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continued on the back inside cover

Cover: The nine vultures of India, digital art made on Krita by Dupati Poojitha.

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ARTICLE

Niche characterization and distribution of Sikkim Himalayan *Begonia* (Begoniaceae), India: a niche modeling approach

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Abstract: Understanding species' ecological niches and distribution patterns is crucial for biodiversity conservation and management, particularly in ecologically sensitive regions. We used an NDVI-based ecological niche modeling (ENM) approach for *Begonia* species for this purpose, where we achieved high predictive accuracy (AUC: 0.82–0.97). Niche breadth analysis revealed a positive correlation (r = 0.747, p = 0.003) between broader niche breadth and larger predicted distribution areas, aligning with the notion that better-performing models tend to capture either highly specialized (narrow-breadth) or ecologically flexible (broad-breadth) niches. Models for *Begonia picta, B. panchtharensis, B. sikkimensis,* and *B. xanthina* were classified as fair (0.8 < AUC < 0.9), and exhibited broader niche breadth, with ranges extending from the western Himalaya to the eastern Himalaya, encompassing Nepal, Bhutan, and China. In contrast, *B. satrapis, B. gemmipara,* and *B. nepalensis* showed very good model performance (AUC > 0.95) but had the narrowest niche breadth (0.102–0.195), suggesting specialized habitat requirements and restricted distributions. Given their limited ecological flexibility and smaller suitable areas, these species warrant immediate conservation attention to mitigate extinction risks.

Keywords: Conservation, Darjeeling, diversity, endemic, ENM, MaxEnt, NDVI, niche overlap, niche breadth, northeastern India.

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Author details: Dr. Aditya Pradhan is an assistant professor at SRM University Sikkim, with research interests in plant taxonomy and biodiversity conservation. Dr. Dibyendu Adhikari is a principal scientist at CSIR-NBRI, Lucknow, specializing in environmental science and forest ecology. Dr. Arun Chettri is an associate professor and head of the Department of Botany at Sikkim University, with a research focus on molecular taxonomy and ecology.

Author contributions: AP conducted the field survey, collected data, performed the modeling, and drafted the manuscript. DA refined the model and contributed to manuscript revision. AC was responsible for the research design, provided overall supervision, and approved the final version of the manuscript

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INTRODUCTION

For centuries, ecologists and biologists have been fascinated on why species vary greatly in the extent of its distribution. Some species have a narrow distribution range, whilst some closely related species have a broader distribution, ranging from the continental to the global scale (Willis 1922). It is widely believed that narrowly distributed species have specialized environmental requirements while the widely distributed species have broader environmental tolerance. Therefore, a positive correlation between environmental niche breadth and range size is widely accepted in macro ecological studies (Gaston 2000; Gaston & Spicer 2001; Slatyer et al. 2013). However, it is difficult to conclude the above hypothesis because the environmental niche of a species is usually defined by the set of occurrence records. Hence, a larger number of presence locality data are likely to have a wider distribution range, unlike species having a lesser number of occurrence records (Burgman 1989; Gaston & Blackburn 2000; Gregory & Gaston 2000; Gaston & Spicer 2001). Therefore, the species-rich genus *Begonia* in Sikkim Himalaya was chosen as the model plant to answer this question.

Begonia L. is the sixth largest genus of flowering plants and provides several important ecosystem services. For instance, they help stabilize soil in humid understory environments, support local invertebrates, and contribute to microhabitat maintenance in forested areas. Some Begonias also hold ornamental and economic value, being used in horticulture for their diverse foliage, and showy flowers. In certain regions, they have recognized medicinal uses, underscoring their cultural and economic importance. Consequently, conserving Begonias will not only preserve the essential ecological interactions but also safeguard potential benefits for local communities.

Being one of the largest genera of flowering plants, they provide an excellent opportunity to study the processes underlying the theory of rapid radiation. A sufficient amount of occurrence data is required to develop a robust distribution model and to test the above mentioned theory (Moonlight 2017). However, the unavailability of geo-referenced occurrence data in herbaria and other online sources such as GBIF (Global Biodiversity Information Facility) limits the use of such techniques. At present, there is a growing need to estimate the species distribution range for theoretical as well as applied reasons, e.g., understanding species geography to its conservation. Limited species occurrence data pose enormous challenge to the researchers. Moreover, quantifying the environmental factors which contribute the most to the distribution of species becomes even more complicated and challenging (Guisan & Thuiller 2005; Colwell & Rangel 2009). The factors that govern the distribution of species are biotic factors, abiotic factors (soil and topography), species interaction, competition, predators, and parasites (Gaston 2003). In practice, the species distribution model is developed using only the occurrence data, and abiotic variables. Recently several studies have indicated the importance of biotic interaction in shaping the spatial distribution of species (Gotelli et al. 2010; Sunday et al. 2011). The factors such as biotic interaction and dispersal are usually ignored, and their effect considered negligible at broader geographical scale or spatial scales (Soberón 2007; Colwell & Rangel 2009; Gotzenberger et al. 2012; Araújo et al. 2014). Thus, abiotic factors, such as bioclimatic variables, NDVI, slope, and aspect are often used in predicting, and identifying the suitable habitat of species (Pradhan et al. 2020). The selection of predictor variables is fundamental before modelling, yet the choice of input variables is still debatable (Synes & Osborne 2011). The ecologically relevant variables are capable of generating robust models and vice versa. For example, the soil type variables might be good predictor variables for plants whilst temperature, and forest fragmentation related variables might be a good choice for animals. The use of NDVI contributes to the modelling process by providing information about the phenological status, canopy cover, and the water content variation (Amaral et al. 2007). In addition to capturing phenological status and canopy cover, NDVI also provides insights into spatial variation in plant health & productivity, reflecting factors such as vegetation stress, and soil nutrient availability. Consequently, NDVI data can be used as a proxy for detecting water deficits, drought stress, or nutrient limitations, all of which are critical for understanding *Begonia* establishment, and persistence. Thus, this study aimed to (1) predict the suitable habitat of *Begonia* species in Sikkim Himalaya, and (2) define the ecological niche of *Begonia* species and quantify the similarities between them using ENM techniques. The ENMs constructed were compared to assess the similarities of the ecological niche of the *Begonia* species, and to know if they share the same ecological niche or not.

MATERIALS AND METHODS

Study area

The district of Darjeeling shares a continuous geological and physiographic landscape with Sikkim, rendering the two regions inseparable in these respects (Basu 2013). The region lies adjacent to Nepal in the east, China in the north, and Bhutan in the west, making it a geopolitically, and biogeographically significant segment of the Eastern Himalaya. The physical features of Darjeeling and Sikkim are very similar, separated by rivers Teesta, and Rungit which act as a natural boundary dividing the two geographically consonant regions (Figure 1). Therefore, the state of Sikkim along with Darjeeling together constitutes the Sikkim Himalaya. The two regions from herein will be referred to as Sikkim Himalayas (Rai et al. 2000). The region lies amid the eastern Himalayan regions, roofed by a snow clad-mountain in the north, and planes in the south. It is bordered by countries such as Nepal in the east, China in the north, and Bhutan in the west, and is tectonically one of the most active areas of the Himalaya.

Collection of occurrence record

The primary occurrence data or the presence data (i.e., geographic coordinate/Latitude and Longitude) for 13 species of *Begonia* (viz., *B. satrapis*, *B. gemmipara*, *B. josephii, B. picta, B. xanthina, B. cathcartii, B. flaviflora, B. megaptera, B. nepalensis, B. palmata, B. sikkimensis, B. panchtharensis, B. roxburghii*) were collected from the hills of Darjeeling and Sikkim Himalaya using Garmin GPS (Global Positioning System). The occurrence data were collected with an accuracy of 3–10 m.

The geographic coordinate was collected in the form of Degree Minute Second (DMS) which was later converted to decimal degrees (DD) using the formula:

$$DD = D + M/60 + S/3600$$

The converted presence data was later rearranged in Microsoft Excel in the following order, i.e., species name, longitude, latitude, and then saved in CSV (comma delimited) format, and was later used for modelling.

Predictor Variables

The model was developed using normalized difference vegetative index (NDVI) raster data for January to December obtained from GLCF (Global Land Cover Facility) (University of Maryland, USA). The NDVI is a numerical indicator that quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs), and is given by the formula:

$$NDVI = (NIR-RED) / (NIR+RED)$$

Where; NIR = near-infrared and
RED = Red light

The 12 NDVI variables were first subjected to correlated tests (r>0.9) using ENM Tools 1.3 software (Warren et al. 2010). Thus, out of 12 NDVI variables, 10 were used to model the distribution of *Begonia* in Sikkim Himalaya along with altitude (Table 1). Although NDVI data for August and September were initially considered, both months showed high correlation (r>0.9) with July NDVI, risking over fitting if included simultaneously. Following best practices to reduce multicollinearity, we retained July NDVI as representative of the monsoon peak and excluded August and September. This approach helps ensure model parsimony and avoids redundant variables.

Ecological Niche Modelling

MaxEnt v.3.3. 3k Software (Phillips & Dudík 2008) was used to model the distribution of *Begonia* species in Sikkim Himalaya. MaxEnt modelling was used because it has a high accuracy rate and performs better with small size (Elith et al. 2006). The 10 percentile training presence logistic threshold was used, with 20 replicates run, and maximum of 5,000 iterations for each species. All other settings were kept default as it has been calibrated with a wide range of species (Phillips & Dudík 2008). From 20 replicated runs for each species, the average, and maximum, minimum, median, and standard deviation was obtained. Each *Begonia* species were modelled individually using a set of NDVI variables.

Using Niche Toolbox (http://shiny.conabio.gob.mx:3838/nichetoolb2/) binary maps were obtained and suitable areas for each species of *Begonia* were calculated using 10 percentile training presence logistic threshold cut off values.

Niche Overlap

ENM Tools software was used to examine the degree of niche overlap between *Begonia* species. Schoener's D and Hellinger's I metrics were used to estimate the niche overlap between the species.

Schoener's D is given by the formula:

$$D(p_X, p_Y) = 1\tfrac{1}{2}\sum_i \left|p_{X,i} - p_{Y,i}\right|,$$

Where $p_{X,i}$ and $p_{Y,I}$ are the normalized suitability scores for species X and Y in grid cell *i*, similarly Hellinger's I is given by the formula:

$$I(p_X, p_Y) = 1 - \frac{1}{2}\sqrt{\sum_i \left(\sqrt{p_{X,i}} - \sqrt{p_{Y,i}}\right)}$$

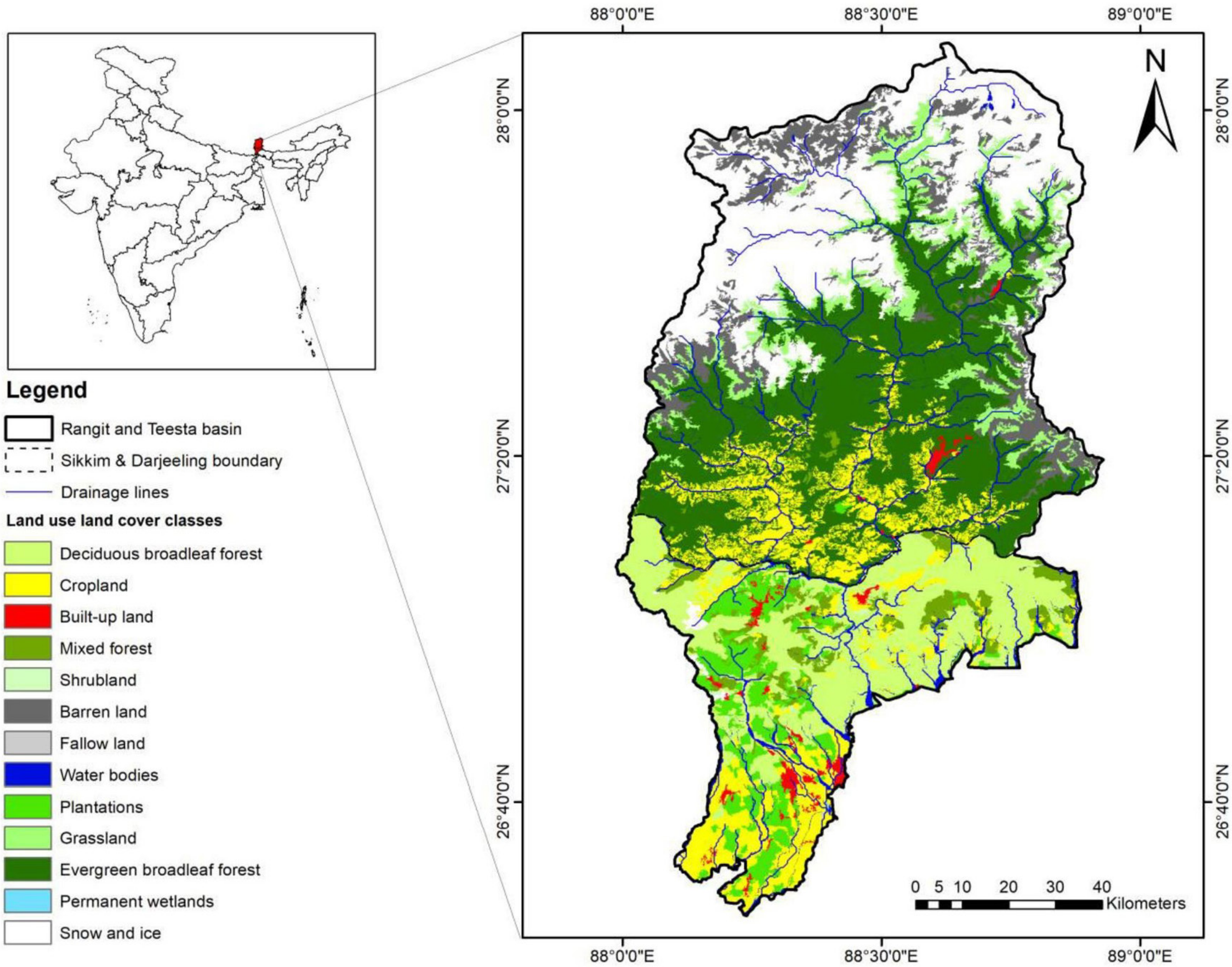

Figure 1. Land use land cover in Sikkim and Darjeeling of northeastern India. Data source for land use land cover: Roy et al. (2016), https://daac.ornl.gov/VEGETATION/guides/Decadal_LULC_India.html).

The niche similarity measures are obtained after comparing the predicted suitable habitat calculated for each grid cell from a model developed through MaxEnt. The niche overlap values ranges vary from 0–1. The value 0 indicates no overlap and the value of 1 indicates a complete overlap of niches. If only two ENM outputs of two species are loaded in ENM Tools, single values of *D* and *I* will be produced and if more than two populations of different species are loaded pair wise *D* and *I* values will be produced in simple Microsoft excel file (Warren et al. 2010).

Niche Breadth

Niche breadth was also assessed using the same set of output predicted distribution models for each species (Phillips et al. 2006; Warren et al. 2010).

Model evaluation and Performance

The model developed for each species was classified and evaluated based on "area under the curve" or AUC values. The model was further graded as: poor (AUC < 0.8), fair (0.8 < AUC < 0.9), good (0.9 < AUC < 0.95), and very good (0.95 < AUC < 1.0) following Thuiller et al. (2005).

RESULTS

Occurrence record

A total of 108 occurrence records or geographic coordinates (*B. gemmipara* = 8, *B. josephii = 12*, *B. satrapis = 10*, *B. picta* = 12, *B. nepalensis* = 4, *B. palmata* = 14, *B. panchtharensis* = 5, *B. sikkimensis* = 8, *B. cathcartii* = 7, *B. megaptera* = 5, *B. xanthina* = 5, *B. flaviflora* = 5, *B. roxburghii* = 13) were collected from Sikkim Himalayas.

The individual occurrence data were then correlated with the set of NDVI variables.

Predicted habitat distribution

ENM was computed individually for each *Begonia* species. The model developed for 13 species of *Begonia* are presented in Figure 2. The 10 percentile training presence logistic threshold values for each species of *Begonia* are also provided in table 4. Using the threshold values of individuals *Begonia* species suitable habitat was calculated. Therefore based on NDVI dataset, *B. panchtharensis* had the maximum area predicted to be suitable (~4306.88 km^2), followed by *B. sikkimensis* (~3,804.62 km^2), *B. picta* (~3,785.4 km^2), *B. cathcartii* (~2,480.01 km^2), *B. xanthina* (~1,905.8 km^2), *B. josephii* (~1,833.28 km^2), *B. flaviflora* (~1,634.74 km^2), *B. megaptera* (~1,412.58 km^2), *B. satrapis* (~1,274.37 km^2), *B. gemmipara* (~1,131.25 km^2), *B. palmata* (~783.446 km^2), *B. roxburghii* (~766.19 km^2), *B. nepalensis* (~60.36 km^2).

Model evaluation and validation

Our model performance showed high accuracy and demonstrated high predictive ability based on AUC scores. The mean AUC; ranged from 0.82 in *B. panchtharensis* and *B. sikkimensis* to 0.97 in *B. satrapis* (Table 4).

Contributing variables and Environmental constraints for Begonia species

The different NDVI variables used to model the distribution of *Begonia* species in Sikkim Himalaya showed a varying degree of contribution to each species model developed. The NDVI for July contributed the most in *B. cathcartii* (68.7 %) followed by *B. sikkimensis* (62.6 %), *B. josephii* (50.5 %), *B. flaviflora* (48.5 %), and *B. gemmipara* (47.6 %). The NDVI for November contributed the most in the case of *B. picta* (32.3 %), *B. palmate* (37.3 %), *B. megaptera* (56.8 %), and *B. roxburghii* (29.6 %). The NDVI for May, January, and March each contributed the most in *B. satrapis* (63.6 %), *B. nepalensis* (24.5 %), and *B. xanthina* (53.1 %) respectively to the final predictive model (Figure 3; Table 3). Considering the permutation importance, the NDVI for July contributed the most in *B. gemmipara* (71.9 %), *B. josephii* (39.5 %), *B. catcarthii* (60.6 %) and *B. flaviflora* (67.7 %). The NDVI for November contributed the most in *B. picta* (72.7 %), *B. palmata* (40.3 %), and *B. megaptera* (53.3 %), *B. xanthina* (33.6 %). The NDVI for January, May, October, and December contributed the most in *B. nepalensis* (30.3 %), *B. satrapis* (72.1 %), *B. sikkimensis* (43.0 %), and *B. panchtharensis* (53.3 %), and altitude contributed the most in *B. roxburghii* (35.0 %) (Table 3).

Niche overlap

The niche overlap test resulted in significantly different levels of overlaps in *Begonia* species. The Hellinger's I niche overlap values were highest between *B. picta*, *B. sikkimensis,* and *B. megaptera* (overlap value = 0.96) indicating the high level to niche overlap whereas the lowest level of niche overlap was estimated between *B. satrapis*, and *B. flaviflora* (overlap value = 0.35) (Table 2).

Similarly, the Schoener's D niche overlap values were highest between *B. picta*, *B. sikkimensis*, and *B. megaptera* (overlap value = 0.81) indicating the high

Table 1. Correlation analysis for the 12 NDVI layers to check multicollinearity using ENM Tools 1.3 (Warren et al. 2010).

Predictor variables	eu1 (Jan)	eu2 (Feb)	eu3 (Mar)	eu4 (Apr)	eu5 (May)	eu6 (Jun)	eu7 (Jul)	eu8 (Aug)	eu9 (Sep)	eu10 (Oct)	eu11 (Nov)	eu12 (Dec)
Alt	-0.56	-0.77	-0.24	-0.53	-0.57	-0.16	-0.76	-0.75	-0.61	-0.10	-0.53	-0.51
eu1 (Jan)		0.57	0.15	0.45	0.35	0.07	0.58	0.61	0.60	0.13	0.46	0.45
eu2 (Feb)			0.12	0.54	0.60	0.22	0.62	0.58	0.46	0.23	0.54	0.54
eu3 (Mar)				0.03	-0.01	-0.16	0.18	0.22	0.22	-0.15	0.09	0.04
eu4 (Apr)					0.67	0.56	0.69	0.67	0.60	0.59	0.69	0.75
eu5 (May)						0.47	0.58	0.54	0.43	0.45	0.63	0.65
eu6 (Jun)							0.39	0.35	0.29	0.73	0.51	0.59
eu7 (Jul)								**0.96**	0.88	0.37	0.75	0.71
eu8 (Aug)									**0.92**	0.35	0.74	0.69
eu9 (Sep)										0.33	0.71	0.63
eu10 (Oct)											0.56	0.72
eu11 (Nov)												0.75

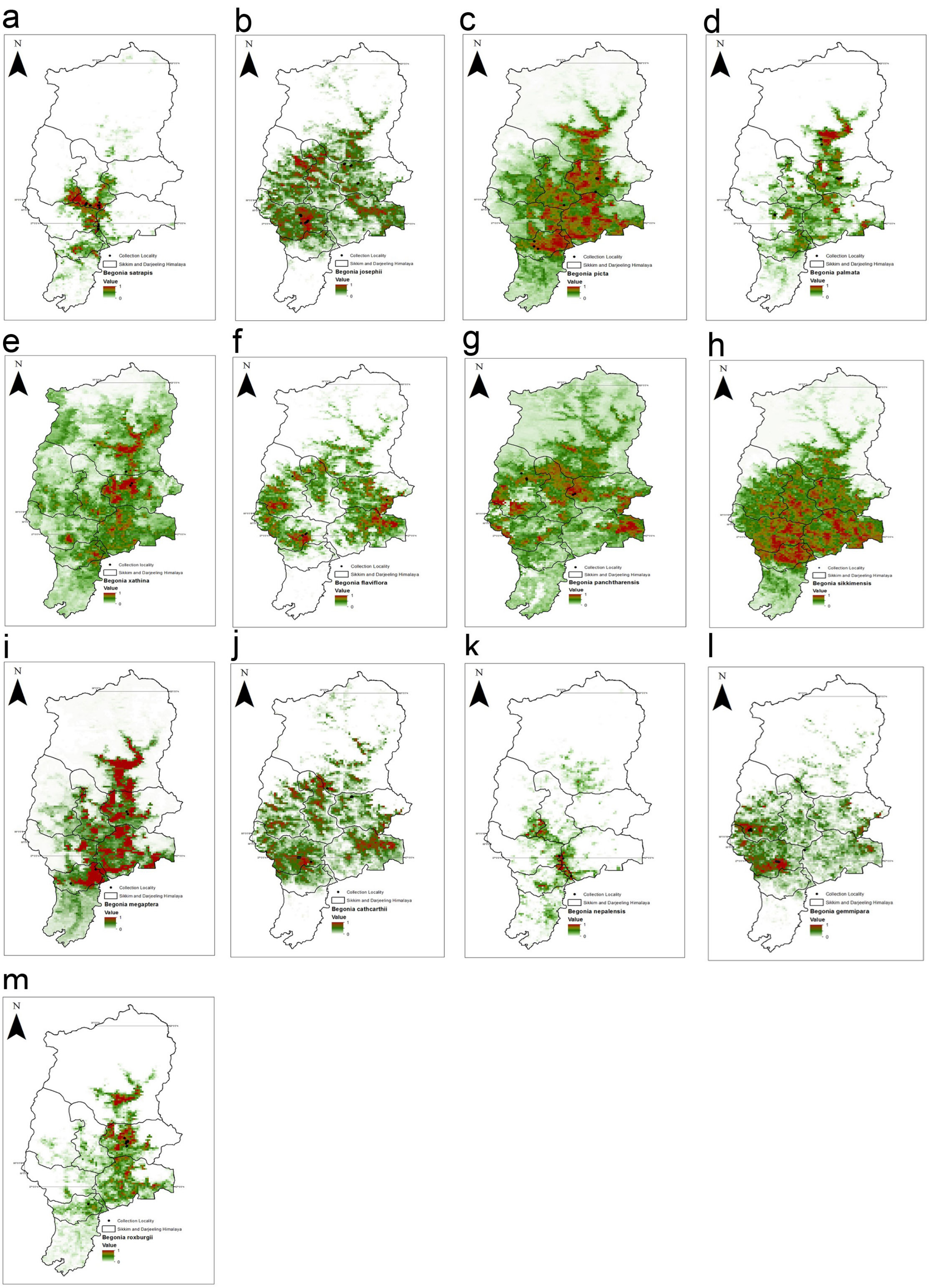

Figure 2. Predicted distribution map based on NDVI variables: a—*B. satrapis* | b—*B. josephii* | c—*B. picta* | d—*B. palmata* | e—*B. xanthina* | f—*B. flaviflora* | g—*B. panchtharensis* | h—*B. sikkimensis* | i—*B. megaptera* | j—*B. cathcartii* | k—*B. nepalensis* | l—*B. gemmipara* | m—*B. roxburghii*.

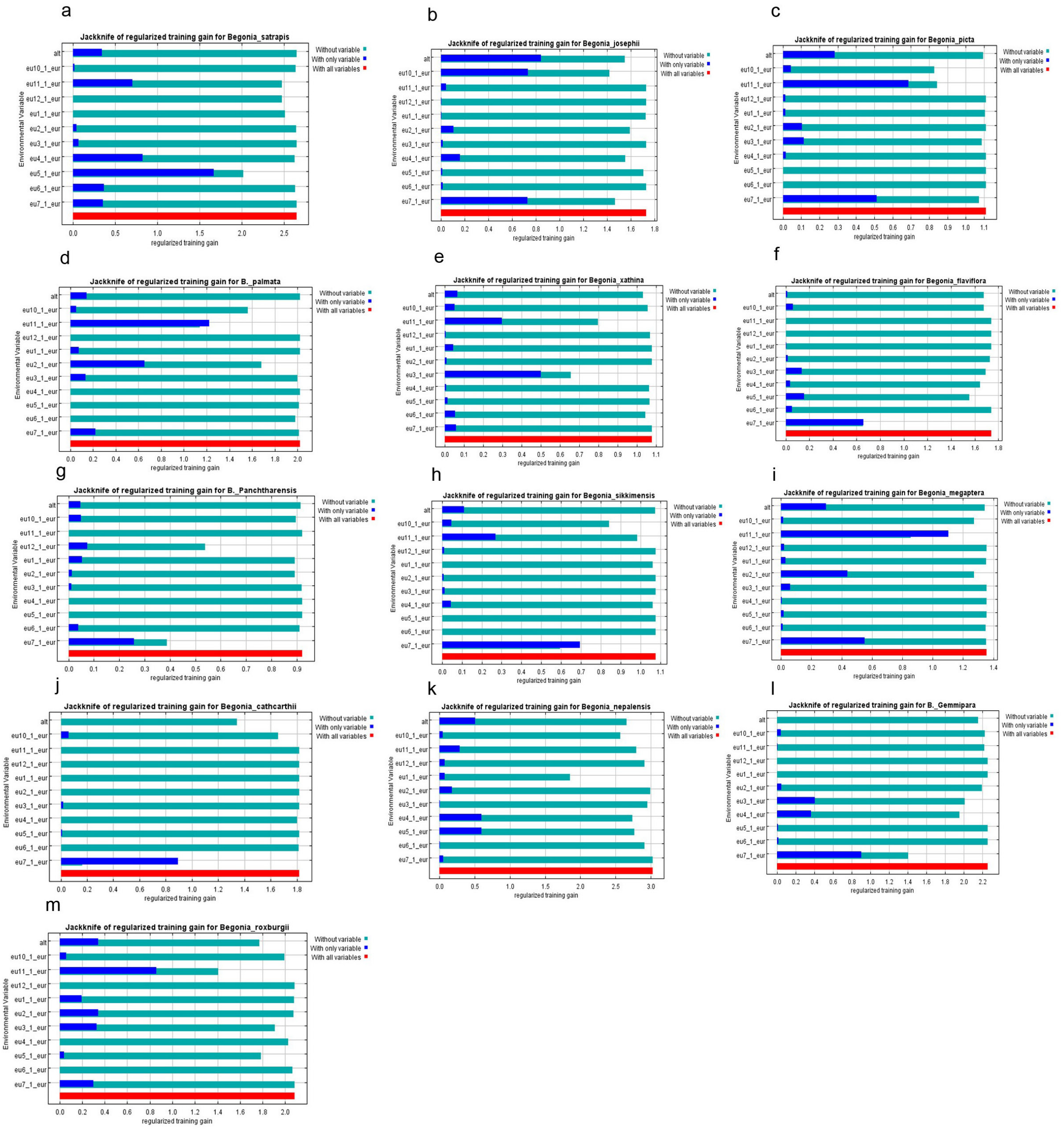

Figure 3. Results of jackknife test for variables importance in *Begonia* species using NDVI variable. a—*B. satrapis* | b—*B. josephii* | c—*B. picta* | d—*B. palmata* | e—*B. xanthina* | f—*B. flaviflora* | g—*B. panchtharensis* | h—*B. sikkimensis* | i—*B. megaptera* | j—*B. cathcartii* | k—*B. nepalensis* | l—*B. gemmipara* | m—*B. roxburghii*.

level to niche overlap whereas a low level of niche overlap was estimated between *B. satrapis*, and *B. flaviflora* (0.12) (Table 2).

Niche Breadth

The niche breadth analysis resulted in narrower niches in some *Begonia* species. *Begonia panchtharensis* had the highest niche breadth value (NBV) of 0.642, indicating broader niches compared to other related species of *Begonia*, which also presented the broadest distribution of suitable habitat. Similarly, the niche breadth for *B. sikkimensis* (NBV = 0.412) and *B. picta* (NBV = 0.384) were also high with broader distribution of suitable habitat compared to other species of *Begonia*. The lowest niche breadth value was estimated in *B. satrapis* (NBV = 0.102) indicating a very narrow niche. Species like *B. nepalensis* (NBV = 0.110) and *B. palmata* (NBV = 0.180) also showed low niche breadth with a

Table 2. Summary of niche overlap values based on NDVI dataset [Schoener's D (above diagonal) and Hellinger's I (below diagonal)].

Schoener's D / Hellinger's I	*B. gemmipara*	*B. josephii*	*B. satrapis*	*B. picta*	*B. nepalensis*	*B. palmata*	*B. panchtharensis*	*B. sikkimensis*	*B. cathcartii*	*B. megaptera*	*B. xanthina*	*B. flaviflora*	*B. roxburghii*
B. gemmipara		0.65	0.25	0.50	0.24	0.33	0.49	0.63	0.69	0.38	0.45	0.68	0.32
B. josephii	0.89		**0.22**	0.55	0.27	0.46	0.49	0.68	0.76	0.46	0.43	0.68	0.37
B. satrapis	0.53	0.49		0.43	0.55	0.38	0.32	0.37	0.20	0.43	0.34	**0.12**	0.28
B. picta	0.81	0.81	0.73		0.44	0.67	0.57	**0.81**	0.49	**0.81**	0.70	0.48	0.66
B. nepalensis	0.50	0.52	0.81	0.73		0.39	0.31	0.39	0.21	0.44	0.34	0.18	0.33
B. palmata	0.61	0.71	0.68	0.91	0.68		0.37	0.56	0.35	0.75	0.52	0.32	0.67
B. panchtharensis	0.79	0.75	0.63	0.85	0.59	0.67		0.64	0.49	0.48	0.65	0.53	0.40
B. sikkimensis	0.89	0.89	0.68	**0.96**	0.68	0.82	0.88		0.64	0.67	0.63	0.60	0.54
B. cathcartii	0.93	0.95	0.46	0.77	0.45	0.62	0.76	0.88		0.39	0.40	0.75	0.31
B. megaptera	0.67	0.69	0.74	**0.96**	0.73	0.95	0.79	0.89	0.65		0.65	0.37	0.70
B. xanthina	0.76	0.71	0.66	0.91	0.88	0.88	0.88	0.87	0.68	0.88		0.43	0.55
B. flaviflora	0.90	0.90	**0.35**	0.77	0.41	0.60	0.82	0.87	0.93	0.65	0.75		0.34
B. roxburghii	0.60	0.62	0.57	0.90	0.61	0.91	0.67	0.81	0.57	0.92	0.80	0.63	

Note: Species are grouped by sections. Highest and lowest overlap values are in bold

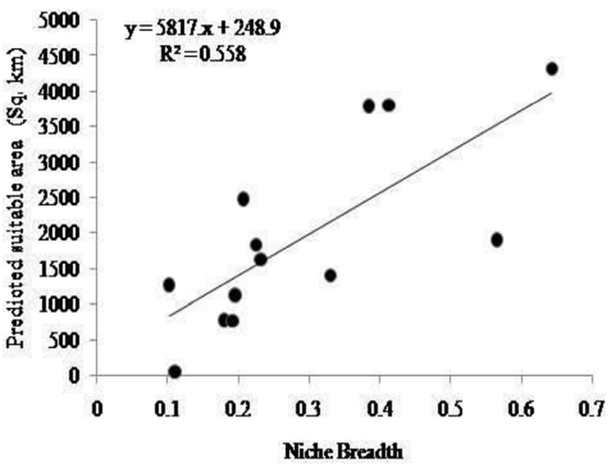

Figure 4. Correlation between predicted suitable area and niche breadth of *Begonia* species using NDVI variables.

narrow distribution of suitable habitat (Table 4).

Relationship between predicted suitable habitat and niche breadth

A strong positive correlation (r = 0.747, p = 0.003) was observed between predicted suitable habitat and niche breadth indicating that the species with higher predicted area retains broader niche breadth and vice versa (Figure 4).

DISCUSSION

Niche characterization in *Begonia* species

The distribution of *Begonia* species is correlated with NDVI based on niche modeling. The importance of NDVI variables contributing to the final predictive model varied across species. The model developed for *B. gemmipara*, *B. josephii*, *B. sikkimensis*, *B. cathcartii,* and *B. flaviflora* showed the highest contribution by NDVI for July. Species like *B. picta*, *B. palmata*, *B. megaptera,* and *B. roxburghii*, usually flowers late after the monsoon, and thereby NDVI for November might have been the most important predictor variables affecting the distribution of species. Interestingly NDVI for November contributed the most in predicted the distribution of *B. nepalensis*. The month of November might have contributed the most in *B. nepalensis* as the species flowers late during dry season i.e. December–January. Amongst all the 13 species of *Begonia*, *B. satrapis* is considered Critically Endangered and is endemic to Sikkim and Darjeeling District of West Bengal (Adhikari et al. 2018). Due to narrow geographic range having restricted distribution, such taxa are more sensitive to habitat disturbance leading to extinction (Peterson & Watson 1998). The distribution of *B. satrapis* is strictly affected by NDVI for May, when the species begins to regenerate from the tuber.

Table 3. Average contribution of input NDVI variables to model output for each species of *Begonia* distributed in Sikkim Himalaya.

Taxon / Variables	*B. gemmipara*	*B. josephii*	*B. satrapis*	*B. picta*	*B. nepalensis*	*B. palmata*	*B. panchtharensis*	*B. sikkimensis*	*B. cathcartii*	*B. megaptera*	*B. xanthina*	*B. flaviflora*	*B. roxburghii*
Percentage contribution													
Eu1 (Jan)	0	0.9	12.5	0.3	**24.5**	0	1.3	0.8	0	0.3	0.1	0	0.1
Eu2 (Feb)	14.1	3.8	1.2	0	0.9	30.9	6.0	0	0.3	21.2	0	4.2	5.3
Eu3 (Mar)	19.2	0	1.0	5.0	2.0	4.0	1.2	0	0	0	**53.1**	4.3	18.2
Eu4 (Apr)	11.3	4.7	3.2	0	10.8	0.2	0.1	0.8	0.5	0.3	1.3	2.0	2.6
Eu5 (May)	0	4.6	**63.6**	0	18.2	1.8	0	0	0.2	0	0.5	31.6	12.3
Eu6 (Jun)	0.1	0	1.1	0	3.5	1.2	0.7	0	0.2	1.1	4.1	0.1	0.6
Eu7 (Jul)	**47.6**	**50.5**	0	12.5	0	0.6	37.2	**62.6**	**68.7**	0.4	0.1	**48.5**	0
Eu10 (Oct)	1.6	23.2	0.7	28.2	9.6	24.1	2.4	26.9	9.3	12.1	9.6	4.4	12.0
Eu11 (Nov)	2.2	0	6.2	**32.3**	10.2	**37.3**	0	8.2	0	**56.8**	22.6	1.5	**29.6**
Eu12 (Dec)	0	0	7.0	0	2.5	0	**45.9**	0	0	0.2	1.1	0	0.1
Altitude	0	0	3.5	21.5	17.9	0.1	5.1	0.6	20.8	7.5	7.5	3.3	19.2
Permutation importance													
Eu1 (Jan)	0	0.9	4.5	0.2	**30.3**	0	5.7	0	0	1.3	0	0.2	0
Eu2 (Feb)	7.2	8.4	0.3	0.3	0.6	23.7	7.9	0	0	0	0	2.7	0
Eu3 (Mar)	6.2	0	0.1	2.2	0.3	1.5	0	0	0	0	17.6	0.6	7.5
Eu4 (Apr)	2.4	1.8	1.6	0	2.3	0	0.3	4.7	0.2	0.4	2.9	5.1	5.1
Eu5 (May)	0	1.4	**72.1**	0	17.0	0.1	0	0	0	0	2	7.3	19.5
Eu6 (Jun)	0.7	0	0.2	0	2.9	3.4	2.7	0.1	0.7	3.4	12.3	1	1.7
Eu7 (Jul)	**71.9**	**39.5**	0	6.2	0	3.1	25.8	41.8	**60.6**	1.9	0	**67.7**	0
Eu10 (Oct)	1.5	27.7	0.6	9.4	6.4	27.4	0.1	**43.0**	9.9	15.9	5.9	10.4	5.5
Eu11 (Nov)	0.8	0.1	14.8	**72.7**	18.5	**40.3**	0	9.7	0	**67.3**	**33.6**	0	25.6
Eu12 (Dec)	0	0	5.8	0	0.4	0	**53.3**	0	0	2.2	11.7	0	0.1
Altitude	9.2	20.2	0	8.9	21.3	0.6	4.0	0.6	28.5	7.5	14	4.9	**35.0**

Niche overlap and Niche Breadth

It is often assumed that closely related species are morphologically and physiologically alike, and have similar environmental requirements, i.e., niche retention (Futuyma & Mitter 1996; Webb 2000; Violle et al. 2011). The niche overlap test for *Begonia* species resulted in great variability in niche overlap values between morphologically similar species. The low niche overlaps values between species of section *Diploclinium*, viz., *B. satrapis* and *B. josephii* might have resulted due to competitive interaction leading to niche partitioning (Hardin 1960). Moreover, the highest niche overlap values between species of section *Diploclinium*, viz., *B. picta* and *Platycentrum*, viz., *B. sikkimensis* and *B. megaptera* support the 'limiting similarity hypothesis' (MacArthur & Levins 1967) which posits that competitive exclusion among closely related species leads to the frequent coexistence of more distantly related species within ecological communities.

The results of niche breadth analysis support the idea that better-performing models are associated with more specialized and narrow niche breadth and vice-versa (Fuchs et al. 2018). The model developed for *Begonia* species *viz*. *B. picta*, *B. panchtharensis*, *B. sikkimensis,* and *B. xanthina* were considered fair (0.8 < AUC < 0.9), with higher niche breadth indicating more ecological flexibility compared to other species of *Begonia.* These species in addition to having broader niche breadth have larger distribution areas, ranging from Western Himalaya to entire Eastern Himalaya, covering countries like Nepal, Bhutan, and China (Rajbhandari et al. 2010; Rana 2016; Camfield & Hughes 2018; Hughes et al.

Table 4. Niche breadth values and predicted suitable area (10 percentile training presence logistic threshold value).

	Species	AUC	Niche breadth	Threshold value/ Area (km²)
1	*B. gemmipara*	0.93	0.195	0.304/1131.25
2	*B. josephii*	0.94	0.225	0.384/1833.27
3	*B. picta*	**0.89**	**0.384**	**0.396/3785.40**
4	*B. satrapis*	**0.97**	**0.102**	0.133/1274.37
5	*B. flaviflora*	0.91	0.231	0.416/1634.74
6	*B. cathcartii*	0.91	0.206	0.283/2480.00
7	*B. megaptera*	0.91	0.329	0.521/1412.57
8	*B. nepalensis*	**0.89**	**0.110**	**0.605/60.36**
9	*B. palmata*	**0.95**	**0.180**	**0.469/783.44**
10	*B. panchtharensis*	**0.82**	**0.642**	**0.333/4306.88**
11	*B. sikkimensis*	**0.82**	**0.412**	**0.445/3804.61**
12	*B. xanthina*	0.84	0.565	0.449/1905.79
13	*B. roxburghii*	0.94	0.191	0.448/766.19

Note: The highest and the lowest niche breadth are highlighted in bold. Values range from 0–1: 0 is equal to one grid cell being suitable (specialized niche); whereas 1 is where all grid cells are suitable (broad niche).

2018; Pradhan et al. 2019). Thus, these species have wider climatic tolerance with larger variation within and amongst the population and sometimes even recognized at a variety level (Camfield & Hughes 2018). In addition to having a wider niche breadth, these species also have a wider predicted distribution area compared to other species. A case apart in *B. xanthina* with broader niche breadth and smaller area (~1905 km²) predicted to be suitable. However, the model developed for *B. satrapis*, *B. gemmipara,* and *B. nepalensis* were considered a very good performing model with the lowest niche breadth (ranging 0.102–0.195) indicating lesser ecological flexibility. Such species with smaller niche breadth have lesser tolerance to climatic variation preferring homogenous environmental conditions (Kassen 2002; Dennis et al. 2011). The study thus displays a positive correlation between species' niche breadth and suitable predicted area, except in the case of *B. xanthina* the results were otherwise. Niche breadth of most species was consistent with their geographic distributions, as narrowly distributed species have smaller niche breadth and broader distributed species have wider niche breadth (Gaston 1993; Kunin & Gatson 1997). The narrow distribution range of *B. satrapis*, *B. gemmipara,* and *B. nepalensis* might be primarily due to narrow niche breadth. The study is in line with the study on the Mexican genus of globular cacti and numerous other similar studies (Zhu et al. 2016; Mosco 2017). Therefore, such rare species with narrow niche breadth have a higher probability of extinction (Futuyma & Moreno 1988; McKinney 1997) and thus require immediate conservation initiatives to conserve the existing extant population.

CONCLUSION

The predictive distribution model for *Begonia* species, like *B. picta*, *B. panchtharensis*, *B. sikkimensis*, and *B. xanthina*, showed wider niche breadths, indicating greater ecological flexibility. In addition to their broader niche breadths, these species have larger distribution areas that range from the western to eastern Himalaya. In contrast, the models for *B. satrapis*, *B. gemmipara*, and *B. nepalensis* demonstrated very strong performance with narrower niche breadths, indicating less ecological flexibility. As a result, these species require immediate attention, as their smaller suitable habitats and narrow niche breadths make them more vulnerable to extinction.

REFERENCES

Adhikari, D., Z. Reshi, B.K. Datta, S.S. Samant, A. Chettri, K. Upadhaya, M.A. Shah, P.P. Singh, T. Tiwary, K. Majumdar, A. Pradhan, M.L. Thakur, N. Salam, Z. Zahoor, S.H. Mir, Z.A. Kaloo & S.K. Barik (2018). Inventory and characterization of new populations through ecological niche modelling improve threat assessment. *Current Science* 114(3): 0468–0595. https://doi.org/10.185 20/cs%2Fv114%2Fi03%2F519-531

Amaral, S., C.B. Costa & C.D. Renno (2007). Normalized Difference Vegetation Index (NDVI) improving species distribution models: an example with the Neotropical genus *Coccocypselum* (Rubiaceae). Anais XIII Simposio Brasileiro de Sensoriamento Remote, Florianopolis, Brazil, 21–26 April, INPE, pp 2275–2282.

Araújo, C., L. Marcondes-Machado & G. Costa (2014). The importance of biotic interactions in species distribution models: A test of the Eltonian noise hypothesis using parrots. *Journal of Biogeography* 41(3): 513–523. https://doi.org/ 10.1111/j bi.12234

Basu, S.K. (2013). *Geology of Sikkim State and Darjeeling District of West Bengal*. Geological Society of India, Bangalore, ix + 255 pp.

Burgman, M.A. (1989). The habitat volumes of scarce and ubiquitous plants: A test of the model of environmental control. *The American Naturalist* 133: 228–239. https://doi.org/10.1086/284912

Camfield, R. & M. Hughes (2018). A revision and one new species of *Begonia* L. (Begoniaceae, Cucurbitales) in Northeast India. *European Journal of Taxonomy* 396: 1–116. https://doi.org/10.5852/ejt.2018.396

Colwell, R.K. & T.F. Rangel (2009). Hutchinson's duality: The once and future niche. *Proceedings of the National Academy of Sciences* 106: 19651–19658. https://doi.org/10.1073/pnas.0901650106

Dennis, R.L., L. Dapporto, S. Fattorini & L.M. Cook (2011). The generalism–specialism debate: the role of generalists in the life and death of species. *Biological Journal of the Linnean Society* 104: 725–737. https://doi.org/10.111 1/j.1095-8312.2011.01789.x

Elith, J., C. Graham & the NCEAS species distribution modelling group (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129–151.

Fuchs, A., C. Gilbert & J. Kamilar (2018). Ecological niche modeling of the genus Papio. *American Journal of Biological Anthropology* 166(4): 812–823.

Futuyma, D. & G. Moreno (1988). The evolution of ecological specialization. *Annual Review of Ecology Evolution and Systematics* 19: 201–233.

Futuyma, D.J. & C. Mitter (1996). Insect-plant interactions: the evolution of component communities. Philosophical Transactions of the Royal Society of London. *Series B: Biological Sciences* 351: 1361–1366. https://doi.org/10.1098/rs tb.1996.0119

Gaston, K.J. (1993). *Rarity*. Chapman and Hall, London. 205 pp. https://doi.org/10.1007/978-94-011-0701-3

Gaston, K.J. (2000). Global patterns in biodiversity. *Nature* 405: 220–227. https://doi.org/10.1038/35012228

Gaston, K.J. (2003). *The Structure and Dynamics of Geographic Ranges*. Oxford University Press, Oxford, UK, 278 pp.

Gaston, K.J. & J.I. Spicer (2001). The relationship between range size and niche breadth: A test using five species of Gammarus (Amphipoda). *Global Ecology and Biogeography* 10: 179–188. https://doi.org/10.1046/j.1466-822x.200 1.00225.x

Gaston, K.J. & T.M. Blackburn (2000). *Pattern and Process in Macroecology*. Wiley, U.S., 377 pp.

Gotelli, N.J., G.R. Graves & C. Rahbek (2010). Macroecological signals of species interactions in the Danish avifauna. *Proceedings of the National Academy of Sciences of the United States of America* 107: 5030–5035. https://doi.org/10.1073/pnas.0914089107

Gotzenberger, L., F. de Bello, K.A. Brathen, J. Davison, A. Dubuis, A. Guisan, J. Leps, R. Lindborg, M. Moora, M. Partel, L. Pellissier, J. Pottier, P. Vittoz, K. Zobel & M. Zobel (2012). Ecological assembly rules in plant communities approaches, patterns and prospects. *Biological Reviews* 87: 111–127. https://doi.org/10.11 11/j.1469-185X.2011.00187.x

Gregory, R.D. & K.J. Gaston (2000). Explanations of commonness and rarity in British breeding birds: Separating resource use and resource availability. *Oikos* 88: 515–526. https://doi.org/10.1034/j.1600-0706.2000.880307.x

Guisan, A. & W. Thuiller (2005). Predicting species distribution: offering more than simple habitat models. *Ecology Letters* 8: 993–1009. https://doi.org/1 0.1111 /j.1461-0248.2005.00792.x

Hardin, G. (1960). The competitive exclusion principle. *Science* 131: 1292–1297. https://doi.org/10.1126/science.131.3409.1292

Hughes, M., C.I. Peng, C.W. Lin, R.R. Rubite, P. Blanc & K.F. Chung (2018). Chloroplast and nuclear DNA exchanges among *Begonia* sect. *Baryandra* species (*Begoniaceae*) from Palawan Island, Philippines, and descriptions of five new species. *PLoS ONE* 13(5) : e0194877. https://doi.org/10.1371/journal.pone.0194877

Kassen, R. (2002). The experimental evolution of specialists, generalists, and the maintenance of diversity. *Journal of Evolutionary Biology* 15(2): 173–190. https://doi.org/10.1046/j.1420-9101.2002.00377.x

Kunin, W.E. & K.J. Gaston (1997). *The Biology of Rarity: Causes and Consequences of Rare Common Differences*. Chapman and Hall, London.

MacArthur, R. & R. Levins (1967). The limiting similarity, convergence, and divergence of coexisting species. *The American Naturalist* 101(921): 377–385. https://doi.org/10.1086/282505

McKinney, M.L (1997). Extinction vulnerability and selectivity: Combining ecological and paleontological views. *Annual Review of Ecology and Systematics* 28: 495–516. http://doi.org/10.1146/annurev.ecolsys.28.1.495

Moonlight, P.W. (2017*).* Linking speciation and the niche: taxonomy, phylogeny and niche evolution in neotropical *Begonia.* PhD thesis. University of Glasgow. http://theses.gla.ac.uk/id/eprint/8397

Mosco, A. (2017). Niche characteristics and potential distribution of *Thelocactus* species, a Mexican genus of globular cacti. *bioRxiv* 124511. https://doi.org/10.1101/124511

Peterson, A.T. & D.M. Watson (1998). Problems with areal definitions of endemism: the effects of spatial scaling. *Diversity and Distribution* 4(4): 189–194. https://doi.org/10.1046/j.1472-4642.1998.00021.x

Phillips, S.J., R.P. Anderson & R.E. Schapire (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190 (3–4): 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S.J. & M. Dudík (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31(2): 161–175. https://doi.org/101111/j.0906-7590.2008.5203.x

Pradhan, A., D. Rai, S.K. Barik & A. Chettri (2019). *Begonia panchtharensis* (Begoniaceae), a new record to India from Sikkim, Eastern Himalaya. *Journal of Japanese Botany* 94: 56–57.

Rai, L.K., P. Prasad & E. Sharma (2000). Conservation threats to some important medicinal plants of the Sikkim Himalaya. *Biological Conservation* 93: 27–33. https://doi.org/10.1016/S0006-3207(99)00116-0

Rajbhandary, S., M. Hughes & K. Shrestha (2010). Three new species of *Begonia* sect. *platycentrum* from Nepal. *Gardens' Bulletin Singapore* 62: 151–162.

Roy, P.S., P. Meiyappan, P.K. Joshi, M.P. Kale, V.K. Srivastav, S.K. Srivasatava, M.D. Behera, A. Roy, Y. Sharma, R.M. Ramachandran, P. Bhavani, A.K. Jain & Y.V.N. Krishnamurthy (2016). Decadal Land Use and Land Cover Classifications across India, 1985, 1995, 2005. ORNL DAAC, Oak Ridge, Tennessee, USA.

Slatyer, R.A., M. Hirst & J.P. Sexton (2013). Niche breadth predicts geographical range size: A general ecological pattern. *Ecology Letters* 16: 1104–1114. https://doi.org/10.1111/ele.12140

Soberón, J. (2007). Grinnellian and Eltonian niches and geographic distributions of species. *Ecology Letters* 10: 1115–1123. https://doi.org/10.1111/j.1461-0248. 2007.01107.x

Sunday, J.M., A.E. Bates & N.K. Dulvy (2011). Global analysis of thermal tolerance and latitude in ectotherms. *Proceeding of the Royal Society B* 278: 1823–1830. https://doi.org/10.1098/rspb.2010.1295

Synes, N.W. & P.E. Osborne (2011). Choice of predictor variables as a source of uncertainty in continental-scale species distribution modelling under climate change. *Global Ecology and Biogeography* 20(6): 904–914. https://doi.org/10.1 111/j.1466-8238.2010.00635.x

Thuiller, W., D.M. Richardson, P. Pyˇsek, G.F. Midgley, G.O. Hughes & M. Rouget (2005). Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biology* 11: 2234–2250. https://doi.org/10.1111/j.1365-2486.2005.001018.x

Violle, C., D.R. Nemergut, Z. Pu & L. Jiang (2011). Phylogenetic limiting similarity and competitive exclusion. *Ecology Letters* 14: 782–787.

Warren, D., G. Richard & M. Turelli (2010). ENM Tools: A toolbox for comparative studies of environmental niche models. *Ecography* 33: 607–611.

Webb, C.O. (2000). Exploring the phylogenetic structure of ecological communities: an example for rain forest trees. *The American Naturalist* 156: 145–155. https://doi.org/10.1086/303378

Willis, J.C. (1922). *Age and Area; A Study in Geographical Distribution and Origin of Species*. The University Press, Cambridge, UK. https://doi.org/10.5962/bh l.title.30741

Zhu, G.P., H.Q. Li, L. Zhao, L. Man & Q. Liu (2016). Mapping the ecological dimensions and potential distributions of endangered relic shrubs in Western Ordos Biodiversity Centre. *Scientific Report* 6: 26268. https://doi.org/10.1038/s rep26268

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