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Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk., a critically endangered tree species of northeastern India

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ABSTRACT

Only ca. 3000 individuals of *Ilex khasiana* Purk. are surviving today. The tree species is endemic to Khasi hills of northeast India, and is critically endangered. For improving the conservation status of the species, potential area and habitat for reintroduction were predicted using Maximum Entropy (MaxEnt) distribution modelling algorithm. The model was developed using 16 locality data in the native range of Khasi hills, and 16 environmental parameters including enhanced vegetation index (EVI) and digital elevation data. The model predicted that the suitable habitats of *I. khasiana* was restricted to an area of ≈500 km^2 in the Khasi hills of Meghalaya. The distribution of potential habitats was strongly influenced by elevation and the EVI layers for the period April–May, which corresponds to the flowering phase of the species, thus indicating the importance of flowering stage in determining the species distribution. Population status was positively correlated with higher model thresholds in the undisturbed habitats confirming the usefulness of the habitat model in population monitoring, particularly in predicting the successful establishment of the species. The study delineated the potential habitats in the higher elevations of Khasi hills within the current home range where the species can be reintroduced.

1. Introduction

Rapidly changing climate, habitat fragmentation, invasion of alien species and pathogens, pollution, over-exploitation, and escalating human population are the most important factors responsible for ecosystem degradation worldwide that alter the structural and functional integrity of the ecosystems (Barnosky et al., 2011). Such alterations have brought approximately one fifth of the plant species to the brink of extinction (Brummitt and Bachman, 2010). Species (re)introduction is one of the successful ecological engineering techniques for restoration of the depleted species populations, and degraded habitats and ecosystems (Leaper et al., 1999; Martinez-Meyer et al., 2006; Kuzovkina and Volk, 2009; Ren et al., 2009; Zai et al., 2009; Rodríguez-Salinas et al., 2010; Nazeri et al., 2010; Polak and Saltz, 2011). In order to reintroduce and rehabilitate the threatened species in terrestrial ecosystems, a detailed knowledge on the distribution of their potential habitats is essential. Habitat distribution modelling therefore helps to identify the areas for species reserves, reintroduction, and in developing effective species conservation measures. It has been successfully used in restoring critical habitats and predicting the impact of environmental and climate change on species and ecosystems (Brooks et al., 2004; Samways, 2005; Giriraj et al., 2008; Franklin, 2009; Gogol-Prokurat, 2011; Barik and Adhikari, 2011).

New insights into the factors governing the distribution of species have been developed using habitat distribution modelling or ecological niche modelling (ENM) (Guisan and Zimmermann, 2000; Elith et al., 2006; Kozak et al., 2008). The technique of ENM uses computer algorithms that predict species distribution in a geographic space based on mathematical representation of the ecological niche of the species. By definition, ecological niche is a set of ecological conditions that allows a species to persist and produce offsprings (Grinnell, 1917). ENM considers environmental factors as ecological conditions e.g., temperature, precipitation, soil, vegetation and landcover, and uses the dataset from Geographic Information System (GIS) databases such as www.worldclim.org and www.diva-gis.org. Availability of high resolution satellite imageries, downscaling tools for environmental variables, and interpolated spatial datasets on climate and vegetation has enhanced the accuracy of prediction of the models manifold. ENM facilitates interpolation as well as extrapolation of species distributions in geographic space across different time periods. This has made it possible to prepare species distribution maps with high level of statistical confidence and identify areas suitable

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for reintroduction of threatened species (Irfan-Ullah et al., 2006; Martinez-Meyer et al., 2006; Papes, 2006; Kumar and Stohlgren, 2009; Moran-Ordonez et al., 2011; Ray et al., 2011).

We modelled the potential habitat distribution of *Ilex khasiana* Purk., a tree species endemic to the Khasi Hills of Meghalaya in northeast India (Fig. 1a–c). The species was reported to be at the brink of extinction with only a few surviving matured individuals (Rao and Haridasan, 1983; Haridasan and Rao, 1985; WCMC, 1998; Williams, 1998), and was classified as critically endangered (CR B1 + 2c, C2b, D) by the World Conservation Monitoring Centre (WCMC, 1998). Recently, Upadhaya et al. (2009) studied the regeneration ecology and population status of the species in 5 localities in East Khasi Hills and reported ca. 3000 individuals, confined to an area of approximately 100 km^2. Dang et al. (2011) developed protocols for in vitro mass propagation of the species to augment the species population. Identification of suitable habitats for reintroduction of the species is the next logical step in species conservation effort. Therefore, the present work was undertaken with the following specific objectives: (i) to model the potential habitat distribution of *I. khasiana* in its native range, (ii) to identify the major factors determining the distribution of potential habitats, and (iii) to assess the population status in the predicted habitats through field inventories and relate it with model thresholds.

2. Materials and methods

2.1. Study species

I. khasiana Purk. (Aquifoliaceae) is an evergreen, late successional species with a height of 15–20 m and usually forms the sub-canopy in humid subtropical forest up to 1990 m asl (Haridasan and Rao, 1985). The species starts flowering during the months of April–May and fruiting during November–December. It bears purplish red fruits measuring 7–8 mm across with seeds which are 3 mm long and are obovoid-ellipsoid or ellipsoid.

2.2. Habitat distribution modelling

Sixteen primary distributional records of the species were collected through field surveys. The coordinates of all the occurrence points were recorded to an accuracy of 10–40 m using a Global Positioning System (Garmin). The coordinates were then converted to decimal degrees for use in modelling the distribution of potential habitats of the species in its native range.

Over the years, a variety of environmental datasets has been accumulating in the public domain websites which can be used in distributional modelling of species. Use of different formulation of environmental datasets however, yields different results for the same set of species (Peterson and Nakazawa, 2008). Hence, selection of appropriate data type and pixel resolution is a prerequisite prior to predictive modelling (Parra et al., 2004). In the present study, remotely sensed data on elevation and enhanced vegetation index (EVI) were used to summarize the habitat boundaries for the species in the native range of the Khasi Hills of Meghalaya in northeast India. Digital elevation data (90 m resolution) was obtained from CGIAR-CSI (http://srtm.csi.cgiar.org, Jarvis et al., 2008). We did not use climatic layers as their influence on species richness and distribution is best defined at a regional scale (Waring et al., 2006). Similarly, topographic variables such as slope and aspect were also not included in the model as MODIS EVI dataset has been proved to be quite sensitive to the variations in topographic conditions (Matsushita et al., 2007). In other words, the topographic effect is indirectly represented in the EVI dataset.

Twenty three layers of MODIS images (MOD13Q1) with a spatial resolution of 250 m were obtained from Oak Ridge National Laboratory Distributed Active Archive Centre (http://daac.ornl.gov/MODIS/modis.html, Santhana et al., 2009). These layers correspond to the year 2009 during which the field survey was undertaken and characterize the spatial aggregates of EVI at 16 days interval. Enhanced Vegetation Index (EVI) has been preferred over Normalized Difference Vegetation Index (NDVI) because of its improved sensitivity to saturation in the degree of greenness in the humid forested areas and higher capability to discriminate changes in vegetation across spatial and temporal scale (Huete and Justice, 1999). The images were downloaded in geotif format and converted to ASCII raster grids in ArcGIS 9.3. In order to identify the highly correlated pair of layers ($r > 0.9$), the 23 EVI layers were subjected to correlation test using ENM Tools 1.3 (Warren et al., 2010). One of the EVI layers from each of the highly correlated pair of layers was excluded from the ecological niche modelling analysis. Finally, a formulation of 16 environmental data layers which included elevation and 15 other EVI layers was used for habitat distribution modelling. In order to match with the MODIS EVI layers, 90 m elevation layer of CGIAR-CSI dataset was resampled to 250 m pixel resolution using nearest neighbourhood method of ArcGIS 9.3. Subsequently, all the analyses were conducted at the spatial resolution of 250 m.

2.3. Validation of model robustness

Following Grinnell (1917), the potential habitat of *I. khasiana* was defined as 'a habitat which bears a set of ecological conditions that allows the species to persist and regenerate'. For habitat modelling, the pixel dimension was 250 m × 250 m grid cell and the model was developed using maximum entropy modelling (MaxEnt version 3.3.3e, Phillips et al., 2006). MaxEnt estimates the maximum entropy probability distribution function to predict the geographic location of a species based on environmental variables and reconstructs the boundaries of the ecological niche by placing constraints on the probability distribution based on the environmental parameters of the grid-cell presence record (Phillips et al., 2006). It is one amongst the 'presence-only' group of species distribution modelling methods which has been widely used. The strong attributes of MaxEnt are: (i) it holds a strict mathematical definition, (ii) gives a continuous probabilistic output, (iii) can simultaneously handle both continuous and categorical environmental data, (iv) can investigate variable importance through jackknife procedure, (v) has the capacity to handle low sample sizes, and (vi) simplicity for model interpretation (Phillips et al., 2006; Pearson et al., 2007; Elith et al., 2011). It also facilitates replicated runs to allow cross-validation, bootstrapping and repeated subsampling in order to test model robustness.

Of the 16 records, seventy five percent were used for model training and twenty five percent for testing. To validate the model robustness, we executed 20 replicated model runs for the species with a threshold rule of 10 percentile training presence. In the replicated runs, we employed cross validation technique where samples were divided into replicate folds and each fold was used for test data. Other parameters were set to default as the program is already calibrated on a wide range of species datasets (Phillips and Dudík, 2008). From the replicated runs, average, maximum, minimum, median and standard deviation were generated. Model quality was evaluated based on Area Under Curve (AUC) value and the model was graded following Thuiller et al. (2005) 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). Further, potential area of distribution and/or reintroduction were categorized into five classes based on logistic threshold of 10 percentile training presence i.e.

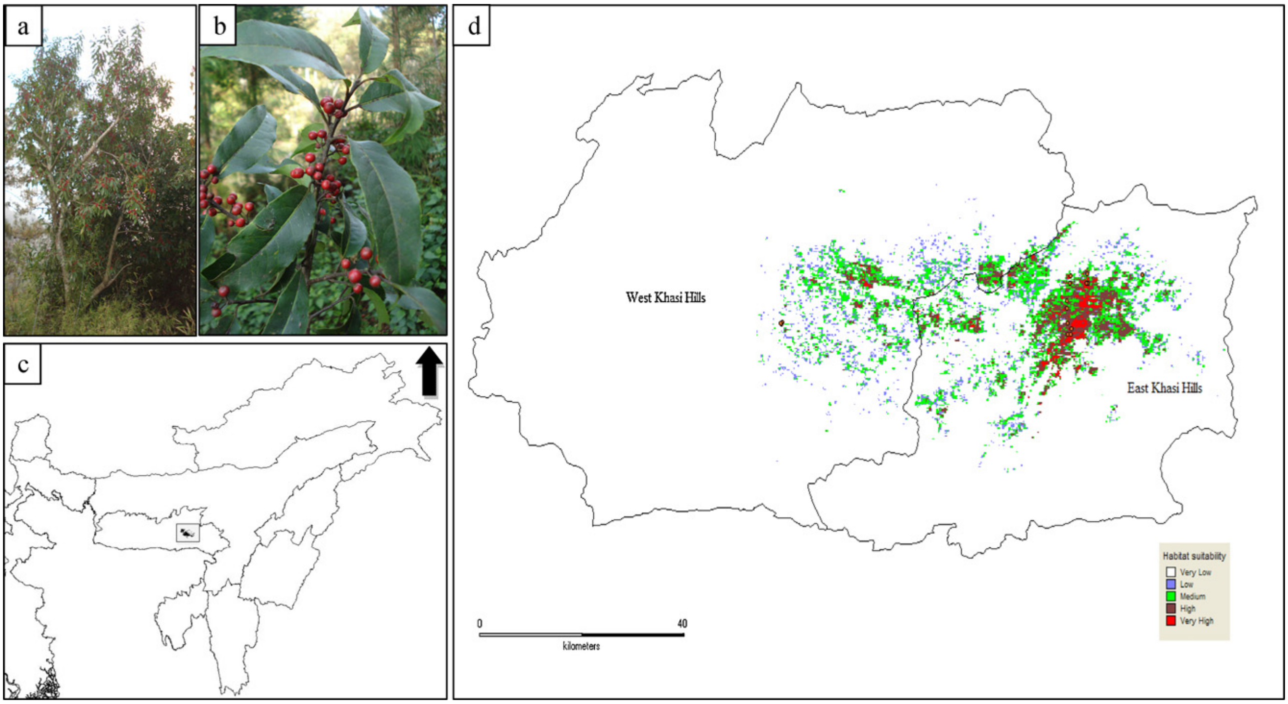

Fig. 1. (a and b) Tree and fruiting twig of *Ilex khasiana*, (c) location of the native range (Khasi hills) in Meghalaya, northeast India (d)Potential habitat distribution of the species in Khasi hills of Meghalaya. The brown circles in the map represent the occurrence localities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

very-high (0.762–1), high (0.572–0.761), medium (0.381–0.571), low (0.325–0.570) and very low (0–0.324).

2.4. Population status vis-à-vis model thresholds

Extensive field surveys were carried out in order to explore the robustness and pertinence of the model in predicting the population status of the species in each occurrence locality as predicted under various model thresholds. Total population of the species was ascertained through direct count of all the individuals of seedlings (<1 m height), saplings (<5 cm dbh and >1 m height) and matured individuals (≥5 cm dbh at 1.37 m height) in each 250 m × 250 m grid of occurrence within the predicted localities. The population data of *I. khasiana* in each locality was then correlated with the corresponding threshold level of the distribution models to assess whether regions covered in the higher thresholds maintain higher populations thus approving better habitat conditions for the species establishment and vice versa.

2.5. Assessment of habitat status and identification of areas for reintroduction

Assessment of the actual habitat type of the species in the localities of occurrence as well as in the entire predicted potential area was done through repeated field surveys. We also superimposed the predicted potential areas on Google Earth Ver. 6 (www.google.com/earth) imageries for habitat quality assessment. The predicted suitability maps were exported in KMZ format using Diva GIS ver. 7.3 (www.diva-gis.org). KMZs are zipped Keyhole Markup Language (KML) files which specifies a set of features such as place marks, images, polygons, 3D models or textual descriptions for display in Google Earth. The exported KMZ files were overlaid on satellite imageries in Google Earth to ascertain the actual habitat condition prevailing in the areas of occurrence. The imageries for the Khasi hills in Meghalaya covered a time frame of 7 years i.e. from 2002 to 2009.

3. Results

3.1. Calibration of models

The model calibration test for *I. khasiana* yielded satisfactory results ($AUC_{train} = 0.99 \pm 0.002$ and $AUC_{test} = 0.97 \pm 0.015$). Amongst the input environmental variables, elevation was the most influential and contributed 81.6% to the MaxEnt model. Sixteen layers of EVI collectively contributed 18.4% to the habitat model of the species of which EVI 8 had maximum contribution (7.9%), while EVI 17, 19 and 21 collectively contributed to 6.4% (Fig. 2 and Table 1). Considering the permutation importance, elevation also had the maximum influence on the habitat model and contributed to 65.3%, while EVI 8, 17, 19 and 21 together contributed to 32.3% (Table 1).

3.2. Potential habitat distribution area

Potential habitats with high suitability thresholds were distributed in the higher elevations of the East Khasi hills district of Meghalaya in northeastern India (Fig. 1d and Table 2). Primary field surveys revealed that the predicted potential habitats were mostly located in the subtropical broad leaved, subtropical pine forests and degraded open forests (Table 2). Areas with medium to low habitat suitability are those with sparse tree cover, grasslands, cultivation lands, settlements, roads, and river banks. A total potential area of ca. 500 km^2 in the East and West Khasi hills was predicted to be suitable for *I. khasiana* reintroduction (Fig. 3). Most of the areas fall under medium suitability class and covers an area of 244 km^2. Area of high suitability was restricted only to about 107 km^2, and 20 km^2 area was very highly suitable. Area of low suitability was 128 km^2.

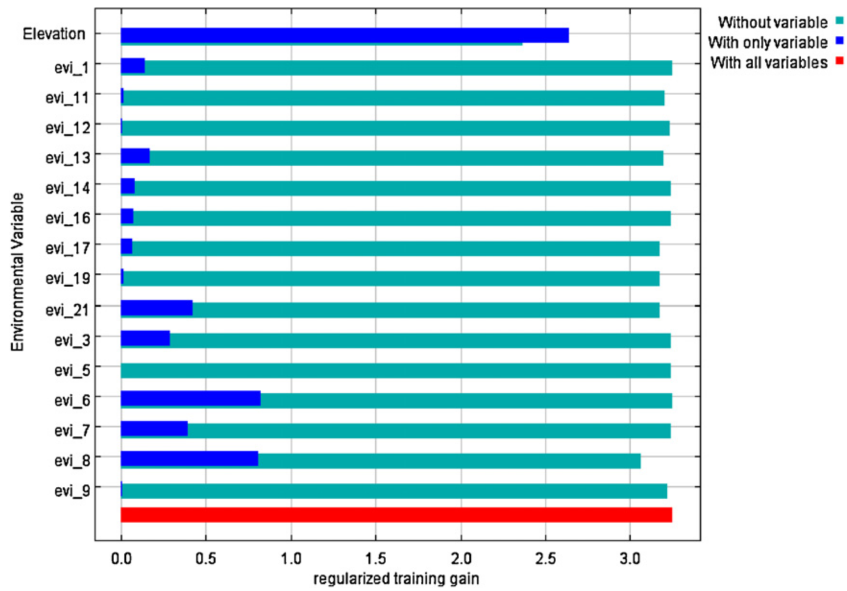

Fig. 2. Result of jackknife test for evaluating the relative contribution of the predictor environmental variables to the habitat model of *Ilex khasiana* in Khasi hills.

Table 1
Estimates of relative contributions and permutation importance of the predictor environmental variables to the MaxEnt model. Enhanced Vegetation Index (EVI) in the table represents the spatial aggregates of the degree of greenness of the same at 16 days interval.

Predictor variables	Percent contribution	Permutation importance
EVI 5 (6 March–21 March)	0	0.1
EVI 16 (29 August–13 September)	0	0.2
EVI 1(1 January–16 January)	0.1	0.1
EVI 3 (2 February–17 February)	0.1	0.4
EVI 6 (22 March–6 April)	0.1	0.1
EVI 7 (7 April–22 April)	0.1	0.3
EVI 14 (28 July–12 August)	0.1	0.1
EVI 12 (26 June–11 July)	0.4	0.1
EVI 9 (9 May–24 May)	0.6	0.5
EVI 13 (12 July–27 July)	1	0.2
EVI 19 (16 October–31 October)	1.2	2.1
EVI 11 (10 June–25 June)	1.5	0.5
EVI 21 (17 November–2 December)	2.4	9.1
EVI 17 (14 September–29 September)	2.8	4.6
EVI 8 (23 April–8 May)	7.9	16.5
Elevation	81.6	65.3

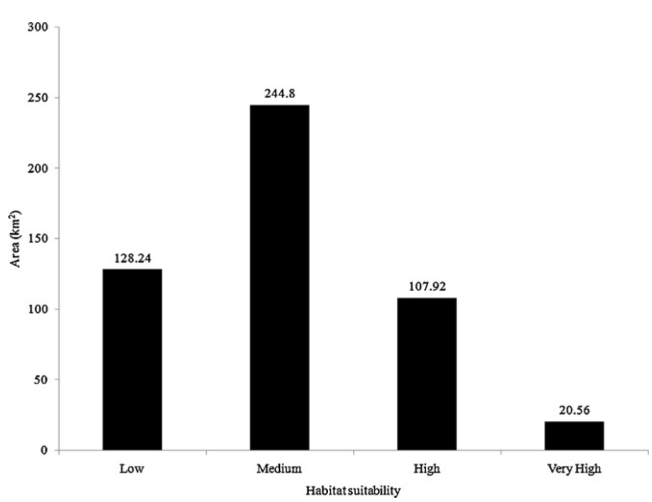

Fig. 3. Area under different suitability grades for the optimal average model. The figures at the top of each bar represent the area.

3.3. Population status vis-à-vis model thresholds

A total of 3728 individuals were inventoried within the area of occurrence spread over sixteen 250 m × 250 m grids. Of these, 637 were matured individuals, 860 saplings and 2231 were seedlings (Table 2). The analysis of population structure at each locality revealed that the highest number of matured individuals were in Mylliem5 (453) followed by Laitkor (70), Shillong peak (46), Upper Shillong (46) and Nongpiyur (19). The population size including all trees, saplings and seedlings, was larger in the localities under medium to very high habitat suitability threshold categories than those under very low category (Table 2). Areas predicted as high and very high suitable classes represented 86% of the total population, followed by medium and low thresholds. This confirms the strong correlation between population size and level of model threshold. Of the 16 localities, 5 localities fell under very high suitable class, 4 localities under high, 2 localities under medium, 1 locality under low and 4 localities under very low habitat suitability class.

In most of the localities the seedlings and saplings were either poorly represented or absent. Number of seedlings was highest in Mylliem5 with 1600 seedlings, followed by Upper Shillong with 375 seedlings and Laitkor with 204 seedlings. Similarly, number of sapling was also highest in Mylliem5 with 634 individuals, followed by Laitkor with 120 individuals and Nongpiyur with 60 individuals. The population structure based on seedling, sapling and adult individuals revealed relatively good regeneration in Mylliem5, Upper Shillong, Laitkor and Nongpiyur localities whereas in other areas it depicted poor regeneration (Table 2).

3.4. Habitat status assessment and identification of areas for reintroduction

Field surveys for assessing the habitat types of *I. khasiana* in the predicted potential areas revealed that the species occurred both in disturbed and undisturbed subtropical broadleaved and pine forests. The species was also present around human settlement areas and settled cultivation lands (Table 2). Superimposing the predicted potential habitat map of the species on Google Earth satellite imageries revealed a mosaic of habitats to be suitable for the species persistence. The areas with high to very high habitat suitability for the species were continuous patches of

Table 2
Population status of *Ilex khasiana* related to model thresholds.

Occurrence localities	Elevation (m asl)	Habitat suitability thresholds	Current habitat status	Number of individuals			
				Trees	Saplings	Seedlings	Total
Upper Shillong	1762	Very high	Sub tropical pine forest	21	23	375	419
Shillong Peak	1900	Very high	Sub tropical broad leaved forest	46	12	8	66
Below Shillong Peak	1800	Very high	Degraded subtropical broad leaved forest	2	0	0	2
Umtangar	1813	Very high	Degraded open forest	1	0	0	1
Mylliem 5	1777	Very high	Human settlement, cultivation areas	453	634	1600	2687
Mylliem 1	1733	High	Human settlement, cultivation areas	4	1	2	7
Mylliem 2	1726	High	Human settlement, cultivation areas	5	0	0	5
Mylliem 3	1692	High	Human settlement, cultivation areas	6	0	1	7
Mylliem 4	1778	High	Human settlement, cultivation areas	3	0	0	3
Laitkor	1642	Medium	Subtropical pine forest	70	120	204	394
Sweet Falls	1568	Medium	Degraded open forest	2	0	0	2
Nongpiyur	1690	Medium	Subtropical pine forest	19	60	40	119
Nongstoin	1445	Very low	Degraded sub tropical broad leaved forest	3	8	1	12
Nongstoin	1458	Very low	Degraded sub tropical broad leaved forest	0	2	0	2
Nongstoin	1457	Very low	Degraded sub tropical broad leaved forest	1	0	0	1
Nongstoin	1450	Very low	Degraded sub tropical broad leaved forest	1	0	0	1
Total				637	860	2231	3728

Habitat suitability thresholds: very low, 0–0.32; low, 0.32–0.38; medium, 0.38–0.57; high, 0.57–0.76; very high: 0.76–1.

Table 3
Habitat types of *Ilex khasiana* identified through field surveys and high resolution Google Earth satellite imageries.

Habitat suitability thresholds	Habitat types identified using high resolution Google Earth satellite imageries
Very high	Continuous forest patches viz. pine and broad-leaved forests, small groves, human settlements
High	Continuous forest patches viz. pine and broad-leaved forests, small groves, human settlements
Medium	Degraded open forest areas, cultivation areas, home stead gardens, human settlements
Low	Degraded open forest areas, cultivation areas, home stead gardens, human settlements
Very low	Grasslands, degraded open forests, scrub lands, human settlements

subtropical pine and broad-leaved forests, and a mosaic of fragmented groves, settled cultivation areas and human settlements. The areas with medium to low habitat suitability were degraded open forest areas, settled cultivation areas, homestead gardens and human settlements. The areas with very low habitat suitability were grasslands, degraded open forests, scrublands and human settlements (Table 3).

The superimposition of predicted potential habitat distribution map on Google Earth imageries identified three forest areas *viz*. the Riat Laban Reserve Forest, the Laitkor Reserve Forest, the Upper Shillong Protected Forest and several community owned forest lands which would serve as highly suitable habitats for persistence of the species. These forest areas would act as in situ conservation area for the species and could also be used for reintroduction/recovery of the species in the wild (Table 4).

4. Discussion

Elevation played a key role in determining the distribution of potential habitats of *I. khasiana* in its native range. Model output and field surveys revealed that suitable natural habitats of the species concurred with the distribution of humid subtropical forests in the higher elevations (≈1700–1900 m asl) of Khasi hills. The restricted distribution of the highly suitable habitats of *I. khasiana* to the higher elevations indicates that the species is indubitably narrowly endemic. Past field surveys, herbarium records and published literature also suggested that the species does not occur beyond Khasi Hills of Meghalaya (Haridasan and Rao, 1985; Williams, 1998; IUCN, 2007; Upadhaya et al., 2009). EVI layers offered reasonable explanation on the underlying role of other environmental factors which determined the habitat suitability of the species. Various environmental factors such as geology, soil and climate have plausible influence on vegetation indices of a given place at a given time (Soleimani et al., 2008). The effects of such underlying environmental factors are reflected through the spatial and temporal variation in the vegetation indices such as NDVI and EVI. The greater contribution of some of the EVI layers such as EVI 8, EVI 17, EVI 19 and EVI 21 to the overall habitat model reiterates the subtle role played by these factors in defining habitat suitability. Interestingly, the layers EVI 8 and EVI 21 which contributed the most to the habitat model correspond to the period of flowering and fruiting of the species. Hence, EVIs can also act as powerful and informative surrogate variables representing the complex formulations of the underlying environmental factors which determine the boundaries of the potential habitat of the species.

Better population status of the species in areas of higher model thresholds such as Upper Shillong, Shillong peak and Mylliem5 indicates that these areas have ideal habitat conditions for persistence of the species. However, localities such as Mylliem 1–4, Umtangar and Below Shillong peak had lower population size in spite of being predicted as highly suitable. The reason for this as revealed from the direct field observation was concurrent anthropogenic disturbances in these localities due to selective extraction of *I. khasiana* trees for household use (Upadhaya et al., 2009) which otherwise were not present in the former locations. From the above observations, we can subtly assume that population status of a species in undisturbed habitats in the native range could be ascertained with reasonable level of confidence from the model output, i.e. areas with greater population size are predicted as

Table 4
Current protected area setting for conservation of *Ilex khasiana* in the wild in East Khasi Hills district of Meghalaya.

District	Name of Forest	Area (km^2)
East Khasi Hills	Riat Laban Reserve Forest	2.05
	Laitkor Reserve Forest	3.25
	Upper Shillong Protected Forest	7.66

models with higher threshold level and vice versa. Such assumption however, may not hold good if the habitats are modified through human influences. Considering the numbers of seedling and sapling at different localities, the sub-populations at Upper Shillong, Shillong Peak, Mylliem5 and Laitkor may be considered as growing while Below Shillong Peak, Umtangar and Nongstoin populations were declining.

Overall, the results of actual habitat assessment through Google Earth superimposition and field surveys were identical. Through both the methods, the prevalence of *I. khasiana* was in similar landuse and landcover types. This analysis confirms the application of Google Earth superimposition along with limited field survey as a powerful tool for habitat assessment of the species and could be a substitute of extensive field survey (Benham et al., 2011).

Conservation of a species and its habitat cannot be done in isolation outside the sphere of the anthropobiome (Ellis and Ramankutty, 2008). Habitat status assessment through primary field survey and secondary survey using Google Earth satellite imageries revealed that the predicted potential areas of the species under all suitability threshold levels i.e. low to very high suitability, encompass a mosaic of disturbed/undisturbed forest patches, scrubs, grasslands and human generated landuse elements such as rural/urban settlements, settled cultivation areas, homestead gardens, small groves, etc. which essentially are components of the anthropobiome. Species reintroduction plan should therefore carefully select appropriate areas under such a setting. In the present study, some areas consisting of continuous and intact patches of subtropical broadleaved and pine forests and degraded forest patches offer as potential habitats at higher levels of probability. Hence, such forest areas could serve as habitats for in situ conservation and reintroduction. However, predicted less suitable areas such as small groves and homestead gardens could also be used for reintroduction of the species provided that adequate measures are taken for the habitat protection. To achieve this, awareness and active participation of local people, Non Government Organizations (NGOs), and Community Based Organizations is warranted.

The present study demonstrated that habitat distribution modelling could be of great help in predicting the potential habitats of threatened species for reintroduction. Results of the study also suggested the strong relationship between the population size and model thresholds thereby indicating the high potential value of ENM in population studies. The areas identified in the present study for reintroduction of *I. khasiana* would not only help in eco-restoration of degraded forests and habitats where the species had existed before but also in rehabilitating the species population and improving its conservation status. Therefore, the results would be quite useful for natural resource managers in management of this species and conserving overall biological diversity in the region.

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