Borneo Journal of Resource Science and Technology (2022), 12(1): 166-176
DOI: https:doi.org/10.33736/bjrst.4422.2022

Geospatial Analysis of Habitat Suitability for Greater One-horned Rhino *Rhinoceros unicornis* (Linnaeus, 1758) in Central lowlands of Nepal using MaxEnt Model

SUNJEEP PUN[1], RAJEEV JOSHI*[2], RAJAN SUBEDI[3], SUMAN BHATTARAI[4] & BISHOW POUDEL[5]

[1]Tribhuvan University, Institute of Forestry, Pokhara Campus, Post Box No.43, Hariyokharka-15, Pokhara, Gandaki Province, Nepal; [2] Department of Forestry, Amity Global Education (Lord Buddha College), CTEVT, Tokha -11, Kathmandu-44600, Nepal; [3]Tribhuvan University, Institute of Forestry, Pokhara Campus, Post Box No.43, Hariyokharka15, Pokhara, Gandaki Province, Nepal; [4]Tribhuvan University, Institute of Forestry, Pokhara Campus, Post Box No.43, Hariyokharka15, Pokhara, Gandaki Province, Nepal; [5]Protected Area Management and Biodiversity Conservation, Institute of Forestry, Tribhuvan University, Kritipur-44618, Nepal
*Corresponding author: joshi.rajeev20@gmail.com
Received: 3 January 2022 Accepted: 9 June 2022 Published: 30 June 2022

ABSTRACT

The prime Greater One-horned Rhino's (*Rhinoceros unicornis*) habitats include a mosaic of grasses, oxbow lakes, *Shorea robusta* forests, and alluvial floodplains and the major habitat of this species is riverine grasslands dominated by *Imperata cylindrica* and riverine forests dominated by *Trewia nudiflora*. This study was mainly focused on the analysis of habitat suitability of *Rhinoceros unicornis* in Nawalparasi, Chitwan, and Parsa districts of Nepal. The secondary data such as bioclimatic and topographical variables were collected from relevant sources. Spatial data were processed using various tools of ArcGIS while the presence data were converted using Excel, and analysis was done with Maxent. The results showed that approximately 75.17% (53.32 sq. km) of suitable area is occupied by Chitwan National Park. Similarly, Barandabhar Corridor Forest occupies 7.38% (18.89 sq. km) of the suitable area of the landscape. While, there is no area suitable for Greater One-horned Rhinoceros in Parsa National Park. Among Land Use Land Cover (LULC), the riverbed was found to be the most important variable. Invasion of invasive plants was found to be the most frequent disturbance factor followed by human disturbances and forest fires. Though grassland management is an important part of habitat management, it is highly recommended that the management of waterholes should be done. Protected Area manager should conduct localised habitat suitability assessment once the area is found suitable at the landscape level and further field verification should be done. Invasive plant control measures and alternatives to meet the forest product demand should be promoted.

Keywords: Buffer zone, environmental layers, habitat threat, vegetation analysis

Copyright: This is an open access article distributed under the terms of the CC-BY-NC-SA (Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License) which permits unrestricted use, distribution, and reproduction in any medium, for non-commercial purposes, provided the original work of the author(s) is properly cited.

INTRODUCTION

The Greater One-horned Rhino (*Rhinoceros unicornis*) is a vulnerable species (Talukdar *et al*., 2008) widely distributed throughout the Brahmaputra, Indus, and Ganges plains of South Asia. However, indiscriminate poaching and unprecedented habitat loss nearly pushed them to extinction (Dinerstein, 2003; Harini *et al*., 2008). The main habitats of the rhinoceros include a mosaic of grasses, oxbow lakes, Sal (*Shorea robusta*) forests, and alluvial floodplains (Thapa *et al*., 2014); among these the most critical habitat is the riverine grasslands dominated by *Saccharum spontaneum*, 4-6 m height, which is a major forage plant. The rhinoceros also prefer the riverine forests that heavily dominated by *Trewia nudiflora*, *Etheria elliptica*, and *Bombax ceiba* during the cool season (November-February) and heavily browses understory shrubs and saplings (Gyawali, 1986). Dinerstein and Price (1991) divided Chitwan National Park into four blocks and studied demography and habitat use by the Greater One-horned rhino (GOh rhino), and found similar results "that density was positively correlated with the percentage of the blocks covered by *Saccharum spontaneum*". Only five subspecies of the rhinoceros are left in the world, three of them are found in Asia. In the early 1990s, GOh rhino was reported to be found in west Burma, several parts of India and Nepal

(Laurie, 1978), but at present this species exists in protected areas of India and Nepal (Jnawali *et al*., 2011). Until 1950s, over 800 rhinos lived in Chitwan valley alone, the valley and its rich biodiversity were protected by then ruling Rana regime for hunting purpose (Ghimire, 2020). The GOh rhino suffered a catastrophic decline in Nepal during 1960s, when government started Rapti-Dun Resettlement Program in Chitwan valley. Seventy percentages of the forests were cleared in Chitwan valley alone (Laurie, 1978; Dinerstein, 2003). According to recent report on national Rhino count in 2015, a total of 645 GOh rhino were recorded in Nepal including Parsa Wildlife Reserve (3 individuals), Chitwan National Park (605), Bardia National Park (29), and Shuklaphanta Wildlife Reserve (8). According to an assessment made by Talukdar *et al*. (2008), this subspecies was classified as vulnerable (VU) based on the parameters viz. population reduction, area of occupancy, and probability of extinction (Chakraborty, 2021).

The National Red List Series 2011 lists a total of 48 mammals under the IUCN (2013) threatened category including Greater One-horned Rhino categorised as nationally endangered (EN) under the C1 criterion because of its small populations fragmented and restricted in Chitwan National Park, Bardia National Park, and Shuklaphanta Wildlife Reserve (Jnawali *et al*., 2011). Similarly, the Convention on International Trade in Endangered Species of fauna and flora (CITES) listed this species in Appendix-1. This means they are threatened with extinction and CITES prohibits international trade in specimens of these species except when the purpose of the import is not commercial (CITES, 2017). This species has been listed as protected priority species in the National Park and Wildlife Conservation Act, 1973 (Annex – I of NPWC Act 1973). Therefore, it has become essential to develop species-specific habitat suitability maps. Satellite remote sensing and GIS (Geographic Information Systems) offer an opportunity to contribute knowledge about habitat, ecology, and conservation science (Thakur *et al.*, 2017). Focuses on five broad capabilities such as observation of habitat, analysis, and measurement of biological and physical variables, mapping condition of a specific area in a specific time, monitoring over time and space how features have changed in the past, and decision support using trend information derived from remotely sensed products (Horning *et al*., 2010). A niche-based model represents an estimation of a species' ecological niche in the examined environmental dimensions (Peterson, 2011). Species Distribution Models (SDMs) are often referred to as Ecological Niche Models which allow the assessment of the suitability of a given area for one or multiple species and provide important information on ecological factors determining species distributions (Sillero, 2011). The output of SDMs is increasingly used for multiple purposes, including the identification of conservation priorities, the prediction of species invasions, and analyses of the impact of environmental changes on biodiversity (Elith & Leathwick, 2009). There are a variety of techniques accessible to model species distribution: i) profile techniques, which require the presence of only data, environmental type of space inhabited by a species methods such as BIOCLIM, Surface Range Envelope (SRE), distance-based methods as DOMAIN, Ecological Niche Factor Analysis (ENFA), etc; ii) discriminative techniques, which require presence-absence data, General Linear Model (GLM), General Additive Models (GAM), Multivariate Adaptive Regression Splines (MARS), etc.; and iii) mix modelling approach which uses both techniques, Biomod, Generalized Regression Analysis and Spatial Prediction (GRASP), OpenModeller (Lazo, 2013). Moreover, SDM can also be classified by their algorithms as Regression methods such as GAM, GLM, and MARS; Machine-learning methods such as ANN, BRT, MaxEnt, and RF; Classification methods such as CTA and FDA; and Enveloping methods such as SRE and BIOCLIM (Hallgren *et al*., 2019).

MaxEnt was first proposed by Phillips *et al*. (2004) to study the problem of modelling the geographic distribution of a given animal or plant species. Hutchinson (1957) highlighted the importance of suitable habitat to save a threatened species; one first needs to know where the species prefers to live, and what its requirements are for survival, i.e., its ecological niche. Similarly, in Nepal, several studies have been carried out regarding species habitat suitability using MaxEnt (Bai *et al*., 2018). The habitat suitability for mammals, birds, vegetation, and even invasive plant species habitat analysis was previously conducted (Khadka & Pandey, 2014; Baidar *et al*., 2017;

Linshan *et al*., 2017; Acharya *et al*., 2018; Bista *et al*., 2018; Chhetri *et al*., 2018; Lamsal *et al*., 2018; Rana *et al*., 2018; Thapa *et al*., 2018). More specifically, Kafley *et al*. (2009) used data for MaxEnt modelling of species geographic distributions for predicting the probability of occurrence of rhinos in Chitwan National Park and found that the national park can sustain more individuals (then time individuals; 512). The Government of Nepal has expressed its commitment to increase the populations of rhinoceros and wild buffalo by 50 percent from the current 635 and 259, respectively by 2025 (NBSAP, 2014).

Loss of habitat connectivity can have a significant impact on wide-ranging species including GOh rhino and on the surrounding communities through compression effects and increasing human-wildlife conflict (Jnawali *et al*., 2011). Over the longer term, there will be a loss of genetic variation as subpopulations become increasingly isolated (GoN, 2015). Though there are various studies have been carried out on the habitat suitability of Greater One-horned Rhinoceros, this study focused on the habitat suitability mapping of this species outside protected areas i.e., Chitwan National Park. The main objective of the study was to analyse the habitat and geospatial analysis of environmental factors to determine the suitability of Greater One-horned Rhinoceros in forests outside the protected area in the Chitwan district of Nepal.

MATERIALS AND METHODS

Study Area

The southern part (South to Churia hill) of Nawalparasi, Chitwan, and Parsa districts of Nepal were selected (Figure 1). Landscape-level habitat suitability map was prepared using Greater One-horned Rhinoceros presence data (direct sighting) which was collected from National Rhino Count report (2015). The landscape covers Chitwan National Park (CNP) which harbors the highest number of Greater One-horned Rhinoceros in Nepal, Barandabhar Corridor Forest (BCF), Parsa National Park (PNP), and adjoining forest areas. The landscape has a remarkable history in the conservation of Greater One-horned Rhinoceros in Nepal. In 1963, south of Rapti River was demarked as Rhino Sanctuary. Only in 1973, it was gazetted as the first national park of the country with the coordinates 27.5341° N and 84.4525° E and also included in UNESCO World Heritage Site in 1984.

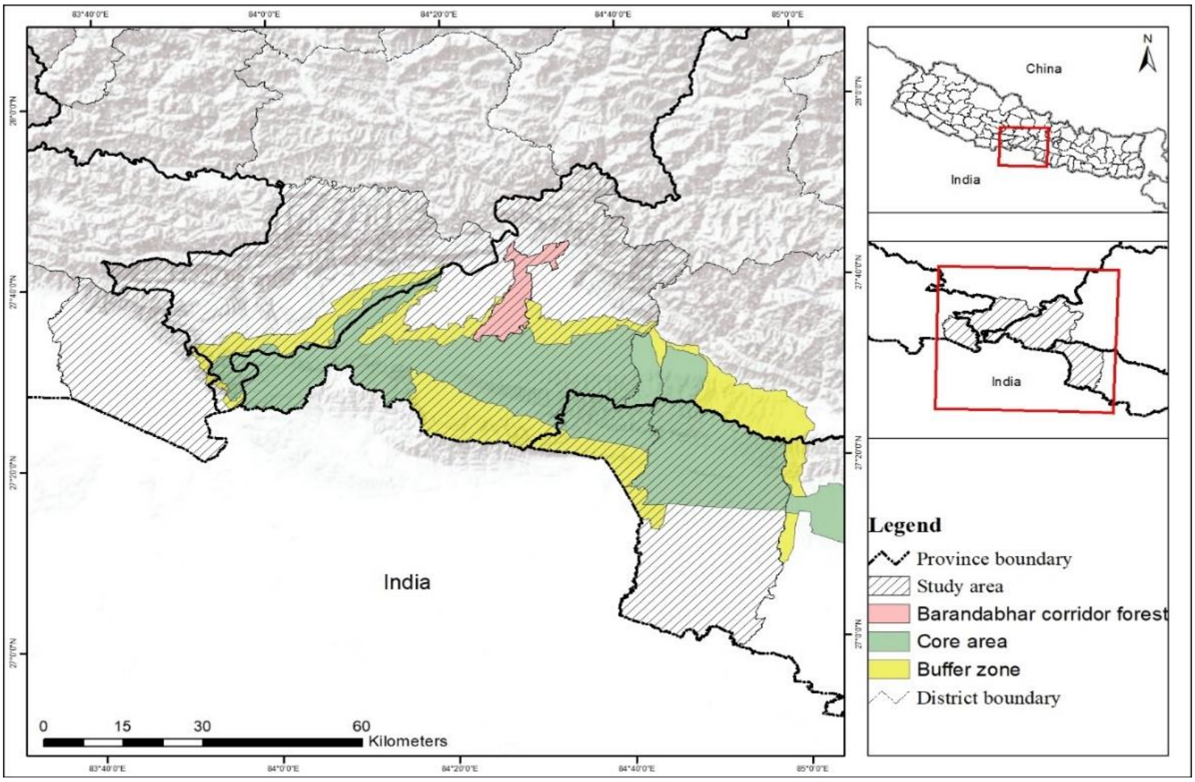

Figure 1. Map showing study area and landscape

Data Used

A number of variables i.e., topographical variable (Digital Elevation Model (DEM), slope, and aspect), bioclimatic variable (*worldclim*), land-use land cover, waterbody, road, and riverbeds were used in this study. Table 1 gives a brief description of the input variables used for MaxEnt suitability prediction.

Table 1. List of input variables before processing

S.N.	Layer Name	Spatial Resolution	Pixel Depth	Spatial data Type	Projection System	Source
1	Presence data			xlsx	UTM 45N	Field visit/NRC 2015
2	District boundary			Polygon/Line	WGS 84	ICIMOD
3	PAs Boundary			Polygon/Line	WGS 84	ICIMOD
4	Settlement			Point	WGS 84	ICIMOD
5	Southern side of Chure hill			Polygon/Line	WGS 84	PCTMCB
6	Land use			Polygon	WGS 84	PCTMCB
7	Water bodies			Polygon	WGS 84	Land use
8	River Beds			Polygon	WGS 84	Land use
9	DEM	30	16 bit signed	Grid	WGS 84	ASTER
10	Slope	30	8 bit signed	Grid	WGS 84	DEM
11	Aspect	30	16 bit signed	Grid	WGS 84	DEM
12	Climate	1K	16 bit signed	Grid	WGS 84	Worldclim

Topographical Variables

The Digital Elevation Model (DEM) shows an array of elevations of the land surface at each spatial location (*i*, *j*). Terrain visualisation using satellite images in association with DEMs has long been explored as a promising tool in environmental studies. This data layer was downloaded from earthexplorer.usgs.gov/ which was used for the generation of elevation, slope, and aspect. Similarly, slope represents the rate of change of elevation for each DEM cell. It is the first derivative of a DEM.

The slope was derived from the ASTERGTM using spatial analysis tool of ArcGIS desktop. For the purpose of habitat suitability analysis, the generated slope was reclassified into five classes. Aspect is the direction towards which the slope is facing. It was derived using the "spatial analysis" tool of ArcGIS desktop and further reclassified into five classes (flat, northern, eastern, southern, and western). Bioclimatic variables are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. Several studies have highlighted strong relationships between species abundance and bioclimatic variables (*current version 2.0*) (Phillips *et al*., 2006; Jeschke & Strayer, 2008). In this study, 19 bioclimatic layers were used which were acquired from worldclim website http://worldclim.org/. This scheme follows that of ANUCLIM, except that for temperature seasonality the standard deviation was used because a coefficient of variation does not make sense with temperatures between -1 and 1 (worldclim.org).

Land Use and Land Cover (LULC) databases can distinguish a large number of classes, and it is not always easy to identify a priori how many (and which) land use categories are actually relevant and should be included in the analyses. Relevant land use classes should be included in the analysis but there are limited guidelines for SDMs at the landscape level. The land use and land cover map were acquired from President Chure Terai-Madhesh Conservation Board (PCTMCB). Altogether 61 presence data were collected during field visits around the study area. In addition to field data, 607 sighting data of the 2015 National rhino count was also incorporated for the purpose of running the MaxEnt model.

Software and Tools Used

The various software and tools such as ArcGIS 10.5, Microsoft Office Suite 2013, Google Earth Pro, and MaxEnt 3.4.1 (prediction mapping) were used for the processing of the data depending on its nature. Input variables were processed with relevant software to make them readable to MaxEnt Model (Table 2). Presence data were converted to Comma Separated Value (CSV) using MS Excel 2013. Presence data collected were in WGS UTM format which was plotted and transformed to WGS 1984 (DD) using ArcGIS data management tools. After the transformation attributes were exported to MS Excel 2013 and converted to CSV format. All the grid format and shapefile format variables were exported to ArcGIS and processed using ArcGIS 10.5 model builder. For the processing of grid format, data management tool was used. Vector (shapefile) format data were processed in ArcGIS model builder using data management and conversion tools.

Table 2. List of input variables after processing

S.N.	Layer Name	Spatial Resolution (M)	Pixel Depth (Radiometric Resolution)	Spatial Data Type	Projection System	Variable
1	Presence Data			CSV	WGS 84	
2	District boundary			Polygon/Line	WGS 84	
3	Southern side of Chure hill			Polygon/Line	WGS 84	
4	Settlement	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
5	Land use	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
6	Water bodies	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
7	River Beds	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
8	DEM	30	16 bit unsigned	GeoTIFF	WGS 84	Continuous
9	Slope	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
10	Aspect	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
11	Water bodies	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical
12	Climate	30	16 bit unsigned	GeoTIFF	WGS 84	Categorical

MaxEnt

All the processed variables were then imported to the MaxEnt model for the prediction of the probability of distribution of Greater One-horned Rhinoceros both at the landscape level and localised level. At landscape-level distribution prediction, 607 direct sightings during National Rhino Census 2015 were used whereas at localised level distribution prediction 61 sign records collected during the field visits were used. The sample requires a presence point (CSV format) directory while an environmental layer takes environmental variables (ASCII format). The create response curves, pictures of predictions, and jackknife test were used to check and measure the importance of variables and finally, the output format was chosen for logistics.

A total of 15 random partitions of the occurrence localities were made in order to assess the average behavior of the algorithms (via Wilcoxon signed-rank tests). Each partition was created by randomly selecting 70% of the occurrence localities as training data, with the remaining 30% reserved for testing the resulting models. There is a risk of over prediction or under prediction of the relationship by the model if the model doesn’t have enough time to converge. To avoid this maximum number of iterations increased to 5000 (where it is 500 by default). The algorithms were run with two sets of habitat sites; first at the landscape level in which presence points (direct sighting) were extracted from National Rhino Count 2015, second at the localised level in which presence points (direct sightings and signs) were collected during a field visit by the researcher himself.

RESULTS

Analysis of Omission/Commission

Figure 2 shows the test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.

ROC/AUC

Figure 3 shows the receiver operating characteristic (ROC) curve for the same data, again averaged over the replicate runs. Note that the specificity is defined using predicted area, rather than true commission. The average test AUC for the replicate runs is 0.958, and the standard deviation is 0.003.

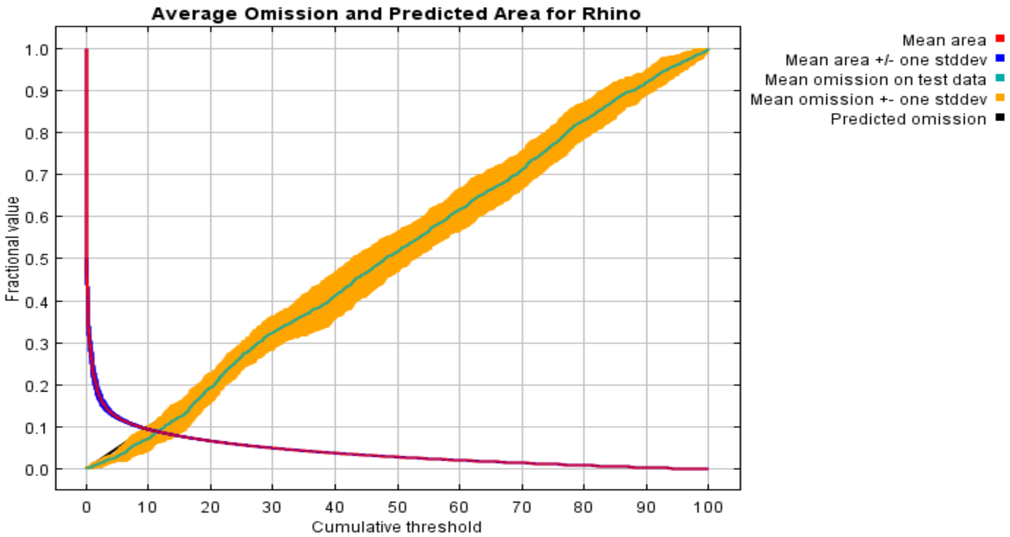

Figure 2. Analysis of omission

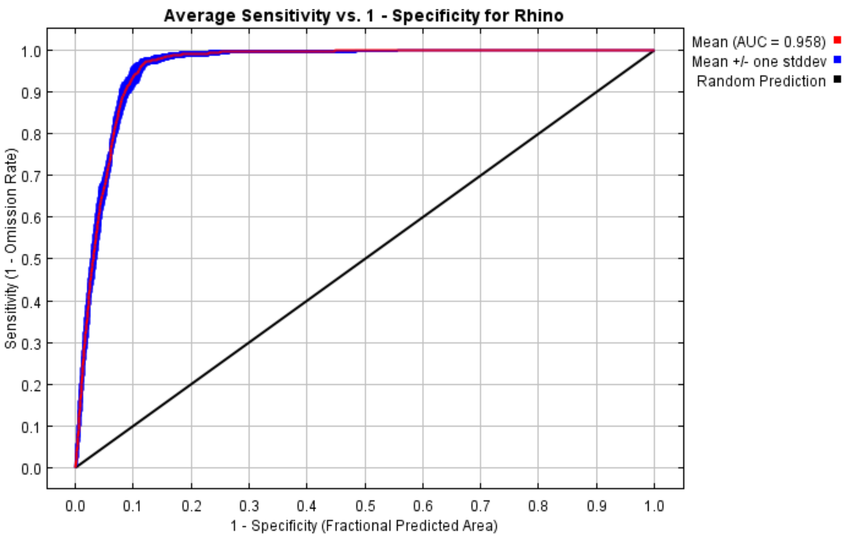

Figure 3. AUC curve for suitability modelling

Suitability Map

Figure 4 shows the probability of the occurrence of Greater One-horned Rhinoceros generated by the MaxEnt model, the probability of the occurrence range between 0 (represented by blue color) to 1 (represented by red color) (Figure 4). Further, the data was processed in ArcGIS to produce a binary map using 10 percentile training presence logistic thresholds i.e., the area below 0.3211 probability is unsuitable (Figure 5). Out of the total area (4720.75 sq. km.) of the landscape, only 5.42% (256.03 sq. km.) area was found to be suitable whereas 94.58% (4464.72 sq. km.) area was found to be non-suitable.

Approximately, 75.17% (53.32 sq. km.) of the suitable area is occupied by Chitwan National Park. Similarly, Barandabhar corridor forest occupies 7.38 % (18.89 sq. km.) of the suitable area of the landscape. While there is no area suitable for Greater One-horned Rhinoceros in Parsa National Park (Figure 5).

Figure 6 shows the results of the jackknife test of variable importance. The environmental variable with the highest gain, when used in isolation, is elevation, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is Land Use Land Cover (LULC), which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over replicate runs.

Figure 7 shows that, among LULC, variable 3 (riverbed) was the most important variable for the model followed by variable 6 (bush/grass) and variable 1 (waterbody). The curve reflects the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. The curves show the mean response of the 15 replicate MaxEnt runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables).

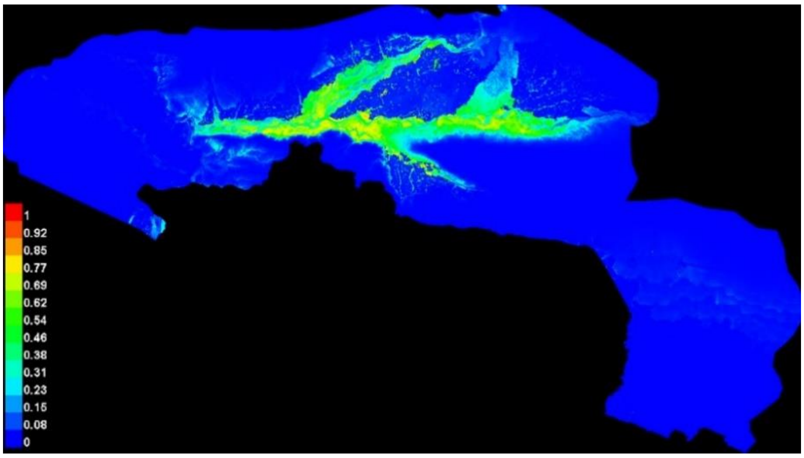

Figure 4. MaxEnt suitability map at landscape level

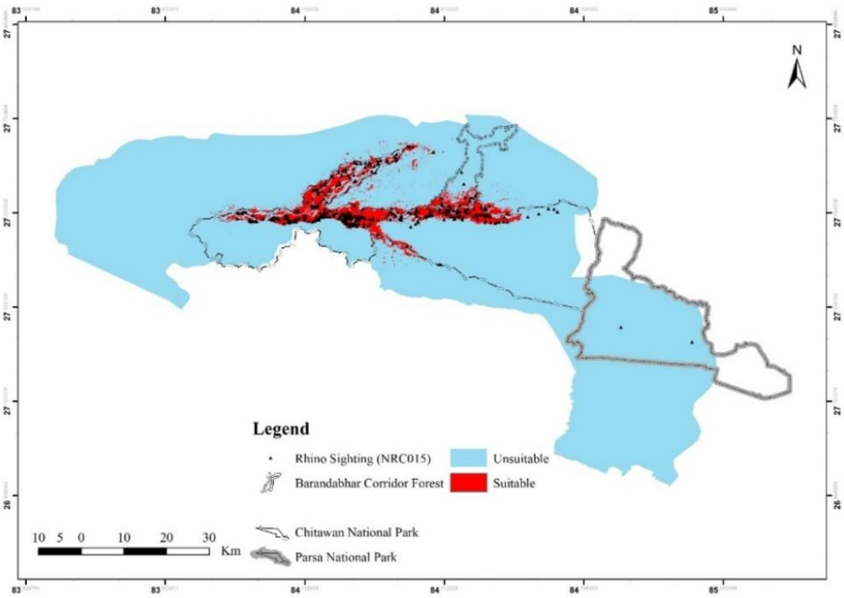

Figure 5. Map showing habitat suitability and PAs

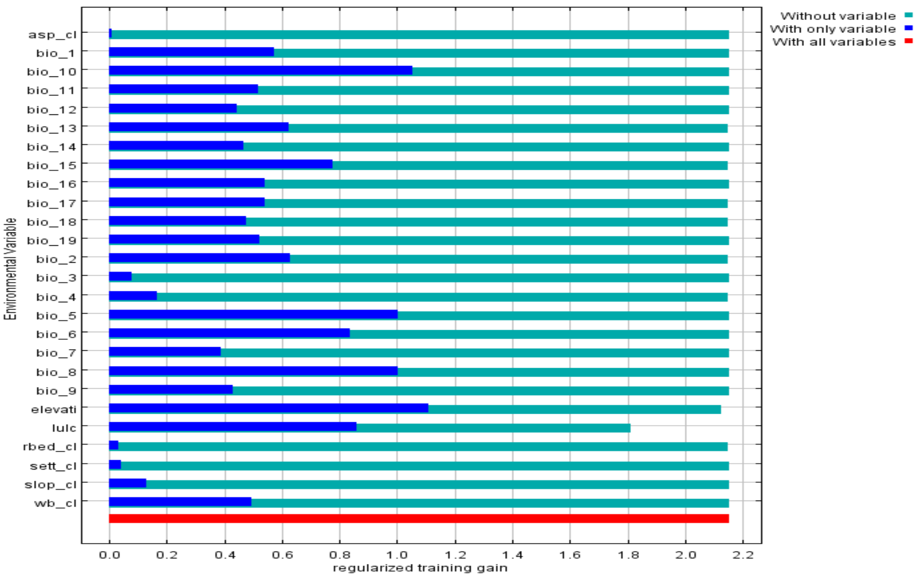

Figure 6. Jackknife test of importance of variable in model

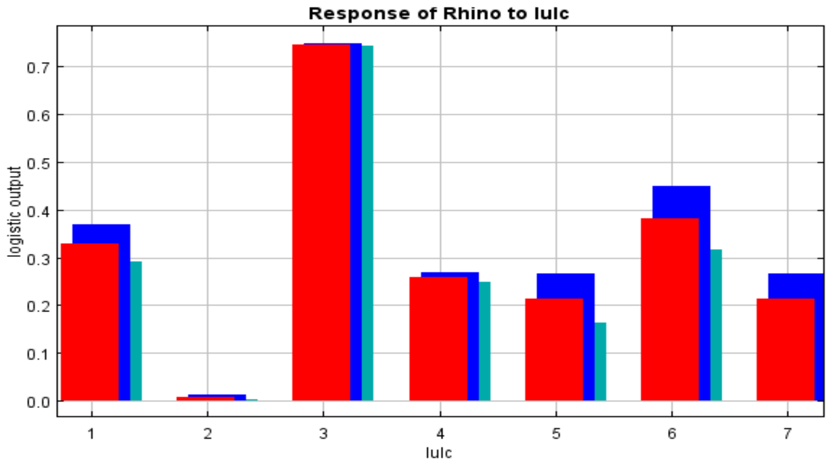

Figure 7. Landscape level LULC response curve

For each environmental variable, a response curve is created. Response curves show how the variables affect the MaxEnt prediction, which indicates the values of each variable that is suitable.

DISCUSSION

Results showed that there is no significantly suitable habitat exists in Parsa National Park (PNP). The result is similar to National Rhino Count Report 2015. This is because PNP covers drier areas of fragile Churia hills and Bhabar, which is unsuitable for Greater One-horned Rhinoceros. The report also stated that some good habitats have been created within the park after the relocation of settlements. The most contributing variables are LULC and Wb_Cl (waterbody classified as 500 m buffer, 1000 m buffer, and area farther than 1000 m) which are similar contributing variables. Bio_6 is the third most contributing variable which is a minimum temperature of the coldest month. Many researchers did use conventional radio-telemetry and GPS collars to study habitat use but they focused mainly on finding the mean annual home range, habitat preference, seasonal distribution, and feeding habits (Laurie, 1982; Dinerstein & Price, 1991; Subedi, 2017). Therefore, the study of the effect of edge on a rhino movement is still deficient and such studies could provide vital information about the distribution and movement of a rhino within its suitable habitat and its influence on its behavior due to adjoining unsuitable habitat - an open area for future study.

The highest frequency of occurrence of the disturbance in the study area is invasive species followed by other human disturbances and forest fire. The study area is contiguous to CNP which is severely affected by the invasion of *Mikania micrantha* and *Chromolaena odorata*. Another major disturbance observed is other human disturbances which include road trails, foot trails, and noise produced by nearby settlement. Because the study area and nearby CNP is a Greater One-horned Rhinoceros hotspot highly recognised around the world. A high number of foreign and national tourists come to the area to see the species in its natural habitat. Major activities preferred by tourists are jungle walks, jeep safari, and elephant rides around the protected area. This compels tourism entrepreneurs to construct and manage the trails to satisfy tourists' needs. Nowadays, elephant rides, jeep safari, and jungle walk activities are frequent in the buffer zone and BFC. Even the buffer zone management committee has registered their own bill/receipt to allow the tourists to visit their area.

CONCLUSION

The habitat suitability map was prepared using MaxEnt using presence point based on direct sighting and other bioclimatic variables showed only 5.42% of the total study area are suitable for Greater One-horned Rhinoceros at the landscape level. A large portion of the suitable area lies in Chitwan national park followed by Barandabhar forest corridor. Whereas the model showed that Parsa National Park did not occupy any suitable area for greater one-horned rhinoceros. Land use land cover was found to be the most important environmental factor among the others in determining the habitat as suitable for the rhino. Elevation if alone was used for the suitability mapping, would have contributed the most. The model also depicted that the riverbed followed by the bushland and waterbody respectively were the best habitat for the greater one-horned rhinoceros. This proved that the other land uses despite the riverbeds and grasslands are also important components in the habitat management for the rhino.

ACKNOWLEDGEMENTS

We are grateful to the Department of National Park and Wildlife Conservation (DNPWC), and the Department of Forest and Soil Conservation (DoFSC) for permitting us to conduct this research. The author(s) would like to express sincere thanks to Mr. Abhinaya Pathak, Mr. Nurendra Aryal and Mr. Buddhan Chaudhary of Chitwan National Park for their untiring support during this field visit.

REFERENCES

Acharya, B.K., Cao, C., Xu, M., Khanal, L., Naeem, S. & Pandit, S. (2018). Present and future of dengue fever in Nepal: Mapping climatic suitability by ecological niche model. *International Journal of Environmental Research and Public Health*, 15(2): 187. DOI: https://doi.org/10.3390/ijerph15020187

Bai, D.F., Chen, P.J., Atzeni, L., Cering, L., Li, Q. & Shi, K. (2018). Assessment of habitat suitability of the snow leopard (*Panthera uncia*) in Qomolangma National Nature Reserve based on MaxEnt modelling. *Zoological Research*, 39(6): 373. DOI: 10.24272/j.issn.2095-8137.2018.057

Baidar, T., Shrestha, A.B., Ranjit, R., Adhikari, R., Ghimire, S. & Shrestha, N. (2017). Impact assessment of *Mikania micrantha* on land cover and MaxEnt modelling to predict its potential invasion sites. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42: 305.

Bista, M., Panthi, S. & Weiskopf, S.R. (2018). Habitat overlap between Asiatic black bear *Ursus thibetanus* and red panda *Ailurus fulgens* in Himalaya. *PloS ONE*, 13(9): e0203697. DOI: https://doi.org/10.1371/journal.pone.0203697

Chakraborty, S.K. (2021). Diversity and conservation of wildlife associated with rivers: An eco-ethological analysis. In *Riverine Ecology Volume 2*. Switzerland, Cham: Springer. Pp. 287-441.

Chhetri, P.K., Gaddis, K.D. & Cairns, D.M. (2018). Predicting the suitable habitat of treeline species in the Nepalese Himalayas under climate change. Mountain Research and Development, 38(2): 153-163. DOI: https://doi.org/10.1659/MRD-JOURNAL-D-17-00071.1

CITES (2017). *Convention on International Trade in Endangered Species of wild fauna and flora*. 17th Meeting of the Conference of Parties. Johannesburg (South Africa) (2016). https://www.cites.org/eng/app/appendices.php [Accessed on 1 February 2020].

Dinerstein, E. (2003). *The Return of the Unicornis: The Natural History and Conservafion of the Greater One-horned Rhinoceros*. *Biology and*

Resource Management Series. Washington DC: World Wildlife Fund. Pp. 320.

Dinerstein, E. & Price, L. (1991). Demography and habitat use by greater one-horned rhinoceros in Nepal. *The Journal of Wildlife Management*, 55(3): 401-411. DOI: https://doi.org/ 10.2307/3808968

Elith, J. & Leathwick, J.R. (2009). Species distribution models: Ecological explanation and prediction across space and time. *Annual review of Ecology, Evolution, and Systematics*, 40: 677-697.

Ghimire, P. (2020). Conservation status of Greater One-horned Rhinoceros (*Rhinoceros unicornis*) in Nepal: A review of current efforts and challenges. *Grassroots Journal of Natural Resources*, 3(1): 1-14. DOI: https://doi.org/10 .33002/nr2581.6853.03011

GoN (2015). Nature Conservation National Strategic Framework for Sustainable Development (2015-2030). *National Planning Commission*. Singha Durbar, Kathmandu.

Gyawali, S.R. (1986). *Diet analysis of greater one-horned rhinoceros by fecal analysis* (Doctoral dissertation), Tribhuvan University Kathmandu, Nepal. Pp.34

Hallgren, W., Santana, F., Low-Choy, S., Zhao, Y. & Mackey, B. (2019). Species distribution models can be highly sensitive to algorithm configuration. *Ecological Modelling*, 408: 108719. DOI: https://doi.org/10.1016/j.ecol model.2019.108719

Harini, N., Pareeth, S., Sharma, B., Schweik, C.M. & Adhikari, K.R. (2008). Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology*, 23: 41-54. DOI: https://doi.org/10.1007/s10980-007-9162-y

Horning, N., Robinson, J.A., Sterling, E.J., Spector, S. & Turner, W. (2010). *Remote sensing for ecology and conservation: a handbook of techniques*. Oxford University Press.

Hutchinson, G.E. (1957). Concluding remarks. Cold Spring Harbor Symposia on Quant. Biol. 22: 415-427. 1959. Homage to Santa Rosalia or why are there so many kinds of animals? *The American Naturalist*, 93: 145-159.

Jeschke, J.M. & Strayer, D.L. (2008). Usefulness of bioclimatic models for studying climate change and invasive species. *Annals of the New york Academy of Sciences*, 1134(1): 1-24. DOI: https://doi.org/10.1196/annals.1439.002

Jnawali, S.R., Baral, H.S., Lee, S., Acharya, K.P., Upadhyay, G.P., Pandey, M. & Amin, R. (2011). *The Status of Nepal's Mammals: The National Red List Series-IUCN*. Kathmandu: Department of National Parks and Wildlife Conservation. Pp. 276.

Kafley, H., Khadka, M. & Sharma, M. (2009). Habitat evaluation and suitability modelling of *Rhinoceros unicornis* in Chitwan National Park, Nepal: a geospatial approach. In *XIII World Forestry Congress. Buenos Aires, Argentina*.

Khadka, K.K. & Pandey, R. (2014). Changes in the distribution of lesser adjutant storks (*Leptoptilos javanicus*) in south and southeast Asia: A plausible evidence of global climate and land-use change effect. *International Journal of Zoological Research*, 10(1): 9.

Lamsal, P., Kumar, L., Aryal, A. & Atreya, K. (2018). Future climate and habitat distribution of Himalayan Musk Deer (*Moschus chrysogaster*). *Ecological Informatics*, 44: 101-108. DOI: https://doi.org/10.1016/j.ecoinf .2018.02.004

Laurie, A. (1982). Behavioural ecology of the greater one-horned rhinoceros (*Rhinoceros unicornis*). *Journal of Zoology*, 196(3): 307-341. DOI: https://doi.org/10.1111/j.1469-7998.1982.tb03506.x

Laurie, W.A. (1978). *The ecology and behaviour of the Greater One-horned Rhinoceros* (Doctoral dissertation), University of Cambridge.

Lazo, J.D., van Gils, H., Groen, T. & Navarro-Cerrillo, R. (2013). *Transferability of species distribution models: A case study of the fungus Phytophthora cinnamomi in andalusia and Southwest Australia*. University of Twente Faculty of Geo-Information and Earth Observation (ITC).

Linshan, L., Zhilong, Z., Yili, Z. & Xue, W. (2017). Using MaxEnt model to predict suitable habitat changes for key protected species in Koshi Basin, Central Himalayas. *Journal of Resources and Ecology*, 8(1): 77-87. DOI: https://doi.org/10. 5814 /j.issn.1674-764x.2017.01.010

NBSAP (2014). National Biodiversity Strategy and Action plan 2014. *Ministry of Forests and Soil Conservation*, Government of Nepal.

Peterson, A.T. (2011). Ecological niche conservatism: A time-structured review of evidence. *Journal of Biogeography*, 38(5): 817-827. DOI: https://doi.org/10.1111/j.1365-2699.2010.02456.x

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190(3-4): 231-259. DOI: https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S.J., Dudík, M. & Schapire, R.E. (2004). A maximum entropy approach to species distribution modelling. In *Proceedings of the twenty-first international conference on Machine learning*. Pp. 83. DOI: https://doi.org/10.1145/1015330.1015412

Rana, S.K., Rana, H.K., Shrestha, K.K., Sujakhu, S. & Ranjitkar, S. (2018). Determining bioclimatic space of Himalayan alder for agroforestry systems in Nepal. *Plant Diversity*, 40(1): 1-18. DOI: https://doi.org/10.1016/j.pld.2017.11.002

Sillero, N. (2011). What does ecological modelling model? A proposed classification of ecological niche models based on their underlying methods. *Ecological Modelling*, 222(8), 1343-1346. DOI: https://doi.org/10.1016/j.ecolmodel.2011.01.018

Subedi, N., Lamichhane, B.R., Amin, R., Jnawali, S. R. & Jhala, Y.V. (2017). Demography and viability of the largest population of greater one-horned Rhinoceros in Nepal. *Global Ecology and Conservation*, 12: 241-252. DOI: https://doi.org/10.1016/j.gecco.2017.11.008

Talukdar, B.K., Emslie, R., Bist, S.S., Choudhury, A., Ellis, S., Bonal, B.S., Malakar, M.C., Talukdar, B.N. & Barua, M. (2008). *Rhinoceros unicornis*. In: IUCN 2012. IUCN Red list of threatened species. Version 2012.2. www.iucnredlist.org.

Thakur, J.K., Singh, S.K. & Ekanthalu, V.S. (2017). Integrating remote sensing, geographic information systems and global positioning system techniques with hydrological modeling. *Applied Water Science*, 7(4): 1595-1608. DOI: https://doi.org/10.1007/s13201-016-0384-5

Thapa, S., Chitale, V., Rijal, S.J., Bisht, N. & Shrestha, B.B. (2018). Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PloS ONE*, 13(4): e0195752. DOI: https://doi.org/10.1371/journal.pone.0195752

Thapa, V., Acevedo, M.F. & Limbu, K.P. (2014). An analysis of the habitat of the greater one-horned Rhinoceros *Rhinoceros unicornis* (Mammalia: Perissodactyla: Rhinocerotidae) at the Chitwan National Park, Nepal. *Journal of Threatened Taxa*, 6(10): 6313-6325.