Biological Forum – An International Journal **13(4): 589-595(2021)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Possible Shift in Distribution Range of Himalayan Vulture viz a viz of Future Bioclimatic Variables

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(Received 02 September 2021, Accepted 04 November, 2021)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Himalayan Vulture (*Gyps himalayensis* Hume, 1869) has been categorized under the near-threatened list by IUCN. The current investigation was done to predict the present and future species distribution range under various bioclimatic variables using MaxEnt modelling in the Himalayan range of Indian subcontinent. Present study provides preliminary information about the present and future distribution range of *G. himalayensis.* The study reveals that the suitable distribution range for *G. himalayensis* will increase in near future *i.e.* 2021-40 while the highly suitable range will decrease slightly from 2041-60 with overall increase towards the north-eastern Himalayas. The region already has rich biodiversity and also facing elevation range shifts by many other species due to climate warming, therefore, the coming finest hours need a proactive approach to conserve the declining population of *G. himalayensis* by developing an effective conservation strategy by using stacked species distribution models on multiple species responses and climatic variables in synergistic system.

Keywords: *G. himalayensis,* Bioclimatic Variables, MaxEnt, Distribution Range shift, Indian subcontinent.

INTRODUCTION

Different ecosystems on earth are suffering from intense environmental changes and pushing species extinction rate and anthropogenic activities are acting like a catalyst in this process. The current rate of climate change is expected to cause severe impacts on biodiversity in the near to medium future (Silva *et al.*, 2019). Vultures belong to Gyps genus which often considered as indicators of environmental health and flagship species has declined by 97% in last few decades due to both environmental and anthropogenic activities. Himalayan Vulture (*Gyps himalayensis*) is widespread from mountains of Himalayas to Central Asia. Generally, they are resident of Himalayan valleys and higher parts of the Himalayas range (Ferguson-Lees and Christie 2001). Most species of this genus are critically endangered category in IUCN list (Parkash *et al.*, 2012). The thresholds population decline criterion of IUCN evaluated *G. himalayensis* as 'Least Concern' till 2007 (IUCN, 2007) now which has been categorized under near threatened list (Birdlife International, 2021) shows the concerns of population decline in recent years. Knowledge of geographic distributions of species plays an important role and increases the efficiency of species conservation plans (Silva *et al.,* 2019). In case of vultures, this depends on environmental variables like availability of food, temperature and frequency of thermals (Dodge *et al.,* 2014) here climate change and temperature fluctuations can cause significant role in population decline (Saran, 2017). Long term strategic planning is required for making fruitful action plan for conservation of a species.

Species distribution modeling (SDM) provides reliable information to predict the suitable distribution range of an organism on the basis of various climatic variables (Phillips *et al.,* 2006). It is a valuable tool for disclosing range and distribution patterns of species (Elith *et al.*, 2011). In SDM, occurrence records are utilized along with long duration average climate variables to disclose ecological niche of an organism (Pearson and Dawson 2003). MaxEnt is one of the best advance machine learning software tools available for SDM then other predictive distribution models (Merow *et al*., 2013) like Generalised linear models (GLM) and Generalised additive models (GAM) (Elith *et al.,* 2006). Variation in climatic conditions are altering the ecology of Himalayas (Tewari *et al*., 2017) and can cause decline in population of *G. himalayensis* makes it important to investigate distribution range of this species. Therefore, the present study was done to investigate present and future predictive distribution ranges of *G. himalayensis* using Maxent Species distribution modeling to develop suitable long-term overall habitat conservation strategies.

MATERIALS AND METHODS

A. Study area and Presence data

The study area includes distribution range of *G. himalayensis* in Himalayan region of Indian subcontinent including India, Nepal, Bhutan, and Bangladesh. Identification and presence data was recorded along with geo references using point count (Verner, 1985) method in north-western region of India for period of two years from July 2018 to June 2020 using binoculars (Nikon-A211,10-22 × 50 zoom) and digital camera (Nikon D7200, 200-500mm lens). A total of 40 observations were recorded during the period. To make an appropriate species distribution model, more than 1500 presence records in studied area in last 5 years were also downloaded from global biodiversity information facility (www.gbif.org). The downloaded dataset was sponge down by eliminating records with no geo referenced location and duplicated occurrence records (Liu *et al.,* 2018). Literature was explored to examine the presence records of *G. himalayensis* in Himalayan region of Indian subcontinent (Prakash *et al.,* 2007; Acharya *et al.*, 2009; Li and Kasorndorkbua, 2008; Hla *et al.*, 2011; Thakur, 2014; Jha, 2015; Paudel *et al.,* 2015; Shah *et al.,* 2016; Deori *et al.*, 2017; Gupta *et al.,* 2017; Sherub *et al*., 2017; Kataria *et al.*, 2018; Sharief *et al.*, 2018). Any aberration between given presence record and literature cited was eliminated from the data set. Spatial auto-correlation and sampling bias was reduced by removing cluster occurrence points using spatial filtering (Boria *et al*., 2014). After data cleaning, 293 geo referenced records were selected and used for the species distribution modeling. Sample size is a common issue, especially for rare and endangered species like Himalayan Vulture (Bean *et al.,* 2012) however geo referenced records obtained after data filtering and cleaning and filtering were considered suitable for SDM (Wisz *et al.,* 2008).

B. Climate Data Extraction and Analysis

Data was obtained for twenty environmental raster layers including present nineteen bioclimatic raster (average for 1970-2000) and future projections (average 2021-40, 2041-60) with one elevation raster layers from World Clim 2.1 at resolution of 2.5 minute arc (Fick and Hijmans, 2017). Future projections were assessed under Representative Concentration Pathway (RCP) scenario using General Circulation Model (GCM) of Micro6 at ssp126 for year 2021-40 and 2041-60. Prior to SDM developments, all raster layers were introduced to QGIS (version 3.12) and clipped the area under study (Indian subcontinent) to reduce area for background selection points in prediction model (Radosavljevic and Anderson 2014). Presence only data selected for SDM was incorporated with clipped layers and numeric values from all rasters were extracted using point sampling tool. Multi collinearity can results in biased prediction model (Dormann *et al.*, 2013) therefore multi collinearity was tested for all selected variables using R package with USDM statistical tool (Naimi *et al.,* 2014) for variance inflation factor (VIF) analysis. The independent bioclimatic variables obtained with VIF values (< 3 were selected for further development of models (Table 1) (Zuur *et al.,* 2010).

Table 1: Environmental variables selected for development of model out of total variables under study.

Sr. No.	Codes	Environmental variables*	Model 1 (Present)	Model 2 (2021-40)	Model 3 (2041-60)
1.	Bio1	Annual mean temperature (°C)			
2.	Bio2	Mean Diurnal Range (°C)	✔	✔	✔
3.	Bio3	Isothermality %	✔	✔	✔
4.	Bio8	Mean Temperature of Wettest Quarter (°C)		✔	✔
5.	Bio9	Mean Temperature of Driest Quarter (°C)	✔		
6.	Bio13	Precipitation of Wettest Month (mm)	✔		
7.	Bio14	Precipitation of Driest Month (mm)	✔	✔	✔
8.	Bio15	Precipitation Seasonality	✔	✔	✔
9.	Bio18	Precipitation of Warmest Quarter (mm)		✔	✔
10.	Alt	Altitude from mean Sea Level (m)	✔	✔	✔

* https://www.worldclim.org/data/bioclim.html

C. Model building

Three species prediction models were developed i.e. present (Model 1), year 2021-2040 (Model 2), Year 2041-60 (Model 3). Maximum entropy general purpose machine learning software (Maxent version 3.4.1) (Phillips *et al.,* 2006; Phillips and Dudik, 2008; Phillips *et al.,* 2017) was used for development of all species prediction models for this study. A total of 10,000 maximum background points were selected after calculating total points available for evaluating the models. Goodness of statistical model fittings is determined by AIC (Akaike information criterion) where priority is given to smaller AIC value to be used in MaxEnt SDM (Zhang *et al*., 2019) therefore AIC was tested by using ENMeval data package in statistical software R (Version 1.2.5033). A ratio of 80:20 was assigned between training and testing data as input in Maxent. Model parameters were formulated by using training data whereas testing data points were used to evaluate the accuracy. Data was analyzed using basic settings with delete duplicate presence records and random seed feature. Data was evaluated for SDM in ten replicates for all modes including present and future models (Baggenstoss, 2018; Phillips and Dudik, 2008). Jackknife was used to evaluate the importance of each variable used in SDM (Elith *et al.,* 2011). Receiver operating characteristic (ROC) analyses was used to assess the predictive performance and consistency of models (Pearce and Ferrier 2000). Further AUC was calculated using average of ten cross validations (mean± SD) to make strong predictive performance for ROC. The whole procedure of modeling was done with all present and future projection rasters with species presences data. All three models were developed by MaxEnt than the area under suitable distribution range was analyzed on QGIS using Plugin named Raster layer unique value report. The species distribution range was considered as the mean latitude and longitude of each pixel cores while it was assumed that bird would be able to show movement through the landscape without landscape or environmental barriers.

RESULTS AND DISCUSSION

Three models (Model 1, 2 and 3) were developed for where Model 1 was developed for present status of distribution range whereas model 2 and 3 were developed for futuristic predictive distribution i.e. year 2021-40 and 2041-60 respectively. The reliability of a model is tested on the basis of independent nature of data used in development of perdition model. Maxent provides omission and predicted graphs which are crucial to investigate the goodness of model by providing information about the independent nature of test and training data (Merow *et al.*, 2013). The orange and blue shading surrounding the lines on the graph denoted variability (Figure 1). Orange shading shows omission on test samples and black shading shows the predicted omission rate. The calculated omission of test sample and predicted omission was very close to each other in all the three models which anticipate that the test and training data were independent (Phillips *et al*., 2017). Independent nature of data suggests that the models are highly suitable and reliable (Phillips and Dudik, 2008).

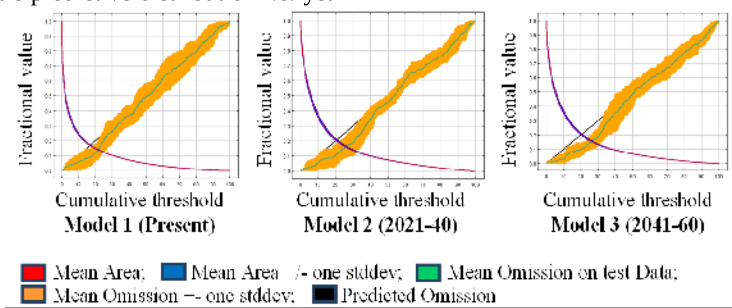

Fig. 1. Average Omission and Predicted area of *G. himalayensis.*

The other parameter used to validate the models is ROC (Receiver operating characteristic). AUC (Area under curve) in ROC calculate the quality of a ranking (0 to 1) and helps to avoid the difficulties associated with threshold effects (Fielding and Bell, 1997). ROC plots were developed using 80% of occurrence data points in model trainings and model testing was done by using the remaining 20% independent data points. Each model was run for ROC and averaged for ten cross validations (mean± SD) to develop more robust predictive performance. The average test AUC for the replicate runs for model 1, 2 and 3 were 0.919, 0.895 and 0.905 with standard deviation 0.015, 0.028 and 0.022 respectively (Fig. 2). AUC of ROC calculates the probability where presence site are chosen and ranked randomly on chosen absence site (Phillips *et al.,* 2017). An average AUC 0.5 for a model determines that model is not better than random whereas a perfect ranking achieves the AUC of 1.0 (Swets, 1988; Elith *et al.,* 2002). Higher the value of AUC, better is the model (Pearce and Ferrier, 2000). Swets (1988) explained that the value of AUC near 0.9 is considered excellent for preparation of a model. The AUC values were near 0.9 in all the models under study suggests the sound performance of models with extraordinary predictive accuracy. The combination of both omission and ROC graphs suggests that the models provided in the study contains potentially useful information.

The study provided the information about the relatively more important environmental variables out of all selected variables for development of models. Results of jackknife analysis have shown that the precipitation in driest period plays crucial role in distribution of species. Bio 17 is important in distribution of species in preset time however in near future (2021-40, 2041-60), Bio14 will be more important predicting the distribution of species. The other important variable was elevation from mean sea level (Alt) which had also shown significant influence on in all three models (Table 2). Bio 2 and Bio 3 had shown minimum contribution to models.

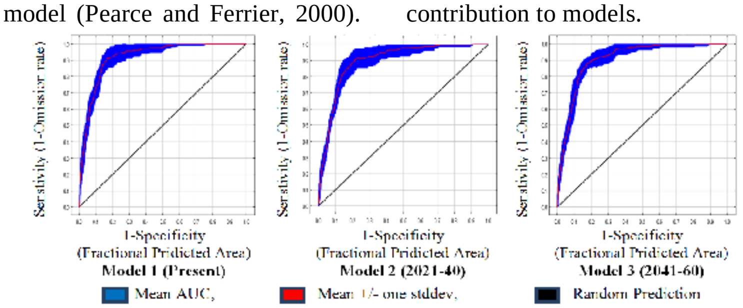

Fig. 2. Average sensitivity vs. 1-Specificity for AUC.

All three Distribution models were analyzed on QGIS which showed that less than 5% of the total studied area is suitable for the *G. himalayensis* (Table 3). It was observed that suitable range for *G. himalayensis* will increase in near future i.e. 2021-40 while it again decreases from 2041-60 as compared to present distribution range as shown in Figure 3. Species distribution prediction model 2 and 3 has interpreted that the north–eastern Himalayan region of Indian subcontinent will be more suitable in near future. Model 1 shows that the entire belt of Himalayan ranges is suitable for *G. himalayensis* whereas model 2 and 3 has shown that the distribution range of *G. himalayensis* will moves toward north eastern region of Himalayan ranges.

Table 2: Percent contribution and permutation importance of environmental variables understudy on Maxent.

Codes	Model 1 (Present)		Model 2 (2021-40)		Model 3 (2041-60)	
	PC	PI	PC	PI	PC	PI
Bio2	2.6	1.7	0.1	0.1	0.3	1.3
Bio3	2.5	9.7	1.5	1.2	1.9	1.2
Bio8	-	-	0	0.7	0.2	3.6
BIo9	0.8	1.1	-	-	-	-
Bio14	13.2	37.9	60.4	41.3	61.4	42.0
Bio15	10.7	17.0	2.3	9.8	3.3	11.3
Bio17	4.3	9.3	-	-	-	-
Bio18	-	-	22.4	24.7	19.6	18.4
Alt	65.8	23.4	13.4	22.2	13.3	22.2

* PC= Percent contribution, **PI= Permutation importance

Table 3: Suitable distribution range of *G. himalayensis* in Indian Subcontinent.

Area (%)	Model 1 (Present)	Model 2 (2021-40)	Model 3 (2041-60)
Suitable	2.99	5.85	5.22
Medium	1.18	1.34	1.39
Low	1.67	1.27	1.31
Non Suitable	94.16	91.54	92.08
Total area	100.00	100.00	100.00

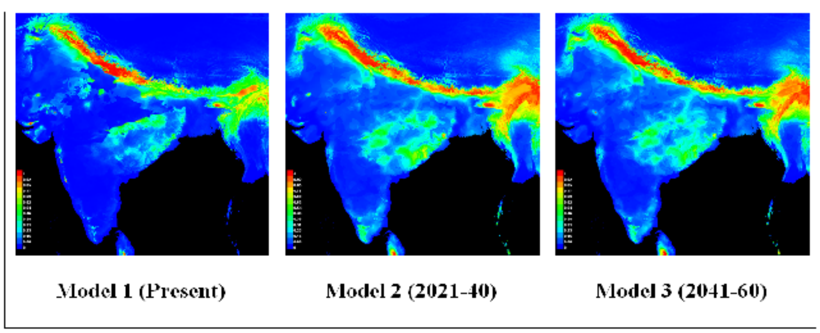

Fig. 3. Species distribution predictive models for *G. himalayensis* developed using MaxEnt.

Variation in temperature and precipitation in near future will affect the distribution range of the species. The species is already present in the north-eastern region of Indian subcontinent (Li and Kasorndorkbua, 2008; Acharya *et al*., 2009; Hla *et al.*, 2011; Zhang *et al*., 2017). The study explains the theoretical expansion under climate change regimes of rainfall where precipitation of driest month of year has significantly more contribution in present and future distribution models. The species perdition model predicts enchantment of the potentially suitable distribution range for bird with range shift and equivalent spatial response toward north eastern Himalayas. Distribution range towards the upper and north eastern Himalayas was also influenced by elevation from mean sea level. During the near future (2021-40) of climate change, the limited pressure exerted on Himalayan ranges generates the distributional responses. When climate change progresses (2021-60) the population may be expected to increases under the increased suitable distribution range.

The species population is expected to grow under increased suitable area for the bird as observed by MaxEnt under future climatic scenarios. However, the progression should not be taken as granted as the population of vultures has experiences a drastic decline in near past due to anthropogenic activities including use of non-steroidal anti-inflammatory drugs (Das *et al*., 2011). Similar incidences of has been reported in recent time in many parts of the world, which is a matter of deep concern (Safford *et al.*, 2019). The removal of NSAIDs from vulture habitats is difficult in practical (Safford *et al.,* 2019). In India, the ban has been imposed on the use of NSAIDs which are toxic to vultures which has shown its effect and vulture decline has decreased and even reversed in some parts of India (Prakash *et al*., 2019). The present study emphasize that a close check should be maintained on the population dynamics of the species in future predicted distribution ranges for the bird in near future to boost the conservation of the species.

It might seems as a sigh-of-relief for the conservationist however the study shows some concerns related to the futuristic predicted distribution regions. Model has shown a distributions shift of the species toward the north eastern Himalayan region of Indian subcontinent. High mountain regions are forage for significant percentage of endemic and vulnerable species and harbor rich biodiversity (Dirnbock *et al*., 2011). Elevation-range shifts by many species due to climate warming has already started which may predicted to have significant impacts on already existing biodiversity on high elevations (Sekercioglu *et al*., 2008; Dirnbock *et al*., 2011). The present study shows the movement of *G. himalayensis* in same regions led to increase in overall pressure on biodiversity thus careful management strategies of mountains is crucial for conservation in near future. Climate change may threaten the mountain regions (Salick *et al.,* 2019), however, habitat changes caused by human action may have more severe consequences (Jetz *et al.,* 2007). The synergistic effects of both the factors may show unfavorable effects (Mantyka-Pringle *et al.,* 2012) that need to take into consideration to develop long term conservation strategies. The models for the *G. Himalayans* have considered range shifts with expansion towards north-eastern Himalayas. More elaborated outcomes could be predicted by using more number of variables including behavioral adaptation of other species in same distribution range. Even under the relatively conservative scenarios adopted here, there are nonetheless some major increase in distribution range and increased competition predicted. The coming finest hour need to be exploited to conserve the declining species (*G. himalayensis*) nevertheless it may not be possible without conservation management interventions.

The study conclude that the future population of *G. himalayensis* is likely to increase as per futuristic bioclimatic variables, if responsiveness of species is taken as granted ruling out extreme events both anthropogenic and natural encounters. Findings of predictive responsiveness are based on evidences from prerecorded data where MaxEnt modeling has indicated that suitable range for species will increase from year 2021-40 while slight decrease from year 2041-60. The suitable predictive distribution range is likely to increase towards north eastern Himalayan region of Indian subcontinent which might seem good for the conservation of said species. However, it might end up trigger competition for already existing dominant/most abundant avian species and impacting their intertwined food chains. Possible scenario might trigger the competition with conspecific species which may lengthen towards other hetero-specific species in the extended futuristic predicted distribution range. Understanding of multitude of species-specific adaptations like elevation shift in relation to multiple climatic factors requires further implementation of stacked species distribution models to develop more detailed avian conservation strategies.

Acknowledgement. Authors would like to thank Council of Scientific & Industrial Research and University Grants Commission (New Delhi), Indian Council of Agricultural Research (New Delhi), Punjab Pollution Control Board (Punjab) and Department of Forest and Wildlife Preservation (Punjab) for financial and technical support. We also acknowledge Head, Department of Zoology for constant encouragement and for providing facilities.

Conflicts of Interest. The authors certified that there is no conflict of interest for the present work.

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How to cite this article: Kumar, S. and Kler, T. (2021). Possible Shift in Distribution Range of Himalayan Vulture viz a viz of Future Bioclimatic Variables. *Biological Forum – An International Journal*, *13*(4): 589-595.