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Original Research

Modelling Impacts of Climate Change on Habitat Suitability of Three Endemic Plant Species in Pakistan

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Abstract

The use of species distribution modelling under climate change to anticipate alterations in species' habitats is a concern in ecological conservation. This research aimed to simulate the present suitable habitat distribution of three species that are rare and endemic to Pakistan and to analyse the possible climate change consequences on habitat suitability in the future (2050 and 2070). We projected potentially suitable habitat distributions using two shared socioeconomic pathways scenarios (SSPs 245 and SSPs 585). The potential distribution was modelled with MaxEnt using species presence-only data, and environmental variables. The modelling approach included seven climate-related variables in total. The model was validated using AUC, TSS, and Jackknife. For all species, the AUC score was >0.85. The present distribution of all three species has been significantly impacted by precipitation-related factors (bio 14, bio 17, and bio 18). The temperature and topographic diversity also impacted the distribution. The potentially suitable habitat for *Buxus papillosa* and *Rydingia limbata* is projected to increase (39 % and 44 % respectively) in the 2050s under SSPs 245, and the potentially suitable habitat for *Gentiana kurroo* is projected to decrease (24%) in 2070s under SSPs 585. All species may expect appropriate habitats to expand or shrink, however, there will probably be a significant loss of native habitats. We recommend designating climate-change-affected places as conservation protection zones based on these results.

Keywords: endemic, species distribution modelling, AUC, MaxEnt, habitat suitability

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Introduction

Since the turn of the twenty-first century, changing climate has posed substantial threats to the environment. Also, it is predicted that these dangers will become more severe as climate change proceeds and most likely quickens their pace [1, 2]. Conservation biologists and ecologists are studying how climate change impacts areas and species [3]. Climate change is anticipated to cause a rise in average temperature and a rise in rainfall during the rainy seasons. [4, 5], and a decrease in rainfall during the dry period. This will, in turn, cause a decrease in the amount of natural vegetation. This is especially important given that future climate estimates show a growing trend in greenhouse gas emissions and temperature. For instance, the average global warming is predicted to be between 0.3ºC and 4.5ºC by 2100 [6]. One of the fundamental actions that may be taken to protect plant species is called habitat restoration. To be successful, this action needs precise knowledge about the existing and potential distributions of species within each habitat [7, 8]. Therefore, the primary task that ecologists have is to comprehend the connections that exist between different species and the various aspects of their environments [9], as well as to anticipate the changes that these relationships will undergo [10]. The abundance and variety of flora are significantly being affected by climate change across the world, particularly in south Asia, and Pakistan, where there is an exceptionally high variety and richness of plant life. Pakistan is a prominent global conservation "hotspot" that is home to several rare and endemic plant species [11].

The conservation of endemic plant species requires consideration of how the distribution of these plants may be altered by a variety of natural and human processes, depending on the particular climate change scenario being considered. In this context, species distribution modelling, often known as SDM, is an important technique that may be used to make predictions and gain an understanding of the future distribution of natural vegetation [12].

SDM uses suitability indices to explain the interactions between various ecological variables and to assess the suitability of habitat for certain species. There are numerous different modelling algorithms, such as CLIMEX, maximum entropy (Maxent), and BIOMAPPER, that can be employed to investigate the requirements of species and the places in which they are found [13], as well as anticipate the habitat quality and species geographic distribution [14]. In general, these algorithms detect predictor factors and their correlations with responder variables and then forecast habitat appropriateness for a specific species in its distribution region [15]. The modelling methods for these models are constantly being refined to promote their broader application in the analysis of biogeography, species conservation and environmental management [16, 17].

Previously, SDMs were employed to figure out the suitable habitat distributions [18-20] and to simulate the possible consequences of changing climate on biological diversity [21, 22]. For predicting a species' distribution, MaxEnt is frequently utilized and solely uses species presence data records [23]. Numerous researchers proposed this method [24, 25] making it among the most powerful tools for identifying appropriate habitats and predicting potential distributions of species [26, 27]. Pakistan is an important global biodiversity hotspot and home to many endemic and rare plant species. Three species that are endemic to Pakistan, have different habitat statuses (herb, shrub and tree), and are rare in Pakistan are selected for potentially suitable habitat modeling in this study. These species are *Buxus papillosa* (tree), *Gentiana kurroo* (herb), and *Rydingia limbata* (shrub).

We utilized the Maxent model in this research to (1) anticipate the existing and potential habitat suitability of selected species endemic to Pakistan, and (2) determine the key climatic variables affecting the species' distribution. To accomplish these goals, we have utilized bioclimatic variables data and species' existence data, and two climate change scenarios of Shared Socioeconomic Pathways (SSPs) (SSP245 and SSP585) future projection (2050s and 2070s). Our modelling emphasizes the gradual loss of original habitat caused by climate change. The results might support to comprehend the patterns and processes of species distribution and adaptability to changing environmental conditions. They might also serve as conceptual underpinnings and a framework for more specialized management approaches for endemic and rare species threatened by climate change. These results may assist policymakers to identify additional protected areas for endemic and rare species.

Materials and Methods

Species Occurrence and Environmental Data

Several sources were used to gather existing occurrence records (the latitude and longitude) of endemic plant species. These sources include our field surveys in 2018-2021, iNaturalist (www.inaturalist.org), GBIF (www.gbif.org), and herbarium records. 141 occurrence sites of three species (39 for *Buxus papillosa*, 57 for *Gentiana kurroo* and 45 for *Rydingia limbata*) were retained for the analysis after removing duplicates (Fig. 1).

A total of 23 predictor variables were employed in the study. These include 19 bioclimatic variables collected directly from WorldClim (Source: www.worldclimate.org; accessed on 15 August, 2022) and 4 topographic variables (Earth Engine Data Catalogue). The environmental variables are detailed in Table 1. The elevation and bioclimatic data were retrieved directly from WorldClim, while the remaining

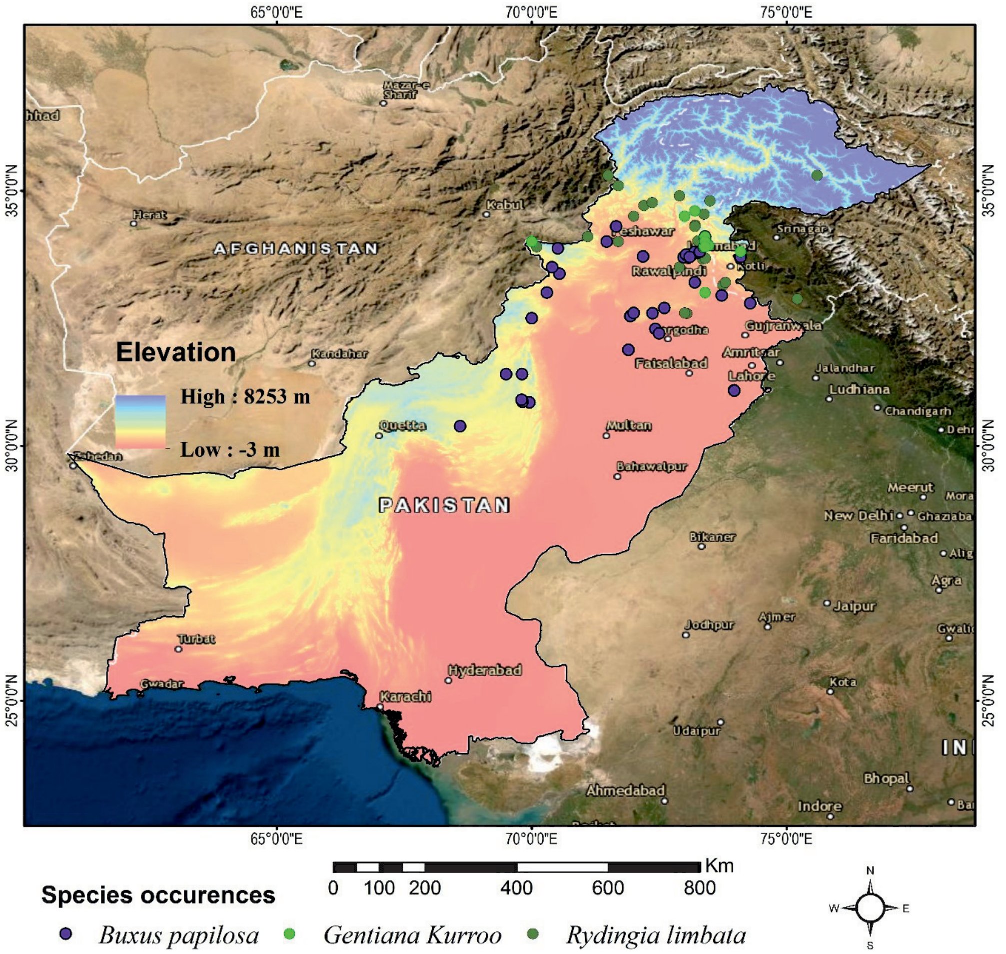

Fig. 1. Map illustrating the study area and known distribution range of three endemic plant species in Pakistan.

variables were retrieved and clipped to research area extent using the Google Earth Engine. The study utilized two climate change scenarios (SSP245 and SSP585) over two periods: 2050s (avg. of 2041-2060) and 2070s (avg. of 2061-2080). The Coupled Model Inter-comparison Project, Phase 6 (CMIP6) was used to simulate how climate change would alter appropriate species' suitable habitats. Predictions were produced using the BCC-CSM2-MR (resolution: 30 arc seconds), a Global Climate Model (GCM).

Table 1. The details of environmental variables employed in MaxEnt SDM of three endemic plant species in the study area.

Code	Database	Name of Variable	Resolution
Bio 4	WorldClim.	Temperature Seasonality	30 arc sec
Bio 6	WorldClim.	Minimum Temperature of Coldest Month	30 arc sec
Bio 7	WorldClim.	Temperature Annual Range	30 arc sec
Bio 14	WorldClim.	Precipitation of Driest Month	30 arc sec
Bio 17	WorldClim.	Precipitation of Driest Quarter	30 arc sec
Bio 18	WorldClim.	Precipitation of Warmest Quarter	30 arc sec
Elev.	SRTM DEM Global.	Elevation	30 arc sec
Hillshade	SRTM DEM Global.	Hillshade	30 arc sec
Slope	SRTM DEM Global.	Slope	30 arc sec
Tdiv	SRTM DEM Global.	Topographic Diversity	30 arc sec

Variable Selection

The maximum entropy algorithm (MaxEnt 3.4.4) was used to perform a SDM of three endemic species. The detailed flow chart of methodology is presented in Fig. 2. To screen the most influential variables, a complete model with all variables and default MaxEnt parameters was performed in the first phase of SDM. The variable with no contribution were exclude in this phase. Then, to eliminate highly correlated variables, Pearson correlation analysis [28] was executed on remaining variables. This resulted in the selection of 7 variables (Table 2).

Modelling Procedure

Using the MaxEnt 3.4.4 program [29], the existing climatic data was utilized to predict the present suitable habitat distribution. For modelling, the auto features tool was utilized, and the random test percentage with 10 repetitions was 20%. Cross-validation run type was set for replication, while all other settings were set as default. To validate the sensitivity and specificity of our model to the test data, we computed the Area Under Curve (AUC) [30]. These models were then projected using data from climate change scenarios to anticipate appropriate habitats in the years 2050s and 2070s. Using ArcMap's reclassification feature, we divided each species' potential habitat into four classes based on modelling results: the high habitat suitability (0.75-1), moderate (0.5-0.75), least suitability (0.25-0.5), and no suitability (<0.25). The area of suitable habitat under each class was calculated using the map algebra in ArcGIS ver. 10.8 [31, 32]. The rate of change in potential habitat suitability is calculated as conveyed by [32].

Results

Model Performance and the Significance of Variables

To assess model performance, the area under the ROC curve (AUC) was utilised. Each of the three species had an AUC greater than 0.85, showing that the models based on these datasets outperformed those based on a randomly selected absence site. The AUC score for three species is, 0.89 for *Buxus papillosa*, 0.95 for *Gentiana kurroo* and 0.91 for *Rydingia limbata*. In current distribution modelling, the bioclimatic factors that were most important to each species' model were different (Table 2). For two of the three species (*Gentiana kurroo* and *Rydingia limbata)* both of the model's most significant variables were precipitation-related (bio 14, bio 17 and bio 18). For *Buxus papillosa*,

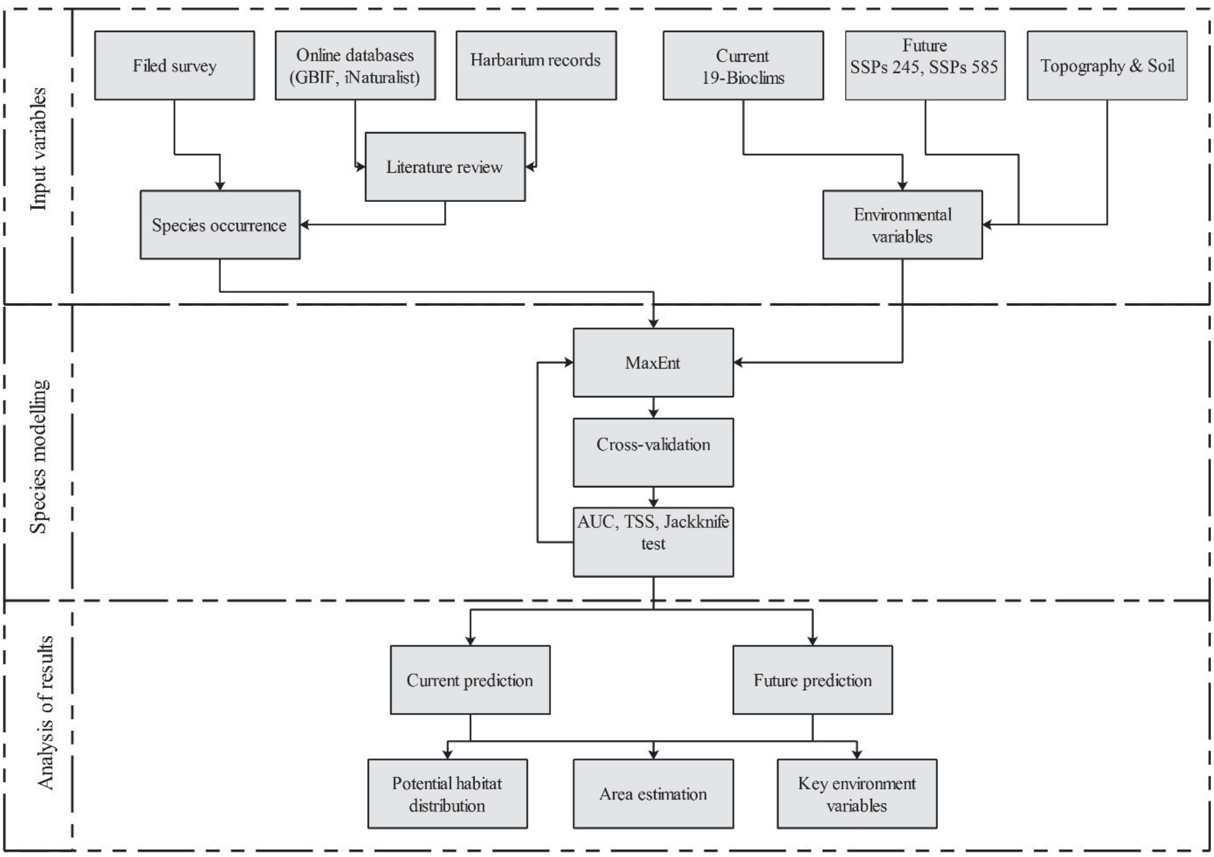

Fig. 2. Flow chart diagram methodology used in species distribution modelling of three enemic plant species.

Table 2. Contribution (%) of most influential seven environmental variables and Area Under the Curve (AUC) in SDM of three endemic plant species. (-) represents that variable not was not included for particular species.

Variable	Code	*Buxus papillosa*	*Gentiana kurroo*	*Rydingia limbata*
Temperature Seasonality	bio 04	6.8	-	-
Minimum temperature of Coldest Month	bio 06	29.1	17.4	-
Temperature Annual Range	bio 07	-	6.9	7.6
Precipitation of Driest Month	bio 14	37.2	-	24.5
Precipitation of Driest Quarter	bio 17	-	30.2	12.5
Precipitation of Wettest Quarter	bio 18	6.3	21.9	38.7
Topographic Diversity	T. div	20.6	23.6	16.7

precipitation related variables also contributed largely, but temperature (bio 6 and bio 7) had a significant impact on distribution of *Buxus papillosa.* T. div also had a significant impact on all species, especially *Gentiana kurroo*. The Jackknife test indicates the permutation-based relevance of explanatory variables, and it highlighted the significance of key variables such as bio 6, bio 7, bio 8, bio 14, bio 17, bio 18 and T. div. These findings demonstrated that each variable contributed to the model's gain. As a result, all of the added explanatory factors contributed to an increase in prediction probability with higher reliability.

Current Distribution of Endemic Species

The modelling shows that the current probable distribution of all three endemic species is found to be situated at high elevations (mostly above 1000m). The potentially suitable habitat for *Buxus papillosa, Gentiana kurroo,* and *Rydingia limbata* are relatively widely distributed, and mostly located in the lesser Himalayan region of Pakistan (Fig. 3). For *Buxus papillosa*, the total projected (>0.25) suitable habitat is 38629 km^2 (5.7%) and the projected high suitable area is 4551 km^2 (0.7%). For *Gentiana Kurroo*, the total projected (>0.25) suitable habitat is 6410 km^2 (0.9%) and the projected high suitable area is 4551 km^2 (0.7%). For *Rydingia limbata*, the total projected (>0.25) suitable habitat is 9732 km^2 (1.4%) and the projected high suitable area is 1718 km^2 (0.25%) (Table 3).

Future Predictions

This research predicted the potential habitat suitability of three endemic plant species using four anticipated climate change scenarios (SSPs 245 and SSPs 585) for 2050 and 2070. For each species, the probable consequences of climate change on suitable habitats vary (Fig. 4). In the 2050s, very high habitat suitability is anticipated to be increased under SSPs245 for *Buxus papillosa* and *Rydingia limbata.* The total suitable area (>0.25) for *Buxus papillosa* is projected to increase from 38629 km^2 to 55449 km^2 (44%), compared to the current climate. The high (>0.75) suitability area is projected to increase from 4551 km^2 to 6371 km^2 (39%) (Table 3). Similarly, the total suitable area (>0.25) for *Rydingia limbata* is projected to increase from 9732 km^2 to 18047 km^2 (44%). The high (>0.75) suitability area is projected to increase from 1718 km^2 to 4836 km^2 (182%) under SSPs 585. For *Gentiana kurroo*, the projected suitable habitat will decrease in the 2050s under SSPs 245. The total suitable (>0.25) area will decrease from 6410 km^2 to 5981 km^2 (-7%), and high (>0.75) suitable area is projected to decrease in the 2070s from 477 km^2 to 362 km^2 (-24%) under SSPs 585 (Table 3). Regardless of the anticipated increase in suitable habitat areas for certain species, it is predicted that the current suitable habitat for all species would decline. For each of the four potential future climate change scenarios being considered, the projected habitat suitability classes are mapped and provided in (Fig. 4).

Discussion

We modelled the current suitable habitat distribution of three endemic species in this study. According to the modelling we've done, the distribution pattern is significantly influenced by both the temperature and the amount of precipitation. According to prior study results, temperature and precipitation are the critical elements prompting plant species distribution patterns [33, 34]. The amount of precipitation that an area receives changes from place to place geographically and has a significant impact on biogeography more broadly at the levels of traits and biomes [35].

Pakistan, the present study area is located in a monsoon zone, and monsoon rains usually begin in June, reach their height in August, and eventually come to an end in September. The four summer months of monsoon always receive some good precipitation, Northern areas get a lot more rain on average than southern parts of the country [36]. This suggests that our endemic and rare species may be sensitive to the amount of precipitation they receive. In addition, we

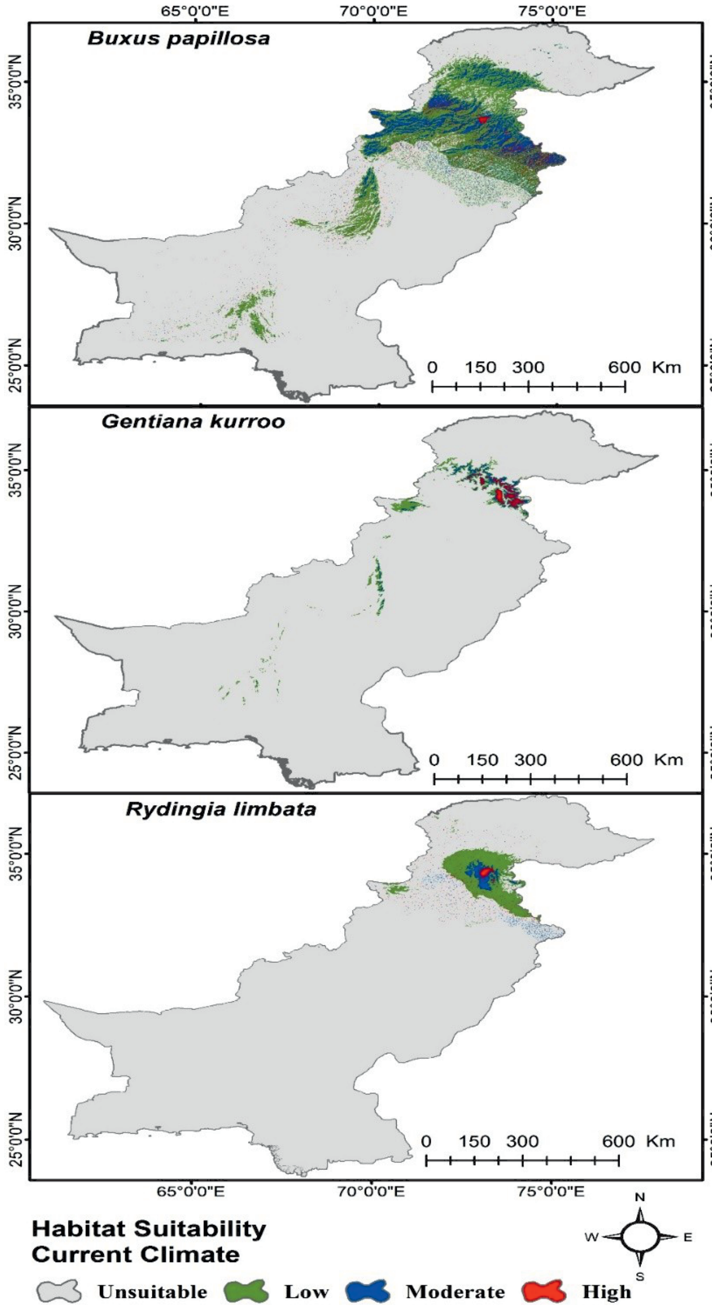

Fig. 3. Predicted habitat suitability of three endemic plant species in Pakistan under current climate. The highly suitable habitat is shown in red, while blue and green represent moderate to less suitability, and the unsuitable habitat is shown in grey.

developed a model to analyse how climate change may effects the suitable habitat distribution in the future for species that are endemic. According to our modelling, the distribution of suitable habitats is expected to go through both contractions and expansions in the future. Concerning conservation, we desire to emphasize that the shrinkage of the original habitat should get greater attention than habitat extension. Because our model anticipates the increase of appropriate habitat based only on climatic data, the compression of suitable habitat should be taken into account. However, human activities, biological interactions, and geological conditions may hinder this habitat extension [37].

On the other hand, because endemic species tend to have more restricted distributions, they are frequently more susceptible to extinction as a result of local impacts such as the destruction of their natural habitat and their contact with invasive species; climate change is exacerbating the impacts of these issues [38, 39]. The endemics have restricted geographic distributions that are frequently linked to a particular environmental niche. Endemics also have narrow population sizes, dispersion capacities, and the potential to adjust to changing conditions [40]. As a consequence of this, Locations with a substantial percentage of endemism are presumably more susceptible to impacts

Table 3. The potential suitable habitat distribution (area in km^2) for three endemic plant species under current and future climate change scenarios. The area was calculated using map algebra in ArcGis 10.8.

Climate scenario	Low (0.25-0.5)	Moderate (0.5-75)	High (>0.75)	Total Suitable area (>0.25)
Buxus papillosa				
Current climate	30611	3467	4551	38629
SSPs 245 (2050s)	41263	7869	6317	55449
Rate of change (%)	35	127	39	44
SSPs 245 (2070s)	36225	4537	5488	46250
Rate of change (%)	18	31	21	20
SSPs 585 (2050s)	37686	7550	5954	51190
Rate of change (%)	23	118	31	33
SSPs 585 (2070s)	34739	5469	5331	45539
Rate of change (%)	13	58	17	18
Gentiana kurroo				
Current climate	3827	2106	477	6410
SSPs 245 (2050s)	4309	1179	492	5981
Rate of change (%)	13	-44	3	-7
SSPs 245 (2070s)	5111	2451	1072	8635
Rate of change (%)	34	16	125	35
SSPs 585 (2050s)	4891	1266	362	6518
Rate of change (%)	28	-40	-24	2
SSPs 585 (2070s)	5169	2135	353	7658
Rate of change (%)	35%	1%	-26%	19
Rydingia limbata				
Current climate	5498	2516	1718	9732
SSPs 245 (2050s)	9188	5376	3482	18047
Rate of change (%)	67	114	103	85
SSPs 245 (2070s)	8105	4498	2699	15302
Rate of change (%)	47	79	57	57
SSPs 585 (2050s)	6911	4444	2468	13823
Rate of change (%)	26	77	44	42
SSPs 585 (2070s)	7420	5332	4836	17587
Rate of change (%)	35	112	182	81

of climate change on both individual species and entire groups [41, 42]. One limitation in our present study is that our modelling for suitable habitats for endemic species distribution was purely based on climate factors only. The distribution of species during climate change was determined solely by climatic considerations. Other environmental variables, such as anthropogenic activities, the soil type, and the quantity of pollinators may also impact dispersal [43]. Nevertheless, it is difficult to anticipate how all of these components would respond to global climate change.

We may conclude from our findings that the models utilized in this study are an effective strategy for determining suitable habitats for endemic species with a narrow distribution in Pakistan. In addition, the current and potential species distribution may also be projected with accuracy by the model. Numerous research has shown the usefulness of SDMs for determining optimal sites [7, 44]. However, SDMs have certain

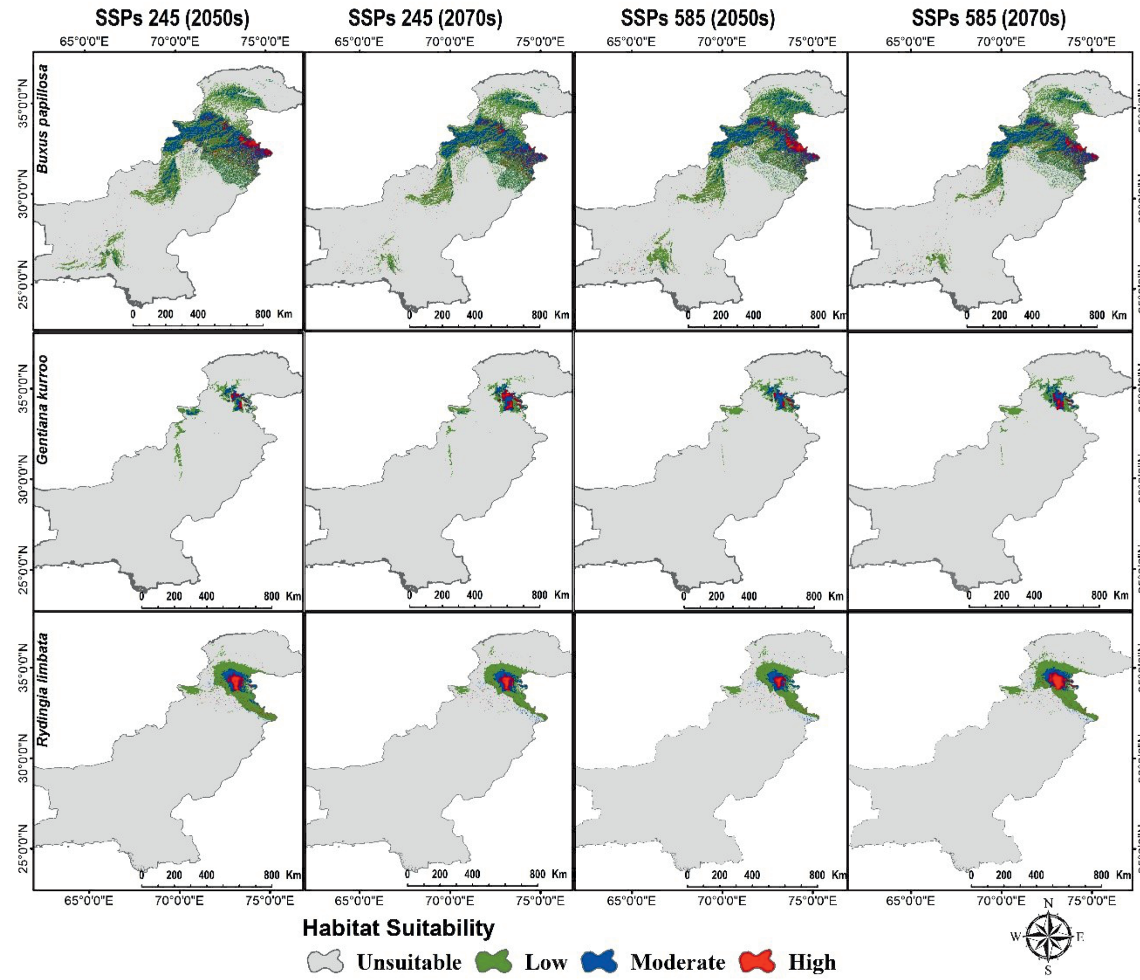

Fig. 4. Predicted habitat suitability of three endemic plant species in Pakistan under future (2050s, 2070s) climate scenarios SSPs (245 and 585). The highly suitable habitat is shown in red, while blue and green represent moderate to less suitability, and the unsuitable habitat is shown in grey.

limits, particularly when there is little data available for an efficient modelling procedure [45]. According to recent studies, SDMs are effective for anticipating the habitat suitability of endemic species, particularly when projected climate change is properly considered, despite enormous uncertainty [12, 25, 46]. SDMs accuracy is dependent on data quality, especially the inclusion of anthropogenic activities and species interactions that are typically absent in regions like our area of study. Although making effective decisions to minimize climate change is a global problem [47], there should be specific recommendations for how to protect endemic species from the threats that climate change brings. Along with climate change, other causes, including logging, fire, and changing agriculture, may threaten the natural suitable habitat. These anthropogenic activities should be restricted to lessen the pace of habitat loss in these regions. The vulnerable endemic species may also be protected from climate change by preserving and reintroducing them into places where appropriate habitat is anticipated to grow. Conservationists must devote resources and time, to prevent the extinction of these species endemic to Pakistan.

Conclusion

Long-term climate change has the potential to alter the habitat distributions for various species since habitats are confined to favorable climate regions. Our study found that species distribution may contract and expand. This change may affect their populations. Temperature and precipitation are two key climatic variables that significantly affect the distribution of species. Long-term preservation depends on developing a strategy for species protection to prevent habitat loss. The findings might be used to management strategies and programs for biodiversity protection. This may help to increase adaptability to changing climatic scenarios while preserving the variety of species in natural habitats. Administrators may use these maps to prioritize conservation activities in high-risk regions. Future surveys, conservation, monitoring, and management strategies will benefit from this research. Finally, these approaches must be accompanied by public awareness and governmental actions aimed at reducing human activity.

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Conflict of Interest

The authors declare no conflict of interest.

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