



# Predicting Habitat Suitability and Climate Change Impact on Medicinal plant *Dalbergia latifolia* and *Dillenia pentagyna* Using Ecological Niche Modelling

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## Abstract

**Background:** *Dalbergia latifolia* and *Dillenia pentagyna* are medicinally significant tree species threatened by habitat loss and climate change. Identifying their current and future suitable habitats is crucial for conservation planning. **Methods:** We used Maxent (version 3.4.1) ecological niche modelling with 260 occurrence points and 19 bioclimatic variables from the WorldClim dataset to predict the potential distribution of these species in India. Seventy-five percent of the data were used for model training and 25% for testing, with 10 replicates under cross-validation. Future distribution under the 2050 A2a emission scenario was modelled using downscaled climate projections. **Results:** Maxent performed well, yielding high AUC values of 0.91 for *D. latifolia* and 0.938 for *D. pentagyna*, indicating strong predictive performance. The Western Ghats and parts of Central India emerged as the most suitable habitats. Key climatic predictors included minimum temperature of the coldest month and precipitation of the wettest month. Current suitable habitats were estimated at 111,242 km<sup>2</sup> for *D.*

*latifolia* and 176,238 km<sup>2</sup> for *D. pentagyna*, while future projections indicated a reduction of 38.86% and 40.90% in suitable areas, respectively. **Conclusions:** Climate change is likely to significantly reduce the suitable habitat for both species by 2050. Conservation strategies should prioritize areas identified through modelling for both in-situ and ex-situ conservation efforts. Ecological niche modelling, as demonstrated here, is a powerful tool for guiding future habitat management and conservation of threatened species.

**Keywords:** *Dalbergia latifolia*, *Dillenia pentagyna*, Maxent, climate change, habitat suitability

## 1. Introduction

*Dalbergia latifolia* Roxb. (Indian rosewood) and *Dillenia pentagyna* Roxb. are two economically and medicinally significant tree species native to South and Southeast Asia. It has ethnomedicinal relevance in traditional systems of medicine, including uses for treating skin ailments, fever, and diarrhea. *D. pentagyna*, on the other hand, is a deciduous tree valued for its bark and leaves, which possess anti-inflammatory, antioxidant, and antimicrobial properties. It is commonly utilized in traditional remedies for digestive disorders, wounds, and respiratory issues.

The global resurgence of interest in traditional medicine has significantly amplified the demand for medicinal plants. In both developed and developing nations, the therapeutic properties of herbs are increasingly recognized as viable alternatives or complements to allopathic medicine (WHO, 2013). This heightened demand, however, is primarily met through

**Significance** | This study models current and future habitats, highlighting climate-driven distribution shifts and guiding conservation strategies for two economically valuable medicinal plants.

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unsystematic and excessive harvesting from wild populations, leading to the depletion of many valuable species and the degradation of natural ecosystems (Hanski, 2011). The lack of structured harvesting protocols, coupled with rising international trade and unsustainable exploitation, has placed immense pressure on wild medicinal plant populations, with rates of extraction often surpassing their natural regenerative capacities.

Currently, over 80% of medicinal plant species used globally are gathered from wild sources, and approximately 90% of the total biomass used in herbal preparations is collected from natural habitats (Suman, 2006). Alarming, around 70% of this collection occurs through destructive harvesting techniques, including uprooting entire plants or removing essential structures such as roots, bark, or flowers—practices that critically impair plant survival and regeneration (Hamilton, 2004). Consequently, the global conservation community has raised serious concerns regarding biodiversity loss. The Threatened Plants Species Committee (TPSSC) of the International Union for Conservation of Nature (IUCN) estimates that up to 10% of all vascular plant species are at risk of extinction, driven primarily by overharvesting and habitat loss (IUCN, 2022). Several studies (Maikhuri et al., 2000; Nautiyal et al., 2003) suggest that if current trends continue, up to 60,000 plant species could disappear within the next few decades due to genetic erosion, deforestation, and climate change.

Among the highly threatened yet economically and ecologically significant species is *Dalbergia latifolia* Roxb., commonly known as Indian rosewood. Native to the Indian subcontinent, this species has long been valued for its durable and aesthetically pleasing timber, often used in the production of furniture, musical instruments, carvings, and luxury items (Praciak et al., 2013). Additionally, the bark and leaves of *D. latifolia* are traditionally utilized in ethnomedicine and ethnoveterinary applications in India, particularly for treating inflammation and other ailments (Jain et al., 2005; Padal et al., 2010; Selvaraju et al., 2011). Due to its increasing scarcity and high market demand, illegal logging and overexploitation have significantly reduced its population in the wild. Though *D. latifolia* is now protected under forest laws in India and Nepal, enforcement remains inconsistent, and habitat destruction from human settlement and agriculture continues unabated. While plantations exist, the species' slow growth rate and long rotation period hinder their ability to meet commercial demand. As a result, *D. latifolia* was included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2016 (Hassold et al., 2016) and has been listed as 'Vulnerable' by the IUCN Red List.

Similarly, *Dillenia pentagyna* Roxb., a lesser-known but equally important medicinal tree, is facing severe ecological threats. Indigenous to the dry deciduous forests of central India, *D. pentagyna* is a deciduous tree recognized for its smooth pale bark

and medicinal value. The species is named in honor of the botanist Johann Jacob Dillenius, with "pentagyna" referring to the flower's five styles. Traditional knowledge systems attribute various healing properties to different parts of the plant. The flower buds and young fruits are consumed for their acidic taste, while the roots and fruits are used to alleviate pain and treat dropsy (Dubey et al., 2009; Nyman et al., 1998). The leaf juice is reputed for its wound-healing capabilities and is used externally by indigenous communities in the North Andaman Islands (Prasad et al., 2008; Sharma et al., 2001). Despite its diverse ethnobotanical uses, *D. pentagyna* remains underrepresented in conservation efforts. Although it has not yet been assessed by the IUCN, field surveys and ecological assessments report an alarming decline in its population, with some sources indicating that it may be critically endangered due to limited distribution and poor germination rates (Saxena et al., 2022; Sikarwar et al., 2016).

Given the precarious status of these species, it is imperative to develop robust conservation strategies informed by accurate ecological assessments. Phytosociological analysis, remote sensing, and ecological niche modelling are indispensable tools in this context. Among these, environmental niche modelling (ENM), particularly using the maximum entropy approach, has emerged as a reliable method for predicting species distribution based on presence-only data (Elith et al., 2006; Phillips et al., 2006). Maxent, a machine learning algorithm grounded in the principle of maximum entropy, has proven effective even with limited data sets and is especially suited for modelling rare or endangered species (Pearson et al., 2007; Kumar & Stohlgren, 2009). The algorithm generates habitat suitability maps by estimating the most uniform distribution of a species constrained by environmental variables, while inherently managing variable interactions and preventing model overfitting through regularization (Elith et al., 2011).

Despite the availability of such advanced tools, efforts to conserve *D. latifolia* and *D. pentagyna* are hindered by a lack of comprehensive data on their ecological preferences and geographic distribution. This knowledge gap complicates the formulation of targeted management interventions and the establishment of effective in situ or ex situ conservation programs. Therefore, this study sets out with the following objectives: (1) to develop detailed habitat suitability models for *Dalbergia latifolia* and *Dillenia pentagyna* under current climatic conditions using the Maxent algorithm; and (2) to perform spatial analyses of potential changes in their distributions under future climate scenarios projected for the year 2050.

The findings of this research will not only contribute to the ecological understanding of these two endangered species but will also offer practical insights for conservation planning, habitat restoration, and sustainable cultivation efforts. By integrating traditional knowledge with modern ecological modelling, this study

aims to foster a multidisciplinary approach toward biodiversity conservation and the sustainable use of medicinal plants.

## 2. Methodology

### 2.1 Study Area and Species Occurrence Data

The study was conducted across regions in the Indian subcontinent, encompassing dry deciduous forests, tropical zones, and fragmented habitats known to support *Dalbergia latifolia* and *Dillenia pentagyna*. Species occurrence records were compiled from multiple sources including field surveys, herbarium records, and credible databases such as the Global Biodiversity Information Facility (GBIF). GPS coordinates were recorded for all field-verified presence points to ensure spatial accuracy. To minimize spatial autocorrelation and sampling bias, duplicate occurrence points within a 1 km<sup>2</sup> grid were removed using the spatial thinning algorithm available in the 'spThin' package in R.

### 2.2 Occurrence Data Collection

Primary occurrence records were obtained through extensive field surveys conducted across multiple regions of India, focusing on habitats suitable for the target species. Each georeferenced point was recorded using a handheld GPS device (Garmin), with an accuracy of  $\leq 10$  meters. Coordinates were subsequently converted to decimal degrees for compatibility with GIS-based modeling platforms.

In addition to field surveys, secondary occurrence data were retrieved from the Global Biodiversity Information Facility (GBIF; <http://www.gbif.org>) and peer-reviewed literature (Latifah & Nurdin, 2014; Sikarwar et al., 2016; Singh et al., 2017; Damaiyani & Prabowo, 2019; Mahatara et al., 2021; Saxena et al., 2023). To minimize spatial autocorrelation and sampling bias, a spatial thinning process was applied, allowing only one presence point per 1 km  $\times$  1 km grid cell. Following data cleaning and deduplication, a total of 260 unique occurrence records were compiled and used for both current and future habitat modeling.

### 2.3 Environmental Variables

A total of 19 bioclimatic variables were obtained from the WorldClim 2.1 database at a spatial resolution of 30 arc-seconds ( $\sim 1$  km<sup>2</sup>; Fick & Hijmans, 2017). These variables represent biologically meaningful aspects of temperature and precipitation that influence plant distribution. To avoid multicollinearity among predictor variables, a pairwise Pearson correlation test (threshold  $|r| > 0.8$ ) was performed, and only uncorrelated variables were retained for model building. In addition to bioclimatic variables, topographic layers (elevation, slope, and aspect) and land cover data were included to improve model precision.

### 2.4 Species Distribution Modeling with Maxent

Species distribution models (SDMs) were generated using the Maxent software version 3.3.3k (Phillips et al., 2006). Maxent is a machine-learning algorithm based on the principle of maximum

entropy, which estimates the most uniform distribution of a species constrained by the environmental conditions at known presence sites. The model is especially well-suited for presence-only datasets and performs robustly even with small sample sizes (Elith et al., 2006; Pearson et al., 2007; Kumar & Stohlgren, 2009).

For each species, the model was run with the following settings:

**Feature types:** Auto features (linear, quadratic, product, threshold, and hinge).

**Regularization multiplier:** Default setting (1.0) to balance model complexity and avoid overfitting.

**Number of background points:** 10,000 random points drawn from the study area.

**Replicates:** 10 bootstrap replicates to assess model stability.

**Test-training split:** 75% of the occurrence data were used for training and 25% for testing.

**Output format:** Logistic output indicating the relative habitat suitability from 0 (unsuitable) to 1 (highly suitable).

### 2.5 Climate Data

To model species–climate relationships, 19 bioclimatic variables were sourced from the WorldClim dataset (version 1.4; Hijmans et al., 2005; Booth et al., 2014), available at a spatial resolution of 30 arc-seconds ( $\sim 1$  km<sup>2</sup>). These bioclimatic layers, derived from long-term (1950–2000) interpolated temperature and precipitation records, are widely used in ecological niche modeling due to their relevance in capturing seasonality, annual trends, and climate extremes (Evangelista et al., 2008; Kumar et al., 2009; Sanchez et al., 2011).

Future climate data projections for the year 2050 were obtained under the A2a emissions scenario of the IPCC Fourth Assessment Report. These projections were retrieved from the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) via <http://ccafs-climate.org>. The future layers were statistically downscaled and bias-corrected based on current climatic conditions to ensure comparability.

### 2.6 Future Climate Projections and Scenario Analysis

To assess potential shifts in suitable habitats under future climatic scenarios, species distribution models were projected to the year 2050 using data from the Coupled Model Intercomparison Project Phase 6 (CMIP6). The Shared Socioeconomic Pathway 2-4.5 (SSP2-4.5) was selected as a moderate-emission scenario. Climate layers were downscaled and bias-corrected using the WorldClim data processing framework. Area change analysis was conducted by comparing present and future binary suitability maps derived using the 10th percentile training presence threshold.

### 2.7 Model Evaluation and Variable Importance

Model performance was assessed using the Area Under the Receiver Operating Characteristic Curve (AUC), which evaluates discriminatory power across all classification thresholds (Fielding & Bell, 1997). AUC values range from 0.5 (no better than random)

**Table 1.** Comparative table of environmental variables and their percent contribution in Maxent model for *Dalbergia latifolia* and *Dillenia pentagyna*

Environmental Variables	<i>Dalbergia latifolia</i>	<i>Dillenia pentagyna</i>
Annual Mean Temperature (bio_1)	---	2.9
Mean Diurnal Range (bio_2)	1	4.3
Isothermality (bio_3)	4	3
Temperature Seasonality (bio_4)	17.6	2.4
Min Temperature of Coldest Month (bio_6)	19.8	15.8
Temperature Annual Range (bio_7)	1.9	1.1
Mean Temperature of Wettest Quarter (bio_8)	2.9	---
Mean Temperature of Driest Quarter (bio_9)	2.3	0.7
Mean Temperature of Warmest Quarter (bio_10)	0.7	---
Mean Temperature of Coldest Quarter (bio_11)	0.9	8.6
Annual Precipitation (bio_12)	4.6	10.5
Precipitation of Wettest Month (bio_13)	7.3	23.6
Precipitation of Driest Month (bio_14)	---	0.6
Precipitation Seasonality (bio_15)	10.7	14
Precipitation of Wettest Quarter (bio_16)	3.9	1.3
Precipitation of Driest Quarter (bio_17)	0.4	1.3
Precipitation of Warmest Quarter (bio_18)	12	5.5
Precipitation of Coldest Quarter (bio_19)	10	4.4

to 1.0 (perfect discrimination), with values above 0.8 generally considered indicative of strong predictive performance. Maps were validated using occurrence data overlays and interpreted in the context of known ecological preferences of *D. latifolia* and *D. pentagyna*.

The importance of predictor variables was examined through the jackknife test and percent contribution scores provided by Maxent. The jackknife test isolates the influence of each variable by running models with and without individual predictors, offering insight into their relative contribution to the final model.

**3. Results**

The predictive performance of the Maxent models was evaluated using the Area Under the Receiver Operating Characteristic Curve (AUC), where values closer to 1.0 indicate better model discrimination and values near 0.5 suggest random prediction (Swets, 1988). The models for *Dalbergia latifolia* and *Dillenia pentagyna* demonstrated high predictive accuracy, with average

Current habitat suitability modeling revealed that the Western Ghats and certain regions of central India provide the most favorable environments for both species. The total area identified as highly suitable habitat was approximately 111,242 km<sup>2</sup> for *Dalbergia latifolia* (Figure 5a) and 176,238 km<sup>2</sup> for *Dillenia pentagyna* (Figure 6a).

The contribution of environmental predictors to the model is summarized in Table 1. For *Dalbergia latifolia*, the most influential variables were:

- Minimum Temperature of the Coldest Month (19.8%)
- Temperature Seasonality (17.6%)
- Precipitation of the Warmest Quarter (12%)

For *Dillenia pentagyna*, the strongest predictors were:

- Precipitation of the Wettest Month (23.6%)
- Minimum Temperature of the Coldest Month (15.8%)
- Precipitation Seasonality (14%) (Figure 7)

Future projections for the year 2050, modeled under the A2a emission scenario, indicated a substantial decline in suitable habitat

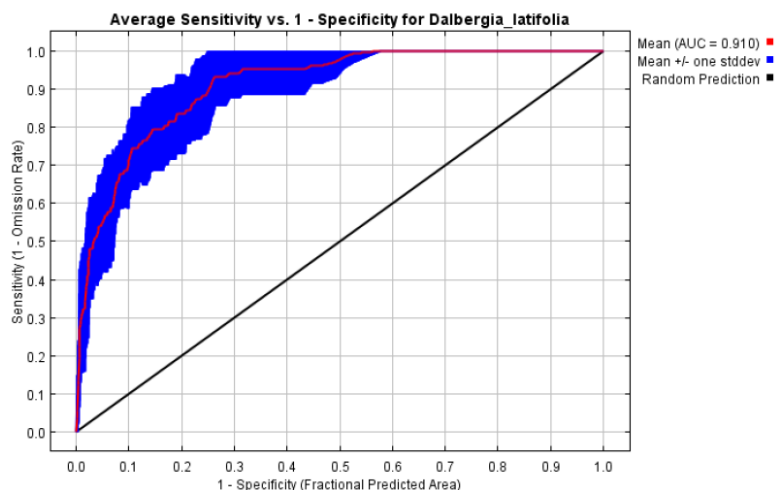


Figure 1: Result of AUC in developing habitat suitability model for *Dalbergia latifolia*

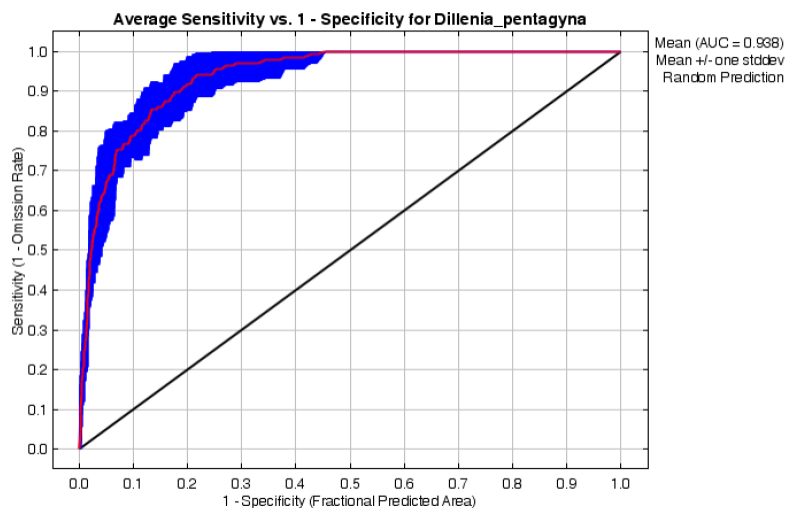


Figure 2: Result of AUC in developing habitat suitability model for *Dillenia pentagyna*

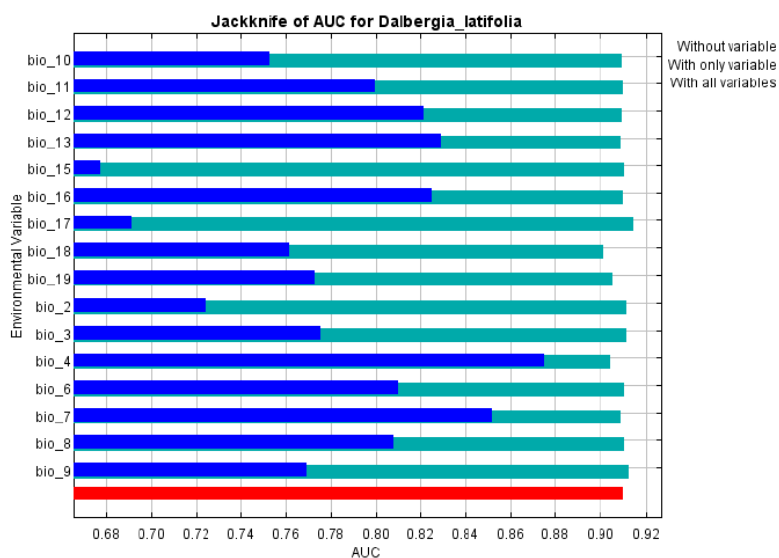


Figure 3: Relative predictive power of different bioclimatic variables based on the jackknife of regularized training gain in maxent model for *D. latifolia*

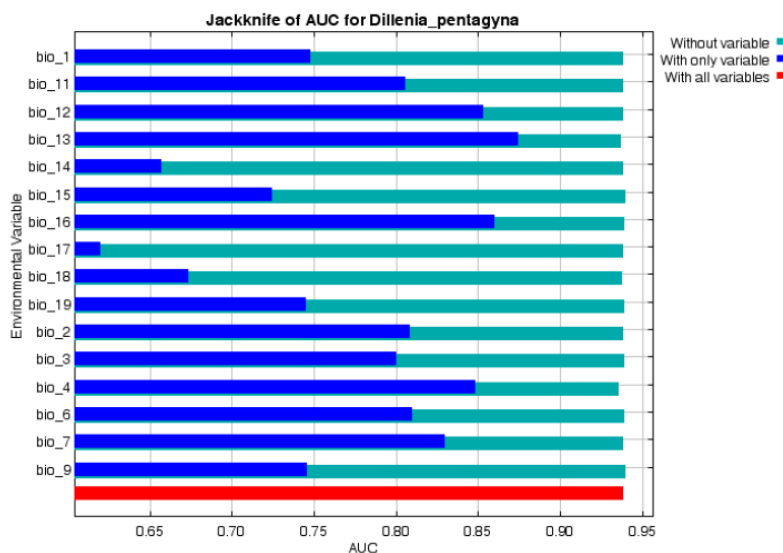


Figure 4: Relative predictive power of different bioclimatic variables based on the jackknife of regularized training gain in maxent model for *Dillenia pentagyna*

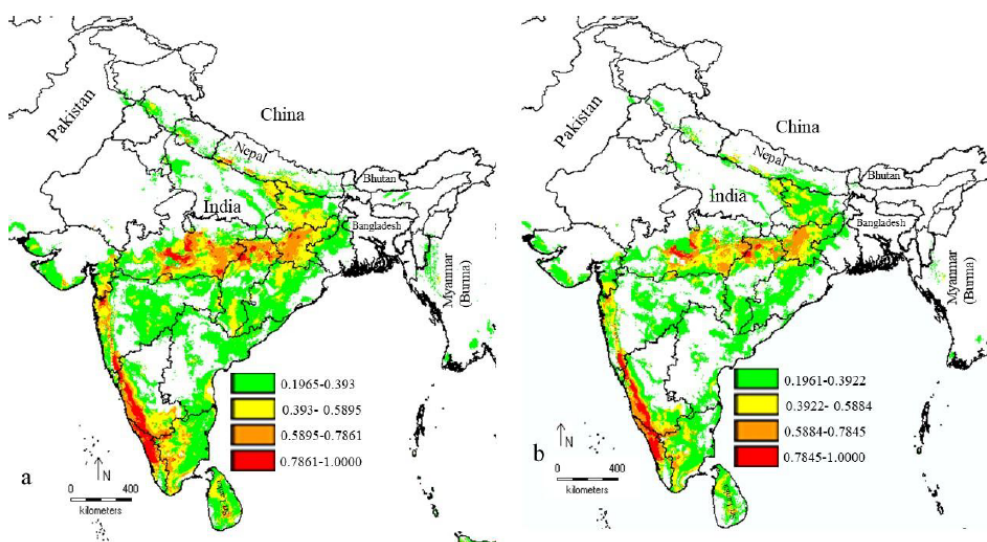


Figure 5: Predicted current (a) and future (b) potential suitable habitat of *D. latifolia*

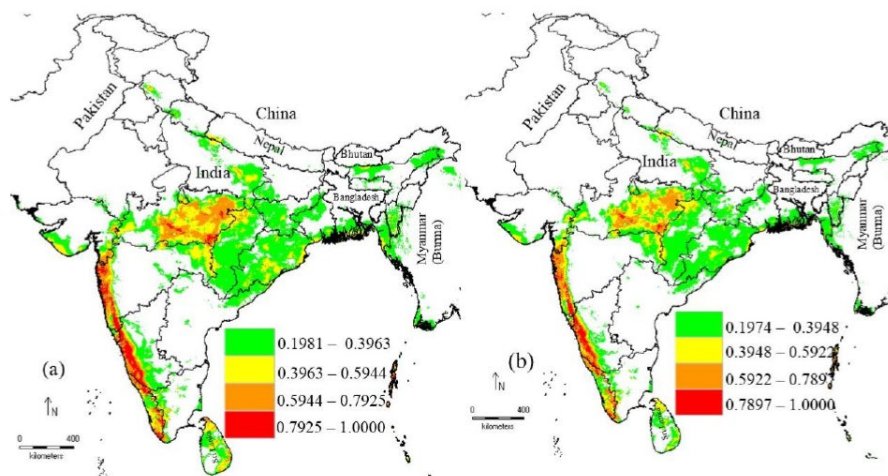


Figure 6: Predicted current (a) and future (b) potential suitable habitat of *Dillenia pentagyna*

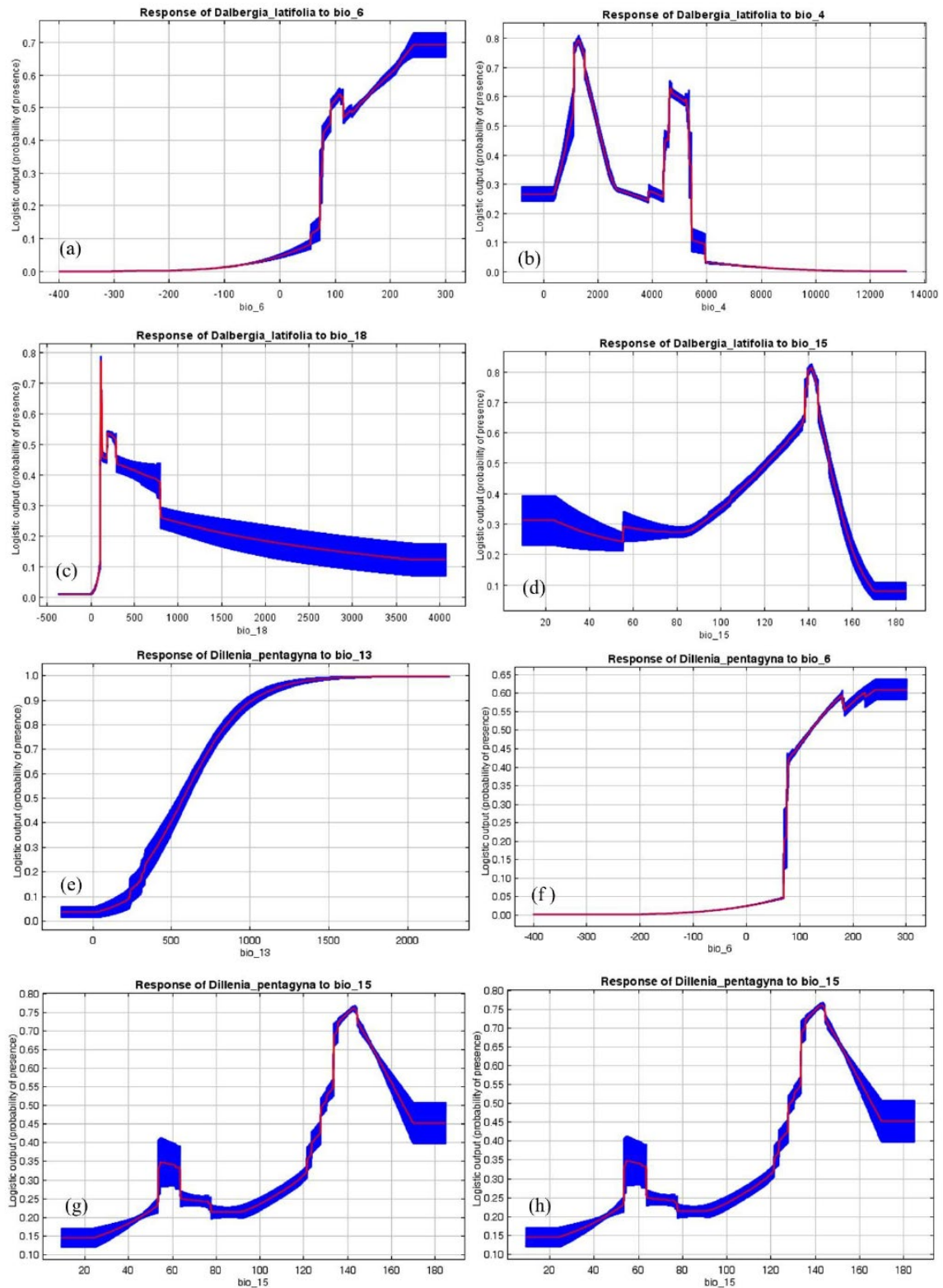


Figure 7: Response curves showing relationships between probability of presence of a species and top bioclimatic predictor of *Dalbergia latifolia* (a-d) & *Dillenia pentagyna* (e-h)

area for both species. Predicted optimal habitat areas reduced to 68,013 km<sup>2</sup> for *Dalbergia latifolia* (Figure 5b) and 104,140 km<sup>2</sup> for *Dillenia pentagyna* (Figure 6b). Compared to current estimates, this represents a decline of approximately 38.86% and 40.90% in highly suitable habitat areas for *Dalbergia latifolia* and *Dillenia pentagyna*, respectively. Although the spatial patterns of future distribution broadly resembled current potential ranges, the extent of optimal habitats is expected to shrink considerably.

#### 4. Discussion

The results of this study highlight the significant role of climatic variables, particularly the *Minimum Temperature of the Coldest Month* (BIO6) and the *Precipitation of the Wettest Month* (BIO13), in determining the potential habitat distribution of *Dalbergia latifolia* and *Dillenia pentagyna*. Notably, BIO6 emerged as a strong predictor for both species, indicating that cold temperature extremes exert considerable influence on their ecological niches. For *Dalbergia latifolia*, the high percent contribution of BIO6 suggests that cold temperature anomalies are a critical limiting factor affecting its geographical distribution throughout the year.

For *Dillenia pentagyna*, in addition to BIO6, the *Precipitation of the Wettest Month* (BIO13) and *Precipitation Seasonality* (BIO15) were also important predictors. These findings suggest that *D. pentagyna* responds strongly to variations in moisture availability, particularly during peak rainfall periods and in regions with fluctuating precipitation patterns. The increasing probability of presence with rising precipitation values (as shown in Figure 4a) reinforces the species' dependence on wet conditions for growth and survival.

The model consistently identified the Western Ghats as the most suitable natural habitat for both species. This region's unique climatic conditions and ecological stability likely provide an ideal environment for the persistence of these moisture- and temperature-sensitive species. However, the projected habitat reduction by 2050—approximately 38.86% for *D. latifolia* and 40.90% for *D. pentagyna*—raises significant conservation concerns. These species, known for their ecological and economic importance, face increasing threats from habitat degradation driven by climate change, deforestation, land use change, and overexploitation (Khanum et al., 2013). As anthropogenic activities continue to fragment landscapes and alter environmental conditions, the available suitable habitats for these species are expected to decline, as evidenced by the future projections under the A2a scenario.

To mitigate these threats, a comprehensive conservation strategy is essential. **In-situ** conservation within legally protected areas that align with suitable ecological zones should be prioritized to preserve natural populations. Complementary **ex-situ** measures, including the use of macropropagation and micropropagation techniques, can support the production of healthy plantlets for restoration and

reintroduction programs (Urbina & Flores, 2010; Adhikari et al., 2012). Targeted introduction of these plantlets into suitable habitats identified by ecological niche modeling can enhance species resilience in the face of ongoing environmental changes.

Overall, this study underscores the need for proactive habitat management and conservation planning that integrates climate projections and ecological modeling to ensure the long-term survival of *Dalbergia latifolia* and *Dillenia pentagyna* under future climate scenarios.

#### 5. Conclusion

This study demonstrates the effectiveness of ecological niche modelling in identifying current and future suitable habitats for *Dalbergia latifolia* and *Dillenia pentagyna*. Using the Maxent model, we found that key climatic variables—particularly minimum temperature and precipitation—strongly influence the distribution of both species. Projected habitat contraction under future climate scenarios underscores the urgent need for targeted conservation efforts. The predicted suitable areas can guide in-situ and ex-situ conservation strategies, including reintroduction programs and captive propagation, to enhance species survival and support long-term biodiversity conservation.

#### Author contributions

P.S. conceptualized the study, developed the methodology, and prepared the original draft. R.P. contributed to data analysis and participated in reviewing and editing the manuscript. R.K. assisted in literature review and contributed to the revision and finalization of the manuscript.

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#### Competing financial interests

The authors have no conflict of interest.

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