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Research Article

Impacts of rising temperatures and precipitation on the survival of Near-Threatened reptiles in Pakistan

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Abstract

The Near-Threatened reptilian species of Pakistan are particularly vulnerable to climate change, especially due to variations in temperature and precipitation. This country hosts a diverse and exceptional reptilian fauna, owing to its varied ecological gradients and complex zoogeographic regions. In the present study, we evaluated the impact of temperature and precipitation on Near-Threatened reptile species viz. (*Crossobamon orientalis*, *Eryx conicus*, *Eryx johnii*, and *Python molurus*) under the current and future conditions for the years 2050 and 2070. To achieve this, we utilized present and projected climatic data from Worldclim and species occurrence records from GBIF (Global Biodiversity Information Facility). We modelled current distributions (1980-2019) and future distributions (averaged between 2050 and 2070) using MaxEnt. For future climatic scenarios, we considered two peak carbon-emission pathways: RCP 4.5 and RCP 8.5, providing an overview of environmental conditions and habitat suitability for the species in question. Our results indicate that under both RCP 4.5 and RCP 8.5 scenarios, the distribution of all four targeted reptilian species is projected to shift toward higher northern altitudes and from central-eastern regions extending into lower eastern altitudes. Compared to current suitable habitats, we estimate an average habitat loss of approximately 35 % by 2050 and 50 % by 2070. These findings are critical for policymakers and conservationists as they highlight specific geographic areas and timeframes where habitat loss is most severe.

Keywords: Species distribution modeling, Temperature, Precipitation, Near-Threatened species, RCP 4.5 and 8.5

Introduction

Pakistan is ranked high in vulnerability to climate change, especially temperature and precipitation. It's critical to assess the potential responses of threatened fauna towards these changes in the near and far future. Because of the predominating arid to semi-arid zone makes the habitat situation appropriate for the majority of reptiles in this part of the region. (Khan, 2004, 2011). Few studies have focused on changes in Pakistan's faunal ecological communities; still, we lack a systematic assessment of climate change's influence on species distribution and habitat suitability in terms of geographical range shifts. Pakistan is host to extremely varied and exceptional reptilian fauna, regardless of its exclusive landscapes; the reptilian biodiversity of this diversified region remained unexplored in the current climatic fluctuation scenario and future predictions (Xu et al., 2009). In terms of comparing temperature change and precipitation, the reptiles are a particularly suitable model group among all animals. The temperatures and moisture affect multiple characteristics of reptile biology, making them vulnerable to such changes and are considered as excellent indicators of climate on biodiversity.

At multiple scales, the geographical distribution of species and habitat suitability can easily be predicted by using a species distribution modeling approach (Jetz & Rahbek, 2002; Jones et al., 2007). A species distribution model SDM was used to assess species rarity and mobility. Several studies based on species atlas or presence/ absence data established the fact that species having either a large number of occurrence records or occupying a very large area have a larger range size, and are found over a greater range of environmental conditions via generated models having lower accuracy than those species with a smaller range (Araújo et al., 2011; Brotons et al., 2004; Segurado & Araujo, 2004). According to the report of IUCN for the year 2009, about 1895 species out of 6285 (30%) Reptilian species are designated as threatened at the global level due to habitat destruction as a result of climate change (Collins & Storfer, 2003; Gibbons & Stangel, 1999).

In past times, momentous episodes of increased global warming and cooling, with average global temperature and precipitation of certain past eras elevated above the current temperature (Zachos et al., 2001). It is categorically far from the capability of any species to acclimate to this rate of change in their surroundings (Kingsolver, 2009; Markham, 1996). There is also experimental confirmation that temperature changes already have innumerable effects on distinctive phases of the ecology of an organism, including reptiles (Boone et al., 2003). Demonstrating the temperature requirements of any species and matching their temperature envelope with expected climate settings of the future to show that many of them will face shifts in their ranges and have a considerable threat of extinction at the global scale (Araújo et al., 2006; Thuiller, 2003). Keeping all in view, the study was devised to achieve the following objectives:

- To analyze the impact of current and projected temperatures on the distribution pattern of Near-Threatened species of reptiles in Pakistan.
- To access the habitat suitability for the studied group during the projected temperature scenario.

Materials and methods

Species occurrence record and bioclimatic variables data

Data collected over the past forty years (1980 – 2019) from GBIF (https:// www. gbif. org), including human observations, and excluded the points having no geographical coordinates from the estimations of absence and presence of species in altered localities (Araújo et al., 2011). We used 19 bio-climate variables, reportedly directly related to the distributions of these vertebrates, and were taken from the WorldClim Version 1.4 datasets. We resampled distribution maps and environmental data onto a one kilometers by1km equal-area grid, which was used for fitting models of distribution. We fitted distribution models using three methods frequently used (i.e, MAXENT, generalized linear model (GLM), and Bioclim. To sidestep step impact of multi-collinearity amongst variables to predict results, we made several changes. Firstly, we used the jack-knife test for evaluation of the contribution of each variable, thus variables contributing less than 1percent in MaxEnt were removed. Afterwards, Pearson's correlation coefficient was applied to test the multicollinearity among the remaining variables, and only variables with a Pearson's |r| having a value equal to or greater than 0.8 were taken. Lastly, the remaining variables were used for further developing S.D.Ms. For predictions in the future, we utilized two general circulation models (GCMs) for the prediction of near-threatened reptile species distributions: CCSM (Community Climate System Model), and HadGEM2-ES (Hadley Center Global Environment Model version 2) for the projection of species distributions in the future. In case of each G.C.M, we designated two carbon emission scenarios (Representative Concentration Pathways), RCP 4.5 and 8.5 (Araújo & New, 2007).

Species distribution modeling (SDM)

The simulations forecasting spatial (spreading in given space and time) can mimic the fitness of species' habitats on diverse scales, based on characteristics of the site and records of species, to gain awareness into ecological/evolutionary drivers, or to assess the suitability of habitat over vast scales. The SDM approach has become a vital tool in biology, ecology, and conservation biology (Phillips et al., 2006). To draw up predictive maps of species regarding distribution and habitat suitability, SDM templates are based on presence-only or presence-absence data used extensively in the characterization of the ecological niche of species and to forecast the geographical dissemination of their habitat in biogeography. Presence-only data is a dominant source depicting species occurrence data, it also allows for easy private and public participation in biological monitoring (Elith et al., 2011).

Among all algorithms existing, the most extensively used procedure of creating SDMs is MaxEnt. MaxEnt utilizes entropy to simplify unambiguous observations of presence-only data and doesn't entail or include areas with species' absence within the theoretical framework. Maxent model imitates the suitable geographical distribution of species, is advantageous than other paradigms, because it includes a good presentation having incomplete datasets, runs in short times, is easily operated, and has high simulation precision (Hernandez et al., 2006).

Results

Species Occurrence Records

A total of 472 occurrence records were found for all four near-threatened species from GBIF (https:// www.gbif.org), including human observations, and excluded the points having no geographical coordinates (Table 1).

Table 1. Occurrence records and IUCN status of threatened reptilian species of Pakistan

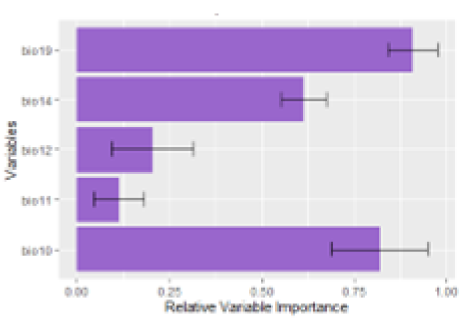
Species Name	No of observations	Order	IUCN status
Eryx conicus	152	Squamata	Near threatened
Eryx johnii	76	Squamata	Near threatened
Python molurus	214	Squamata	Near threatened
Crossobamon orientalis	30	Squamata	Endemic/ vulnerable

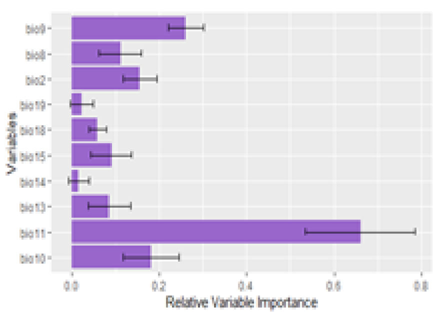
The results of the jack-knife test showed the importance of various bioclimatic variables on these species. The test results exhibited the relative contribution of the bioclimatic variables' mean value on animal distribution in current and future times. It was revealed that different environmental variables exhibited maximum contribution on the distribution of four species under RCP 4.5 (year 2050), with (Bio-19) 60.4% on *C. orientalis*, (Bio-11) 54.5% on *E. conicus*, (Bio-08) 28.9% on *E. johnii,* and (Bio-13) 14.6% on *P. molurus* (Table 2, Figure 1). Whereas, under RCP 8.5 (year 2070), (Bio-19) 60% on *C. orientalis*, (Bio-11) 34.7% on *E. conicus*, (Bio-08) 34.8% on *E. johnii,* and (Bio-08) 45.7% on *P. molurus* showed maximum contribution (Table 3, Figure 2).

Table 2. Percentage contribution of bioclimatic variables for modeling on four Near-Threatened reptiles of Pakistan under RCP 4.5 for the year 2050.

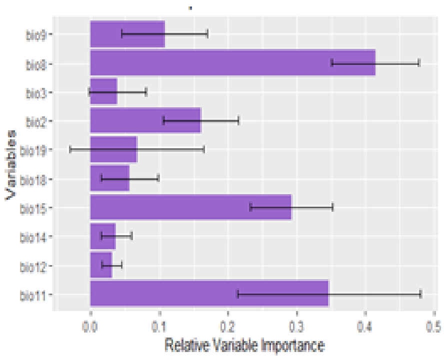
Variable	Description	Units	***Crossobamon orientalis***	***Eryx conicus***	***Eryx Johnii***	***Python molurus***
Bio-1	Annual averaged temperature	°C	0%	0%	0%	13.9%
Bio-2	Average diurnal range	°C	0%	6.2%	4.3%	0.9%
Bio-3	Temperature consistency	°C	0%	0%	0.7%	0.7%
Bio-4	Temperature seasonality	°C	0%	0%	0%	0%
Bio-5	Maximum temperature of the warmest month	°C	0%	0%	0%	0%

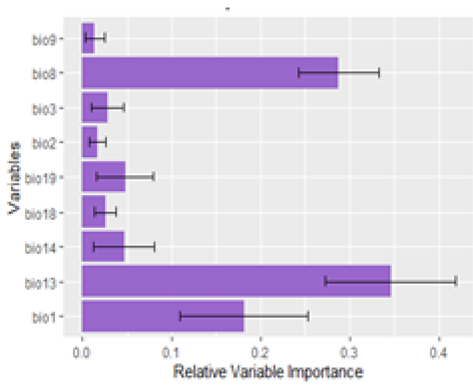
Bio-6	Minimum temperature of the coldest month	°C	0%	0%	0%	0%
Bio-7	Annual temperature range	°C	0%	0%	0%	0%
Bio-8	Mean temperature of the wettest quarter	°C	0%	3.2%	28.9%	25.2%
Bio-9	Mean temperature of driest quarter	°C	0%	9.9%	3.3%	0.7%
Bio-10	Mean temperature of the warmest quarter	°C	54.4%	7.8%	0%	0%
Bio-11	Mean temperature of the coldest quarter	°C	1.4%	54.5%	25.3%	0%
Bio-12	Annual precipitation	Mm	5.2%	0%	0.9%	0%
Bio-13	Precipitation of the wettest month	Mm	0%	2.1%	0%	14.6%
Bio-14	Precipitation of the driest month	Mm	12.3%	0.7%	0.6%	1%
Bio-15	Precipitation seasonality	Mm	0%	2.1%	6.9%	0%
Bio-16	Precipitation of the wettest quarter	Mm	0%	0%	0%	0%
Bio-17	Precipitation of the driest quarter	Mm	0%	0%	0%	0%
Bio-18	Precipitation of the warmest quarter	Mm	0%	2.6%	1.2%	0.7%
Bio-19	Precipitation of the coldest quarter	Mm	60.4%	0.6%	0.1%	1.3%





a. *C. orientalis* b. *E. conicus*



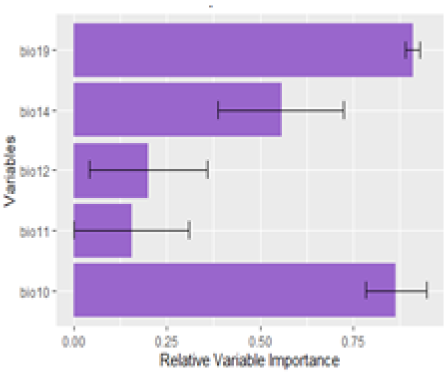


c. *E. johnii* d. *P. molurus*

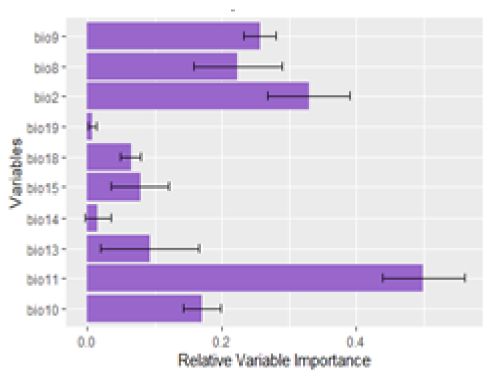
Figure 1. The bar-chart showing the relative variable importance of various bioclimatic variables on four reptilian species distribution model at RCP 4.5, year 2050.

Table 3. Percentage contribution of bioclimatic variables for modeling on four Near-Threatened reptiles of Pakistan under RCP 8.5 for year 2070.

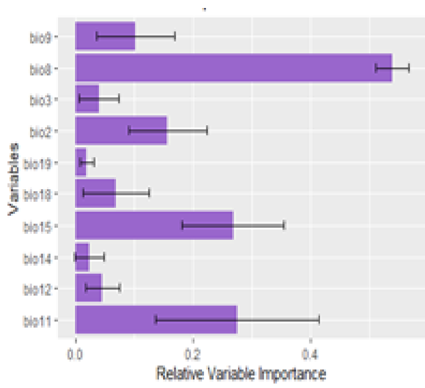
Variable	Description	Units	*C. orientalis*	*E. conicus*	*E. Johnii*	*P. molurus*
Bio-01	Annual averaged temperature	°C	0%	0%	0%	6.2%
Bio-02	Average diurnal range	°C	0%	11.9%	3.1%	2.1%
Bio-03	Temperature consistency	°C	0%	0%	1.4%	0.6%
Bio-04	Temperature seasonality	°C	0%	0%	0%	0%
Bio-05	Maximum temperature of the warmest month	°C	0%	0%	0%	0%
Bio-06	Minimum temperature of the coldest month	°C	0%	0%	0%	0%
Bio-07	Annual temperature range	°C	0%	0%	0%	0%
Bio-08	Mean temperature of the wettest quarter	°C	0%	9.1%	34.8%	45.7%
Bio-09	Mean temperature of driest quarter	°C	0%	9.6%	3.1%	6.4%
Bio-10	Mean temperature of the warmest quarter	°C	54.7%	8.1%	0%	0%
Bio-11	Mean temperature of the coldest quarter	°C	7%	34.7%	14.4%	0%
Bio-12	Annual precipitation	Mm	6.7%	0%	0.7%	0%
Bio-13	Precipitation of the wettest month	Mm	0%	2.6%	0%	17.8%
Bio-14	Precipitation of driest month	Mm	9.6%	0.6%	0.7%	0.3%
Bio-15	Precipitation seasonality	Mm	0%	2%	8.6%	0%
Bio-16	Precipitation of the wettest quarter	Mm	0%	0%	0%	0%
Bio-17	Precipitation of the driest quarter	Mm	0%	0%	0%	0%
Bio-18	Precipitation of the warmest quarter	Mm	0%	2.7%	2.3%	1.6%
Bio-19	Precipitation of the coldest quarter	Mm	60%	0.2%	0.4%	0.4%



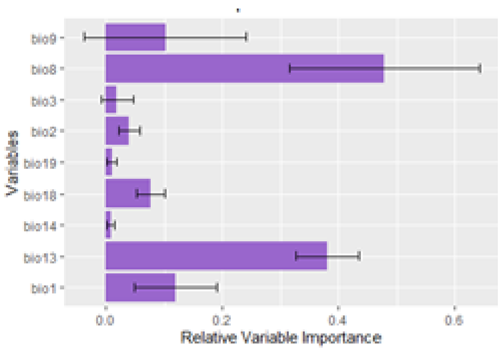
a.C. orientalis



b. *E. conicus*



c. *E. johnii*



d. *P. molurus*

Figure 2. The bar-chart showing the relative variable importance of various bioclimatic variables on four reptilian species distribution model at RCP 8.5, year 2070.

Species distribution model (SDM)

Model accuracy was assessed using the ROC-AUC curve, because of its ability to demonstrate the fraction of true absence and presence rate. The maximum TS (training-sensitivity) plus (specificity) logistic threshold (M.T.S.P.S) values of AUC aimed at *C. orientalis, E. conicus, E. johnii,* and *P. molurus* were greater than 0.9 in all four species, respectively, clearly indicating an excellent model performance. The values obtained through Maxent output for Area (R.O.C) and area under the curve (A.U.C) for four reptilian species by splitting species presence-data into test (30%) and training (70%) with standard deviation 'SD' (Table 4, Figure 3).

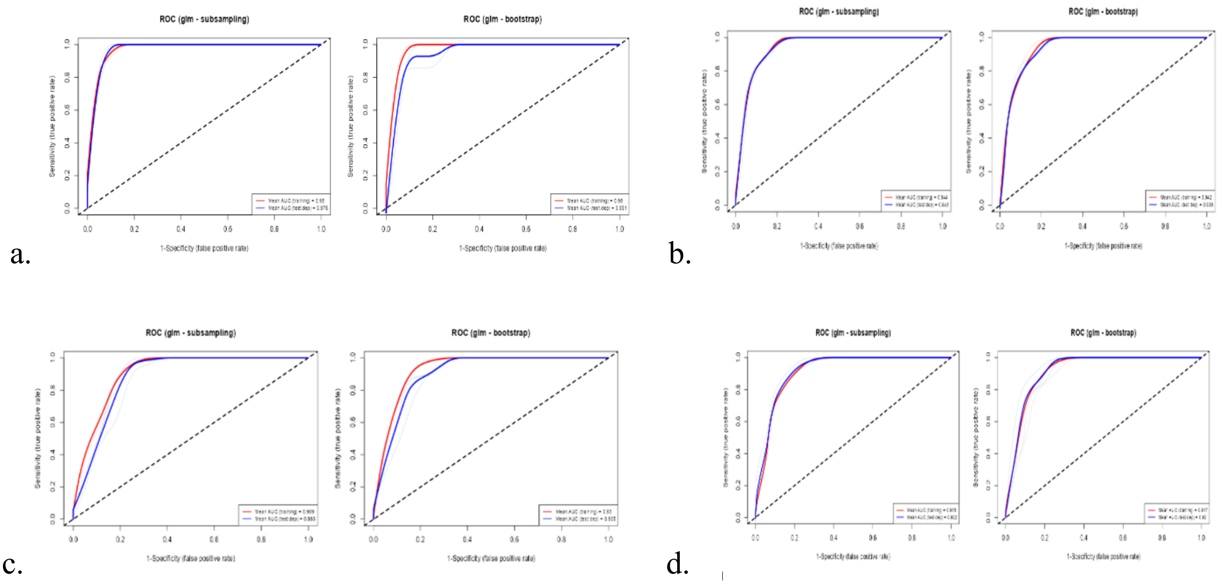


Figure 3. (a, b, c, d) showed receiver operator characteristics (ROC) curves for different species distribution models by using replication methods like sub-sampling and bootstrapping, and AUC for the prediction of habitat suitability for *C. orientalis, E. conicus, E. johnii,* and *P. molurus*. ROC curves showed (positive rate false-specificity) on the x-axis and (positive rate true-sensitivity) on the Y-axis, which described the correct and incorrect proportion of classified samples, while blue and red curves depict the mean value of AUC by using test and training datasets.

Table 4. Performance evaluation of SDMs using different statistical parameters. Sensitivity and specificity describe the rate of true positive and negative respectively.

Vulnerable Species **MaxEnt output**	**Training AUC±SD** **Test AUC±SD**
Crossobamon orientalis	(0.98±0.98) (0.976±0.951)
Eryx conicus	(0.944±0.942) (0.943±0.938)
Eryx johnii	(0.909±0.93) 0.883±0.905)
Python molurus	(0.915±0.917) (0.922±0.92)

Projected species distributions of four Near-Threatened reptilian species

The maximum training-sensitivity-plus-specificity logistic threshold (M.T.S.P.S) values for *C. orientalis, E. conicus, E. johnii,* and *P. molurus* were 0.98, 0.944, 0.909, and 0.915, respectively. The current species distributions of *C. orientalis, E. conicus, E. johnii, and P. molurus* is shown in Pakistan (Figure 4). The probability of species occurrence changed on the basis of presence and absence records due to bioclimatic variables under the future scenarios of RCP 4.5 and 8.5.

The probability of colonization of *C. orientalis* was 1% in 2050 towards higher northern latitudes and towards lower latitudes of the north in 2070, while the probability of extinction (-1%) was towards the center of the north in 2070, respectively (Figures 5 and Figure 6). The *E. conicus* expansion probability was (1%) toward higher altitudes of north and from the center of east to the lower altitude of east in 2050 and 2070, while a 0.5% extinction was observed in the upper altitude of north in 2070. The *E. johnii* expansion occurred (1%) toward the upper northern latitude and extended towards the lower altitude of the east in 2050 and from the lower northern latitudes to the center of the east in 2070, while the risk of extinction was observed (-0.5%) in the center of the east. Probability of expansion for *P. molurus* is extended (1%) from upper northern latitude toward altitudes of east in 2050 and extended towards the center of east and lower altitudes of east in 2070 while the extinction risk (0.2%) in 2070 in all regions from upper altitude to lower latitude of north and from the upper eastern latitude to the lower altitudes of east. Among the four species in the subject, three were mainly affected by temperature changes during 2050 and 2070 under both RCPs (Figure 5 and Figure 6).

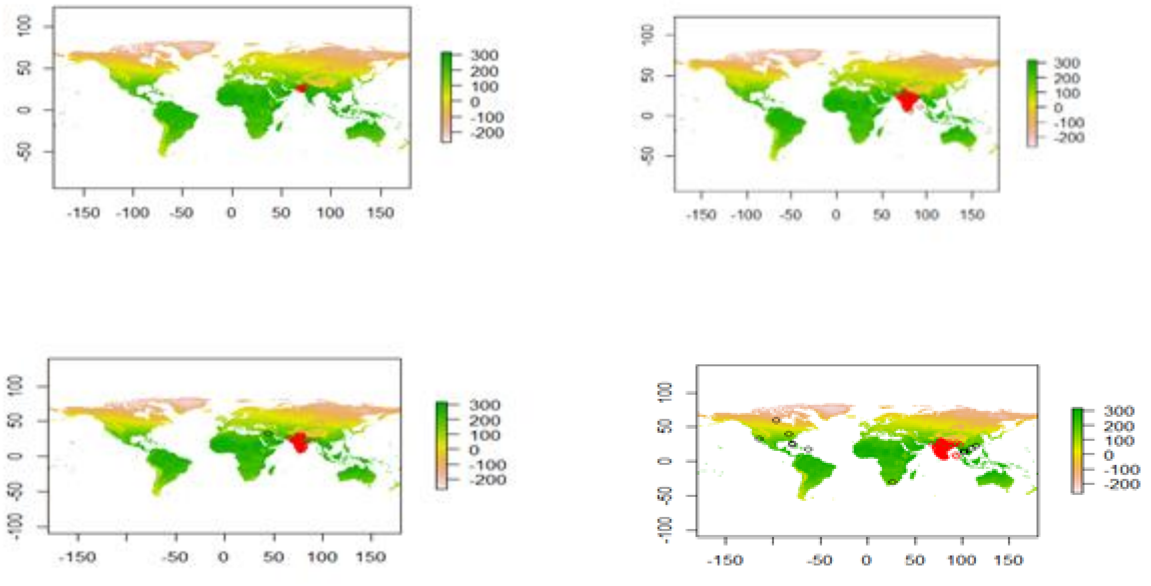


Figure 4. Location map showing the current distribution model for *the C. orientalis, E. conicus, E. johnii* and *P. molurus.* Red-filled circles indicate known occurrences, respectively.

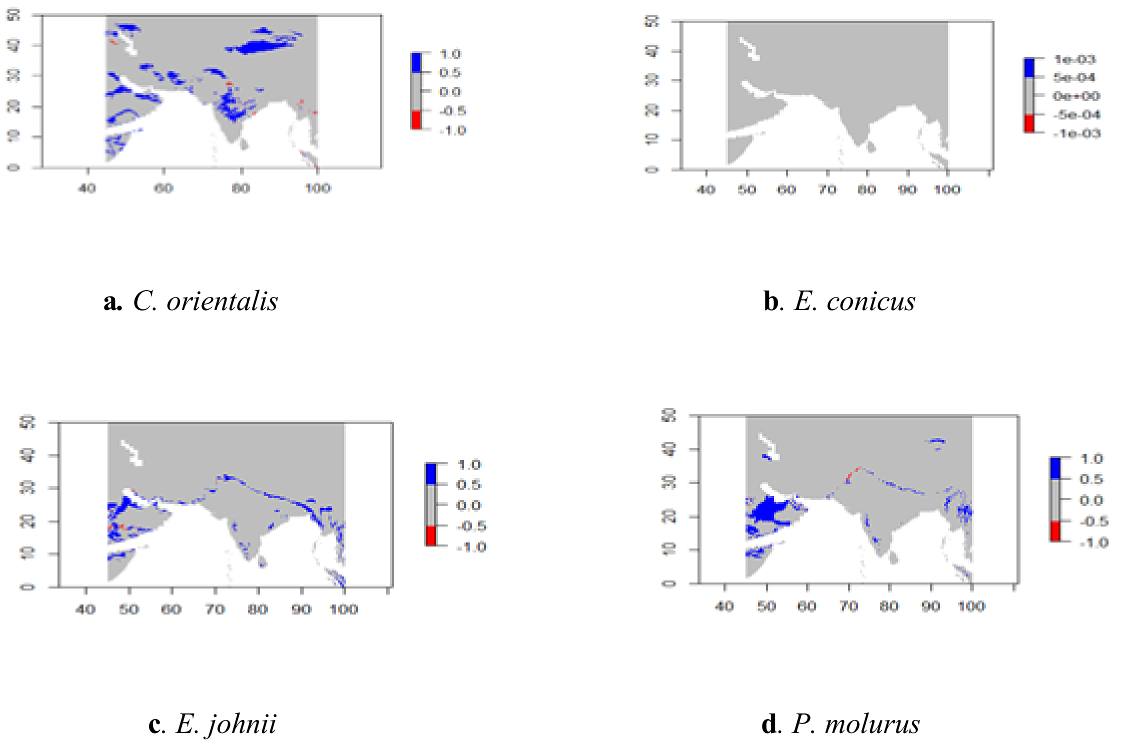
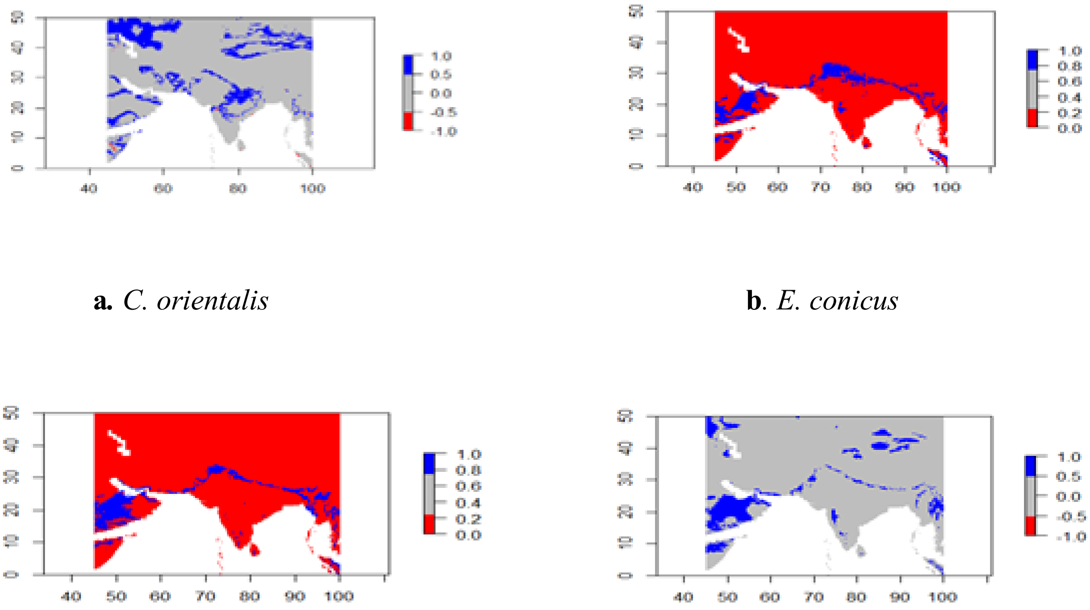


Figure 5 (a-d). Predicted distribution in 2050 for four species under the low Carbon-Emissions-Scenario (RCP 4.5). Maps designate continuous logistic prediction with blue areas (0.5 to 1) showing the maximum congregation range of species, while the red color (-0.5 to -1) shows areas where the species are lesser in number, along with decreased range.



a. *C. orientalis*

b. *E. conicus*

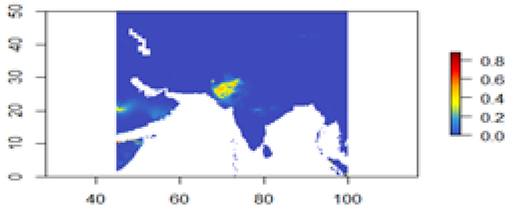
c. *E. johnii*

d. *P. molurus*

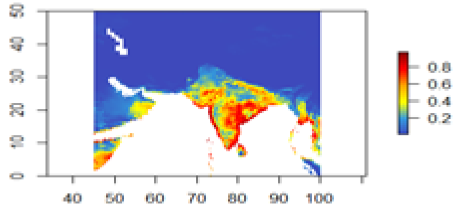
Figure 6 (a-d). Predicted distribution in 2070 for four species under high Carbon-Emissions-Scenario (RCP 8.5).

Current Habitat Suitability

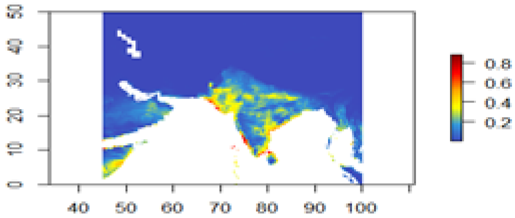
Maps symbolize continuous logistic prediction with red areas (values closer to 0.8) indicating the most suitable for the species where it resides most of the time. Plot 1 showed a suitable habitat range for *C. orientalis that* extends towards latitudes of the east, whereas Plot 2 showed a suitable habitat range of *E. conicus that* extends from altitudes of the east and towards latitudes of the north. Plot 3 showed the suitable habitat range of *E, johnii* extends from the latitudes of east to the center of east, while Plot 4 showed the suitable habitat range of *P. molurus* extends from the center of east to the northern latitude and altitude (Figure 7).



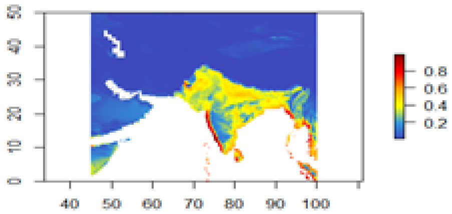
a. *C. orientalis*



b. *E. conicus*



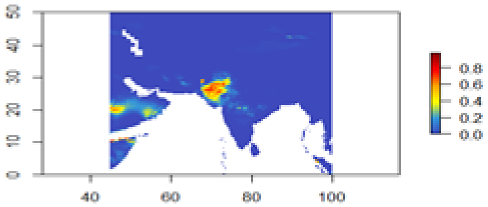
c. *E. johnii*



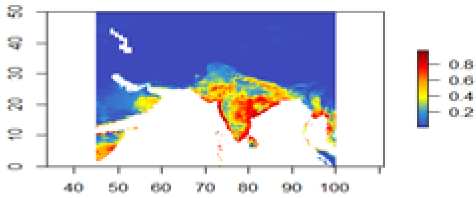
d. *P. molurus*

Figure 7 (a-d). Current habitat suitability for four species at RCP 4.5 by using General Circulation Models (GCMs) with values closer to 0.8 having high suitability.

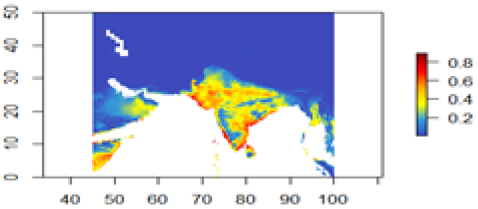
Future Habitat suitability



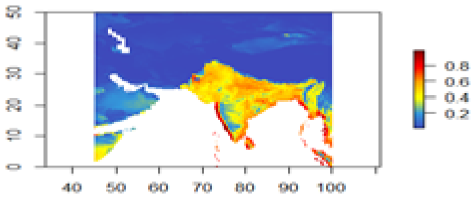
a. *C. orientalis*



b. *E. conicus*

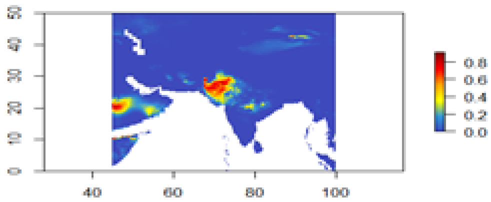


c. *E. johnii*

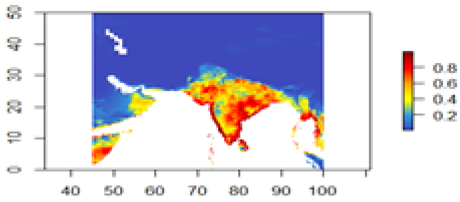


d. *P. molurus*

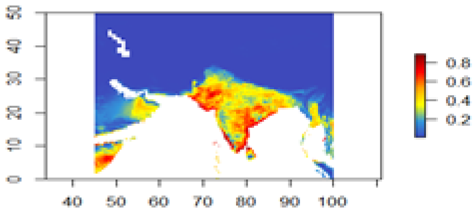
Figure 8 (a-d). Predicted distribution of four species in 2050 under the low Carbon-Emissions-Scenario (RCP 4.5).



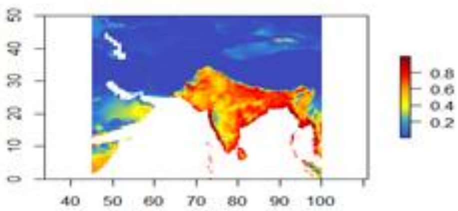
a. *C. orientalis*



b. *E. conicus*



c. *E. johnii*



d. *P. molurus*

Figure 9 (a-d). Predicted distribution of four species in (2070) under the high Carbon-Emissions-Scenario (RCP 8.5).

Discussion

Under the future climate scenarios, *the distribution of C. orientalis was predicted to shift towards the* north in 2050 and 2070, encompassing the coldest quarter. An indefinite distribution pattern was observed for *E. conicus.* The distribution of *E. johnii* and *P. molurus* was predicted to shift towards higher latitudes in 2050, with further expansion expected in 2070. All four species of reptiles are projected to experience a shift in their ranges due to bioclimatic variables under both RCPs 4.5 and 8.5 (for the years 2050 and 2070) (Fig. 8 and 9). Temperature inconsistency and changes in precipitation patterns affect biodiversity, resulting in contraction in species distribution and range shift changes, as well as changes in habitat suitability. Genetic variability and dispersal ability may help a species to adapt to temperature changes, whereas Reptiles do not move abundantly and are unable to cope with a stressful environment by dispersing from their native region to a new environment (Halpin, 1997). A lot of research work emphasized on vulnerable nature of reptiles to temperature-driven changes in their habitat (Mac, 1998). In the present work, the projected model emphasized on maximum suitable habitat area for *P. molurus*, while minimum suitable habitat for *C. orientalis, E. conicus and E. johnii* in future based on their skin covered with scales to tolerate higher temperatures and are mobile enough to escape stress caused by temperature rise (Brown, 1993) but still their habitats are vulnerable to changing temperatures

(Alvarez et al., 2017). Increased drought frequencies may affect reptilian species that are semiaquatic and depend on rivers, streams, and wetlands (Janzen, 1994).

Spatial response by any species to temperature changes is important for consideration in the alteration of geographical ranges. Species incapable of achieving sufficient spatial and adaptive responses have to undergo extinction in some regions, and in a few scenarios at the global scale. Therefore, species having a lower rate of dispersal and a narrow temperature range are likely to suffer most severely (Bradshaw & McNeilly, 1991). Thus, in the current study, current suitable habitats based on animal presence and future predictions about habitat suitability for these species under different carbon emission scenarios are precisely lined up. Our results are consistent with previous findings by (Biber et al., 2023) who reported that reptilian species richness and distribution patterns are projected to decline significantly across many regions at the global scale. Species distribution, habitat preference, and richness were all recorded to be uppermost in hot as well as moist territories, with these areas being estimated to shift more toward temperature extremes in the future. Range sizes are probably to decrease noticeably in the future, with a lower degree of overlap between current and future.

Conclusion

For the four reptilian species (*C. orientalis, E. conicus, E. johnii* and *P. molurus*), species distribution modelling predicted current and future habitat suitability in Pakistan for 2050 and 2070. The results revealed that different environmental variables exhibited maximum contribution on distribution of four species under RCP 4.5 (2050) and RCP 8.5 (2070) were (Bio-19) 60.4% and 60% for *C. orientalis*, (Bio-11) 54.5% and 34.7% for *E. conicus*, (Bio-08) 28.9% and 34.8% for *E. johnii* whereas, (Bio-13) 14.6% and 45.7% for *P. molurus.* Overall, under future climate scenarios, *C. orientalis, E.johnii,* and *P. molurus* are predicted to shift toward northern latitudes by 2050 and 2070, favoring areas with higher precipitation during the coldest quarter. These findings provide a solid framework for conservation planning and improving the status of these four reptilian species in Pakistan.

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