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RESEARCH ARTICLE

Ecological niche modelling to identify suitable sites for cultivation of two important medicinal lianas of the Western Ghats, India

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Abstract

Due to unsustainable harvesting and land use changes, two medicinally valuable, endangered liana species *Coscinium fenestratum* and *Embelia ribes* face severe threat in the wild. Climate change could also have profound impact on the distribution of these species which could result in contraction and/or expansion in geographical range of these species. *Coscinium fenestratum* and *E. ribes* are medicinally important species used for treating multiple ailments in humans. While the domestic demands for these species are on the rise, the resource availability has been shrinking. For long term sustenance of these species, it is imperative that these species are brought under cultivation. In this study, we used maximum entropy approach to identify suitable areas of cultivation of these species under both current and future scenarios viz., RCP's 2.6 and 8.5 by 2070. Our study suggests that due to climate change there is a very small gain in the suitable area in future which could help sustain the populations of both the species in the wild. In addition, we provide spatially explicit maps for different suitability areas which can be effectively used for prioritizing the cultivation sites for each species. For both the species, areas adjoining tropical broadleaved forest patches in the Western Ghats offer potential habitats at higher levels of probability for cultivation of species. We recommend that due consideration should be given for the sustainability of these two species by promoting cultivation outside the wild habitats and provide adequate protection of the two studied species in the wild. These results should also be useful for conservation planning and for prioritizing areas for protection as well as for large-scale commercial cultivation of these two species.

Keywords Climate change · Conservation · *Coscinium fenestratum* · Cultivation sites · Domestication · *Embelia ribes*

Introduction

Coscinium fenestratum (Gaertn) Coleb. and *Embelia ribes* are the two rare lianas of the Western Ghats of India, that are known for their medicinal properties and are being harvested extensively from this eco region. *Coscinium fenestratum* is a critically endangered liana due to harvest and at the global level it is data deficient. And it is belonging to the family Menispermaceae, which is one among the families comprising of several species with high medicinal value especially from its root to fruit tissues (Rai et al. 2013). The plant contains berberine as an active constituent which has been mainly used for treating diabetes mellitus and is commonly known to contain several active ingredients with diverse therapeutic purposes. Recently, this species has been classified as critically endangered due extensive harvesting of its woody stem from the wild populations in Western Ghats for its medicinal properties (Ravikumar et al. 2000). In addition to this, rampant destruction of habitat, poor rate of regeneration of this species are also contributing to the decline in the wild (Thriveni et al. 2014).

Embelia ribes (Family: Myrsinaceae) is another liana which is categorized as vulnerable (Ravikumar et al. 2000). It is also commonly known as false black pepper or vidanga. *Embelia ribes* is one of the 32 highly medicinal plant species identified by the Medicinal Board, Govt. of India (Anon 2008). It contains embelin as an active constituent and is reported to have antibacterial (Chopra et al. 1999), antifungal, analgesic, anti inflammatory, antioxidant, antidiabetic, anticancer, anti-hyper lipidemic, antifertility and

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antiprotozoal properties (Chitra et al. 1994). It is extensively used in the treatment of mouth ulcer, sore throat, pneumonia, obesity, constipation and in wound healing (Lal and Mishra 2013).

The current domestic demand of the above two mentioned species far exceeds the supply from the natural populations. The increasing demand for these species has led to large-scale extraction from the natural populations (Thriveni et al. 2015). In fact, since both the species are restricted to only the Western Ghats, the populations of these species are sparse, and in many places, have also been reported as locally extinct (Thriveni et al. 2014). In recent years, ecological niche models are being used to study distribution of medicinally and economically important species and identify areas for conservation as well as for cultivation of these species (Sen et al. 2016; Joshi et al. 2017). Efforts are also being made to understand the impact of climate change on the distribution of these species. A number of studies have shown substantial change in climate can cause niche shift or reduction in habitat, which could lead to isolation of populations of these species (Priti et al. 2016). In order to cultivate these long-lived species, appropriate areas need to be identified which would provide higher yield.

Ecological Niche Models (ENM) use mathematical techniques to relate the occurrence of species to environmental data (Guisan and Zimmermann 2000). ENM has received increased attention in recent years as it has been widely employed not only to estimate the relative suitability of habitat known to be occupied by the species, but also to estimate the relative suitability of habitat in geographic areas not known to be occupied but has potential for cultivation of the species (Kearney and Porter 2009; Nagaraju et al. 2013; Sen et al. 2016). Apart from this important application, ENM tools are also being used increasingly to monitor the spread of invasive species (Peterson and Vieglais 2001; Peterson 2003; Sarma et al. 2018; Ahmad et al. 2019), understand the response of species to global climate change (Peterson et al. 2004; Kumar et al. 2020), to understand species native distribution (Peterson and Vieglais 2001), to estimate changes in the suitability of habitat over time given a specific scenario for environmental change and to identify newer habitats for conservation (Godown and Peterson 2000; Joshi et al. 2017).

In this paper, using distribution data of *Coscinium fenestratum* and *Embelia ribes,* we have attempted to (a) identify the current geographical distribution of these important medicinal lianas in India and predict the possible sites of occurrence of these species using niche modelling tools, (b) predict the impact of future climate on potential distribution of these species for two climate change scenarios, and (c) provide spatially explicit maps for prioritizing the cultivation sites. The results of the study are discussed with reference to long-term conservation as well as for initiating large scale captive plantations of the species.

Materials and methods

Species occurrence records

Presence-only records for *Coscinium fenestratum* and *Embelia ribes* were collected from secondary sources including published literature (See annexure for details) and Global Biodiversity Facility (GBIF, http://www.gbif.org). The occurrence records obtained from secondary source often have sampling biases (Hijmans et al. 2000; Reddy and Davalos 2003; Graham et al. 2004; Kadmon et al. 2004; Hijmans 2012). Such sampling biases can cause the model to over fit to environmental biases that correspond to these influences in geographic space (Fourcade et al. 2014). Over fitting occurs when a model fits too tightly to calibration data, limiting the model's ability to predict independent evaluation data (Veloz 2009; Hijmans 2012). We reduced the effect of sampling bias by performing spatial thinning of occurrence records using nearest neighborhood distance (NND) of 10 km^2 (Radosavljevic and Anderson 2014) with spThin R package (Aiello-Lammens et al. 2015). Spatial thinning results in species occurrence data that yield better performing ENMs (Pearson et al. 2007). The number of records obtained after spatial thinning are 27 and 45 for *C. fenestratum* and *E. ribes* respectively (Fig. 1).

Bioclimatic data

Ecological niche modelling requires environmental dataset that influences the distribution of species. Hence, ecological variables *i.e.,* bioclimatic variables (Bioclim1–Bioclim19) were downloaded from World Clim database version 1.4 (Table 1, https://www.worldbioclim.org). These bioclimatic factors averaged for 40 years are high resolution interpolated climatic grids and represent current climatic scenario i.e., annual trends and seasonality such as mean temperature, precipitation, annual temperature range and limiting environmental factors such as temperature of coldest or hottest month and precipitation over land surfaces (Hijmans et al. 2005). To predict future distribution of the studied species under different climatic scenarios, we used datasets that are governed recommendations by Inter governmental Panel on Climate Change (IPCC) data in its fifth Assessment Report (AR5) (Moss et al. 2010). These datasets are represented taking into consideration possible greenhouse concentrations and are known as Representation Concentration Pathway (RCP). The RCPs are sub-divided into four different scenarios viz., RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 indicating possible concentration of greenhouse gases (GHG). In this study, we

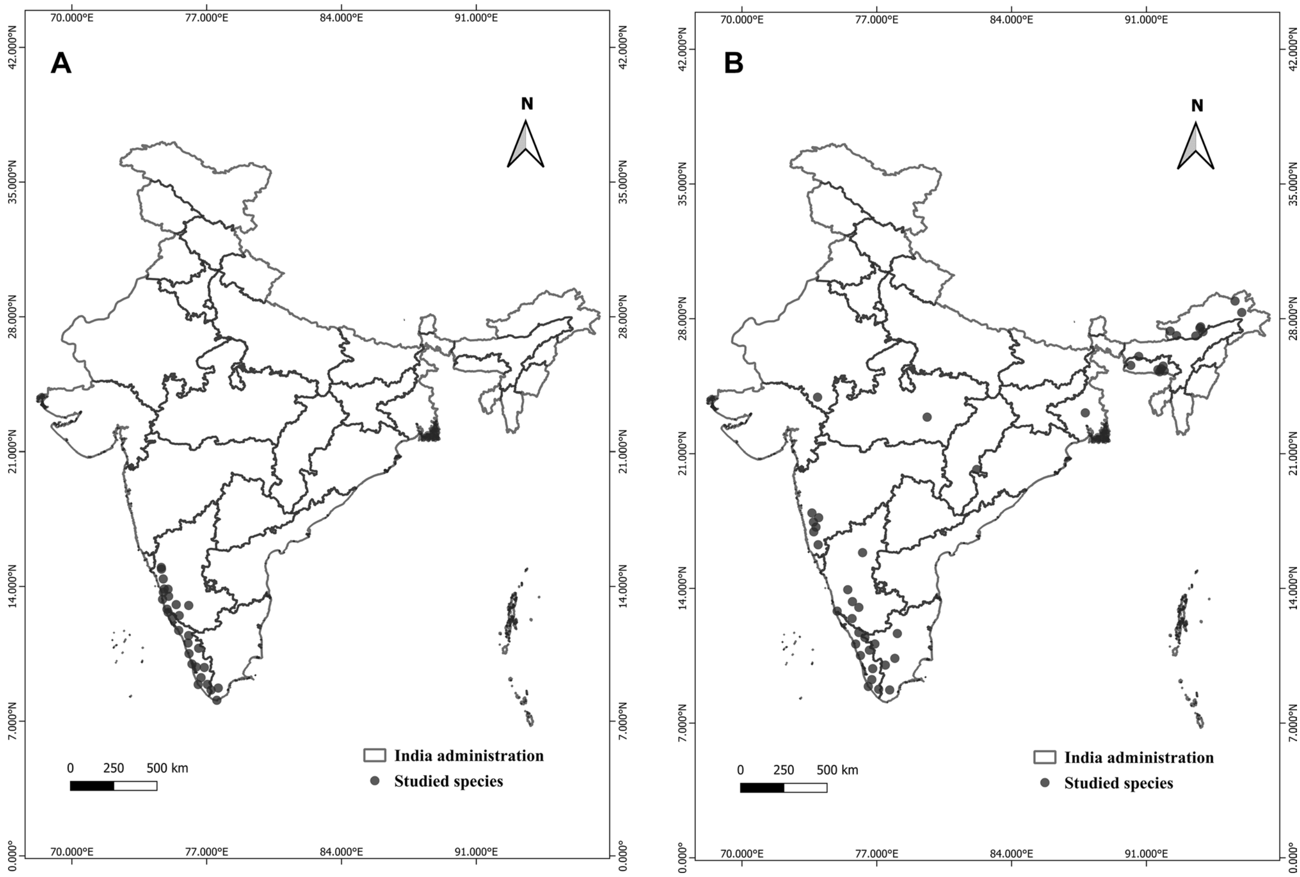

Fig. 1 Distribution map of (**A**) *Coscinium fenestratum* and **B** *Embelia ribes* in India

choose RCP 2.6 (minimum greenhouse gas scenario) and RCP 8.5 (maximum greenhouse gas scenario) to stimulate the habitat suitability distribution of species (Wei et al. 2018). All bioclimatic data used in this model had a spatial resolution of 1 km^2 (30 arc seconds). The environmental variables often have high correlation. Therefore, we tested for collinearity by examining pairwise correlations between the variables. Among the pair of variables, the candidates having Pearson's correlation coefficient > 0.75 were excluded from the analysis (Sarma et al. 2018). Final set of variables used for modelling *E. ribes* are altitude, Bio2, Bio3, Bio12, Bio14, Bio15, Bio18 and Bio19 and for modelling *C. fenestratum* we used altitude, Bio2, Bio5, Bio12, Bio14 and Bio16 (Table1) (Fig. 2).

Ecological niche modelling

In this study, we used maximum entropy methods to model the ecological niche of the studied species. The Maximum Entropy principle is built in MaxEnt Software v 3.4.1 for quantifying the suitable habitats (Sharma et al. 2018). MaxEnt was chosen for modelling as it requires presence only and background data for modelling ecological niches (i.e. absence data are not required), the performance is robust and relatively better than other modelling algorithms (Phillips et al. 2006) and the model is not influenced much by small sample sizes and prediction will be relatively robust (Pearson et al. 2007).

Model development and selection

The models were developed with following criteria. We used following combination of feature types *viz.,* LQPH, LQPT, LQPTH and Auto features with 'raw out puts'. In total, we developed eight models (four models for each species). All the other settings were set to default. The MaxEnt produced outputs i.e., predictions and lambdas file associated with each model were used for model selection in ENM Tools (Warren et al. 2010). The ENM Tools uses the suitability scores and occurrence points and estimates the likelihood of observing the occurrence records under a selected model. Once observed a suite of parameters captured in lambdas file counting any parameter with weightage having non-zero will be estimated and produces an output with criterion-based model selection using AIC, AICc, and BIC (Burnham and Anderson 2002; Warren and Seifert 2011).To

Table 1 Bioclimatic data used for Ecological Niche Modelling (ENM)

Code	Description of bioclimatic variables	*Coscinium fenestratum*	*Embelia ribes*
Alt	Altitude	✓	✓
BIO 1	Annual mean temperature		
BIO 2	Mean diurnal range [mean of monthly (max temp–min temp)]	✓	✓
BIO 3	Isothermally (BIO2/BIO7) (*100)		✓
BIO 4	Temperature seasonality (standard deviation *100)		
BIO 5	Max temperature of warmest month	✓	
BIO 6	Min temperature of coldest month		
BIO 7	Temperature annual range (BIO5-BIO6)		
BIO 8	Mean temperature of wettest quarter		
BIO 9	Mean temperature of driest quarter		
BIO 10	Mean temperature of warmest quarter		
BIO 11	Mean temperature of coldest quarter		
BIO 12	Annual precipitation	✓	✓
BIO 13	Precipitation of wettest month		
BIO 14	Precipitation of driest month	✓	✓
BIO 15	Precipitation seasonality (coefficient of variation)		✓
BIO 16	Precipitation of wettest quarter		
BIO 17	Precipitation of driest quarter		
BIO 18	Precipitation of warmest quarter	✓	✓
BIO 19	Precipitation of coldest quarter		✓

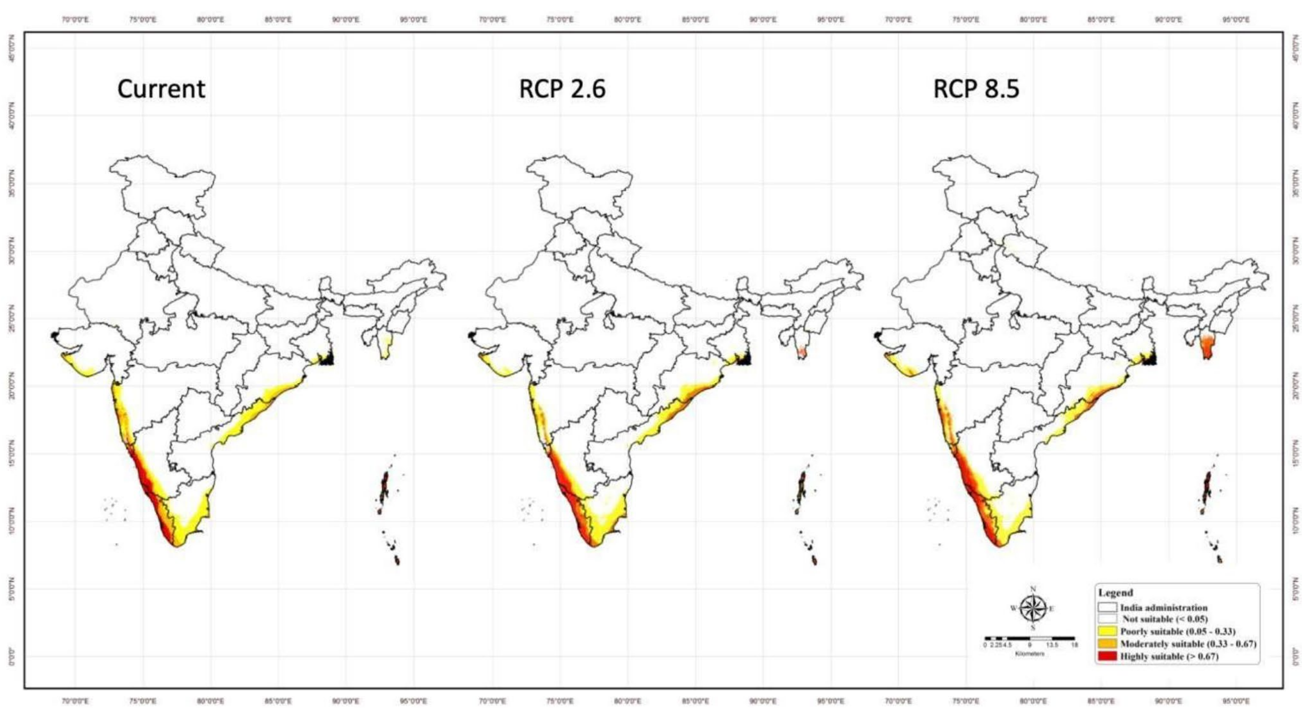

Fig. 2 MaxEnt predicted distribution map of *Coscinium fenestratum* in India

accomplish this, we used script with relative path to the files (predictions and lambdas). Previous studies indicate that AICc out performs BIC in selecting models on simulated data (Warren and Seifert 2011) hence, we selected the models having low AIC value. The model selected for final distribution modelling is 'LQPT' (Fig 3).

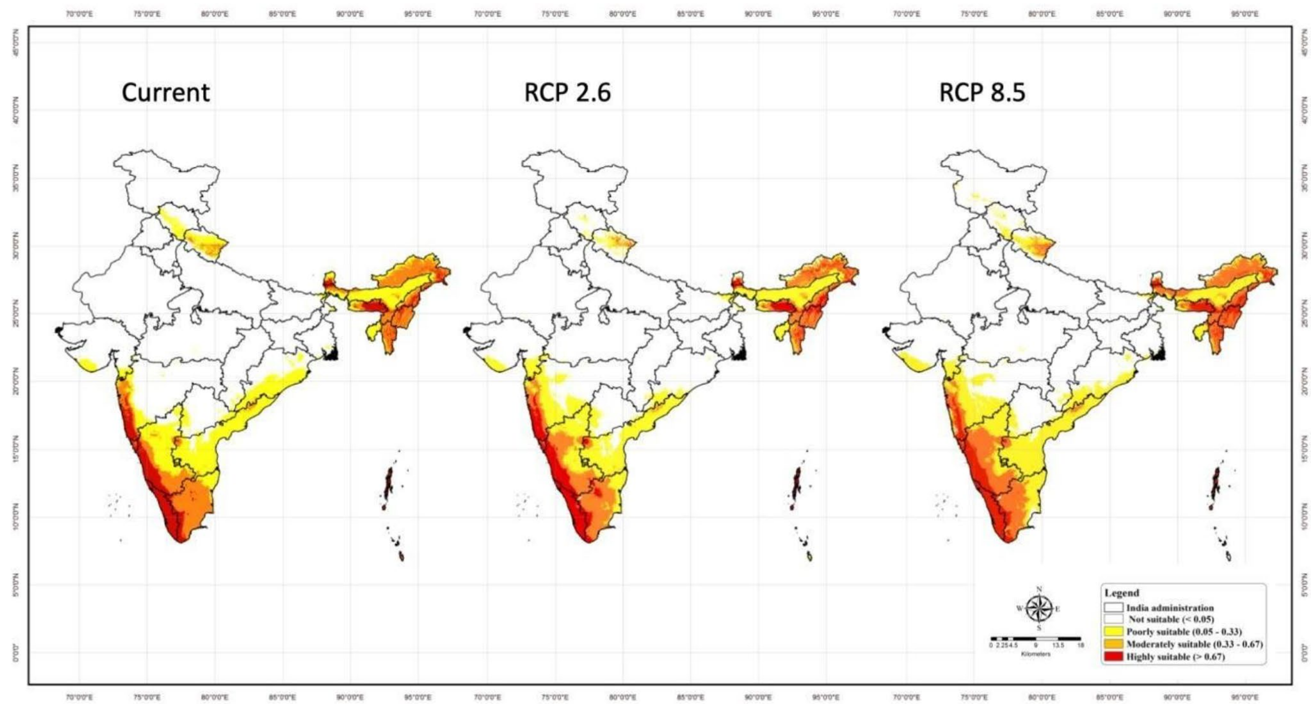

Fig. 3 MaxEnt predicted distribution map of *Embelia ribes* in India

For generating the final model for each studied species, we used following settings. The number of iterations was set to 5000; number of background points to 10000, replicated type as "sub-sample", 15 replicates, output type as 'cloglog' and feature selected is 'LQPT' (Linear, Quadratic, Product and Threshold). We used 75 percent of the occurrence points for model calibration and 25 percent for model testing. The variable importance was measured using jackknife test to determine the dominant climatic factors (Li et al. 2016) and all other settings were set based on Elith et al. (2006). The final predicted model of habitat suitability was divided into four levels: unsuitable habitat (< 5%), poorly suitable habitat (5–33%), moderately suitable habitat (33–67%), and highly suitable habitat (> 67%).

Changes in the potential niche

We analyzed the changes in the potential niche for studied species due to future climate change scenario's (2070, all representative concentration pathways). We extracted the frequency of pixels for each category using DIVA-GIS software (Fand et al. 2014). The total area of predicted habitat of studied species was estimated under current and future climatic conditions by multiplying the number of 'presence' grid cells multiplied by their spatial resolution of the MaxEnt output.

Model validation

The area under the Receiver Operating Characteristic curve (AUC) is an effective threshold independent index that can evaluate the model's performance (Swets 1988). The AUC value ranges from 0.0 to 1.0. The AUC value < 0.5 represents worse than random, 0.5–0.7 represents poor performance, 0.7–0.9 signifies reasonable performance, 0.8–0.9 signifies moderate performance and > 0.9 signifies good performance (Fig. 4).

Results

Model performance and variable contribution analysis

The final model predicted by MaxEnt after validation (using both training and test models) for both the species under current period was quite accurate (*C. fenestratum*—Training: 0.987 ± 0.008, test: 0.980 ± 0.008 and *E. ribes* Training: 0.913 ± 0.046 and Test: 0.889 ± 0.040). The jackknife analysis of variable contribution indicated that Mean Diurnal Range (BIO 2), Annual precipitation (BIO 12) and Precipitation of Warmest Quarter (BIO 18) are the top three variables contributing to 44.1%, 33.6% and 10.2% respectively. The remaining variables had 12.1% contribution in predicting potential distribution of *C. fenestratum*. Similarly, Annual

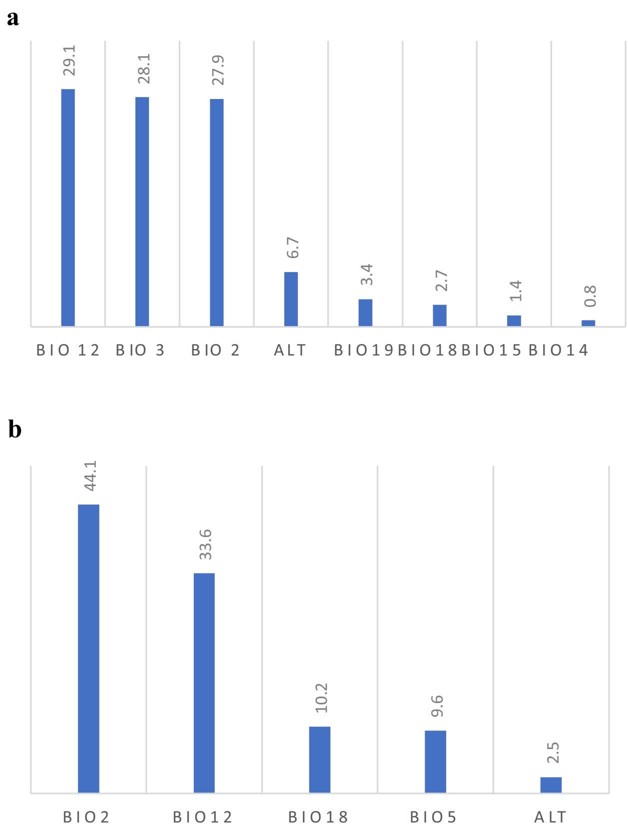

Fig. 4 **a** Variable contribution prediction using Jackknife for *Embelia ribes*. **b** Variable contribution prediction using Jackknife for *Coscinium fenestratum*

precipitation (BIO 12), Iso-thermality (BIO 3) and Mean Diurnal Range (BIO 2) are the top three variables contributing to 29.1%, 28.1% and 27.9% respectively. The remaining variables had 15% contribution in predicting potential distribution of *E. ribes.*

Suitable areas of cultivation under current scenario

The MaxEnt model prediction under current climatic condition for *C. fenestratum* revealed that highly suitable areas are found in the Western Ghats eco region of Karnataka, Kerala, Goa and Maharashtra states. As shown in the analysis, areas adjoining tropical broadleaved and degraded forest patches offer potential habitats at higher levels of probability. Hence, such forest areas could serve as habitats for cultivation. Moderately suitable areas are found in the northern Western Ghats in parts of Gujarat, as well as in Andhra Pradesh and Odisha. In case of *E. ribes,* the model prediction under current climatic condition revealed that highly suitable areas are found in the Western Ghats of Karnataka, Kerala, Goa, Maharashtra and Tamil Nadu and in North Eastern parts of India, especially in Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Nagaland, Sikkim and West Bengal. As shown in the analysis, areas adjoining forests as well as other tree patches offer potential habitats at higher levels of probability. Hence, potentially larger areas could serve as habitats for cultivation for *E. ribes*. Moderately suitable areas are found in Andhra Pradesh, Orissa, and Uttrakhand.

Suitable areas of cultivation under future scenario

The MaxEnt model prediction under RCP 2.6 climatic condition revealed that highly suitable areas for *C. fenestratum* are found in the Western Ghats of Karnataka, Kerala, Goa, Maharashtra and North Eastern parts of Mizoram. Moderately suitable areas are found in Andhra Pradesh, Gujarat, Odisha, Tamil Nadu and West Bengal. Under RCP 8.5, the model predicts that highly suitable areas are found in the Central and Southern Western Ghats and Maharashtra. North Eastern parts of Mizoram. Moderately suitable areas are predicted by maxent in Andhra Pradesh, Gujarat, Orissa, Tamil Nadu, Tripura and West Bengal. In case of *E. ribes,* the MaxEnt model prediction under RCP 2.6 climatic condition revealed that highly suitable areas for *E. ribes* are found in the Western Ghats of Karnataka, Kerala, Goa, Maharashtra and Tamil Nadu. North Eastern parts of Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Nagaland, Sikkim and West Bengal. Moderately suitable areas are found in Andhra Pradesh and Uttrakhand. The MaxEnt model prediction under RCP 8.5 climatic condition revealed that highly suitable areas are found in the Western Ghats (parts of Karnataka, Kerala, Goa, Maharashtra and Tamil Nadu), North Eastern parts of Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Nagaland, Sikkim and West Bengal. Moderately suitable areas are found in Andhra Pradesh, Tripura and Uttrakhand.

Spatial delineation of range contraction or expansion

Our analysis showed that by 2070, there will be increase in the highly suitable habitat for *C. fenestratum* from 435.68 km^2 (current) to 476.94 km^2 (RCP 2.6), however, under RCP 8.5 scenario, there will be a marginal decrease to 458.01 km^2. The potential area of expansion was not fragmented but a contiguous one. The moderately suitable habitat decreases from 599.45 km^2 (current) to 566.49 km^2 (RCP 2.6); a drastic increase to 701.14 km^2 was predicted under RCP 8.5. Similarly, it was found that there will be increase in the poor habitat from 2,334 km^2 (current) to 2485.29 km^2 (RCP 2.6) and an equal decrease of 2338.59 km^2 under RCP 8.5 scenarios. Not suitable habitat decreases from 31,441.17 km^2 (current) to 31,281.56 km^2 (RCP 2.6) followed by a marginal increase to 31,312.55 km^2 (RCP 8.5). For *E.*

ribes there will be decrease in the highly suitable habitat from 1658.93 km^2 (current) to 1603.51 km^2 (RCP 2.6) followed by a marginal increase to 1644.17 km^2 (RCP 8.5).

The moderately suitable habitat decreases from 3,855.41 km^2 (current) to 3487.10 km^2 (RCP 2.6) followed by increase to 3877.93 km^2 (RCP8.5). The poorly suitable habitat was found to decrease from 17,173.66 km^2 (current) to 15,289.58 km^2 (RCP 2.6) followed by a drastic increase to 19,064.37 km^2 (RCP 8.5) (Table 2).

Discussion

Lianas are long-stemmed, woody vines which occupy an important position in the tropical forest ecosystems. Lianas have special adaptive features such as twining stems, tendrils, hooks, thorns and spines which act as specialized organs to climb on to their host plants and form arboreal paths to primates (Darlong and Bhattacharyya 2012). They influence ecosystem function and stabilize the microclimate of the forest floor by formation of leafy vegetation to close canopy gaps. Besides this, a number of lianas are medicinally important for treating variety of diseases. The lianas in tropical forests are sensitive to human disturbances. Previous studies highlight the decreasing trend in the distribution and abundance of lianas due to tree species removal which has significant impact on forest structure and soil properties (Addo-Fordjour et al. 2013).

Coscinium fenestratum and *E.ribes* are two important and threatened lianas (http://envis.frlht.org/) that are known for their incredible medicinal properties and hence have been harvested extensively in the Western Ghats for a long period of time (Chitra et al. 1994). With extensive habitat destruction and change in land use patterns in the Western Ghats (Jha et al. 2000), these species could be pushed to the brink of extinction. In addition, climate change could significantly impact the distribution of these species. Species distribution models (SDMs) were used to predict the impact of climate change on the distributions of two lianas, and to identify suitable areas for cultivation of these species. Growing demand for natural health products and herbal medicine has resulted in a surge in the use of medicinal plants with an annual growth rate of 10–20%. It is also estimated that the current extinction rate of these medicinal plants are at 100 to 1000 times higher than the natural background extinction rate, hence it is important to predict suitable habitats for prioritization of sites for cultivation and conservation as well as assess the possible impacts of climate change on the distribution of these species.

Medicinal plant trade- quantity, source and livelihoods

The Western Ghats has lost 22 percent of evergreen forests in last three to four decades (Jha et al. 2000). The species studied here are the main components such moist forests especially in the Western Ghats and NE India. The habitat loss along with the excessive harvest and encroachment are considered as a serious threat to many economically important wild genetic resources. Our analysis using niche modelling tools does not show significant loss or increase in suitable habitats for both the species studied. However, considering the demand for these species and the existing threats to the species in the present habitats, it is imperative that more areas are brought under cultivation and the existing populations in the wild be conserved.

Only 5% of existing geographical area of India and around 8% of the Western Ghats is protected under Protected Area (PA) network (Raghavan et al. 2016). Though these PA's are managed and collection is totally prohibited, much of the population of these lianas are found outside the PA network. The protection for the populations outside the PA network is difficult unless there is an involvement of communities. Involving local communities in raising nursery for supply of the plant material is important for long term survival of these species. A similar effort of raising plantations and domestication of medicinal plants has been shown to be successful in this region (Srivastava et al. 1996). Integrated forest management and plantation management by forest department needs to be undertaken. In order to increase the supply of the highly important medicinal plants, the Forest Department, should undertake multi-species tree plantations of indigenous species and promote the plantations of lianas such as *C. fenestratum* and *E. ribes.* The sites where these species could be introduced (cultivated) should be selected based on the results of the niche models. Such approach has been used

Table 2 Change in suitable habitats between current and future

Category	*C. fenestratum*			*E. ribes*		
Scenario	Current	RCP 2.6	RCP 8.5	Current	RCP 2.6	RCP 8.5
0.00–0.05	31,441.17	31,281.56	31,312.55	12,122.29	14,430.01	10,223.81
0.05–0.33	2,334.00	2,485.29	2,338.59	17,173.66	15,289.58	19,064.37
0.33–0.67	599.45	566.49	701.14	3,855.41	3,487.19	3,877.93
0.67–1.00	435.68	476.94	458.01	1,658.93	1,603.51	1,644.17

elsewhere for species reintroduction of threatened species and for identifying critical areas for long-term conservation of gene bank (Munt et al. 2016; Joshi et al. 2017; Kaky and Gilbert 2017).

Globally, SDMs are used extensively for variety of application ranging from systematics to prioritization of conservation sites. SDMs has also been used for mapping the potential distribution of medicinal plants (Ray et al. 2011; Munt et al. 2016; Sumangala et al. 2017; Kaky and Gilbert 2017; Sarma et al. 2018). One of the challenges in identifying areas for cultivation of medicinal plants which produce specific plant metabolites is to develop algorithms or approaches that can help predict cultivation sites where the metabolite yield is also high. Prediction of such sites are areas and validation of the chemical yields from such sites would not only help focus efforts in collecting the planting material (seeds/vegetative cuttings) from such sites, but also serves to prioritize sites for cultivation or for conservation (Uma Shaanker et al. 2008). The assumption of the ENM prediction is that, the plants would accumulate secondary metabolites at sites where the models predict to be highly suitable for a given species compared to sites that are predicted to be unsuitable. Uma Shaanker et al. (2008) have shown that in case of *Nothapodytes nimmoniana,* a medicinally important tree species, individuals occurring in highly suitable areas (as predicted by the niche models) accumulated significantly higher levels of camptothecin, an important anti-cancer metabolite, compared to those that occurred in unsuitable or poorly suitable areas. Their study also showed that over 60% of the trees that accumulated greater that 1% camptothecin were from regions predicted to be highly suitable. These results have clearly demonstrated the utility of the ENMs in predicting the spatial richness of plant metabolites.

The SDMs results presented also carry certain caveats. For example, we have not considered land use categories while modelling the distribution and it is possible that land use patterns may change in the future. Similarly, the outcome of the SDM is also influenced by the input variables and the accuracy of the data points used, though we have ensured that the data points reflect the actual distribution of the species. Further, many regions where the suitable habitats are predicted might not have any habitat left for either cultivation or have any natural population of the species. For example, much of the coastal area of the Western India is urbanized and there is very limited possibility of either finding natural population or for cultivation of the species. In summary, while areas adjoining tropical broadleaved forest patches in the Western Ghats offer potential habitats at higher levels of probability for cultivation for both the species, additional regions in northeast India are potential sites for cultivation of *E. ribes*.

Conclusion

In this study, we have studied potential distribution of liana species under climate change using MaxEnt. This study provides potential habitat distribution map for two endangered liana species which have high medicinal value. Although the MaxEnt has been successfully used for effective conservation purposes we highlight that while developing management policies due consideration should be given to other local factors such as the edaphic factors while adopting regions for cultivation. Finally, we conclude that ENM can be used as guidelines for managing PAs and identification of suitable areas outside PAs for possible cultivation of these endangered lianas for not only their long term survival but also for constant supply of these commercially important medicinal plant species.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42965-021-00207-9.

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