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SPECIES DISTRIBUTION MODELING (SDM) OF VARIABLE TAWNY RAJAH (*CHARAXES BERNARDUS HIERAX*) IN WEST BENGAL, INDIA: IMPLICATIONS FOR CONSERVATION

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Abstract.

Lepidopteran species play a crucial role as pollinators in ecosystems, and they have also coevolved with their nectaring plants. Their high sensitivity to changes in environmental variables makes them one of the good indicators of ecosystem health. There are numerous butterfly and moth species found in India, whose possible habitat distribution in geographic areas is yet to be known. In our present study, we attempt to determine the predicted distribution area of Variable Tawny Rajah (Charaxes bernardus hierax) in West Bengal using the MaxEnt 3.4.4 program. We observed that the northern part of West Bengal has more habitat areas with suitable environmental conditions (maximum and moderate) than the southern part. This type of study may help to provide an idea about the predicted distribution of Charaxes bernardus hierax in West Bengal and the selection of conservation strategies for this butterfly species in particular geographical regions.

Keywords: *MaxEnt, butterfly, conservation*

Introduction

Information on the distribution of the species of the taxonomically diverse group like insects (Arthropoda: Mandibulata) is limited and often less detailed, partly due to the inadequate and incomplete surveys (Jiménez-Valverde & Hortal 2003) and insufficient sampling effort (Romo & García-Barros 2005). Besides, many of the techniques that are used for arthropod sampling not axiomatically standardized (Jiménez-Valverde &Lobo 2004) for one or more taxonomically similar groups. As a pre-requisite condition for framing conservation strategy for any species, a background knowledge of its biology, population structure, sensitivity to environmental perturbations and distribution of the species are necessary (New 2014), both at the local and regional scales. In many instances, the predictive models for the distribution of the species become a priority to supplement the information to project the future distribution pattern within the geographical limits (Rawat et al. 2021; Purohit & Rawat 2021).The prediction of the prospective distribution is more a necessity in view of the global climate change. Thus species distribution models (SDMs) that include a combination of the climatic and the environmental factor as the explanatory variables for projecting the distribution of a particular species are considered highly useful. In this context, the maximum entropy (MaxEnt) based model may serve as a valid approach to predict the distribution pattern of a reference species. In the maximum entropy modelling (Maxent), applied to presence-only data is thought to be resilient to the sparsely populated occurrence locations of species and is capable of establishing relationship that is non-linear between the predictor and response variables (Phillips et al. 2004, 2006; Benito de Pando & Peñas de Giles; 2007, Gupta et al. 2022). As a consequence, several studies have utilized the MaxEnt model for the prediction of distribution of species deserving conservation priority and population management. Among the invertebrates the distribution of the butterflies (Jacinto-Padilla et al. 2017), snails (Barman et al. 2021) and slugs (Gupta et al. 2022) were predicted using the MaxEnt model of species distribution.

Although the taxonomic diversity (Mukherjee et al. 2015), adaptations (Kunte 2007) and morphological features (Mukherjee & Hossain 2021, 2022) have been studied from various parts of the world, the application of the SDMs for the predictive distribution of butterflies (Insecta: Lepidoptera) has been little emphasized (Schröder et al. 2009, Mainali et al. 2020). Butterflies execute significant role as pollinator and qualify as herbivores that coevolved with the host plants (Kunte 2000; Tiple et al. 2006). At the same time these are highly sensitive to the changes in environmental parameters and thus are often considered as important indicators for ecosystem health (Doré et al. 2021). Adult butterfly species mostly rely on flowers for their food, but some butterfly species never visit flowers. They mostly depend on other organic sources such as dung, urine, and overripe fruits (Kehimkar 2016; Mukherjee et al. 2022). *Charaxes bernardus* is a butterfly species that never depends on flowers and relies on dead- decaying materials for its food (Kehimkar 2016; Mukherjee et al. 2022). *Charaxes bernardus* is commonly known as variable tawny rajah and belongs to subfamily Charaxinae under the Nymphalidae family. *Charaxes bernardus* was first described by Fabricius (1793), later the subspecies *Charaxes bernardus hierax* was described by Felder and Felder (1867). The Himalayan subspecies of *Charaxes bernardus hemana* described by Butler (1870) (Lepidoptera: Nymphalidae) is legally protected under Schedule II of the wildlife (Protection) Act, 1972 of India (Das et al. 2018; Kunte et al. 2021). On global scale *Charaxes bernardus hierax* has fewer presence records from Myanmar, Cambodia and Yunnan, a province in southwestern China (Coene & Vis 2008, Kosterin 2020; Choi et al. 2021). In India, presence of the butterfly *Charaxes bernardus hierax* has been reported principally from Meghalaya, Assam, Mizoram, Arunachal Pradesh, Tripura, Nagaland, Sikkim, northern most part of West Bengal and some sparse distribution from Odisha and Chattisgarh (Kunte et al. 2021). Distribution of butterfly species can be affected by the changes in climatic conditions (Kehimkar 2016). The study aims to develop a map for potential distribution of *C. bernardus hierax* in West Bengal to determine the areas suitable for sustenance of this species along with highlighting the role of environmental variables for this species.

Materials and Methods

Study area

The survey was carried out in Purulia, West Bengal, India and during a survey on 8 august 2020 a single specimen of *C. bernardus hierax* was recorded and photographed from Garh Panchkot Hill (86.752 E, 23.614 N), located in the Purulia district. That is the first written literature about the presence of the species from Purulia, West Bengal, India (Mukherjee et al. 2022).

Data collection

A detailed literature review and internet survey revealed that the butterfly *Charaxes bernardus hierax* was also recorded from nearby areas like Baghmundi, Ajodhya Hill and Kamalpur (Kunte et al. 2021) localities of the study area. Occurrence of this butterfly species have not been reported from any other area of southern part of West Bengal so far. Further data on the occurrence points of *Charaxes bernardus hierax* throughout the West Bengal were collected from global and Indian data bases for butterfly species, namely, Global Biodiversity Information Facility (GBIF) (GBIF.org) and ifoundbutterflies.org (Kunte et al. 2021).

Environmental data

GeoTiff files of the environmental variables with a resolution of 30 arc seconds were obtained from the WorldClim and EarthEnv databases (http://www.worldclim.org; https://www.earthenv.org/). Using QGIS 3.28 (http://qgis.osgeo.org/), data for the environmental variables for West Bengal were extracted. The EnmTools package R v4.2.2 (R studio Team, 2020) was used to perform correlation analysis across all the variables in order to address the issue of multi-collinearity among variables, which led to the model's overfitting. Environmental variables were eliminated from the study when the correlation coefficient between two variables was $\geq \pm 0.8$. Finally, rest of the environmental determinants were used for the final model development.

Modeling overview

Distribution of *Charaxes bernardus hierax*, commonly known as variable tawny rajah modeled by using maximum entropy modeling (MaxEnt) software 3.4.4 (https://www.cs.princeton.edu/~schapire/maxent/). MaxEnt predict the possibility of presence of a species in the scale ranging from 0 as the lowest to 1 as the highest distribution possibility in a particular area.

As variables are used with 30s resolution (1Km X 1Km) spatial thinning for the occurrence points (5km X 5Km) was done by using the spThin package in R v4.2.2 (R studio Team 2020)for removing the geographic biases (Gupta et al. 2022). After that 13 occurrence points were used to developed the model (Fig. 1).

Model testing

We tested the distribution of *Charaxes bernardus hierax* using the "leave one out" strategy, which has been shown to be effective when there are a few available presence records (Pearson et al. 2007). We took a locality out of the dataset for each of the 13 (n=13) observed locales, and then we used the n-1 localities that were left to build the model. As a result, we developed distinct testing models, each of which sought to forecast the one location that was left out of the dataset (Pearson et al. 2007). We evaluated each model's ability to forecast the excluded locality in order to determine its predictive performance. Applying a threshold was required for the "leave one out" technique. For each of the predicted models, we choose here the minimum training presence logistic threshold. The "pValueCompute.exe" programme (Pearson et al. 2007) was used to compute a p-value for the jackknife predictions. Default features of the MaxEnt was used to develop the models.

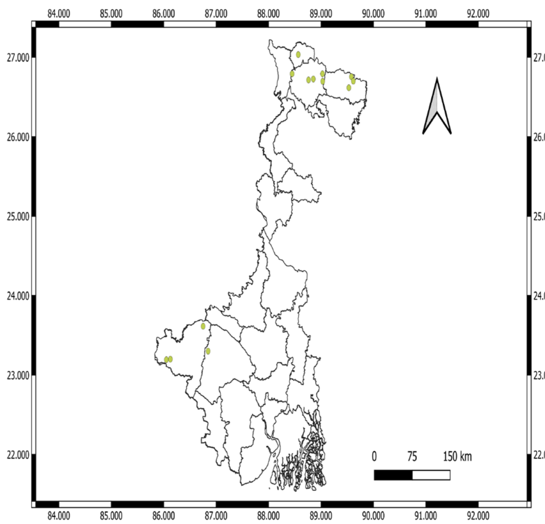


Fig. 1 Geographical distribution of *Charaxes bernardus hierax* in West Bengal.

AUC values values 0.5-0.7 and >0.7 categorised as moderate and high (Thapa et al. 2018). The output generated from MaxEnt were imported into QGIS and classified into four groups: 0-0.2, 0.2-0.4, 0.4-0.6, and 0.6-1. These classes corresponded to the not applicable, minimum, moderate, and highest potential areas for the distribution of species, respectively.

Results

The butterfly species *Charaxes bernardus hierax* were recorded from three sites viz. Garh Panchkot Hill (86.752 E; 23.614 N), Baghmundi (86.0.5046 E; 23.19335 N) and Ajodhya Hill (86.12681 E; 23.20036 N) in Purulia district, West Bengal, India. Apart from Purulia, the butterfly species was also recorded from Bankura, Alipurduar, Kalimpong and Jalpaiguri districts of West Bengal. Apart from the record of the abundance of the specific butterfly, the species distribution model included 14 explanatory variables in which two are bioclimatic variables viz. Isothermality (Bio3) and Precipitation Seasonality (Bio15). Isothermality can be calculated by the following formula: (Mean Diurnal Range/ Temperature Annual Range) (×100) (http://www.worldclim.org), whereas, Precipitation Seasonality defined as the annual range of precipitation (http://www.worldclim.org). Other explanatory variables include 12 consensus land cover variables viz. Evergreen/ Deciduous Needleleaf Trees (CON1), Evergreen Broadleaf Trees (CON2), Deciduous Broadleaf Trees (CON3), Mixed/Other Trees (CON4), Shrubs (CON5), Herbaceous Vegetation (CON6), Cultivated and Managed Vegetation (CON7), Regularly Flooded Vegetation (CON8), Urban/ Built-up (CON9), Snow/Ice (CON10), Barren (CON11), and Open Water (CON12) were used for the model development (Table 1). Land-cover data is essential for sustainable development and efficient resource management, in addition to helping to comprehend and simulate the dynamics of the Earth system (Hijmas et al. 2005).Thirteen separate potential distribution models are showed in Fig. 2. The Jackknife test or "leave one out" method's results show that the success rate was high (0.769) and was statistically significant ($p<0.05$). The models' AUC values are influenced by each locality (Table 2). The models' AUC values range from 0.897 to 0.924 (Table 2).The final model that incorporates all the presence records demonstrated that con4 (41%) contribute highest in the model development followed by bio15 (35.6%), bio3 (12.2%), con12 (4.3%) and con9 (4.2%) (Fig. 3). The final model demonstrated that in case of West Bengal 11982 km2 and 5056 km2 contain moderate and maximum potential habitat for *Charaxes bernardus hierax* (Fig. 4). It was also observed that Northern part of West Bengal, Birbhum, Murshidabad and Purulia contains potential suitable habitat for this butterfly species.

Discussion

The species distribution analysis is a prerequisite for identifying and predicting geographic areas where targeted species may be present or conservation strategies may be initiated further if conditions and resources are preferable for them (Rawat et al. 2022). Environmental conditions are pivotal for any living organism's survival in a new condition. The main idea behind species distribution using MaxEnt is to detect probability distribution that has been explained during model analysis. Environmental characteristics and species occurrence data are must for such types of distribution analysis. Previous studies demonstrate that climatic factors play a major role in lepidopteran abundance (Hernandez-Baz et al. 2022). As with other species deserving conservation management, information obtained on the distribution pattern of *C. bernardus hierax* will be useful in promoting the conditions that sustain the population. Of particular relevance will be the environmental and the climatic factors that favours the distribution and thus the population abundance of *C. bernardus hierax*. As discussed for the distribution modeling of the Smith's Blue butterfly, Euphilotes enoptes smithi, the correspondence of the vegetation, edaphic factors and the environmental variables was useful in understanding and predicting the distribution pattern in the Santa Lucia Mountains along the Big Sur coast in Monterey County, California, USA (Arnold & Jensen 2022). A more elaborative approach for linking conservation management of butterflies and SDM is observed through the studies on the Ithomiini across the Neotropics (Doré et al. 2021). Apart from the vegetation and the climatic pattern predicting the distribution pattern of the entire Ithomiini tribe, the effects of the anthropogenic activities could be deduced from the studies. As a consequence, specific steps could be taken for conservation and sustenance of the taxonomic diversity of the Ithomiini tribe of butterflies (Doré et al. 2021). Similar approach of linking vegetation and climatic factors with the species occurrence was adopted for predicting the distribution

Fig. 2: Potential distribution of 13 different models of *Charaxes bernardus hierax* in West Bengal following Jackknife validation.

Fig. 3. Response curves showed the relation between the presence probability of *Charaxes bernardus hierax* and environmental variables.

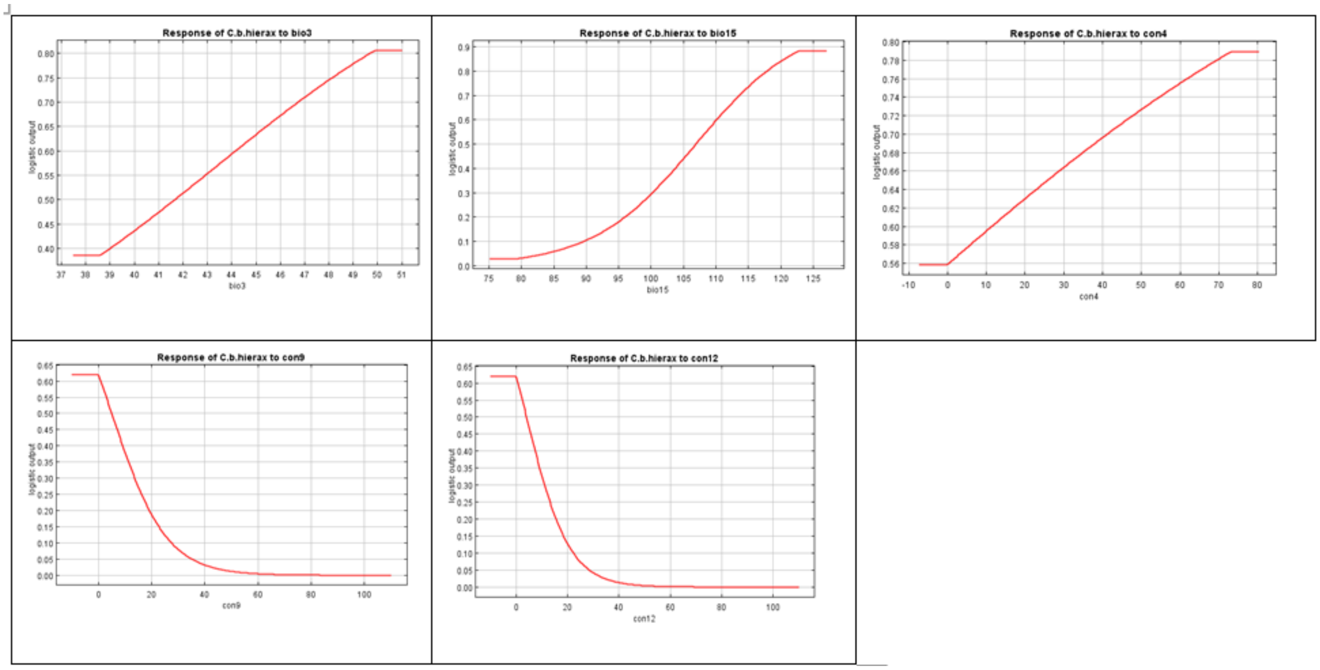


Table 1. List of environmental variables that are used for final model development

Variable	Abbreviation
Isothermality (BIO2/BIO7) (×100)	Bio 3
Precipitation Seasonality (Coefficient of Variation)	Bio 15
Evergreen/Deciduous Needleleaf Trees	Con 1
Evergreen Broadleaf Trees	Con 2
Deciduous Broadleaf Trees	Con 3
Mixed/Other Trees	Con 4
Shrubs	Con 5
Herbaceous Vegetation	Con 6
Cultivated and Managed Vegetation	Con 7
Regularly Flooded Vegetation	Con 8
Urban/Built-up	Con 9
Snow/Ice	Con 10
Barren	Con 11
Open Water	Con 12

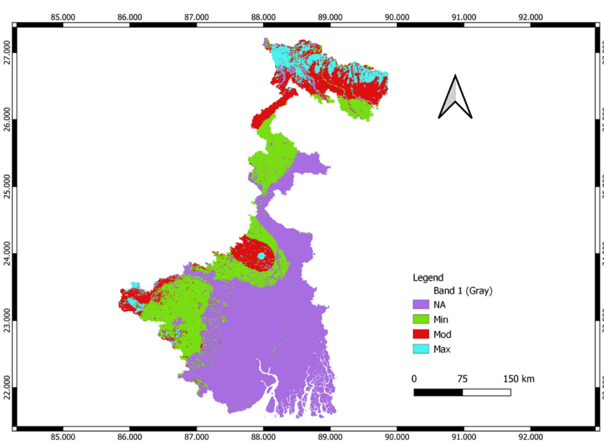
Table 2. Thirteen separate model (MaxEnt) output for *Charaxes bernardus hierax*.

Success	Minimum training presence area	Minimum training presence logistic threshold	AUC
1	0.2811	0.37	0.8986
1	0.2807	0.3389	0.897
1	0.2922	0.3047	0.9027
1	0.2763	0.3574	0.8917
0	0.2486	0.3035	0.9156
0	0.2695	0.3324	0.8967
1	0.2893	0.3098	0.9015
1	0.2891	0.3275	0.8968
1	0.2876	0.3537	0.9037
0	0.2222	0.3401	0.9241
1	0.3009	0.286	0.9122
1	0.2966	0.3094	0.9039
1	0.2988	0.3054	0.9082

pattern for Alpine endemic species *Erebia calcaria* in Slovenia and Austria (DeGroot et al. 2009). Since, the climatic, topographic and edaphic factors influence the availability of the host plant, so will the dependent taxa like the butterfly vary accordingly. For instance, the prediction of the current distributions for showy milkweed (*A. speciosa*), swamp milkweed (*A. incarnata*), and monarch (*Danaus plexippus*) butterflies corresponded with the distribution of the milkweed *Asclepias spp*., in Idaho, USA (Svancara et al. 2019). In Mexico, the SDM was applied to decipher the distribution pattern of several butterfly species like *Pyrisitia proterpia, Danaus gilippus, Zerene cesonia, Archaeoprepona demophon*, and *Anteos maerula*, where vegetation pattern and the climatic factors were the reasonable predictors for the observed pattern of the distribution of the species (Jacinto-Padilla et al. 2017). In China, the distribution and the habitat utilization pattern of the Gainville fritillary butterfly *Melitaea cinxia* was deduced through SDM (Zhou et al. 2012). The butterfly *M. cinxia* exhibited strong dependence on the distribution pattern fo the host plant *Veronica spicata*, justifying that plants, edaphic factors, tophography and the climatic conditions portrays the distribution pattern for the species with high specificity. Apparently, the distribution of the butterflies, like other dependent taxa, will vary with the availability of the host plants which on the other hand will depend on the climatic and edaphic factors. This applies for several other invertebrate species, which are linked with the abundance of the resources at the spatio-temporal scales for a concerned geographical region.

Consideration of bioclimatic variables for species distribution modeling has become more familiar (Franklin 2009). Predictions derived from species distribution modeling can be linked with other ecological parameters like productivity and species abundance (Pearce & Ferrier 2001; Brambilla & Ficetola 2012). The results of the

Fig. 4. Aereal distribution of *Charaxes bernardus hierax* in West Bengal.



present study suggest that increase in mixed/ other trees (con 4) also associated with increase in probability of the occurrence of the species. The results also associated with increase in probability of occurrence with decrease in open water (con 12) and urban / built up (con 9). The results also suggest that precipitation variable (bio15) is positively related with occurrence probability of *Charaxes bernardus hierax*. Previous studies showed that butterfly diversity decreases with increase in urban characteristics (Ruszczyk & De Araujo 1992; Blair & Launer 1997; Stefanescu et al. 2004; Dover & Settele 2009) and the increase in precipitation positively associated with buttery diversity (Kehimkar 2016). Empirical studies have demonstrated that both mean annual precipitation and real evapotranspiration, which measure the water-energy balance, are well-known and influential factors in the distribution of butterflies (Hawkins & Porter 2003; Stefanescu et al. 2004). Vegetation and anthropogenic factors are also considered influential variables for the distribution of butterfly species (Kerr 2001; Kerr et al. 2001; Stefanescu et al. 2004; Mukherjee & Hossain 2024). The tropical region is crucial for butterfly diversity and density due to its abundant and diverse green vegetation (Farhat et al. 2014). Minor changes in habitat can trigger mass migrations of butterflies from one area to another, potentially leading to local extinctions of butterfly species (Schtickzelle & Baguette 2003). The present study demonstrated that Northern part of West Bengal, Purulia, Birbhum and Murshidabad has the suitable condition (maximum and moderate) to sustain this species. The study also indicate that our study area also contain suitable environmental conditions to sustain this species.

Conclussion

The distribution of butterfly *Charaxes bernardus hierax* was modeled by using MaxEnt throughout the India. Bioclimatic variables were used to predict the distribution of this butterfly. Results show Mixed/Other Trees (con4) is the most important variable to predict the distribution of *Charaxes bernardus hierax*. The results showed that in West Bengal Northern part of West Bengal, Purulia, Birbhum and Murshidabad has the suitable condition to sustain this species. The present study helps to determine the suitable areas that are capable to sustaining this species and it also helps to find out the role of environmental variables for this species. Therefore, this report on the potential distribution of *Charaxes bernardus hierax* aims to motivate and enhance conservation efforts for the suitable habitats of this butterfly, which will, in turn, be useful for the conservation of the species in these particular areas. This type of study may also be crucial for selecting proper conservation strategies for this species in right geographical location.

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