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# Journal of Threatened Taxa

10.11609/jott.2025.17.3.26571-26762
www.threatenedtaxa.org

26 March 2025 (Online & Print)
17(3): 26571–26762
ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

Open Access

Zooreach Zoo Outreach Organisation 40 Years

ISSN 0974-7907 (Online); ISSN 0974-7893 (Print)

Publisher
**Wildlife Information Liaison Development Society**
www.wild.zooreach.org

Host
**Zoo Outreach Organization**
www.zooreach.org

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**Cover: A bag worm with its beautiful heap of junk. Acrylics on 300 GSM paper by Dupati Poojitha based on a picture by Sanjay Molur.**

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 March 2025 | 17(3): 26616–26626

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

https://doi.org/10.11609/jott.9282.17.3.26616-26626

#9282 | Received 07 July 2024 | Final received 10 January 2025 | Finally accepted 05 March 2025

ARTICLE



# Conservation strategies for *Vatica lanceifolia* (Roxb.) Blume: habitat distribution modelling and reintroduction in northeastern India

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**Abstract:** *Vatica lanceifolia* (Roxb.) Blume is a Critically Endangered species and native to the northeastern India, faces significant conservation challenges. Habitat distribution modelling approach was adopted to determine the potential region and suitable habitat for reintroduction of this species in order to improve its conservation status. The model incorporated six key variables: normalized difference vegetation index (NDVI), elevation, slope, stress index, soil type, and soil moisture based on weighted overlay modelling approach. The study identified prospective locations for species reintroduction in the lower altitudes (175–470 m) and moderate slope of 10–30 degrees with excessively drained loamy soils within its present home range. NDVI exhibited a crucial role with intermediate magnitudes of 0.2–0.43 along with soil moisture of moderate range of 30–60 % respectively. The physiological impact in the study site was assessed in terms of stress index, which exhibited values of 0.2–0.31. These values indicate a moderate magnitude of stress, highlighting the fragile state of the ecosystem supporting the species. The model delineated the study area into three habitat zones, highly suitable (51%), moderately suitable (46%), and least suitable (3%) for reintroducing *V. lanceifolia*. This study provides comprehensive scientific evidence to enhance biodiversity conservation initiatives and optimize management strategies.

**Keywords:** East Karbi Anglong, habitat fragmentation, in-situ conservation, management strategy, native species, protected area, species diversity, species preference area, species reintroduction, weighted overlay modelling.

**Editor:** A.J. Solomon Raju, Andhra University, Visakhapatnam, India. **Date of publication:** 26 March 2025 (online & print)

**Citation:** Mipun, P., A. Bora, P.K. Mishra, B. Doley & R.M. Kalita (2025). Conservation strategies for *Vatica lanceifolia* (Roxb.) Blume: habitat distribution modelling and reintroduction in northeastern India. *Journal of Threatened Taxa* 17(3): 26616–26626. https://doi.org/10.11609/jott.9282.17.3.26616-26626



**Funding:** Self-funded.

**Competing interests:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Author contributions:** PM, RMK, AB, and PKM conceived the ideas. PM, AB, and RMK designed methodology. PM, BD and RMK collected the data. PM, RMK, and AB analysed the data; PM and RMK led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

**Acknowledgements:** We thank the Department of Geography, North Eastern Hill University, Shillong, for providing technical support and the Botanical Survey of India, Eastern Regional Circle for allowing us to consult the herbarium. The help and cooperation received from the local people is also thankfully acknowledged.

## INTRODUCTION

Ecosystem destruction by altering structural and functional integrity have been driven by rapid changes in climatic conditions, habitat fragmentation, anthropogenic intervention, pollution, coupling invasion of unwanted species, and pathogens. A healthy ecosystem with proper functioning depends on the status of biodiversity and anthropogenic factors to a great extent. Some species act as keystone species and serve as flagships to drive larger conservation programmes (Rivers et al. 2015). An increase in the number of threatened species and their gradual extinction at global level indicates that biodiversity is under serious threat (Pimm et al. 1995; Balmford et al. 2003; Jenkins et al. 2003). Therefore, it is inevitable to conserve individual species to sustain the existing biodiversity.

Alterations of ecosystems have been accounted for the decline of about one fifth of the economically important plant species (Brummitt et al. 2008). The knowledge of distribution of threatened species is important for their conservation, restoration, and rehabilitation. Potentially, habitat modelling can support the ecosystem by identifying the region for the mass propagation of the species along with its conservation (Barik & Adhikari 2011; Zurell et al. 2020).

*Vatica lanceifolia* (Roxb.) Blume belonging to the family Dipterocarpaceae is an evergreen species distributed throughout the moist tropical forests of India (Assam), Bangladesh, eastern Himalaya, Myanmar, and Tibet. The plant is listed in the IUCN Red List of Threatened Species as 'Critically Endangered' (IUCN 2024) under criteria A1cd, C2a. It is an important source of non-timber forest product (NTFP). Its bark is useful as incense and in charcoal production in eastern Asian countries. Besides having immense potential as an economically important species, the population of *V. lanceifolia* is found to be declining at an alarming rate. The human activities such as over-exploitation, habitat destruction, and fragmentation of forest areas have substantially altered the natural landscapes, affecting the *V. lanceifolia* population in its native habitats and preventing its sufficient propagation in its natural state (Borah & Devi 2014). The distribution of a species is a crucial spatial trait that is impacted by the environment and human activity. The occurrence of new species, changes in a species' range, species extinction, loss of biodiversity, loss of ecosystem resilience and disturbance regimes have all been linked to climate change (Piirainen et al. 2023). Due to mass extraction, the native species of the region are mostly confined to the protected areas like national parks, biosphere reserves, wildlife sanctuaries, and reserve forest with few populations' counts. The number of species with constrained ranges of suitable habitat is rapidly rising globally, and it also applies to well-known taxa. By connecting a species' occurrence to the predictor variables, distribution modelling seeks to comprehend and display a species' spatial distribution in hypothetical climate scenarios from the past, present or future. Due to its diversity and the presence of numerous endemic species, the sustainable management of the flora and fauna of the Indian subcontinent is a matter of global importance. Habitat distribution modelling identifies optimal environmental conditions for a species and maps their actual and potential geographic distribution. They increase our understanding of the ecological niche of the species by demonstrating the relationship between environmental variables and the logistic probability of presence also known as habitat appropriateness (Chandra et al. 2021). The geographical range of a species is frequently estimated using habitat distribution modelling based on the occurrence data and environmental factors that are thought to affect their dispersion (Tsegmed et al. 2023).

The noticeable presence of *V. lanceifolia* have been reported from Gibbon Wildlife Sanctuary, Nambor Wildlife Sanctuary, Jeypore Reserve Forest, Tinkupani Reserve Forest, Abhaypur Reserve Forest, Kukuramora Reserve Forest in the region (Sankar & Devi 2014; Giri et al. 2019). Mass multiplication of species through seeds, awareness and active participation of locals, community-based organizations, non-government organizations, and the forest department are essential for both in situ and ex situ conservation. For predicting the geographic distribution of plant species, a variety of species distribution models, including the generalised additive model, the domain environmental envelope, the genetic algorithm for rule-set construction, maximum entropy model (Maxent) and weighted overlay model are often utilised. Among them, the weighted overlay model has been demonstrated to be one of the reliable and consistent ones to estimate and predict current and future suitable habitats for various threatened and important medicinal plants with minimal input and ease of analysis of parameters for fruitful application (Paudel et al. 2012; Nath et al. 2021). The study depicts population size and habitat distribution of *V. lanceifolia* in the study area. The destruction of ecosystems caused by climate change, habitat fragmentation, anthropogenic intervention, and invasive species has significantly affected biodiversity. *V. lanceifolia,* a Critically Endangered tree species in northeastern India, is experiencing drastic population

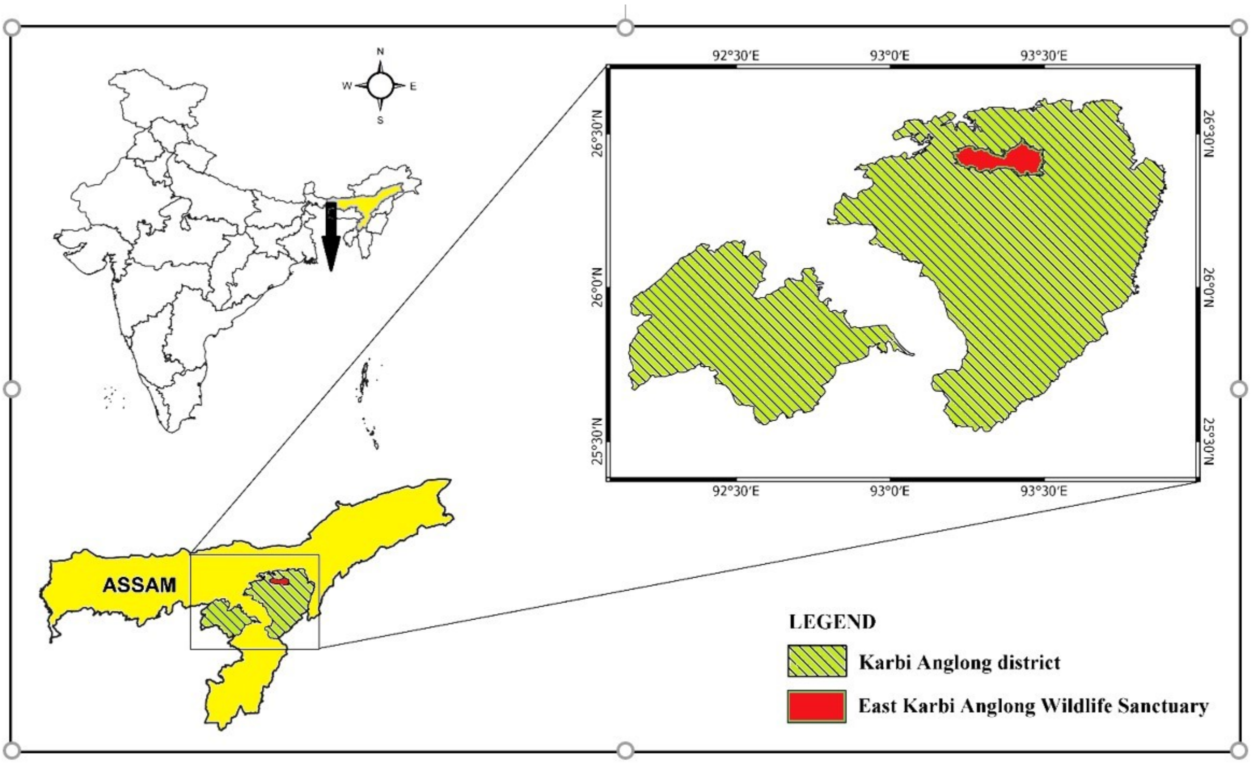


**Figure 1. Map of the study area with geographic location.**

declines due to over-exploitation and habitat loss. Understanding its potential distribution through habitat modelling would provide valuable insights for developing targeted conservation strategies.

## MATERIAL AND METHODS

### Study Area

East Karbi Anglong Wildlife Sanctuary is located in Karbianglong District of Assam, India. It is one of the major forests of the state covering an area of 221.81 km². It is situated in 24°33'–26°35' N and 92°10'–93°50' E and is 80–600 m (Figure 1). The site is an important component of the Karbi Anglong-Kaziranga landscape and Kaziranga-Karbi Anglong Elephant Reserve. It has also been recognized as one of the rich floral and faunal diversity region within the Indo-Burma biodiversity hotspots (WWF 2002). The region experiences a sub-tropical humid climate with an annual rainfall of 1,800 mm. The average maximum temperature is around 30 °C in August, and the minimum goes down to 6.5 °C in winter. The topography of the study site ranges from undulating hills to wide valleys and steep gorges with rivers and creeks, as well as annual and perennial streams. The soil is well-drained, sandy loamy to clayey loamy.

### Description

*Vatica lanceifolia* is a middle canopy evergreen tree species which attains an average height of about 12 m. Its bark is smooth and mottled pale greyish-green in color. Mature leaves are elliptic or oblong measuring 10.15–22.9 cm in length and 3–8.9 cm in breadth. Leaves bear 11–15 slender and arched lateral nerves accompanying reticulated tertiary nerves on each half. Petioles are slightly swollen below the insertion of the blade. The pentamerous white flower is axillary, solitary or fascicled and pubescent with fragrance. The calyx is about 0.25 cm long with velvet aestivation having five segments that are deltoid-acute but are uniformly accreted in fruit. Petals are imbricate, oblanceolate or strap-shaped. Stamens are 15 with unequal anthers. The ovary is turbinate and puberulous and 0.20 cm long. The stout and clad style is as long as the ovary with a tridentate stigma. Fruit is ovoid, globose and brown velvety with fleshy cotyledons supported by thin ovate wings (Image 1).

Distribution: Assam, Bangladesh, eastern Himalaya, Myanmar, Tibet (POWO 2023).

Flowering and fruiting: April to May (Sharma et al. 2022).

### Conservation status

Global assessment was based on IUCN Red List criteria A1cd, C2a which uses the geographic range size of a species and evidence of declining or fragmented population (Ashton 1998).

### Method of studying population status

Field visits to East Karbi Anglong Wildlife Sanctuary were made in the first week of alternate months, during the period from 2019 to 2022. To record the existing population status, random sampling strategy was adopted. The assessment of *V. lanceifolia* was made by counting all individuals, including saplings (>1 m in height) and stems with a circumference of ≥10 cm at 1.35 m height, within 31.62 × 31.62 m quadrats located in each 250 × 250 m grid of occurrence across the study area.

### Occurrence data and environmental variables

The occurrence coordinates of *V. lanceifolia* were recorded using GPS (Garmin eTrex H). A total of 14 occurrence coordinates of *V. lanceifolia* considering minimum proximity area of 1 $km^2$ for sampling were used for modelling suitable habitat across the entire study area. Maximum likelihood area of occurrence approach was adopted for collecting coordinates for the modelling purpose. A total of six environmental variables such as normalized difference vegetation index (NDVI), elevation, slope, stress index, soil type, and soil moisture were used to predict the distribution of the potential habitats of *V. lanceifolia*. Slope and elevation were derived from ASTER global digital elevation map (GDEM) with a spatial resolution of 30 m. NDVI, soil moisture, and stress index were derived from Landsat-8 OLI/TIRS data with a spatial resolution of 30 m. The soil type of the study area was determined from the Soil Series of Assam. Soil type 1 represents soil with deep somewhat excessively drained, loamy skeletal soil occurring on moderately sloping site, slopes of hill with severe erosion hazard and slight stoniness. Soil type 2 represents soil with characteristics of very deep well drained loamy skeletal soil occurring on moderately steeped sloping side and slopes of hills with severe erosion hazards. Soil type 3 represents soil with characteristics of moderately deep well drained clayey soil occurring on moderately sloping sites, slopes of hill with moderate erosion hazards and regoliths. The predictor variables were selected on the basis of their plausible ecological significance for habitat suitability analysis (Table 1).

### Variables ranges and weightage assigning

All the six environmental variables in the final habitat suitability map shows different ranges such as elevation 175–890 m, slope 0.00–56.42 degree, NDVI 0.01–0.55, stress index 0.01–0.41 si, soil moisture 0.16–1.00 bar, and soil type 1–3. After reclassification of each of the parameters, the next important step during the multi-criteria analysis done was to assign a weightage percent to each of the parameter according to their importance. NDVI reflects vegetation type & health, and elevation influences climatic conditions. Slope affects plant growth and root stability. Soil moisture index is associated with the level of moisture available to plants. Leaf stress index indicates photosynthetic activity & water content of leaves, and soil type determines the availability of minerals, pH, drainage, and aeration (Table 1). The rationale behind the selection of environmental variables is based on interviews with field experts and local informants, using a standard analytical hierarchy process (AHP) questionnaire. It was used to estimate the significance of the selected parameters for identifying suitable sites for the species (Satty 1980). The highest weightage, 25% each, was assigned to elevation and soil moisture while NDVI, slope, stress index, and soil type were each assigned a weightage of 12.5% (Table 2).

**Table 1. Model predictors and their plausible ecological relevance for habitat suitability.**

| Predictor variables | Ecological relevance |
|---|---|
| Normalized difference vegetation index (NDVI) | Linked with vegetation type and vigor (Xue & Su 2017) |
| Elevation | Related to climatic variation (Körner 2007) |
| Slope | Related to plant growth and root failure (Lan et al. 2020) |
| Soil moisture index | Moisture availability for plants (Veihmeyer & Hendrickson 1927) |
| Leaf stress index | Related to leaf photosynthetic response and leaf water content (Argyrokastritis et al. 2015) |
| Soil type | Linked with the availability of minerals, pH, drainage, aeration (Sharma et al. 1980) |

### Model calibration and evaluation

The models were ensembled using the weighted overlay model based on six variables NDVI, elevation, slope, soil moisture, stress index, and soil type as predictors of habitat suitability of *V. lanceifolia*. Species distribution maps were generated based on the variables considered. The attribute data of six criteria maps were prepared based on empirical data and classified into five classes to examine the study areas more clearly in different ranges. Weightage were assigned to the criteria based on field-based observations and through pixel count of the occurrence coordinates in each variable generated map. After the weightage assigned, the soil

**Table 2. Parameters with their ranges and weightage (%).**

| Criteria | Ranges of values | Computed weightage % |
|---|---|---|
| Elevation | 175–890 m | 25 |
| Slope | 0.00–56.42 deg | 12.5 |
| Normalized difference vegetation index | 0.01–0.55 (NDVI) | 12.5 |
| Stress index | 0.01–0.41(SI) | 12.5 |
| Soil moisture | 0.16–1.00 (Bar) | 12.5 |
| Soil type | 1–2 | 25 |

series of Assam was over layered to compare the soil types of the species in the study site and generate the habitat distribution map with selected variables (Figure 2). For determining the appropriate weightage percentage to each of variables, AHP developed by Satty (1980) was applied. The model classification was performed from those generated maps with pixels count and a final map was obtained by using ArcGIS version 9.3. The final habitat distribution map was prepared adopting weighted overlay model from the six criteria reference maps and reclassified into four suitable habitat classes – Class 1 represents low, Class 2 moderate, Class 3 high, and Class 4 very high for *V. lanceifolia*, respectively.

## RESULTS

### Population status

Field survey and post modelling validation revealed that *V. lanceifolia* was present in 21 localities in the wildlife sanctuary. Overall, 112 individuals comprising of 40 seedlings, 27 saplings, and 45 adults were enumerated during the entire study period. The dominant species associated with *V. Lanceifolia* were *Bridelia retusa* (L) Spreng., *Bauhinia variegata* L., *Careya arborea* Roxb., *Dillenia indica* L., *Magnolia hodgsonii* (Hk.f. & Thomson) H.Keng and *Wrightia coccinea* (Roxb. ex Hornem.) Sims. The distribution of *V. lanceifolia* within the wildlife sanctuary was scattered due to the sporadic occurrence of bamboo patches over large areas. *Bambusa affinis*, *B. balcooa*, *B. pallida*, and *B. tulda* exhibited gregarious encroachment in the forest area leading to scattered and sparse distribution of the diverse tree species.

### Habitat suitability

*V. lanceifolia* was distributed over an area of 217 $km^2$. The selected parameters NDVI, elevation, slope, soil moisture, stress index, and soil type recognized the optimal growth and establishment of *V. lanceifolia* in the study site. Among the six used variables, elevation and soil type with 50% computed weightage play a significant role for the successful establishment of the species in the final habitat map. Lower elevation (175–470 m) admits ample number of individuals across the elevation range of 175–890 m at the study area (Image 2). The regions with lower elevation with gentle slope are the favourable topography for reintroduction of *V. lanceifolia*. Considerable distribution of *V. lanceifolia* was encountered in the moderate slope of 10–30 degrees with excessively drained loamy soils within its present home range (Image 2). Excessively deep, drained, loamy skeletal soil occurring on moderately sloping site, slopes of hill with severe erosion hazard and regolith which represent the soil taxonomic type 1 Fine, Typic Hapludalfs and type 2 Loamy-skeletal, Umbric Dystrochrepts, which were found to be predominant in the site of species occurrence. In the study area, these two classes occupy more than 60% of land area with a promising potential of being suitable habitat for *V. lanceifolia* (Image 2). NDVI exhibited a crucial role with intermediate magnitudes of 0.2–0.43. This may be attributed to the dominating widespread bamboo patches in the moderate and higher elevation areas (Image 2). The species preferred lower elevation areas with soil moisture of 30–60% showcasing its preferable soil type across the sites observed (Image 2). Along the study site, physiological impact in the form of stress index was estimated in moderate magnitude with the value of 0.2–0.31 indicating the fragility of the ecosystem holding the species (Image 2). The formulated modelling delineated the study area with 51% of highly suitable, 46% as moderately preferred and 3% as least suitable habitat for *V. lanceifolia* (Image 3). Only 17% of the total area of East Karbi-Anglong Wildlife Sanctuary is under very high suitable zone followed by high suitable zone (33%), moderately suitable (47%), and low-level suitability (3%).

### Model performance for distribution

The model formulated delineation of highly suitable areas at lower altitudes with moderate slope and excessively drained loamy soils having moderate magnitude of stress (33%), moderately preferred (47%) and least suitable habitat (3%) for *V. lanceifolia* for its survival and flourishing potential. Field study revealed that the density of *V. lanceifolia* in the sampling plots varied along with the area of suitability proposed by the model. Across the study area, *V. lanceifolia* density varied from 10 stem $ha^{-1}$ to 140 stem $ha^{-1}$ covering different habitat criteria. The mean density of *V. lanceifolia* estimated was 65 ± 11.86 stem $ha^{-1}$ in the


Image 1. *Vatica lanceifolia*: A—Tree | B–C—Flowering inflorescences. © Puranjoy Mipun.

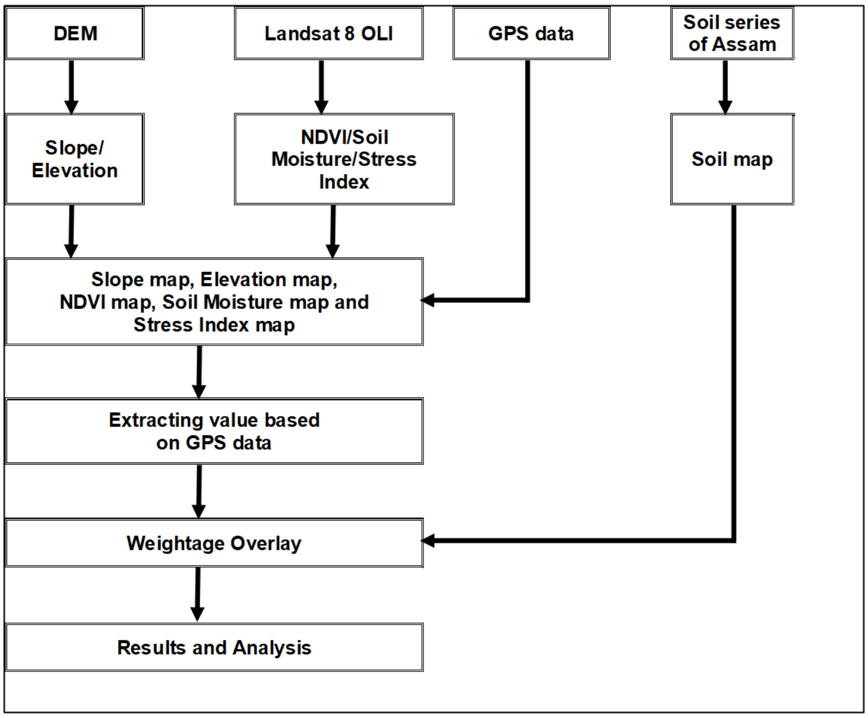


Figure 2. Flow diagram of weighted overlay modelling.

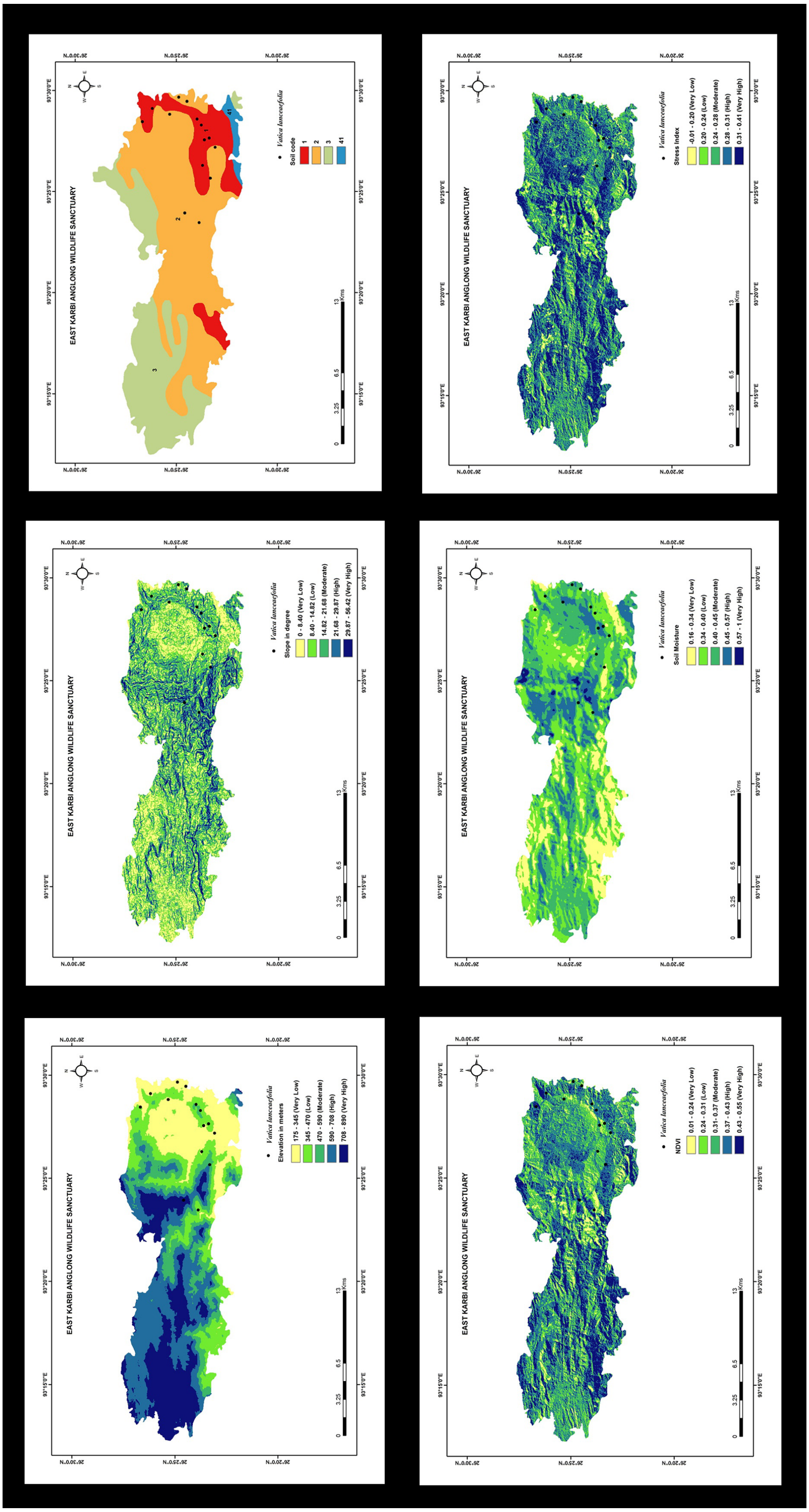


**Image 2. Variable (elevation, slope, soil, NDVI, soil moisture and stress index) maps of the study site showing distribution of *Vatica lanceifolia*.**

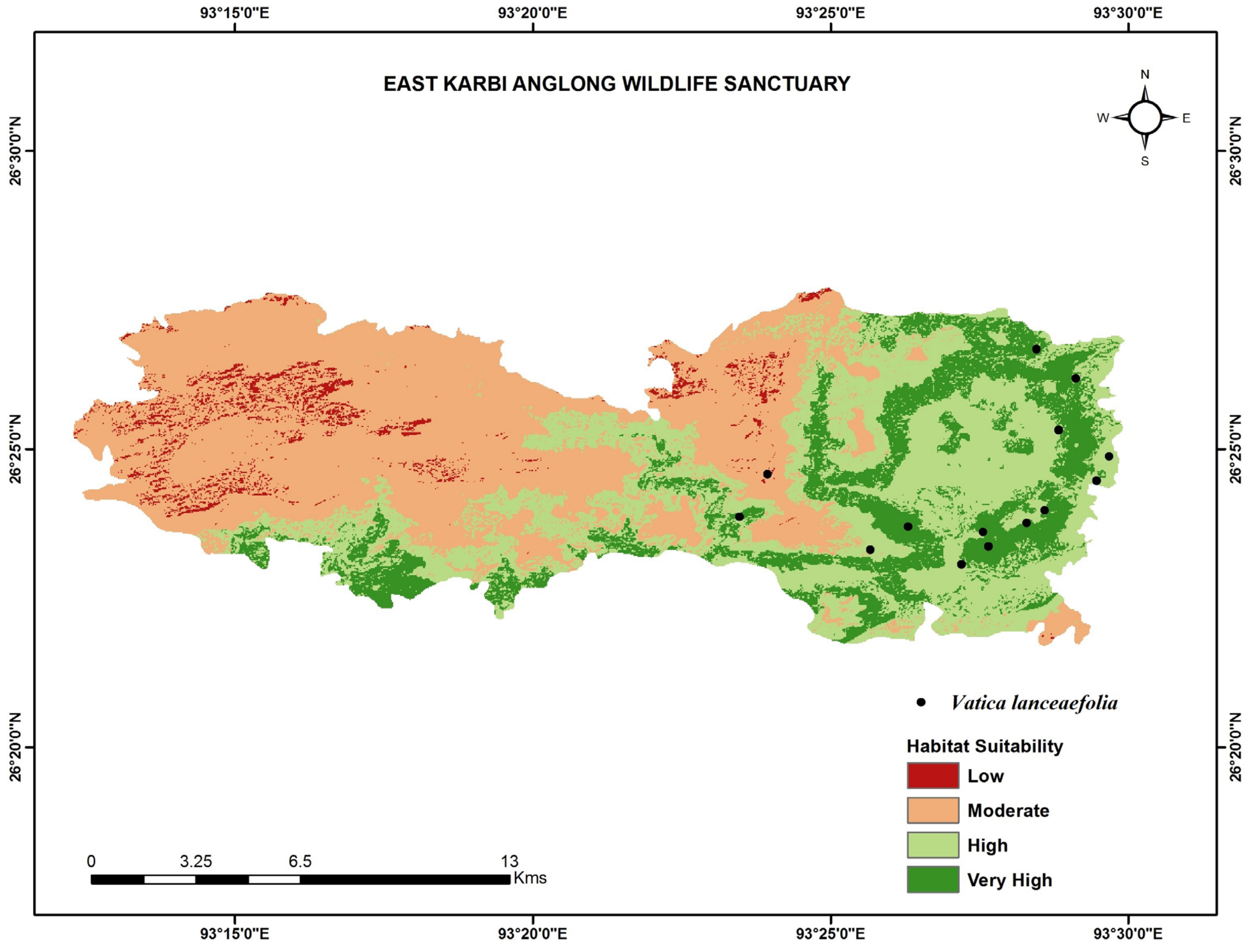


Image 3. Habitat suitability map of *Vatica lanceifolia* in the study site.

highly suitable sites followed by 30 ± 3.54 stem ha$^{-1}$ and 15 ± 3.5 stem ha$^{-1}$ in the moderately preferred and least suitable habitat sampling plots.

## DISCUSSION

In this study, we performed a detailed analysis on the suitable habitat of the *V. lanceifolia* under current and future climate conditions, which will function as an important step in formulating sustainable strategies for its conservation. The present study explores both the habitat assessment of *V. lanceifolia* and its spatial distribution. Our model indicated that the suitable habitat area encompassed more than 50% of the total study area. Previous studies documented the habitat suitability for some species, namely, *Angelica glauca* Kitam. (Singh et al. 2020), *Rosa arabica* (Crép. ex Boiss.) Déségl. (Abdelaal et al. 2019), *Ixora* sp. (Banag et al. 2015), *Berkheya cuneata* (Thunb.) Willd. (Pots et al. 2013), *Acer cappadocicum* ssp. *lobelia* (Ten.) A.E. Murray (Sumarga 2011), *Pterocarpus santalinus* L.f. (Babar et al. 2012), *Aglaia bourdillonii* Gamble (Irfan-Ullah et al. 2006). In the Indian Himalayan region, a large number of studies have been carried out on the ecology, systematics, and inventorisation of phytodiversity (Dhar et al. 1997; Joshi & Samant 2004); however, a few studies are available on the population ecology and ecological niche modelling (ENM) (Adhikari et al. 2012; Yang et al. 2013; Samant & Lal 2015) in the region. The adopted weighted overlay modelling illustrates comparatively simplified approach compared to contemporary species distribution modelling (SDM). This simplified and easier approach may be adopted for better outcome through identification of suitable habitat areas and re-introduction of the species in the areas to regain the earlier status of the species in the native zone of occurrence. Habitat modelling illustrated that the area under high and very high zone have prime habitats for *V. lanceifolia*. These areas would act as an in-situ conservation area for the species and could be used for natural assisted regeneration sites. Field based surveys reveal that *V. lanceifolia* has more suitable habitats near the treeline. Moreover, the habitat is poor in some areas due to bamboo patches. Superimposing the predicted map on high-resolution satellite images revealed that mosaic of habitats are more suitable for *V. lanceifolia* in the study areas having 175–890 m elevation and soil type 1–2. Low population density may be due to over-exploitation for household utilization, ethno-medicinal purposes, poor regeneration, low seed germination, habitat loss, and anthropogenic pressure.

The maximum numbers of populations were represented by grassy slope habitats indicating that such habitats form the best platform for the overall development of the species. The high density of the species in grassy slope margin habitats indicated that such habitat is suitable for the germination of seeds and development of seedlings. Remotely sensing enabled landscape-level vegetation study could be an effective strategy for suitable habitat identification and prediction for threatened species. Anthropogenic alterations coupled with climate change lead to land cover fragility for holding the critically endangered species in its natural habitat. Fragmentation of forest and degradation of habitat expedite discontinuity in the distribution of species leading extinction which may be checked through re-establishment of the species in suitable habitable areas for its conservation (Krauss et al. 2003). The present study brings insight into the formulation of strategies for proper management and protection of critically endangered species in the habitable ecosystems. The scattered distribution has been driven by fragmentation of the habitat by other entities like bamboo patches which is better adapted and flourished in the study area. Along with other factors considered in the modelling, the biological and anthropogenic factors may be considered for reintroduction of the species in the favourable patches prevailing in the region as effective conservation strategies (Mirhashemi et al. 2023). In the Indian subcontinent, most of the studies were focused on potential distribution, habitat loss, or future range shifts of native species in changing climate. The investigations incorporated several variables or factors and highlighted efficient utility of findings to design native tree-based agroforestry systems, protected area network, endemic, endangered, or threatened species but analysis did not incline toward charismatic species that can affect the related species conservation and management process (Roy et al. 2022).

Habitat distribution models can relate the occurrences of taxa to their ecological conditions to quantify the realized niche, i.e., species known locations due to environmental tolerance observed in the field (Hutchinson 1957). These habitat distribution models generate geographic predictions of species habitat suitability that can be used to stratify and optimize sampling efficiency (Chiffard et al. 2020). Moreover, integrating the new spatial data from model-guided sampling can reduce spatial bias in subsequent modelling iterations, improve the predictive accuracy of habitat distribution models for rare species, and reliably identify biologically relevant environmental factors (Singh et al. 2009). The areas identified in the present study for the reintroduction of *V. lanceifolia* 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. Ecosystem destruction driven by habitat fragmentation, climate change, human intervention, and invasive species has profoundly impacted biodiversity. Species may be threatened in fragmented forest landscapes due to bamboo encroachment, physiological and other physiographic and human induced factors. *V. lanceifolia* population is undergoing drastic reduction because of over-exploitation and loss of suitable habitats. Predicting its potential distribution can contribute valuable insights for formulating conservation strategies. Understanding the species abundance and habitat suitability relationship could offer an effective approach for the reintroduction and successful establishment of the threatened species. Therefore, the results would be quite useful for natural resource managers in the management of this species and in-situ conservation of overall biological diversity in the region.

## CONCLUSION

This study aimed to delineate suitable habitat for *V. lanceifolia* in East Karbi Anglong Wildlife Sanctuary on the basis of current spatial distribution and allied associated parameters. The study revealed that more than 50% of the area is highly or moderately suitable for the growth and survival of the species. The primal determinants of habitat suitability were elevation (175–470 m), soil type (excessively drained loamy soils), and moderate slopes (10–30 degrees), which create ideal conditions for the establishment of the species. Habitat fragmentation driven by bamboo encroachment, environmental stress, and anthropogenic disturbances has led to a scattered distribution of the species, posing a substantial threat to its natural regeneration. The findings underscore the urgent need for in situ conservation strategies, including habitat protection, restoration initiatives, and strategic reintroduction programs in highly suitable areas. A predictive framework to identify prime conservation zones, facilitate species recovery, and develop long-term management strategies was provided by the habitat modelling approach. The study further highlights the importance of steady population monitoring, climate impact assessments, and community involvement in conservation efforts to ensure the sustained survival of *V. lanceifolia*. The study offers a scientific ground for conservation and re-establishment of this critically endangered species connecting species abundance and habitat suitability. Integration of these insights into conservation planning will assist in habitat loss mitigation, raising ecosystem resilience, and ensuring the ecological stability of *V. lanceifolia* in its native range.

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**Journal of Threatened Taxa** is indexed/abstracted in Bibliography of Systematic Mycology, Biological Abstracts, BIOSIS Previews, CAB Abstracts, EBSCO, Google Scholar, Index Copernicus, Index Fungorum, JournalSeek, National Academy of Agricultural Sciences, NewJour, OCLC WorldCat, SCOPUS, Stanford University Libraries, Virtual Library of Biology, Zoological Records.

NAAS rating (India) 5.64



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Journal of Threatened Taxa

www.threatenedtaxa.org



**ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)**

**March 2025 | Vol. 17 | No. 3 | Pages: 26571–26762**
**Date of Publication: 26 March 2025 (Online & Print)**
**DOI: 10.11609/jott.2025.17.3.26571-26762**

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