Indian Brahmaputra valley offers significant potential for cultivation of rubber trees under changed climate

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In a warming world, species distribution models have become a useful tool for predicting plausible shifts of a species occurrence enforced by climate change. Using maximum entropy (Maxent) model, we analysed present and future distribution patterns of rubber tree (*Hevea brasiliensis*) in two distinct bio-geographical regions of India: the Western Ghats having a good distribution of rubber plantations at present and the Brahmaputra valley, where rubber trees are recently being cultivated. The model-derived suitable regions of the Western Ghats and Brahmaputra valley provided good conformity with a satellite-derived rubber plantation distribution map. Annual range of temperature and mean temperature in the coldest months, temperature seasonality and rainfall in the warmest quarter would be the major decisive variables in the distribution of this species as revealed by the area under receiver operating curve. Interestingly, we predict that more areas will become suitable for rubber cultivation by the middle of the 21st century in the Brahmaputra valley, while some areas under current cultivation may become partially unsuitable for this species in the Western Ghats. This result can help planners in deriving a comprehensive rubber plantation policy for India considering the existing land-use scenarios.

Keywords: Climate change, maximum entropy, rubber plantations, species distribution model.

RUBBER tree (*Hevea brasiliensis*) is the prime source of natural rubber. The milky latex produced in the specialized cells in its bark is tapped and the rubber present in it (poly-isoprene) is separated and processed into useable forms[1]. Because of the versatile usage of rubber (often termed as natural rubber), there is increasing global demand for it. However, rubber trees grow only in limited regions of the world and therefore, identification of suitable locations for expansion of rubber tree cultivation is needed. The climatically suitable areas for rubber tree may further be qualified on the basis of soil, physiography and socio-economic characteristics for the policy planners, who may use the information to decide on expansion or contraction owing to area suitability.

Traditionally, rubber trees are grown in the southern region of the Western Ghats in India, which accounts for over 90% of its production in this country. However, the Brahmaputra valley region[2] of India has become an alternate area for cultivating rubber trees since 1960s. The price of natural rubber remains high, which prompts farmers to take up rubber tree cultivation in Brahmaputra valley as a livelihood option. Rubber tree plantations provide valuable ecosystem services in the marginal and 'jhummed' barren lands, where it is predominantly grown in the Brahmaputra valley[2]. According to the directives of the Government of India, the Rubber Board has taken up a target to bring 5000 ha/year area under rubber plantation. Any approach of mapping suitable land area based on scientific study will certainly help reaching out the target.

With the advancement of mathematical modelling, it has become relatively easy to locate the distribution of any species in relation to its climatological requirements[3]. The species distribution model (SDM) has become a widely accepted approach for predicting species distribution and estimation of their realized environmental niche[4]. The SDM also offers the provision to include bioclimatic variables of temporal scales. Basically, the models are developed to estimate the relationship between the species presence records and the environmental/spatial variables of the site, and then extrapolate the prediction in different space and time[5]. They have been implemented to assess the distribution of various plants and animal species which are native to a particular ecological region[6,7] and to predict new areas for re-colonizing by an expanding species[5,8,9].

We have implemented maximum entropy model (Maxent) for assessing the current and future distribution of rubber trees. In the last two decades, there have been remarkable developments in SDMs and one of the basic criteria for choosing the method is the availability of presence only data instead of unreliable absence records, particularly emphasizing the bearing of a strong relationship of biotic interactions and dispersal constraints with

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absence data[10]. This model has been used in studies of species richness[11], invasive species[12], climate change effect on species distribution[13,14], etc. It also investigated the degree to which climate constrained the distribution of species[15]. Chitale and Behera[16] used the Maxent model for assessing the distribution of *Shorea robusta* in India for the year 2020. Maxent is more advantageous than other approaches as the number of training and test samples does not affect the model prediction and it can use both continuous and categorical input variables. Therefore, we have adapted this model for predicting the potential distribution of rubber trees using limited number of training sites and input bioclimatic variables.

Here, we predict present and future distribution of rubber tree plantations in the Western Ghats and Brahmaputra valley regions of India under climate change scenario SRES-A1B (for 2020 and 2050), with the current presence-only data of 2010. The changed climate scenario, A1B is according to the special report on emission scenario (SRES) of the Intergovernmental Panel on Climate Change (IPCC).

Maximum entropy model simulation

Study area

The study area includes two rubber tree-growing regions in India: the Western Ghats and Brahmaputra valley (Figure 1). These two regions also represent two biodiversity hotspots differing in prevailing climatic conditions and sharing similar monsoon-driven rainfall pattern (Table 1). The southern Indian states such as Kerala, Tamil Nadu and Karnataka in the Western Ghats constitute the traditional rubber tree-growing regions, whereas Tripura, Assam and Meghalaya are the states in the Brahmaputra valley considered as relatively new regions for rubber tree cultivation. The Brahmaputra valley region (89.46°–97.3°E and 21.57°–29.3°N) is located at the junction of two global biodiversity hotspots, i.e. Indo-Burma and the Himalaya. Both these regions face the threat of ecosystem disturbance due to mining activity in the Western Ghats and shifting cultivation (jhumming) in the Brahmaputra valley region.

Figure 1. Study area of two regions in India: (A) Brahmaputra valley (northeastern states). (B) The Western Ghats (southern states). 1, Tripura; 2, Assam; 3, Meghalaya; 4, Mizoram; 5, Manipur; 6, Nagaland; 7, Arunachal Pradesh; 8, Kerela; 9, Tamil Nadu; 10, Karnataka; 11, Maharashtra.

Occurrence data of rubber trees and predictor variables

A total of 95 occurrence data points of rubber tree plantations in the Brahmaputra valley and 130 points in the Western Ghats region were extracted from the ground sampled locations recorded during 2011–12. Satellite-derived false colour composite image of March 2010 was used to locate rubber plantations based on the unique texture and colour of the plantation patch due to its defoliation phase during satellite pass time (March 2012). The representative locations of rubber tree plantations were ascertained during the two field visits to major rubber tree-growing areas in the Brahmaputra valley and the Westerns Ghats region. The points of rubber tree occurrence have been overlaid on the map of both regions (Figure 2). The occurrence records of rubber trees were divided into training and test samples: 20% of total points were taken by 'random data splitting' method as test samples. The 19 bioclimatic data layers with 30 sec (ca. 1 km) spatial resolution were downloaded from WorldClim website (www.worldclim.org/bioclim) provided by IPCC and used in Maxent model as described by Phillips *et al.*[17]. Elevation data were obtained from the USGS website (http://www.usgs.gov.in/#Find_Data/Products_and_Data_Available/SRT) in 1 km spatial resolution. The climate data layers were converted into grid format and then data for the required study area were extracted using ArcGIS v9.2 software through masking with respective shape file. Multi-collinearity among the climate variables was tested using Pearson correlation method. However, correlated variables were not excluded from the predictive variables, as it did not result in significant increase in test AUC (already AUC > 0.95). Therefore, all 19 bioclimatic variables were considered as the input data in the present study.

Modelling approach

We used the free version of Maxent software version 3.3.3e (http://www.cs.princeton.edu/~schapire/maxent/), which generates an estimate of probability of presence of the species that varies from 0 to 1, i.e. from lowest to highest probability. Rubber tree occurrence data were imported into ArcGIS v9.2 as feature class, and

Table 1. Bio-geographic profile of the two study areas

	Western ghats	Brahmaputra valley
Agro-climatic zonation	West coast plains and ghats regions	Eastern Himalayan region
Climate-based ecosystems	Hot humid per humid eco-regions	Warm per humid eco-regions
Soil type	Red, lateritic and alluvial derived soil	Red and lateritic soil
Annual rainfall	2000–3200 mm (mainly due to southwest monsoon; 20% contributed by northeast monsoon)	1600–2600 mm (mainly by southwest monsoon)
Temperature	Average annual temperature is 15°C. Mean temperature ranges from 20°C in the south to 24°C in the north	15°–32°C during summer, 2°–26°C during winter season

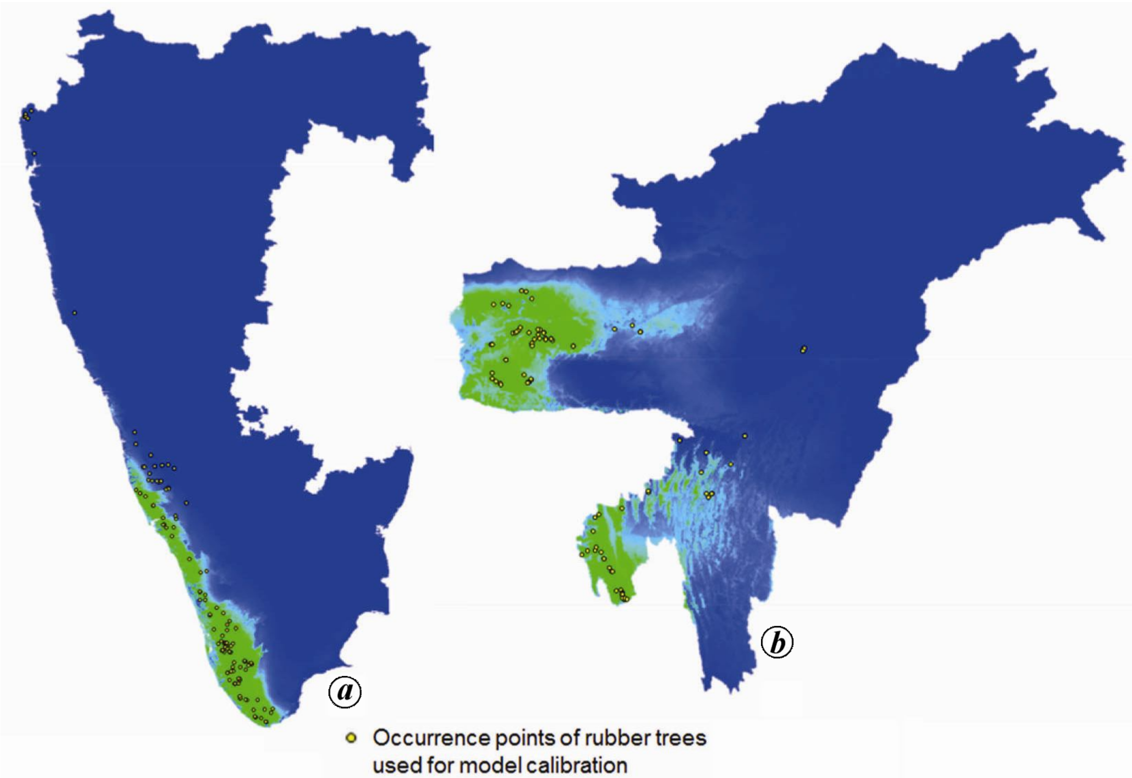

Figure 2. Rubber tree occurrence point data used for model calibration in (***a***) the Western Ghats and (***b***) Brahmaputra valley region.

distribution points for this species were checked. Out of total occurrence sample points, 20% was randomly used as test sites in both the Brahmaputra valley and the Western Ghats region. The model was run separately for each region and replicated ten times.

Rubber tree distribution model was generated in Maxent using the default settings outlined by Phillips and Dudik[18]. The methodology followed in the present study to generate rubber tree distribution map with some suitable modifications is depicted in Figure 3. Logistic output and ASCII file format was chosen with auto feature type of model simulation, where feature types were automatically chosen based on the number of presence samples. The model has adapted sub-sample type of replicated run. The cross-validation of occurrence data was set at ten fold and the threshold values were fixed at 0.00001 at 1000 iterations.

Assessment of model accuracy and validation of model prediction

The accuracy of model prediction was assessed through receiver operating curves (ROCs) that describe the relationship between the proportion of correctly predicted observed presences, i.e. sensitivity and the proportion of incorrectly predicted observed absences, i.e. (1-specificity). A precise prediction model generates an ROC that follows the left axis and top of the plot, while a model with predictions worse than a random model will generate an ROC that follows the 1 : 1 line. The validation of model-derived area suitability map has been done using IRS-P6 LISS IV satellite-derived image based rubber tree distribution map (Figure 4) of one state in the Brahmaputra valley (Tripura). The results of model simulation, i.e. highly suitable area in the model-derived map corroborated with the concentrated distribution of rubber tree plantations in West and South Tripura districts of the state. The classification of the areas based on species suitability was determined by histogram analysis technique in DIVA-GIS open source software and classified data were exported into Excel spread sheet for further calculation and analysis.

Results

Analysis of predicted results

The Maxent model provided potential distribution of rubber trees, wherein the probability of presence is represented as an estimate ranging between 0 and 1. The model simulation has revealed that the suitable area at present for rubber plantations in the Brahmaputra valley is 23,095 sq. km (8.8% of the total area), which is mainly concentrated in the western part of the valley consisting of West and South districts of Tripura, Goalpara district of Assam, and the state of Meghalaya (Figure 5 *a* and *d*). The prediction for 2050 scenario indicates that there is no significant difference in suitable region in Brahmaputra valley of India between 2020 (31,940 sq. km) and 2050 (31,535 sq. km). Best suitable area predicted for 2020 is going to further decrease to 2318 sq. km. Moderately suitable and less suitable areas predicted for 2020 will change to 3605 and 7016 sq. km in 2050 respectively, thereby suitable areas may increase from 17,464 to 18,596 sq. km (Figure 5 *e* and *f*). In the Western Ghats region, the present distribution of rubber plantations is

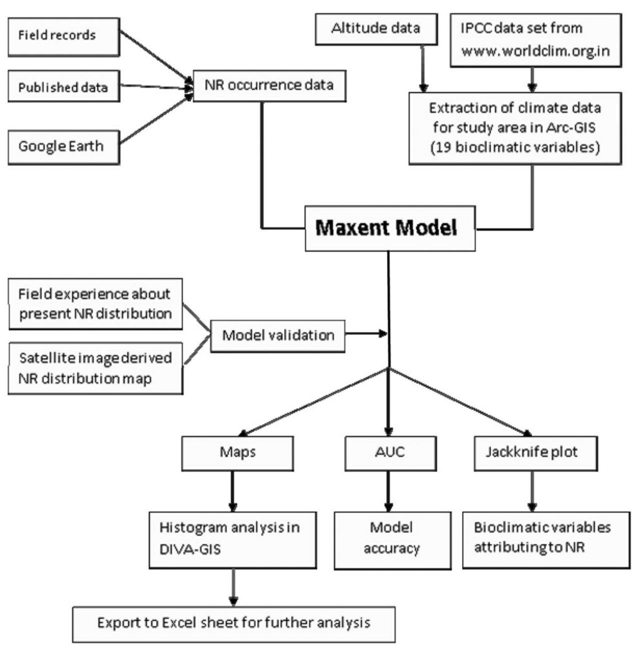

Figure 3. Flow chart showing different steps in the methodology followed in this study.

spread over 30,963 sq. km, which is 4.6% of the study area (Figure 6 *a* and *d*). In 2020 projected climate scenario, the model-predicted suitable regions for rubber tree cultivation in the Brahmaputra valley region is 31,940 sq. km (12.2%), expanding the rubber tree cultivation upwards in Assam and northern parts of Tripura and Mizoram (Figure 5 *b* and *c*). The most suitable area of 1970 sq. km in the present scenario would expand to 2557 sq. km in the Brahmaputra valley in 2020 (Figure 5 *d* and *e*). Similarly, some parts of the northern Western Ghats will also be suitable for rubber tree cultivation in 2020; however, there is no significant temporal difference in the total area with different levels of suitability for rubber trees in the Western Ghats region, which would decrease from 4310 sq. km at present to 2496 sq. km in 2020 (Figure 6 *d* and *e*).

Assessment of predictor variables

The Jackknife plot of the Maxent model indicated that mean annual temperature, mean temperature of coldest months, mean temperature of driest months, minimum temperature of coldest months, mean temperature of warmest months and maximum temperature of warmest months are the most important parameters contributing maximally towards the distribution of rubber trees in the Brahmaputra valley. Other parameters such as altitude, rainfall in the driest months and temperature seasonality are also important contributors (Figure 5 *g*). In the predicted scenario of 2020, minimum temperature in the coldest months, annual range of temperature, mean diurnal range of temperature and isothermality appeared to be more decisive factors for rubber tree distribution in the Brahmaputra valley (Figure 5 *h*). The variables like mean temperature in coldest months and mean temperature in driest quarter may be important in 2050 scenario in this region (Figure 5 *i*). This may be due to predicted extreme climates foreseen for the future, which may be acting as major decisive variables at that time. However, the impact of these decisive variables is in decreasing trend across the timescale.

The jackknife plot of AUC and training gain resulting from model simulation for the Western Ghats region indicates that annual range of temperature, temperature seasonality, rainfall in warmest quarter and isothermality are the most significant variables for predicting the distribution of rubber trees. However, the precipitation seasonality did not show any significant contribution as indicated by the lowest gain shown in the AUC. It can be clearly seen from the plot for training gain that, if the model uses only precipitation seasonality, it achieves almost no gain. So the variable is not (by itself) useful for estimating the distribution of rubber trees. On the other hand, annual range of temperature and temperature seasonality allow a reasonably good fit to the training data. The AUC for

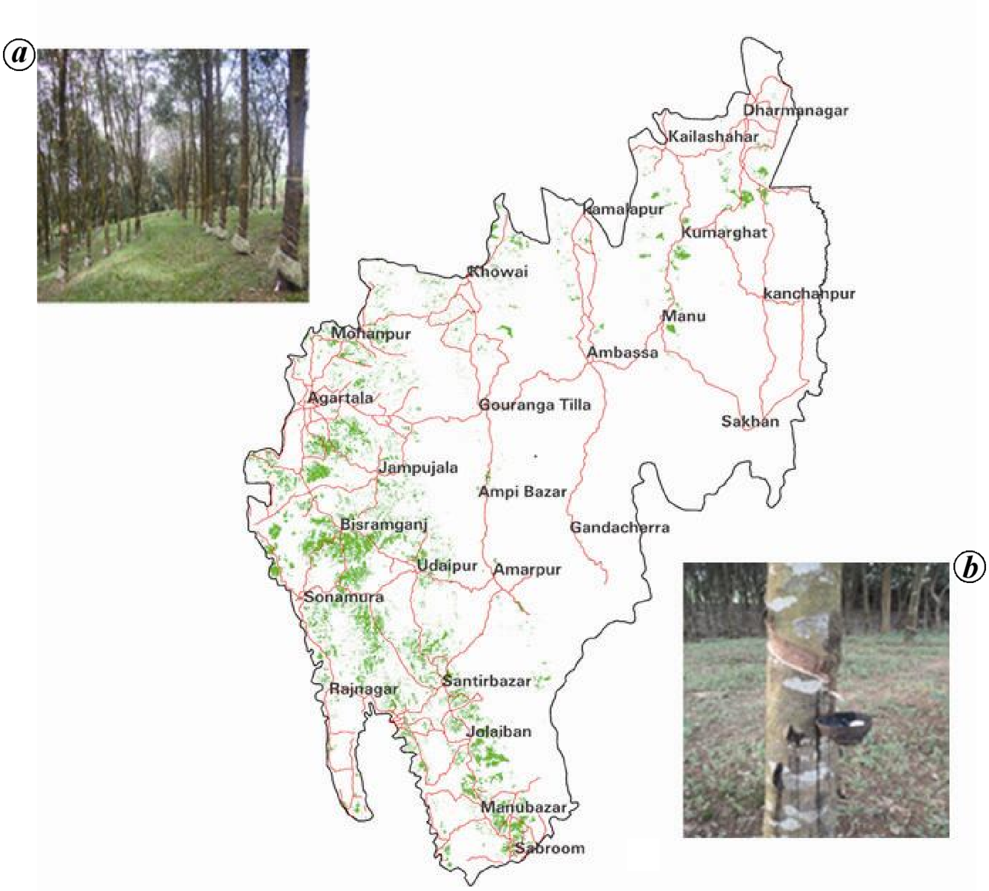

Figure 4. Natural rubber plantation distribution map for Tripura in the Brahmaputra valley region derived from IRS P6 LISSIV satellite image of 2008. (Inset) Field photographs of natural rubber: ***a***, View of mature plantation in Kerala in the Western Ghats region; ***b***, Closeup view of a tree in a plantation in Tripura where latex is being collected in a cup.

training data and test data of rubber trees was 0.98 and 0.99 respectively, indicating that the omission of training and test data by the classifier is less than 30% and 10% respectively (Figure 5 *g*). In the Western Ghats region, isothermality, temperature seasonality, precipitation in driest month, precipitation in driest quarter and precipitation in warmest quarter appear to be more effective for rubber tree distribution in 2020, indicating that predicted erratic monsoon behaviour may be the deciding factor for growth of the trees in the Western Ghats. However, in 2050 scenario, other sets of variables mainly related to temperature such as annual range of temperature, isothermality, mean diurnal range of temperature, temperature seasonality and mean temperature in the coldest months become more decisive factors for its distribution in the Western Ghats (Figure 6 *h* and *i*).

Distribution of rubber trees

Prediction of future distribution of a species using projected changed climate data of IPCC is a potential application of SDMs. These models are basically statistical relationship between presence data and species climatic requirements that are prevalent in those locations; but they can be used to predict the future distribution of the species under changed climate scenario provided the interaction between the species and climate remains unchanged[19]. It is worth mentioning in this context that the new climatic data are also output of climate models where certain uncertainties are inbuilt[20]. With this limitation in mind, we applied Maxent model for projecting the future distribution of rubber trees. During the past few years the Maxent model has been implemented for predicting the future distribution of native flora and fauna[16,17,21]; however, in the present study we attempted to predict the distribution of a cultivated plant species like rubber trees in two regions of India under present and future climate scenarios. Our results indicate that the Maxent model can predict suitable areas quite reliably based on climate suitability of rubber trees. The predicted distribution has corroborated with actual distribution of the plantations in Tripura, the western part of study area adjacent to Bangladesh and Goalpara district of Assam in the Brahmaputra valley (Figures 4 and 5 *a*). According to

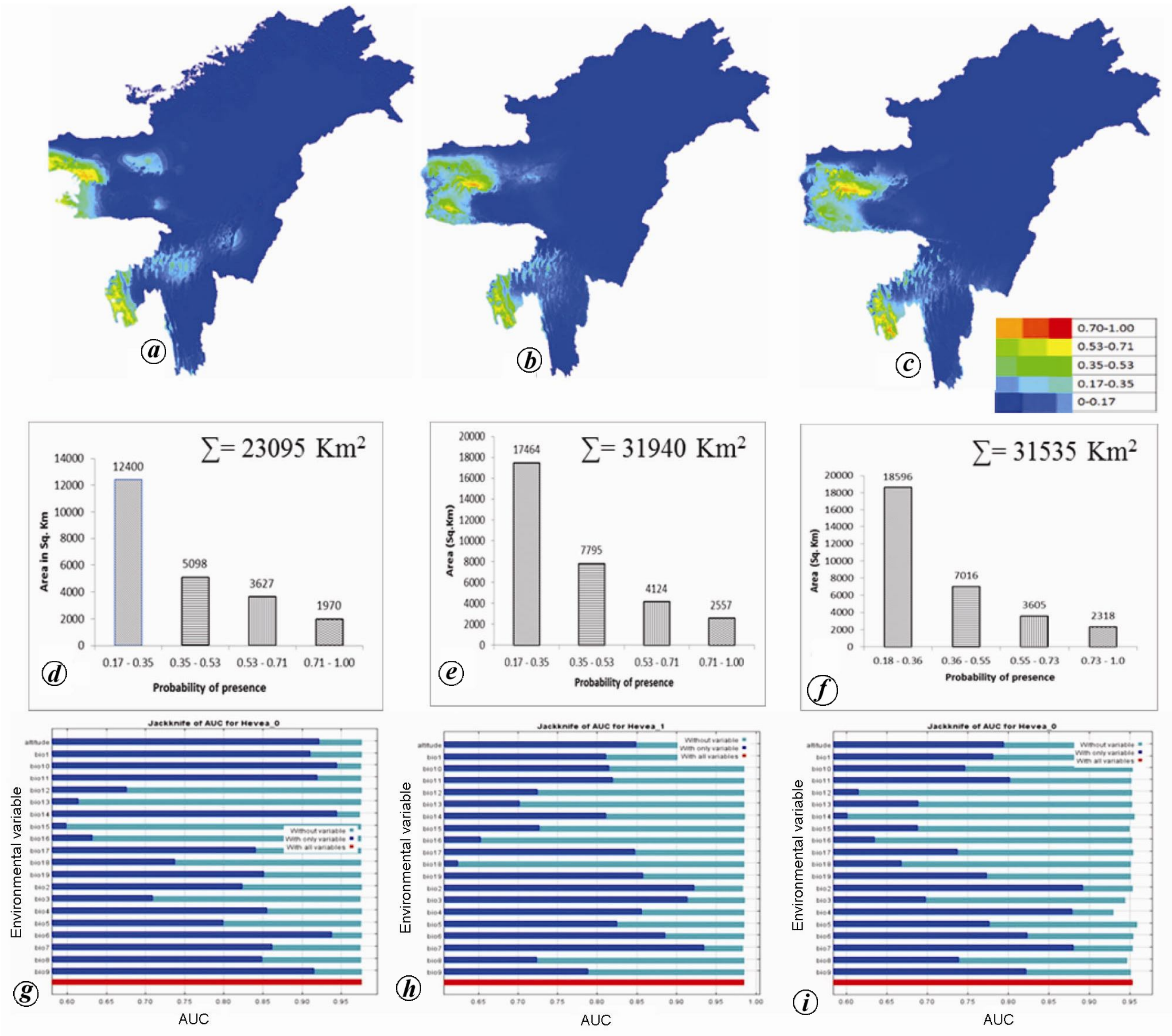

Figure 5. ***a***, Current distribution map of rubber trees. ***b***, ***c***, Prediction of its future expansion in the Brahmaputra valley region in 2020 (***b***) and (***c***) 2050. ***d–f***, Area under different levels of probability for presence of rubber trees in the Brahmaputra valley for (***d***) present conditions and for future predictions under (***e***) 2020 and (***f***) 2050 projected scenarios. ***g–i***, Maxent model generated jackknife plot indicating the importance of different climate variables in rubber tree distribution in Brahmaputra valley in (***g***) present, (***h***) 2020 and (***i***) 2050 scenarios. Warmer colours indicate the areas with better predicted conditions for the species (referred here as best suitable areas having probability between 0.75 and 1 and moderate conditions (probability 0.5 to 0.75) and lighter shades (below 0.5) indicate low predicted probability of suitable conditions.

the Indian Rubber Board, current extension activities of the plantation are being undertaken mainly in Goalpara district. This ground truth information has been reflected in the Maxent model predicted rubber tree distribution map, where the same region has come up as the best niche for the species. Therefore, we consider that prediction for 2020 climate scenario is justified and it reflects the correctness of the policy taken by Indian Rubber Board for current extension activities in the Brahmaputra valley region. The limited scope of further expansion of rubber tree cultivation in the Western Ghats region has been well depicted in the modelled results as declining trend of total suitable area and best suitable niche area of rubber trees from the present scenario to 2020 and further down to 2050 (Figure 6 *e* and *f*) and on the contrary, there is further scope for expansion of rubber plantation in the upper Brahmaputra valley till 2020 (Figure 5 *e*). We predict that climatic suitability for rubber tree cultivation will be challenging in 2050 even in this part of India (Figure 5 *f*). Therefore, we believe that the predicted distribution of rubber trees can act as a guideline for further expansion of its cultivation in future.

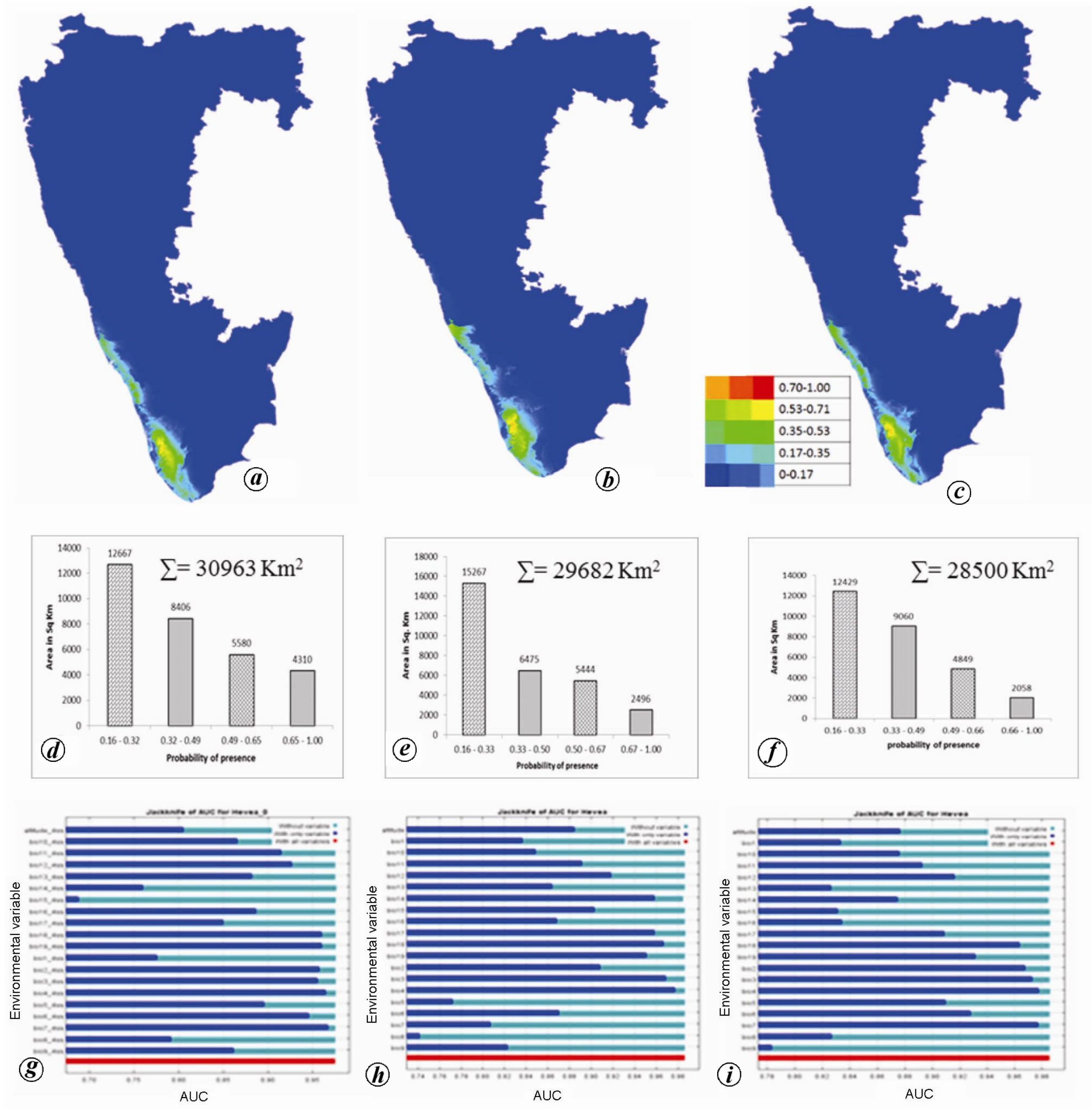

Figure 6. ***a***, Current distribution map of rubber trees. ***b***, ***c***, Future prediction in the Western Ghats region in (***b***) 2020 and (***c***) 2050. ***d–f***, Area under different levels of probability of presence in the Western Ghats region for (***d***) present conditions and future predictions under (***e***) 2020 and (***f***) 2050 scenario. ***g–i***, Maxent model generated jackknife plot indicating the importance of different climate variables in rubber tree distribution in the Western Ghats region at different timescales, i.e. (***g***) present, (***h***) 2020 and (***i***) 2050. Warmer colours indicate the areas with better predicted conditions for the species (referred here as best suitable areas having probability between 0.75 and 1 and moderate conditions (probability 0.5 to 0.75) and lighter shades (below 0.5) indicate low predicted probability of suitable conditions.

Discussion and conclusion

Factors contributing to rubber tree distribution

The additional advantage of species distribution modelling can be the capability of identifying the attributing factors for colonizing a particular species in an ecological set up. Loo *et al.*[22] indicated that soil nutrient status was the crucial factor for invasion of an aquatic plant, *Glyceria maxima,* in Australia. Similar studies with 48 tropical plant species revealed that soil water availability is a direct determinant for distribution of tropical tree species both at local as well as regional scale[23,24]. In the present study, the results indicated that climatic parameters related to temperature and rainfall are the most important factors contributing towards the distribution of rubber tree in these two regions of India. More specifically, temperature-related parameters used in Maxent model play a major role in the Brahmaputra valley for expansion of rubber plantation as it comes under sub-Himalayan region where low winter temperature is the typical climatic determinant. Meteorologically, monsoon-driven rainfall pattern in both regions of the study area indicates that precipitation, i.e. the soil moisture conditions are not the major limiting factor for rubber tree cultivation.

The present study was extended further to test the inter-predictability of the model calibrating with occurrence data points from the Western Ghats and projected in the Brahmaputra valley and vice versa. The preliminary results indicate that model calibrated with the Western Ghats data can predict the possibility of species presence in the Brahmaputra valley reasonably well (data not shown here); but the model over-predicts for the Western Ghats. This indicates the dissimilarity of bioclimatic variables between two regions and could be a major issue in model transferability in space.

However, previous field-based studies on climatic requirements of rubber trees indicated that any climate with minimum temperature of <10°C during peak winter season and maximum temperature of >36°C during peak summer season has a prominent negative impact on the annual growth and yield[25]. It was also observed that less fluctuation in temperature with adequate precipitation is the climatic characteristic of the areas with higher rubber productivity[26]. In general, Tripura and other parts of the Brahmaputra valley experience per-humid climatic conditions due to monsoon-driven rainfall pattern[27]. The soil moisture deficit condition experienced in certain parts of this region during winter period was found to be comparable with that of the South Kerala region that appears to be the attributing factor for rubber yield in both the regions[28]. The Maxent model simulation for rubber tree distribution also results in similar inferences based on jackknife plots, indicating the importance of climatic factors like annual range of temperature and minimum temperature in coldest months and precipitation in driest month in the distribution of rubber plantations. In another study, long-term changes in climate in major rubber-growing regions of India were quantified and their impact on natural rubber productivity was estimated using multiple regression models and the analysis indicates that natural rubber productivity in Brahmaputra valley will increase in next decade if the present trend of climate warming continues[29].

The Maxent model has predicted the current distribution of rubber trees fairly reliably both in the Brahmaputra valley and the Western Ghats region. The model predicted future distribution of rubber plantations corroborates with the ongoing extension activities of Indian Rubber Board in the Brahmaputra valley region. In spite of the limitation of the Maxent model being a statistical relationship between the species presence and its climatic requirement, identification of suitable drivers for determining expansion of its cultivation may improve the predictability of the model. During our field visit to the study area, it was observed that social factors such as the institutional support by the local government, land availability and availability of labour (urban/rural) contributed to rapid expansion of rubber cultivation in certain parts of the study area. Soil health-related parameters such as soil depth, nutrient availability, etc. are crucial for rubber tree cultivation, though the crop has got wide adaptability for its growth and development. Integration of social and soil parameters into the Maxent model can certainly improve its predictability, as indicated by Wise *et al.*[29]. In addition, incorporation of existing land use and land cover (LULC) scenario of Brahmaputra valley may improve the accuracy of the model output. LULC map-based determination of new areas for further expansion of plantations will certainly help the policy makers to plan for new planting programmes in the region. Identification of decisive variables for rubber tree cultivation in future climate scenarios may lead scientists to plan crop improvement programmes for developing clones suitable to future climate.

In the present scenario of higher price of natural rubber in the global market, temporal change in the regions suitable for rubber trees can have economic implications. Any future work on assessment of economic loss or gain associated with shifting of rubber tree niches in India will draw the attention of policy makers. Regional developments are closely associated with successful invasion of such cash crops like rubber and therefore, the relevance of species distribution model in economic development of rubber tree-growing regions is prominent. Thus, we can conclude that the Maxent species distribution model has simulated the current distribution of rubber trees, which is quite close to the ground realities. The model has successfully adapted the projected future climate data and revealed that climatic suitability of rubber trees will be more prominent in the Brahmaputra valley region compared to the Western Ghats of India in 2020. In both the regions, chances of further increase in suitable areas for rubber tree cultivation are limited in 2050 climate. However, the need is felt for refinement of the model by taking soil parameters, social drivers and other related factors into consideration, which will transform the Maxent model into a habitat suitability model for a cultivated species like the rubber trees. We also foresee to derive a framework consisting of other mechanistic models to generate species suitability mapping based on physiological requirement of the species.

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