Inventory and characterization of new populations through ecological niche modelling improve threat assessment

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Categorization of species under different threat classes is a pre-requisite for planning, management and monitoring of any species conservation programme. However, data availability, particularly at the population level, has been a major bottleneck in the correct categorization of threatened species. Till date, threat assessments have been mostly based on expert opinion and/or herbarium records. The availability of primary data on distribution of species and their population attributes is limited in India because of inadequate field survey, which has been ascribed to resource constraints and inaccessibility. In this study, we demonstrate that ecological niche modelling (ENM) can be an economical and effective tool to guide surveys overcoming the above two constraints leading to the discovery of new populations of threatened species. Such data lead to improved threat assessment and more accurate categorization. We selected 14 threatened plants comprising 5 trees (*Acer hookeri* Miq., *Bhesa robusta* (Roxb.) Ding Hou, *Gynocardia odorata* Roxb., *Ilex venulosa* Hook. f. and *Lagerstroemia minuticarpa* Debb. ex P.C. Kanjilal), 8 herbs (*Angelica glauca* Edgew., *Aquilegia nivalis* Falc. ex Jackson, *Artemisia amygdalina* DC., *Begonia satrapis* C.B. Clarke, *Corydalis cashmeriana* Royle, *Dactylorhiza hatagirea* (D. Don) Soo, *Podophyllum hexandrum* Royle, and *Rheum australe* D. Don), and 1 pteridophyte (*Angiopteris evecta* (Forst.) Hoffm.) having distribution range in North East India, Eastern and Western Himalaya, and Jammu and Kashmir. The study was carried out between 2012 and 2016. ENM-based survey led to the discovery and characterization of 348 new populations. The data so obtained helped in assigning conservation status to 10 species, which earlier were never classified due to data deficiency. Using the new population and distribution data of the remaining four species, only one was confirmed regarding its existing status and two species were classified as 'Critically endangered' instead of the present classification as 'Endangered'. The fourth species was classified as 'Critically endangered' against the earlier category of 'Least concerned'.

Keywords: Niche modelling, population characterization, threatened plants, threat assessment.

Introduction

PRIORITIZATION of species through threat assessment is a pre-requisite for conservation planning, action, monitoring and evaluation purposes[1–3]. Lack of data pertaining to occurrence and population status of threatened species is a major bottleneck in the proper threat assessment and categorization process[4]. The data deficiency has been attributed to: (i) limited knowledge about the potential distributional range, (ii) inadequate survey, and (iii) poor knowledge about the population status in nature and other population attributes[5]. The International Union for Conservation of Nature (IUCN) and the Conservation Data Center (CDC) have devised various approaches/ methodologies to categorize species under various threat classes. These include population inventory and characterization (following field surveys), herbarium records, expert opinions, qualitative scoring techniques, and determining area of occupancy (AOO) and extent of occurrence (EOO). Conservation assessment following field survey is an exhaustive process requiring substantial

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effort and investment of human and financial resources. Therefore, most of the threat assessments follow a faster subjective approach. This, however, compromises with the objectivity, reliability and inclusiveness of the threat assessment process. In India, threat assessment of species was undertaken through Conservation Assessment and Management Plan (CAMP) workshops to make the categorization more useful in conservation practices, where data on various aspects of the species are compiled through active participation by a panel of experts. Thus, the issue of data deficiency for threat assessment remains per se.

Field survey associated with study of population demography of threatened plants is the fundamental aspect of threat classification. Assessing new populations and the associated ecological factors help in having a better appraisal of the threat levels. It also requires meticulous survey, field observations and demographic data analysis. Designing an effective conservation plan for any threatened species requires unbiased empirical data on its geographical range, ecological niche, biotopes and suitable habitats[6]. Usually, population surveys are guided by expert opinion and field experience of the researcher[7]. However, undertaking field surveys in novel areas under inhospitable terrain and in remote and inaccessible areas poses logistic challenges to have adequate survey. Thus, field surveys are often undertaken according to the convenience of the researchers, e.g. sampling efforts are mostly concentrated in the most accessible areas such as roadsides, or during the most comfortable time of the year. Such issues lead to spatial and temporal biases in data collection resulting in incomplete information or data deficiency on ecology and distribution of the threatened species. Such spatial and temporal biases are visible in the plant sample collections stored in most herbaria or natural history museums[8]. The biased and incomplete surveys eventually reduce the accuracy of the threat assessment[9].

Ecological niche modelling (ENM) has emerged as a robust tool for undertaking targetted biodiversity surveys and discovering new occurrences for species and populations[10–13]. In ENM, the niche of a species is estimated by correlating known occurrence records with the associated environmental data in an ecological space. The estimated niche is then projected and visualized in a geographic space in the form of predictive distribution map using geographic information system (GIS) software. This map may be treated as a testable hypothesis, which is subsequently verified and validated through field survey[14]. Also, various model calibration and evaluation procedures along with statistical operations help in constructing a formal distributional model for the species. The niche models are then extrapolated to geographic space and time[15], and are used to prepare guide maps for intended plant survey and delineation of conservation areas for selected species[13].

The availability of primary data on the distribution of species and their population attributes is limited in India because of inadequate field survey, which has been ascribed to resource constraints and inaccessibility. In this study, we demonstrate that ENM can be an economical and effective tool to guide surveys overcoming the above two constraints leading to the discovery of new populations of threatened species. Such data lead to improved threat assessment and more accurate categorization.

Material and methods

Survey and analysis

Fourteen threatened species comprising five trees (*Acer hookeri*, *Bhesa robusta*, *Gynocardia odorata*, *Ilex venulosa* and *Lagerstroemia minuticarpa*), eight herbs (*Angelica glauca*, *Aquilegia nivalis*, *Artemisia amygdalina*, *Begonia satrapis*, *Corydalis cashmeriana*, *Dactylorhiza hatagirea*, *Podophyllum hexandrum* and *Rheum australe*), and one pteridophyte (*Angiopteris evecta*) having distribution range in North East India, Eastern and Western Himalaya, and Jammu and Kashmir (J&K) were selected (Box 1). The study was carried out between the years 2012 and 2016. Secondary information on the occurrence, distribution and conservation status of the threatened plants was collated from various sources, viz. scientific publications, books[16–27] and on-line sources (www.envis.frlht.org, www.bsienvis.nic.in, www.nbaindia.org, www.moef.nic.in, www.iucnredlist.org). The information obtained through secondary sources was then subjected to data triangulation for taxonomic and distribution discrepancies.

Informed grid-based survey

Initial field studies were carried out during 2012–13 to locate populations of the selected species following informed grid-based survey. Here, the study areas were divided into 10×10 km grids, and the survey was then carried out in the grids identified through the historical record on occurrence of species such as herbarium, published literature and expert opinion. Geographic coordinates of species occurrence were recorded to an accuracy level of <10 m using geographical positioning system (GPS).

Generation of ENMs for guiding field surveys

Ecological niche models were generated using the primary occurrence data obtained through informed grid-based surveys during 2012 and 2013, with elevation and 19 bioclimatic variables as predictors. Raster data on elevation and 19 bioclimatic variables with a resolution of 30 arcsec (~1 km) were downloaded from www.worldclim.org. The species-specific predicted potential distribution maps

Box 1. Species selected for the present study

1. *Acer hookeri* is a medium to large tree belonging to family Aceraceae. The species is distributed in India (West Bengal – Darjeeling Hills, Sikkim, Arunachal Pradesh, Assam, Darjeeling), Nepal, Bhutan, South Tibet and Myanmar. It has become endangered due to overexploitation for timber and firewood and massive deforestation for cultivation by hill people[21–23].
2. *Angelica glauca* is a perennial, glabrous herb with thick, aromatic rootstock belonging to family Apiaceae. It is endemic to the Himalayan region and is distributed between 2400 and 3800 m from temperate to alpine zones of Kashmir, Himachal Pradesh (Kullu, Mandi, Shimla, Chamba, Kinnaur, Kangra, Sirmour and Lahaul and Spiti districts) and Uttarakhand. The species has become endangered due to overexploitation and habitat degradation.
3. *Angiopteris evecta* is a very large fern belonging to family Marattiaceae. It has a thick rhizome, large spreading fronds and sori along the margin. The species has global distribution. It is threatened due to habitat degradation.
4. *Aquilegia nivalis* is a perennial herb belonging to family Ranunculaceae. It is endemic to Kashmir Himalayan region and grows along an altitudinal range from 3000 to 4000 m (amsl). In the small-sized populations, very few individuals reach the reproductive stage. The species is not only overexploited in view of myriad medicinal uses, but its individuals are also damaged by herbivores. These factors along with hostile habitat conditions and enhanced anthropogenic pressures contribute to the present threat status of this endemic species.
5. *Artemisia amygdalina* is a perennial herb belonging to family Asteraceae. The plant grows at an altitude ranging from 2500 to 2800 m amsl. It is medicinally very important and hence faces a severe threat due to over-exploitation.
6. *Begonia satrapis* is a dwarf succulent herb belonging to family Begoniaceae. It is endemic to Sikkim Himalaya and has very localized distribution with a low extent of occurrence. The species is threatened due to habitat degradation.
7. *Bhesa robusta* is a medium to large tree belonging to family Centroplacaceae. It is distributed in India (Andaman Islands, Arunachal Pradesh, Assam), Indonesia, Malaysia, Myanmar, Singapore and Vietnam.
8. *Corydalis cashmiriana* is an alpine herb belonging to family Papaveraceae. It is endemic to the Kashmir Himalayan region. The species is severely threatened in its natural habitats by various anthropogenic activities like road constructions and overgrazing.
9. *Dactylorhiza hatagirea* is a perennial herb belonging to family Orchidaceae. The species is distributed in India, Bhutan, China and Pakistan. In India, it is distributed in the Himalayan region, i.e. temperate to alpine regions of Kashmir (2500–5000 m amsl in Drass, Suru valley, Pir ki gali), Tungnath (3500–4000 m amsl); Himachal Pradesh (Kullu, Mandi, Shimla, Chamba, Kinnaur, Kangra, Sirmour and Lahaul–Spiti districts). The species is critically endangered due to habitat degradation.
10. *Gynocardia odorata* is an evergreen tree species belonging to family Achariaceae. It is distributed in India, South-East China, Bangladesh, Nepal and Myanmar. In India, it is distributed in Tripura (Kaptoli, Jampui Ranges, Atharamura and Shakan Hill ranges), Meghalaya and Mizoram. The species is threatened because of over-extraction and habitat degradation.
11. *Ilex venulosa* is a moderate-sized tree belong to family Aquifoliaceae. It is endemic to Meghalaya, in India. The species has become endangered because of over-extraction.
12. *Lagerstroemia minuticarpa* is a large tree species belonging to family Lythraceae. It is endemic to the northeastern region of India. It has been classified as rare by Nayar and Sastry[21–23] and are earlier reported only from two localities, i.e. Garampani in Assam and Singtam in Sikkim. Recently, we have located several new populations in Arunachal Pradesh and Sikkim, where the species is under threat due to shifting cultivation and dam construction. The species is classified as Endangered according to IUCN Red List.
13. *Podophyllum hexandrum* is a perennial herb belonging to family Berberidaceae. The species is distributed in temperate, subalpine and alpine regions of the Himalaya from Afghanistan to Southwest China and Myanmar between 2800 and 4000 m. In India, the species is found in J&K, Uttarakhand and Himachal Pradesh in shady, moist slopes and bouldery habitats. In Himachal Pradesh, it is reported from Shimla, Kullu, Mandi, Lahaul and Spiti, Kangra, Dharamsala, Kinnaur and Chamba districts.
14. *Rheum australe* is a perennial herb belonging to family Polygonaceae. The species is distributed in Sri Lanka, Nepal and India. In India, it is found in the Himalaya from Kashmir to Sikkim between 2800 and 5200 m; and in Himachal Pradesh (Kangra, Chamba, Kullu, Shimla, Kinnaur, Sirmour and Lahaul and Spiti districts). The species is threatened due to habitat degradation.

were then used as a field guide for undertaking surveys. The iterative process of model prediction and field survey was continued till December 2016. Population status of the selected tree species was assessed by totalling the individual counts of adults, saplings and seedlings in demarcated 250 × 250 m grids in the areas of occurrence. For herb and pteridophyte species, quadrats of 5 × 5 m size were laid in the areas of occurrence.

Potential habitat distribution modelling

Potential habitat distribution for each species was modelled using all the occurrence records. Selection of appropriate predictor variables in ENM is crucial as it influences the predictive ability of the model[28]. Having known the habitat-specialist nature of the selected species through field surveys, we selected elevation, normalized difference vegetation index (NDVI) and potential evapotranspiration (PET) for January to December as predictors to model their potential distribution areas. These variables are functionally more relevant to species potential distribution compared to the bioclimatic variables and often yield better models[29,30]. Digital elevation data of 90 m resolution for the study area were downloaded from Consultative Group for International Agricultural Research (CGIAR) (http://srtm.csi.cgiar.org/). Raster data on Advanced Very High Resolution Radiometer (AVHRR-NDVI) were obtained from Global Land Cover Facility (GLCF) (University of Maryland, USA), and potential evapotranspiration data were obtained from CGIAR[31]. As high dimensionality in the dataset, i.e. a total of 25 variables might possibly lead to data redundancy and multicollinearity issues, we performed principal component analysis (PCA) to compress the information content into a lesser number of principal component images[32]. Here, the input variables differentially contribute information content to each of the axes in the form of variances. Subsequently, the first 15 principal component images (PCIs) explaining ~99.99% of the total variation in the dataset were selected as predictors of the potential distribution of the selected species. Elevation had the highest contribution to the first principal component axis (PC_1), the contribution of NDVI was the highest to the second axis (PC_2), and PET had the highest collective contribution to the third principal component axis (PC_3) (Annexure 1). The selected PCIs were converted to ASCII file format for use as predictors. All analyses were done using ArcGIS software at a spatial resolution of ≈1 km.

Selection of appropriate calibration area extent is crucial in species distribution modelling for generating acceptable models[33,34]. Hence, species-specific convex hulls were drawn using the final set of occurrence records for delineating model calibration areas. A 1 km buffer area was added to each of the convex hulls in the surveyed landscape for each of the species.

Maxent ver. 3.3.3e was used to predict the potential distribution areas[35]. Maxent is a machine learning algorithm that computes the suitability of a pixel in a defined landscape by contrasting random background pixels against the ones with actual species presence[36]. A pixel corresponds to the grid of a particular size in the real world. The landscape is characterized by a set of gridded environmental variables, e.g. temperature, precipitation and vegetation index. The species presence data in the raster grids are indicated as geographic coordinates. Thus, it estimates a probability surface representing the distribution of pixels with a suitability range of zero to unity[37].

Model parameterization was done using 10,000 background points, 5,000 iterations and a convergence threshold of 0.00001. We used the hinge, linear and quadratic feature type to optimize complexity in model-fitting because of low presence records[37]. Model overfitting was restrained using a regularization multiplier of 1. Ten bootstrap runs were executed for each species to achieve model consistency and derive optimized logistic models.

Model performance was evaluated based on traditional area under curve (AUC) metrics, where an AUC value of ≤0.5 indicates that the model could not perform better than random expectations, whereas a value of 1 indicates perfect discrimination between true and false positive rates[35]. The conservative guide suggested by Thuiller *et al.*[38] was used for classifying the ecological niche models into random (AUC < 0.8), fair (0.8 < AUC < 0.9), good (0.9 < AUC < 0.95) and very good (0.95 < AUC < 1.0) categories. We also used the partial AUC metric for evaluating model performance[39,40]. Partial AUC was estimated using Niche Toolbox, available on-line at http://shiny.conabio.gob.mx:3838/nichetoolb2/. The tool calculates the ratio of AUC_{random} (at 0.5 level) and AUC_{actual} (with a defined level of omission, e.g. 0.05) using the occurrence data and the predicted distribution model. Bootstrap iterations are executed for a user-defined number of folds utilizing different combinations of the occurrence data. These give a graphical output of the distribution of the estimated random and actual AUC values, along with statistical significance tests for the difference between the distributions. In this study, we executed 500 bootstrap iterations with 5% omission to obtain the distribution curves for AUC_{random} and AUC_{actual}. Finally, the hypothesis that the predictive model performed better than random expectations was tested.

Threat assessment

The IUCN ver. 1.3 classification scheme was followed for assigning threat status to the selected species[41]. The criteria B, C and D were used for threat assessment that include geographic range of occurrence, population size and status, number of existing matured individuals,

Table 1. Number of locations recorded for the selected threatened species during 2012–2016 in North East (NE) India, Jammu and Kashmir (J&K) and Western Himalaya. Locations for the years 2012 and 2013 are based on preliminary grid surveys, and those of 2014–16 are based on ENM-guided surveys

	Number of locations recorded during the survey period					
	Grid-based survey		ENM-guided surveys			
Species	2012	2013	2014	2015	2016	Total
Acer hookeri	–	4	2	3	4	13
Angelica glauca	–	13	7	17	–	37
Angiopteris evecta	–	5	1	6	–	12
Aquilegia nivalis	–	6	9	12	17	44
Artemisia amygdalina	–	3	4	6	7	20
Begonia satrapis	–	3	4	5	–	12
Bhesa robusta	4	6	4	3	3	20
Corydalis cashmeriana	–	6	10	15	18	49
Dactylorhiza hatagirea	–	2	19	19	–	40
Gynocardia odorata	3	2	2	3	1	11
Ilex venulosa	8	15	17	20	22	82
Lagerstroemia minuticarpa	–	5	6	–	–	11
Podophyllum hexandrum	–	14	24	24	–	62
Rheum australe	–	7	20	14	–	41
Total	15	91	129	147	72	454

temporal changes in population size, etc. The geographic range of the species was assessed through EOO. This was delineated using the conservation assessment tool, an extension for ArcView, which provides conservation assessments based on IUCN Categories and Criteria[42]. Small population size and its decline were assessed based on the enumerating matured individuals in their natural habitats. This being the first quantitative study for all the 14 species, the criteria A and E could not be applied due to absence of baseline empirical population data.

Results and discussion

The 14 species selected were present in 454 locations in NE India, Eastern and Western Himalaya, and J&K region. Of this, 106 locations were discovered following informed grid-based surveys, while 348 locations were discovered through ENM-based surveys (Table 1).

The highest number of individuals amongst the tree species was recorded for *I. venulosa* (1119 adults, 195 saplings and 6 seedlings), followed by *A. hookeri* (105 adults, 146 saplings and 110 seedlings), *L. minuticarpa* (157 adults), *B. robusta* (15 adults, 13 saplings and 25 seedlings) and *G. odorata* (8 adults, 9 saplings and 15 seedlings) (Table 2). Highest number of individuals amongst herbaceous species was recorded for *C. cashmeriana* (15,686 mature and 17,065 seedlings), followed by *A. nivalis* (10,867 mature and 11,883 seedlings), *A. amygdalina* (7,165 mature and 7,473 seedlings), *B. satrapis* (1,243 mature and 2,636 seedlings), *D. hatagirea* (1,568 mature), *P. hexandrum* (1,365 mature), *R. australe* (971 mature), *A. glauca* (781 mature) and the fern *A. evecta* (251 mature, 112 saplings and 47 seedlings).

The ENM-based surveys led to the discovery of 933 adult trees of *I. venulosa* and 103 adult trees of *A. hookeri* in their natural habitats. The number of adult individuals recorded for *L. minuticarpa* (41), *B. robusta* (7) and *G. odorata* (5) was comparatively less. In the case of herbaceous species, the highest number of matured individuals was recorded for *C. cashmeriana* (11,752) followed by *A. nivalis* (7991) and *A. amygdalina* (5365) (Table 2). It is noteworthy that for habitat-specific species such as *A. hookeri*, *A. evecta*, *B. satrapis*, *D. hatagirea*, *I. venulosa* and *P. hexandrum*, the ENM-based surveys yielded better results than the random grid-based surveys. Thus, ENM-based surveys proved to be quite effective in discovering species occurrences under a wide range of conditions. Earlier studies from different parts of the world have successfully established the efficiency and utility of ENM in discovering new populations of rare, endemic and threatened plants[10–13].

Utility of ENM-based surveys in threat assessment and classification

We used the informed and ENM-based field surveys to delineate the extent of occurrence, record the factors responsible for population decline and obtain the demographic data for all the species under study (Tables 2 and 3). It is evident that ENM as a tool for assisting field surveys is highly successful. Use of ENM substantially enhances the conciseness of survey areas and reduces biases in the identification of suitable areas for the species. This leads to proper population inventory and helps in obtaining accurate demographic data. All these

Table 2. Number of individuals recorded for the selected threatened species in 2012 and 2016 during field surveys in NE India, J&K, and Eastern and Western Himalaya. Populations for 2012 and 2013 are based on a preliminary grid-based survey, and those of 2014–16 are based on ENM-guided surveys

	Number of individuals recorded																				Total			
	Grid-based survey								ENM-guided surveys															
	2012				2013				2014				2015				2016							
Species	Seedling	Sapling	Adult	Total	Seedling	Sapling	Adult	Total	Seedling	Sapling	Adult	Total	Seedling	Sapling	Adult	Total	Seedling	Sapling	Adult	Total	Seedling	Sapling	Adult	Total
Acer hookeri					9	1	2	12	12	25	53	12	27	56	12	34	62	64	38	12	110	146	105	361
Angelica glauca							286	286			170	170			325	325							781	781
Angiopteris evecta						1	10	11	2	4	11	17	32	78	174	284	13	29	56		47	112	251	410
Aquilegia nivalis					3170		2876	6046	3030		2705	5735	2863		2606	5469	2820		2680	5500	11883		10867	22750
Artemisia amygdalina					1905		1800	3705	1840		1745	3585	1924		1853	3777	1804		1767	3571	7473		7165	14638
Begonia satrapis					3		4	7	1334		317	1651	881		922	1803	418			418	2636		1243	3879
Bhesa robusta	5	3	5	13	3	4	3	10	7	3	4	14	6	3	1	10	4		2	6	25	13	15	53
Corydalis cashmeriana					4446		3934	8380	4366		3946	8312	4163		3916	8079	4090		3890	7980	17065		15686	32751
Dactylorhiza hatagirea							243	243			1078	1078			247	247							1568	1568
Gynocardia odorata	2	2	1	5	2	3	2	7	4	2	2	8	5	1	2	8	2	1	1	4	15	9	8	32
Ilex venulosa		6	51	57		20	135	155		18	149	167		39	319	358	6	112	465	583	6	195	1119	1320
Lagerstroemia minuticarpa							116	116			41	41											157	157
Podophyllum hexandrum							119	119			622	622			624	624							1365	1365
Rheum australe							313	313			398	398			260	260							971	971

Table 3. Extent of occurrence and the recorded constraints to population decline in the natural habitats for the selected species

Species	Extent of occurrence (km^2)	Constraints
Acer hookeri	15,032	Forest degradation and fragmentation, loss of habitat due to expansion of agriculture, road construction, firewood collection
Angelica glauca	6,875	Extraction for medicinal purpose, habitat degradation, grazing
Angiopteris evecta	66,946	Extraction for edible rhizome, habitat specificity, isolated population
Aquilegia nivalis	9,573	Overgrazing, overexploitation for medicinal purpose, landslide, fragile habitat, military shelling, road construction, small population
Artemisia amygdalina	871	Agriculture and construction, power projects, habitat degradation
Begonia satrapis	81	Agricultural expansion, road-widening, grazing pressure, fodder collection, stem of plant used for making pickle, few small populations
Bhesa robusta	1,487	Over-extraction for timber
Corydalis cashmeriana	12,960	Landslides, overgrazing, small populations
Dactylorhiza hatagirea	3011	Over-extraction for medicinal purpose, habitat degradation
Gynocardia odorata	88,387	Over-extraction for medicinal purpose, habitat loss
Ilex venulosa	1,685	Poor seed germination, habitat loss
Lagerstroemia minuticarpa	67,910	No seedling population located, extraction for fuelwood
Podophyllum hexandrum	4,552	Over-extraction for medicinal purpose, habitat degradation
Rheum australe	2,721	Over-extraction for medicinal purpose

Table 4. Threat status of the selected species assessed using IUCN criteria with population data obtained through ENM-based surveys

Species	Current IUCN status	Assessment based on the present study using IUCN Criteria ver. 3.1	Status based on present study
Acer hookeri	Not assessed	C2a(i) + 2b	CR
Angelica glauca	EN (A2cd ver. 3.1)	B2b(iv)c(iii, iv); C2a(i) + 2b	EN
Angiopteris evecta	Not assessed	B2b(iv)c(iii, iv); C2a(i) + 2b	EN
Aquilegia nivalis	Not assessed	B2b(iv)c(iii, iv)	EN
Artemisia amygdalina	Not assessed	B1b(iv)c(ii, iii, iv) + 2b(iv)c(iii, iv)	EN
Begonia satrapis	Not assessed	B1b(iv)c(i, ii, iii, iv); D	CR
Bhesa robusta	LC (ver. 2.3)	C2a(i) + 2b	CR
Corydalis cashmeriana	Not assessed	B2b(iv)c(iii, iv)	EN
Dactylorhiza hatagirea	Not assessed	B1b(iv)c(iii, iv) + 2b(iv)c(iii, iv); C2a(i) + 2b	EN
Gynocardia odorata	Not assessed	C2a(i) + 2b	CR
Ilex venulosa	EN(B1 + 2c ver. 2.3)	B1b(iv)c(iii, iv) + 2b(iv)c(iii, iv); C2a(i) + 2b	EN
Lagerstroemia minuticarpa	EN(B1 + 2c ver. 2.3)	C2a(i) + 2b	CR
Podophyllum hexandrum	Not assessed	B1b(iv)c(iii, iv) + 2b(iv)c(iii, iv); C2a(i) + 2b	EN
Rheum australe	Not assessed	B1b(iv)c(iii, iv) + 2b(iv)c(iii, iv); C2a(i) + 2b	EN

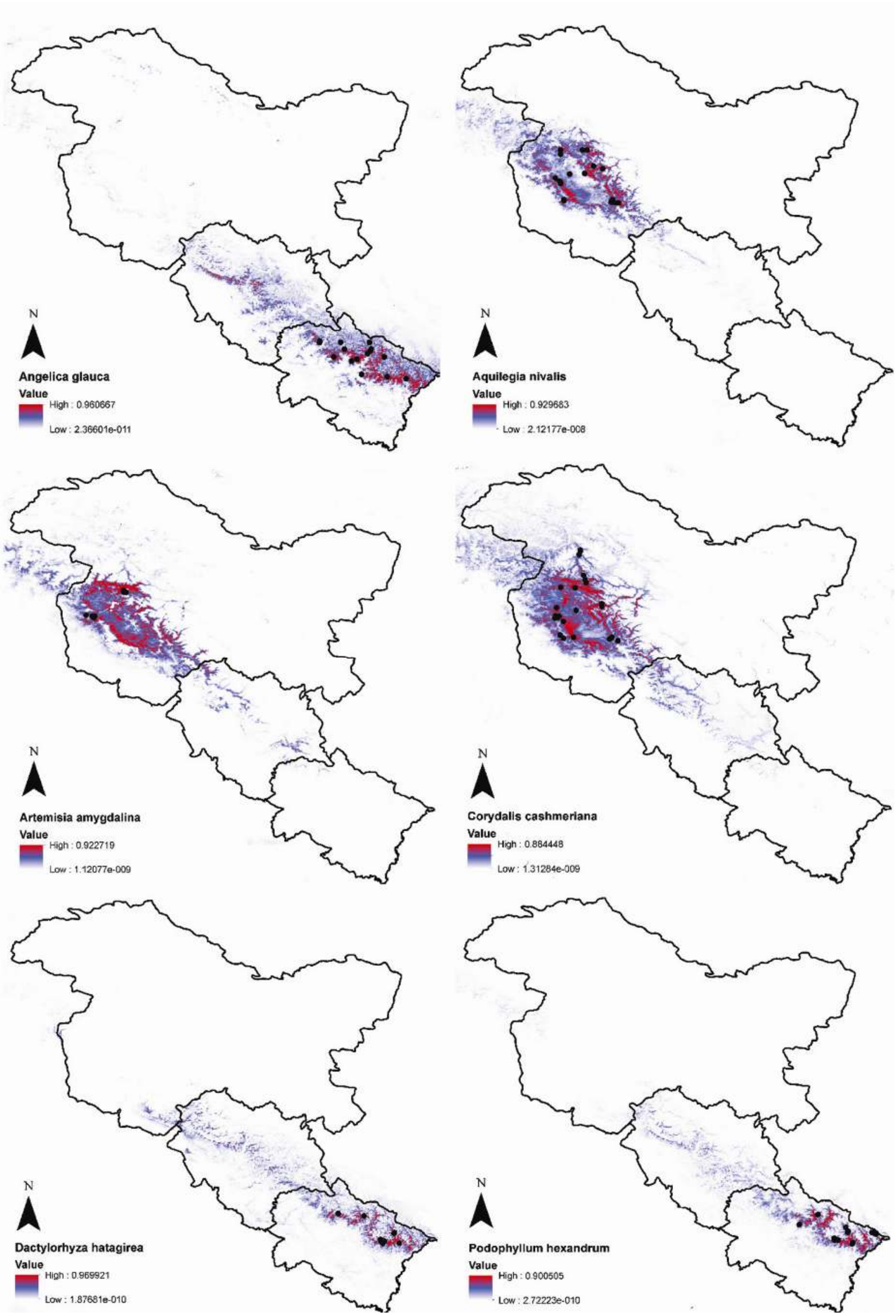
CR, Critically endangered; EN, Endangered; LC, Least concerned.

factors contribute to assign accurate and verifiable threat status for conservation prioritization.

The species-level data thus generated were used to assess and assign the threat status to each species. Of the 14 species, *A. glauca*, *I. venulosa* and *L. minuticarpa* were classified earlier as 'Endangered' (EN) category and *B. robustaas* 'Least concern' (LC) category (www.iucnredlist.org). The remaining species have not been assessed till date. Through the present study, *A. hookeri*, *B. satrapis*, *B. robusta*, *G. odorata* and *L. minuticarpa* are assigned to 'Critically endangered' (CR) category and *A. glauca*, *A. evecta*, *A. nivalis*, *A. amygdalina*, *C. cashmeriana*, *D. hatagirea*, *I. venulosa*, *P. hexandrum* and *R. australe* as EN (Table 4).

Modelling the distribution of potential habitats for conservation

We used all the survey records from 2012 to 2016 to model the distribution of potential habitats for the selected species (Figure 1). Tests of model performance showed that Maxent differentiated the true presence from false presence with high accuracy, demonstrating its high predictive ability (ROC_{full} (mean AUC range: 0.97–0.99) and $ROC_{partial}$ (mean range AUC: 0.96–0.99)) (Table 5). The distribution of AUC ratios, calculated from the bootstrap values as $AUC_{partial}/AUC_{random}$ for all the species was significantly higher than random expectations, which indicate very good model consistency (Table 5). The


N
Angelica glauca
Value
High : 0.960667
Low : 2.36601e-011
N
Aquilegia nivalis
Value
High : 0.929683
Low : 2.12177e-008
N
Artemisia amygdalina
Value
High : 0.922719
Low : 1.12077e-009
N
Corydalis cashmeriana
Value
High : 0.884448
Low : 1.31284e-009
N
Dactylorhyza hatagirea
Value
High : 0.969921
Low : 1.87681e-010
N
Podophyllum hexandrum
Value
High : 0.900505
Low : 2.72223e-010

(*Contd*)

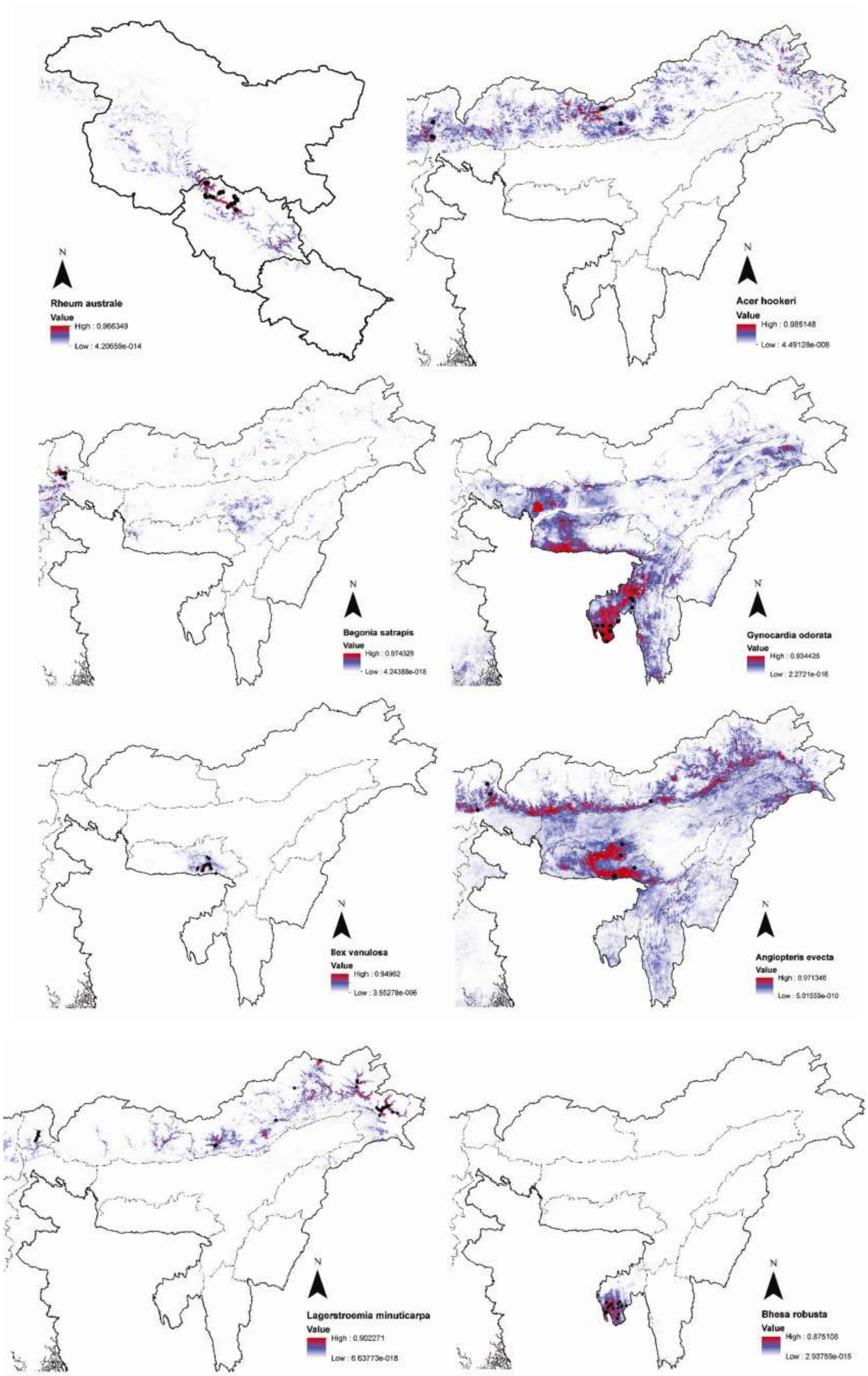


Figure 1. Potential distribution areas of selected species in North East India, including Bhutan, Eastern and Western Himalaya, and Jammu and Kashmir. The colour ramp and values in the maps represent the degree of environmental suitability, and the black dots represent the location of actual occurrence of the selected species.

Table 5. Results of the final Maxent model calibration for the selected species

Species	Number of records	Full AUC metrics (mean ± SD)	Partial AUC metrics: AUC at 0.5 level (mean ± SD)	AUC at 0.05 level (mean ± SD)	AUC ratio (mean ± SD)	*P*-value obtained after executing Welch two sample *t*-test for difference between means of AUC from model prediction and AUC at random
Acer hookeri	13	0.99 ± 0.005	0.5 ± 4.37E-11	0.97 ± 0.006	1.95 ± 0.013	<2.2e-16
Angelica glauca	37	0.99 ± 0.001	0.5 ± 5.32E-12	0.99 ± 0.002	1.98 ± 0.004	<2.2e-16
Angiopteris evecta	12	0.97 ± 0.013	0.5 ± 1.06E-11	0.97 ± 0.010	1.95 ± 0.021	<2.2e-16
Aquilegia nivalis	44	0.99 ± 0.001	0.5 ± 2.62E-10	0.99 ± 0.002	1.98 ± 0.005	<2.2e-16
Artemisia amygdalina	20	0.99 ± 0.001	0.5 ± 2.82E-11	0.99 ± 0.002	1.99 ± 0.004	<2.2e-16
Begonia satrapis	12	0.99 ± 0.0001	0.5 ± 1.09E-12	0.99 ± 0.0001	1.99 ± 0.0003	<2.2e-16
Bhesa robusta	20	0.99 ± 0.003	0.5 ± 7.96E-11	0.98 ± 0.004	1.97 ± 0.009	<2.2e-16
Corydalis cashmeriana	49	0.99 ± 0.001	0.5 ± 7.72E-12	0.99 ± 0.002	1.98 ± 0.005	<2.2e-16
Dactylorhiza hatagirea	40	0.99 ± 0.001	0.5 ± 1.73E-12	0.99 ± 0.001	1.99 ± 0.003	<2.2e-16
Gynocardia odorata	11	0.97 ± 0.009	0.5 ± 8.45E-09	0.96 ± 0.017	1.93 ± 0.035	<2.2e-16
Ilex venulosa	82	0.99 ± 0.005	0.5 ± 7.92E-09	0.97 ± 0.022	1.95 ± 0.045	<2.2e-16
Lagerstroemia minuticarpa	11	0.99 ± 0.001	0.5 ± 1.67E-10	0.99 ± 0.003	1.98 ± 0.006	<2.2e-16
Podophyllum hexandrum	62	0.99 ± 0.0004	0.5 ± 6.82E-13	0.99 ± 0.0008	1.99 ± 0.001	<2.2e-16
Rheum australe	41	0.99 ± 0.0001	0.5 ± 6.65E-14	0.99 ± 0.0003	1.99 ± 0.0007	<2.2e-16

Table 6. Analysis of variable contributions to ecological niche models of the selected species. The variable contributions to the individual principal component (PC) axis are represented in Annexure I

	Per cent contribution of different PC axis														
Species	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14	PC 15
Acer hookeri	0.4	1.2	1.0	1.1	1.5	0.0	5.2	25.6	0.2	0.0	0.1	57.6	4.6	1.0	0.5
Angelica glauca	17.5	0.0	57.4	0.0	6.7	1.7	2.9	0.5	1.1	0.1	0.5	1.1	2.9	3.7	3.9
Angiopteris evecta	12.8	1.8	7.1	14.6	0.0	5.0	0.8	0.4	22.6	1.3	30.0	0.9	0.2	2.1	0.4
Aquilegia nivalis	8.2	0.6	0.9	2.0	16.7	36.5	0.8	2.3	0.2	2.1	0.1	0.1	24.1	1.0	4.5
Artemisia amygdalina	0.1	0.7	0.0	15.6	0.4	25.1	1.8	0.0	17.7	0.6	0.6	2.7	31.0	1.9	1.7
Begonia satrapis	0.0	1.0	3.5	0.2	0.0	51.0	7.3	8.5	26.3	0.9	0.2	0.6	0.1	0.2	0.1
Bhesa robusta	37.8	28.4	5.8	3.2	0.1	0.3	0.1	5.0	0.0	12.3	0.3	1.3	1.0	4.2	0.3
Corydalis cashmeriana	10.9	4.0	1.5	15.0	4.0	13.2	1.9	2.4	2.4	3.0	0.4	1.7	38.0	1.0	0.6
Dactylorhiza hatagirea	5.3	9.0	66.5	0.0	0.2	0.0	7.1	0.1	0.6	0.2	0.7	0.0	2.3	0.9	7.1
Gynocardia odorata	36.7	4.7	0.4	6.2	11.8	0.6	0.0	0.3	0.0	29.8	2.6	0.5	5.0	1.2	0.1
Ilex venulosa	45.9	3.7	7.8	0.0	2.7	0.7	0.7	0.6	18.6	2.9	1.9	3.7	0.1	1.5	9.1
Lagerstroemia minuticarpa	17.6	5.5	0.8	36.8	1.8	9.0	0.6	1.9	2.8	2.4	5.4	1.6	0.8	8.1	4.7
Podophyllum hexandrum	14.5	1.1	55.7	0.8	6.2	0.0	4.8	4.6	0.8	0.0	0.8	0.6	5.8	2.1	2.3
Rheum australe	8.7	5.0	0.3	20.3	0.5	4.1	38.1	4.3	2.7	1.5	1.4	0.6	10.9	1.4	0.2

analysis of variable contributions to the modelled niche showed that the occurrence and distribution of the selected species were governed by different environmental conditions (Table 6 and Annexure I). The identified potential areas would also help in planning species re-introduction and *in situ* conservation.

Conclusion

ENM has been a convenient and effective tool for the prediction of potentially suitable habitats[13]. In this study, the threat status of selected species has been determined using ENM-based surveys that guided the discovery of

Annexure 1. Component matrix showing the eigenvalues and eigenvectors of the first 15 principal components for the PCA run for Western Himalayas and North East India using elevation, and monthly data for normalized difference vegetation index (NDVI) and potential evapotranspiration (PET). The colour bars represent the strength and directionality of the factor loadings. The red bar indicates negative and blue indicates positive loadings. The dotted line represents the origin of the individual PC axes.

PC Layer	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	PC 11	PC 12	PC 13	PC 14	PC 15
Eigenvalues	2706138.0	46810.3	4496.4	970.5	558.4	365.8	211.3	174.4	130.1	118.9	78.7	62.5	41.5	31.1	22.6
Eigenvectors															
Elevation	0.999	0.014	0.029	0.013	-0.003	0.006	0.000	0.001	0.001	0.001	-0.002	0.001	0.000	0.001	0.000
NDVI January	-0.003	0.274	-0.015	-0.115	0.113	0.205	0.596	-0.005	0.131	0.043	-0.057	0.005	-0.035	0.216	-0.173
NDVI February	-0.003	0.275	0.001	-0.137	0.114	0.225	0.551	-0.030	-0.007	0.036	-0.102	-0.178	0.015	-0.252	0.207
NDVI March	0.000	0.267	-0.011	-0.200	0.827	0.194	-0.388	-0.023	-0.014	0.050	0.095	0.056	0.002	0.031	0.005
NDVI April	-0.001	0.283	-0.005	-0.028	-0.090	-0.169	-0.064	0.142	-0.332	-0.064	0.400	-0.727	0.134	0.170	0.004
NDVI May	-0.002	0.291	-0.009	-0.014	0.022	-0.247	0.095	0.381	-0.530	-0.453	-0.110	0.434	0.000	-0.089	-0.064
NDVI June	-0.004	0.276	-0.078	0.152	-0.082	-0.171	-0.023	0.253	-0.152	0.848	0.027	0.187	-0.009	-0.097	-0.062
NDVI July	-0.006	0.308	0.016	0.057	-0.086	-0.158	-0.133	-0.248	-0.033	0.020	-0.456	-0.013	-0.100	0.424	0.505
NDVI August	-0.006	0.308	0.034	0.016	-0.115	-0.058	-0.163	-0.323	-0.044	-0.026	-0.338	-0.122	-0.110	-0.034	-0.214
NDVI September	-0.005	0.307	0.023	0.038	-0.138	0.043	-0.178	-0.247	0.082	-0.081	-0.168	-0.109	0.027	-0.456	-0.481
NDVI October	-0.006	0.292	-0.028	0.128	-0.156	0.110	-0.120	0.052	0.249	-0.125	0.245	0.092	0.038	-0.430	0.541
NDVI November	-0.005	0.290	-0.024	0.065	-0.154	0.048	-0.080	0.049	0.311	-0.107	0.272	0.155	0.074	0.046	0.012
NDVI December	-0.005	0.287	-0.024	0.009	-0.161	0.014	-0.038	0.053	0.332	-0.091	0.258	0.219	-0.025	0.482	-0.279
PET January	-0.008	0.006	0.185	0.024	-0.131	0.375	-0.085	0.057	-0.170	0.018	0.038	0.027	-0.175	0.028	-0.045
PET February	-0.007	0.005	0.163	-0.023	-0.093	0.257	-0.091	0.188	-0.035	-0.025	-0.033	-0.033	-0.256	0.042	-0.009
PET March	-0.006	0.006	0.184	-0.143	-0.070	0.111	-0.107	0.366	0.140	-0.022	-0.174	-0.126	-0.300	0.029	0.012
PET April	-0.003	0.007	0.192	-0.314	-0.072	-0.025	-0.119	0.403	0.215	0.049	-0.238	-0.135	-0.056	-0.050	0.030
PET May	-0.002	0.009	0.271	-0.514	-0.142	-0.048	-0.075	0.065	0.060	0.062	-0.109	0.047	0.517	-0.015	-0.004
PET June	-0.004	0.011	0.353	-0.395	-0.100	-0.143	0.051	-0.365	-0.132	0.093	0.260	0.233	0.066	0.006	0.077
PET July	-0.008	0.012	0.390	-0.054	0.079	-0.302	0.099	-0.178	0.000	0.018	0.245	0.006	-0.511	-0.114	0.016
PET August	-0.012	0.012	0.381	0.231	0.180	-0.288	0.098	0.094	0.191	-0.029	-0.001	-0.066	-0.128	-0.038	-0.043
PET September	-0.014	0.011	0.353	0.353	0.168	-0.130	0.065	0.112	0.167	-0.045	-0.091	-0.045	0.295	-0.001	-0.052
PET October	-0.016	0.011	0.341	0.345	0.082	0.098	0.018	-0.003	-0.036	0.007	-0.090	-0.003	0.340	0.070	0.019
PET November	-0.013	0.008	0.273	0.175	-0.064	0.319	-0.032	-0.083	-0.225	0.034	0.037	0.056	0.083	0.088	0.049
PET December	-0.010	0.007	0.216	0.081	-0.131	0.401	-0.062	-0.044	-0.239	0.050	0.078	0.059	-0.052	0.033	-0.021

several new populations and detailed study on population attributes. The ENM approach being much faster than the conventional survey could determine the threat status of several species within a short span of time. With empirical distribution area and population size data, the accuracy level of threat classification significantly increased in comparison to the conventional methods. This is evident from the fact that *B. robusta* which was earlier classified as LC, actually falls under CR category. Similarly, *G. odorata* and *L. minuticarpa* earlier classified as EN are actually CR.

Species are presumed to occur in the predicted suitable habitats unless they are limited by migration constraints or biotic pressure[43]. This necessitates undertaking field surveys in the predicted potential areas for confirming the presence of the species. The present study clearly demonstrates that ecological niche modelling is effective in undertaking population inventory, delimiting the distribution range and identifying natural habitats for (re)introduction. However, the species-specific niche models are dynamic in nature and need to be updated after each field visit or discovery of a new population. Thus, an iterative process of model prediction and field validation has to be continuously followed. Although intensive surveys have been undertaken in potential geographical areas as predicted by the models, there could still be possibility of discovering new populations for a few species, thereby offering the scope for improving the model predictions.

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