Climate change shifts the habitat suitability of range-restricted bird species (Catreus wallichii) in the Himalayan ecosystem: evidence from the Indian Himalayan Ecosystem

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Abstract

Climate change affects ecosystems' functioning and composition by changing living organisms' habitats under adverse climate conditions. India's Himalayan ecosystem (IHE) is more sensitive and vulnerable to climate change. Changes in the habitats of range-restricted and vulnerable avifauna of IHE under climate change are not well understood. In the present study, we used ensemble species distribution modeling to delineate the climate-driven habitat shift of cheer pheasant (*Catreus wallichii*) under the projected climate change scenario (representative concentrations pathways, RCPs) viz RCP 4.5, RCP 6.0, and RCP 8.5 by 2050 and 2070. We reported an increment in climatically suitable habitats, shifting towards higher altitudes, reflecting that higher altitudes would be the more favorable/suitable habitat in changing climate conditions. The model predicted an area of habitat as very highly suitable (4.24 km2) followed by highly suitable (50.35 km2), moderately suitable (109.29 km2), low suitable (91.03 km2), and rarely suitable (88.89 km2) in the current scenario. Projected enhancement of suitable habitat was 88.36 km2 and 80.75 km2 under RCP 4.5 and RCP 6.0 and reduced (12.05 km2) in RCP 8.5 along with no change (approx. 2805.23 to 2810.60 km2) in RCP 4.5 and RCP 6.0, respectively by 2050. By 2070, the expanded suitable habitat was 93.52.36 km2, 163.01 km2, and 133.33 km2 with a reduction of 12.87 km2, 14.14 km2, and 10.01 km2 with no change of approx. 2799.69 km2, 2728.91 km2, and 2762.68 km2 in RCP 4.5, RCP 6.0, and RCP 8.5, respectively by 2070. Based on the analysis, we inferred that the species' climatically suitable habitat would disintegrate in the future climate change. Further, the mean diurnal temperature range was identified as a critical driver, followed by isothermally and precipitation which drove the species to shift towards suitable habitats, i.e., higher altitudes. This study helps policymakers formulate effective conservation plans for protecting Himalayan range-restricted bird species at the pace of climate change.

Introduction

Climate is critical in determining habitat distribution and affects ecosystem function and composition. Climate change is attributed to anthropogenic activities altering an organism’s adaptability and shifting patterns (Chen et al. 2011). The earth's surface's mean average temperature has risen by approx. 0.85°C over the last three decades (IPCC, 2014). It is projected that the mean global surface temperature will increase by 0.3–4.8°C by the end of the 21st century. Climate change may significantly influence diverse ecological phenomena such as structure, function, and composition, including habitat distribution and range shift resulting in biodiversity change. The Indian Himalayan Ecosystem (IHE) is very sensitive and vulnerable to climate change and its associated variables (IPCC, 2007). The biological organism combats climate change and its associated impacts in several ways. They make efforts to survive in the environment by developing adaptations to novel environmental conditions and shifting their habitat to suitable environmental conditions. They face extinction if organisms are unable to move or develop adaptation mechanisms. The species' survival frequency is considerable, aligning with the climate throughout their range in the specific environment. Nevertheless, conserving this ecological balance in climate change would require continuous monitoring to trace the shift in the ecological system.

The Indian Himalayan Ecosystem (IHE) is very sensitive and vulnerable to climate change and its associated variables (IPCC, 2007). In the IHE, an abnormal temperature and precipitation pattern will become more extreme. Potential climate change impacts on biodiversity include habitat loss, variations in phenotypic expression, alien species invasions, habitat shifting towards the higher elevation, reduction in population and diversity, etc. (Bellard et al. 2012). These consequences could drive habitat loss of threatened species beyond the edge of extinction. Therefore, it is urgent to understand the potential impacts of climate change on the habitat distribution of range-restricted and endangered species in IHE, which is experiencing climate change impacts faster than other ecosystems, to conserve and protect biological diversity (Singh et al. 2010; Singh et al. 2020).

Habitat suitability modelling is the most commonly adopted approach to predict climate change impacts on the species distribution for formulating strategies for conserving and managing biodiversity. This approach provides ways of understanding species responses to climate change and inferring related species predicted distributions over regions, therefore allowing adaptive and effective diversity conservation and management strategies to be adequately applied (Dawson et al., 2011). Predictions of climate change impacts on species distributions are made by integrating various factors such as bioclimatic, physiographic, land use, types, etc. (Wiens et al., 2010). Limited studies are available in the IHE, which focus on the effects of climate change on the suitable habitat distribution and habitat shift of the avifaunal species (Galbreath et al., 2009).

The ensemble modelling approach provides an accurate and more reliable prediction of species distribution or habitats under the influence of climate change (Araujo and New, 2007). If various models are combined using plurality methods (including the mean of all the models), these can form a more accurate projection that outperforms single models (Grenouillet et al., 2011). Spatial and temporal predictions of species distribution models are exceptionally well suited for ensemble modelling and consensus projections. The study demonstrated that single models have an optimal outcome on existing data (Singh et al., 2020). Still, it is not necessary to provide the most reliable results for future predictions, while consensus projections can provide more effective results in the current and future climatic scenarios (Latif et al., 2013; Ahmad et al., 2020). The present study sought to fulfill this gap by using an ensemble modelling approach to understand the climate change impacts on the future habitat suitability of the Himalayan cheer pheasant (*Catreus wallichii*), a range-restricted species in the Indian Himalayan Ecosystem.

The cheer pheasant (*Catreus wallichii*) is a range-restricted and vulnerable bird species found in the southern foothills of the western Himalayas, particularly in northern Pakistan, central Nepal, and India at elevations from ~ 1,500 to 2,700 m (Garson et al., 1992; Birdlife International, 2019). The cheer pheasant dwells in the outer hilly range of the Himalayas, which has tall grass and scattered clumps of trees (Singh et al. 2011). Its distribution is patchy due to its specialized habitat requirements and population decline. Climate change may affect cheer pheasant habitat in the coming decades (Inskipp et al. 2016). Cheer pheasant (*Catreus wallichii*) shift to heights of more than 10,000 feet during summer. Cheer pheasants like beetles, grubs, and snails commonly dig for their food. This species can also consume berries and grass from the ground.

The present study was performed in the Indian Western Himalayas (IWH), consisting of two states (i.e., Himachal Pradesh and Uttarakhand) and one Union Territories (i.e., Jammu and Kashmir) (Fig. 2A). The Himalayan region features four distinct physiographic zones, i.e., Shivalik, Middle Himalayas, Upper Himalayas, and Trans-Himalayas. The Himalayas account for around 80% of the Indian sub-continental total birds (Price et al., 2003). Besides, it is home to the most endangered Asian bird species (Acharya and Vijayan, 2010). The changing climate and increased anthropogenic activities affect the Himalayan biodiversity. Significant latitudinal and altitudinal differences occur in the western Himalayas that manage the surrounding environment. This region has uneven planes with higher altitudinal variations. Besides, various degrees of slope and aspect often control the climate to create several microclimate regions. Alterations in the Himalayan region's precipitation and temperature patterns contribute to significant implications for the threatened species.

Materials And Methods

Study area and gathering of species occurrence data

The present study was restricted to three Himalayan states of Indian Western Himalayas (IWH) namely Himachal Pradesh, Uttarakhand, and Jammu and Kashmir (Fig. 2A). From 2018 to 2019, we performed a detailed field survey to gather information on the presence locations in the states of Jammu & Kashmir, Himachal Pradesh, and Uttarakhand. We used a handheld GPS (Garmin Etrex 20X) with a precision of ±3 m to identify the location of the occurrence of the chosen species. We recorded observations from 05:30 am to 07:00 pm during field surveys. A total of 120 presence locations were identified during the field survey. Besides, we gathered 95 occurrence data from the ebird open access (https:/ebird.org/) and the forest department officials, etc. Hence, we used 225 presence locations for developing the species distribution model.

Bioclimatic, environmental, and other associated variables

We used nineteen bioclimatic variables retrieved from www.worldclim.org at a resolution of 1000 m. We generated topographic variables from the digital elevation model (https://earthexplorer.usgs.gov) at 30 m resolution. The soil variables (soil texture defined by the percentage of sand, silt, and clay, bulk density, soil taxonomy order, and soil pH) were obtained from the https://earthexplorer.usgs.gov at 250 m resolution. Land use/land cover data were retrieved from the Forestry Survey of India at 23.4 m resolution. Only thirteen out of thirty-one variables were chosen based on the correlation to reduce the collinearity study (Fig. 3). For this purpose, we used the caret package function in R-language to remove pair-wise correlation with a cutoff value of 70%. With a correlation coefficient >70%, only one variable was used for selecting the correct variables in the model by logical inference. We converted all variables into ASCII format for the model preparation using the ArcGIS program. The variables used for model development were four bioclimatic (mean diurnal range, isothermality, precipitation of driest month, precipitation seasonality), four physiographic (slope, aspect, heat load index, topographic wetness index), four soil (bulk density, absolute depth to bedrock, sand percentage, soil order) and land-use/ land-cover data.

Future climate change scenario

We used the future climate change scenario in the form of Representative Concentration Pathways (RCPs) for further modeling in the present study. RCPs expound on four multiple pathways associated with greenhouse gas emissions that might increase greenhouse gas atmospheric concentrations (Table 2). These RCPs pathways are utilized by the global scientific community in long-term and near-term modeling experiments. The pathways are characterized by the radiative forcing generated by the late 21st century. Radiative forcing defines the change in the net, downward minus upward, the radiative flux in W m^{-2} at the top of the atmosphere owing to greenhouse gas emissions. Further, RCPs provide a mitigation scenario resulting in a very low level of forcing (RCP2.6), two medium stabilization scenarios (RCP4.5 and RCP6), and a very high baseline emission scenario (RCP8.5). In this present study, we used climate data version 5 (MIROC5) of global climate models for RCPs for the years 2050 and 2070. It has been proven that MIROC5 best reflects the South Asian region and Himalayan climatic variability (Sharmila et al., 2015; Das et al., 2018; Jena et al., 2016).

Habitat distribution modelling of chosen species

Habitat modelling was performed using the stacked species distribution models (SSDM) package (Schmitt et al., 2017) in the R package (Phillips et al., 2006; Phillips and Dudik, 2008). We ran eight algorithms through ensemble modelling especially generalized linear models (GLM), multivariate adaptive regression splines (MARS), classification tree analysis (CTA), artificial neural networks (ANN), generalized boosted models (GBM), maximum entropy (MaxEnt), Random Forest (RF), and Support vector machine (SVM). GLM and ANN were not used for the ensemble model as they displayed AUC (area under the curve) values of less than 0.75. Within the model, 215 presence locations were used, which were further partitioned into training (70%) and validation (30%). Such splitting was used to test the stability and resilience of the model against initial conditions. Besides, the Jackknife test was used to calculate the significance of variables in the habitat suitability mapping. We selected the models based on AUC> 0.75, and weighted AUC was used to ensemble different chosen models. Furthermore, the ensemble model was used to project the habitat suitability map for potential habitats under current and future scenarios. To determine model stability, AUC and the kappa coefficient were used to assess model stability and accuracy, which often signify the ability to distinguish the model's presence and absence of data and model performance (Allouche et al., 2006) (Fig. 1).

Results

Model accuracy

The models with the AUC value >0.8 were chosen, indicating better model efficiency. Hence, we selected the models with an AUC value >0.8 for further study. Six models achieved an AUC value >0.8 among eight models. Out of six chosen models, the maximum AUC (0.96) was acquired by the MaxEnt and RF, whereas the minimum (0.83) for the CTA model. Such AUC values from different models showed distribution was a near approximation of the likelihood of real-world distribution. Further, we calculated the Kappa value for each model and the highest reported for MaxEnt (0.79) and RF (0.77). The Kappa values indicate the model's reliability for predicting suitable habitats under the influence of climate change (Table 5).

Response of environmental variables in model preparation

The kappa value executed model validation while mapping habitat suitability in climate change. The test results showed the relative contribution of climate variables to the current distribution. This result was a mean value of 20 replicates runs for each model's preparation, which was further ensemble using the weighted mean model. The outcome showed that the model's response to the different variables was positively nonlinear. The variables, i.e., mean diurnal temperature range (Bio2), precipitation seasonality (Bio 15), isothermality (Bio 3), land use classes, and soil sand proportion contributed more to habitat suitability by, on average more than 75 percent in the ensemble modeling (Fig. 5). The response curves display the impact of single variables on model prediction.

Modeling suitable habitat for cheer pheasant under the current climate

The suitable potential habitat for the cheer pheasant under current climatic conditions is shown in fig. 2 B. The probability habitat distribution of cheer pheasant was classified into five categories i.e., very highly suitable (>90 %), highly suitable (80-90%), moderately suitable (70–80%), low suitable (60–70%), and rarely suitable (50-60 %). Under current climatic conditions, the model identified an area of 4.24 km^2 as very highly suitable, 50.35 km^2 as highly suitable, 109.29 km^2 as moderately suitable, and 91.03 km^2 as low suitable. In comparison, 88.89 km^2 of the area was observed as rarely suitable for the cheer pheasant's current habitat (Fig. 2 B).

Modeling suitable habitat for cheer pheasant under future changing climatic conditions

The future habitat suitability of the cheer pheasant delineated by the ensemble modeling in the climate change scenario displayed that future climate change will significantly alter the potentially suitable habitats in the IHE. The habitat distribution of selected species was delineated in three climatic change scenarios, i.e., RCP 4.5, RCP 6.0, and RCP 8.5 for the years 2050 and 2070. The results revealed that the suitable habitat of cheer pheasant would increase and shift towards higher elevation in the future changing climatic scenario. For 2050, under RCP 4.5, there was an increment in the area with high suitability found by 88.36 km2 while reduced suitable area by 12.50 km^2. Further, we reported no change in suitability classes for an area of 2805.23 km^2 under RCP 4.5 for 2050. In the prevailing scenario of RCP 8.5, the suitability area decreased by 12.05 km^2 compared to the current climate. Similarly, under the

RCP 6.0 area for the suitable habitat was increased by 80.75 km^2 and declined by 14.75 km^2 compared to the suitable area observed under the current climate. In comparison, no change was observed for a total area of 2810.60 km^2. We observed the habitat loss of the cheer pheasant resulted in upwards shifts toward the higher elevation to the present scenario under future changing climatic conditions (Fig. 4). By 2070, under RCP 4.5, a suitable area would decrease by 12.87 km^2 compared to the current climate. Changes in habitat suitability under different scenarios for the years 2050 and 2070 are displayed in table 3.

Discussion

Ecological changes viz species distribution and phenology are greatly influenced by climate change and its associated variability, including land use change, thereby aggravating the extinction or prosperity of species. Climate change is one of the herculean challenges for the distribution and conservation of species in the 21st century due to changes in the range-restricted species' behavior and function (Singh et al., 2020). Hence, the ensemble modeling approach is preferred to predict the changes in the suitable habitat distribution of vulnerable and endemic species under climate change scenarios (Freeman and Freeman, 2014). The changing climatic conditions alter species' phenologic, genetic, population-level, and biogeographic changes. In particular, a decrease in migratory activity, a shift in migratory distances and differences in breeding behavior, breeding timing, and an increase in breeding season length of the species (Smallegange et al., 2010; Moller et al., 2010).

In the present study, we reported that the habitat of the cheer pheasant would shift by more than 40% towards the higher elevations in response to future climate change under RCPs, i.e., 4.5, 6.0, and 8.5. It was emphasized that the selected bird species would move towards higher altitudes to adapt to novel habitat conditions for breeding and survival. Various researchers reported that changing climatic circumstances have altered many species' geographical ranges, including plants and animals (Latif et al., 2013; Ahmad et al., 2020; Singh et al., 2020). The changes in climatic force species shift upward in elevation and poleward in search of suitable habitats and adapt to a new environment (IPCC, 2014; Singh et al., 2020). Singh et al. (2020) reported a significant shifting of suitable habitat of western tragopan (*Tragopan melanocephalus*), a range-restricted and vulnerable bird species in Indian western Himalayan states (Uttarakhand, Himachal Pradesh, and Jammu and Kashmir) to higher elevations under the RCPs viz. RCP 4.5, RCP 6.0, and RCP 8.0 for the years 2050 and 2070.

Further, other factors such as human activities and land-use changes would significantly impact habitat shifts. However, climate change will aggravate range shifts, but it is challenging to identify the species' habitat under changing climatic conditions. It might be due to the lack of data related to the historical range of a particular species. It is also tricky for individual species to tolerate changing environmental conditions. Notwithstanding this, bird species may face a considerable problem of community composition and structure of the particular location, resulting in further relocations or pressures on inhabitants (Jones and Cresswell 2010).

Changing climatic conditions in the wintering area during breeding leads to less flexibility for adaptation towards the changes, contributing to tremendous potential for migrants to be at risk, apart from those changes of wintering or passage conditions due to climate change causing adverse effects on bird populations (Lehikoinen et al., 2013; Potvin et al., 2016). Depending upon particular species' adaptability to new conditions, the ranges of the bird species shifting can expand or shrink due to climate change (Massimino et al., 2015). In the present study, we observed that the bird's suitable habitat would alter with the future changing climatic conditions. It was recorded that the habitat of cheer pheasant was highly affected by the mean diurnal range of temperature (26.51%), followed by isothermality (15.11%), precipitation seasonality (15.04%), bulk density (8.17%), precipitation of driest month (5.27%) while remaining variable has a more negligible effect on the habitat suitability.

Researchers have reported that northern-temperate birds have been recorded to have changed their breeding and non-breeding ranges to greater latitudes due to climate change. In contrast, tropical birds have changed their breeding ranges to higher altitudes, and these shifts directly alter the species' structure, composition, and migration strategies (Sorte and Jetz, 2010). Similarly, the bird species (Cheer pheasant) might also shift from their native place towards the higher altitudinal regions due to future changing climatic conditions. Therefore it is necessary to focus on the conservation of bird species, i.e., cheer pheasant. Such predictions will help policymakers develop strategies for conservation and management plans of range-restricted Himalayan bird species in future climate change.

Conclusion

In the present study, we predicted the potential habitat suitability of Himalayan cheer pheasant (*Catreus wallichii*) in response to current and future changing climatic scenarios, viz RCP 4.5, RCP 6.0, and RCP 8.5, using the ensemble modelling approach. Ensemble species distribution modelling framework had shown a decline of climatically suitable habitats and shifting elevation in the Himalayan region upwards in response to various climatic scenarios of 2050 and 2070. We reported that environmental variables (Bio2, Bio3, and Bio15) contributed more to the shifting of habitat suitability of the selected bird species toward higher altitudes. Further, we reported that the climatically suitable habitat distribution area of the species in the Indian Himalayas is envisaged to become more disintegrate in the future climate change. The present study results would be beneficial to policymakers to formulate conservation and management strategies for range-restricted bird species to protect from climate change and other threats.

Declarations

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Statements & Declarations

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Author Contributions

All authors contributed to the study’s conception and design. Material preparation, data collection, and analysis were performed by Hukum Singh and Narendra Kumar. The first draft of the manuscript was written by Hukum Singh and Narendra Kumar and the authors Manoj Kumar and Ranjeet Singh commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors declared that they have no conflict of interest for this publication.

Ethics approval

The study did not harm any human or animal. National and international guidelines are followed for the protection of social welfare.

Consent to participate

Not applicable.

Consent for publication

All the authors have studied the manuscript thoroughly and given consent for the publication.

Competing interests

The authors declare no competing interests.

Availability of data and materials

The data will be made available after the publication of the manuscript of the request.

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Tables

Table 1. Environmental variables and their units.

Code	Environmental variables	Unit
Bio1	Annual mean temperature	°C
Bio2	Mean diurnal range (mean of monthly (max temp−min temp))	°C
Bio3	Isothermality (Bio2/Bio7) (×100)	–
Bio4	Temperature seasonality (standard deviation ×100)	C of V
Bio5	Max temperature of warmest month	°C
Bio6	Min temperature of coldest month	°C
Bio7	Temperature annual range (Bio5–Bio6)	°C
Bio8	Mean temperature of wettest quarter	°C
Bio9	Mean temperature of driest quarter	°C
Bio10	Mean temperature of warmest quarter	°C
Bio11	Mean temperature of coldest quarter	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest month	mm
Bio14	Precipitation of driest month	mm
Bio15	Precipitation seasonality (coefficient of variation)	
Bio16	Precipitation of wettest quarter	mm
Bio17	Precipitation of driest quarter	mm
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	
LULC	Land use and land cover	
ELE	Elevation	m
SLO	Slope	
ASP	Aspect	
HLI	Heat load index	
TWI	Topographic wetness index	
BD	Bulk density	
ADB	Absolute depth to bedrock	
SP	Sand percentage	

SO	Soil order
LU	Land use

Table 2. Different representative concentration pathways (RCPs)

S.N.	Radiative forcing	Atmospheric CO_2 equivalent (ppm)	Description	References
1.	RCP 8.5	(~1370 ppm)	Rising radiative forcing pathway leading to 8.5 W/m^2	Riahi et al. 2007
2.	RCP 6.0	(~850 ppm)	Stabilization without overshoot pathway to 6 W/m^2	Hijioka et al. 2008; Fujino et al. 2006
3.	RCP 4.5	(~650 ppm)	Stabilization without overshoot pathway to 4.5 W/m^2	Smith and Wigley 2006; Wise et al. 2009
4.	RCP 2.5	(~490 ppm)	Peak in radiative forcing at ~3 W/m^2	Van Vuuren et al. 2006; Van Vuuren et al., 2007a

Table 3: Sources for obtaining the SRTM dataset, soil data set and land use and cover data, bioclimatic parameters, and Species location data.

Data	Resolution	Source
Elevation (SRTM)	30 m	https://earthexplorer.usgs.gov (United States Geological Survey)
Soil parameters	250 m	https://soilgrids.org (International Soil Reference and Information Centre)
Land Use and Land Cover Map	23.4 m	FSI India
BioClimatic parameters	1000 m	http://www.worldclim.org (University of California, Berkeley)
Species location data	Point data	http://www.gbif.org (Global biodiversity information facility)

Table 4. Changes in suitability of Cheer Pheasant under different RCP scenarios

Climate Model	Suitable Class	Species distribution area (Km^2)		
		RCP 4.5	**RCP 6.0**	**RCP 8.5**
2050	No Change	2805.234	2810.594	2778.989
	Increase	88.3555	80.7465	115.0495
	Decrease	12.496	14.7445	12.0465
2070	No Change	2799.689	2728.93	2762.677
	Increase	93.524	163.0155	133.335
	Decrease	12.8725	14.14	10.073

Table 5. Performance of different model including ensemble modelling.

S.No.	Models	AUC	Kappa
1.	**CTA**	0.829	0.688
2.	**MARS**	0.933	0.686
3.	**MAXENT**	0.961	0.798
4.	**RF**	0.961	0.773
5.	**GBM**	0.948	0.750
6.	**SVM**	0.934	0.752
7.	**GLM**	0.625	0.172
8.	**ANN**	0.707	0.417
9.	**Ensemble**	**0.928**	**0.617**

Figures

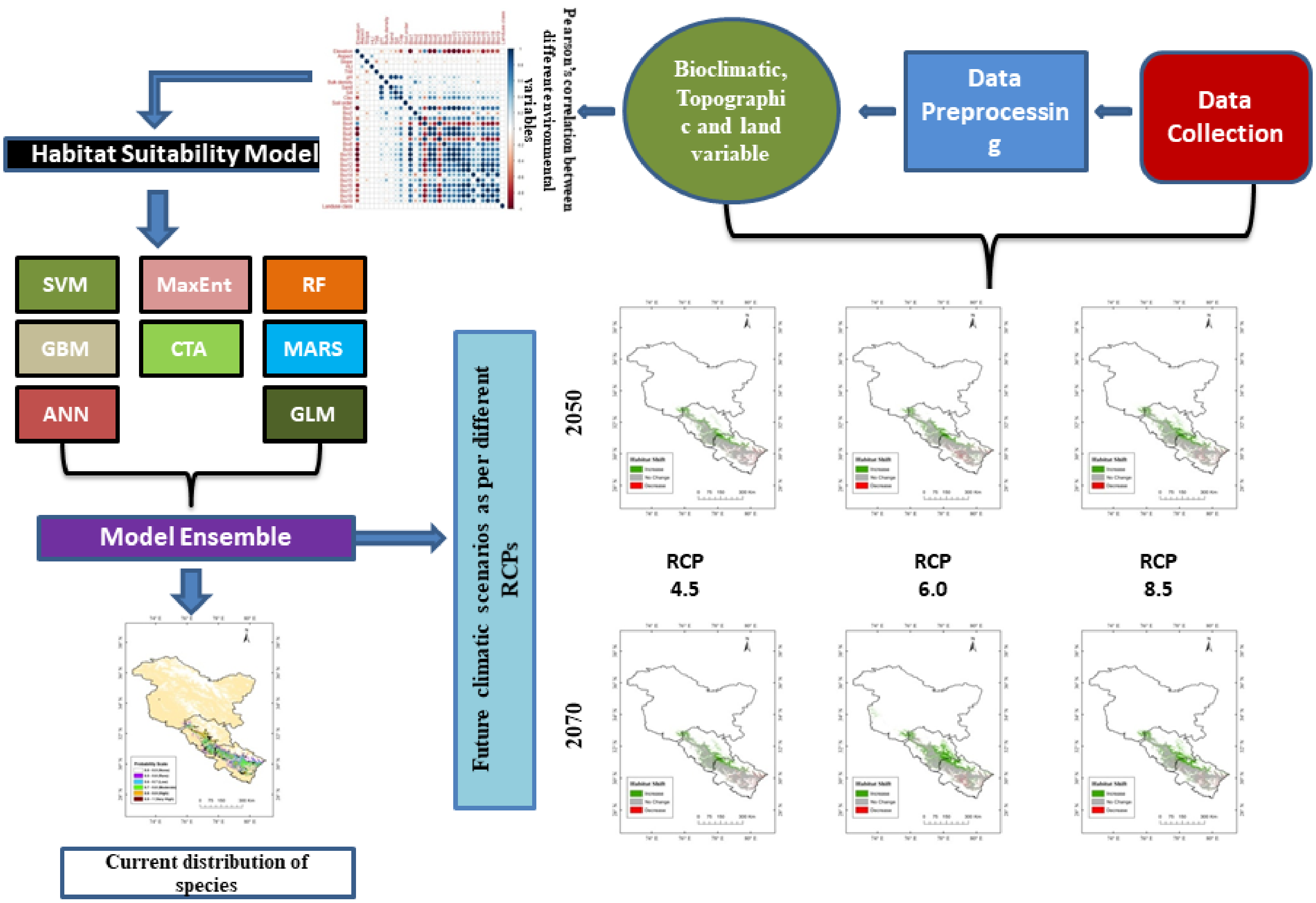

Figure 1

Flow chart of database and methodology for the preparation of the model.

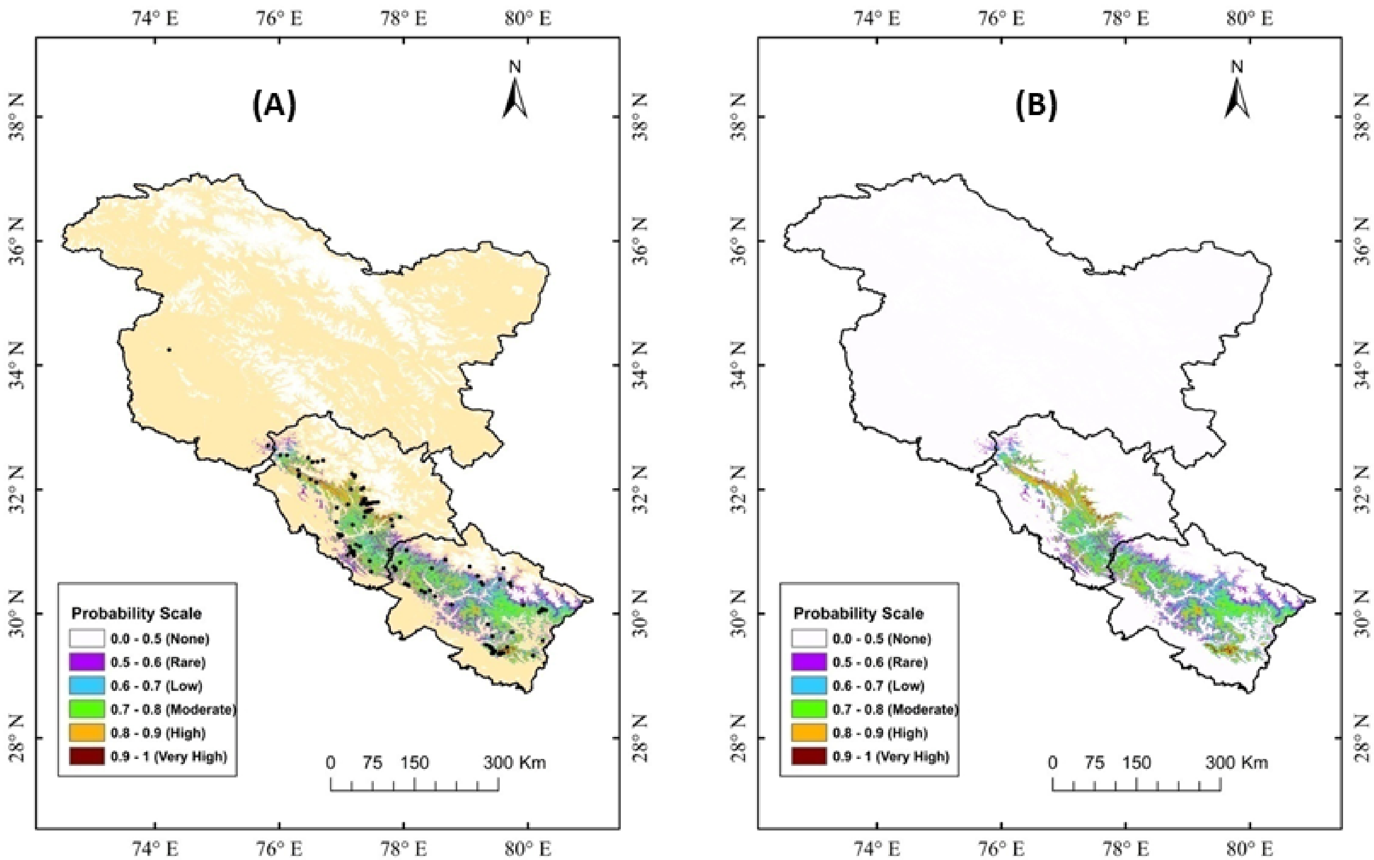

Figure 2

A) Location map of the study area. The black point shows the species occurrence location. B) Potential habitat suitability distribution of Cheer pheasant (*Catreus wallichii*) in current climatic conditions.

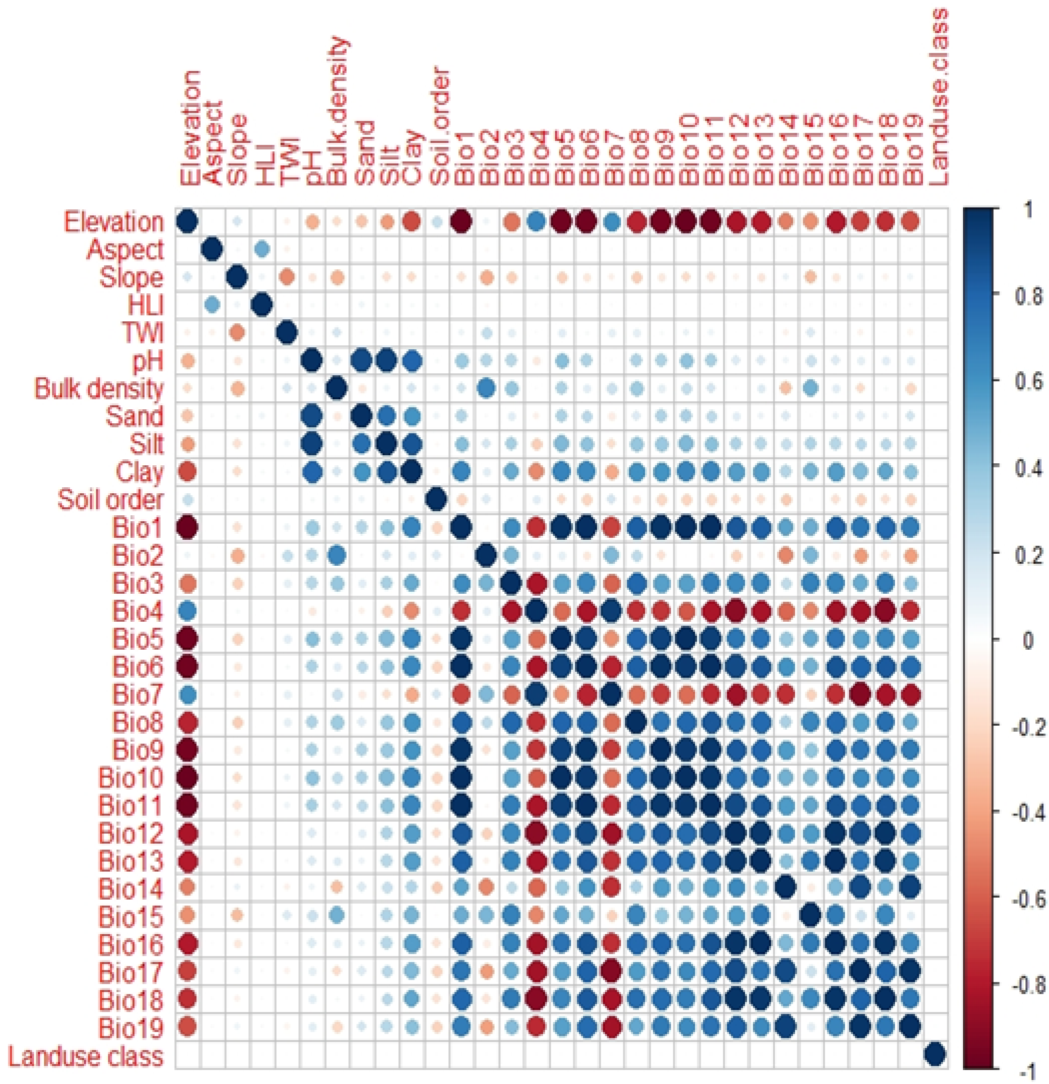

Figure 3

Pearson's correlation between different environmental variables

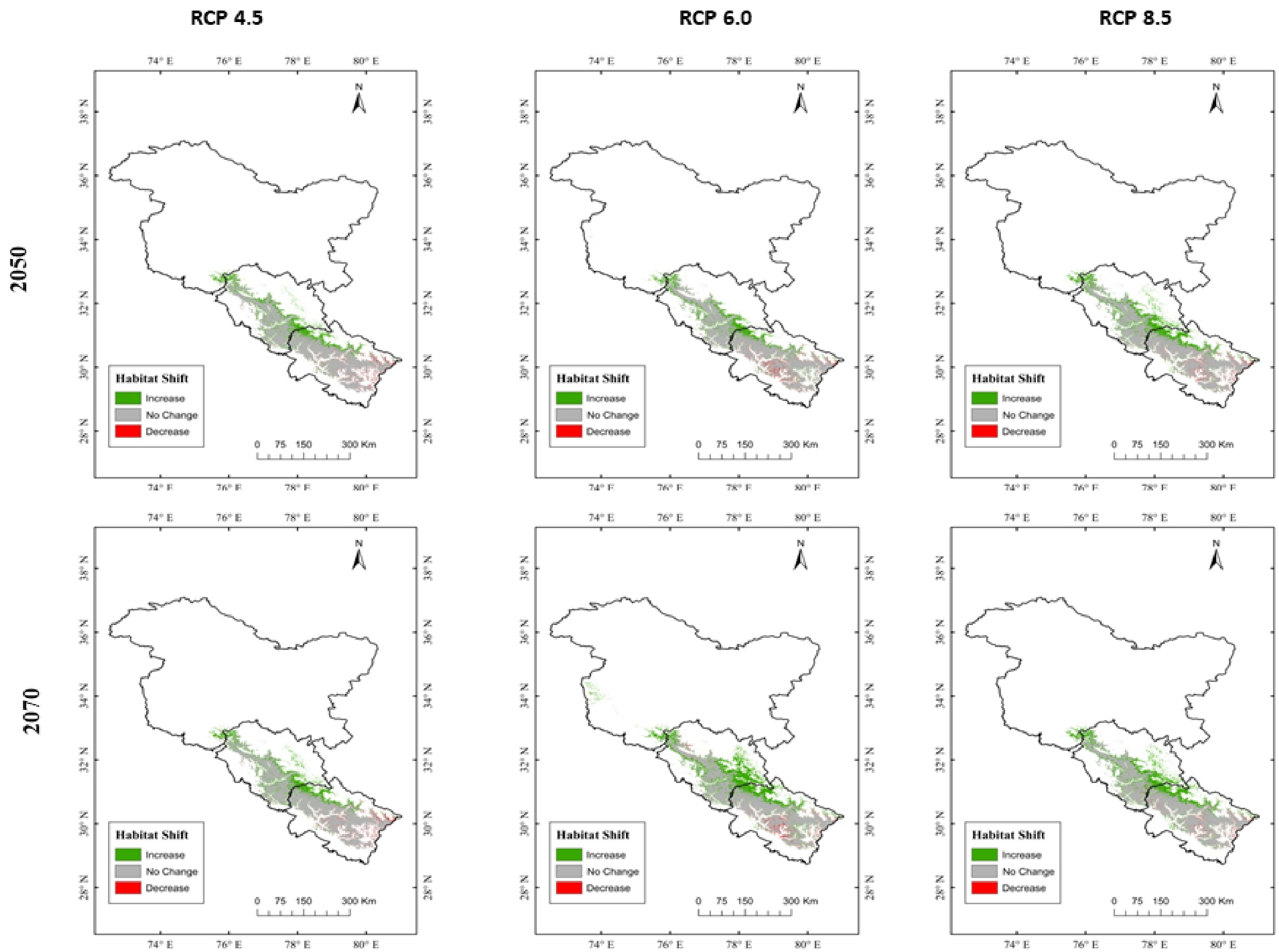

Figure 4

Prediction of suitable future habitat of Cheer pheasant (*Catreus wallichii*) in the RCP 4.5, 6.0 and 8.5 for the year 2050 and 2070.

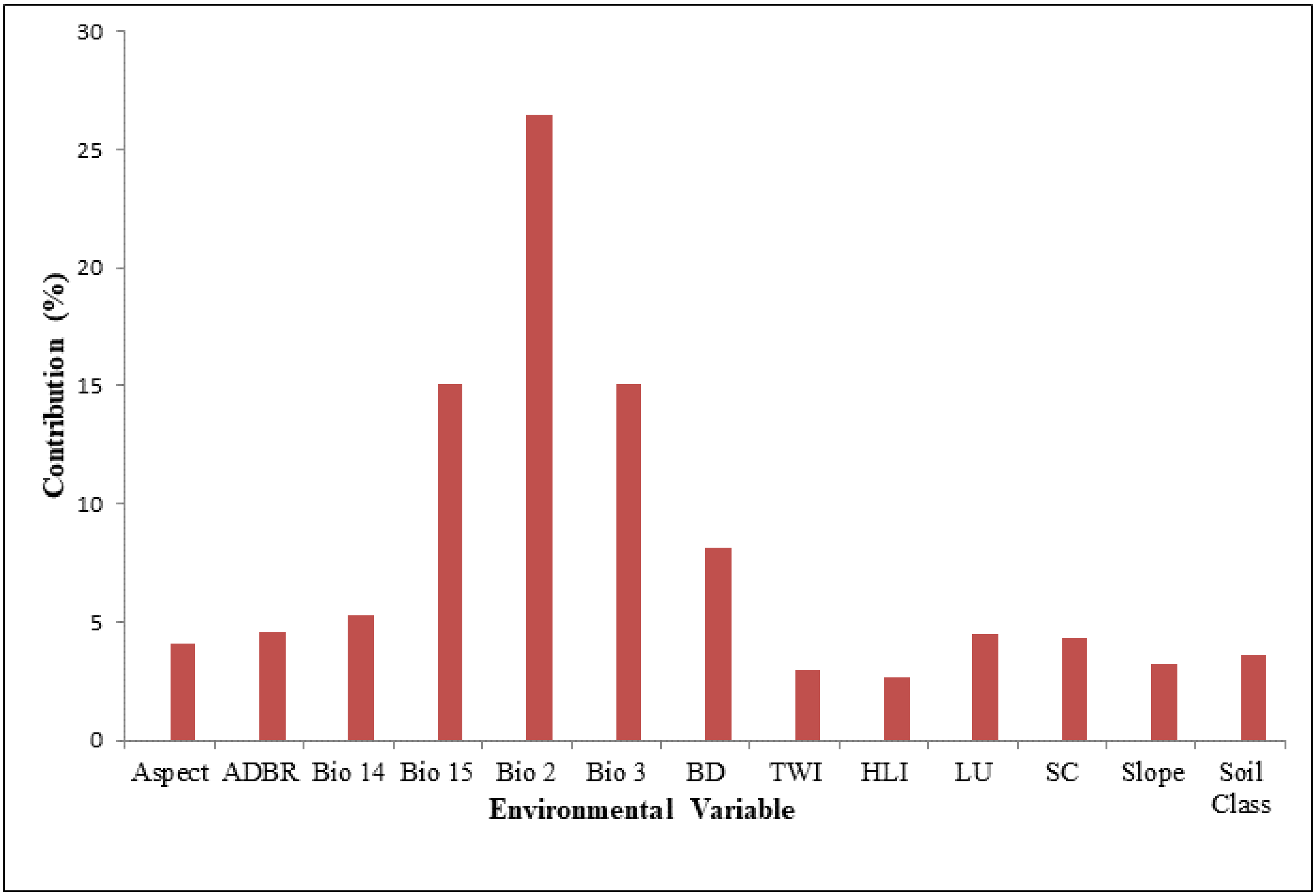

Figure 5

Contribution of environmental variable to ensemble model performance