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Research Article

Impact of climate change on endemic birds of the Indian Subcontinent: ecological consequences and challenges

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Abstract

The increase in global temperature may pose a risk of extinction to many endemic bird species of the Subcontinent by the end of the 21st century. This region, being ranked as one of the most vulnerable regions to climate change, is experiencing the shifting and contraction of species ranges. The distribution data on four endemic bird species (sub-continent) viz. *Ardeotis nigriceps*, *Dendrocopos assimilis*, *Passer pyrrhonotus,* and *Terpsiphone paradisi,* were studied regarding their present and future habitat suitability in the ongoing climate change scenario. We used present and future climate variables from Worldclim and occurrence records obtained from GBIF in the present study. To simulate the present (normal range for 1980-2019) while for future (2050 and 2070) species distribution, we used the model maximum entropy approach (MaxEnt) and generalized linear model (GLM) by using to future peak scenarios of carbon emission RCP 4.5 and RCP 8.5 and two circulation models for 2050 and 2070. Our results showed that under these two climate scenarios, the distribution of species projected towards the altitudes of the east and north, and the latitudes of the north. As well as the accuracy of our species distribution model, it predicted the high climatic suitability towards altitudes of the east and north regions of the Subcontinent for endemic species. Across the eastern regions, one-third that was projected to drop by the end of 2050 as well as one-half by the end of 2070 of the present habitat. Our study highlighted the risks for endemic species of the subcontinent due to future environmental changes, and such findings are useful for policymakers to moderate the negative effects of future climate on these species within the Subcontinent.

Keywords: Climate variation, Endemic bird species, Species distribution model, Indian Subcontinent

Introduction

A major worldwide danger to ecosystems and biodiversity is climate change (Freeman et al., 2019; Lees et al., 2022). At a global level, the average temperature has increased in the last few years by 0.74°C, and by the end of the century is estimated to increase further (Zahoor et al., 2022). The temperature of global conditions in the 21st century, as a result of anthropogenic activities, would lead to a rise between 1.4 to 5.8°C (Lee et al., 2023) whereas, at northern latitudes, there is a greater increase in global temperature (Kumar & Chopra, 2009; Pachauri & Reisinger, 2007). The report on the status of different bird species by BirdLife indicated the alarming situation for birds worldwide due to climate change (BirdLife, 2018). If warming is limited, then changes in the pattern of monsoon rainfall may be more significant than changes in the temperature range, which is suggested by changes in the communities of birds in the last few decades (Tyrberg, 2010).

Environmental variables are important for species that have limited distribution, as their performance tends to decline outside their native ranges (Hargreaves et al., 2014). The maintenance of ecosystem and biodiversity services under future climate changes mainly depend on the ability of organisms to adapt to these changes. Similarly, if species adapt to new conditions of the environment, ultimately, it can reduce their risk of extinction and environmental distributions (Gonçalves et al., 2023). Recent global climate changes have affected species at different scales, including changes in communities at the local level due to habitat alteration and shifts in species ranges in response to climate change. Mainly, two threats have been documented: the rapid pace of climate change and reduced habitat suitability (Barnagaud et al., 2012).

Species living in the tropics tend to contract their distributions due to a warming climate and shifting towards higher elevations (Chen et al., 2011). If species continue to shift their distribution and experience range reductions, it may lead to population decline due to fragmentation. This is particularly harmful for endemic species as they already have small ranges (Velásquez-Tibatá et al., 2013). Therefore, biodiversity hotspots that contain a greater diversity of species with small ranges are particularly vulnerable to the impacts of climate change (RAXWORTHY et al., 2008). Ecological niche models follow methods that use environmental data and species occurrence records to ultimately predict habitat suitability with the help of a correlative model, according to the ecological requirements of species (Warren & Seifert, 2011). The Maxent algorithm uses only presence data on the maximum entropy principle, and training data testing is done by reserved parts, which gives a response curve as well as distribution maps on the basis of variable values. Maxent model uses ecological niche algorithms to test the composition and richness of species for areas that need to be conserved and are already unsampled (Kaky et al., 2020).

Based on assessments of environmental factors that restrict species distributions along with species occurrence and abundance data, species distribution models are statistical representations of the interactions between species and their environments. Species distribution models (SDMs) are effective tools for assessing biodiversity and supporting conservation planning. Understanding how environmental changes affect biodiversity is important, and SDMs are widely used to project species distributions across different times and locations (Elith & Franklin, 2013).

Among the countries of the Indian subcontinent, Pakistan has been the most affected by climate-driven cworlclhanges, according to the Climate Risk Index (Adil et al., 2025). Like other Asian countries, Pakistan is also facing an alarming situation due to changing climatic patterns (N. A. Khan et al., 2021) including rising temperatures, melting glaciers, changes in monsoon patterns, and an increase in natural disasters related to climatic events (Malik et al., 2012). The major effect of undesirable fluctuations in climate are observed in birds leading to shifts in their ranges and affecting habitat suitability. Thus, changes are expected to pose a serious threat to the endemic birds of the subcontinent (Yasin, 2021). In the present study, habitat suitability was estimated of four endemic bird species of subcontinent based on presence data and climatic variables. The study aimed to: (i) determine the current distribution of the four endemic bird species, (ii) assess the effect of climatic variables on their dispersal, and (iii) project their future distribution as a result of climate change under RCP (Representative Concentration Pathways) 4.5 and RCP 8.5. It is projected that colonization will contract and shift in multiple directions due to climate change.

Material and methods

In the South Asian region, Pakistan is a predominant country with strong latitudinal and altitudinal gradients, with a variety of environmental variables extending from north to east. In the present study, we generated world maps and cropped the extent of the Subcontinent range on the x-axis, considered as longitude (east or west) used coordinates (45,100), and on the y-axis, latitude (North or south), coordinates (0,50) all maps were generated in R by code.

Species Occurrence Data

Occurrence records of 26862 of four endemic species of the subcontinent (*Ardeotis nigriceps*=1037; *Dendrocopos assimilis=1090*; *Passer pyrrhonotus* = 1614; *Terpsiphone paradisi*=23121) from the period 1980-2019 were obtained from Global Biodiversity Information Facility (GBIF) (Table 1). Presence points were collected (i.e., from 1980 to 2019) based on human observations. By using the processes of spatial thinning, the area was divided by 1 km multiplied by 1 km, and only presence points were selected to minimize the autocorrelation (using the net tool in ArcGIS 10.2.2) as reported by (Zahoor et al., 2022).

Table 1. Records of species occurrence of four endemic bird species of Subcontinent.

Species	Presence point	Source
Ardeotis nigriceps	1037	Human observation (Vigores, 1831) https://www.gbif.org
Dendrocopos assimilis	1090	Human observation (Blyth, 1849) https://www.gbif.org
Passer pyrrhonotus	1614	Human observation (Blyth, 1845) https://www.gbif.org
Terpsiphone paradise	23121	Human observation (Linnaeus, 1758) https://www.gbif.org

Climate variables data

Data from 19 climatic predictors were downloaded at a resolution of 10 arc-seconds with an area of 1km for the present (1980-2019) and for the future (2050-2070) from the database Worldclim 1.4 (Hijmans et al., 2005). On a broad scale, climate is considered an important factor in the distribution of species; therefore, bioclimatic variables were of significance in the present study (Chhetri et al., 2021; Sutton, 2020). The temperature range selected as a mean diurnal, an important one for species in arid environments, because fluctuation in daily temperature ranges affects the survival and viability of the population (Briga & Verhulst, 2015). Rainfall and seasonality were projected to have a strong impact on birds' reproductive efforts, food availability, and survival in unfertile ecosystems (Dean et al., 2009). Based on available information, we selected the variables related to precipitation reflecting seasonal and monthly extremes for avian species in arid environments (Cavalcanti et al., 2016) at the equator with a resolution of 10 minutes. For future projection of species distribution, two models were used, such as General Circulation Models (GCMs) and Hadley Centre Global Environment model version 2 (HadGEM2-ES version 2) from Coupled Model Intercomparison Project Phase 5 (CMIP5 project phase five) (Ali et al., 2021). For each model, two scenarios of carbon emission were used, RCPs (4.5 and 8.5) (Zahoor et al., 2022) to determine the minimum and maximum peak concentration of greenhouse gases (Weyant, 2009).

Species distribution models

For this purpose, MaxEnt (maximum entropy) and GLM (statistical regression model) were used to study the distribution of four endemic avian species of the subcontinent by using presence-only data (Dai et al., 2021; Liu et al., 2013; Phillips et al., 2006). To verify the models, two replicate methods were used: sub-sampling and bootstrapping. 70% of the presence data was used for training, while the remaining 30% was used for testing. The contribution of climatic variables (in percent) was estimated using the jackknife test, and distribution maps as well as marginal response curves for the endemic species were generated (Elith et al., 2011). For habitat suitability, the probability of values was considered greater than the threshold for grids' maximum training sensitivity plus specificity (MTSPS). Logistic threshold values were used to distinguish the suitable and unsuitable habitats (Liu et al., 2013; Zahoor, Liu, Kumar, et al., 2021). Model output accuracy was validated by an independent threshold value, i.e., AUC (area under the curve). Model performance was assessed based on AUC values which range from 0 to 1, using following criteria: >0.9 = excellent, 0.8-0.9 = better, 0.7-0.8 = good, 0.6-0.7 = bad, and <0.6 = flop, following the criteria of (Kamyo & Asanok, 2020; Phillips et al., 2006; Singh et al., 2020). To eliminate the multicollinearity among variables, statistical tools in ArcGIS 10.2.2 were used, and variables with a correlation coefficient (r) greater than 0.8 were removed (Brown, 2014; Zahoor et al., 2022), as shown in Tables 2 and 3.

Results

Based on model performance, the habitat suitability of four endemic species (sub-continent) was obtained with presence records and climate variables for each species, such as (1039 and 4) for *Ardeotis nigriceps*, (1090 and 5) for *Dendrocopos assimilis*, (1614 and 8) for *Passer pyrrhonotus*, and (23121 and 8) *Terpsiphone paradisi*.

Environmental Predictors Contribution

The results revealed the contribution of different environmental variables (Fig. 1 and 2) under RCP 4.5 (2050) and RCP 8.5 (2070) scenarios on the distribution of four endemic species (sub-continent). A prominent impact of the mean temperature of warmest quarter Bio climate variable-10 (Bio-10) with 64.1 and 71.1 % for *A. nigriceps*, (Bio-10) with 74.4 and 77 % for *D. assimilis*, mean temperature of wettest quarter (Bio-8) with 61.9 and 81.6% for *P. pyrrhonotus* and precipitation of wettest month (Bio-13) with 35.6 and 45.2 % for *T. paradisi* (Table 2 and 3).

Table 2. Values of climatic predictors for endemic bird species of the Subcontinent under RCP 4.5 temperature (°c) and precipitation (mm).

Codes	**Variables**	**Unit**	***Ardeotis nigriceps***	***Dendrocopos assimilis***	***Passer pyrrhonotus***	***Terpsiphone paradisi***
Bio1	Annual mean temperature	^{0}c	0	0	0	0
Bio2	Mean diurnal range	^{0}c	0	0	0	0.2
Bio3	Temperature consistency	^{0}c	0	29.7	0.3	0
Bio4	Temperature seasonality	^{0}c	0	37.8	16.4	8.7
Bio5	Maximum temperature of warmest month	^{0}c	0	0	0	0

Bio6	Minimum temperature of coldest month	^{0}c	0	0	0	0
Bio7	Annual temperature range	^{0}c	0	0	0	0
Bio8	Mean temperature of wettest quarter	^{0}c	0	1.8	61.9	0.2
Bio9	Mean temperature of driest quarter	^{0}c	15.8	0	9.1	0.4
Bio10	Mean temperature of warmest quarter	^{0}c	64.1	74.4	0.9	0.3
Bio11	Mean temperature of coldest quarter	^{0}c	0	0	0	0
Bio12	Annual precipitation	Mm	0	0	0	0
Bio13	Precipitation of wettest month	Mm	0	0	0	35.6
Bio14	Precipitation of driest month	Mm	12.3	0	0	4.2
Bio15	Precipitation seasonality	Mm	19.9	0.4	9.7	0.1
Bio16	Precipitation of wettest quarter	Mm	0	0	0	0
Bio17	Precipitation of driest quarter	Mm	0	0	0	0
Bio18	Precipitation of warmest quarter	Mm	0	0	1.7	2
Bio19	Precipitation of coldest quarter	Mm	0	0	0.3	10.8

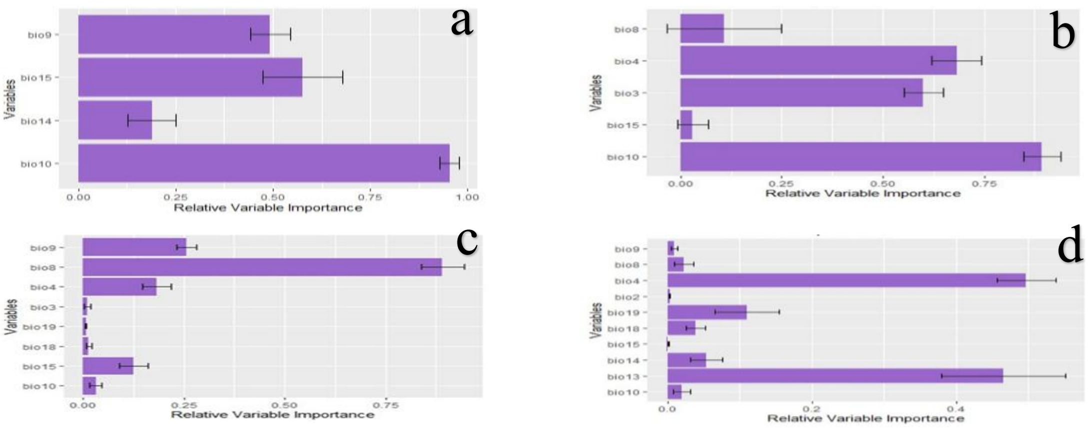

Figure 1 a-d. Importance of climate variables for (a) *A. nigriceps*, (b) *D. assimilis*, (c) *P. pyrrhonotus, and* (d) *T. paradisi* obtained with the jack-knife test for RCP 4.5 (2050). Dark black bar represents the gain of one variable, while light bars show variation for all variables. All temperature variables (°C) and precipitation variables (mm).

Table 3. Values of climatic predictors for endemic bird species of Subcontinent under RCP 8.5 temperature (°c) and precipitation (mm).

Codes	**Variables**	**Unit**	***Ardeotis nigriceps***	***Dendrocopos assimilis***	***Passer pyrrhonotus***	***Terpsiphone paradisi***
Bio1	Annual mean temperature	^{0}c	0	0	0	0
Bio2	Mean diurnal range	^{0}c	0	0	0	0.1
Bio3	Temperature consistency	^{0}c	0	27	0.6	0
Bio4	Temperature seasonality	^{0}c	0	31.6	11.6	5.9
Bio5	Max temperature of warmest month	^{0}c	0	0	0	0
Bio6	Min temperature of coldest month	^{0}c	0	0	0	0
Bio7	Annual temperature range	^{0}c	0	0	0	0
Bio8	Mean temperature of wettest quarter	^{0}c	0	0.1	81.4	0
Bio9	Mean temperature of driest quarter	^{0}c	15.5	0	12.4	0
Bio10	Mean temperature of warmest quarter	^{0}c	71.1	77	1.6	0.1
Bio11	Mean temperature of coldest quarter	^{0}c	0	0	0	0
Bio12	Annual precipitation	Mm	0	0	0	0
Bio13	Precipitation of wettest month	Mm	0	0	0	45.2
Bio14	Precipitation of driest month	Mm	3	0	0	4.7
Bio15	Precipitation seasonality	Mm	23.1	0.2	4.4	0
Bio16	Precipitation of wettest quarter	Mm	0	0	0	0
Bio17	Precipitation of driest quarter	Mm	0	0	0	0
Bio18	Precipitation of warmest quarter	Mm	0	0	1.5	3.1
Bio19	Precipitation of coldest quarter	Mm	0	0	0.4	6

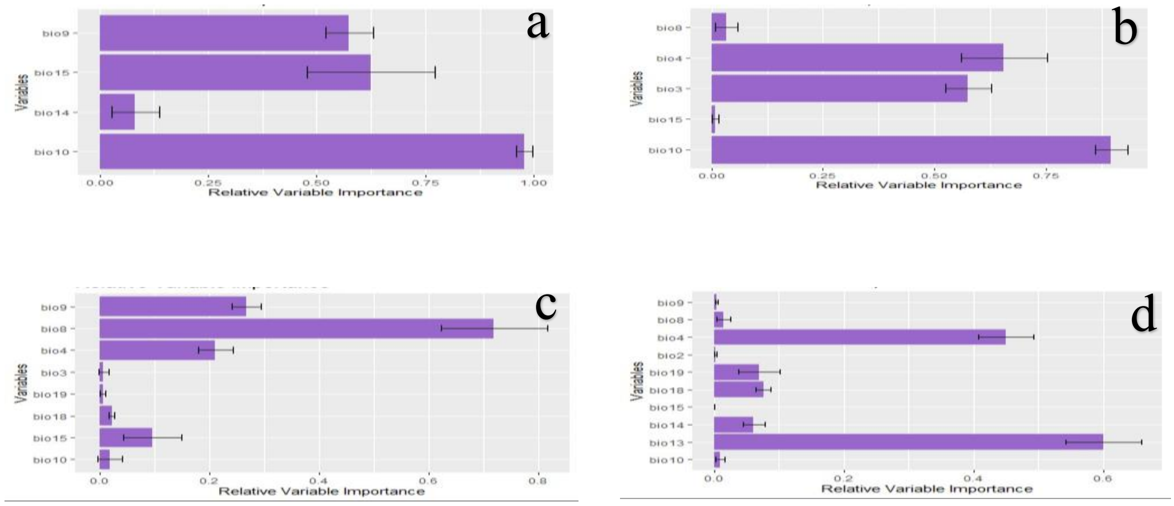

Figure 2 a-d. Percentage importance of climatic predictors for the (a) *A. nigriceps*, (b) *D. assimilis*, (c) *P. pyrrhonotus, and* (d)*T. paradisi* obtained by results of jack-knife test for RCP 8.5 (2070). Dark black graph bars indicate regularized gain with just one variable, and light graph bars indicate regularized gain for all variables. All variables of temperature (°C) and variables of precipitation (mm).

Performances of Species Distribution Modelling

The model performance was evaluated through the rate of presence and absence proportion of the curve-ROC (receiver operating characteristic curve) as shown in Figure 3. The values of the logistic threshold, such as sensitivity and specificity, area under the curve for four endemic species (sub-continent) were>0.9, which indicates excellent performance. The values given as output of MaxEnt were obtained by data splitting into training (70%) and testing (30%), with standard deviation given in Table 4.

Table 4. MaxEnt output of the model under the area curve of endemic bird species of the Subcontinent.

Endemic Species (subcontinent) MaxEnt output	Training AUC±SD	Test AUC±SD
Ardeotis nigriceps	(0.971±0959)	(0.956±0.96)
Dendrocopos assimilis	(0.951±0.944)	(0.948±0.957)
Passer Pyrrhonotus	(0.98±0.982)	0.975±0.978)
Terpsiphone paradise	(0.949±0.947)	(0.946±0.945)

SD: Standard Deviation

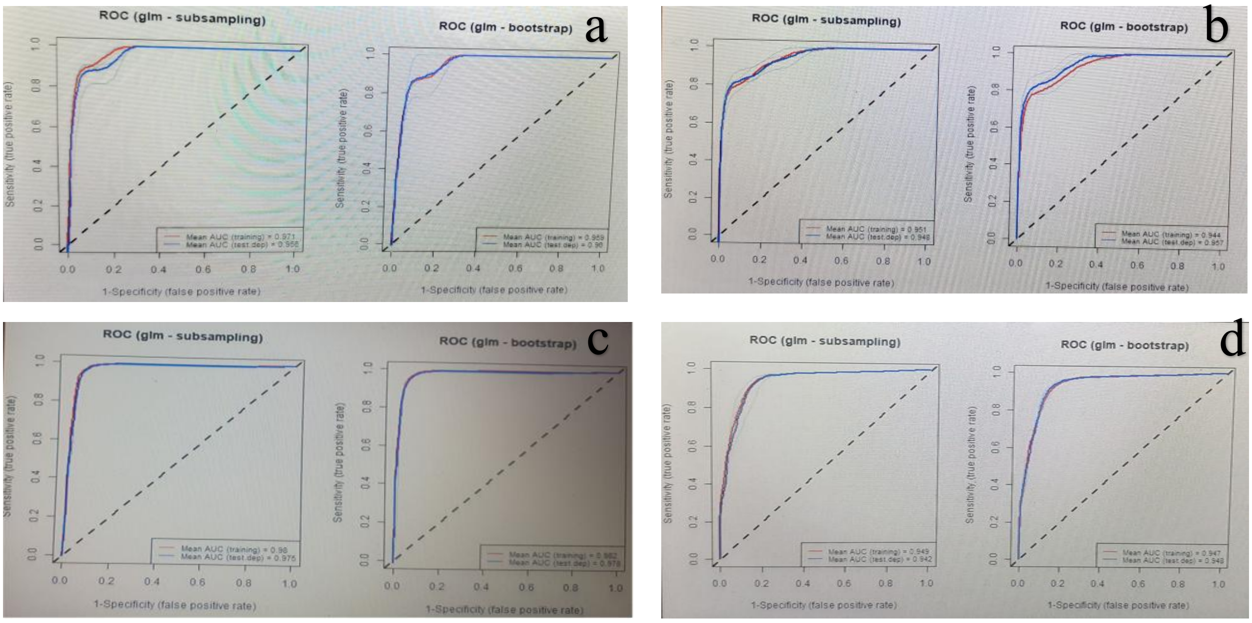

Figure 3 a-d. For different species distribution models, receiver operator characteristics (ROC) curves by using methods such as subsampling and bootstrap replication and AUC for the prediction of habitat suitability for (a) *A. nigriceps,* (b) *D. assimilis,* (c) *P. pyrrhonotus,* and (d) *T. paradisi,* respectively. ROC curves indicate the horizontal line (specificity-false positive rate) and vertical line (Sensitivity-true positive rate) for samples that are classified. Curved red and blue lines indicate the values of AUC.

Projected distributions of four Endemic species

Current Distribution

Maximum logistic threshold values as testing and training data of four endemic species (sub-continent) viz. 0.971 (*A. nigriceps*)*,* 0.951 (*D. assimilis*)*,* 0.98 (*P. pyrrhonotus*) and 0.949 (*T. paradisi*). The binary distribution maps of four endemic species were obtained from the above values. The current distributions of four endemic species as *A. nigriceps, D. assimilis, P. pyrrhonotus, and T. paradisi,* under the current climate, are shown in the Subcontinent (Fig. 4).

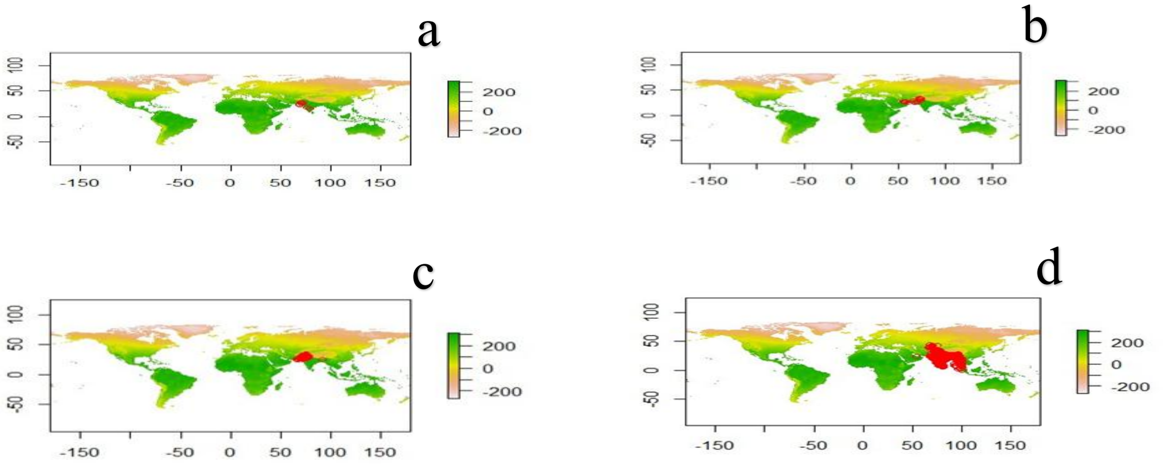

Figure 4 a-d. Predicted maps of current time distribution for *the (a) A. nigriceps*, (b) *D.assimilis,* (c) *P. pyrrhonotus,* and (d) *T. paradisi.* Red-filled circles indicate about known presence of four species.

Future distribution

Moreover, the probability of species occurrence with absence and presence records due to bioclimatic variables under the future climate scenario of RCP 4.5 and 8.5 were obtained. The probability of colonization for *A. nigriceps* is projected 1% in 2050 towards eastern altitudes 1% toward higher altitudes of the east and 0.5% toward lower latitudes of north in 2070. While the probability of extinction is predicted -0.5% toward higher altitudes of east and lower latitudes of north in 2050; -1% toward lower latitudes of north and higher altitudes of east in 2070 (Fig. 5 and 6). The probability of settlement for *D. assimilis* toward higher altitudes of the east is 1%, toward north 0.5% in 2050; 1% towards higher altitudes of east and north in 2070 while 0.2% extinction in the center of the east. *P. pyrrhonotus* establishment occurred at 0.5% toward higher altitudes of the east and 0.5% toward northern latitudes in 2050; 1% towards higher altitudes of the east in 2070 and the risk of extinction was -1% in the east. The probability of settlement for *T. paradisi* was 0.5% toward altitudes of the east, northern altitude, and latitude while extinction risk was -1% in 2050. The probability of colonization towards altitudes of east and north and latitudes of north was 0.5% in 2027. All the species were affected by climate changes in 2050 and 2070 under both RCPs (Fig.5 and 6).

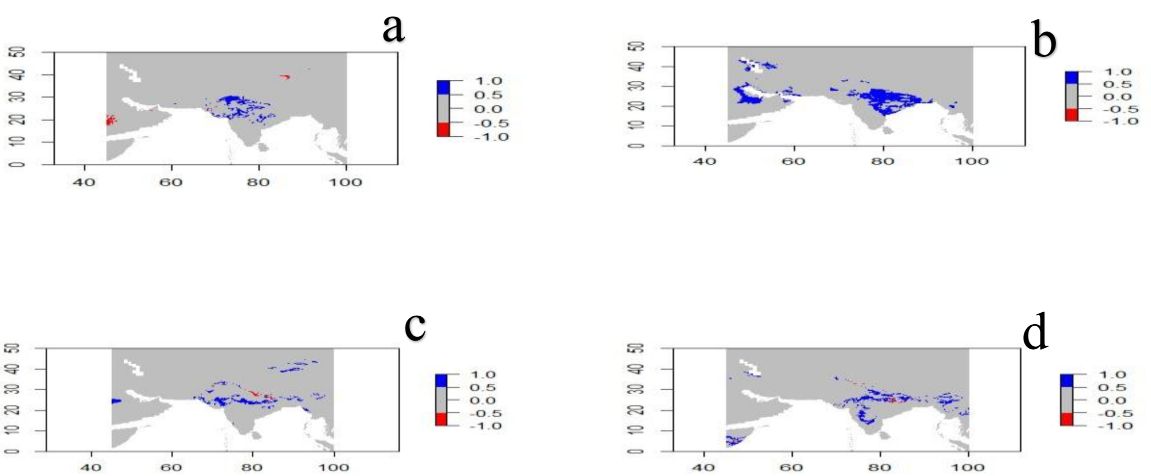

Figure 5 a-d. Projected distribution maps of (a) *A. nigriceps,* (b) *D. assimilis,* (c) *P. pyrrhonotus, and* (d) *T. paradisi* in 2050 obtained by general circulation models with RCP 4.5. Model logistic prediction indicates by maps with area of blue color showing `colonization.

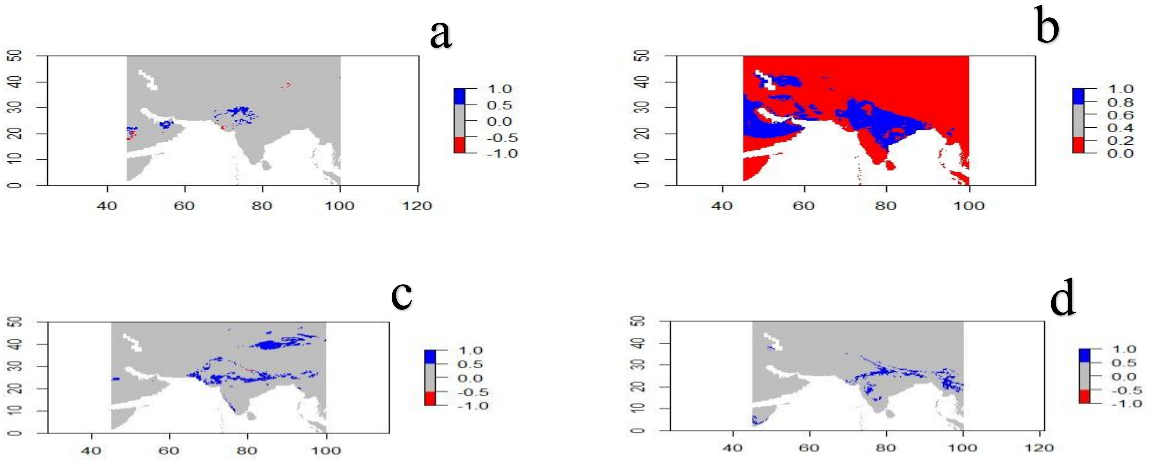

Figure 6 a-d. Projected distribution map of (a) *A. nigriceps,* (b) *D. assimilis*, (c) *P. pyrrhonotus, and* (d) *T. paradisi* in 2070 obtained by a general circulation model with RCP 8.5. Model logistic prediction is indicated by maps with an area of blue color showing colonization.

Projected changes in habitat suitability of four endemic species of the Subcontinent

Current habitat suitability

The current habitat suitability of four endemic species (subcontinent) has declined less compared to future climate scenarios under RCP 4.5 and 8.5 for 2050 and 2070 in the east and north regions, due to bioclimate variables for A. nigriceps, D. assimilis, P. pyrrhonotus, and T. paradisi (Fig. 7).

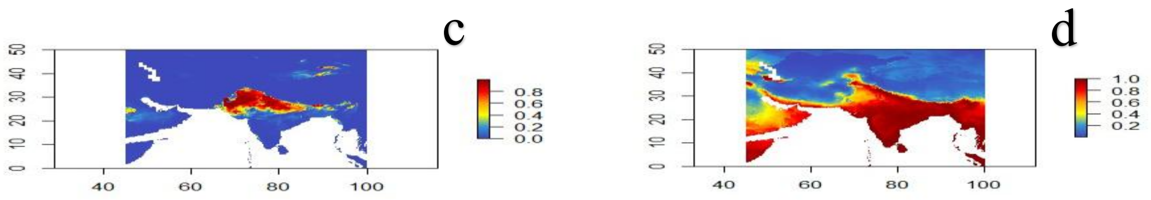

Figure 7a-d. Current habitat suitability for the (a) *A. nigriceps*, (b) *D. assimilis,* (c) *P. pyrrhonotus, and* (d) *T. paradisi* by using general circulation models (GCMs). Maps predicted the habitat suitability with red color area.

Future Habitat Suitability

Under projected future climate scenarios, *A. nigriceps* habitat suitability is expected to decline by more than 0.8% in 2050 and 2070 in the center of the east, for *D. assimilis* it declined by 0.8% in 2050 and 2070 toward higher altitudes of north and east, for *P. pyrrhonotus* it declined by 0.6% in 2050 and 0.8% in 2070 towards higher altitudes of the east. Similarly, the habitat suitability for *T. paradisi* was contracted by 1% in 2050 and 2070 towards the east. The bioclimatic variables, such as temperature (Bio-10) and precipitation (Bio-14), seemed to be responsible for the shift toward higher altitudes in the east and lower latitudes in the north in *A. nigriceps.* Similarly, higher temperature (Bio-10) and less seasonal precipitation (Bio-15) affected future habitat suitability for *D. assimilis* towards the east and north altitudes. The bio-climate variations of the wettest quarter temperature (Bio-8) and the coldest quarter precipitation (Bio-19) were quite effective for the future habitat shift of *P. pyrrhonotus* toward higher altitudes of the east. Similarly, the variation in seasonal temperature (Bio-4) and precipitation (Bio-13) is predicted to control the shift in habitat suitability of *T. paradisi* towards higher altitudes of the east and to some extent towards the north latitude. Resultantly, these endemic species (sub-continent) were projected to experience range shifts and contractions due to climatic variables under both RCPs 4.5 and 8.5 (in 2050 and 2070) (Figs 8 and 9).

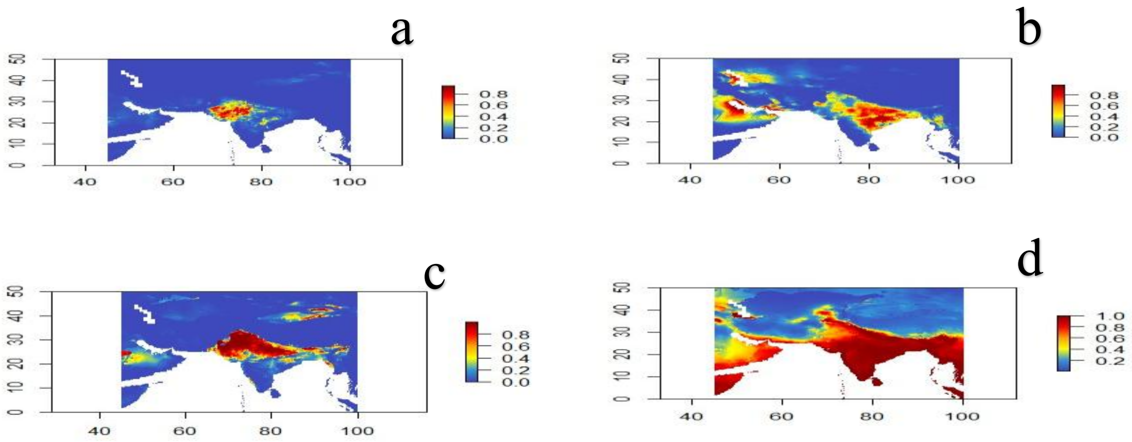

Figure 8 a-d. Predicted maps of future distribution of (a) *A. nigriceps*, (b) *D.assimilis*, (c) *P. pyrrhonotus, and*(d) *T. paradisi* in 2050 at RCP 4.5. Maps predicted the habitat suitability with red color area.

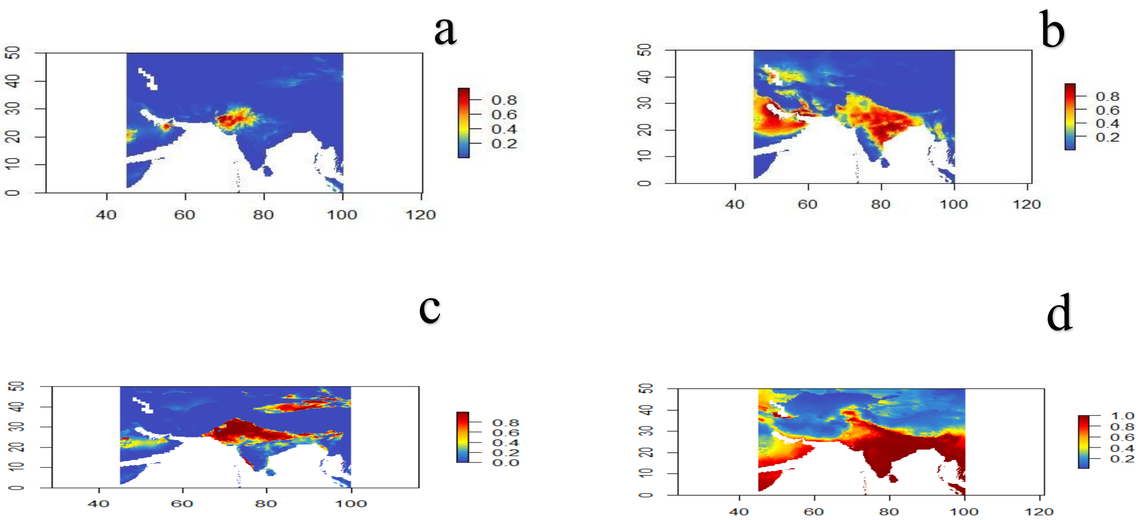

Figure 9a-d. Predicted maps of future distribution of (a) *A. nigriceps*, (b) *D.assimilis*, (c) *P. pyrrhonotus, and* (d) *T. paradisi* in 2070 at RCP 8.5. Maps predicted the habitat suitability with a red color area.

Discussion

In any model forecasting species' future distribution pattern and habitat suitability under climate change scenarios, SDMs are significant tools for understanding the ecological, ethological, and biological requirements of species (Morelli et al., 2020; Penteriani et al., 2019). Preliminary research has indicated that climate change induces alteration in habitat distribution patterns with shift towards higher altitudes and lower latitudes (Lenoir & Svenning, 2015; Zahoor et al., 2022). In developing countries where conservation planning is inadequate, assessing the future of these endemic birds by filling the knowledge gaps related to environmental conditions, distribution, and habitat suitability would be highly beneficial.

Projected effect of change in climate on the endemic bird' species of the Subcontinent

The changes in habitat suitability and bird species shifting toward east and north altitudinal ranges is in accordance with the preliminary studies that indicate a decline in habitat suitability of many of the birds under the global warming situation (Chhetri et al., 2021). However, projected habitat alteration up to 2050 and 2070 is based on fluctuations in carbon dioxide emissions, a major gas responsible for environmental perturbation, as reported by (Abbasi et al., 2020). Out of four species, the maximum future habitat suitable area is for *P. pyrrhonotus* as compared to *A. nigriceps*, *D. assimilis,* and *T. paradisi*. Our findings projected that the ranges of north and east altitudes and lower north latitudinal would provide suitable habitats in the future for the endemic species. The ground birds at higher altitudes get diet and protection to a limited extent; thus, a shift towards elevation and decline in suitable habitat could limit the natural resources and increase intra- and interspecific competition for food, water, and shelter, which would lead to species extirpations.

In all regions of the subcontinent, the eastern part will face a decline as compared to other parts, as the present distribution of *A. nigriceps* showed the habitat suitability contracted from the east. However, earlier investigations showed its maximum distribution in eastern Punjab (A. A. Khan et al., 2008). Records of occurrence were obtained based on human observation from GBIF for 1980 to 2019. It is important to conduct a survey in the eastern regions of Punjab for protection and conservation in those regions where it is found critically endangered and needs to be recovered in all possible situations. Anthropogenic activities should be reduced, such as hunting, deforestation, and egg damage, and the site of breeding sites for birds must be taken into consideration.

Projected effect of the change in climate on endemic species of the Subcontinent extinction

In population reduction, factors such as climate change and decline in habitat suitability are associated with each other, especially for restricted-range and endemic species (de Moraes et al., 2020). When suitable habitat is reduced, it also causes a prominent decline in species distribution, the risks of species extinction would increase (Powers & Jetz, 2019). Present findings are consistent with the work by (Jetz et al., 2007) Those who assessed the impact of an increase in temperature had a severe effect on bird species worldwide, most commonly on birds of a specific region and lowland areas (de Moraes et al., 2020).

In the present study under RCP 4.5, three species, *A. nigriceps, D. assimilis* and *P. pyrrhontus* have a probability of extinction -1%, and for *T. paradisi,* 0.5% in the year 2050. Additionally, under RCP 8.5, *D. assimilis* has a probability of extinction of 2% in the year 2070. In the subcontinent, a large human population and rapid change in two environmental drivers, temperature and precipitation hurt birds. It is expected that in the future, an increase in human population activities will directly affect hunting, deforestation, and agricultural activities which would greatly impact bird diversity (Kabir et al., 2017; Zahoor, Liu, Ahmad, et al., 2021). For the evaluation of climatic impact on birds, it is important to consider the predictors of climate to devise a useful conservation strategy (Eyres et al., 2017).

Study Limitations

The study limitations are such that we used only species presence data for species distribution plots, while for future modeling, some layers were used. Although maps of ranges provide a general projection of changes in species distribution patterns. During the current study, non-climatic factors like methods of distribution, epidemics, and the effect of exotic species were disregarded, which may have hampered the ability to track the distribution of species. Despite the study's uncertainties and assumptions, these models may be very helpful in developing conservation plans that will reduce the future impact of changes in climate on these endemic species (subcontinent) (Ackerly et al., 2010; Wiens et al., 2010).

Conclusion

For four endemic species of the subcontinent, viz. *A. nigriceps, D. assimilis, P. pyrrhonotus* and *T. paradisi*, the suitability of habitat was predicted by SDM for current and future up to 2050 and 2070. The models predicted changes in habitat suitability for all four endemic species in the future due to changes in climate patterns. Our findings indicated the habitat contraction and expansion of colonization to higher altitudes of the northeast and lower latitudes of northern areas. A clear decline in suitable areas was observed up to 2050 and 2070 under RCP 4.5 and 8.5, respectively. For conservation implications and status improvement of these four endemic species, a proper framework is required for the management of protected areas in the subcontinent to mitigate the impacts of climate change.

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