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MaxEnt modelling for predicting habitat suitability and future range of Black-breasted Parrotbill (*Paradoxornis flavirostris* Gould, 1836) in Northeast India

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Abstract Habitat suitability models are powerful tools in predicting species distributions and assessing the potential impacts of environmental changes. In this article, a habitat suitability model was developed for *Paradoxornis flavirostris*, a threatened (Vulnerable) bird species found in the northeastern part of India, using remote sensing data and machine learning techniques. The occurrence records for *P. flavirostris* were considered from primary as well as multiple secondary sources like GBIF & eBird, and bioclimatic variables such as temperature, precipitation, and humidity were collected from www.worldclim.org. Then, MaxEnt algorithm was used to model the habitat suitability of *P. flavirostris* based on the collected data. Additionally, the model was also run to project the future range of *P. flavirostris* under different climate change scenarios. The model also predicts potentially suitable habitats for *P. flavirostris* outside of its current range, suggesting areas where the species may expand or contract its distribution in the future. This research provides valuable insights into the habitat suitability and potential range dynamics of *P. flavirostris*, and can inform conservation planning and management efforts for this threatened bird species.

Keywords: Habitat Suitability Model, MaxEnt, vulnerable, climate change, *Paradoxornis flavirostris*

Összefoglalás Az élőhely-alkalmassági modellek hatékony eszközök a fajok elterjedésének prediktálására és a környezeti változások potenciális hatásainak becslésére. A jelen cikkben egy veszélyeztetett (Sérülékeny – IUCN), India északkeleti részén élő madárfaj, a dzsungel-papagájcsőrű cinege *Paradoxornis flavirostris* élőhely-alkalmassági modelljét készítettük el távérzékelési adatok és géptanulásos technikák alkalmazásával. A vizsgált faj előfordulási adatait elsődleges és számos másodlagos forrásból gyűjtöttük, mint amilyen a GBIF vagy az eBird, míg a bioklimatikus változókat (hőmérséklet, csapadék és páratartalom) a worldclim.org adatbázisból töltöttük le. Ezt követően a MaxEnt algoritmust alkalmaztuk a *P. flavirostris* élőhely-alkalmassági modelljének elkészítéséhez. A modellt arra is alkalmaztuk, hogy a faj különböző klímaváltozási szcenáriók szerinti jövőbeli elterjedési területeit jósoljuk. A modell alkalmas élőhelyeket jelez a *P. flavirostris* számára a jelenlegi elterjedési területén kívül, illetve olyan területeket is jelez, amelyekre a faj jövőbeli elterjedése kiterjedhet vagy szűkülhet. A kutatás értékes szempontokat fogalmaz meg a vizsgált faj élőhely-alkalmassági és potenciális elterjedési területbeli dinamikája szempontjából, valamint e veszélyeztett faj megmentését célzó fajmegőrzési és élőhelykezelési programokhoz.

Kulcsszavak: élőhely-alkalmassági modell, MaxEnt, veszélyeztett, klímaváltozás, *Paradoxornis flavirostris*

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Introduction

Black-breasted Parrotbill (*Paradoxornis flavirostris* Gould 1836) is a globally threatened passerine that has been listed as a Vulnerable species in the IUCN Red List. This species is endemic to the Indian subcontinent, appearing in the plains and foothills of Arunachal Pradesh and Assam of northeastern India (BirdLife International 2001). Individuals are known for their distinct black breast and yellow bill, and are a popular subject for ornithologists and bird enthusiasts *(Figure 1A)*. This species is one of the few that specializes in lowland reed swamps and tall grassland habitats *(Figure 1B)*. Formerly the species was recorded commonly, from the upper Assam region (India), particularly observed from many localities, like Dhansirimukh (near Kaziranga) in the west, to Dibrugarh in the east, and in the basin of the Subansiri river near North Lakhimpur, from where series of specimens were collected (Stevens 1914). Subsequently, it seems that the species was unreported for a significant portion of the 1900s, and by the 1990s, it was included among the rarest birds of India. Except for one oral report from Jaldapara Wildlife Sanctuary in 1984 (which was the last time the species was documented at this location), the species was virtually unknown from 1911, until it was re-discovered at Dibru-Saikhowa National Park (Choudhury 1995, Allen 2002, Choudhury 2006, Krishnan 2021) and Kaziranga National Park (Barua & Sharma 1999) in the 1990s. It was also discovered at D'Ering Memorial Wildlife Sanctuary, Arunachal Pradesh around the same time (Singh 1995). Additionally, it has since been discovered in Manas National Park, Assam (Choudhury 2011), considerably to the west of recently known areas, and Keibul Lamjao National Park, Manipur (Rahmani 2016, Rahmani *et al.* 2018), from where it was previously unknown, grasslands in the Siang (A. Choudhury, personal observation, Krishnam 2021) and Dibang river valleys (Rahmani *et al.* 2018). However, there are no recent records from West Bengal, Cachar, the Subansiri basin in Assam, or Bangladesh. The remaining populations appear severely fragmented and isolated from each other and are likely declining. Formerly, the species may have occurred wherever

Figure 1. **A.** Black-breasted Parrotbill. **B.** Habitat of Black-breasted Parrotbill (Photo: © Chiranjib Bora)
1. ábra **A.** dzsungel-papagájcsőrű cinege. **B.** A dzsungel-papagájcsőrű cinege élőhelye (Fotó: Chiranjib Bora)

there was suitable grassland in its range, suggesting that the extensive loss of grassland has isolated populations from each other (Collar *et al.* 2001). The primary threat to the Black-breasted Parrotbill (BBP) is habitat loss due to the drainage and conversion of floodplain grasslands (Rahmani 2016, Krishnan 2021).

Climate change is an important determinant of the range of many species (Pearson & Dawson 2003), also birds are highly sensitive to it, with a strong ability to move. They are often considered as pioneering indicator species of climate change on animals (Stephens *et al.* 2016). Changes in the climate are correlated with the temporal organization of bird species, including migration and breeding (Brown *et al.* 1999). Several bird species are likely to be affected by climate change in the future (Sekercioglu *et al.* 2008). Therefore, assessing the suitable habitat as well as the impact of climate change on threatened and endemic bird species is crucial for its conservation efforts. Habitat Suitability Models (HSM) are powerful tools and are applied in many fields of ecology, yet their outputs are based on several assumptions. Specially, in studies on biological consequences of climate change, HSMs have been used extensively to estimate the current distributions and future range shifts of species (Araujo & New 2007, Thuiller *et al.* 2008, Li *et al.* 2010, Li & Wang 2012). Researchers have described a wide variety of Habitat Suitability Models (HSMs) based on the algorithms. (Li & Wang 2013, Jha 2021).

Objective of the study

This study aims to estimate the current as well as the future geographic range of the Black-breasted Parrotbill, also the influential bioclimatic variables for the northeastern region of India using Habitat Suitability Modelling.

Materials and Methods

Study extent

The HSM was performed for the northeastern region of India which is an entity of eight states (Assam, Arunachal Pradesh, Manipur, Nagaland, Meghalaya, Tripura, Mizoram, and Sikkim). However, seven states (excluding Sikkim) were considered for this study. Presently, BBP is restricted only in the 3 states of NE India (Assam, Arunachal Pradesh, and Manipur), to evaluate the future range of BBP, the other 4 states were also considered.

Species occurrence data and bioclimatic predictors

Occurrence records of BBP were considered from primary field surveys as well as secondary sources like available literature and the Global Biodiversity Information Facility (GBIF, https://www.gbif.org). Literature were searched using the Google Scholar search engine and for model purposes, 84 occurrence points were considered *(Figure 2)*. To assess the current as well as future distribution range of BBP 19 bioclimatic variables *(Table 1)* downloaded

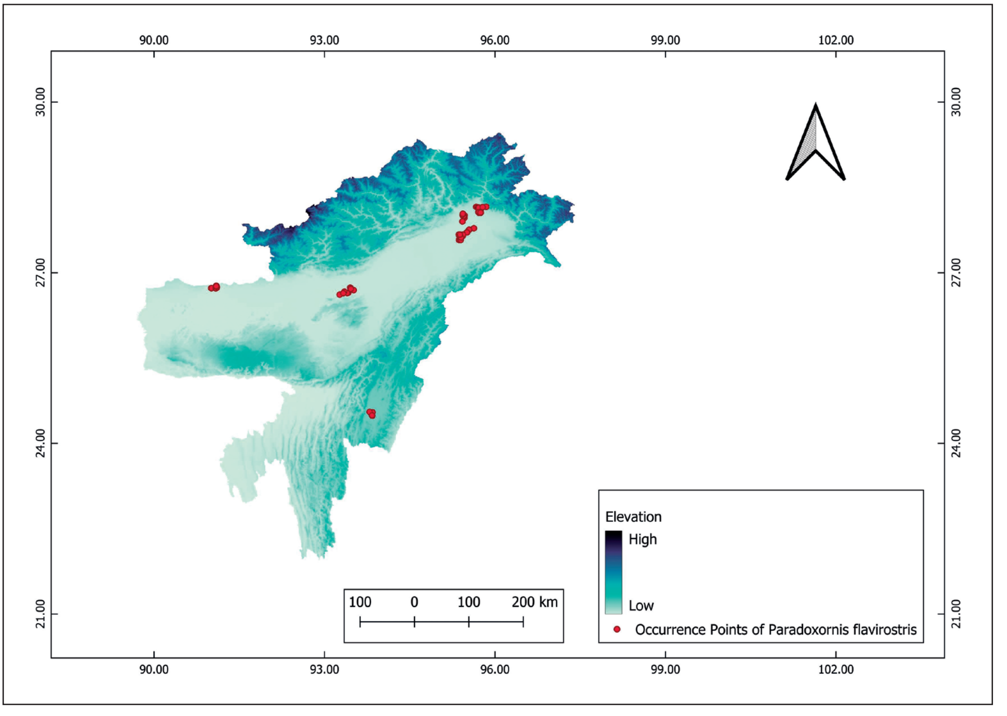


Figure 2. Map showing the study extent and the locations of the BBP
2. ábra A vizsgált terület és a vizsgált faj előfordulási adatainak térképe

at a spatial resolution of 30 arc sec (approx. 1 km resolution at the equator) from the Worldclim Climate database, version 2.1 (https://www.worldclim.org, Hijmans *et al.* 2005). These variables were calculated from minimum, maximum and average values of monthly, quarterly, and annual ambient temperature as well as precipitation values recorded from 1950–2000. As these bioclimatic variables are often correlated, this results in poor model performance and misleading interpretations (Dormann *et al.* 2013). Therefore, Pearson's correlation analysis was performed and the variables which had a correlation coefficient ($r<0.7$) were selected for modelling. A total of 7 bioclimatic variables viz., Bio1, Bio2, Bio3, Bio4, Bio5, Bio12, and Bio18 *(Table 1)* along with the elevation were retained for modelling the distribution of *Paradoxornis flavirostris* in Northeast India. For future climatic scenarios, bioclimatic variables from HadGEM3-GC31-LL of the Coupled Model Intercomparison Project Phase 6 (CMIP6) model for Shared Socio-economic Pathways (SSPs) 126 and 585 for the period "2041–2060" (2060s) and "2081–2100" (2100s) were considered to look into two different future scenarios with enough temporal intervals to allow for the observation of potential medium- and long-term trends and changes in species distributions.

Model algorithm

Maximum entropy (MaxEnt) is an efficient modelling algorithm for making predictions from presence-only data on species' distribution (Phillips *et al.* 2006, Tesfamariam *et al.* 2022).

Table 1. List of Bioclimatic variables (https://www.worldclim.org)
1. táblázat A bioklimatikus változók listája (https://www.worldclim.org)

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
Bio5*	**Max Temperature of Warmest Mont**h	˚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	mm

Used for Modelling Purposes

It establishes the relationship between the environmental conditions at the locations where the species occurs and the environmental conditions throughout the remainder of the study area. The main goal of MaxEnt is to find a probability distribution with the largest entropy, or most spread out while taking into account the limitations imposed by the data on species existence and related environmental factors throughout the area of study (Phillips *et al.* 2006, Elith *et al.* 2011, Tesfamariam *et al.* 2022). MaxEnt uses a deterministic sequential-update algorithm that iteratively picks and adjusts the weights of predictors, which is guaranteed to converge to the maximum entropy probability distribution (Phillips *et al.* 2004, 2006, Tesfamariam *et al.* 2022).

Model evaluation

The area under the ROC curve (AUC): The receiver operating characteristic (ROC) curve provides an alternative technique for the assessment of the accuracy of ordinal score models (Fielding & Bell 1997). The sensitivity and specificity of each confusion matrix are obtained by applying all feasible thresholds for score classification, and the resulting ROC curve is constructed by comparing the sensitivity to the corresponding proportion of false positives (equal to 1 – specificity). Using all thresholds avoids the arbitrary choice of a single threshold

(Manel *et al.* 2001, Liu *et al.* 2005), and considers the trade-off of sensitivity and specificity (Pearce & Ferrier 2000, Shabani *et al.* 2018).

Sensitivity and Specificity: Sensitivity is calculated as, $a/a+c$ where a is the number of cells in which the species was detected but whose absence was predicted by the model, and c is the number of cells in which the existence of the species was properly predicted. Specificity is a measure of how many absences are accurately projected, which allows for the calculation of commission errors. Specificity is calculated as $d/b+d$, where d is the number of cells that the model correctly predicts to be absent and b is the number of cells in which the species was not found. It's crucial to remember that when comparing models, sensitivity and specificity are independent of one another, and prevalence, which is the percentage of sites where the species was found to be present (Shabani *et al.* 2018).

Data analysis

The habitat suitability model was performed in RStudio (ver. 2023.09.1+494 „Desert Sunflower") with the help of packages: raster (3.6-23), rgdal (1.6-7) and rjava (1.0-6). The output raster images were reclassified using ArcMap (Ver. 10.8) in four different classes such as: 'Not Suitable'<0.2, 'Moderately Suitable'<0.4, 'Highly Suitable'<0.6 and 'Excellent'>0.6. Then, it was converted to a polygon using the conversion tool in ArcMap and calculated the area of each class. The final maps were also prepared in ArcMap (10.8).

Results

Habitat suitability model

The HSM was performed with 84 BBP locations from the north-eastern region of India. The result shows that the average test AUC (area under curve) for the replicate runs is 0.935 *(Table 2)*. The AUC of the model indicates that above 93.5% of the area was well predicted. The current climatic scenario shows that Temperature Seasonality (Bio4) played a major role from the climatic perspective in the distribution of BBP, with a 17.27% contribution. Further, the future models show that with the global climate change, Temperature Seasonality (Bio4) and Max Temperature of Warmest Month (Bio5) will

Table 2. AUC, Sensitivity, and Specificity values for the model run
2. táblázat A modellfuttatások AUC, modellérzékenységi és specifitási értékei

Parameters	Current Model	Future Models			
		2041–2060		2081–2100	
		SSP_126	SSP_585	SSP_126	SSP_585
AUC	0.935	0.936	0.934	0.921	0.88
Sensitivity	0.94	0.94	0.94	0.92	0.88
Specificity	0.93	0.933	0.928	0.922	0.88

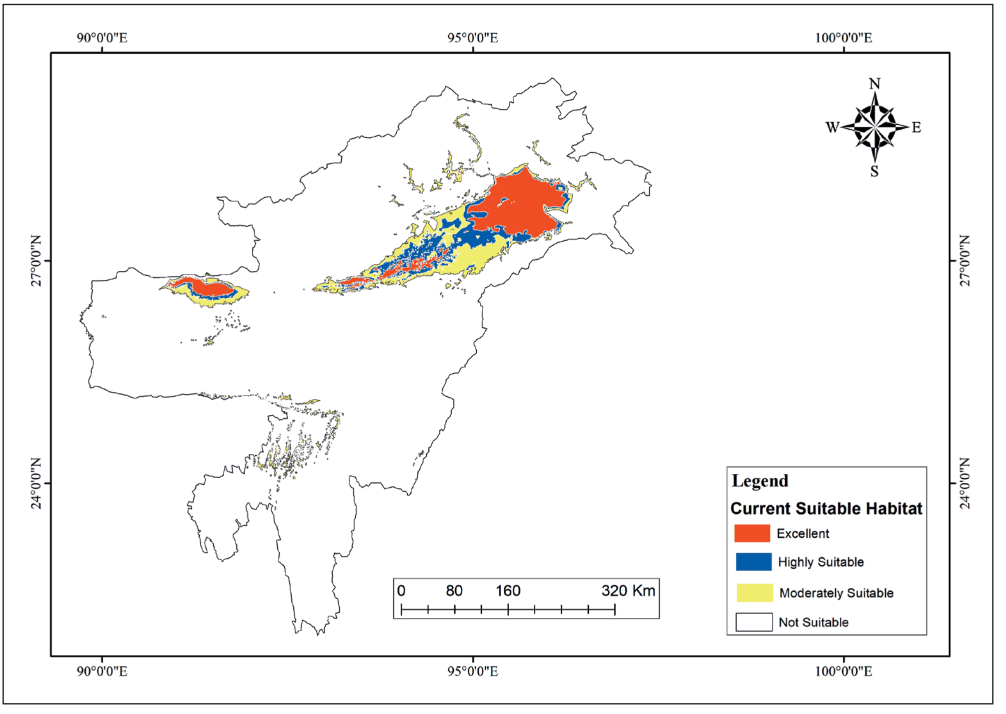


Figure 3. Map showing current potential range of Black-breasted Parrotbill in the study extent
3. ábra A dzsungel-papagájcsőrű cinege vizsgált területen belüli potenciális elterjedési területét ábrázoló térkép

play major roles in the distribution of BBP by the 2060s and 2100s climate scenarios, respectively. However, the geophysical variable i.e. altitude also played a major role in three climatic scenarios for the BBP habitat.

Current suitable habitat of Black-breasted Parrotbill in study extent

The current suitable habitat of BBP is mainly concentrated in the selected areas of Study Extent. Out of the total area of 253,393.02 km^2 in the study extent, 10,848.08 km^2, 7,743.48 km^2, 10,216.89 km^2, and 224,568.62 km^2 were predicted to be 'Excellent', 'Highly suitable', 'Moderately suitable' and 'not suitable' for BBP respectively *(Figure 3)*. The results also showed the potential suitable habitat within the protected areas of Northeast India, where BBP is recorded. Dibru-Saikhowa National Park and D'Erring Wildlife Sanctuary of Arunachal Pradesh fall under the 'excellent' suitable area for the BBP. Also, Kaziranga National Park and Manas National Park showed a substantial percentage of 'Excellent' and 'Highly Suitable' areas but Keibul Lamjao National Park did not show suitable areas for the species *(Figure 4)*.

Future predictive suitable habitat of Black-breasted Parrotbill in study extent

The world's flora and fauna could be severely impacted by global climate change. The study models showed that as climate change accelerates, the total potential habitat of BBP in Northeastern India would decrease. The study models revealed that the overall potential

Table 3. Probable potential area for Black-breasted Parrotbill in current and future climate change scenarios

3. táblázat A dzsungel-papagájcsőrű cinege valószínűsíthető potenciális elterjedési területe a jelenlegi és jövőbeli klímaszcenáriók alapján

Class	Current		2041-2060_SSP 126		2041-2060_SSP 585		2081-2100_SSP 126		2081-2100_SSP 585	
	km²	%	km²	%	km²	%	km²	%	km²	%
Not Suitable	224568.62	88.63	226748.93	89.49	226593.63	89.57	226424.6	89.36	230507.9	90.97
Moderately Suitable	10216.892	4.03	10676.118	4.21	10871.85	4.29	11948.95	4.72	11398.87	4.5
Highly Suitable	7743.486	3.06	7469.248	2.95	7240.672	2.85	6989.38	2.76	4931.49	1.95
Excellent	10848.082	4.28	8472.024	3.34	8300.22	3.27	8004.792	3.16	6533.68	2.57

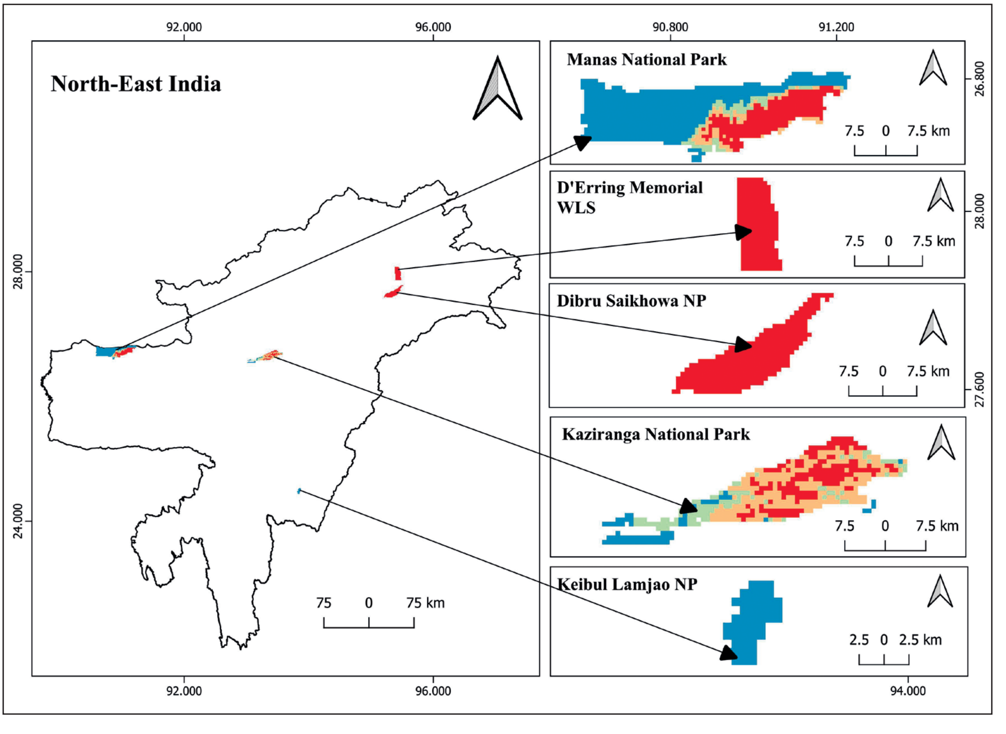
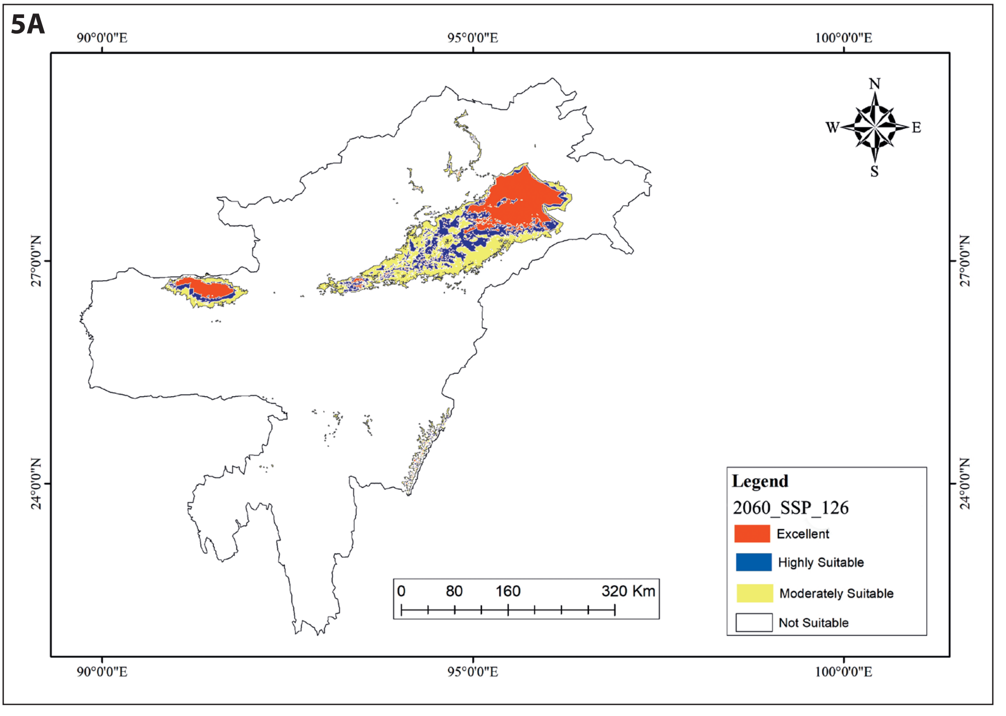


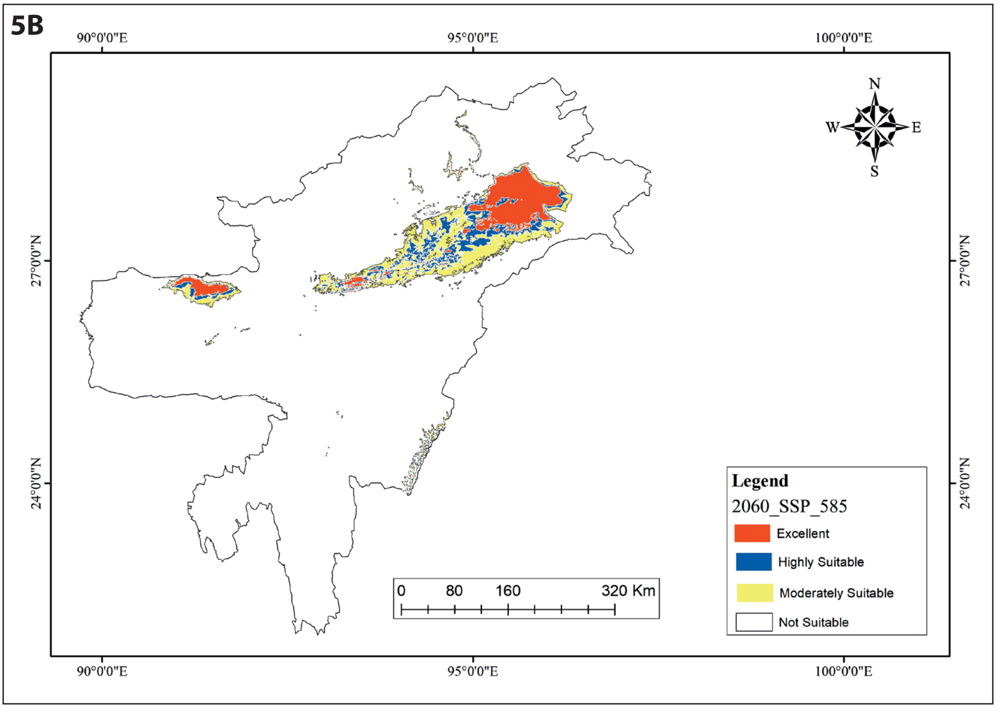
Figure 4. Map showing current potential range of Black-breasted Parrotbill in the Protected areas where the species is still present

4. ábra A dzsungel-papagájcsőrű cinege még jelenlévő állományait tartalmazó védett területeken belüli potenciális elterjedési területét ábrázoló térkép

5A


90°0'0"E
95°0'0"E
100°0'0"E
27°0'0"N
24°0'0"N
N
W
E
S
Legend
2060_SSP_126
Excellent
Highly Suitable
Moderately Suitable
Not Suitable
0 80 160 320 Km

5B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27°0'0"N
24°0'0"N
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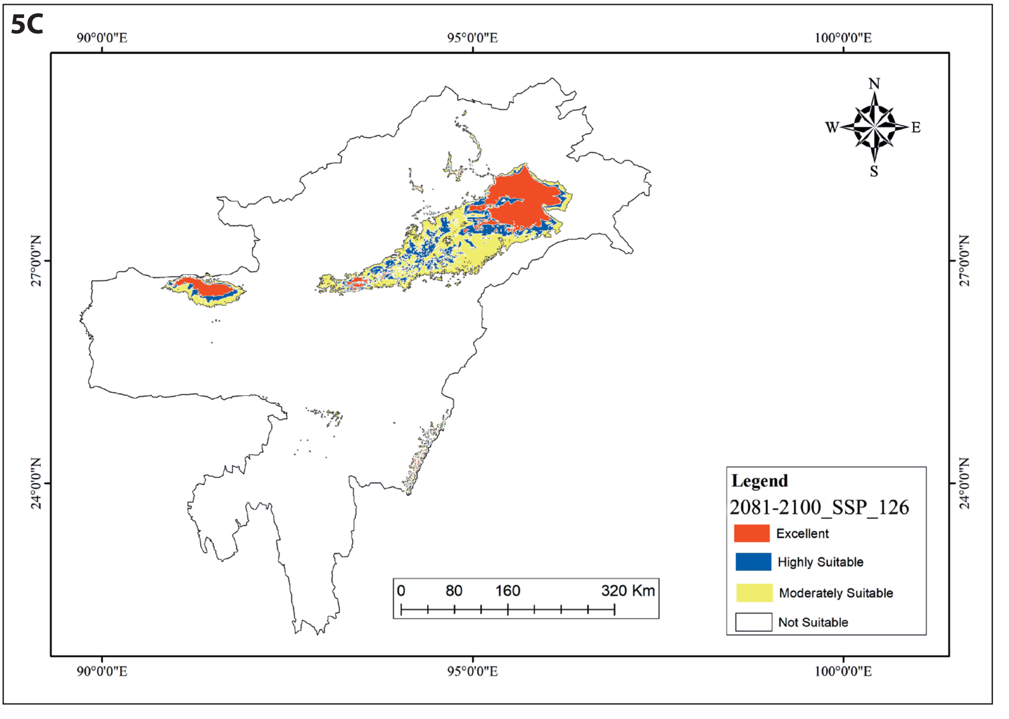
2060_SSP_585
Excellent
Highly Suitable
Moderately Suitable
Not Suitable
0 80 160 320 Km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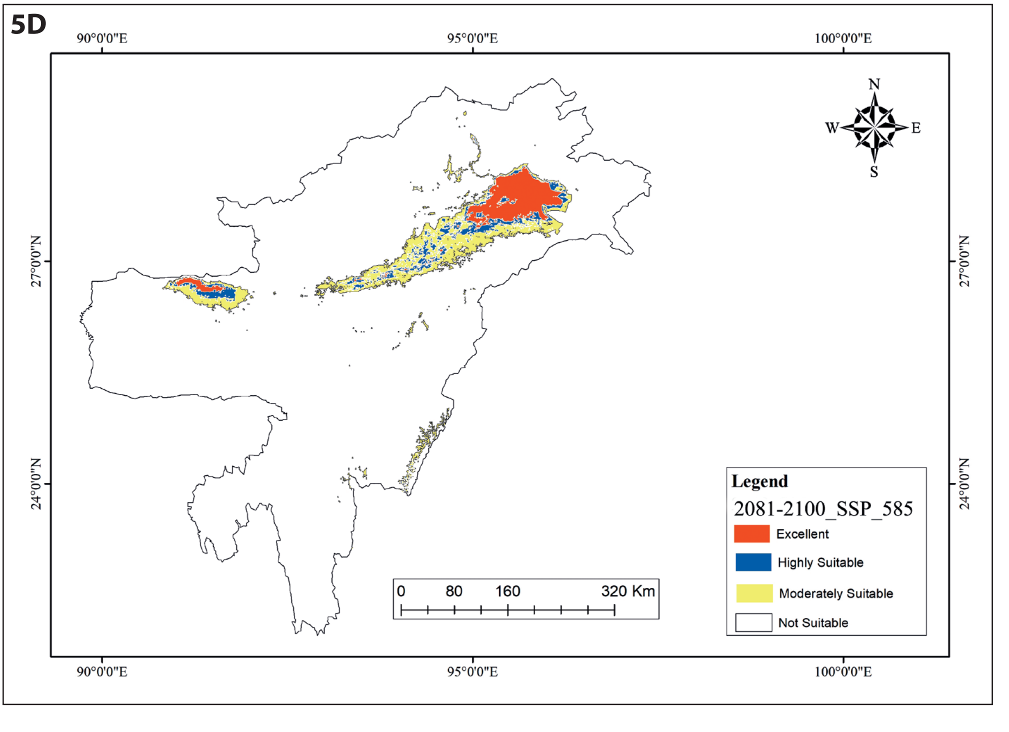
2081-2100_SSP_126
Excellent
Highly Suitable
Moderately Suitable
Not Suitable


5D
90°0'0"E
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W
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S
0 80 160 320 Km
Legend
2081-2100_SSP_585
Excellent
Highly Suitable
Moderately Suitable
Not Suitable

Figure 5. **A.** Map showing future (2041–2060_SSP126) potential range of Black-breasted Parrotbill in the study extent, **B.** Map showing future (2041–2060_SSP585) potential range of Black-breasted Parrotbill in the study extent, **C**. Map showing future (2081–2100_SSP126) potential range of Black-breasted Parrotbill in the study extent, **D.** Map showing future (2081–2100_SSP585) potential range of Black-breasted Parrotbill in the study extent.

5. ábra **A.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2041–2060_SSP126) potenciális elterjedési területét ábrázoló térkép; **B.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2041–2060_SSP585) potenciális elterjedési területét ábrázoló térkép; **C.** A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2081–2100_SSP126) potenciális elterjedési területét ábrázoló térkép; **D**. A dzsungel-papagájcsőrű cinege vizsgált területre eső, jövőbeli (2081–2100_SSP585) potenciális elterjedési területét ábrázoló térkép

habitat of BBP in the region would shrink due to climate acceleration *(Table 3)*. Areas with high potential will be decreased at a higher rate *(Figure 5A–D)*. Only 6,533.68 km^2 of the excellent potential area will exist in 2081–2100 (SSP585) *(Table 3)*. Between 2041–2060 (SSP585) and 2081–2100 (SSP585), there will be a loss of 1,938.34 km^2 of the excellent potential habitat under the influence of climate change. Areas with the non-potential and moderate potential will increase, whereas areas with excellent and high potential will decrease.

Discussion

The small, declining, and fragmented populations of Black-breasted Parrotbill are severely affected by the various anthropogenic factors. Within the range of the species, vast tracts of grassland have been transformed into plantations and agriculture, or have been submerged and changed by dams and irrigation projects. Remaining areas of grassland, even within protected areas, are potentially threatened by overgrazing, harvesting for thatch and fodder, inappropriate fire management practices, and the construction of hydroelectric projects (particularly on the Subansiri, Dibang, and Siang rivers) (Collar 2001, Rahmani 2016, Krishnan 2021). In India, grasslands are generally poorly represented in protected areas, and they are neglected in conservation policy, which further compounds the conservation problems facing the fauna of these habitats (Krishnan 2021). Along with these factors changing climate will also affect the remaining populations of the BBP. The 'current' model showed most of the suitable areas in the eastern part of the study extent. Dibrisaikhowa National Park and D'Erring Wildlife Sanctuary are the two protected areas that hold most of the 'excellent' potential areas, even in future models these two Protected areas also hold a substantial portion of 'excellent' potential areas. So, the grasslands of this region require serious conservation attention.

The ecology and population sizes of species are largely affected by climate change, including by altering ranges (Miller-Rushing *et al.* 2010, Deka *et al.* 2022). The ranges of many bird species are already shifting towards higher altitudes, allowing species to survive in new locations (Root *et al.* 2003, Deka *et al*. 2022). However, changes in climatic conditions can cause range expansions in some species (Miller-Rushing *et al.* 2010, Deka *et al.* 2022). The study revealed the range shift of the species in the future climate scenarios. The easternmost population showed a range shift towards high altitude and the southernmost population showed a range shift towards the eastern direction. The distributions of several terrestrial organisms are currently shifting due to climate change (Chen *et al.* 2011, Deka *et al.* 2022). However, range shifting is determined by a combination of internal species traits and external change drivers. The most common range shifts reported in response to recent climate change are poleward and altitudinal (Lenoir *et al.* 2015, Deka *et al.* 2022). With this regard, BBP may shift its range towards 2060s.

The study forecasted the potential suitable areas for the Black-breasted Parrotbill in the northeastern region of India. The spatial resolution of 1 km helped to precisely predict the suitable habitats through modelling. Bioclimatic factors regarding temperature and precipitation are significant in defining the BBP's distribution. The results showed the potential distribution range for the species which draws a baseline for future research work on this species. Additionally, our result enables the locating of sensitive habitat zones for immediate conservation actions. Also, there is an urgent need for public awareness and capacity-building initiatives from non-governmental organizations (NGOs), other institutions, Government agencies, and forest dwellers to safeguard the Black-breasted Parrotbill population from further declining.

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