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Maxent Modelling for Predicting the Spatial Distribution and Habitat Suitability of Long-billed Vulture *Gyps Indicus* (Scopoli, 1786) in Arunachal Pradesh, India

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Abstract Vultures are ecologically important primarily because of their scavenging role in cleaning carcasses of the environment. The Long-billed vulture *Gyps indicus* has suffered catastrophic declines in parts of its range and, thus, information about its global distribution and factors influencing its occurrence within this range are essential for its conservation. To this end, we estimated the spatial distribution of Long-billed vulture (LBV) and variables affecting this distribution. We used occurrence points (n = 10) from field survey conducted during 2016-2018 and past records and available literature, environmental variables related to these sites and Maximum Entropy (MaxEnt) software to predict the distribution of this species and its relationship to environmental variables. Out of ~82167.58 km^2 study area, the LBV had a predicted range of 1856.79 Km^2 i.e. 2.26 % of study area. The district with densest potential distribution was in East Siang, followed by Namsai, Lower Dibang Valley and a scanter potential distribution was around lower part of Papumpare, Changlang, and areas adjacent to the boundaries of neighboring state Assam. Elevation was related to the vulture's most probable range: in particular higher temperature and low precipitation were important variables regardless of the season of observations examined. Conservation of identified habitats and mitigation of anthropogenic impacts are recommended for immediate and long-term conservation of the LBV in Arunachal Pradesh, India.

Keywords: *vultures, habitat, MaxEnt, environmental variables, conservation*

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1. Introduction

Long-billed vulture (LBV) *Gyps indicus* is an old world vulture with a long robust neck, a strong bill a rounded crown and regal aquiline bearing. LBV is listed as critically endangered by IUCN, as it suffered catastrophic decline of population of over 97% in the wild. The past record shows that occurrence of LBV has been reported from different parts of Arunachal Pradesh (A.P) namely Namsai, Papumpare, East Siang and Daying Ering Memorial Wildlife Sanctuary [1,2,3]. A.P considers as biological frontier and mostly an unexplored land in terms of wildlife is located in North-East India within the North-Eastern Himalayan biodiversity hotspot and eastern edges lies in the confluence of Eastern Himalayan, Indo –Malayan & Mountain of South West China biodiversity hotspot [4,5]. Due to the rough terrain, high unexplored forest areas, high altitudinal gradient, unpredictable climatic condition and poor road connectivity across the state, there is very limited past research work in vultures which is not enough to study the distribution and ecology of vultures in A.P. An efficient solution to this issue is the use of species distribution models (SDMs), i.e. mathematical models for estimating species distributions based on the recorded presence of focal species and the environmental and/or spatial characteristics of potential sites [6]. Maximum Entropy (MaxEnt) model is a popular type of SDM which can perform spatial prediction modeling and estimate the potential geographic distributions of a species across the landscape based on the relationship between the species occurrence data and environmental variables [7]. MaxEnt requires a proper distribution of occurrence points in the ecological space rather than the geographical space [8,9]. The advantages of MaxEnt are that it offers acceptable results even with a limited available sample size [10] and is also capable of projecting shifts in species distribution under various climate change scenarios [11,12,13] and thus extensively used for calculating potential species distributions of plants and animals for many purposes in biogeography, conservation biology and ecology [14,15]. The species occurrence sites are regarded as suitable habitat to meet species' ecological requirements which are taken as the reference data for the favourable environmental variables determining the occurrence of the species. These data are used by MaxEnt to calculate the constraints and explores the possible distribution of maximum entropy under this constraint condition, and then predicts the habitat suitability of the species at the study area [10,16]. Thus, the objectives of this research work are to construct a spatial distribution map and habitat suitability areas of LBV in A.P using MaxEnt modeling prediction. The study will also identify the key environmental factors influencing the distribution ranges. The findings will facilitate the formulation of appropriate conservation measures for LBV in A.P in near future.

2. Materials and Methods

2.1. Study Area

The study area i.e. Arunachal Pradesh (A.P) lies between 26^0 28'N and 29^0 30'N latitude and 91^0 20'E and 97^0 30' longitude and has 83,743 Km^2 area in the extreme North-Eastern part of India (Figure 1). Nestled amid the foothills of the Shivalik ranges the topography in A.P is characterized and marked by lofty hill slopes, sparsely populated mountainous area, enchanting river valleys, and majestic peaks. The forest types can be divided into tropical rainforests, subtropical, temperate forests and alpine meadows and its unique location at the junction of the Eastern Himalaya and Indo-Burma bio geographical zones has contributed to the rich bio-diversity the state [17]. A.P can be divided into 3 major climatic zones- (i) The hot–humid subtropical climatic zone (ii) The cooler or Micro-thermal climatic zone. (iii) The Himadri or Alpine type climate zone, which shows variation in the climatic and geographical topography in the state [18]. Topographically, the average elevation gradient ranges from 97m to 6629m (based on SRTM Digital Elevation Model). The temperature ranges from -19.25° - 28.5°C (WorldClim). In proportion to the altitude, the weather of A.P differ i.e. areas at higher altitude experience tundra climate, areas at lesser elevation enjoy temperate weather, and sea-level areas experience a sub-tropical climate. Precipitation in the state generally follows the wet-dry monsoon pattern where the annual rainfall ranges from 8 mm to 2078 mm (WorldClim).

2.2. Species Occurrence Data

The three year field survey for the study of distribution of Long-billed vulture was conducted between January 2016- December 2018 in A.P. 14 routes of maximum 100 km for each route were laid on the state's motor able roadways (Figure 1) for which Road count method [19] was used to record vulture presence data. Addition to it, the line transect method [20] was used to record the occurrence of vultures in protected areas of the state. The surveys were carried out between 0800 hours to 1600 and the coordinates of LBV occurrence points and the coordinates of survey areas were recorded by using GPS device Garmin Montana 680. Since the study also aims to predict the habitat suitability of LBV in the state; occurrence records of LBV from past records [1,2,3] were also taken into consideration. A total of 10 georeferenced points (occurrence points of LBV) were taken. For better accuracy and precision of MaxEnt modelling, filtering of occurrence points was done by using "Spatially rarefy occurrence data for SDMs" tool from the SDM Toolbox in ArcMap in which points with distances less than one km between the two points were removed randomly [21].

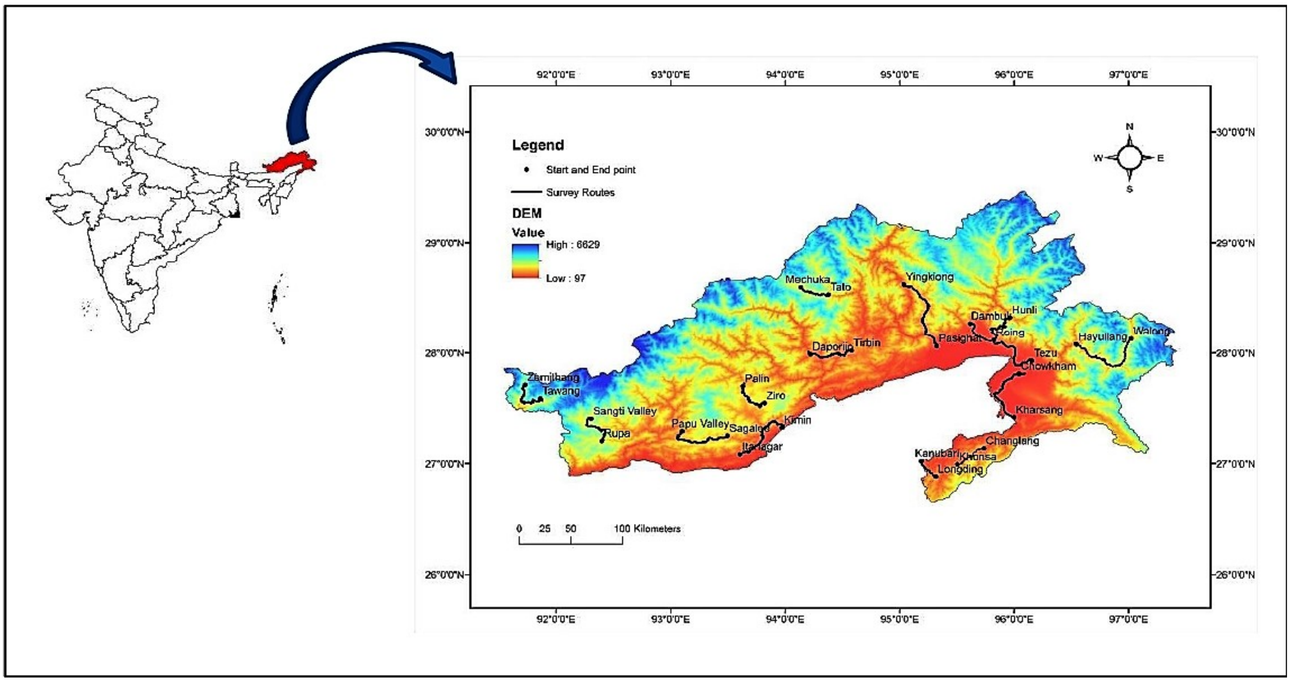

Figure 1. Study Area- Digital Elevation Model (DEM) and Surveyed routes

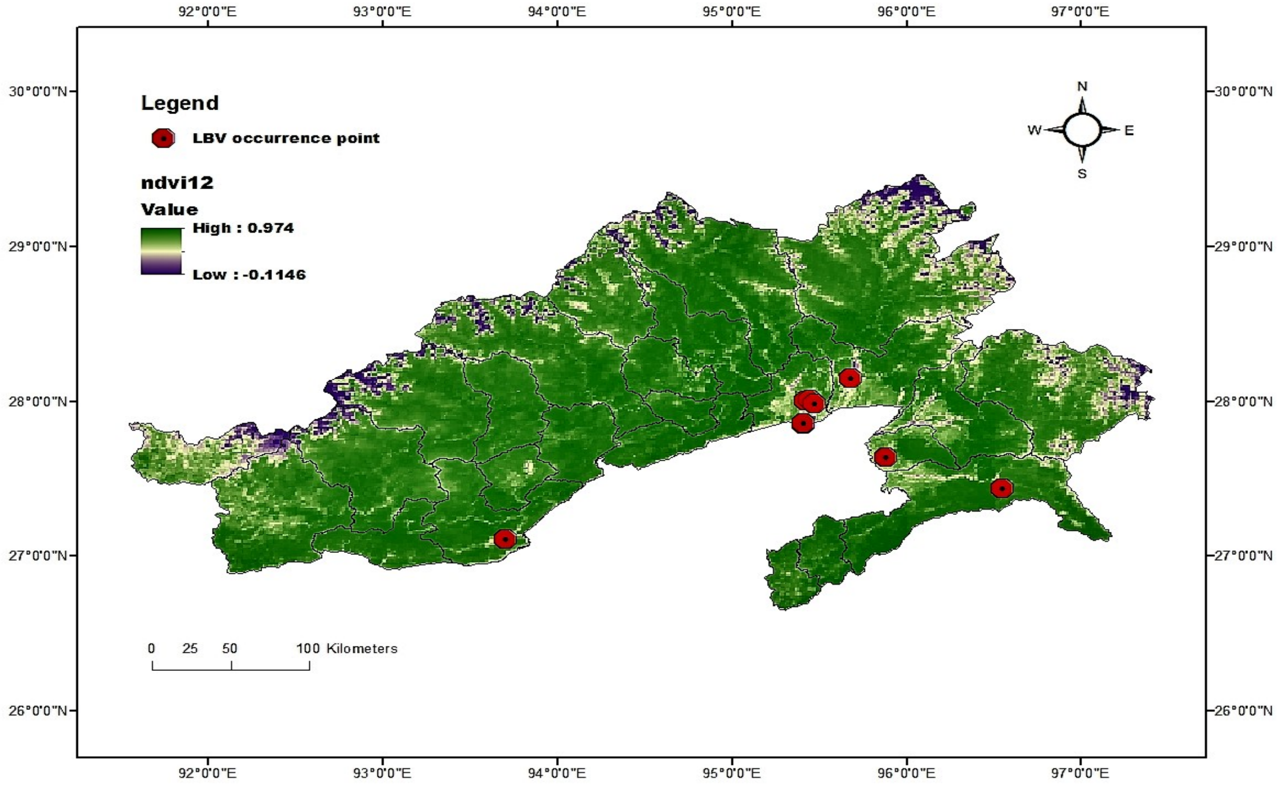

Figure 2. Study Area: - Occurrence Point and Normalized Difference Vegetation Index (NDVI) for the month of December 2018

2.3. Environmental Variables and Processing

Bioclimatic data on temperature and precipitation were procured using WorldClim data [22] which provides the averaged weather data over 30 years (1970 to 2000). For the data on vegetation cover, Normalised Differentiated Vegetation Index (NDVI) [23] was used. For elevation data, Digital elevation model (DEM) data was downloaded using SRTM data [24]. Land use Land cover (LULC) data were procured from ESRI [25]. The LULC data is comprised of 10 components (Table 1).

Table 1. List of LULC Components

S. No	LULC components
1	River
2	Trees
3	Grass
4	Flood vegetation
5	Crops
6	Shrubs
7	Built Area
8	Bare Area
9	Snow/Ice
10	Clouds

For this study, we used four bioclimatic variables, two NDVI data; one DEM data and one LULC data for running MaxEnt modeling. The downloaded Bioclim data file had “0.0083333333 x 0.0083333333” cell size spatial resolution and “GCS_WGS_1984” projection. The NDVI data had spatial resolution of “926.6254331 x 926.6254331” and “sinusoidal grid” projection. DEM layer had a resolution of “0.00027777778 x 0.00027777778” and “GCS_WGS_1984”. The NDVI and DEM layers were resampled to “0.0083333333 x 0.0083333333” spatial resolution and GCS_WGS_1984 projection to match the resolution of bioclimatic variable layers. For DEM, 19 separate tiles of elevation data were laid to cover the study area. Two tiles of LULC layers were laid to cover the study area of “10 x 10” spatial resolution with “WGS_1984_UTM_Zone” projection. The LULC layer projection was also resampled to “0.0083333333 x 0.0083333333” spatial resolution by using “GCS_WGS_1984”. Finally, all the layers were masked to shapefile of the study area and were converted to “ascii” file. The processing of data was done using ArcMap 10.4.

2.4. MaxEnt Modelling

MaxEnt was chosen for the present study to predict habitat suitability of LBV in A.P. This algorithm is highly précis and seems to outperform other modeling methods in quality and predicting power when there is limited information on geographic records [26]. The output quality of MaxEnt depends on the optimization in different parameters of MaxEnt settings [27]. Therefore, in MaxEnt interface, five characteristic parameters (linear, quadratic, product, threshold, and hinge features) are combined. Output format was set to “Cloglog”. Regularization multiplier set to 4, random test percentage set to 25%, maximum iteration set to 5000 times and bootstrap replication with 10 repetitions was used. Jackknife analysis was used to analyze the contribution rate and importance of environmental variables. Area Under the Receiver operating characteristic curve (AUC) (threshold independent) was used to evaluate the accuracy of the model.

3. Results and Discussion

3.1. Model Performance

We evaluated the accuracy of the predicted model using AUC. AUC with higher values than 0.5 shows that the model is good and that significantly differs from randomly predicted one. The average AUCs of habitat suitability of LBV in A.P after 10 repetitions are $AUC_{training}$ = 0.989 (Figure 3) and AUC_{test} = 0.952. This indicates high accuracy of the prediction model.

3.2. Prediction of Habitat Suitability and Spatial Distribution of LBV in A.P

To build the habitat suitability map maximum test sensitivity plus specificity cloglog threshold of 0.37 was used as the suitability threshold. The habitat suitability was reclassified into four classes: unsuitable (< 0.37), lowly suitable (0.37 - 0.6), moderately suitable (0.6 - 0.8) and highly suitable (> 0.8) (Figure 4). The result show that out of total area of 82167.58 $Km^{2,}$ 267.95 Km^2 i.e. 0.33 % falls under highly suitable habitat area, 422.23 Km^2 i.e. 0.51% falls under moderately suitable habitat area and 1166.61 Km^2 i.e. 1.42% falls under lowly suitable habitat area for the distribution of LBV in A.P. Further 80310.79 Km^2 i.e. 97.74 % of the total area is predicted as unsuitable habitat area for the distribution of LBV in A.P (Table 2). The interpretation of MaxEnt output predicts the spatial distribution of LBV in all lower altitude regions near the border of Assam. Most possible occurrence areas for LBV are predicted in East Siang, Lower Dibang valley, Namsai, some part of Changlang and Papumpare districts.

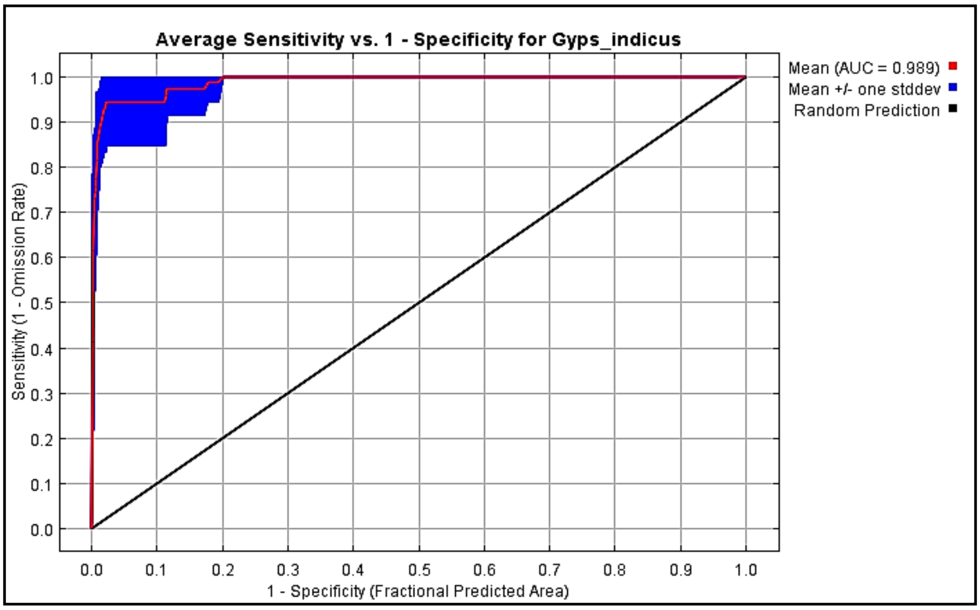

Figure 3. AUC result of training model prediction

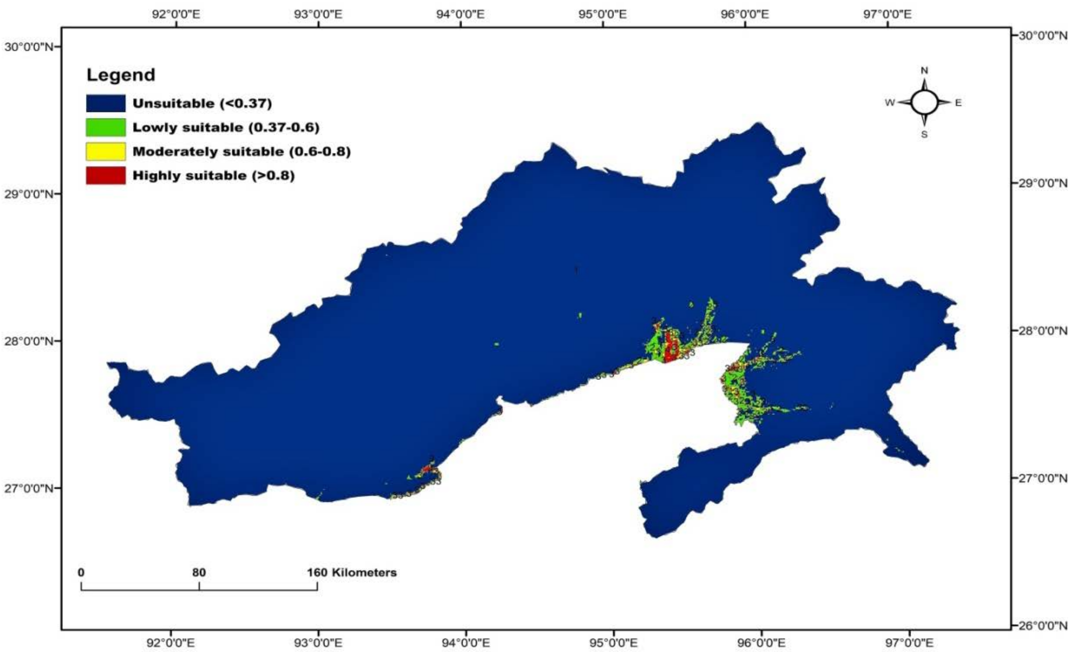

Figure 4. Prediction of spatial distribution and habitat suitability of LBV by MaxEnt in A.P

Table 2. Habitat class determining the suitable area for distribution of LBV in A.P

Habitat class	Area in Km^2	Area in %
Unsuitable	80310.79	97.74
Lowly Suitable	1166.61	1.41
Moderately Suitable	422.23	0.52
Highly Suitable	267.95	0.33
Total	82167.58	100

3.3. Influence of Environmental Variables

The contribution table of MaxEnt output indicated that the DEM (59.6 %) has the highest influence on distribution of LBV, followed by LULC (13%), Bio16 (9.5%), NDVI12 (7.6 %), Bio17 (6.9%), Bio10 (6%), NDVI06 (4.8%) and lastly Bio11 (1.1%) (Table 3). According to the Jackknife analysis, variables that had a moderate or least impact on model training gain are Bio16 and NDVI06 (Figure 5). DEM has the highest regularized training gain when used alone to train the model (Figure 5).

This is the first attempt to describe the spatial distribution of the LBV and the factors related to this distribution in A.P. The result show that the potential habitat suitability mostly lies at the area with lesser vegetation cover, foothill and areas at lower altitude. The MaxEnt Modeling predicted that most of the part of A.P is not suitable for the occurrence of LBV. Only 1856.79 Km^2 i.e. 2.26 % of total areas are falling under the suitable habitat category. Such sparsely potential distribution area of LBV in A.P is seems to be highly influence by the environmental variables like climatic factors, landscape pattern and anthropogenic disturbance. This can be understood by the response curves developed by MaxEnt output (Figure 6). The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The output result shows that vultures prefer lower elevation with elevation range of 90-200 metre, regions with higher temperature with temperature range of above 28^0 C during warmest quarter of the year and 18^0 C in coldest quarter of the year. Also the favourable NDVI value lies between range of 0.1-0.5 for both months of June and December. Areas with NDVI value between ranges of 0.3-0.4 shows highly suitable whereas areas with NDVI value of below 0.1 and above 0.5 shows unsuitable habit for vulture distribution. LULC output predicts that built area and bare area are the highest influential and trees and snow areas are the least influential habitat variables in that effecting the distribution of LBV.

According to Birdlife International, LBV is a Critically Endangered vulture whose population has been declining rampantly across the globe. Understanding a species distribution and the factors affecting its distributional patterns always play an essential role for effective conservation planning [28]. To date, the ecological biogeography of LBV i.e. spatial distribution, habitat suitability and factors affecting it, have never been examined in the past in A.P. This research work is the first attempt to address these objectives at local scales and thus will facilitate in effective management and development of conservation strategies of LBV in A.P.

Table 3. Eight environmental variables of the study area

Variables	Description	Percent contribution	Permutation importance
dem	Representation of elevation data	59.6	30.1
lulc	Land covers classes' data	13.0	1.6
bio16	Precipitation of Wettest quarter	9.5	44.4
ndvi12	Vegetation cover index of December	7.6	1.3
bio17	Precipitation of Driest quarter	6.9	30.3
bio10	Mean Temperature of warmest quarter	6.0	21.0
ndvi06	Vegetation cover index of June	4.8	2.2
bio11	Mean Temperature of coldest quarter	1.1	0

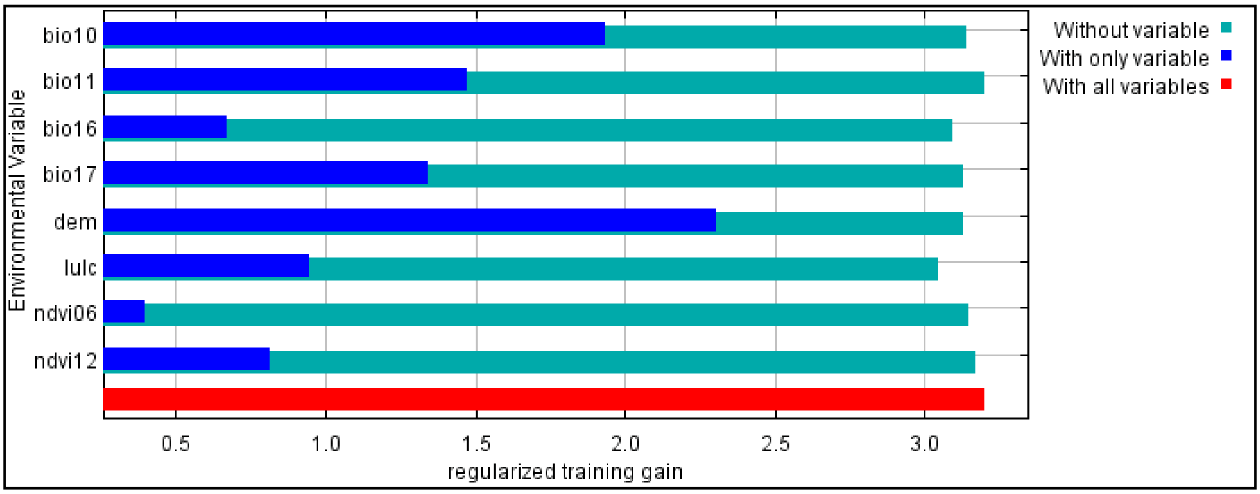

Figure 5. Jacknife of regularized training gain for LBV

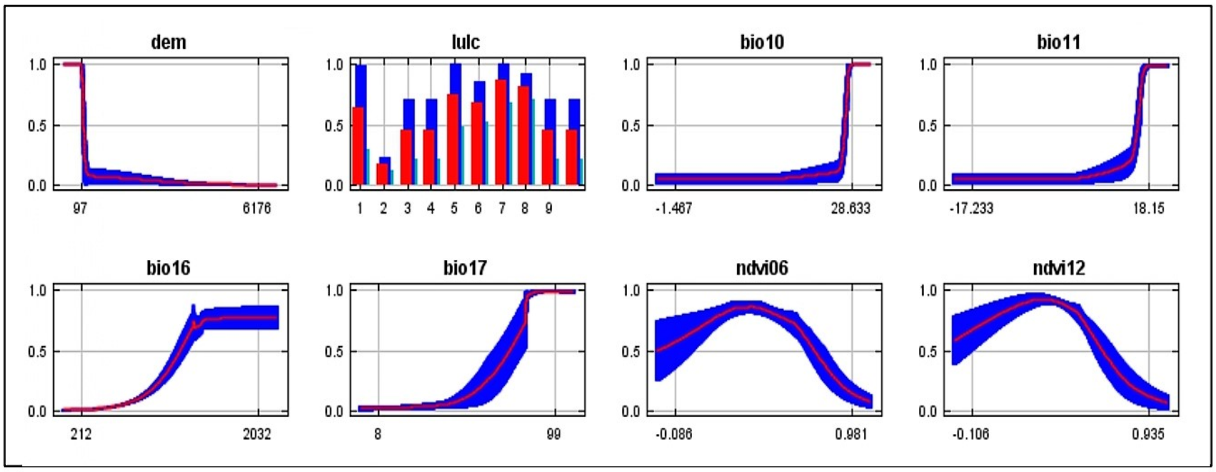

Figure 6. Response curve showing how each environmental variable affects the Maxent prediction. The curves show the mean response of the 10 replicate Maxent runs (red) and and the mean +/- one standard deviation (blue, two shades for categorical variables)

4. Conclusion

Arunachal Pradesh is home to LBV and though a very small portion of area (1856.79 Km^2 i.e. 2.26 % of the total area) is predicted to be suitable for its occurrence, it has enough environmental factors and other requirements for its survival in the state. The strong relationship between environmental factors and vulture occurrence identified in this study can help in management of vulture population and conservation approaches in the state. Availability of food, landscape pattern, riverine vegetation, presence of large open field and lower altitudinal habitat give a safe haven for the sheltering and occurrence of the species in the study area. Regular monitoring of vulture population, complete ban on use of diclofenac, social awareness among local residents, vulture conservation project by government and NGOs are some of the key measures that can be used for the conservation of this threated species in the state. Further rampant habitat destruction, rapid climatic change and disturbance by human activities can play a crucial role in determining the distribution of LBV in A.P.

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