RESEARCH ARTICLE

ECOLOGICAL NICHE MODELLING FOR *MANORANJITHAM*, AN ENDEMIC AND THREATENED BANANA CULTIVAR OF EASTERN GHATS, SOUTH INDIA

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Abstract: Predictive habitat distribution modelling framework for *Manoranjitham* (*Karuvazhai*), an important endemic fragrant banana cultivar of Eastern Ghats, South India has been analyzed using Maximum Entropy method. Presence points (geographical coordinates) were collected using a global positioning system during exploration survey visits for the collection of germplasm in Eastern Ghats, Tamil Nadu. MaxEnt software version 3.3.3k downloaded from www.cs.princeton.edu/~schapire/maxent was used for habitat modelling. The climate models generated for the present and future climates indicating that climate suitable regions for cultivation and on-farm conservation are available in parts of Andhra Pradesh (Prakasam, Chittoor), Tamil Nadu (Chengalpattu, North Arcot Ambedkar, Tiruvannamalai, South Arcot, Dharmapuri, Nilgiri, Periyar, Salem, Tiruchchirappalli, Thanjavur, Coimbatore, Dindigul, Madurai, Pasumpon, Pudukkottai) and Kerala (Kannur, Kozhikode, Malappuram, Palakkad, Thrissur, Ernakulam). Highest probability value of 0.75 to 1.00 has been obtained for the above-mentioned states in India for climate suitability. These districts of South India could be targeted for phased introduction of this elite banana cultivar, selection of cultivation sites based on climate suitability, identifying *on-farm* conservation areas, and for managing other related genetic resources activities in the climate change regime. Accordingly, contingent plan for sustainable cultivation and on-farm conservation of *Manoranjitham* landrace is to be developed.

Keywords: Banana, Conservation, Cultivation, *Manoranjitham*, DIVA-GIS, MaxEnt

INTRODUCTION

South India is endowed with a few endemic banana landraces/cultivars viz., *Manoranjitham, Namaran, Nendran, Poovazhai, Sevvazahi, Sirumalai, Virupakshi, etc.* Of these Manoranjitham, a hill banana cultivar which is restricted to the southern part of Eastern Ghats (Kolli hills) in Tamil Nadu, India is given much importance due to its rarity, sacredness and other economic values. *Manoranjitham* banana landrace is also known as *Kari Vazhai*, *Karu Vazhai*, *Krishna Vazhai* and *Santhana Vazhai*. This critically endangered banana landrace known to possess useful fatty acids/volatile compounds such as n-Hexadecanoic acid, 1-Heptatriacotanol, Diphenyl sulfone, Dihydro-neotigogenin dibenzoate, 19,21-Tetracontadiyne, 1,2-Epoxy-5,9-cyclododecadiene, Trilinolein etc. (Sreejith et al., 2016). These bioactive compounds present in this banana landrace are known to possess industrial and pharmaceutical applications such as lubricant, antiandrogenic, flavour, hypocholesterolaemia, haemolytic, hepatoprotective, antioxidant, nematicide, pesticide and 5- alpha reductase inhibitor, anti-inflammatory, antifungal and antibacterial properties. It is tolerant to Eumusae leaf spot disease (*Mycosphaerella eumusae*) and the rapid genetic erosion in habitats is a major concern in the climate change regime. All the above factors strengthened the need for conserving the critically endangered aromatic banana cultivar. Attempts have been made by Indian Council of Agricultural Research-National Research Centre for Banana (ICAR-NRCB) to rejuvenate this fragrant banana landrace with breeding potential successfully and this has resulted in expansion of area under cultivation in the natural habitat for the economic, food and nutritional security of the tribal farmers of this region. Also, ICAR-NRCB is striving hard to streamline the marketing and branding of *Manoranjitham,* and to obtain Geographical Indication tag. In order to identify climate suitable growing regions and to conserve this rare and fragrant banana landrace *on-farm*, in the changed climatic regime, an attempt has been made to carryout ecological niche modelling studies. Mapping the climate suitable regions using ecological niche modelling is one such step for predicting the spatial distribution, spatial abundance, sustainable cultivation and on-farm conservation. The data so generated, it is hoped, would be used for planning proper conservation strategies and for crop expansion in this area to sustain agricultural development. Thus, improving livelihood and nutritional security among rural population of this region.

Plant Description

Manoranjitham banana land race possesses a very good aromatic flavour which bears a resemblance to fragrance of *Artabotrys* flower. It is characterized by

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a slender, black pseudostem of 2.5–2.9 m high with 4–7 suckers and very robust with dark black blotches extend up to the petiolar base. Leaves dark green and the laminar bass are asymmetric with one side pointed and other one is slightly rounded. Petiole canal is opened with pink lined margins. Peduncle is short, green and hairy nature. Inflorescence sub-horizontal or oblique with a green and densely pubescent peduncle, 50–53 cm long, 10 cm girth. Male bud is dark purple in colour and the bracts are ended with pointed tip. Male flowers are whitish to yellowish in colour. Bract scars are very predominant. Fruits are dark green; change into green yellow or yellow upon ripened and gives very pleasant aromatic odour. Fruit bunch lax, 3– 5 hands and 7–10 fruits per hand in two rows, fingers pedicelled; pedicel very small, 0.5–1 cm long, fused at base. Fruits on mid hand 8–10 cm long, circumference 9–13 cm, straight or slightly curved, pronouncedly ridged in cross section, apex lengthily pointed, without any floral relicts, immature peel colour dark green, become bright yellow with slight greenish tinge at tip on ripening, peel very thin; immature fruit pulp creamy white, becoming cream on ripening, the ripened pulp when pressed at the tip splits in to three longitudinal parts, very sweet with excellent characteristic flavour and taste, seeds completely absent.

Characteristics of the study area

The study area (Kolli hills) falls in southern Eastern Ghats region in Namakkal district, Tamil Nadu and has area of 418.5 Km^2. The geographical coordinates of the study area are between 11^{0}10 - 11^{o}30 N latitude and 75^{o}10 - 75^{o}30' E longitude respectively (Suresh, 2010). It is bounded by Namakkal in the south and South-west. Rasipuram is in the North East. Attur Taluk is in the North and Tiruchirapalli district in the East. The study area contains high rising peaks and ravines. The highest point in Kolli hills is 4663 feet above mean sea level, but the general level of the upper surface of the hills is not more than 3500 feet (1000m). It's Eastern and north eastern flanks drain either into Thurayur valley or the valley of Periyar. Forest occupies 44% of the total geographical area. Farming activities occupy about 56% of the area. The total population of Kolli hills as per 2011 census is 39,716 with 150 persons per Km^2 living in 10,700 households. The main inhabitants are *Malayalis*', one of the tribal communities in the Eastern Ghats of India. *Manoranjitham* banana landrace got high sacred value and the fruit is offered to local goddess, *Kongliamman*. The mean annual temperature ranges from 14^o C to 28^{o}C. The average annual rainfall of the hill is around 1600mm of which a major portion is obtained during the rainy season (September, October and November). The soils are deep to very deep, non- calcareous and developed from weathered granite gneiss.

MATERIALS AND METHODS

Data Collection

In the present study, we analyzed the potential sites for the cultivation of banana cultivar *Manoranjitham*, an endemic and endangered variety using the Maximum Entropy (MaxEnt) niche modelling method (http://www.cs.princeton.edu/~schapire/MaxEnt). The geographical coordinates recorded during the exploration mission conducted in 2015 for germplasm collection of crop wild relatives in the Eastern Ghats are used as used as presence points for the species. In addition, the geographical coordinates for the endemic banana variety collected earlier from this region and data available with PGR portal of ICAR-NBPGR (www.nbpgr.ernet.in) were also used.

Environmental variables

Nineteen bioclimatic predictor variables (BC) were selected for building the ecological niche models which represent annual trends, seasonality and extreme or limiting environmental factors. Bioclimatic variables are generally selected based on species ecology (Roura-Pascual *et al*., 2009). For the current and future climate (baseline) of India we used monthly data from the WorldClim (WC) database sourced from global weather stations. The variables, including annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, and precipitations of the wettest and driest months were downloaded from the WorldClim dataset – (freely available at http://www.worldclim.org). The WorldClim data provides interpolated global climate surfaces using latitude, longitude and elevation as independent variables and represents long term (1950-2000) monthly means of maximum, minimum, mean temperatures and total rainfall as generic 2.5 arc-min grids.

Model building

MaxEnt 3.3.3k software was used as it requires only presence records and its efficacy has been well recognized (Elith *et al*. 2006; Phillips *et al*. 2006; Phillips & Dudik 2008). These models included the regularization multiplier (1), maximum number of iterations (500), maximum number of background points (10, 000) and convergence threshold (0.00001) and 25 % of the data were reserved to test the model. The outputs of ten replicates were combined to give a mean output. A logistic output for constructing the predictive models was selected as it is the easiest to comprehend, giving a value between 0 and 1 as the probability of occurrence of grass species (Phillips & Dudik 2008). Jackknife analyses and mean area-under-curve (AUC) plots were created using MaxEnt. AUC is commonly used as a test of the overall performance of the model and it remains a handy indication of the usefulness of a model (Elith *et al*. 2006, 2011). A value of 1.00 is an exact agreement with the model, while a value of

0.50 represents a random fit. Jackknife analysis indicates which variable has the greatest stimulus on the model and the overall success of the model. DIVA-GIS software version 7.5, freely downloadable software from www.diva-gis.org was used to generate the potential distribution map with input ASCI file obtained in MaxEnt analysis (maxium entropy method).

RESULTS AND DISCUSSION

MaxEnt Analysis
Maximum Entropy (MaxEnt) is a niche modelling approach that has been developed linking species distribution information built only on identified presences and is a general-purpose method for making predictions or inferences from incomplete information. MaxEnt can take the environmental conditions at occurrence locations and produce a probability distribution that can then be used to assess every other location for its likely occurrence. The result is a map of the probability of conditions being favourable to occurrence. It estimates target prospective cultivation sites of *Manoranjitham* in India by finding the highest probability of distribution of the maximum entropy (*i.e*., most spread out or closest to uniform with indication to a set of bioclimatic variables).

Figure 1 & 2 depicts the MaxEnt model for potential climate suitable sites for the cultivation of Manoranjitham landrace based on the present and future climate scenario respectively, in India. Warmer colours indicate the highest probability of climate suitable sites of *Manoranjitham* in India. Three states covering 23 districts, as listed below are the best climate suitable regions for the cultivation of *Manoranjitham* banana landrace. Andhra Pradesh (Prakasam, Chittoor); *Tamil Nadu* (Chengalpattu, North Arcot Ambedkar, Tiruvannamalai, South Arcot, Dharmapuri, Nilgiri, Periyar, Salem, Tiruchchirappalli, Thanjavur, Coimbatore, Dindigul, Madurai, Pasumpon, Pudukkottai; Kerala (Kannur, Kozhikode, Malappuram, Palakkad, Thrissur, Ernakulam).

Highest probability value (Shannon index) ranging from 0.7 to 1.0 observed in all 23 districts covering three states. Interestingly, in addition to these three states, Northern parts of Andaman and Nicobar Islands are also suitable for cultivation as inferred from ecological niche model generated for future climate (Fig. 2).

Figures 3 & 4 shows the omission rate and predicted area as a function of the cumulative threshold for current and future climatic scenario respectively. The omission rate is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.

Table 1 gives estimates of relative contributions of the environmental variables to the MaxEnt model for current and future climatic scenario. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is re-evaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages. The regularized training gain is 5.368, training AUC is 0.999, un regularized training gain is 6.085 in case of current climate scenario while the regularized training gain is 5.199, training AUC is 0.999; unregularized training gain is 6.079 for the future climate. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated. Precipitation of wettest month (Bio 13), Precipitation of driest month (Bio 14), Precipitation of coldest quarter (Bio 19)and Precipitation of driest quarter (Bio 17) are the top four variables contributing maximum to MaxEnt model for current climate with 26.5%, 20.2%, 16.3% and 10.9% respectively, while for future climate model, Isothermality (Bio 3), Precipitation seasonality (Bio15), Precipitation of driest quarter (Bio 17) and Precipitation of wettest month (Bio 13) are the major contributors with 24.65%, 21.6%, 12.4% and 12.1 respectively (see Table 1). Interestingly, the following bioclimatic variables *viz*., Temperature seasonality (Bio 4), Mean temperature of coldest quarter (Bio 11) and Annual precipitation (Bio 12) have no contribution in current and future climate models.

Response curves
Figures 5 (A, B, C, D) are the response curves which shows that how each environmental variable affects the MaxEnt prediction for current climate model influenced by top four environmental variables viz., Precipitation of wettest month (Bio 13), Precipitation of driest month (Bio 14), Precipitation of coldest quarter (Bio 19) and Precipitation of driest quarter (Bio 17). The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The response curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together. In contrast to the above marginal response curves, Figures 5 (E, F, G, H) each of the following curves represents a different model, namely, a MaxEnt model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the

selected variable and other variables. Similarly, Figures 6 (A, B, C, D) represent the response curves for high influence bioclimatic variables such as Isothermality (Bio 3), Precipitation seasonality (Bio15), Precipitation of driest quarter (Bio 17) and Precipitation of wettest month (Bio 13) for future climate prediction model. Figures 6 (E, F, G, H) presents the dependence of predicted suitability for future climatic model.

Maximum entropy (MaxEnt) is considered as the most accurate model performing extremely well in predicting occurrences in relation to other common approaches (Elith *et al*., 2006; Hijmans and Graham, 2006), especially with incomplete information. MaxEnt is a niche modelling method that has been developed involving species distribution information based only on known presences. MaxEnt is a niche modelling method and was selected to model potential current and future climate suitability for cultivation of *Dinanath* grass in the present study. MaxEnt has been successfully used by many researchers earlier to predict distributions such as stony corals (Tittensor *et al*., 2009); green bottle blue fly (Williams *et al*., 2014); macrofungi (Wollan *et al*., 2008); seaweeds (Verbruggen *etal*., 2009); sorghum (Sivaraj et al.,2016); forests (Carnaval and Moritz, 2008); rare plants (Williams *et al*., 2009) and many other species (Elith *et al*., 2006). Several articles describe its use in ecological modelling and explain the various parameters and measures involved (Philips *et al*., 2004, 2006; Elith *et al*., 2011. Reddy *et al*., (2015 a, b) presents a novel approach to assess the potential areas for extending the cultivation of Roselle and Ceylon spinach using MaxEnt with regional-level occurrence data. The identified districts/states in the present study could be targeted for selection of cultivation sites of elite *Manoranjitham* banana landrace based on climate suitability and for identifying *in-situ* conservation areas, and managing other related genetic resources activities.

Table 1. Estimates of relative contributions of the environmental variables to the Maxent model for Manoranjitham banana

Variables	Current Climate		Future Climate	
	Percent contribution	**Permutation importance**	**Percent contribution**	**Permutation importance**
Precipitation of wettest month (Bio 13)	26.5	1	12.1	0.1
Precipitation of driest month (Bio 14)	20.2	38.9	0.2	0
Precipitation of coldest quarter (Bio 19)	16.3	1.2	11.1	0.4
Precipitation of driest quarter (Bio 17)	10.9	39.5	12.4	2.6
Max temperature of warmest month (Bio 5)	7.9	0	0	0
Mean temperature of driest quarter (Bio 9)	7	0	0.5	0.1
Precipitation of warmest quarter (Bio 18)	4.6	0.1	3.8	0
Mean Temperature of westtest quarter (Bio 8)	2	0	0.8	0
Isothermality (Bio 3)	1.9	0.3	24.6	85.8
Mean temperature of warmest quarter (Bio 10)	1.5	0	1.7	0.6
Mean diurnal range (Bio 2)	0.9	18.8	4.7	10.4
Annual mean temperature (Bio 1)	0.2	0	0	0
Min temperature of coldest month (Bio 6)	0.1	0.1	2.3	0
Temperature annual range (Bio 7)	0.1	0	2.7	0
Temperature seasonality (Bio 4)	0	0	0	0
Mean temperature of coldest quarter (Bio 11)	0	0	0	0
Annual precipitation (Bio 12)	0	0	0	0
Precipitation seasonality (Bio15)	0	0	21.6	0
Precipitation of wettest quarter (Bio16)	0	0	1.5	0
Mean temperature of driest quarter (Bio 9)	0	0	0.5	0.1

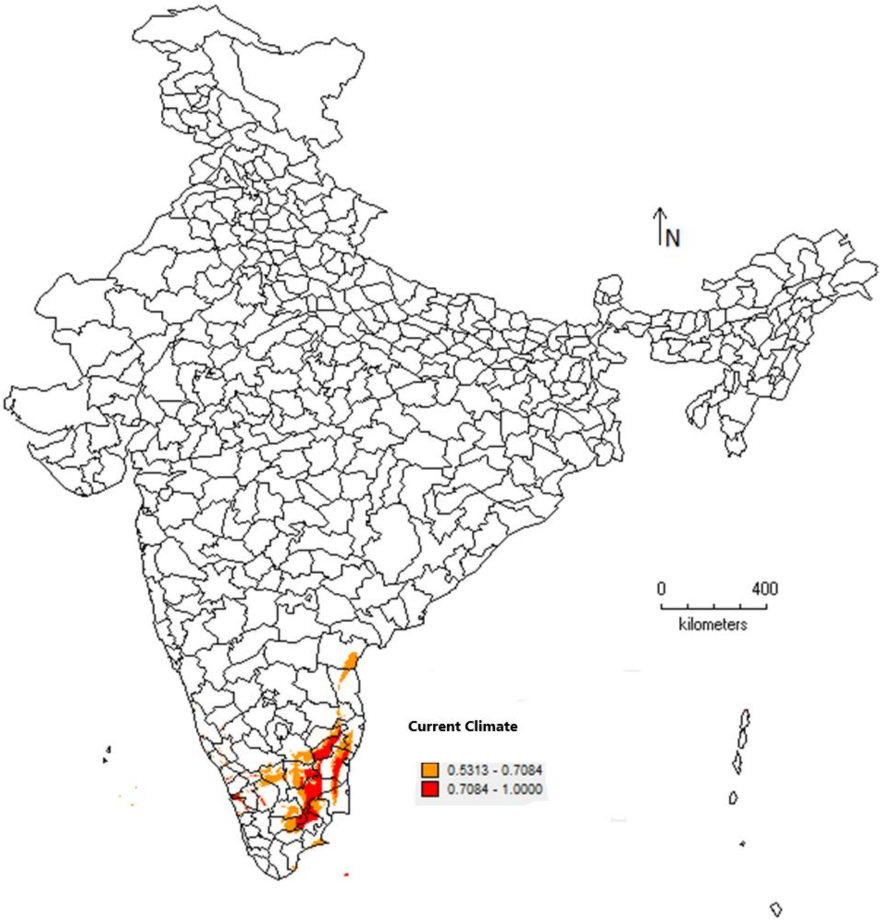

Fig. 1: Ecological Niche Model for Manoranjitham Banana for current Climate

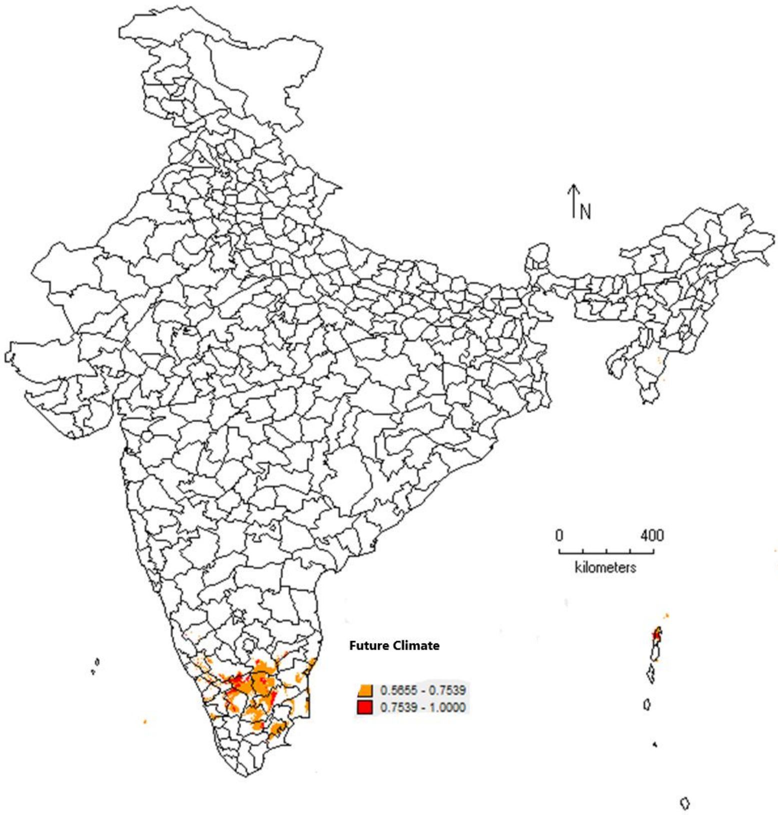

Fig. 2: Ecological Niche Model for Manoranjitham Banana for Future Climate

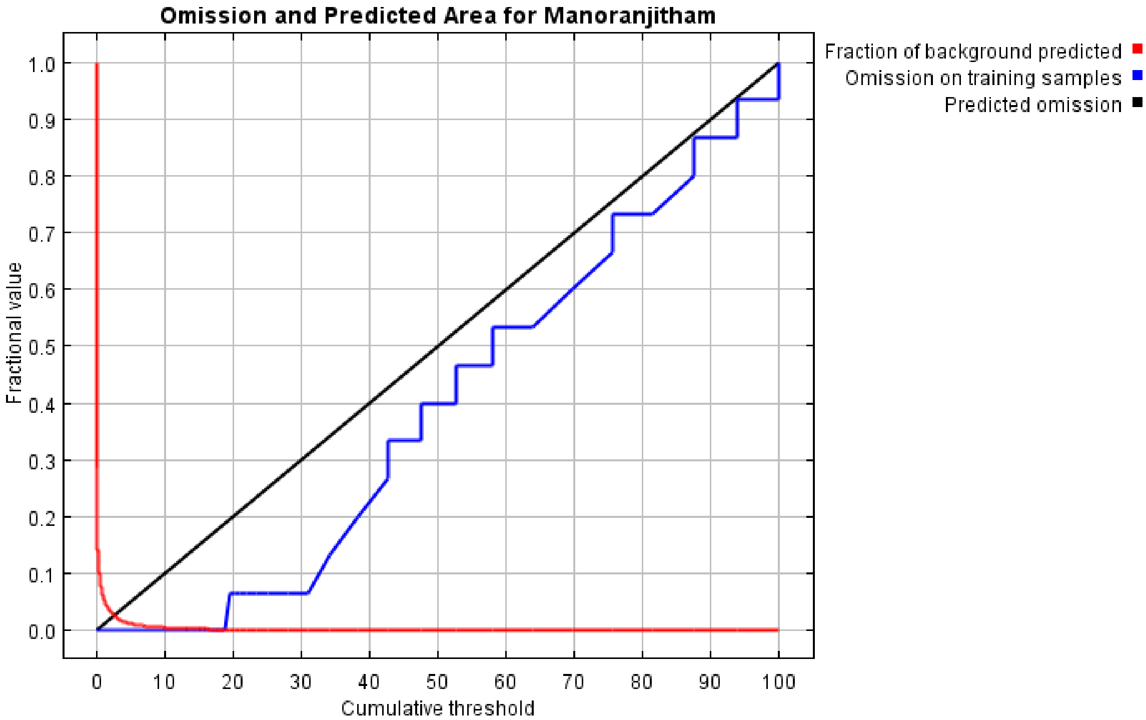

Fig. 3. Omission and Predicted Areas depicted for Manoranjitham in Maxent model (for Current climate)

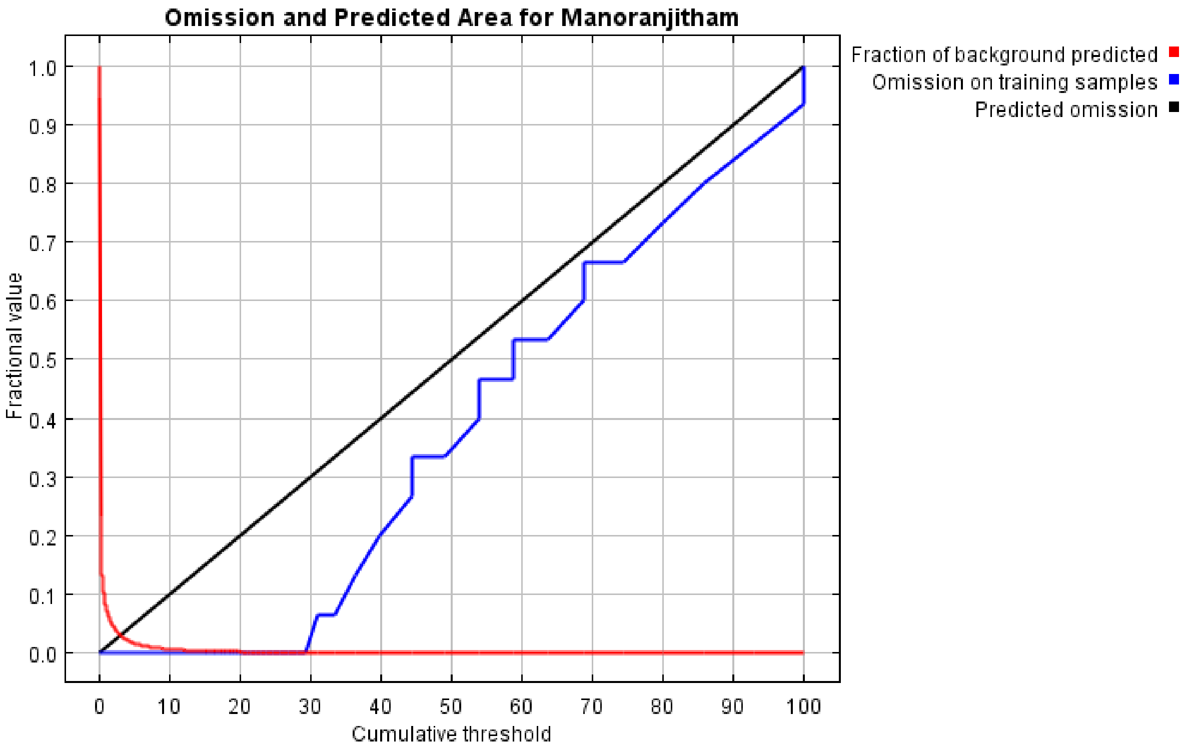

Fig. 4. Omission and Predicted Areas depicted for Manoranjitham in Maxent model (for Future climate)

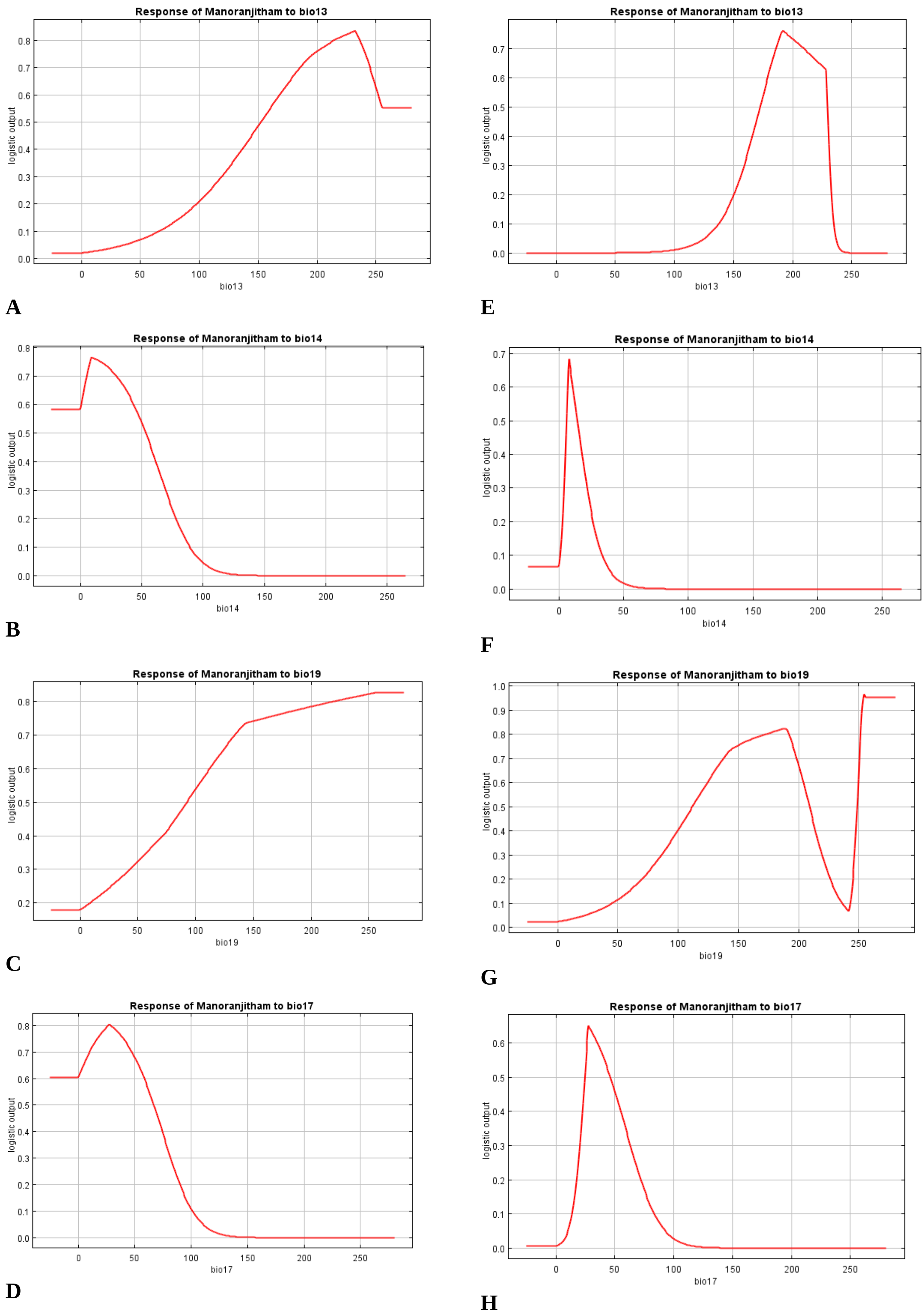

Fig 5. Response curves for bioclimatic variables having high influence on the MaxEnt Model for Current climate (A,B,C,D) and dependencies induced by correlations (E,F,G,H)

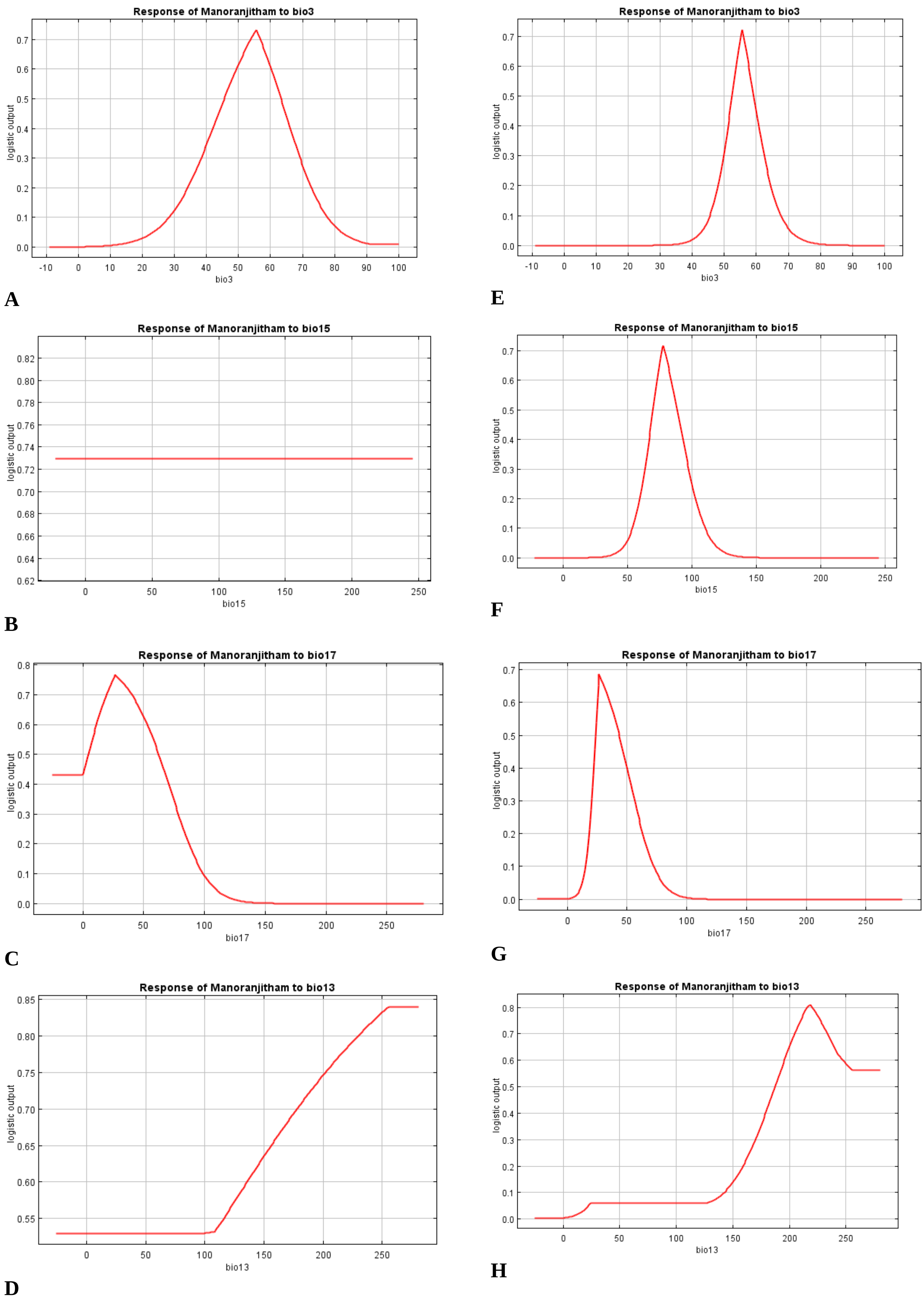

Fig 6. Response curves for bioclimatic variables having high influence on the MaxEnt Model for Future climate (A,B,C,D) and dependencies induced by correlations (E,F,G,H)

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