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Cover: *Geodorum laxiflorum* Griff.—inflorescence (Orchidaceae) © Ashish Ravindra Bhowar.



Ecological niche modeling for reintroduction and conservation of *Aristolochia cathcartii* Hook.f. & Thomson (Aristolochiaceae), a threatened endemic plant in Assam, India

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Abstract: *Aristolochia cathcartii* Hook.f. & Thomson is a medicinal plant species native to Assam (India). Karbi people have traditionally used the plant to treat a variety of ailments. The population stock of this species has been rapidly depleting in its natural habitats due to over-utilization, habitat fragmentation, and other anthropogenic activities. Extensive field surveys were carried out to investigate the population status of *A. cathcartii* in various forest areas of Assam's Karbi Anglong district. In 20 km of transects, a total of 36 quadrats were observed. *A. cathcartii* density, frequency of occurrence, and abundance were recorded to be 0.65, 17.8, and 3.81, respectively. Ecological niche modelling was used to identify suitable habitat for the reintroduction and conservation of this plant in Assam in order to prevent its extinction in the future. The maximum entropy distribution modelling algorithm was used to identify suitable areas and habitat for the species' reintroduction and conservation. Primary data on the occurrence of *A. cathcartii* was gathered from the natural habitat of Karbi Anglong district, Assam, for modelling. The model identified various forest areas in northeastern India that have suitable climatic conditions for plant reinforcement.

Keywords: Abundance, DIVA GIS, forest, habitat, medicinal plant, MaxEnt, NDVI, occurrence, population, survey.

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Author contributions: Both the authors contributed equally.

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INTRODUCTION

Aristolochia cathcartii, belonging to the family Aristolochiaceae, is a large climber. Traditionally, *A. cathcartii* has been used by the Karbi community of Assam to treat cholera, stomach pain, fever, and poisonous bites (Sarma et al. 2015, 2017). Overexploitation, climate change, habitat fragmentation and loss, and rapid urbanization cause gradual depletion of this medicinally important plant from its natural habitat. Species reinforcement is the best technique for the restoration of depleted species populations and degraded habitats and ecosystems (Leaper et al. 2006; Martinez-Meyer et al. 2006; Kuzovkina & Volk 2009; Ren et al. 2009; Rodríguez-Salinas et al. 2010; Polak & Saltz 2011). Ecological niche modeling helps in identifying sites of species occurrence and also helps to spot other suitable habitats for reintroduction. Ecological niche modeling (ENM) is a tool in geographic information system (GIS) software that uses occurrence data of a species across landscapes and correlates them with digital raster GIS coverage to develop a model of environmental conditions that meet ecological requirements and identify the suitable environment of the species (Guisan & Zimmermann 2000; Elith et al. 2006; Kozak et al. 2008). ENM facilitates interpolation as well as the extrapolation of species distributions in geographic space across different periods and it helps to prepare habitat distributional maps by spotting areas suitable for reintroduction of threatened species (Irfan-Ullah et al. 2006; Kumar et al. 2009; Ray et al. 2011). For conservation strategy, it is essential to identify areas which bear appropriate environmental conditions suitable for the species persistence. Therefore, the present work was undertaken to study the population distribution status of *A. cathcartii* and to model the habitat distributional map in its native range.

MATERIALS AND METHODS

Plant material

A. cathcartii Hook.f. & Thomson belonging to the family Aristolochiaceae is a large climber, with corky furrowed bark; young branchlets, and petioles villous. Leaves 5.5–10 by 3.5–6.5 inch, broadly ovate, sometimes ovate-lanceolate, acute or acuminate, entire; base cordate, sometimes slightly lobed along the sinus, 3-nerved or pedately 5-nerved, thinly coriaceous, pubescent along the midrib and larger nerves especially towards the base, otherwise glabrous above, clothed,

often felted with long silky hairs beneath; lateral nerves excluding the basal 5–6 on either side; petioles 1.5–4 inch long, sometimes twining. Flowers usually in short brown villous cymes from axils of existing or fallen leaves; pedicels 0.6–1 inch long, villous. Perianth yellowish-white, with purple veins clothed with spreading hairs outside, 2.5–3 inch long along the bends, sac bent near the short neck, mouth square, densely purple papillose along the edge and the recurved lip. Capsule about 6.5 by 1.7 inch, linear-oblong, bluntly apiculate, softly tomentose, 6-ribbed, grooved between the furrows; seeds about 0.4 inches long, not winged, obovate, acute at the base, margins slightly incurved on the inner face, dorsally more or less truncate and margined (Kanjilal & Bor 1940). This plant is native to Assam, Bangladesh, China south-central, eastern Himalaya, Myanmar, Nepal, and Tibet (Plants of the world online, Royal Botanic Gardens, Kew).

Survey of the plant species and its population status

A frequent field visit was carried out to record the population status of *A. cathcartii* in Dhansiri, Kalioni, Nambar, Lahorijan, and Matipung Reserve Forest of KarbiAnglong district, Assam (India). The forest of KarbiAnglong is moist semievergreen and moist mixed deciduous type. The total population of *A. cathcartii* was calculated through a direct count method for all individuals. The grid size was taken 250 × 250 m and individuals were categorized as seedlings (<1 m height), saplings (>1 m height), and matured individuals (≥1.37 m height). The density, frequency, and abundance of the plant species were calculated with the following formulae:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency} (\%) = \frac{\text{Number of quadrats in which the species occurred} \times 100}{\text{Total number of quadrats studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

Ecological niche modeling

Primary locations of the species were collected through field surveys. To record the coordinates of occurrence points of the species global positioning system (GPS) was used to an accuracy of 10–40 m. Then the coordinates were translated to decimal degrees to be used in habitat distribution modeling software (Adhikari & Barik 2012). For ecological modeling different types

of environmental datasets are available in public domain websites. In our study, the index of normalized difference vegetation (NDVI) was used to model the distributional pattern of *A. cathcartii* in northeastern India (Table 2). The NDVI was obtained from Global Land Cover Facility (GLCF, University of Maryland). All the analyses were conducted at the spatial resolution of 250 m.

Validation of model robustness

For habitat modeling of *A. cathcartii*, the NDVI and the maximum entropy modeling (MEM) was used to develop the model (Adhikari & Barik 2012). MaxEnt uses presence-only data to predict the geographic location of a species based on the principle of maximum entropy (Phillips et al. 2006; Elith et al. 2011). For the calibration, we used the presence and background data locations where 75% of the records were used for training the model and 25% for the test (Adhikari & Barik 2012). We conducted 20 replicated model runs and the replicated run type was cross-validation with a 10-percentile threshold rule of training presence to validate the model robustness (Adhikari & Barik 2012; Sarma et al. 2018). Since the program is already calibrated, therefore, other parameters were set as default (Adhikari & Barik 2012). Replicated runs generated average, maximum, minimum, median, and standard deviation. Quality of the model was assessed based on area under curve (AUC) value and the model was classified according to Thuiller et al. (2007) as very good ($0.95 < \text{AUC} < 1.0$), good ($0.9 < \text{AUC} < 0.95$), fair ($0.8 < \text{AUC} < 0.9$), and poor ($\text{AUC} < 0.8$).

Population status vis-à-vis model thresholds

Extensive field visits were executed to investigate the robustness and relevance of the model in predicting the population status of *A. cathcartii* in each occurrence area as predicted under various model thresholds. The total population of the species was calculated by direct count of all individuals of seedlings, saplings, and mature individuals in each 250×250 m grid of occurrence within the predicted localities. The population data of *A. cathcartii* in each occurrence area was then correlated with the corresponding threshold level of the distribution models to check whether regions fell under higher threshold level sustain higher populations thus favoring improved habitat conditions for species establishment and vice versa.

Analysis of habitat status and recognition of areas for reintroduction

We analyzed the habitat type in the occurrence areas

of the species as well as the predicted potential areas through repeated field surveys. To identify the actual habitat of the species, we imported the ASC (Action Script Communication) file of the model output to Diva GIS ver. 7.3, and then we exported the Grid file as KMZ (Keyhole Markup Language Zipped) format for display in Google Earth (Adhikari & Barik 2012; Sarma et al. 2018; Baruah et al. 2016; Deka et al. 2018). Then we superimposed the exported KMZ files on Google Earth Pro satellite imageries to determine the actual habitat condition of the areas of occurrence and areas that prevailing the same habitat for the reintroduction of the species (Thuiller et al. 2007; Adhikari & Barik 2012; Baruah et al. 2016; Deka et al. 2017; Deka et al. 2018; Sarma et al. 2018).

RESULTS

Population distribution status of *Aristolochia cathcartii*

The population distribution status of a species indicates its importance in conservation. Species with a limited range of distribution needs to be protected more than a wide range of distribution. Considerable field surveys were conducted to explore the population status of *A. cathcartii* in each occurrence area. A total of 36 numbers of quadrats were observed along 20 km of transects. The density, frequency of occurrence, and abundance of *A. cathcartii* are shown in Table 1. The observation tabulated below depicted the mean density of *A. cathcartii* as 0.65, frequency of occurrence 17.77, and abundance concerning other associated species as 3.81.

Calibration of models

The model calibration test for *A. cathcartii* yielded satisfactory results (AUC test= 0.96 ± 0.002).

Response curves

The response curves (Figure 1) reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. The curves show the mean response of the 20 replicate Maxent runs (red) and the mean +/- one standard deviation (blue, two shades for categorical variables).

Analysis of variable contributions

The table 2 gives estimates of relative contributions of the environmental variables to the Maxent model. Figure 2 shows the results of the jackknife test of variable

Table 1. Population status of *A. cathartii*.

Grid no.	No. of adult plants within 250 m ² grid	No. of saplings within 250 m ² grid	No. of seedlings within 250 m ² grid	Total no. of quadrats of occurrence of <i>A. cathartii</i> within 250 m ² grid	Density within 250 m ² grid	Frequency within 250 m ² grid	Abundance within 250 m ² grid
1	15	4	0	5	0.53	13.9	3.8
2	17	7	5	8	0.81	22.2	3.6
3	17	6	2	6	0.69	16.7	4.2
4	13	7	3	6	0.64	16.7	3.8
5	16	8	0	4	0.67	11.1	6
6	10	9	2	7	0.58	19.4	3
7	14	9	6	9	0.81	25	3.2
8	18	11	5	8	0.94	22.2	4.3
9	16	10	0	7	0.72	19.4	3.7
10	17	9	0	7	0.72	19.4	3.7
11	12	10	6	9	0.78	25	3.1
12	10	9	0	6	0.53	16.7	3.2
13	11	5	0	5	0.44	13.9	3.2
14	11	7	3	8	0.58	22.2	2.6
15	16	9	2	6	0.75	16.7	4.5
16	13	4	0	7	0.47	19.4	2.4
17	15	9	4	6	0.78	16.7	4.7
18	13	5	0	6	0.5	16.7	3
19	15	10	5	8	0.83	22.2	3.8
20	11	7	2	7	0.56	19.4	2.9
21	13	6	4	6	0.64	16.7	3.8
22	12	6	3	4	0.58	11.1	5.3
23	11	7	2	6	0.56	16.7	3.3
24	14	8	2	4	0.67	11.1	6
25	15	5	1	5	0.58	13.9	4.2

importance. The environmental variable with the highest gain, when used in isolation, is eu5_1_eur (May), which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is eu4_1_eur (April), which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over replicate runs.

Population status vis-à-vis model thresholds

A total of 589 number of individuals were recorded within the area of occurrence spread over 25 250 x 250 m grids. Of these 345 numbers of individuals were adults, 187 numbers of individuals were sapling and 57 numbers of individuals were seedlings (Table 3). The analysis of population structure at each locality revealed that the highest number of adult individuals were in

Dhansiri (78), Daldali (75), Lahorijan (67), Matipung (65), and Nambar (60). The population size including all adults, saplings, and seedlings was larger in the areas under the high suitability threshold category followed by a medium to low category (Table 3). Areas predicted as a medium to high suitable classes represent 84% of the total population followed by a low threshold. This establishes the strong correlation between population size and level of the model threshold. Of the 25 localities, nine localities fell under high class, 11 localities under medium, and five localities fell under low habitat suitability class.

Saplings were poorly represented in most of the areas. The number of seedlings was also very poor even absent in some areas. The number of seedlings was highest in Daldali with 13 seedlings, followed by Matipung with 12 seedlings, Nambar, and Lahorijan

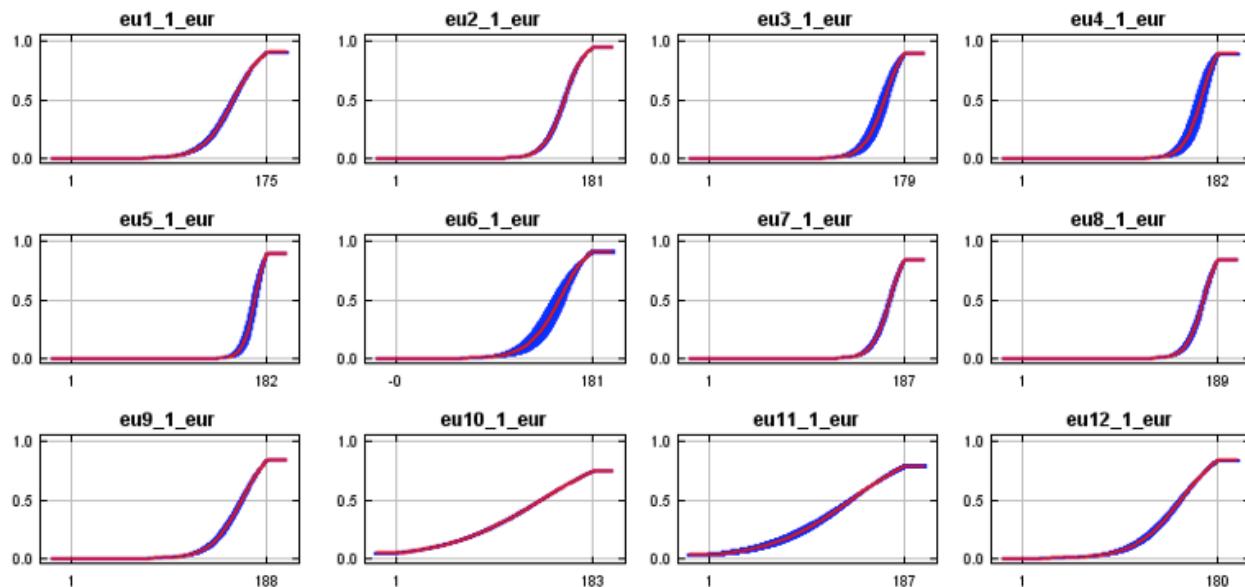


Figure 1. Response curves reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables.

with 11 seedlings each, and Dhansiri with 10 seedlings. Similarly, the number of saplings also highest in Daldali with 48 individuals, followed by Nambar with 40 individuals, Lahorijan with 35 individuals, and Dhansiri and Matipung with 32 individuals each. The population structure based on a seedling, sapling, and adult individuals revealed that good regeneration takes place in the moist semi-evergreen habitat followed by mixed deciduous habitat whereas in other habitats it depicted poor regeneration (Table 3).

Habitat status assessment and identification of areas for reintroduction

Field surveys for assessing the habitat type of *A. cathcartii* in the predicted potential areas revealed that the species occurred in moist semi-evergreen and mixed deciduous forests. Superimposition of the predicted potential habitat distributional map of the species on Google Earth Pro, satellite imageries showed that the areas with high habitat suitability for the species were moist semi-evergreen and evergreen forests. The areas with medium habitat suitability were mixed deciduous forests and grasslands. The areas with low habitat suitability were degraded open forests and homestead gardens (Table 4).

The superimposition of predicted potential habitat distribution map on Google Earth Pro imageries identified different forest areas of northeastern India, viz., KarbiAnglong (Rangapahar, Bokajan) district of Assam, foothills of Assam-Nagaland border (Mokokchung,

Table 2. List of NDVI and variable contribution used in the model.

Variable	Description of the variable	Percent contribution	Permutation importance
eu5	NDVI May	38.9	45.5
eu4	NDVI Apr	20.9	15
eu8	NDVI Aug	11.6	11.9
eu3	NDVI Mar	9.7	9.5
eu6	NDVI June	7.8	0.5
eu10	NDVI Oct	6.7	15.8
eu7	NDVI Jul	2.2	1.2
eu2	NDVI Feb	2.1	0.6
eu9	NDVI Sep	0	0
eu1	NDVI Jan	0	0
eu12	NDVI Dec	0	0
eu11	NDVI Nov	0	0

Wokha, Kohima), Meghalaya (West Khasi Hills, Ri Bhoi), Arunachal Pradesh (East Siang, Papumpare) (Image 1). These areas could be used as in situ conservation and reintroduction of *A. cathcartii* in the wild.

DISCUSSION

A. cathcartii, is best known among the Karbi community of Assam for its high medicinal value. Locally this plant is called ChongaLota. Due to overexploitation of this plant by the local community, and other natural,

Table 3. Population status of *A. cathartii* related to model thresholds.

Occurrence localities	Habitat suitability thresholds	Current habitat status	Number of individuals in occurrence localities			
			Adult	Sapling	Seedling	Total
Dhansiri	Low	Degraded open forest	15	4	0	19
Dhansiri	High	Moist semi evergreen	17	7	5	29
Dhansiri	High	Moist semi evergreen	17	6	2	25
Dhansiri	Medium	Mixed deciduous	13	7	3	23
Dhansiri	Medium	Mixed deciduous	16	8	0	24
Daldali	Low	Degraded open forest	10	9	2	21
Daldali	Medium	Mixed deciduous	14	9	6	29
Daldali	Medium	Mixed deciduous	18	11	5	34
Daldali	High	Moist semi evergreen	16	10	0	26
Daldali	High	Moist semi evergreen	17	9	0	26
Nambar	High	Moist semi evergreen	12	10	6	28
Nambar	High	Moist semi evergreen	10	9	0	19
Nambar	Low	Degraded open forest	11	5	0	16
Nambar	High	Moist semi evergreen	11	7	3	21
Nambar	Medium	Mixed deciduous	16	9	2	27
Lahorijan	Medium	Mixed deciduous	13	4	0	17
Lahorijan	Medium	Mixed deciduous	15	9	4	28
Lahorijan	Low	Degraded open forest	13	5	0	18
Lahorijan	Medium	Mixed deciduous	15	10	5	30
Lahorijan	High	Moist semi evergreen	11	7	2	20
Matipung	High	Moist semi evergreen	13	6	4	23
Matipung	Medium	Mixed deciduous	12	6	3	21
Matipung	Medium	Mixed deciduous	11	7	2	20
Matipung	Medium	Mixed deciduous	14	8	2	24
Matipung	Low	Degraded open forest	15	5	1	21
Total			345	187	57	589

Table 4. Habitat types of *A. cathartii* identified through field surveys and high resolution Google Earth Pro satellite imageries.

Habitat suitability thresholds	Habitat types identified using high resolution Google earth satellite imageries
High	Moist semi evergreen forests and evergreen forests
Medium	Mixed deciduous forests and grasslands
Low	Degraded open forests and home stead gardens

as well as anthropogenic activities, the population stock of this plant, has been exhausting very fast from its natural habitat. In primary field surveys in different forest areas of KarbiAnlong district, we found the mean density 0.65, frequency 17.77, and abundance 3.81 of *A. cathartii* concerning other associated species. To save this plant species from extinction from its near future, we conducted ENM to improve the conservation status

of this plant. In our present study, ENM gave a good result in its native range. NDVI parameters used in the modeling algorithm offered a reasonable explanation in the determination of the habitat suitability of the species. In determining the boundaries of the potential habitat of species, NDVI acts as powerful and informative alternate variables, which represent the complex formulations of the underlying environmental factors (Baruah et al. 2016; Deka et al. 2017; Sarma et al. 2018; Baruah et al. 2019). Overall, the results of actual habitat assessment through Google Earth superimposition and field surveys were identical. The ENM in the present study showed a good overall result (based on Area Under Curve (AUC) value and threshold test) in its native range. The high AUC value, i.e., 0.96 ± 0.002 indicates the good performance of the model. Habitat status analysis through primary field surveys

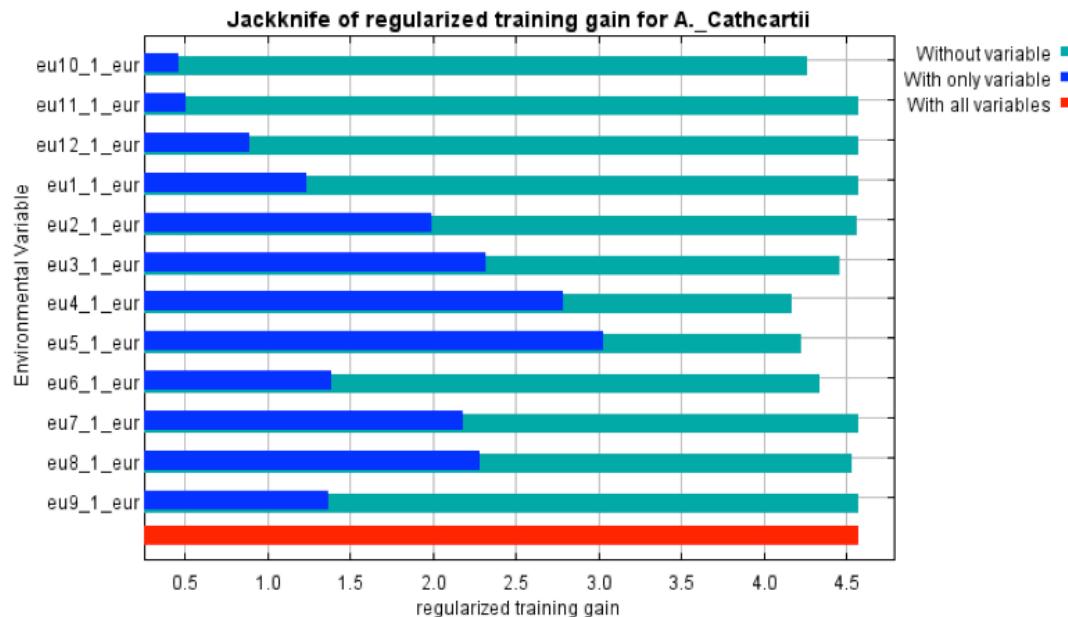


Figure 2. Jackknife test of variable importance for *A. cathcartii* individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar).

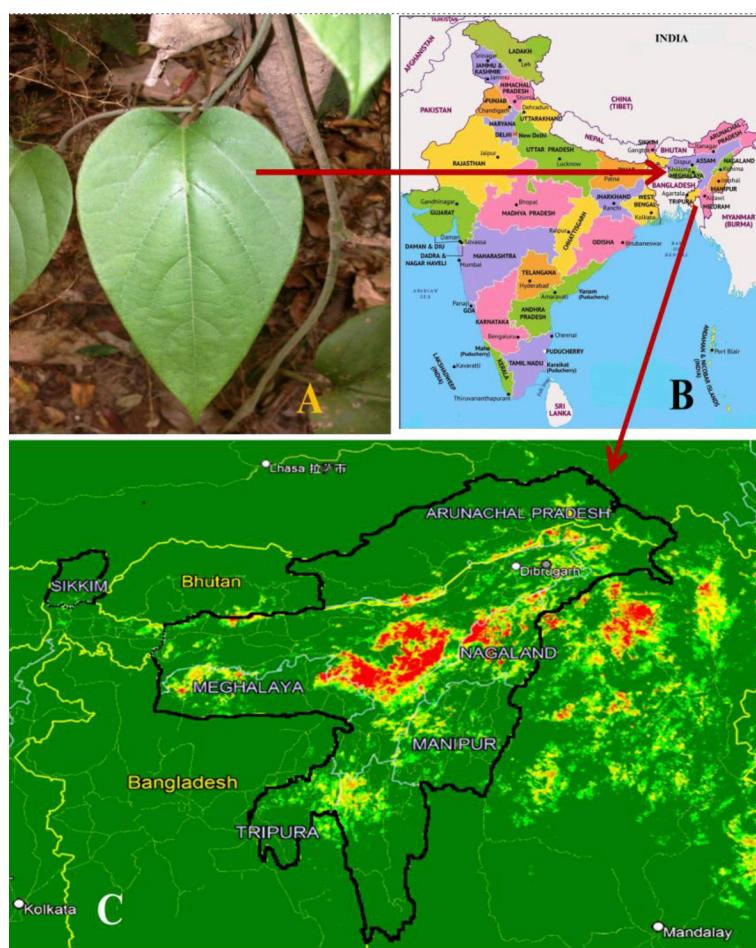


Image 1. A—*Aristolochia cathcartii* plant | B—Map of India | C—Map showing potential habitat distribution of *A. cathcartii* in northeastern India. The red patches in the map indicating suitable habitat conditions for the species.

and secondary surveys using Google Earth Pro satellite imageries established that the predicted potential areas of the species fell under all suitability threshold levels, i.e., low to high suitability. Within 25 250 x 250 m grids, 589 individuals were counted, of which 345 were adults, 187 saplings, and 57 seedlings. The number of saplings and seedlings were very poor in most of the occurrence areas of the species. Areas identified as medium to high suitable classes represent 84% of the total population and it establishes a strong correlation between the population size and the model thresholds. In the present study, evergreen, moist semievergreen, and mixed deciduous forests offer potential habitats at higher levels of probability. Hence, for in situ conservation and reintroduction of *A. cathcartii*, such forest areas could serve as suitable habitats. The present study demonstrates that habitat distribution modeling serves as an important tool in identifying the potential habitats for the reintroduction of threatened species. The areas identified in the present study for reintroduction would help in the improvement of the conservation status of species population of *A. cathcartii*. Therefore, the results would be quite helpful in the management of this species in its natural habitat and conservation of overall biological diversity in the region.

CONCLUSIONS

We present an ecological niche model of *Aristolochia cathcartii* Hook.f. & Thomson, a potential medicinal plant found in some forest pockets of Assam's KarbiAnlong district. We were able to create a distributional map of *A. cathcartii* using our modelling approach. The areas identified in this study for reintroduction would aid in improving the conservation status of the *A. cathcartii* species population. As a result, the findings would be extremely useful in the management of this species in its natural habitat as well as the conservation of the region's overall biological diversity.

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Article

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