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RESEARCH ARTICLE

Future socioeconomic induced climate scenarios may lead to decline in Cinnamomum glaucescens (Nees) Hand.-Mazz population in the Himalayan region

Pramod Chand Lakra[1], Sonu Choudhary[1], Sanjoy Garai[1], Surojit Konar[1], Shibnarayan Pratihar1, Raju Sharma[1], Basant Kumar[1], V Rathna[2], Sharad Tiwari[*1]

[1] *ICFRE - Institute of Forest Productivity, Ranchi-835303, Jharkhand, INDIA*

[2] *ICFRE - Institute of Wood Science and Technology, Bengaluru, INDIA*

*** Corresponding author:** Sharad Tiwari; sharadtiwari8@gmail.com

ABSTRACT

The natural population of *Cinnamomum glaucescens* is declining due to anthropogenic stress and climate change in the Himalayan region. We assessed the potential suitable habitat range of *C. glaucescens* in the North Bengal region, under current and future climate scenarios using Maxent. Two climate models, Institut Pierre-Simon Laplace (IPSL-CM6A-LR) and Model for Interdisciplinary Research on Climate 6 (MIROC6) proxied through the Shared Socioeconomic Pathways (SSP) SSP126, 245,370, and 585 were employed to project future climate scenarios for 2050. The study found that currently 1,302 square kilometers, or ~ 9% of the total study area, comprising the central and northern parts of North Bengal are potentially suitable for the distribution of *C. glaucescens*. The distribution was found up to 1900m elevation range. Depending upon the climate scenario, by 2050, the potential suitable habitat of *C. glaucescens* might decline in the range of ~7-22% (IPSL_6A_LR), and ~39-70 % (MIROC6) across all the SSPs. Overall, the suitable habitat range of *C. glaucescens* might be limited to ~ 6% of the total geographical area of Northern Bengal by 2050. The suitable habitat of *C. glaucescens* is predicted to shift northward by 2050, leading to significant decline from the central part of the region. Out of nine bioclimatic variables used for the modelling the habitat suitability, Precipitation of the warmest quarter (Bio_18) and annual precipitation (Bio_12) contributed most to limiting the distribution of *C. glaucescens.* We recommend establishing a germplasm bank and adopting *in-situ* and *ex-situ* approaches to conserve and promote *C. glaucescens* in the Himalayan region.

Keywords: Cinnamomum glaucescens; climate change; habitat shift; Himalayan region; shared socioeconomic pathways

1. Introduction

The Himalayas, a global biodiversity hotspot, host around 10,000 plant species, with 3160 being endemic[1].The eastern Himalayas are particularly acknowledged for their rich diversity of medicinal

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plants[2],and economically important aromatic species[3].However, the region's ecosystems are highly vulnerable to natural hazards[4] and climate change[5],leading to shifting habitat range and loss of cold-affine species[6].Existing bodies of literature suggest that climate change is altering species distribution and richness[7],impacting both terrestrial[8] and aquatic ecosystems[9].Mountain ecosystems, due to their temperature-dependent floral structures, are predicted to be the most affected[10].

Current study deals with assessing the potential distribution range of *Cinnamomum glaucescens* (Nees) Hand. -Mazz, amid the climate change scenarios. *C. glaucescens* is an evergreen aromatic plant with dark, corky bark and alternate, elliptic leaves[11].The species due to medicinal property contributes to the local economy of Nepal[3]and traditional medicine, treating ailments such as arthritis, muscle pain, and the common cold[12].The essential oil of *C. galucescens* is a neoteric green defense to preserve the nutritional value of food items[13].The wood of the tree also contains oils rich in safrole, myristicin and elemicin[14].

The natural distribution of *C. glaucescens* occurs in India's tropical Himalayan region (North Bengal, Assam, Sikkim, Meghalaya, Nepal [15], Vietnam, Bangladesh, Laos, and Myanmar,[16]. However, the natural population of *C. glaucescens* has been declining primarily due to deforestation and land use conversion [3]and has been assessed as a threatened species by the International Union for Conservation of Nature (IUCN) Red List in 2020.[17]

A substantial amount of literature recognizes the significance of understanding a species response to climate change [18]. According to [19] habitat modeling is essential for identifying hotspots of vulnerability and resilience, which in turn allows for the planning management strategies. Another work by [20] also advocates the use of habitat modeling for monitoring and conservation of vulnerable regions. Evidence from the existing studies show most of the work on *C. glaucescens* is focused mainly on its medicinal properties. We could not find any literature concerning its potential response to climate change scenarios.

The present investigation sets out to model the potential suitable habitat range of *C. glaucescens* under the current and future climate scenarios in the North Bengal region. In the Indian context, North Bengal was chosen because it covers a transitional ecological zone at the interface of the Eastern Himalaya and the Gangetic plains. Compared to relatively better-preserved habitats in Sikkim or Meghalaya, the forests of North Bengal are undergoing rapid landscape transformation, causing their vulnerability to climate-induced shifts in species distribution [21]. The threat to major forestry species in North Bengal, including *C. glaucescens*, is particularly concerning given its socio-economic importance to local communities who depend on medicinal and aromatic plants for both livelihood and traditional healthcare.

These factors call for assessing the potential distribution of *C. glaucescens* under climate change scenarios specifically within North Bengal. Current study intends to answer research questions; 1. What is the current potential suitable habitat range of *C. glaucescens* 2. What will be the suitable habitat range of *C. glaucescens* by 2050, and 3. Which predictor variable contributes most in limiting the distribution of *C. glaucescens*. By answering these questions, the study seeks to provide insights that not only clarify the species' ecological response to climate change but also support conservation planning and management strategies. The outcomes will support sustainable use of *C. glaucescens* in the Himalayan landscape, with North Bengal serving as a critical case study for balancing ecological vulnerability and community dependence.

2. Materials and methods

2.1. Study area

The study area lies between 88° E to 90° E latitude and 26° N to 27°30' N longitude **(Figure 1)**, encompassing northern part of West Bengal within the Indian Sub Himalayan region[22]. North Bengal is the gateway to Northeast India which shares its international borders with Nepal, Bhutan, Bangladesh and state borders with Bihar to the west, Sikkim to the north and Assam to the east. The region exhibits a wide range of climatic variations, from humid subtropical conditions in the north to tropical savanna in the south. The region is categorized in the Northern Hill and the Terai-Tista Alluvial agro-climatic zones [23]. Elevation of the study area ranges up to 3,636 meters, with the highest peak being Sandakphu. The area's vegetation range extends along tropical, subtropical, temperate, cool-temperate, and subalpine zones [24].

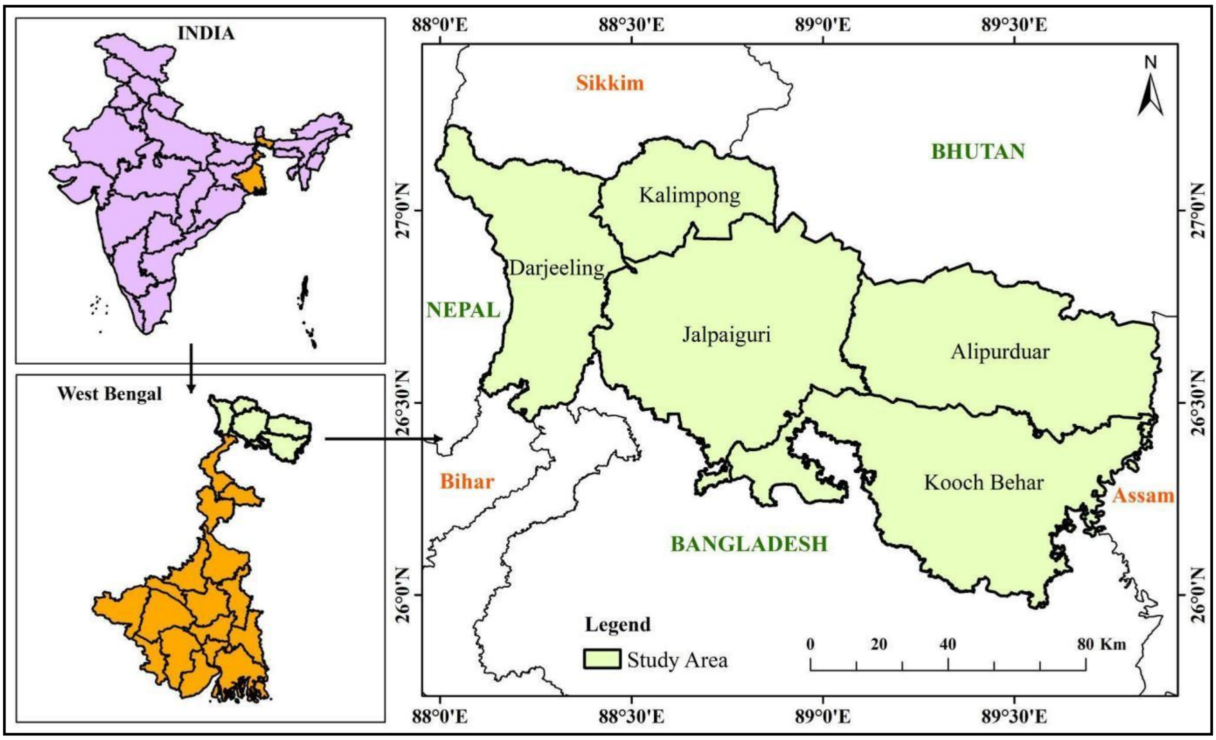

Figure 1. Location map of the study area

2.2. Occurrence data

We conducted an extensive survey of the North Bengal region to assess and record the current distribution of *C. glaucescens*. A total of 52 occurrence points of *C. glaucescens* were collected from different geographical locations using the Garmin etrex 30x GPS in degree decimal format with an accuracy of ± 8. To obtain consistently distributed data, in situ measurements were conducted. The recorded data were stored in an Excel sheet in comma-separated values (CSV) format.

2.3. Environmental variables and climate scenarios

The current study utilizes 19 bioclimatic variables (Bio_1 - Bio_19), acquired from the WorldClim site with a spatial resolution of ~30 arc second[25]. Current and future data are averaged over the years 1970 to 2000 and 2041 to 2060 respectively. Shared Socio-economic Pathways (SSPs) i.e. 126, 245, 370 and 585 were used to proxy for the future climate scenarios Model for Interdisciplinary Research on Climate 6 (MIROC6) and Institut Pierre-Simon Laplace (IPSL-CM6A-LR)[26]. To avoid the model over-fitting due to high correlation between environmental factors[27], we employed correlation analysis at a Pearson's value R at 0.9 [28]. This way ten highly correlated environmental variables were eliminated, and the remaining nine variables were utilized to model the potential suitable habitat of *C. glaucescens.* The modelled suitable habitat output in ASCII form was converted to tiff format using QGIS 3.44 for further analysis. The map parts occurring within the value ranging from 0-0.5 were considered as the non-suitable and > 0.5-1 as the suitable to generate habitat map of *C. glaucescens.*

2.4. Model training and evaluation

The potential distribution range of *C. glaucescens* was estimated using the Maximum Entropy (MaxEnt 3.4.4)[29]. Maxent due to reliability, and precision is considered the most robust machine learning tool for modeling species habitat [30].We masked the bioclimatic variables using the AOI (Area of Interest) and kept all the data in a similar projection system and had a uniform geographical extent to run the model successfully. To evaluate the model, we divided the dataset into a training set (75%) and a testing set (25%) using a random test percentage. The number of replicates were set to 15, with replicated run type as a sub-sample.

2.5. Area Under Curve (AUC) and True Skill Statistics (TSS)

Maxent determines the model authenticity through the AUC (Area Under Curve) value. AUC values vary between 0.0 to 1.0, with a value closer to 1.0 indicating a higher model accuracy [31]. The model exhibited a mean AUC value of 0.858 (Fig. S1), with a standard deviation of 0.052. Additionally, we also employed true skill statistic (TSS) analysis to assess model efficacy. TSS analysis relies on sensitivity and specificity ranging between +1 to -1, measured from the presence and absence records [32]. The calculated TSS value 0.55 and overall accuracy 0.88 for the current study indicate good model performance.

The Jackknife test for AUC (Fig. S2) revealed that the “Annual Precipitation” (Bio_12) and "Precipitation of the Warmest Quarter" (Bio_18) were the most influential factors, limiting the distribution of *C. glaucescens*.

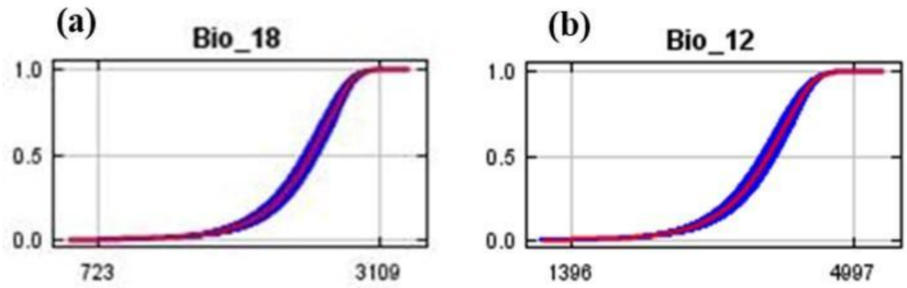

Figure 2. Potential habitat suitability of *C. glaucescens* as a function of (a) precipitation of the warmest quarter (Bio_18) and (b) Annual Precipitation (Bio_12).

The saturation shape curve shows that initially the habitat suitability response is constant up to ~ 1500. Then the mid portion of the curve exhibits a uniform rise in potential suitable habitat for Bio_18 value range ~1500-3000. The range value ~2500-3000 offers the most suitable range for the occurrence of potential suitable habitat. Beyond the value ~3000, the curve again takes a saturated form. For Bio_12, the value ranging ~ 2600-4000 offers the most suitable range, and thereafter it followed a stagnant pattern.

3. Result

3.1. Potential Suitable Habitat of *C. glaucescens* for the current scenario

The first objective of the study was to model the potential suitable habitat sites of *C. glaucescens* for the current climate scenario. Fig. 3a shows the simulated habitat of *C. glaucescens* for the current climate scenario. Looking at this figure, it is apparent that the potentially suitable habitat for *C. glaucescens* lies within the northern and central part of the study area. The study exhibits ~1302 sq. km, constituting ~9.2% of the total geographical area deemed suitable for the *C. glaucescens*. Upon examining elevation wise distribution patterns, it was found that the suitable habitat extends up to 1900 m altitude. The LULC analysis indicated that suitable habitat is primarily occurring within the vegetation class (Fig.3b). As can be seen from the LULC wise distribution graph, approximately 81% of the suitable habitat lies in Trees class (Fig. 4). The tree class comprised a tree population primarily in forests as well as outside forests [33].

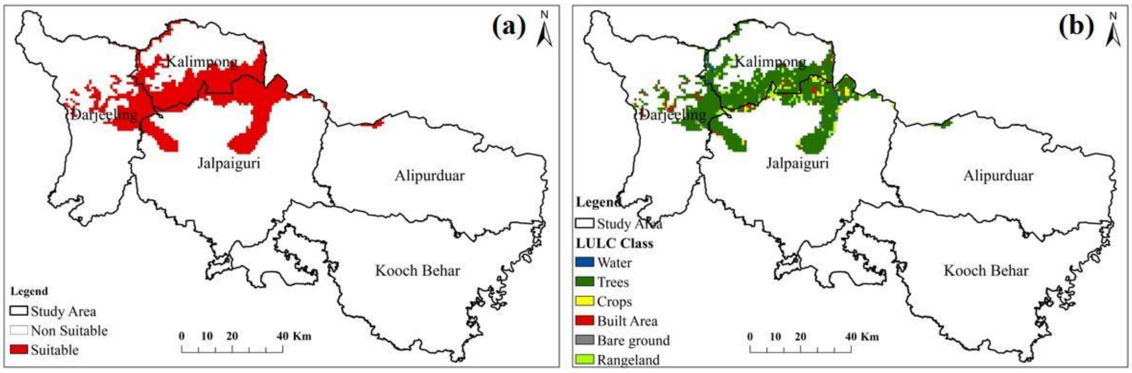

Figure 3. (a) Projected habitat map of *C. glaucescens* for current scenario (b) LULC wise projection of suitable habitat shows that current distribution mostly occurs within the Tree class.

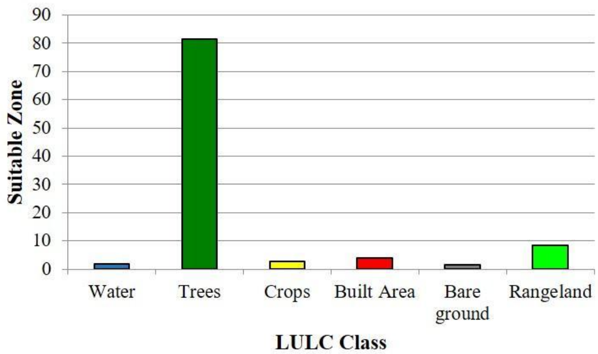

Figure 4. The graph demonstrates that currently ~81% of the distribution range of *C. glaucescens* occurred within the Trees land class.

3.2. Habitat distribution of *C. glaucescens* for the future climate scenarios

Another objective of the study aimed to determine future potential distribution of *C. glaucescens* for the different climate change scenarios. We evaluated the future potential distribution scenario of *C. glaucescens* for two different climate scenarios MIROC6 and IPSL-CM6A-LR proxied through SSPs 126, 245, 370, and 585. The results for these two scenarios are illustrated through Fig. 5. The projected suitable sites show that potential suitable range would largely decrease across both climate scenarios. A comparative result for projected suitable sites of *C. glaucescens* for current and future climate scenarios is represented through a graph (Fig. 6a-b). The results showed that the suitable area for scenarios represented by IPSL_6A_LR and MIROC6 ranges between ~7.11- 11.73% and ~2.69-8.55% respectively. It can be seen from the graph that compared to the current climate scenario the potential suitable range for both the future scenarios will decline in future. Comparing these results for current and future climate scenarios, it reveals that for the climate scenario IPSL_6A_LR, this decline may range ~7-22.8%, with maximum decline ~ 22.8% for SSP 370 (Fig. 6a). Whereas, for the climate scenario MIROC (Fig. 6b), potential habitat area of *C. glaucescens* may decline in the range of ~39-70%, with maximum decline ~ 70% is projected for SSP126. Excluding the climate scenario IPSL_6A_LR proxied through SSP126, that showed possible increase in potential suitable habitat for *C. glaucescens*, the potential area is predicted to decrease in future. The elevation wise analysis shows ~119-2179 m for IPSL_6A_LR, and ~141 to 1909 m for MIROC6 offers suitable habitat for *C. glaucescens*.

The northern region of the research area was found to have a high frequency of *C. glaucescens* distribution that would be suitable for the current climatic environment and across all the SSPs. This indicates that the northern portion of the study area to be more appropriate for this species' survival. "Precipitation of the warmest quarter" (Bio_18) value ranging ~2500-3000 mm and "Annual Precipitation" (Bio_12) value ~2600-4000 mm contributed most to limiting the distribution of *C. glaucescens.* (Fig. 2). Upon analyzing LULC wise distribution, it can be seen that the majority of the distribution ~81% is projected in Tree class (Fig. 4). *C. glaucescens* potential range were mostly found in the higher elevation, and the ideal elevation for *C. glaucescens* is projected to change in the future from lower to higher elevation. Thus, it can be inferred that *C. glaucescens* grow well in higher elevation zones. There is evidence of habitat alterations in several research studies that examined the habitat suitability response of different species to climate change [34].

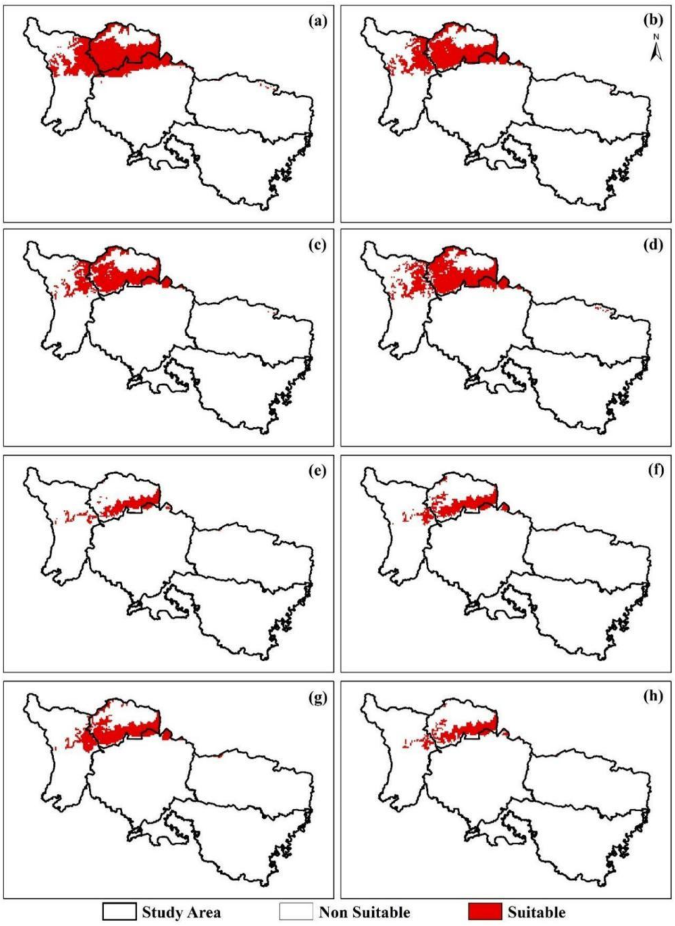

Figure 5. Projected habitat map of *C. glaucescens* for future scenario under different pathways (a) SSP 126 (b) SSP 245, (c) SSP 370, (d) SSP 585 for IPSL climate Model and (e) SSP 126 (f) SSP 245, (g) SSP 370, (h) SSP 585 for MIROC climate model.

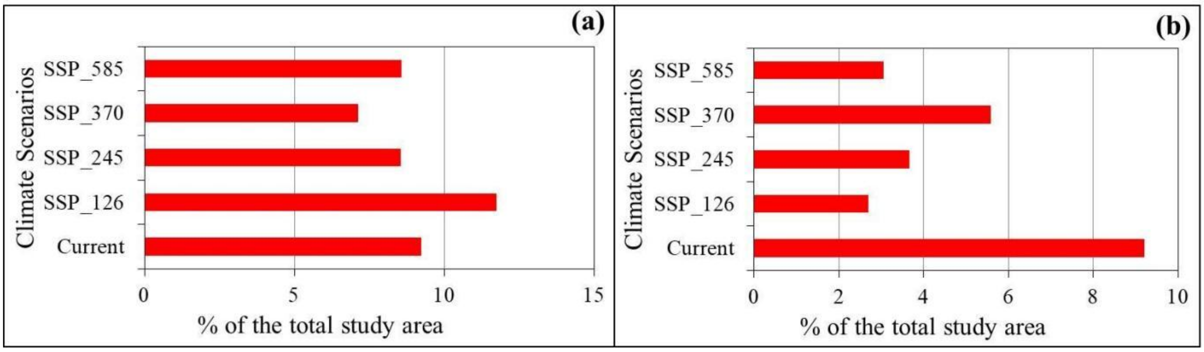

Figure 6. Graph shows the distribution (%) of *C. glaucescens* habitat range by 2050 the climate scenarios (a) IPSL-CM6A-LR, (b) MIROC6.

What emerges from the results reported here is that currently the central and northern part of the study area are potentially suitable for the distribution of *C. glaucescens*. The results suggest a significant decline of *C. glaucescens* population from the central part of the North Bengal region, and the distribution might be limited only in the northern part by 2050.

4. Discussion

Global warming is considered as one of the major factors impacting ecosystem services [35]. Machine learning approach due to its flexibility, robustness, and ease of use is being widely deployed across diverse studies to model the potential suitable habitats of species amid climate change scenarios.[36] Machine learning tools coupled with field observations offer significant insight in assessing species distribution ecology.[37]

This study found the central and northern part of the study area as the suitable habitat for *C. glaucescens.* The distribution was primarily in the natural landscape along elevation zones ranging ~1900 m. The LULC wise distribution analysis showed vegetation class as the major suitable habitat, and the occurrence of *C. glaucescens* on other landscapes was relatively limited. We could not find any relevant study concerning distribution ecology of *C. glaucescens,* and the only available reference had cited its distribution in the north-eastern part of India [38]. This also accords with our field observations, which revealed the occurrence of *C. glaucescens* in the northern part.

On the question of how the *C. glaucescens* will respond to climate change, this study found a potential decline in the suitable habitat of *C. glaucescens* by 2050 across all the SSPs, barring the most optimistic pathway SSP 126. This outcome confirms the existing body of literature in the field of habitat modeling domain, which suggests potential decline in suitable habitat of most of the forestry species of Himalayan region[39]. Comparison of the findings with those of other studies confirms variations in species' habitat ranges due to climate change[40]. A similar study concluded altered plant assemblage in the Sikkim alpine valley range due to climate change[41]. Results for the future climate scenarios exhibit habitat range of *C. glaucescens* to restrict in the northern part only, while completely getting extinguished from the central part. Further, the habitat range is indicated to be shifting northward. This result corroborates with the findings of a great deal of the previous work on habitat modeling of plant species suggesting that most of these species will shift northward[42].

Another important finding of the current study is that environmental variable precipitation for the warmest quarter (Bio_18) contributed most in limiting the distribution of *C. glaucescens.* This finding supports previous investigations in this area which links species distribution to climate variables[43]. The dependency of distribution range to Bio_18 indicates potential alteration in phenological behavior of

Himalayan plant species in the future. According to [44], varying rainfall and temperature scenarios caused alteration in leaf and flowering patterns of major forestry species of Kumaun Himalayan forests. Another study found phenophasal variations among three species of western Himalayan region were strongly influenced by climatic variations[45]. Further, socioeconomic factors such as population growth[46], LULC change[47], and urbanization[48] may indirectly affect the species regeneration and force its migration. Increasing anthropogenic pressure is one of the key drivers for depleting natural resources [49].

In summary, the current study illustrated potential suitable sites for the distribution of *C. glaucescens* in the central and northern part of the Eastern Himalayan region, with the likelihood of further decline due to climate change. We complemented the modeled area for the current scenario with extensive field surveys, which was one of the strengths of this study. While the study provides valuable insights into the distribution of *C. glaucescens and* its response to climate change, certain limitations must be acknowledged. In the current study we evaluated the potential suitable sites of *C. glaucescens* for two climate scenarios. However, considering a minimum of three numbers of climate models can project a more realistic outcome. Another note of caution is due here, as the climate layers used in the current study, being of moderate spatial resolution, may lead to an overestimation of the projected geographical range. Further, before concluding any such outcome, it is essential to consider other regional attributes such as human influence, soil conditions, and LULC changes. Another limitation is related to the approaches used by machine learning tools. The accuracy of these models entirely depends on the quality of the input data layers used to simulate scenarios. Any biases or inaccuracies in data collection can affect the accuracy of the results. In this study, we have attempted to address these data collection issues, but some deviations may still occur. Additionally, using the results of this study to make decisions for other geographical areas requires caution. Data collection methods, available climate model layers, and local environmental issues can vary significantly from one location to another. Addressing these aspects and including environmental layers such as human interference, and population density can be considered in future research work.

The findings of this study have several implications. The study suggests that overall suitable habitat area for *C. glaucescens* will decrease in future. Subsequently, the management can form strategies for the conservation of *C. glaucescens.* Implementing biodiversity-focused adaptation and mitigation approaches [50] can strengthen ecosystem resilience while minimizing the risks to both natural and human ecosystems [51]. The findings provide valuable insights into the distribution ecology of *C. glaucescens*, which are significant for a diverse group of researchers conducting similar studies worldwide.

5. Conclusion

This study has demonstrated the distribution of *C. glaucescens* in the central and northern part of the Himalayan region of North Bengal. The findings clearly indicate that by 2050, the potential suitable habitat range of *C. glaucescens* will shift northward with marked decline in the central part of North Bengal. A key policy priority should therefore be to plan for the long-term protection of *C. glaucescens in* the Himalayan region. *C. glaucescens* should be included into biodiversity action plans, backed by dedicated funding for germplasm banking, restoration, and monitoring. Forest departments must prioritize climate-resilient zones and strengthen in-situ measures such as habitat protection and assisted regeneration. The establishment of nurseries and seed banks along with outreach programmes such as awareness campaigns, community engagement, and participatory conservation models should be adopted to promote *ex-situ* conservation of *C. glaucescens*. We recommend a coordinated action plan across institutions, integrated with both in-situ and ex-situ approaches, to conserve *C. glaucescens* and ensure its long-term survival in the Himalayan region.

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Conflict of interest

The authors declare no conflict of interest

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