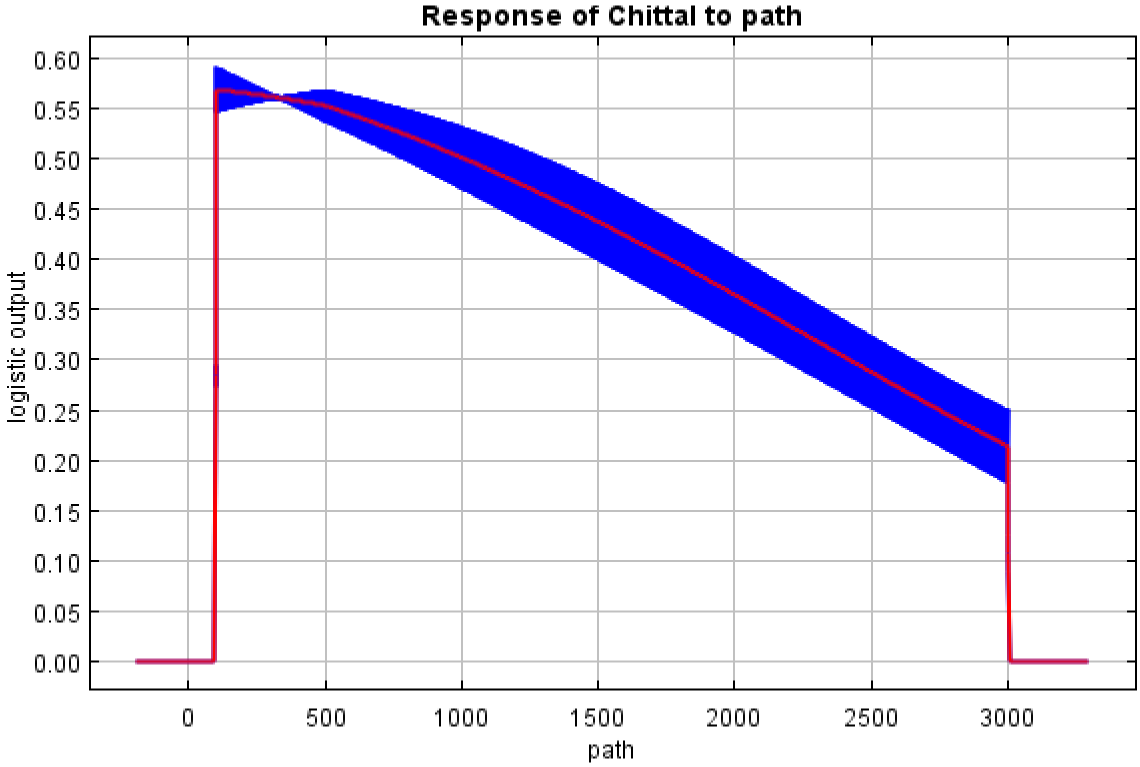


Figure 12: Response of Spotted deer presences to Distance from Path

In figure 13; the probability of spotted deer occurrence in “Distance from Settlement” is high around 1000m from settlement area i.e. 0.61, which gradually decreased to increasing distance from settlement.

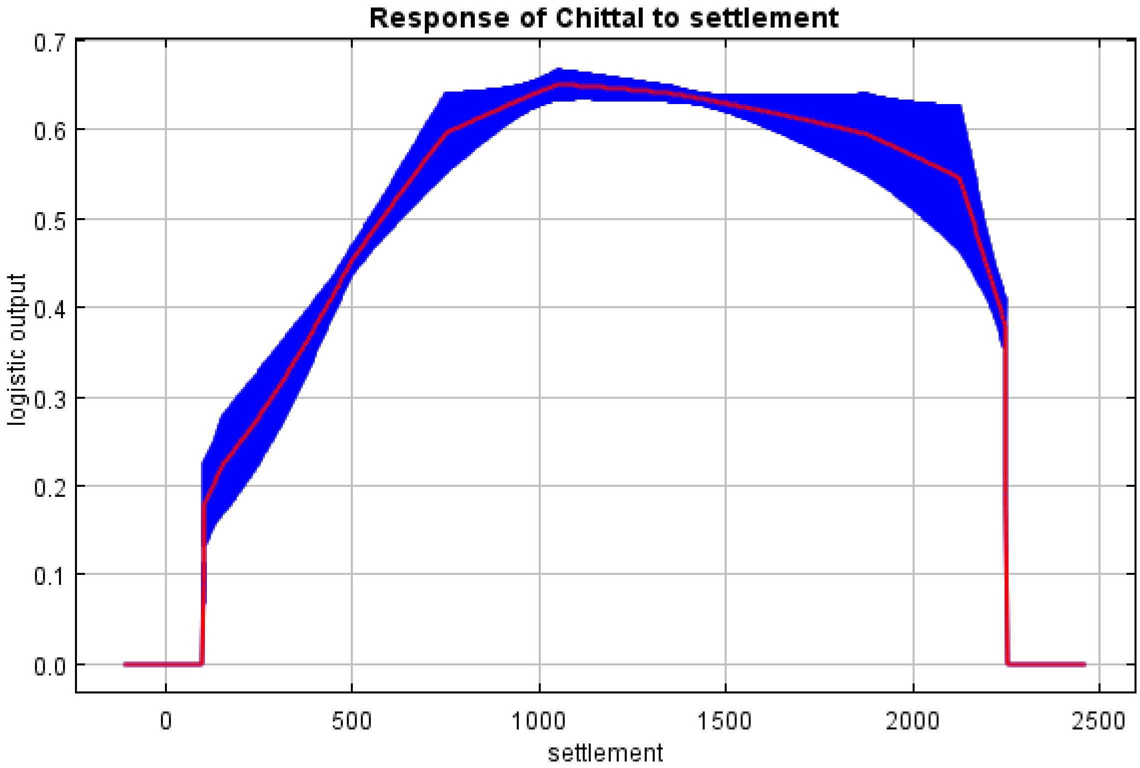


Figure 13: Response of Spotted deer presences to Distance from Settlement

In figure 14; the probability of spotted deer occurrence is higher in very gentle slope (0-5°) i.e. 0.55, which gradually decreases with the increase in slope angle.

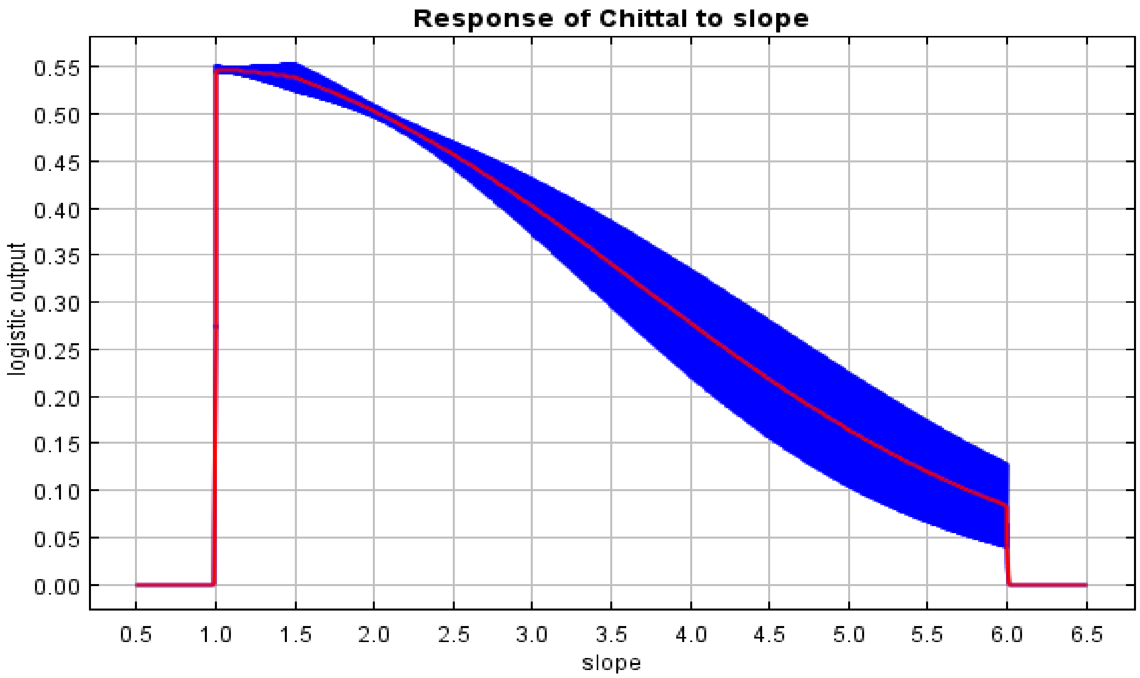


Figure 14: Response of Spotted deer presences to Slope

The probability of spotted deer occurrence in “Distance from Water” is high from 100m to 1000m distance from water i.e. 0.55 which gradually decreased to increasing distance from water. The sign and sightings of the large mammals are found closer to the proximity of water sources as, they visit frequently to the water bodies (Bhattarai and Kindlmann, 2012a; Wegge et al., 2009; Adhikari et al., 2019a).

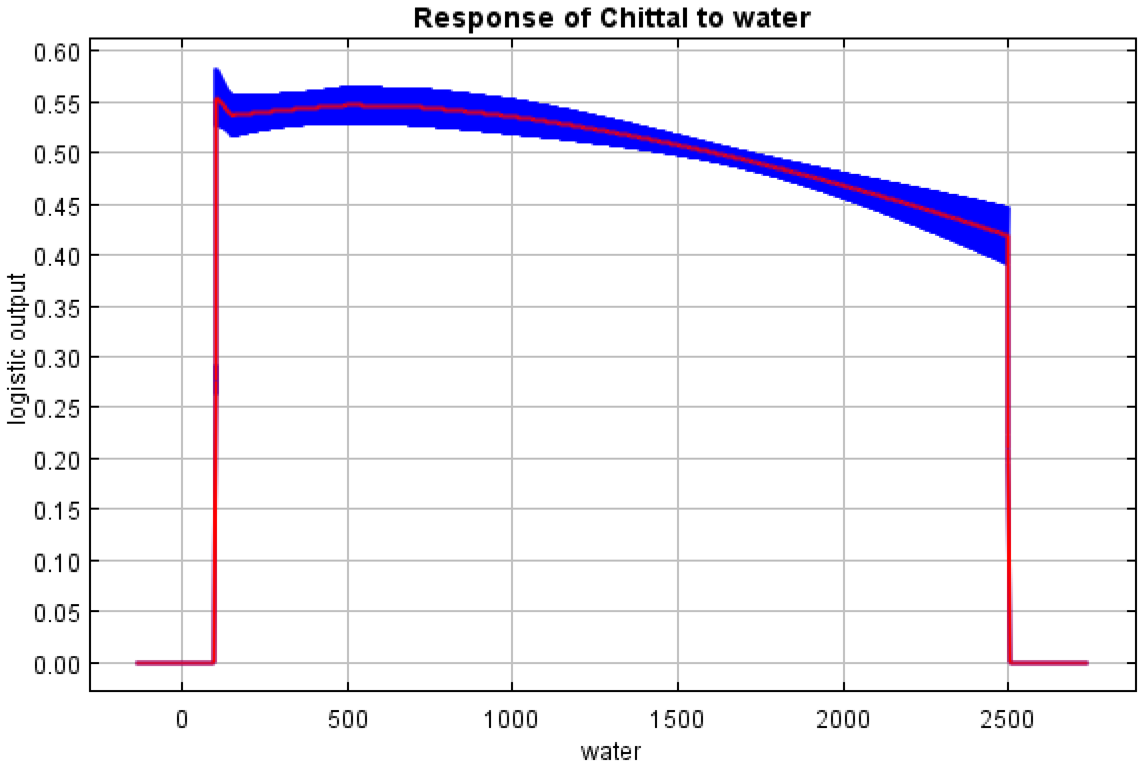
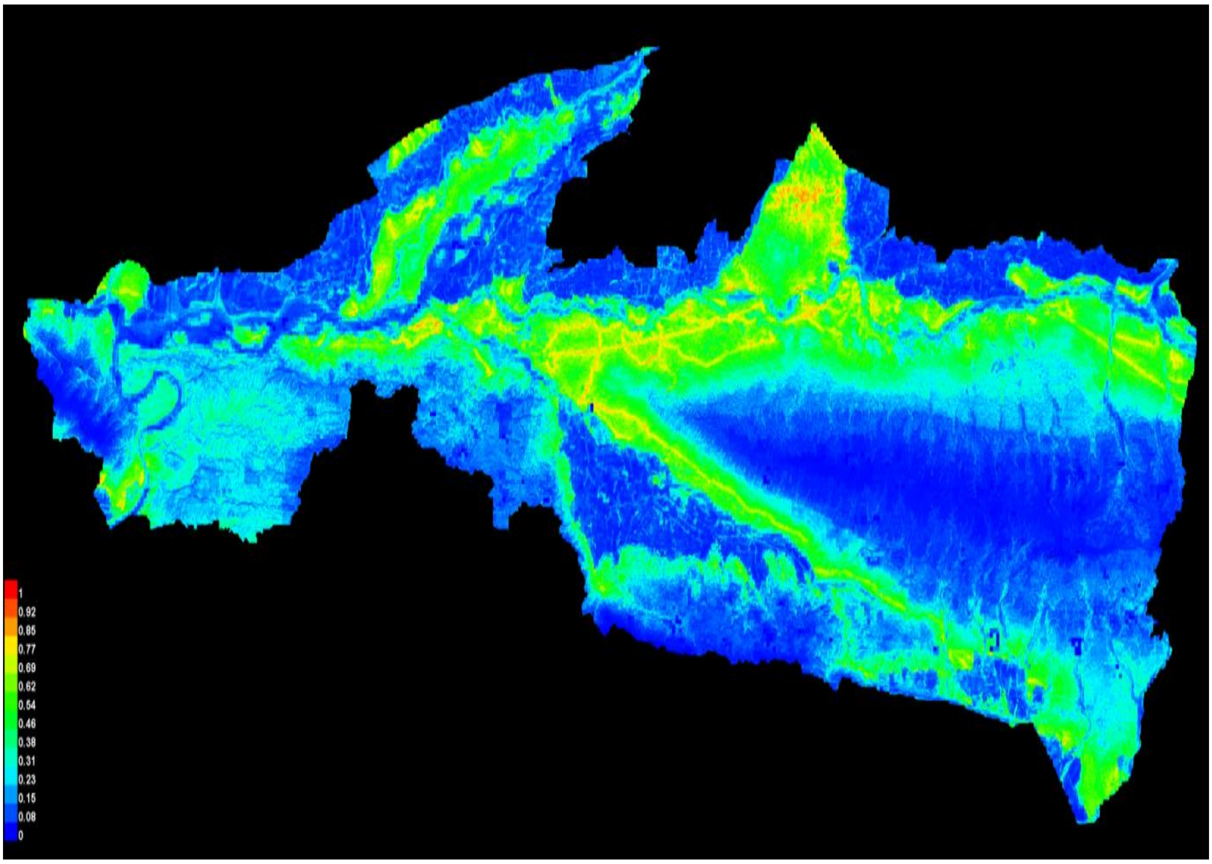


Figure 15: Response of Spotted deer presences to Distance from Water

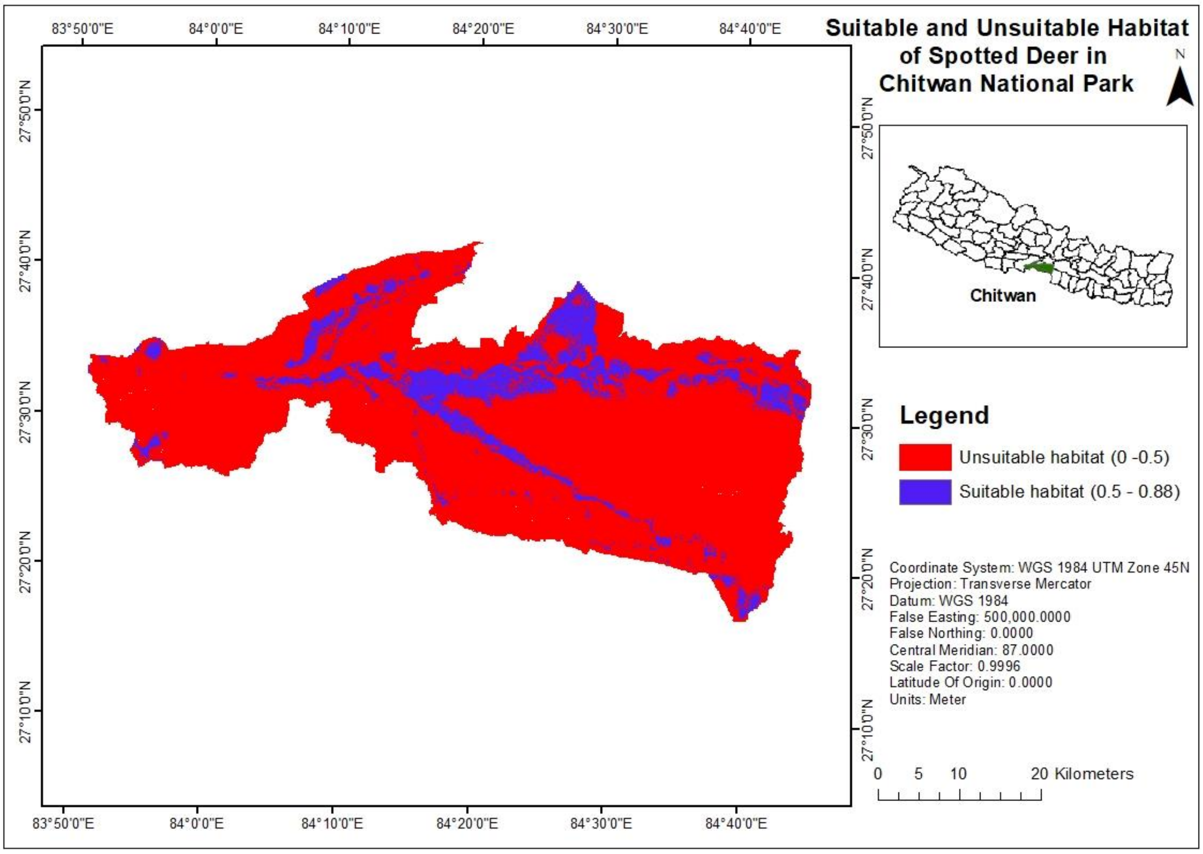
The above display response curve shows how each of the most important predictor variables distance affect the MaxEnt prediction. The response curve for the model showed fairly accurate trend for spotted deer suitability. However in the response curve the probability occurrence of spotted deer decreases as increase in distance of the environmental variable.

4.6.4. Habitat Suitability Map of Spotted Deer

MaxEnt generated a habitat suitability map. This map is then classified on the different species occurrence probability threshold class. By using specific probability thresholds to classify suitability map into different suitability classes. However, the MaxEnt predicted map uses colours that indicate predicted probability conditions are suitable or unsuitable. Warmer colours (red) indicate high probability of suitable conditions for the species and blue indicates low probability. Therefore suitability map was reclassified into two classes; suitable and unsuitable in Map 11 and Figure 12. The Unsuitable category included the areas that have least probability for Spotted Deer to occur.



Map 11: MaxEnt Habitat Suitability Map of Spotted deer



Map 12: Habitat Suitability Map of Spotted deer in CNP

The map was categorized using the threshold 0 – 0.5 as unsuitable while from 0.5 – 0.88 as suitable habitat. The suitability of spotted deer in CNP is categorized in Table 6. The result of habitat suitability map shows that the total potential suitable habitat for spotted deer in CNP is 264.14km^2 while other remain unsuitable habitat for area 1677.34km^2 in CNP.

Table 6: Threshold used to predicted logistic output into classes for Spotted deer

Habitat Class	Probability Value
Unsuitable Habitat	0 - 0.5 (< 5)
Suitable Habitat	0.5 – 0.88 (> 5)

Table 7: Predicted Suitable and Unsuitable areas for Spotted deer in CNP

Habitat Class	**Area (km^2)**
Unsuitable	1677.34
Suitable	264.14

MaxEnt modeling has proven to be very effective at determining habitat use and species distributions for a variety of species and localities. It shows suitability map that shows majority of "Suitable" patches around the CNP.

4.7. MaxEnt Output for Sambar deer

Similar to spotted deer MaxEnt output explained above, given graph (figure 16) shows how testing and training omission and predicted area vary with the choice of cumulative threshold. The following figure shows the test omission rate and predicted area as a function of the cumulative threshold, averaged over the 10 replicate runs.

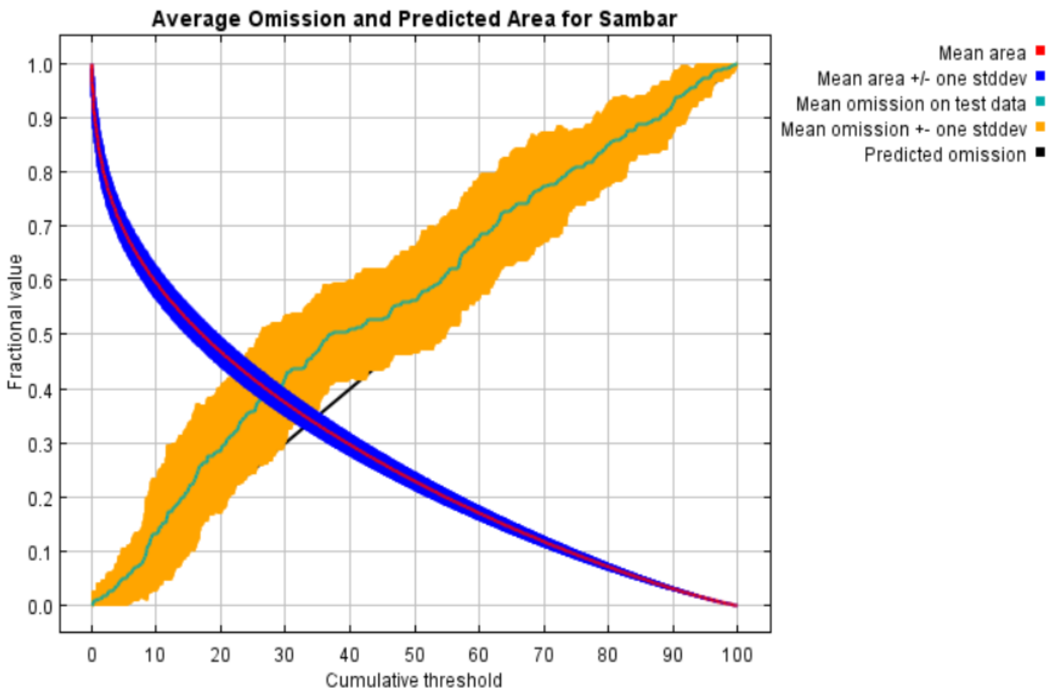


Figure 16: Omission rate and predicted area by using cumulative threshold for Sambar deer

Similarly, in Figure 17; X – Axis shows the (1 – Specificity) which means "fractional predicted area" and Y – axis shows the Sensitivity which means "1 – omission rate". The average test AUC for the replicate runs is 0.678. The black line indicates random prediction.

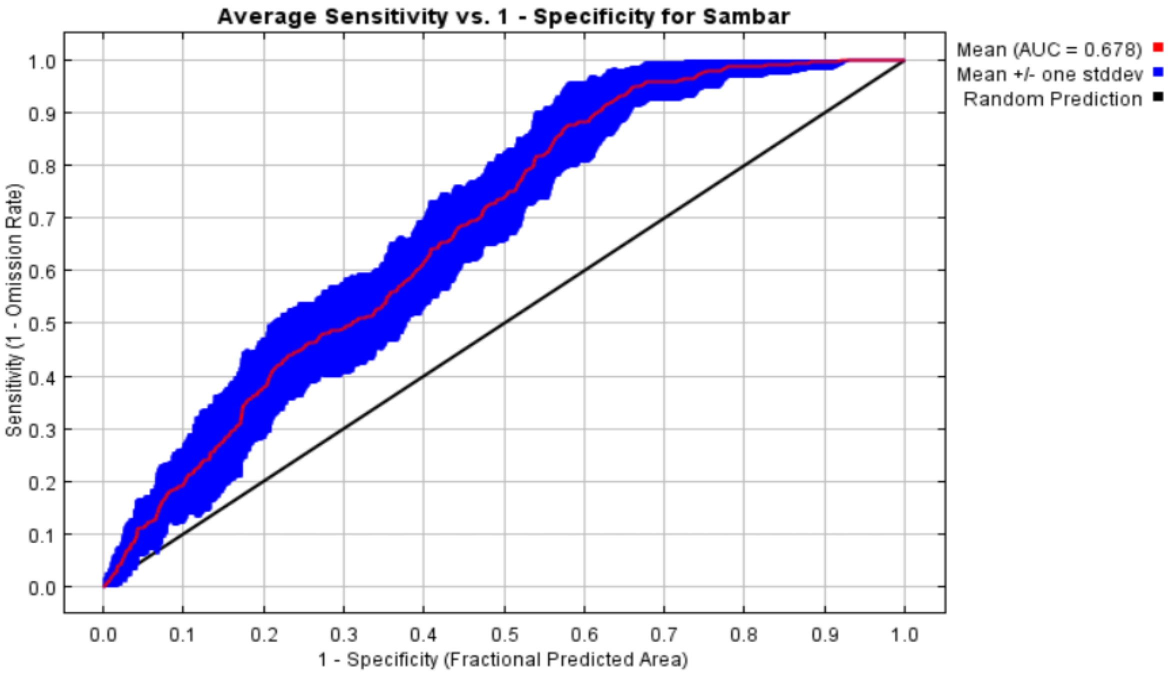


Figure 17: Receiver Operating Characteristics (Sensitivity Vs 1 - Specificity) on Sambar deer

The ROC curves in this model ROC curves shows moderate model performance of the generated model with mean AUC 0.678. As the performed AUC value was greater than 0.5 and slightly closer to 1.0 which indicates moderate model performance.

4.7.1. Analysis of variable contributions

Table 8, gives estimates of relative contributions of the environmental variables to the Maxent model. The values shown on the table are averages over 10 replicate runs.

Table 8: Analysis of Variable Contribution for Sambar deer

Variable	Percent contribution	Permutation importance
LULC	40.7	13
Elevation	17.5	6.4
NDVI	14.4	38.4
Slope	8.6	23.6
Water	5.9	10.3
Aspect	3.5	2.4
Settlement	3.5	1.1
Path	3.3	0.7
Forest cover	2.5	3.9

4.7.2 Jack-knife Test

The following Figure 18; shows the results of the jack-knife test of variable importance. The environmental variable with highest gain when used in isolation is NDVI, which therefore appears to have the most useful information by itself. Values shown are averages over replicate runs. Jack-knife of regularized training gain for sambar deer, it shows the result of jack-knife variable test of variable importance. The environmental variable with highest gain when used in isolation is “NDVI” which therefore appears to have the most useful information through itself. Here X – axis show the regularized training gain and Y – axis shows the environmental variables whereas light blue colour shows the without variables and dark blue colour shows only variable and red colour shows with all variables.

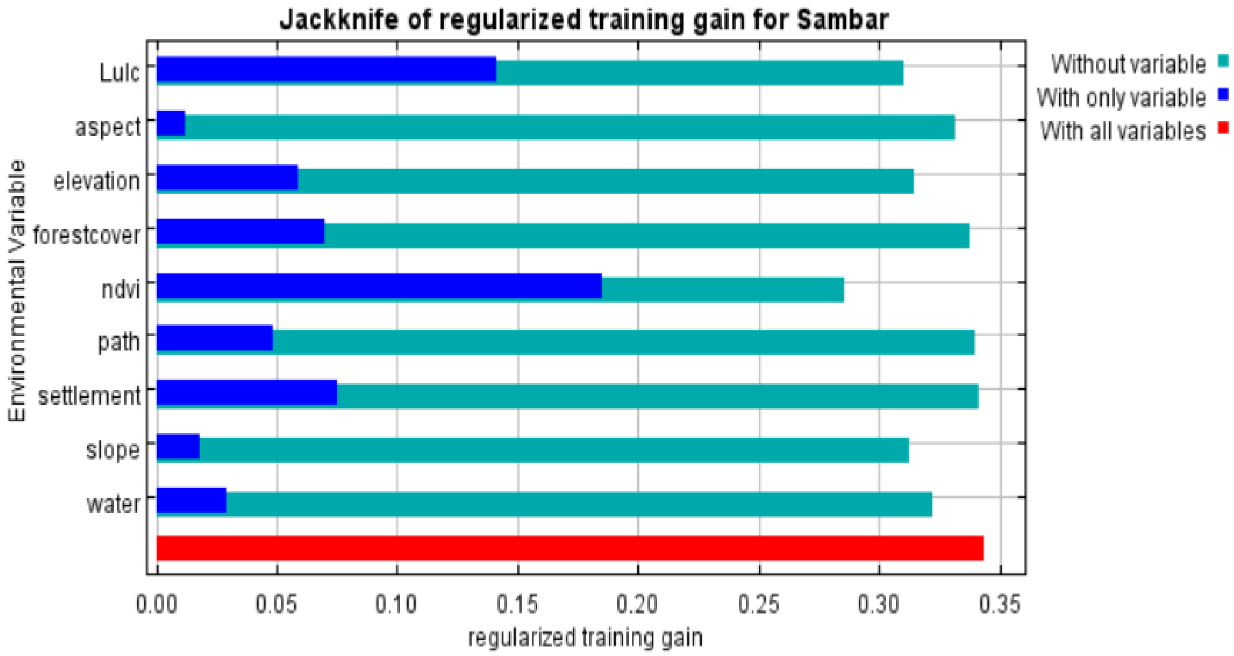


Figure 18: Jack-knife result of variable in regularized training gain for Sambar deer

Likewise, the jack-knife shows the training gain of each variable if the model was run in the isolation and compares it to the training gain all the variables. The sambar deer also provides a jack-knife for test gain of the species and AUC.

Again Figure 19; shows the same jack-knife test using AUC on test data. The AUC plot shows that NDVI, LULC, Forest cover, Elevation and Settlement are the most effective variable for predicting the distribution of the occurrence data that was set aside for testing when predictive performance is measured using AUC.

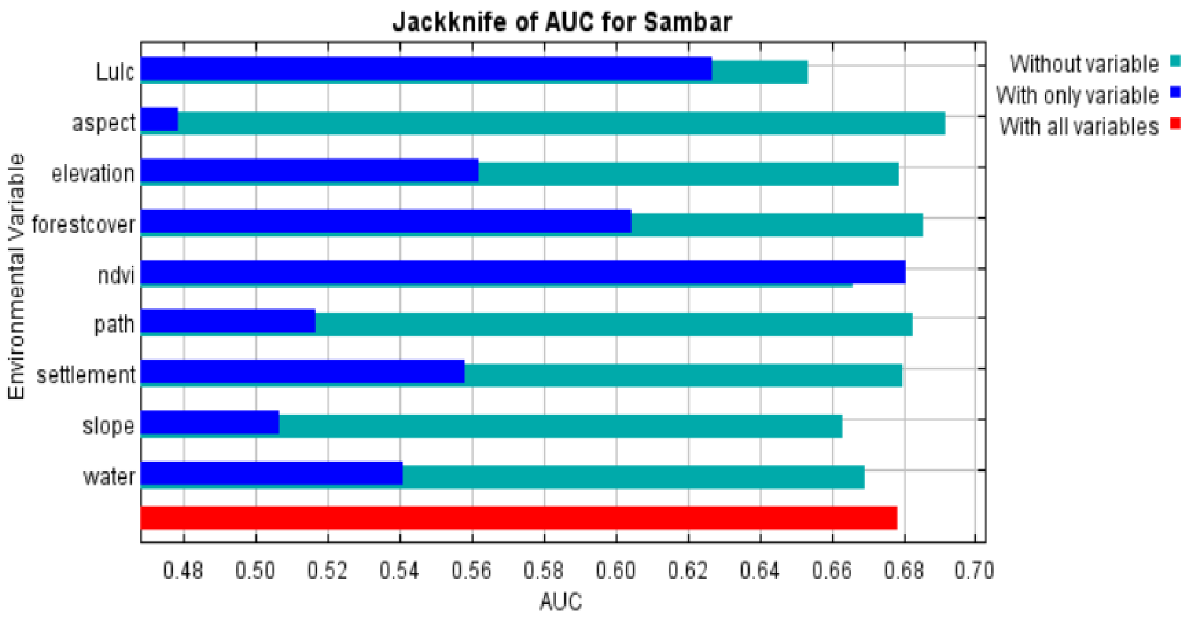


Figure 19: Jack-knife result of variable in the AUC Sambar deer

Similarly, in Figure 20; the aspect, slope and water show opposite trend of environmental variable. That means it does not support jack-knife of test gain for sambar deer. It is remainder that conclusion about which variables are most important can change. So X – axis shows the test gain and Y – axis shows the environmental variables.

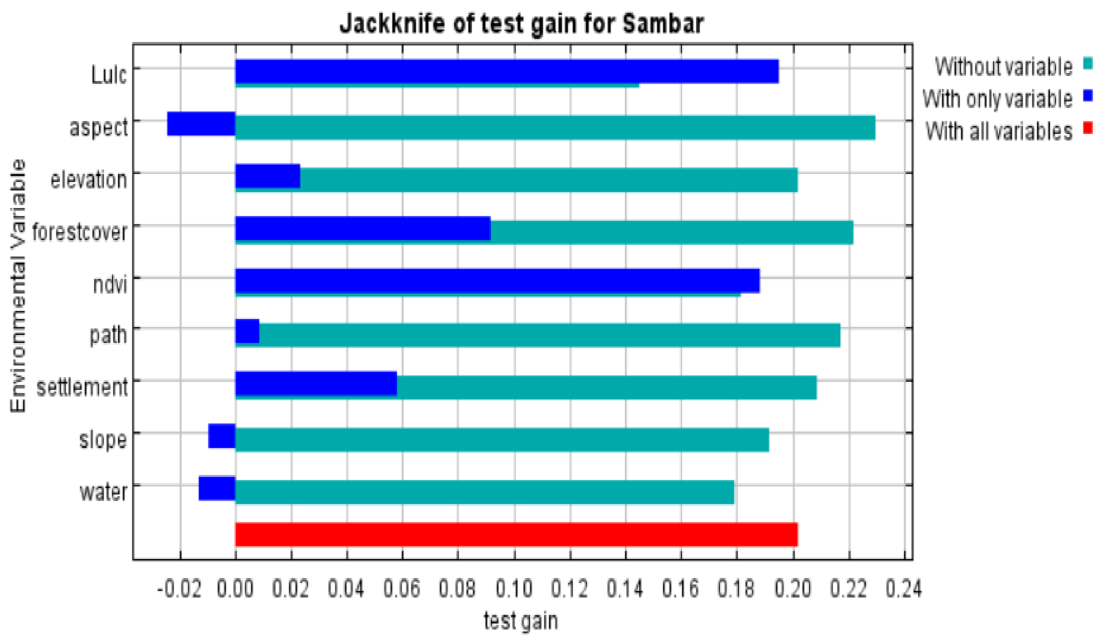


Figure 20: Jack-knife results of variable importance in the test gain for Sambar deer

In general, jack-knife test shows the result of the test of environmental variable importance for this model. The environmental variable with highest training gain when used in isolation is NDVI which become most useful information through itself. This pattern is followed by LULC, forest cover, distance from settlement, elevation, distance from path, distance from water, slope and aspect have low gains when used in isolation. Hence resultant AUC has higher in the case of the variables NDVI, LULC, forest cover, elevation, distance from settlement, distance from water, distance from path, slope and aspect have significant gain.

4.7.3 Response Curve

Similar to spotted deer output response curve, the given curves (Figure 21) for sambar deer also shows how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.

In figure 21; response of sambar deer accordance to the LULC of the study area is shown. Here, 1, 2, 3, 4, 5, 6, 7, 8 is categorized for water, tree or forest, grassland, flooded vegetation, farmland, shrub, built area and bare ground respectively. The probability of occurrence of the sambar deer in forest area is highest. They are relatively abundant in sal forests (Pokharel and Storch, 2016).

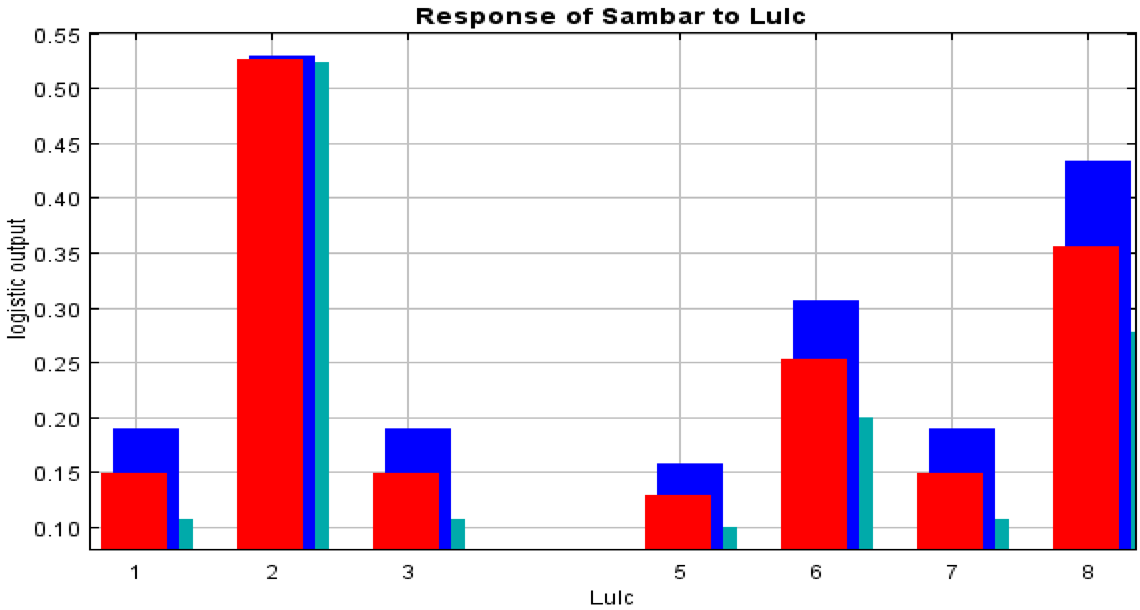


Figure 21: Response of Sambar deer presence to LULC

In figure 22; the probability of occurrence of sambar deer gradually increases from east to west i.e. 0.51 and tends to decrease slightly in north side.

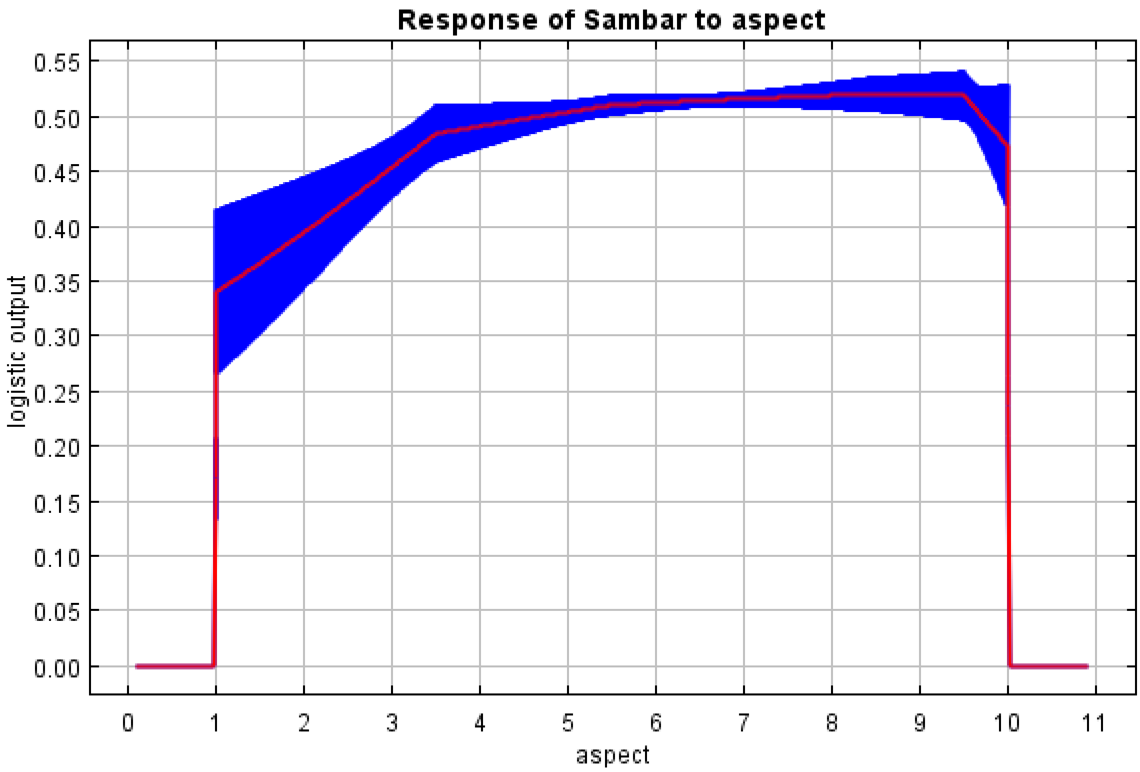


Figure 22: Response of Sambar deer presences to Aspect

Figure 23 shows the probability of sambar deer occurrence is higher around 300-450m i.e. 0.55 and tends to decrease continuously in higher elevation. Sambar Deer were anciently found down to 300m in Taiwan (Kano, 1940) and at lower elevation archaeological sites, the bone of sambar deer were found (Chen, 2000).

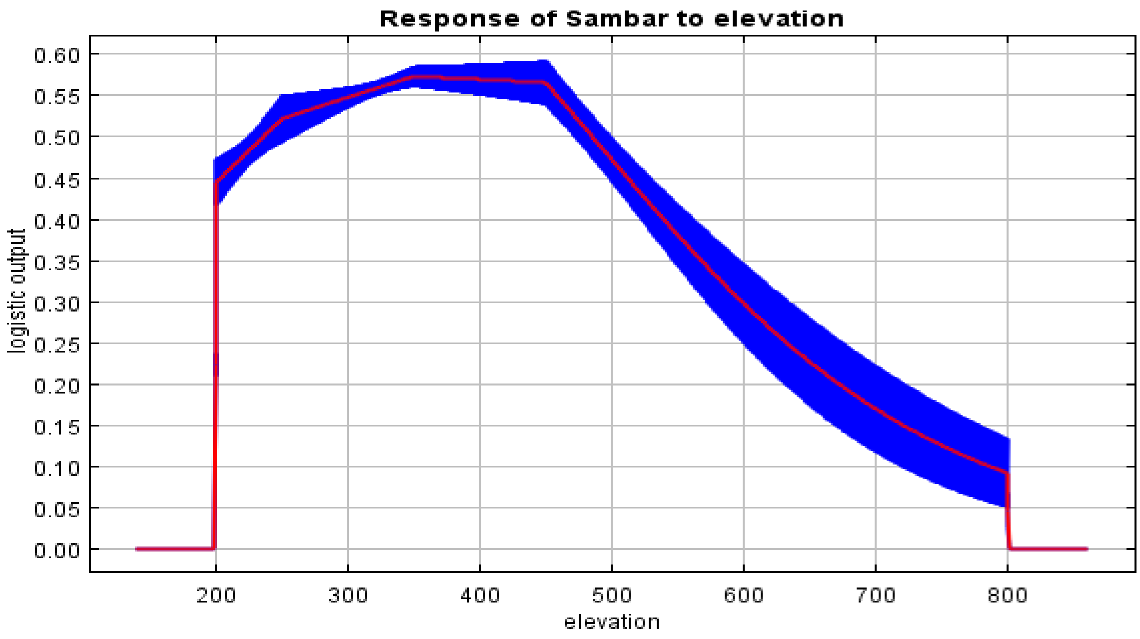


Figure 23: Response of Sambar deer presence to Elevation

Figure 24 shows the probability of sambar deer occurrence in forest cover where it starts increase from 0.31 and gradually increase up to 0.55 and then tends to decrease continuously up to 0.50. The curve shows occurrence of the species is maximum in dense forest in compared to sparse one. Sambar deer prefers the dense cover of deciduous shrubs and grasses (Geist, 1998).

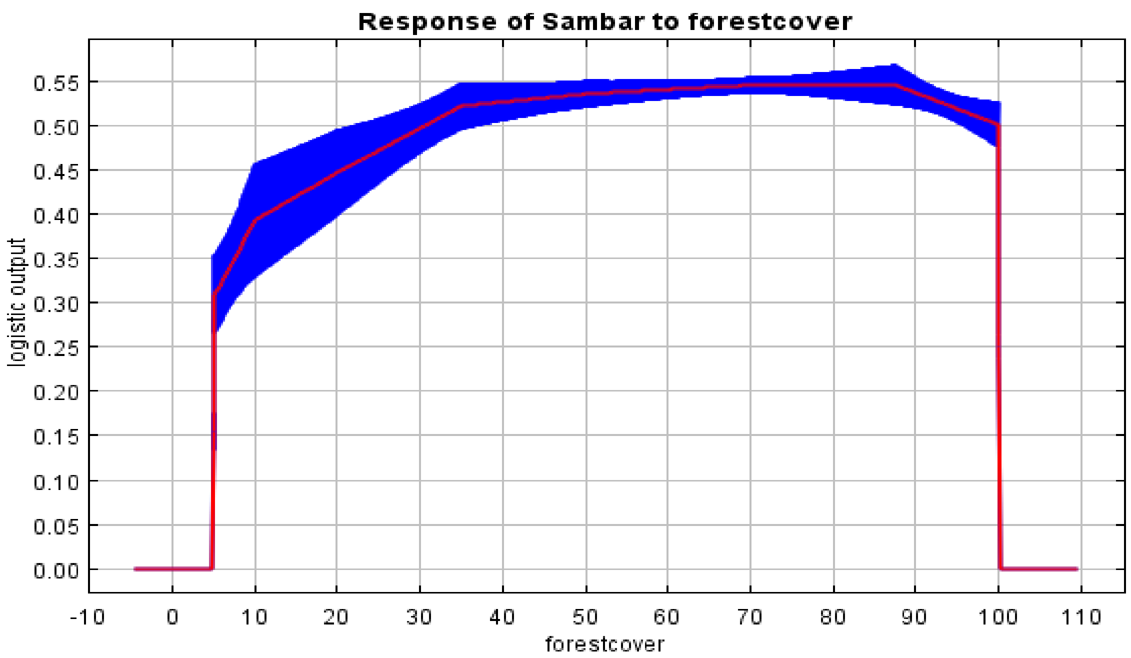


Figure 24: Response of Sambar deer presence to Forest cover

Figure 25 shows that the probability of sambar deer occurrence is the highest (0.61) in NDVI with high forest area i.e. 0.8.

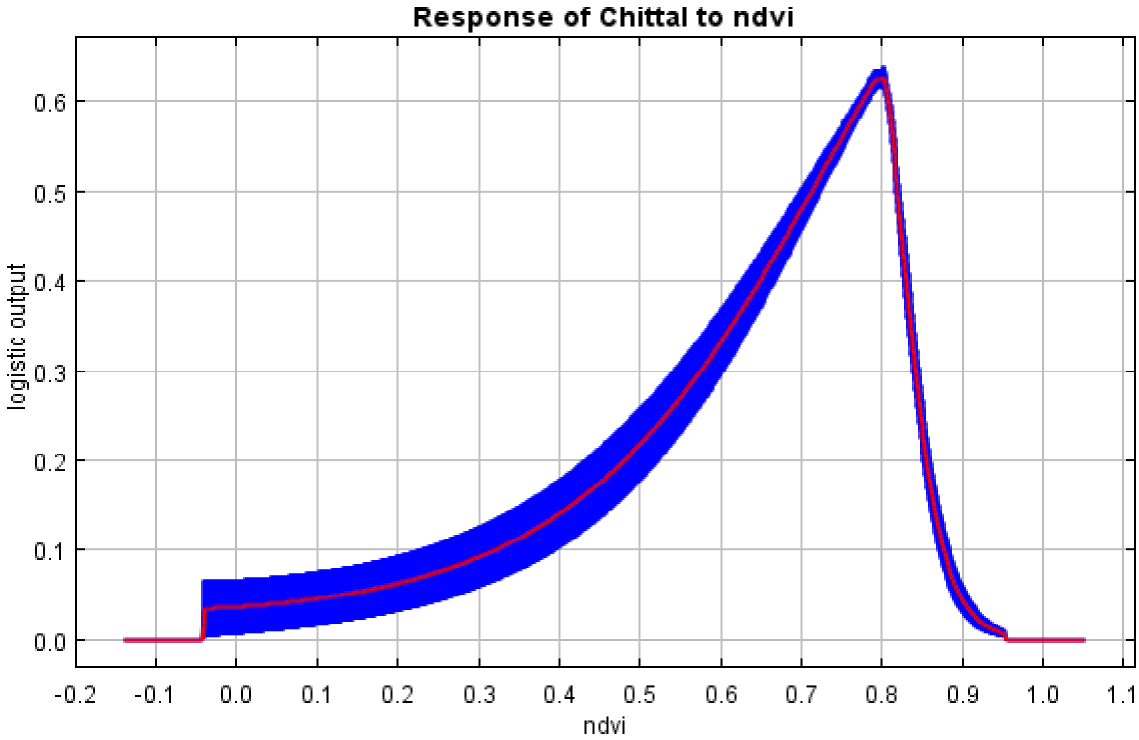


Figure 25: Response of Sambar deer presence to NDVI

In figure 26; the probability of sambar deer occurrence in "Distance from Path" where the deer occurrence gradually increases from 0.30 up to 0.51. The occurrence of sambar deer is not affected by path inside the park according to the shown curve.

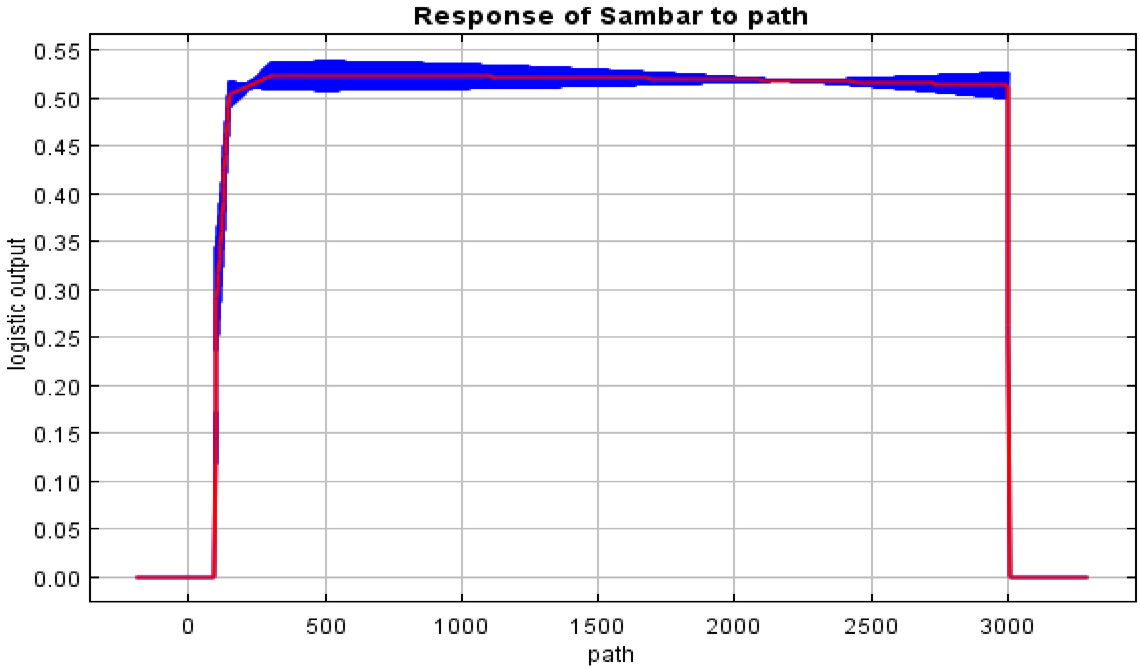


Figure 26: Response of Sambar deer presences to Distance from Path

Figure 27 shows, the probability of sambar deer occurrence in "Distance from Settlement" is high around 750m from settlement area i.e. 0.47, which again gradually increases to increasing distance from settlement. Few studies suggest, there was positive correlation between presence of mammals and distance from human settlements (Laidlaw, 2000; Oberosler et al., 2017).

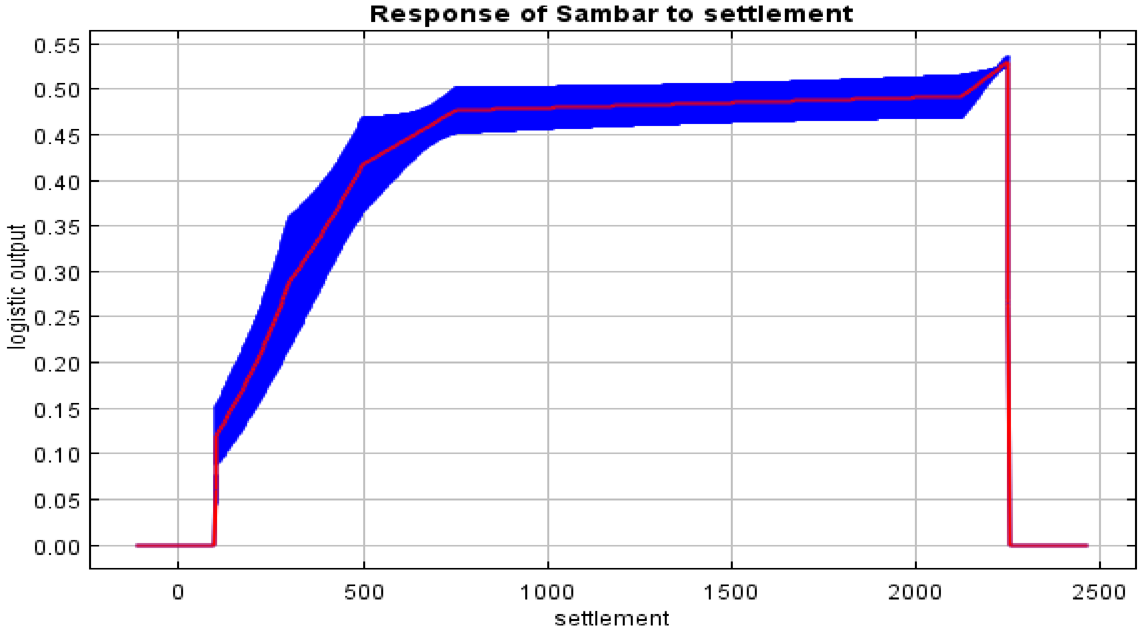


Figure 27: Response of Sambar deer presences to Distance from Settlement

The probability of sambar deer occurrence is higher in very gentle slope (0-5°) i.e. 0.54, which gradually decreases with the increase in slope angle. The present study shows more detection of both the deer species on flatter site. Taylor et al. (1972) states animal movement on steep slopes require energetic cost, so they avoid steep slopes.

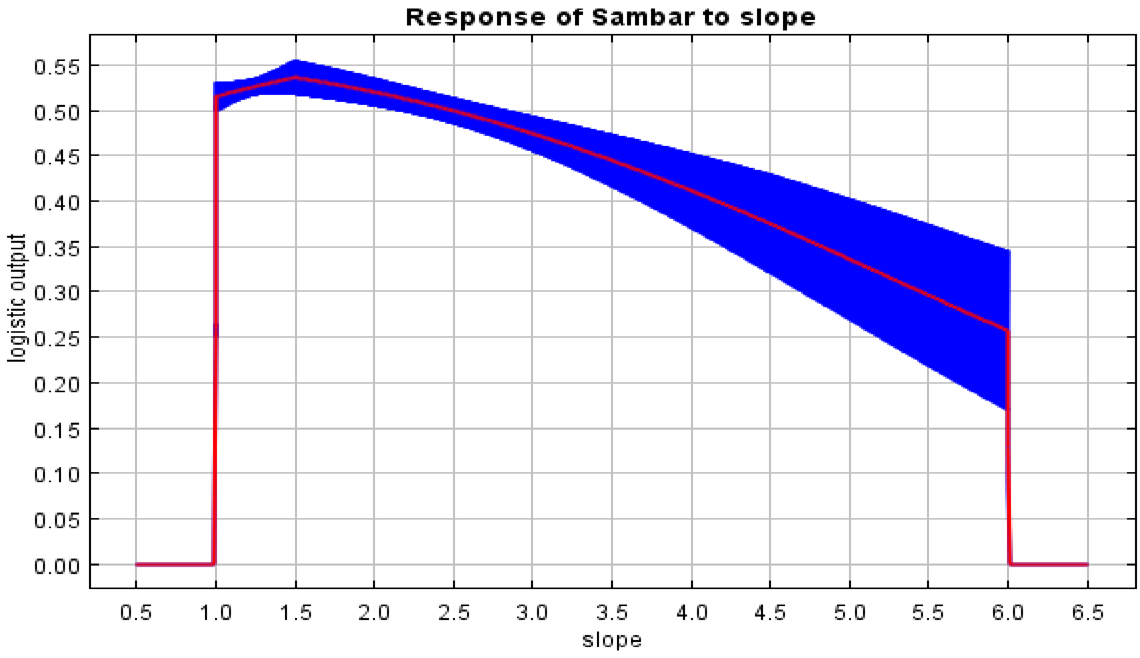


Figure 28: Response of Sambar deer presences to Slope

In figure 29; the probability of sambar deer occurrence in "Distance from Water" decreases from 0.46 to 0.40 and again tends to increase gradually with increase distance from water. Lindenmayer et al. (2015) suggest that the sambar deer could avoid streamside areas due to presence of largely unpalatable plant species characterized by the rainforest vegetation.

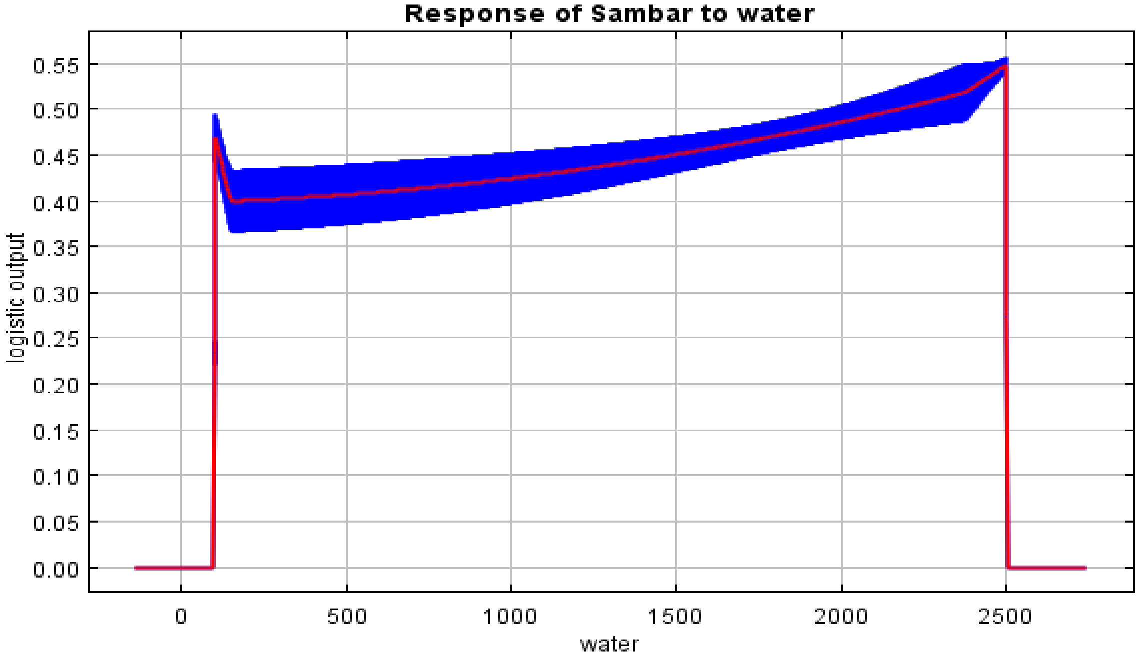
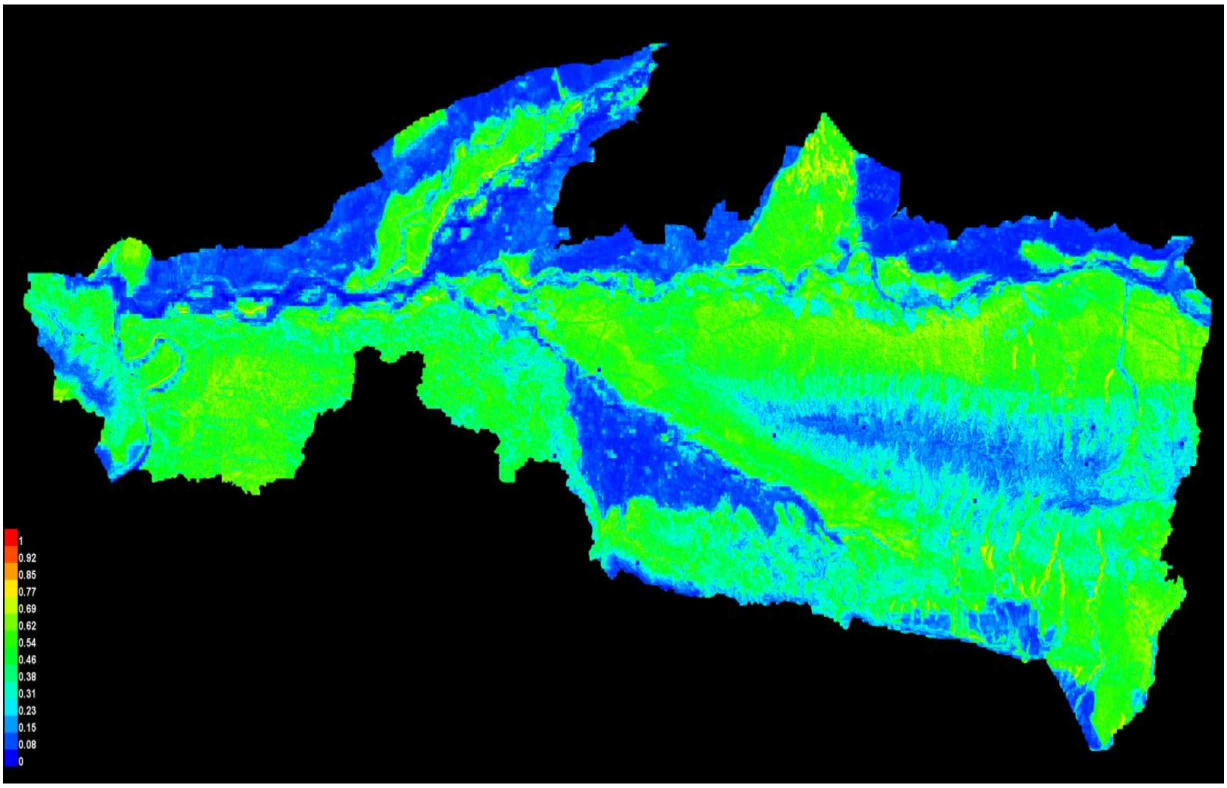


Figure 29: Response of Sambar Deer presences to Distance from Water

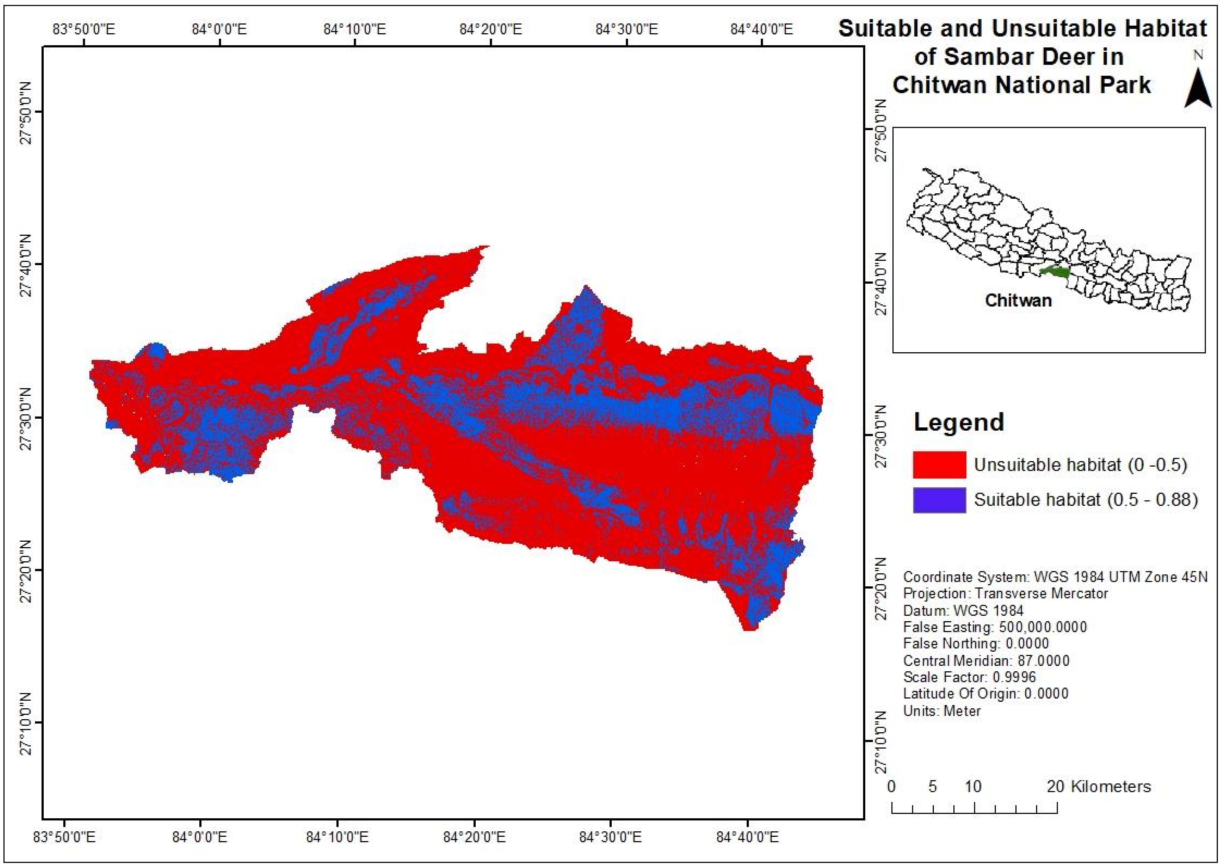
The above display response curve shows how each of the most important predictor variables distance affect the MaxEnt prediction. The response curve for the model showed fairly accurate trend for sambar deer suitability.

4.7.4 Habitat Suitability Map of Sambar Deer

Similar to spotted deer MaxEnt predicted map, it also uses colours that indicate predicted probability that conditions are suitable. Warmer colours (red) indicate high probability of suitable conditions for the species and blue indicates low probability. Therefore suitability map was reclassified into two classes; Suitable and Unsuitable. The Unsuitable category included the areas that have least probability for Sambar Deer to occur.



Map 13: MaxEnt Habitat Suitability Map of Sambar deer



Map 14: Habitat Suitability Map of Sambar deer in CNP

Table 9: Threshold used to predicted logistic output into classes for Sambar deer

Habitat Class	Probability Value
Unsuitable Habitat	0 - 0.5 (< 5)
Suitable Habitat	0.5 – 0.80 (> 5)

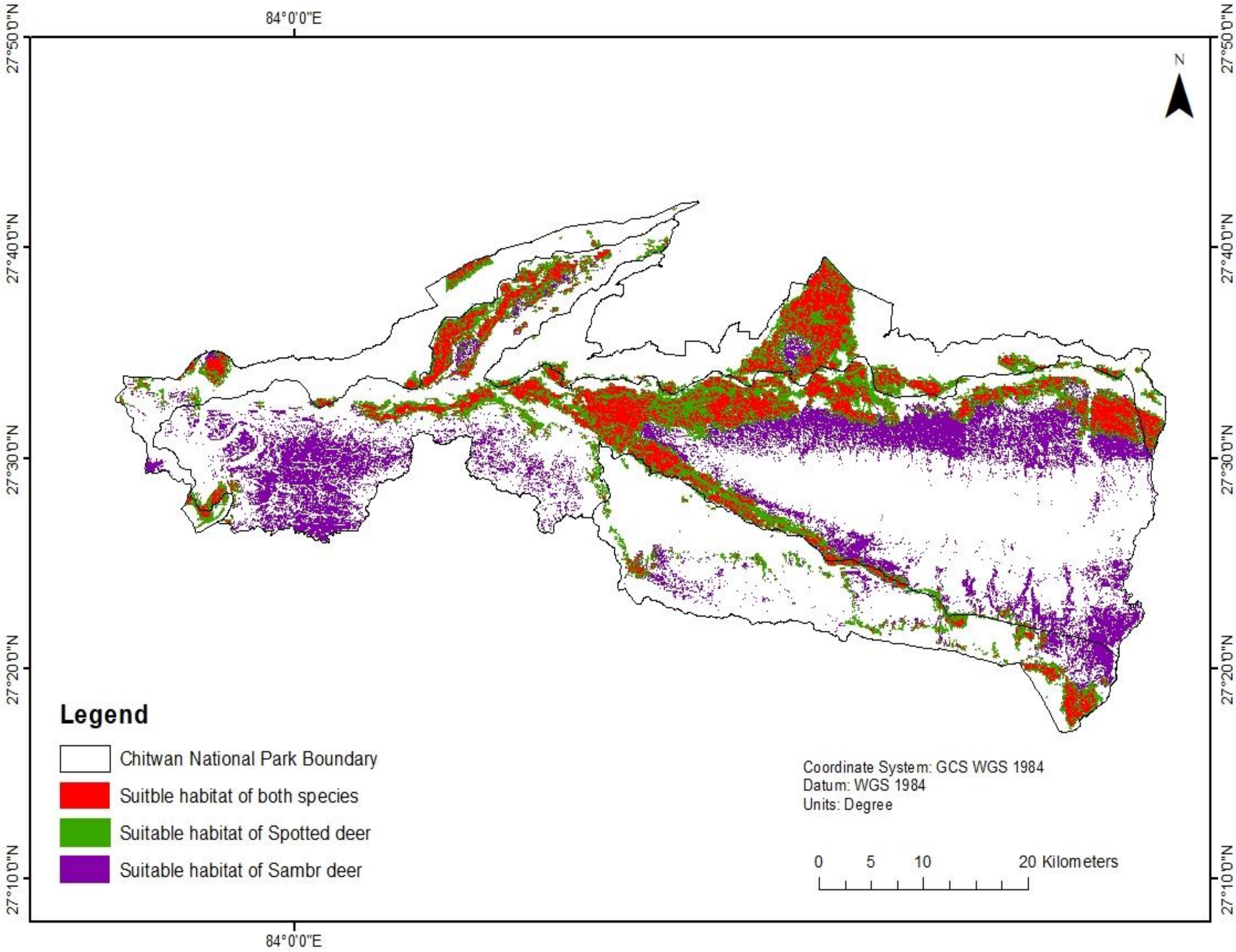
The map was categorized using the threshold 0 – 0.5 as unsuitable while from 0.5 – 0.80 as suitable habitat. The suitability of sambar deer in CNP are categorized (Table 9). The result of habitat suitability map shows that the total potential suitable habitat for sambar deer in CNP is 457.25km^2 while other remain unsuitable habitat for sambar deer of area 1484.23km^2 in CNP.

Table 10: Predicted Suitable and Unsuitable areas of Sambar Deer in CNP

Habitat Class	Area (km^2)
Unsuitable	1484.23
Suitable	457.25

4.8. Habitat Overlap

Study found 264.14km^2 of suitable habitat for spotted deer and 457.25km^2 of suitable habitat for sambar deer throughout the study area (Map 15). The study identified 172.13km^2 of overlapping habitat between the species, which constituted 65% of the habitat of spotted deer and 37% of the habitat of sambar deer. The AUC for the model of spotted deer (Mean AUC=0.756) which was quite good and the AUC for sambar deer (Mean AUC=0.678) which was moderate.



Map 15: Map of Habitat overlap between Spotted deer and Sambar deer

The majority of the study area is covered by trees (forest area), followed by farmland, shrub land, built area, water, bare ground, grass and flooded vegetation but the majority of both spotted deer and sambar deer habitat is covered by forest followed by, water, shrub, bare ground, grassland, farmland and built area (Table 11). Very small portions of habitat of both species fell on bare ground, built area, farmland and grassland, whereas there is not a single evidence of both species present in flooded vegetation.

Table 11: Habitat types covering suitable habitat of Spotted deer and Sambar deer

Land Use and Land Cover	Total Area(km^2)	Spotted deer habitat(km^2)	Sambar deer habitat(km^2)	Habitat of both species(km^2)
Water	57	3.14	1.61	0.56
Tree	1400	250.40	450.57	170.22
Grass	4	1.92	0.09	0.08
Flooded Vegetation	0.29	0.00	0.00	0.00
Farmland	270	0.17	0.13	0.03
Shrub/Scrub	106	7.17	2.08	0.80
Built Area	64	0.42	0.03	0.02
Bare Ground	39	0.67	2.74	0.34
Total	**1941**	**264.14**	**457.25**	**172.13**

Chapter-5: Discussion

Habitat overlap analysis comprises assessment of several dimensions, such as food, habitat, time and space. Although, this study has only considered two dimensions i.e. habitat and space, and evaluated the habitat overlap on the basis of suitable habitat of two sympatric deer species and their area extent. This study inspects the possibility of interspecies competition of spotted deer with sambar deer in CNP through determination of spatial habitat overlap. During field survey, seven types of habitat were found in CNP; including Sal Forest, Mixed Forest, Short Grassland, Tall Grassland, Riverine Forest, Pine Mixed Forest and Sal Mixed Forest. This study explores that the habitat selection and overlap among two sympatric ungulates not only depend on the habitat types but also on the environment variables associated with the habitats such as distance to waterhole, topographic features and anthropogenic disturbances (Wang et al., 2018). The study suggest; NDVI, lulc, forest cover, elevation and human settlement are the most effective environmental variable for predicting the distribution of the occurrence data of spotted deer and sambar deer. The majority of habitat overlap for spotted deer and sambar deer are found on forest land followed by, water, shrub, bare ground, grassland, farm land and built area. Here, the study shows 264.14km^2 of suitable habitat for spotted deer and 457.25km^2 of suitable habitat for sambar deer throughout the study area where, the overlapping habitat between the species was found to be 172.13km^2, which constituted 65% of the habitat of spotted deer and 37% of the habitat of sambar deer. Such overlap in space by sambar and spotted deer was also found by Pokhrel & Storch (2016) in open habitat during the dry season in Bardiya National Park (BNP). Some earlier studies suggest that resource partitioning occurs mainly at the diet level (Endo et al., 2017) but less at spatial level, however the resource competition are also possible to study in small-scale habitat use (Tobler et al., 2009).

In the study, presence of sambar deer were found to be maximum in forest area 450.57 km^2 whereas, that of spotted deer were minimum in forest area 250.40 km^2. Spotted deer is mostly associated with a mixed forest and more open grass along with shrub association (Graf and Nichols, 1966; Mishra, 1982). They were mostly recorded in the ecotones i.e. border between forest and grassland (Schaller, 1967; Eisenberg, 1981; Bagchi, 2001). Similarly, this study also found that spotted deer highly prefers shrub land and grass land in compared to sambar deer, which less preferred shrub land and grass land of total suitable area in CNP. Likewise, spotted deer is mainly a grazer in lowland Nepal, which also highly preferred fruits, leaves, and seedling from a wide variety of tree, shrub, and forb species (Dinerstein, 1982). Field data collection and study result shows both the species prefers same habitat of sal forest, sal mixed forest, mixed forest and riverine forest. The study shows sambar deer prefers dense shed forest area to light shed forest area (Geist, 1998) where, maximum spotted deer were found in open grassland and riverine forest area (Regmi et al., 2022) near the proximity of river area. Sambar deer were mostly occurred in the forested area (Schaller, 1967; Corbert & Hill, 1992). Likewise very few suitable habitat of both the species were found to be in area with high anthropogenic pressure i.e. built area and farmland. It shows there is less human pressure in suitable habitat of the selected deer species.

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Chapter -6: Conclusion

This study explored the possibility of interspecies competition of Spotted Deer with Sambar Deer in CNP through determination of spatial overlap. Their habitats were highly overlapped; indicating that they can co-exist in the same area especially in forest area followed by water, shrub, bare ground, grassland, farm land and built area. The study shows; NDVI, distance from settlement, forest cover, elevation and LULC are the most effective environmental variable for predicting the distribution of the occurrence of spotted deer and sambar deer in the study area. There has been very few scientific research conducted in CNP about habitat overlap between two sympatric ungulates on the spatial extent. Thus a detailed, scientific study of these species is very necessary in CNP. This could provide an estimation of the number of prey species and their suitable habitat to improve the population of endangered tiger in CNP. Although this study covers only one national park and its buffer zone, it is a first step in describing habitat overlap between the Spotted Deer and Sambar Deer and identifying their important habitat in landscape level.

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ANNEX I

Photo Plates of Field Activities


Pellets of Spotted deer


Spotted deer in their habitat


Hoof Marks of Sambar deer


Collecting sign in study site


Wastage materials on riverside