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Predicting Habitat Suitability of Dalbergia latifolia (Indian Rosewood) Using MaxEnt: Implications for Conservation and Sustainable Forest Management

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Abstract

Background *Dalbergia latifolia*(Indian Rosewood), a species of both ecological and economic importance, faces growing threats from habitat degradation, deforestation, and illegal logging. Given its critical role in maintaining ecosystem services and its commercial value, understanding its habitat distribution is vital for developing effective conservation strategies. This study employs the MaxEnt (Maximum Entropy) modeling approach to assess the species' habitat suitability across tropical and subtropical regions of India, which represent its primary distribution range. The results have broader implications for conservation efforts and sustainable management practices.

Results The MaxEnt model highlights tropical dry and moist deciduous forests as the most suitable habitats for *D. latifolia*. The species prefers specific climatic conditions, particularly temperature and precipitation ranges, which were identified as key determinants of its distribution. High-suitability areas were found in Karnataka, Maharashtra, and Madhya Pradesh, characterized by warm climates and moderate rainfall. The model demonstrated robust performance, with the Area Under Curve (AUC) metric validating its predictions. Sensitivity analysis revealed that temperature and precipitation were the most influential environmental factors driving the species' distribution.

Conclusions These findings offer critical insights for conservation strategies aimed at protecting *D. latifolia* from further habitat loss. Identifying regions with high habitat suitability allows for targeted conservation efforts, focusing on areas most at risk from anthropogenic pressures. This study provides a valuable framework for guiding forest management practices in India, with potential applications for similar species globally. The approach can be extended to assess the habitat suitability of other ecologically and economically significant species, contributing to international biodiversity conservation efforts.

Background

Dalbergia latifolia, commonly known as Indian Rosewood or Kala-Shisham, is a species of tremendous ecological and economic importance. Native to South and Southeast Asia, it is primarily found in the Western Ghats of India, a globally recognized biodiversity hotspot. This tropical hardwood is highly prized for its strength, rich color, and durability, making it a sought-after material in international markets for luxury furniture, musical instruments, and other premium wood products [1]. Beyond its commercial significance, *D. latifolia* plays a vital role in its native ecosystem supporting biodiversity by providing critical habitats for various species and contributing to soil fertility through nitrogen fixation [2]. However, despite its ecological and economic value, *D. latifolia* faces numerous threats, including deforestation, overexploitation, illegal logging, and an ever-growing demand from international markets—especially the "Hongmu" trade with China. These pressures have led to a significant decline in its population, prompting its classification as Vulnerable by the International Union for Conservation of Nature (IUCN) and its inclusion in CITES Appendix II since 2016 [3, 4]. The Western Ghats, home to the largest population of *D. latifolia*, has also faced significant environmental degradation. Habitat destruction, forest fires, climate

change, and invasive species have contributed to a 6.9% reduction in tree cover over the past two decades, further intensifying the challenges to the species' survival [5]. The slow growth and lengthy maturation process of *D. latifolia* further complicate sustainable cultivation efforts. While India remains a major supplier of *D. latifolia* timber, with Karnataka contributing over 50% of the total supply, less than 1% of the species is cultivated due to strict conservation regulations and the long time it takes for the trees to mature [6, 7]. To address these challenges, identifying suitable habitats for *D. latifolia's* survival is crucial. This study uses the MaxEnt (Maximum Entropy) modeling approach to assess habitat suitability across India, with a focus on the tropical and subtropical regions where the species is distributed [8]. By integrating species occurrence data with environmental factors such as temperature, precipitation, elevation, and bioclimatic variables, MaxEnt predicts the most suitable habitats for the species. The study also incorporates high-resolution CHELSA (Climatic High-Resolution Dataset for the Study of Ecosystem Services and Agriculture) data to improve the accuracy of habitat predictions [9]. The aim of this study is to guide conservation and restoration efforts at the state, district, and protected area levels. The findings will promote sustainable timber practices, support biodiversity conservation, and contribute to climate change mitigation by identifying areas for habitat restoration that enhance carbon sequestration. Ultimately, this research seeks to ensure the long-term survival of *D. latifolia*, encourage international collaboration in conservation, and contribute to global biodiversity and climate goals [10].

Materials and Methods

Study Area

India spans an area of 3,287,263 square kilometers, featuring a wide range of climatic conditions, from freezing temperatures in the north to desert heat exceeding 50.6°C in the west [11]. Its extensive forests are classified into five major types: Tropical, Montane Subtropical, Montane Temperate, Sub-Alpine, and Alpine, each hosting diverse ecosystems. This study concentrates on regions where *Dalbergia latifolia* (Indian Rosewood) naturally occurs, particularly the Western Ghats and other forested areas across India.

Collection of Location-Based Data

The distribution data for *Dalbergia latifolia* were compiled from 3,224 occurrence records across India, spanning key states such as Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, and Maharashtra (Table 1, Fig. 1). These records were obtained through extensive field surveys conducted by institutions such as the Forest Research Institute (FRI) and the Institute of Wood Science and Technology (IWST). The surveys primarily targeted tropical mixed hardwood forests and subtropical regions, which are the natural habitats of *D. latifolia*. The data collected included geolocation, tree morphometrics (e.g., height, clear bole height), and seed collections. This comprehensive dataset played a critical role in developing an accurate distribution map to model habitat suitability for the species.

Table 1
Species occurrence data collected from different parts of the country

State	No. of locations
Karnataka	2239
Kerala	389
Tamil Nadu	279
Jharkhand	136
Madhya Pradesh	91
Bihar	31
Chhattisgarh	28
Maharashtra	18
Uttarakhand	5
Punjab	4
Uttar Pradesh	3
Andra Pradesh	1
Total	**3224**

Bioclimatic Variables Used in Habitat Suitability Modeling

To predict the habitat suitability for *Dalbergia latifolia*, 19 bioclimatic variables from the CHELSA dataset [5] were employed. These variables, including temperature, precipitation, and humidity, were selected due to their relevance to the species' specific climatic requirements. They capture the essential climatic conditions that impact the growth, distribution, and survival of *D. latifolia* across its habitat range, forming the basis for the habitat suitability modeling process. A summary of these variables and their values is presented in Tables 2 and 3.

Table 2
Bioclimatic Variables

Sl. No.	Bioclimatic Variables
1	Annual Mean Temperature - Average temperature over the year.
2	Mean Diurnal Range - Difference between the mean daily maximum and minimum temperatures.
3	Isothermality - Ratio of the mean diurnal temperature range to the annual temperature range.
4	Temperature Seasonality - Standard deviation of the monthly temperatures.
5	Max Temperature of Warmest Month - Maximum temperature recorded in the warmest month.
6	Min Temperature of Coldest Month - Minimum temperature recorded in the coldest month.
7	Temperature Annual Range - Difference between the maximum temperature of the warmest month and the minimum temperature of the coldest month.
8	Mean Temperature of Wettest Quarter - Average temperature during the wettest quarter of the year.
9	Mean Temperature of Driest Quarter - Average temperature during the driest quarter of the year.
10	Mean Temperature of Warmest Quarter - Average temperature during the warmest quarter of the year.
11	Mean Temperature of Coldest Quarter - Average temperature during the coldest quarter of the year.
12	Annual Precipitation - Total precipitation over the year.
13	Precipitation of Wettest Month - Precipitation amount in the wettest month of the year.
14	Precipitation of Driest Month - Precipitation amount in the driest month of the year.
15	Precipitation Seasonality - Coefficient of variation in monthly precipitation.
16	Precipitation of Wettest Quarter - Total precipitation in the wettest quarter of the year.
17	Precipitation of Driest Quarter - Total precipitation in the driest quarter of the year.
18	Precipitation of Warmest Quarter - Total precipitation in the warmest quarter of the year.
19	Precipitation of Coldest Quarter - Total precipitation in the coldest quarter of the year.

Table 3

Summary of the 19 bioclimatic variables used in the MaxEnt modeling for habitat suitability prediction of *Dalbergia latifolia*: Descriptions and values are based on CHELSA data (16) (Karger *et al.* 2017).

Short Name	Bioclimatic Variable	Unit	Scale	Offset	Explanation
bio1	Mean Annual Air Temperature	°C	0.1	-273.15	The mean annual daily mean air temperatures averaged over one year.
bio2	Mean Diurnal Air Temperature Range	°C	0.1	0	The mean diurnal range of temperatures averaged over one year.
bio3	Isothermality	°C	0.1	0	The ratio of diurnal variation to annual variation in temperatures.
bio4	Temperature Seasonality	°C/100	0.1	0	The standard deviation of the monthly mean temperatures.
bio5	Mean Daily Maximum Air Temperature of the Warmest Month	°C	0.1	-273.15	Highest temperature of any monthly daily mean maximum temperature.
bio6	Mean Daily Minimum Air Temperature of the Coldest Month	°C	0.1	-273.15	The lowest temperature of any monthly daily mean minimum temperature.
bio7	Annual Range of Air Temperature	°C	0.1	0	Difference between the maximum temperature of the warmest month and the minimum temperature of the coldest
bio8	Mean Daily Mean Air Temperatures of the Wettest Quarter	°C	0.1	-273.15	The average temperature of the wettest quarter of the year.
bio9	Mean Daily Mean Air Temperatures of the Driest Quarter	°C	0.1	-273.15	The average temperature of the driest quarter of the year.
bio10	Mean Daily Mean Air Temperatures of the Warmest Quarter	°C	0.1	-273.15	The average temperature of the warmest quarter of the year.
bio11	Mean Daily Mean Air Temperatures of the Coldest Quarter	°C	0.1	-273.15	The average temperature of the coldest quarter of the year.
bio12	Annual Precipitation Amount	kg m^{-2}	0.1	0	Accumulated precipitation amounts over 1 year.
bio13	Precipitation Amount of the Wettest Month	kg m^{-2}	0.1	0	Precipitation amount in the wettest month.
bio14	Precipitation Amount of the Driest Month	kg m^{-2}	0.1	0	Precipitation amounts in the driest month

Short Name	Bioclimatic Variable	Unit	Scale	Offset	Explanation
bio15	Precipitation Seasonality	kg m⁻²	0.1	0	Coefficient of variation in monthly precipitation estimates, expressed as a percentage of the annual mean.
bio16	Mean Monthly Precipitation Amount of the Wettest Quarter	kg m⁻²	0.1	0	Average precipitation in the wettest quarter of the year.
bio17	Mean Monthly Precipitation Amount of the Driest Quarter	kg m⁻²	0.1	0	Average precipitation in the driest quarter of the year.
bio18	Mean Monthly Precipitation Amount of the Warmest Quarter	kg m⁻²	0.1	0	Average precipitation in the warmest quarter of the year.
bio19	Mean Monthly Precipitation Amount of the Coldest Quarter	kg m⁻²	0.1	0	Average precipitation in the coldest quarter of the year.

Modeling with MaxEnt

The study utilized MaxEnt version 3.4.1 software (12,13) to predict suitable habitats for *Dalbergia latifolia*. MaxEnt is a machine learning algorithm that generates a probability distribution model using presence-only data combined with environmental covariates. A total of 775 unique presence data points were selected for modeling after removing duplicates to mitigate spatial bias. These points were fed into the MaxEnt algorithm, which then produced predictions of habitat suitability based on the chosen environmental variables.

Presence Data

A total of 3,224 occurrence records of *Dalbergia latifolia* were initially used in the modeling process. To reduce spatial bias and prevent over-representation of specific regions, duplicate points were removed, ensuring more reliable results. This step was crucial, as Kramer-Schadt et al. (2013) highlight the importance of correcting sampling bias in presence-only data for accurate species distribution models [14]. After removing duplicates, 775 unique points were retained for the final analysis.

Model Calibration and Variable Selection

The MaxEnt model was calibrated over 980 iterations, using 75% of the data for training and 25% for testing. The Cloglog output format was applied to convert raw model values onto a probability scale (0–1), representing the likelihood of species presence based on environmental variables and occurrence data. A jackknife test was performed to evaluate the importance of each bioclimatic variable by generating replicate datasets, which helped identify key factors influencing the species' ecological niche.

After the jackknife test, the model was recalibrated using only the most significant variables to enhance prediction accuracy. Sampling biases were corrected as recommended by Kramer-Schadt et al. (2013) [14], ensuring robust and reliable results. The model's performance was assessed using the Receiver Operating Characteristic (ROC) curve and the Area Under the Curve (AUC). Additionally, response curves were generated to explore the influence of each bioclimatic variable on species distribution.

Habitat Suitability Predictions

The final habitat suitability map was generated using ArcMap 10.8, with suitability determined based on the MaxEnt model's output. This map provides detailed predictions of areas where *Dalbergia latifolia* is most likely to thrive under current environmental conditions. The approach integrates advanced machine learning techniques with extensive field-collected data, offering a comprehensive, data-driven method for assessing habitat suitability.

Evaluation of Model Performance

To evaluate the predictive accuracy of the model, the AUC (Area Under the Curve) method was employed. The model achieved an AUC value of 0.94, indicating exceptional performance in predicting suitable habitats for *Dalbergia latifolia* across India. The model's reliability was further validated using response curves and a jackknife test, ensuring that the results are both accurate and applicable for real-world conservation efforts. This methodology establishes a rigorous framework for predicting the habitat suitability of *Dalbergia latifolia* in India, combining state-of-the-art modeling techniques with extensive field data. The outcomes of this research will be crucial in informing future conservation strategies for the species and supporting ongoing efforts to protect its habitat.

Evaluation of Model Performance

To assess the model's predictive accuracy, the Area Under the Curve (AUC) method was used, achieving an impressive AUC value of 0.94. This indicates exceptional performance in predicting suitable habitats for *Dalbergia latifolia* across India. The model's reliability was further confirmed through response curves and a jackknife test, ensuring the accuracy and applicability of the results for real-world conservation efforts. This methodology provides a robust framework for predicting habitat suitability, combining cutting-edge modeling techniques with extensive field data. The findings will be instrumental in shaping future conservation strategies for the species and supporting ongoing habitat protection efforts.

Results

The results of the MaxEnt modeling for the habitat suitability of *Dalbergia latifolia* (Indian Rosewood) in India provide a comprehensive overview of the species' potential distribution. This section discusses the model's validation, the contributing environmental factors, the extent of suitable habitats across the country, and the role of protected areas in preserving these habitats.

Model Validation and Contributing Environmental Variables

The MaxEnt model demonstrated exceptional predictive accuracy, achieving an Area Under the Curve (AUC) value of 0.94, indicating a high level of reliability in predicting suitable habitats for *Dalbergia latifolia*. Further validation using the Jackknife test highlighted several key bioclimatic variables that contribute significantly to the species' habitat suitability across India. The most influential variables identified include Temperature Seasonality (Bio4), which reflects the standard deviation of monthly mean temperatures and indicates temperature fluctuations throughout the year; Annual Precipitation Amount (Bio12), representing the total precipitation received annually and being critical for the species' growth; and Precipitation of the Coldest Quarter (Bio19), which represents the amount of precipitation during the coldest quarter and influences species' survival during cooler months. Mean Annual Air Temperature (Bio1), the average temperature throughout the year, also plays a central role in the species' habitat suitability. Additionally, Mean Diurnal Air Temperature Range (Bio2), representing the daily temperature variation, can affect the species' growth patterns; Mean Monthly Precipitation Amount of the Warmest Quarter (Bio18), which directly influences water availability during the species' peak growth period; and Isothermality (Bio3), which refers to the temperature uniformity across the region and influences the species' adaptation to climatic variability, were found to be significant. Furthermore, Precipitation Amount of the Driest Month (Bio14), which indicates water stress during dry periods, and Precipitation Seasonality (Bio15), which affects the species' ability to adapt to changing rainfall conditions, were key factors. Finally, Mean Daily Air Temperature of the Warmest Quarter (Bio10), representing the daily temperature levels during the warmest quarter, is vital for the species' survival and growth during hot periods. Among these variables, Bio4 (Temperature Seasonality), Bio12 (Annual Precipitation Amount), Bio19 (Precipitation of the Coldest Quarter), Bio1 (Mean Annual Air Temperature), Bio2 (Mean Diurnal Air Temperature Range), and Bio18 (Mean Monthly Precipitation of the Warmest Quarter) were found to contribute 93% to the model's predictions. This emphasizes their central role in determining the species' favorable environmental conditions, ensuring that the model accurately captures the key climatic factors required for the survival and distribution of *D. latifolia* (5, 9, Table 4, Figs. 2, 3).

Table 4
Contribution of major environmental variables and their percent contribution

Environmental Variables	% Contribution
Bio4	58.0
Bio12	10.7
Bio19	6.6
Bio1	6.4
Bio2	6.1
Bio18	5.2
Bio3	2.7
Bio14	1.9
Bio15	1.7
Bio10	0.8

Predicted Suitable Habitats at State and District Levels

The model predicts suitable habitats for *D. latifolia* across 86.4 million hectares, which represents 26.2% of India's total land area. Of this suitable habitat, 7.8% is classified as very highly suitable, 6.8% as highly suitable, 25% as moderately suitable, and 60.5% as low suitability. Together, the very high and high suitability categories account for 3.8% of India's total geographical area (Table 5, Fig. 4]. Among the states, Karnataka holds the largest share, contributing 34.9% of the total suitable area. This is followed by Kerala (24.8%), Tamil Nadu (16.3%), and Maharashtra (9.0%). Highly suitable habitats are concentrated in districts such as Uttara Kannada, Shivamogga, and Chikkamagaluru in Karnataka, primarily within the Western Ghats. Other areas with moderate to low suitability habitats are found in districts like Kolhapur in Maharashtra and Dindigul in Tamil Nadu. Collectively, Karnataka, Kerala, Tamil Nadu, and Maharashtra account for 85% of the total suitable habitat area. A state-wise and district-wise breakdown of habitat categories is provided in Tables 6 and 7.

Table 5
Predicted habitat suitability for *Dalbergia latifolia* in India based on the MaxEnt model output.

Habitat Suitability	Area (million Hectares)	% Distribution
Very High	6.7	7.8
High	5.8	6.8
Moderate	21.6	25.0
Low	52.2	60.5
Total	86.4	100.0

Table 6
State-wise Predicted habitat suitability for *Dalbergia latifolia* based on the MaxEnt model

	Habitat suitable categories (Area in a million hectares)				
States	Very High	High	Moderate	Low	Total
Karnataka	3.34	2.25	2.96	2.29	10.84
Kerala	2.28	0.99	0.42	0.19	3.87
Tamil Nadu	0.85	1.59	1.99	1.91	6.33
Maharashtra	0.23	0.60	0.79	4.07	5.69
Goa	0.05	0.10	0.05	0.04	0.24
Jharkhand	0.00	0.25	4.95	2.75	7.95
Madhya Pradesh	0.00	0.03	3.77	7.58	11.38
Andhra Pradesh	0.00	0.02	0.22	2.44	2.68
Chhattisgarh	0.00	0.01	4.66	8.25	12.92
Puducherry	0.00	0.00	0.00	0.00	0.00
Odisha	0.00	0.00	0.77	9.22	10.00
Bihar	0.00	0.00	0.79	5.12	5.91
West Bengal	0.00	0.00	0.15	3.98	4.13
Uttar Pradesh	0.00	0.00	0.04	2.36	2.40
Telangana	0.00	0.00	0.01	1.88	1.88
Himachal Pradesh	0.00	0.00	0.00	0.05	0.05
Jammu & Kashmir	0.00	0.00	0.00	0.04	0.04
Andaman & Nicobar	0.00	0.00	0.00	0.03	0.03
Uttarakhand	0.00	0.00	0.00	0.03	0.03
Grand Total	6.75	5.84	21.57	52.22	86.37

Table 7
District-wise predicted suitable habitats for *Dalbergia latifolia*, highlighting moderate and high suitability areas across various states in India.

States	District	Very High	High	Total	%
Karnataka	Uttara Kannada	7254.7	2477.3	9732.0	7.7
Karnataka	Shivamogga	6773.9	1188.5	7962.5	6.3
Karnataka	Chikkamagaluru	4152.3	782.7	4935.0	3.9
Maharashtra	Kolhapur	1805.7	2964.2	4769.9	3.8
Karnataka	Mysuru	1920.1	2521.5	4441.6	3.5
Karnataka	Dakshina Kannada	2356.7	2046.6	4403.3	3.5
Kerala	Idukki	3415.1	926.5	4341.7	3.4
Karnataka	Kodagu	3968.3	134.5	4102.8	3.3
Kerala	Palakkad	3428.3	597.4	4025.7	3.2
Karnataka	Chamarajanagara	952.3	2885.7	3838.0	3
Kerala	Malappuram	2993.2	506.6	3499.8	2.8
Karnataka	Hassan	2263.3	1017.0	3280.4	2.6
Karnataka	Belagavi	2472.2	703.0	3175.3	2.5
Tamil Nadu	Salem	716.6	2155.9	2872.5	2.3
Kerala	Pathanamthitta	2017.9	632.7	2650.6	2.1
Kerala	Thrissur	1869.2	712.7	2581.8	2.1
Kerala	Ernakulam	1700.8	714.2	2415.0	1.9
Tamil Nadu	The Nilgiris	2190.5	218.7	2409.2	1.9
Tamil Nadu	Dindigul	453.6	1883.5	2337.1	1.9
Karnataka	Ramanagara	0.0	2259.5	2259.5	1.8
Maharashtra	Sindhudurg	481.7	1776.5	2258.2	1.8
Kerala	Kannur	1113.5	1135.1	2248.6	1.8
Tamil Nadu	Coimbatore	912.9	1329.9	2242.8	1.8
Karnataka	Haveri	737.9	1462.7	2200.5	1.7
Kerala	Kottayam	1759.9	432.5	2192.4	1.7

Potential Habitats in Protected Areas

The model predicts suitable habitats for *Dalbergia latifolia* within 184 protected areas, covering a total of 4.94 million hectares. Within these areas, 17.2% is classified as very highly suitable, 10.2% as highly suitable, 27.4% as moderately suitable, and 44.7% as low suitability. Key protected areas with very high and high suitability include Annamalai Tiger Reserve, Bandipur Tiger Reserve, Periyar Wildlife Sanctuary, Nagarhole Tiger Reserve, Kudremukh National Park, Biligiri Rangaswami Temple Tiger Reserve, Shettihalli Wildlife Sanctuary, Bhadra Tiger Reserve, Kalakkad-Mundanthurai Tiger Reserve, and Radhanagari Wildlife Sanctuary. These protected areas are vital for the conservation of *D. latifolia*, especially in the Western Ghats and other biodiversity hotspots, where optimal climatic conditions prevail (Table 5). The identification of these regions underscores the importance of focusing conservation efforts on areas with abundant suitable habitats for *D. latifolia*. The results highlight the significance of environmental factors in determining habitat suitability and emphasize that Karnataka, Kerala, Tamil Nadu, and Maharashtra are the key states for conservation. Furthermore, these findings stress the critical role of protected areas in preserving viable populations of *D. latifolia* and the need for targeted conservation strategies to ensure the species' long-term survival.

Discussion

Species Distribution Models (SDMs) are invaluable tools for predicting the potential habitats of species based on environmental factors, occurrence data, and ecological conditions. In this study, the MaxEnt model was used to assess the habitat suitability of *Dalbergia latifolia* (Indian rosewood) in India, highlighting the crucial role of environmental factors in determining the distribution of this species, which is both economically and ecologically significant [12, 15]. SDMs are especially beneficial for identifying optimal habitats for vulnerable species like *D. latifolia*, facilitating targeted conservation and afforestation efforts. For instance, in Nepal, MaxEnt modeling has been applied to map suitable habitats for *D. latifolia*, informing reforestation and restoration initiatives in regions with the greatest potential for the species’ survival and growth [16].

Role of Bioclimatic Variables

This study highlights the crucial role of bioclimatic variables in determining the habitat suitability of *D. latifolia*. Factors such as temperature seasonality, annual precipitation, and temperature patterns were found to be key drivers of the species' distribution. These results align with previous research on *D. latifolia* and other tree species [16]. By leveraging high-resolution CHELSA data, the study effectively captured these environmental variables, providing a robust foundation for the habitat suitability maps. The superior topographical accuracy and resolution of CHELSA make it a valuable resource, surpassing other data sources like MODIS and TRMM [5]. This enhanced precision strengthens the reliability of habitat models, making them an indispensable tool for devising targeted and effective conservation strategies.

Importance of Protected Areas and Biodiversity Hotspots

The Western Ghats, spanning Karnataka, Tamil Nadu, and Kerala, are vital regions for the habitat suitability of *Dalbergia latifolia* (Indian rosewood). These biodiversity-rich areas support substantial populations of the species, playing a key role in its survival amidst climate change and deforestation. Given the species' slow growth and long rotation period, protecting these regions is crucial. Many protected areas currently feature monocultures like teak and eucalyptus, so shifting toward mixed-species plantations is essential to restore ecological balance. Additionally, implementing sustainable management practices, improving cultivation techniques, and consistently monitoring climate impacts is critical for ensuring the species' long-term conservation [16]. Furthermore, the identification of *Dalbergia latifolia*'s suitable habitats within protected areas (e.g., tiger reserves and national parks) highlights the importance of safeguarding these areas to ensure the species' continued survival and the ecological benefits they provide.

Climate Change and Conservation Challenges

One of the key findings of this study is the potential vulnerability of *D. latifolia* to the impacts of climate change. As the climate continues to change, the environmental conditions required for the species' survival may shift, potentially reducing its suitable habitat. Changes in temperature and precipitation patterns could lead to a contraction of suitable areas, threatening the species' future distribution. Continuous monitoring of climate impacts, along with adaptive management strategies, will be crucial to ensure the persistence of *D. latifolia* in the face of these challenges. Additionally, sustainable management practices that account for the species' slow growth and long rotation period are necessary to ensure that its conservation aligns with both ecological and economic objectives. This can involve interventions like climate-resilient breeding programs, assisted migration, and protection of climate refugia, as well as enhanced restoration efforts in areas identified as suitable under future climate scenarios.

Promoting *Dalbergia latifolia* Plantations

Promoting the plantation of *Dalbergia latifolia* offers both ecological and economic benefits. Its ability to fix nitrogen and sequester carbon makes it a key species for afforestation. Integrating *D. latifolia* into large-scale plantation projects can help India meet its carbon reduction goals, improve soil health, and enhance biodiversity. These efforts align with the UN Decade on Ecosystem Restoration (2020–2030), which focuses on restoring degraded ecosystems and mitigating climate change. Programs like MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) can play a vital role in establishing *D. latifolia* plantations in suitable areas, contributing to long-term ecological restoration [17, 18]. By supporting such programs, India can enhance the rehabilitation of degraded forest landscapes, create sustainable livelihoods for local communities, and contribute to the global effort to combat climate change.

Need for a Comprehensive Conservation Approach

For effective conservation of *D. latifolia*, future research should consider additional factors such as land use, soil conditions, elevation, and human impact. These factors play a significant role in shaping habitat suitability but were not extensively addressed in this study. Incorporating these elements into habitat models will refine predictions and guide more targeted conservation strategies. Furthermore, it is essential to assess the genetic diversity of *D. latifolia* populations across India and evaluate the effectiveness of current conservation efforts. Understanding genetic variation can help mitigate risks related to inbreeding and ensure that conservation strategies preserve the species' adaptive potential in the face of changing environmental conditions. A comprehensive approach to conservation will ensure the species' long-term survival and increase the resilience of its populations (16).

Conclusions

This study provides a comprehensive assessment of the habitat suitability of *Dalbergia latifolia* (Indian rosewood) across India using the MaxEnt model and CHELSA bioclimatic data. The model predicts that 14.6% of India’s land area is highly suitable for the species, primarily in the Western Ghats and biodiversity hotspots, which should be prioritized for conservation. The results highlight the importance of protected areas and the need for converting monoculture plantations into mixed-species forests, enhancing biodiversity. Sustainable management practices are essential for addressing the species' slow growth and long rotation period. Furthermore, incorporating adaptive measures that account for future climate scenarios will ensure the long-term persistence of the species. Future research should incorporate factors like land use, elevation, and human activities to improve conservation strategies and make habitat models more comprehensive. The planting of *D. latifolia* in suitable areas can also play a significant role in aiding India’s carbon sequestration efforts, contributing to global climate change mitigation goals. This study underscores the need for integrated conservation efforts and afforestation programs to restore ecosystems and foster sustainable development.

Abbreviations

D. latifolia
Dalbergia latifolia (Indian Rosewood)
IUCN
International Union for Conservation of Nature
CITES
Convention on International Trade in Endangered Species of Wild Fauna and Flora
MaxEnt
Maximum Entropy
FRI
Forest Research Institute
IWST
Institute of Wood Science and Technology
CHELSA

Climate Hazards Group InfraRed Precipitation with Station data
ROC
Receiver Operating Characteristic
AUC
Area Under the Curve
AUC
Area Under Curve

Declarations

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Contributions

T.N. Manohara and S.M. Balakrishna conducted site selection and field data collection. Vazeed Pasha Shaik and Swarada B. were responsible for data curation, habitat suitability modeling, and drafting the manuscript. All authors read and reviewed the final manuscript.

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Ethics declarations

The field data on species occurrence and habitat suitability maps of *Dalbergia latifolia* (Indian rosewood) used in this study have been deposited in the Zenodo Open-Source Repository and can be accessed by researchers who need it. The link is shared here: https://doi.org/10.5281/zenodo.15089253. This project has not involved any human participation, human tissue, or human experiments, and there is therefore no need for approval from any ethical issues committee.

Consent for publication

Not applicable.

AI use

AI prompts from Grammarly software (Grammarly, Inc.) were utilized to enhance the writing process, particularly using prompts to improve text grammar.

Competing interests

The authors declare no competing interests.

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Figures

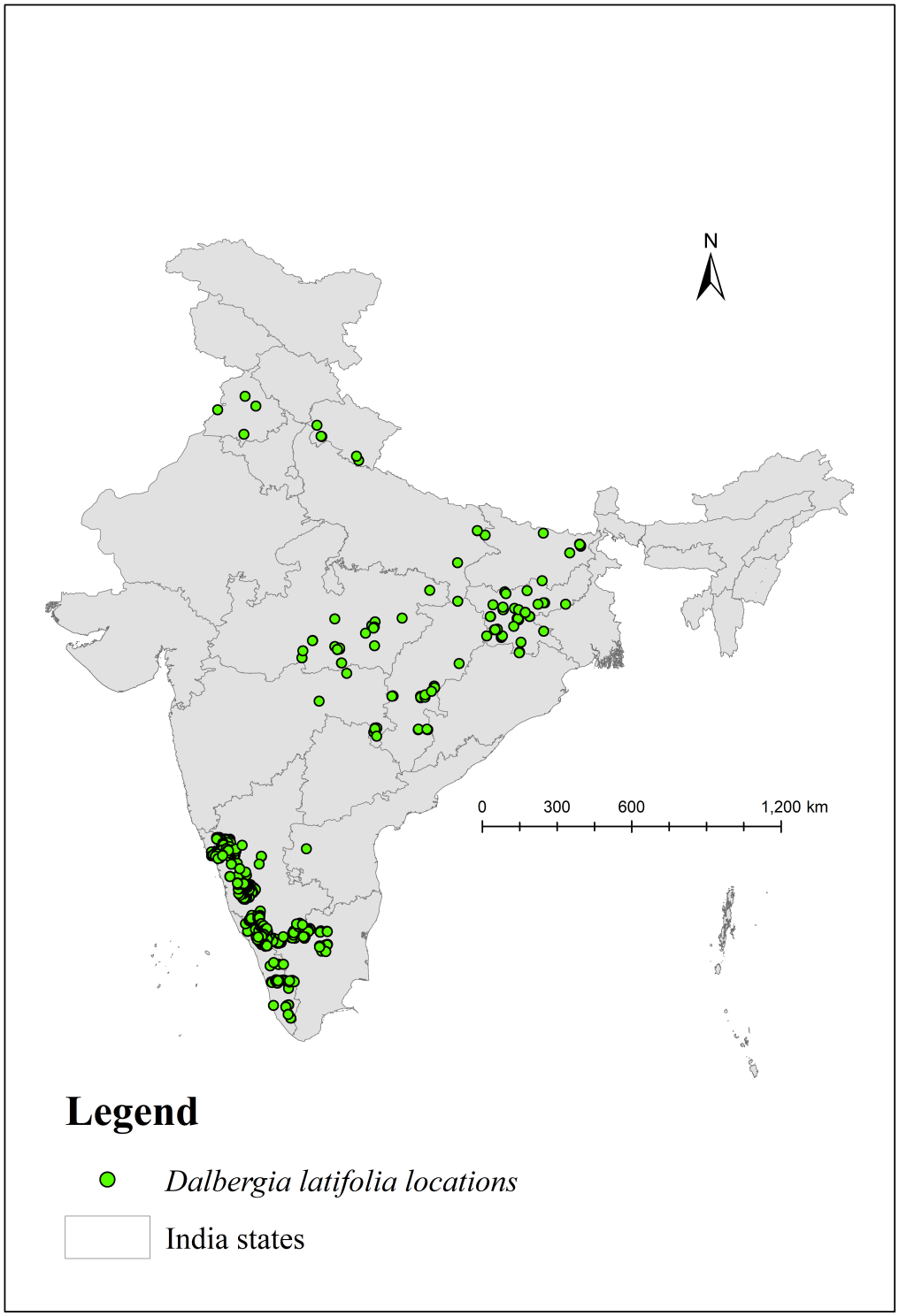


Figure 1

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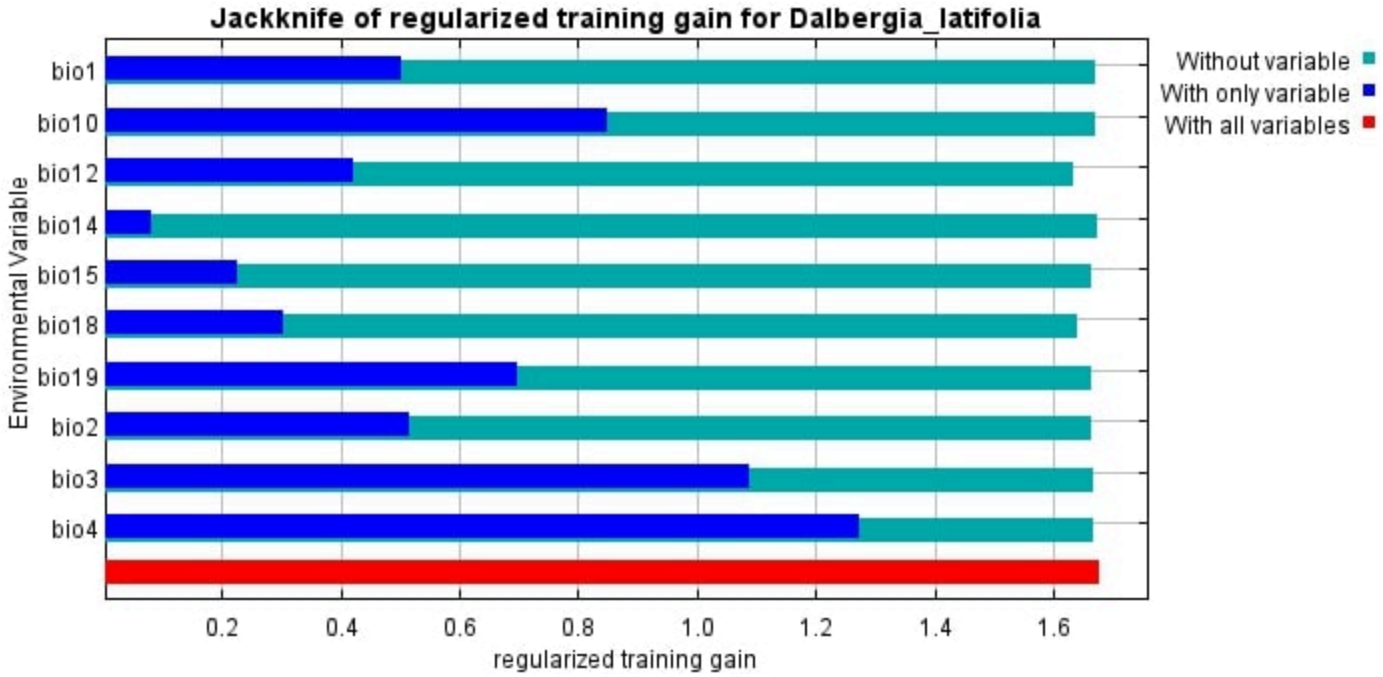


Figure 2

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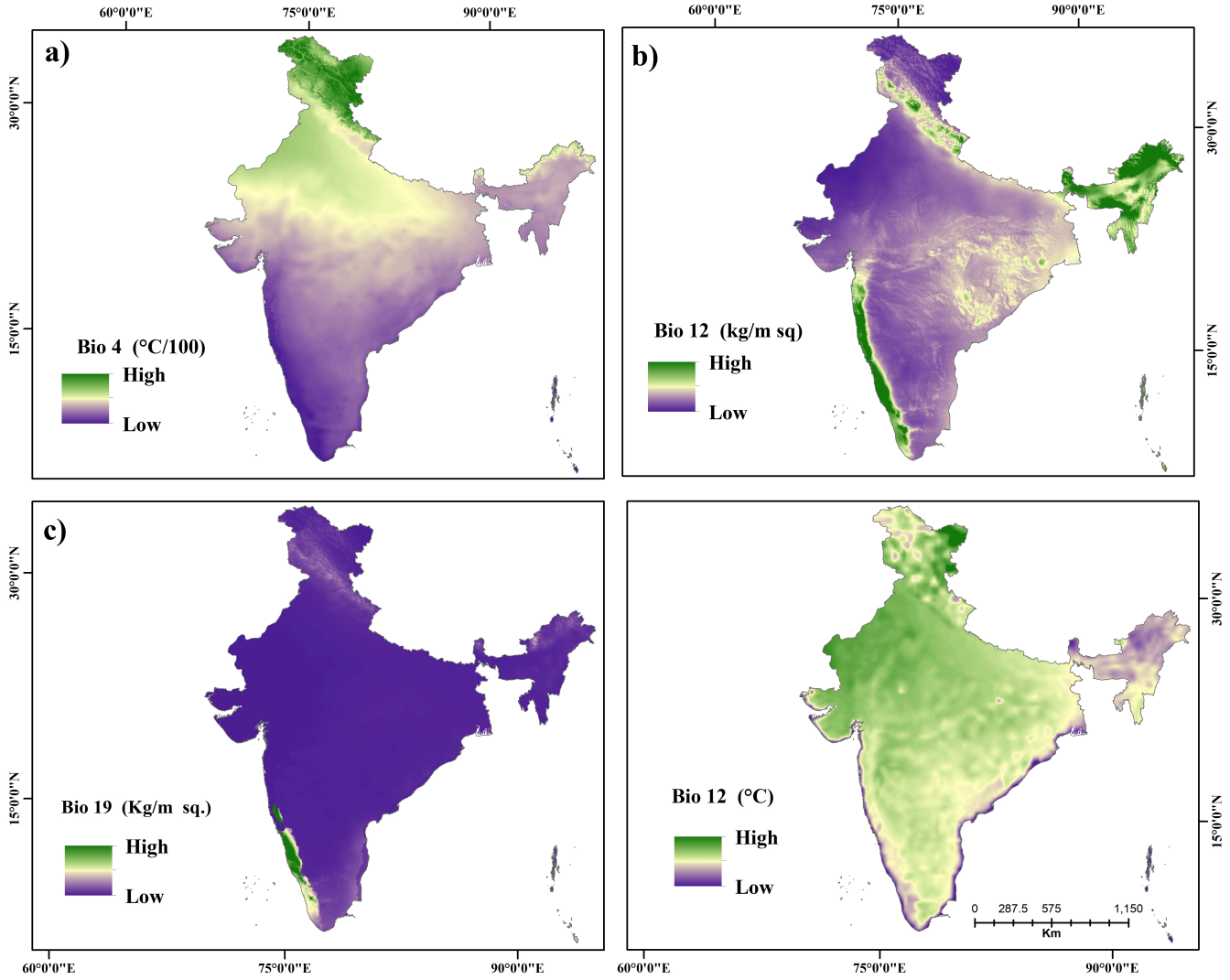


Figure 3

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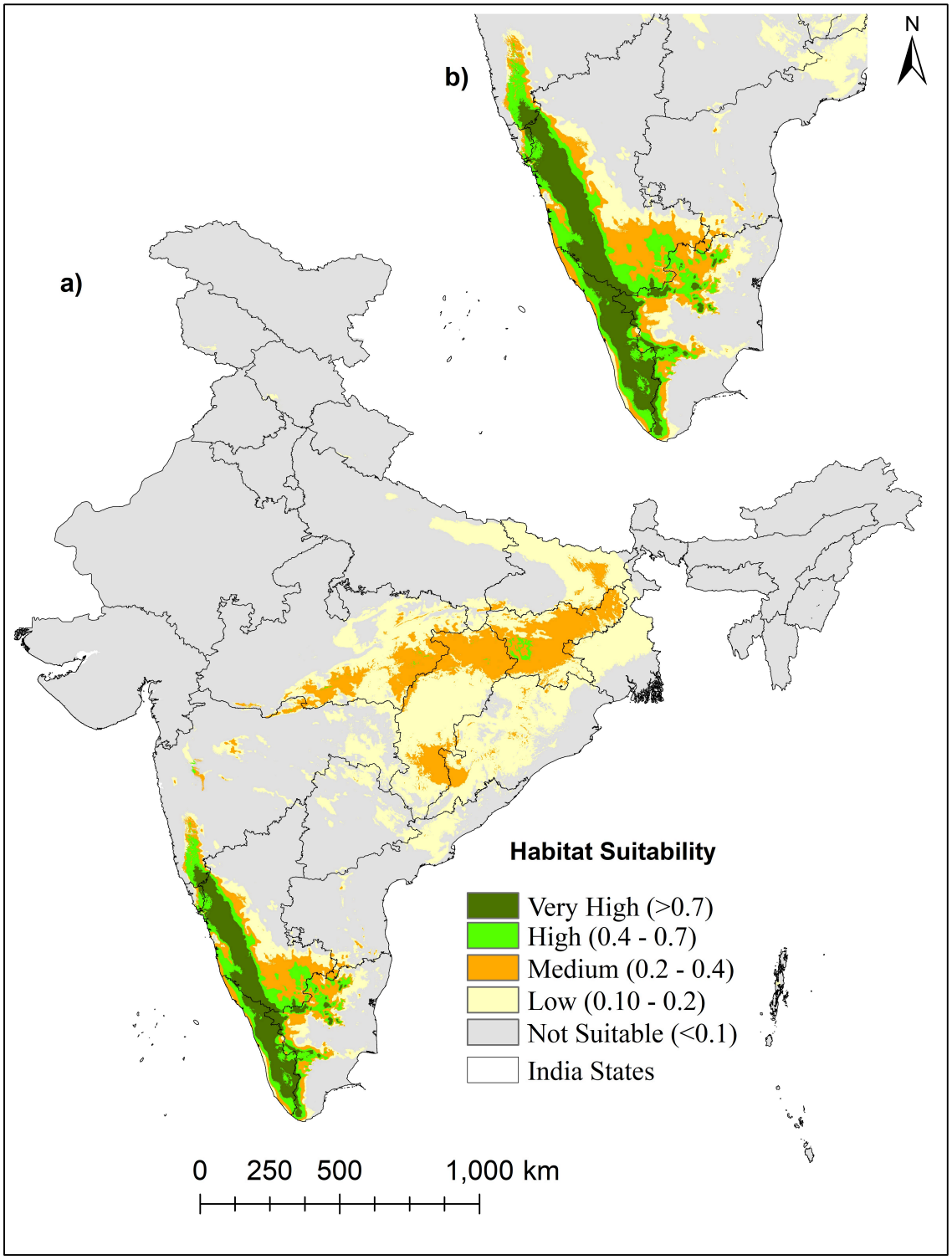


Figure 4

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