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# Climate change impact on the distribution of *Tossa* jute using maximum entropy and educational global climate modelling

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## Abstract

*Tossa* (*Corchorus olitorius* L.) is a significant cash crop, cultivated commercially in the lower flood plain of Bangladesh. The climatic regimes in Bangladesh are changing as well as the world does. However, this species is threatened by climate change. Occurrences of data on threatened and endangered species are frequently sparse which makes it difficult to analyse the species suitable habitat distribution using various modelling approaches. The current paper used maximum entropy (Maxent) and educational global climate model (EdGCM) modelling to predict and conserve the suitable habitat distributions for *Tossa* species in Bangladesh to the year 2100. Nine environmental variables, 239 occurrence data and two Representative Concentration Pathway scenarios (RCP4.5 and RCP8.5) were used for the Maxent modelling to project the impact of climate change on the *Tossa* distributions. Furthermore, the EdGCM was used to study the climatic space suitability for the *Tossa* species in the context of Bangladesh. Both of the climatic scenarios were used for the prediction to the year 2100. The Maxent model performed better than random for the *Tossa* species with a high AUC value of 0.86. Under the RCP scenarios, the Maxent model predicted habitat reduction for RCP4.5 is 2%, RCP8.5 is 9% and EdGCM is 10.2% from the current localities. The predictive modelling approach presented here is promising and can be applied to other important species for conservation planning, monitoring and management, especially those under the threat of extinction due to climate change.

## Introduction

*Tossa* (*Corchorus olitorius* L.) is known as '*sonali ansh*' (the *golden fibre*) of Bangladesh which is the finest-quality natural jute fibre (Mir *et al*., 2008). *Tossa* is broadly cultivated in Bangladesh, India, Nepal, China, Indonesia, Thailand, Myanmar and South American countries (Mukul *et al*., 2021). *Tossa* was cultivated commercially as a traditional cash crop and used as a commercial source of fibre in Bangladesh (Rahman *et al*., 2017). It belongs to the genus *Corchorus* of the family *Malvaceae*, which consists of 50–60 species distributed all over the tropical and sub-tropical region (Bayer and Kubitzki, 2003). Fibres stripped from the *Tossa* stem are used in packaging (bags, ropes, carpet, sacks), for coarse cloth and paper, handicrafts for home decoration, shoes and jewellery, etc. *Tossa* is also used to produce insulation, engineered wood, animal food, seed oil and potential bio-fuel (Das *et al*., 2012; Chakraborty *et al*., 2015). *Tossa* is cultivated in the lower flood plain of Bangladesh from mid-April to September (YAS, 2015). It has tolerance to drought but is prone to waterlogged conditions (Prodhan *et al*., 2001). It has higher productivity in loamy and clay soil (Banerjee, 1955) where, weather condition also influences to grow world's best quality of jute in Bangladesh. Even though Bangladesh is the largest exporting country contributes approximately 39% of the overall raw jute supply cultivated on 39% of the total worldwide jute area (Rahman *et al*., 2017). Its production is estimated lower despite extending planting due to crop damage with excessive rainfall, premature harvesting, lack of labour and farmers' choice of paddy production.

Climate change encompasses both global warmings caused by greenhouse gas emissions and the ensuing large-scale weather pattern adjustments. Climate feedbacks such as the loss of sunlight-reflecting snow and ice cover, increasing water vapour (a greenhouse gas) and changes to land and ocean carbon sinks speed up or slow down temperature rise. Warmer temperatures increase evaporation rates, resulting in more severe storms and weather extremes (IPCC, 2013). Many of the expected effects of climate change will exacerbate Bangladesh's existing environmental problems, i.e. increased flooding, increased drought and temperature extremes (Huq and Ayers, 2008). The production of *Tossa* is detrimental due to global warming, e.g. drought by increased temperature and excessive rainfall or flood, while it can thrive at a minimum temperature of 15°C to maximum temperature of 38°C and may increase up to 46°C (Islam *et al*., 2009). The seed sowing time has been changed over time due to changing response of increased temperature and rainfall. The increased temperature due to climate change is substantial for ecosystem and biodiversity loss, which affects species' natural distribution (Glick *et al*., 2011; Anup, 2021). Conservation is important to mitigate the impacts of climate change on the ecosystem (Balmford and Bond, 2005). Therefore, two Representative Concentration Pathway scenarios (RCP4.5 and RCP8.5) of global warming were selected to identify the climatic influence on the distribution of *Tossa* in Bangladesh for the 21st century (Solomon *et al*., 2007).

Maximum entropy (Maxent) modelling was used to detect the occurrences of *Tossa* in Bangladesh under biophysical and environmental conditions. Maxent is the most widely used method for the prediction and mapping of potentially suitable habitat for threatened species with presence-only data which is critical for monitoring and restoration, and selecting conservation sites for the management of the native habitat (Gaston, 1996; Elith *et al*., 2006). It could be performed using a small number of occurrence records successfully and statistically significant (Kumar and Stohlgren, 2009). There was a recent study in the Journal of *Agricultural Science* that used the state-of-the-art techniques of Maxent in geo-spatial sciences and computer soft supremacy which have aided numerous studies of climate change impact and spatial modelling (Chhogyel *et al*., 2020). In the current study, the significance of Maxent modelling is to predict the potentially suitable habitat for *Tossa* in Bangladesh using nine environmental variables consequently prioritizing conservation needs.

EdGCM has been used to study the climatic variation of Bangladesh at a regional scale to the upcoming decades of 2100 (Ishaque *et al*., 2021). It has the benefit to the climatic model setup, model operation, post-processing, interpretation and scientific visualization developed by NASA and Columbia University (Saadat *et al*., 2012). It deals with the assembly of climate impacts that will occur over the coming decades (Chandler *et al*., 2011).

Recently, global warming is one of the threatening problems due to emissions of greenhouse gases. This leads to the amplified sea level, monsoon shifting, melted glaciers and natural hazards, i.e. floods, cyclones and droughts. *Tossa Jute* production is probable to fall due to deficient monsoon, excessive floods and droughts (Islam *et al*., 2009). The major objectives of the current research were: (1) predicting suitable habitat distribution for threatened *Tossa* to inform conservation planning in Bangladesh; and (2) identifying the environmental factors associated with *Tossa* habitat distribution.

## Materials and methods

### Research site

Bangladesh (20°34′ to 26°38′ North latitude and 88°01′ to 92°41′ East longitude) was primarily a low-lying plain land of about 1 44 000 km$^2$, situated on deltas of large rivers flowing from the Himalayas (Shahid, 2010*a*, 2010*b*). Bangladesh was bordered by India to the west, north and east, by Myanmar to the south-east and by the Bay of Bengal to the south (Fig. 1). Most parts of the country are low-lying land comprising mainly the delta of the Ganges and Brahmaputra rivers (Rashid, 1991). Eighty per cent of the land surface in Bangladesh was a floodplain, 8% terraced and 12% hilly areas (Brammer, 1996; Rahman *et al*., 2005). Only in the extreme northwest are elevations greater than 30 metres above sea level (m a.s.l.). The northeast and southeast portions of the country are hilly, with some tertiary hills over 1000 m a.s.l. (Huq and Asaduzzaman, 1999). Bangladesh has a subtropical humid climate with wide seasonal variations in rainfall and moderately warm temperatures (Shahid, 2010*a*, 2010*b*). The annual average temperature of the country ranges from 17°C to 31°C and annual precipitation varies from 1400 mm in the west to more than 4300 mm in the east of the country (Rahman *et al*., 2021). In Bangladesh rainfall mostly happens in monsoon, instigated by tropical depressions transported from the Bay of Bengal into Bangladesh by the wet monsoon winds (Islam and Uyeda, 2008). The planting time of *Tossa* is during March–April and grows in low-lying land (Gupta *et al*., 2009).

### Species occurrence data

Species occurrence records, Geographical Information System (GIS) environmental layers (bioclimatic and topographic) and the Maxent and educational global climatic modelling (EdGCM) modelling approach were used to predict the potentially suitable habitat for *Tossa* under climate change for the 21st century. The 239 sample points were collected as the zones of *Tossa* in Bangladesh via Global Positioning System (GPS) in 2017 using a stratified random sampling technique. Nine significant environmental variables were subsequently selected as the predictors and used to predict the suitable locations of *Tossa* in Bangladesh. The data of nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) were obtained from Soil Resources Development Institute (SRDI, 2015). Precipitation, temperature, geomorphology and soil pH data were collected from Bangladesh Country Almanac (BCA, 2016). The elevation data were derived from the United States Geological Survey (USGS) (2017). All environmental variables were projected to World Geodetic System (WGS) 1984 Geographic Projection System. All the variables were converted to American Standard Code for Information Interexchange (ASCII) grid format for the analysis at a cell size of (~90 × 90 m) in ArcGIS 10.8.

### Climatic scenarios

The climatic scenarios of RCP4.5 and RCP8.5 were used to project the possible suitable localities of *Tossa* in the context of climatic change (mean temperature rise of 1.8°C and 3.7°C respectively) to the year of 2100 in Bangladesh. While RCP4.5 means radiative forcing increase of 4.5 W/m$^2$, which assumes that greenhouse gas emissions slow down through mid-century and decrease abruptly afterwards (Thomson *et al*., 2011). According to the Intergovernmental Panel on Climate Change (IPCC), RCP8.5 corresponds to persistent increases in greenhouse gas emissions up to the end of the 21st century (IPCC, 2013). 19 bioclimatic variables were used from the Australian Community Climate and Earth-System Simulator (ACCESS1-0) for the year 2070 from the Coupled Model Intercomparison Project (CMIP5) Phase 5 by the IPCC at 30 arc seconds and ~1 km$^2$ resolution (http://worldclim.org/) (Yang *et al*., 2017). Amongst the Global Climate Model (GCM), ACCESS1-0 was used because of the reliable projection of temperature and precipitation which is a historic experiment, projecting the global climate flanked by 1850–2006, by historical forcings (Collier and Uhe, 2012; Dix *et al*., 2013). The bioclimatic variables represent mean annual

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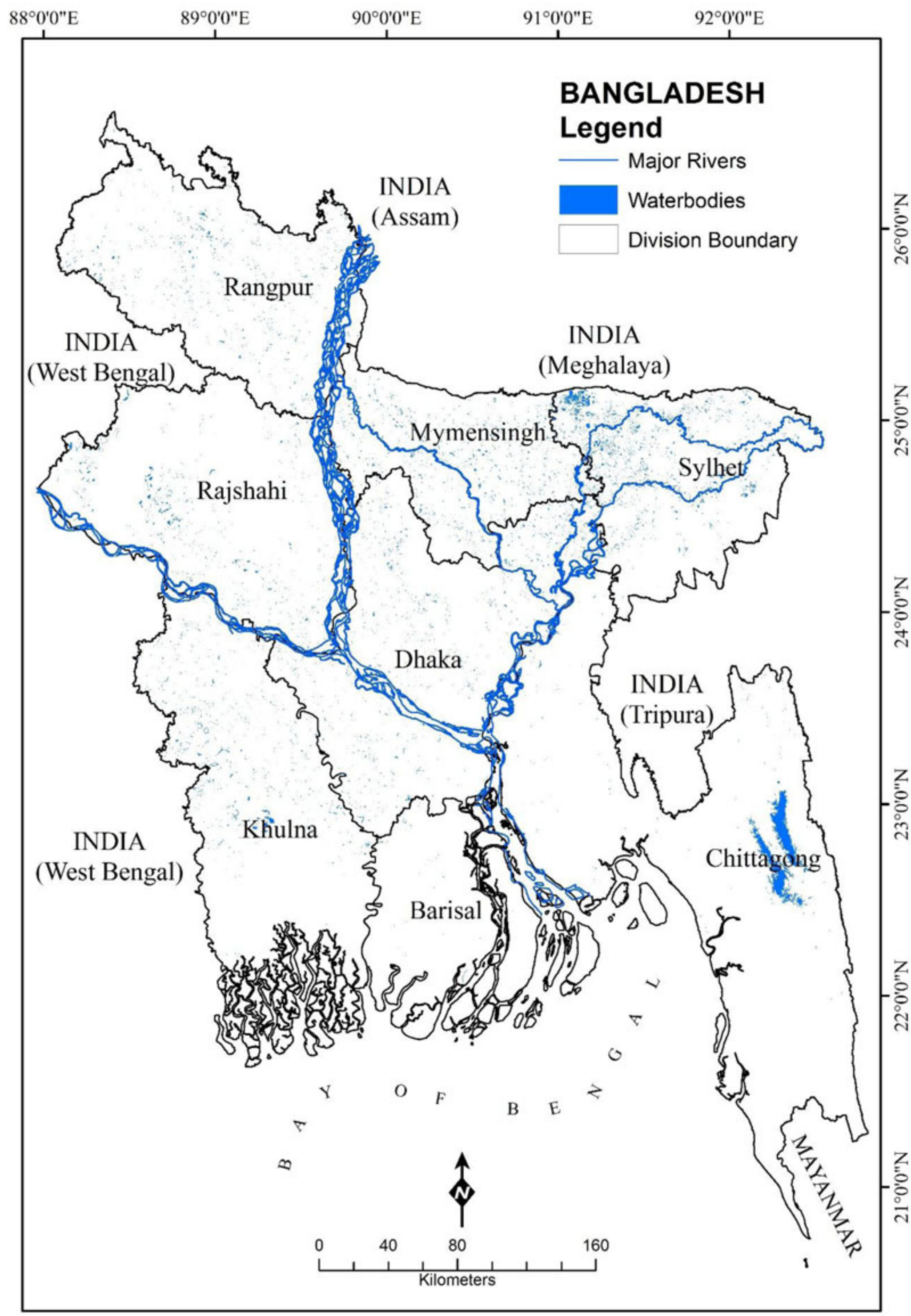


**Fig. 1.** Colour online. The location of Bangladesh including the surrounding border countries.

temperature, annual precipitation; seasonality (e.g. annual range in temperature and precipitation); and temperature of the coldest and warmest month and precipitation of the wet and dry quarters.

### *Maxent modelling algorithm*

Maxent (version 3.3.3, http://www.Cs.princeton.edu/-schapire/maxent/) modelling was used to predict the potential distribution of *Tossa* species from presence-only data and environmental variables (Phillips *et al*., 2004; Zhang *et al*., 2021). Currently, this method is widely used and has the efficiency to handle complex interactions between response and predictor variables (Elith *et al*., 2006). The Maxent modelling was conducted with the default variable responses settings and a logistic output format which resulted in a map of habitat suitability of the species ranging from 0 to 1 per grid cell, wherein the average observation

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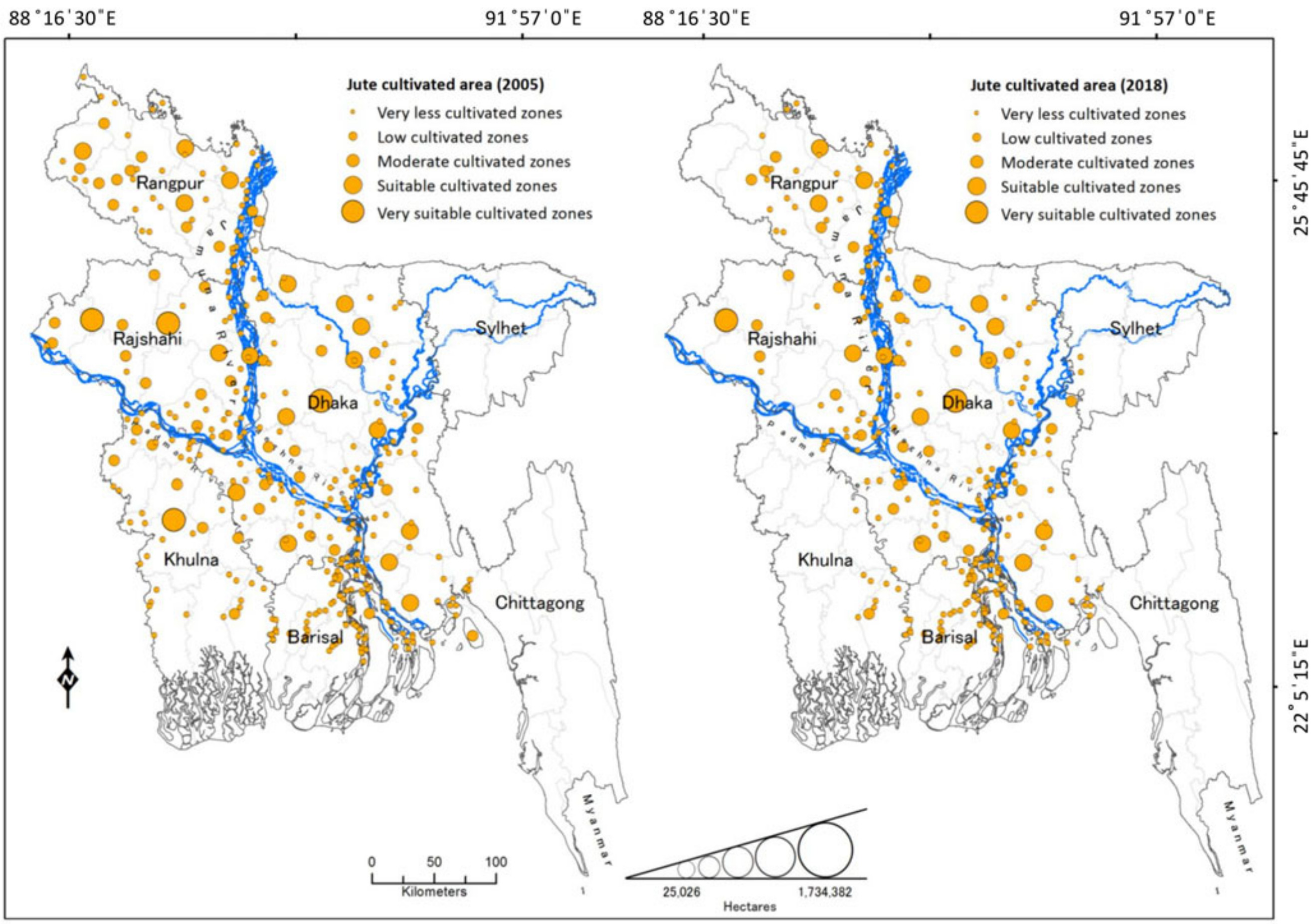


**Fig. 2.** Colour online. The locations of *Tossa* species in 2005 and 2018 through Bangladesh.

should be close to 0.5 (Elith *et al.*, 2011). The models were evaluated by the Area Under the Curve (AUC). The area under the Receiver Operating Curve (ROC), known as AUC which is one of the most common statistics to assess the model performance. AUC can be interpreted as the probability that a presence cell has a higher predicted value than an absence cell, both of them being chosen randomly. 25% data of the samples were used for the testing and 75% for the training in the Maxent modelling algorithm.

### *Educational global climatic modelling (EdGCM)*

EdGCM (version 3.2, build 926) was used to compare the climate modelling results from the scenarios of the IPCC RCP4.5 and RCP8.5 (GISS, 2016). EdGCM is a climate modelling software suite and computationally efficient enough for use on personal computers, which was developed based on the Goddard Institute for Space Studies (GISS) General Circulation Model II, NASA for global climate modelling (Chandler *et al.*, 2005). This model has 7776 grid cells in the atmosphere, with each horizontal column corresponding to the spatial resolution of the climate model is 8° × 10° layers (8° latitude by 10° longitude), containing nine vertical layers, two ground layers (one to model surface absorption and one to model deep ground properties) and two ocean layers (Saadat *et al.*, 2012). It allowed running simulations, post-processing and analysing data using scientific visualization for data display. Scheming for each grid cell was iterated in fifteen-minute (simulation time) during the simulation.

## Results

### *The extinction of* Tossa *in Bangladesh from 2005 to 2018*

The southwestern part of Bangladesh is the most cultivated region of *Tossa* due to favourable weather conditions. Mainly the low-lying flood plain including the riverside area is preferable for the *Tossa* cultivation across the country (Fig. 2). The total area under *Tossa* has been estimated at 677 678 ha in 2018 which is 0.75% higher than that of last year (BBS, 2018). The geographical regions of Brahmaputra Alluvium, Ganges Alluvium and Teesta Silt is known as the Ganges delta in Bangladesh contribute >80% of the jute production in the world (Islam *et al.*, 2015). Brahmaputra Alluvium comprises part of the districts of Dhaka, Mymensingh, Tangail and Comilla of Bangladesh annually receives a fresh deposit of silts carried down by the floodwater including acidic soils with the varied texture from sandy loam to clay loam. The Ganges Alluvium comprises part of the districts of Kushtia, Jessore, Khulna, Rajshahi, Pabna and Dhaka of Bangladesh. The soil of this area is slightly alkaline clay loam to light loam in grey to dark grey colour (NIIR Board of Consultants and Engineers, 2014; Nitu *et al.*, 2019). The northern area of Teesta Silt comprises part of Dinajpur, Rangpur, East

**Table 1.** The contribution of nine environmental variables to the prediction of possible habitats for *Tossa* in Bangladesh

| Variables | Per cent contribution |
|---|---|
| Elevation | 29.1 |
| Nitrogen (N) | 25.9 |
| Temperature | 20.3 |
| Precipitation | 16 |
| Sulphur (S) | 3.9 |
| Potassium (K) | 3.4 |
| Geomorphology | 0.9 |
| Phosphorus (P) | 0.4 |
| Soil pH | 0.1 |

Bogra and Sirajganj districts of Bangladesh, which has sandy soil with low moisture retention capacity including slightly acidic soil retention (Mukund, 2018).

### Evaluation of the Maxent model output

All Maxent model outputs had a high discriminative ability with an average AUC of 0.82 ± 0.02 for the testing data and 0.86 ± 0.02 for the training data while the algorithm terminated after 500 iterations. The threshold-independent Maxent modelling approach performed better with the higher AUC values of 0.86 for ROC (receiver-operation characteristic), because the higher the AUC (ranging from 0.5 to 1.0) the better is the predictive performance and discriminative ability of the model. Based on AUC, the application of the Maxent model has predicted *Tossa* occurrence with high accuracy.

### Contribution of environmental variables

To identify the relative importance of various environmental characteristics for *Tossa* habitat suitability, nine environmental variables were used for the Maxent model. However, the per cent contribution heavily relied on the chosen algorithm and did not reflect correlation among characteristics. Table 1 shows that elevation ranked first (contribution >29%) among all of the nine environmental variables suitable to *Tossa* establishment. N, temperature and precipitation have a cumulative contribution ⩾16% for the suitability prediction of *Tossa.* Soil S and K were also important factors determining the *Tossa* habitat suitability with a contribution of >3%. Geomorphology, soil pH and P gained the least contribution <1% among all the variables.

The most preferred land elevation for *Tossa* was 0 to 3 m since *Tossa* usually grows well in low elevated land and plain alluvial soil (Fig. 3). The preferable N content in the soil was 20–50 kg/ha for *Tossa*. The suitable climate for growing *Tossa* was offered by the monsoon climate (hot and humid). Temperatures ranged from 20°C to 30°C and relative humidity of 70–80% was favourable for successful *Tossa* cultivation. *Tossa* required 1000–2000 mm annual rainfall for the well growing. For healthy *Tossa* cultivation S content in the soil ranged 15–30 kg/ha, K 10–20 kg/ha and P 12–20 kg/ha were suitable. The suitable geomorphology was 0–90 feet and soil pH 4.5–6 for the regeneration *Tossa*.

A Jackknife test was checked to measure the relative importance of each environmental variable (Fig. 4). The environmental variable with the highest gain, when used in isolation, was N, which therefore appeared to have the most useful information by itself. The environmental variable that decreased the gain the most when it is omitted was the temperature, which therefore appeared to have the most information that wasn't present in the other variables. Maxent measured this by ‘gain’, which represented how much better the distribution fitted the sample points.

### *Current potential distribution of* Tossa *species*

The Maxent predictions showed a continuous potential distribution for *Tossa* in Bangladesh. The new high suitability areas occur primarily in the central part of Bangladesh including moderately suitable areas to the south-central part, central-eastern, central-western and central-northern part (Fig. 5). The results showed a larger suitable area of the potential habitat for *Tossa* in Bangladesh which is 5.1% greater than the present area. A low, medium and high habitat suitability of *Tossa* was predicted with different land cover types. Maxent output was categorized into the frequency distribution classes for the habitat suitability as low 0.00–0.23, medium 0.23–0.38, medium-high 0.38–0.62 and high 0.62–1.00 (Yang *et al*., 2013).

### *Global climate impacts on the habitats of* Tossa *to the year 2100*

The two RCP scenarios have varied influences on the distributions of *Tossa* in Bangladesh. Maxent models predicted that the climate suitability for *Tossa* will decline 2% for the RCP4.5 and 9% for the RCP8.5 to the 2100 year (Fig. 6). The RCP4.5 scenario showed the least decrease in the *Tossa* habitat because of the slight projected mean temperature rise (1.8°C), while the RCP8.5 scenario predicted a reasonable decrease in the *Tossa* habitat with the projected mean temperature rise of 3.7°C. The decline for the RCP8.5 scenario was severe because the temperature increase exceeds the tolerable temperature of 30°C, while the decline due to the RCP4.5 scenario was understated. The northern and south-eastern part was predicted as unsuitable with RCP4.5 and RCP8.5 scenarios respectively for the *Tossa* habitat.

RCP4.5 exhibited the three highest-contributing bioclimatic variables as BIO11 (mean air temperature during the coldest quarter; 47.5%), BIO14 (precipitation during the driest month; 17.7%) and BIO8 (mean air temperature during the wettest quarter; 8.8%) (Table 2). BIO17 (precipitation during the driest quarter; 38.6%), BIO18 (precipitation during the warmest quarter; 13.7%) and BIO7 (annual temperature range; 10.5%) presented the highest contributions for RCP8.5. There were no contributions of BIO6 (Min Air Temperature of Coldest Month), BIO15 (seasonal precipitation) and BIO16 (precipitation during the wettest quarter).

The results of EdGCM showed a 4.2°C rise in mean annual temperature and a 1.5 mm decline in rainfall in Bangladesh to the year 2100 (Fig. 7). This increase in temperature and reduced rainfall caused a 10.2% deterioration of the *Tossa* habitat from the existing distribution in Bangladesh.

## Discussion

### Habitat suitability and environmental variables

The distribution of *Tossa* was mostly influenced by the elevation, N, temperature and precipitation (Table 1). It responded slightly

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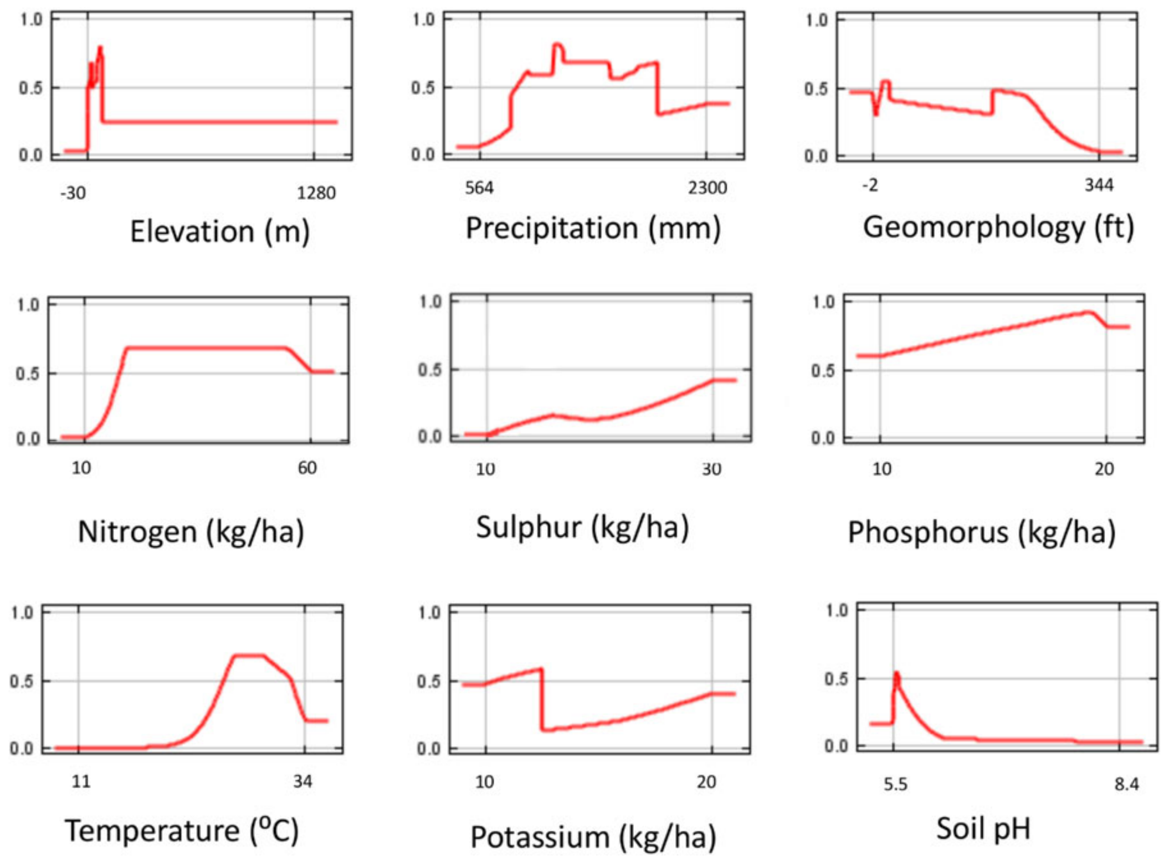


**Fig. 3.** Colour online. The response curves of the environmental variables influencing the suitable locations of *Tossa* species in Bangladesh. *The 0–0.8 legend on the horizontal axis represents the per cent contributions of the environmental variable.

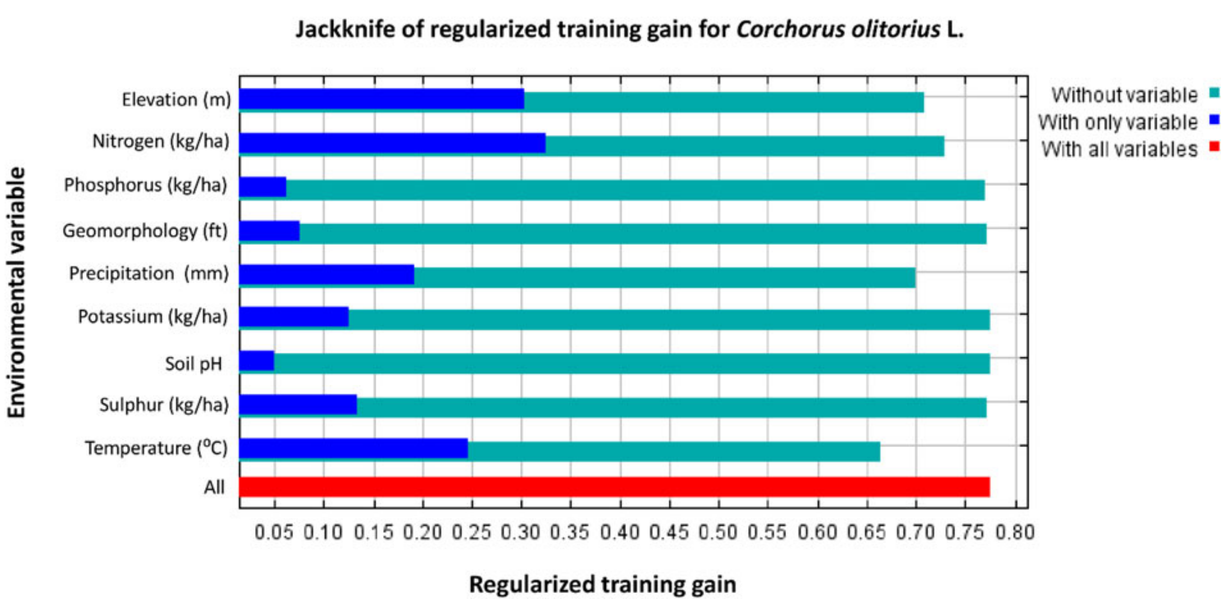


**Fig. 4.** Colour online. The Jackknife test of the environmental variables influencing for identifying the importance of all the variables for *Tossa* species.

to soil S and K, where geomorphology, soil P and pH influenced faintly. Percentage of elevation, N, temperature and precipitation were considered the four most important environmental variables to the model prediction. They had the highest relative contributions, the highest regularized training gain when used in isolation in the Jackknife test and also the highest AUC values when used in isolation. Maxent's projections of predicted *Tossa*'s habitat suitability in restoration scenarios showed an increase of

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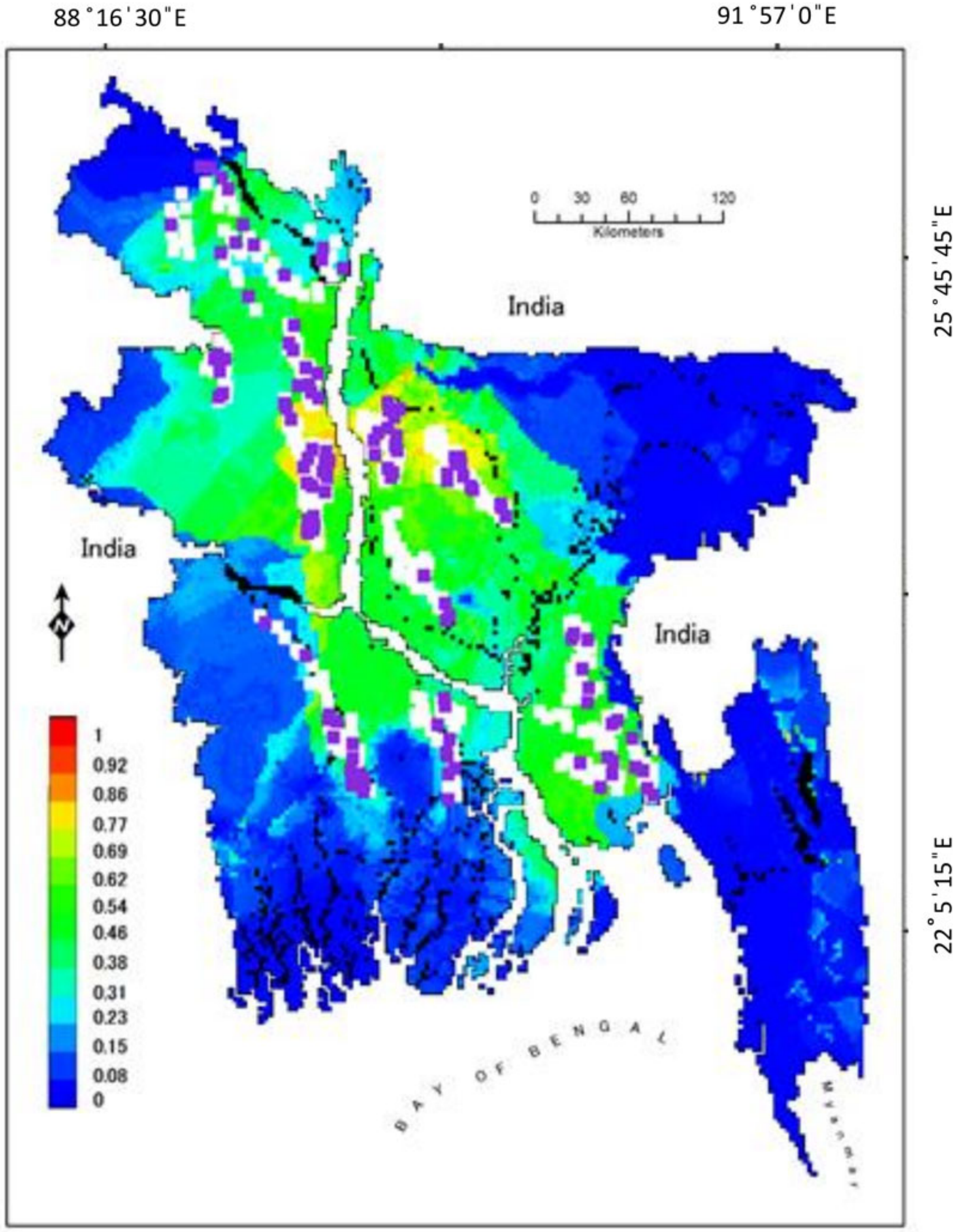


**Fig. 5.** Colour online. The current potential distributions of *Tossa* species in Bangladesh. The modelling was conducted using 239 sample location points. The warmer colour shows better-predicted areas for *Tossa.*

high suitability areas (>0.62 per grid cell, where habitat suitability ranges from 0–1 per grid cell, wherein the typical is near to 0.5) of 0.5% of total country land in all substantial environmental variables (Elith *et al.*, 2011). Nabil and Ashraf (2011) and Musa *et al.* (2010) stated N as an important factor for the growth, yield, nutrient use efficiency and quality of *Tossa*. They also stated that N excites the new leaves formation and increases the size and height of the plant. Precipitation was found significant for growth, yield, stem diameter and the number of branches per plant by Fasinmirin and Olufayo (2009) and Whitfield *et al.* (1986). The presence of K and P offered adequate nutrients for leaf area development and plant stem diameter. These improved the plant height, the number of leaves, stem diameter, total leaf area and the number of branches of *Tossa* (Aliyu, 2000; Katé *et al.*, 2020).

The result of the Maxent showed a strong relationship between *Tossa* probability of distributions and low elevated land in Bangladesh because *Tossa* grows well in low-lying and plain land. The elevation was linked to a range of environmental factors and temperature differences, influencing the growth of *Tossa* (Benor *et al.*, 2011). The modelling showed very low suitability for *Tossa* in high elevated land (Fig. 5). The projected habitat suitability for *Tossa* species is in the central and central-northern regions of Bangladesh. The conservation also depends on the preservation of necessary environmental variables in Bangladesh.

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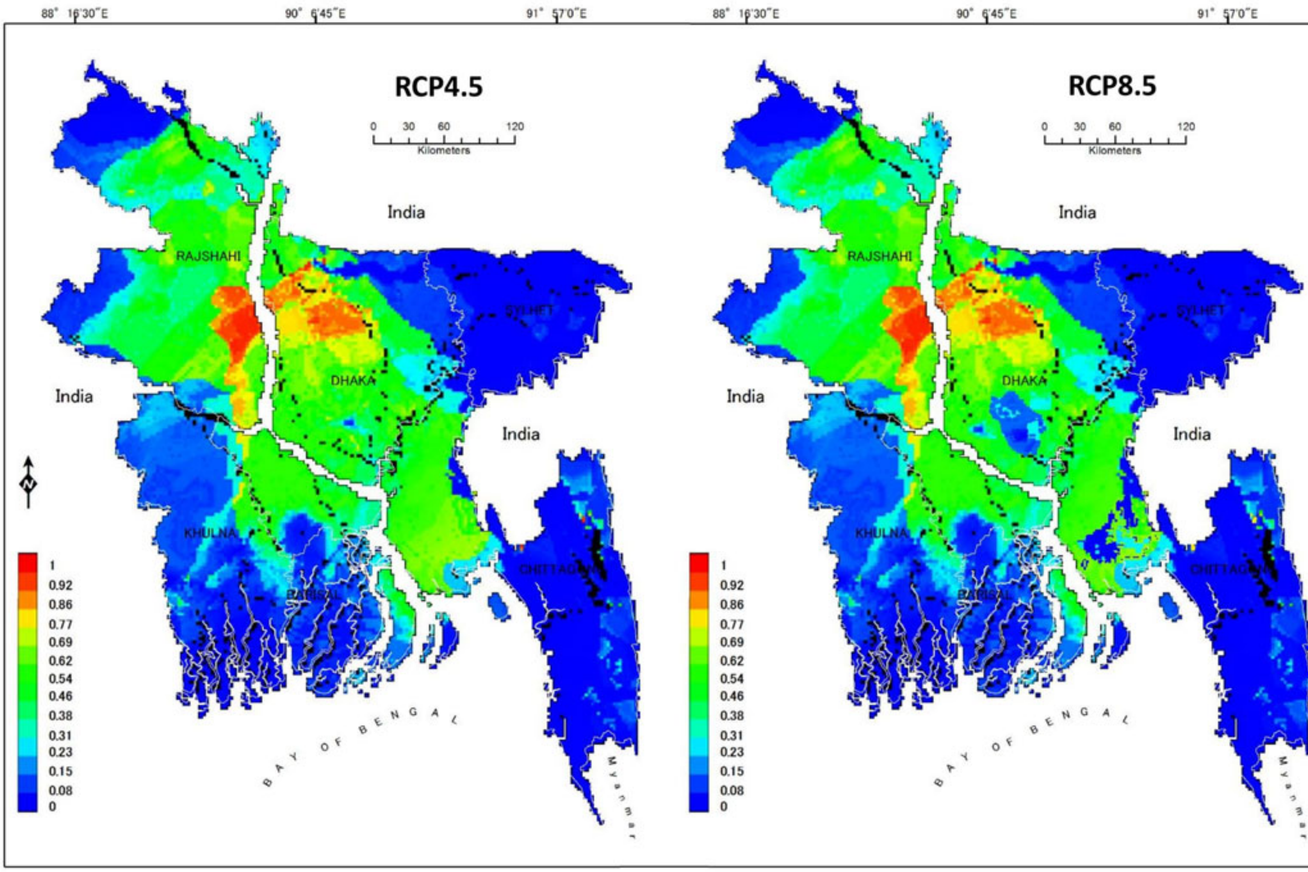


**Fig. 6.** Colour online. The impact of RCP4.5 and RCP8.5 scenarios of the ACCESS1-0 GCM for the distribution predictions of *Tossa* species in Bangladesh to the 2100 year.

### *Climate change impact on the* Tossa

The two scenarios of RCP4.5 and RCP8.5 both have a negative impact on the future distributions of *Tossa* in Bangladesh. The distributions of the *Tossa* will decrease the least percentage (2%) with the RCP4.5 scenario. As well, RCP8.5 will cause a sensible decline of the *Tossa* area of 9% to the year 2100 due to altered average temperatures, rainfall and increased extreme events of heat and cold waves, flooding, etc. (Maheswari *et al.*, 2015). The vital bioclimatic variables elucidating the future suitable *Tossa* distribution were BIO11, BIO17, BIO14, BIO18 and BIO1 for both of the climatic models, and results suggested that BIO14, BIO7 and BIO11 were the most common contributors (Shishir *et al.*, 2020). On the other hand, the EdGCM modelling results showed a comparable negative impact on the *Tossa* distributions. The habitat suitability will be condensed by 10.2% owing to the increased mean temperature of 4.2°C. A reduced annual rainfall of 1.5 mm to the 2100 year also will cause a decline of *Tossa* in Bangladesh because the water supports plants morphological development (plant height, stem diameter, number of green leaves, leaf elongation, leaf area and dry weights) (Franco *et al.*, 2008; Yakoub *et al.*, 2016).

Thus, land and management executives should pay additional consideration to Mean Air Temperature of Coldest Quarter; Precipitation of Driest Month, Driest Quarter and Warmest Quarter; and Temperature Annual Range including Max and Min air temperature. Therefore, this is a vital period to promote awareness against the vulnerability of *Tossa*. In addition, there is a varied range of uncertainties in climate change due to multi-model climate scenarios including scale variabilities. However, additional research is required for a more accurate model using precise climate analysis considering similar spatial resolution data.

### *Conservation planning of* Tossa *species*

The results presented in the current study suggested a larger area can be protected for the cultivation of *Tossa* in Bangladesh in association with the presence of sufficient rainfall and temperature including N content in the soil. Total 7533.32 $km^2$ highly suitable areas might be protected for the conservation of *Tossa* species in Bangladesh. Therefore, highly suitable areas for *Tossa* might be considered for newly potential protected sites via the expansion of the existing areas. Besides, areas of medium and medium-high suitability can be protected which are correspondingly important areas for *Tossa* cultivation. These medium, medium-high and high suitable areas should be considered in the protected areas management plans as necessary to conserve the *Tossa* species.

## Conclusion

In this study, two different models, MaxEnt and EdGCM were used to predict the habitat suitability of *Tossa* in Bangladesh using 239 occurrence records and 19 bioclimatic variables. Both of the two models predicted the future potential distributions towards the 21st century. Results suggested that *Tossa* in

**Table 2.** The contribution percentages of bioclimatic variables used to predict the future distribution of Tossa *in Bangladesh*

| Bioclimatic variables | Contribution (%) | |
|---|---|---|
| | RCP4.5 | RCP8.5 |
| BIO1 (Annual Mean Air Temperature) (°C) | 0 | 11 |
| BIO2 (Mean Diurnal Range (Mean of monthly (max temp – min temp))) (°C) | 0 | 2.3 |
| BIO3 (Isothermality (BIO2/BIO7) (×100)) | 6.4 | 0 |
| BIO4 (Temperature Seasonality (standard deviation ×100)) (C of V) | 2.2 | 0 |
| BIO5 (Max Air Temperature of Warmest Month) (°C) | 7 | 6.3 |
| BIO6 (Min Air Temperature of Coldest Month) (°C) | 0 | 0 |
| BIO7 (Temperature Annual Range (BIO5-BIO6)) (°C) | 0 | 10.5 |
| BIO8 (Mean Air Temperature of Wettest Quarter) (°C) | 8.8 | 6.4 |
| BIO9 (Mean Air Temperature of Driest Quarter) (°C) | 1.5 | 2.1 |
| BIO10 (Mean Air Temperature of Warmest Quarter) (°C) | 5.9 | 0 |
| BIO11 (Mean Air Temperature of Coldest Quarter) (°C) | 47.5 | 5.2 |
| BIO12 (Annual Precipitation) (mm) | 1.1 | 0 |
| BIO13 (Precipitation of Wettest Month) (mm) | 0.4 | 0 |
| BIO14 (Precipitation of Driest Month) (mm) | 17.7 | 0 |
| BIO15 (Precipitation Seasonality (C of V)) | 0 | 0 |
| BIO16 (Precipitation of Wettest Quarter) (mm) | 0 | 0 |
| BIO17 (Precipitation of Driest Quarter) (mm) | 1 | 38.6 |
| BIO18 (Precipitation of Warmest Quarter) (mm) | 0.5 | 13.7 |
| BIO19 (Precipitation of Coldest Quarter) (mm) | 0 | 3.9 |

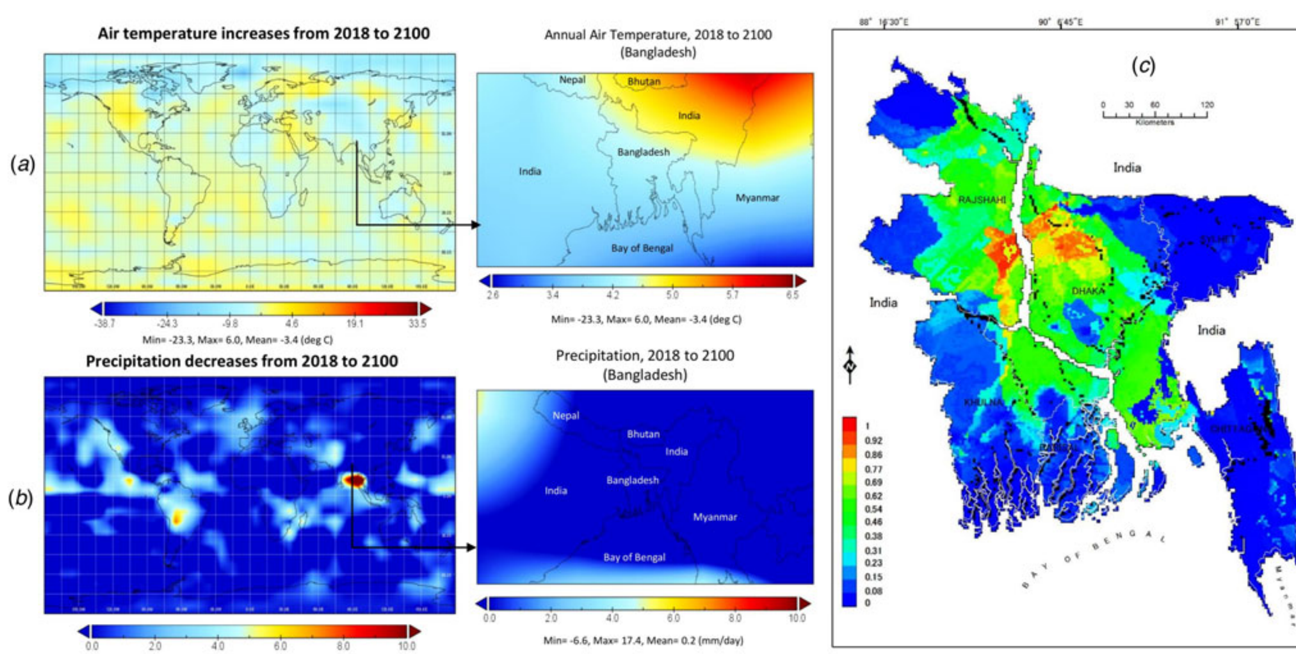


**Fig. 7.** Colour online. Changes in temperature and rainfall from the output of EdGCM predicted for the year 2100; (a) shows the increase of annual air temperature from 2018–2100 in a global scale, (b) demonstrates the precipitation variability in Bangladesh from 2018–2100 in a global scale and (c) displays the existing habitat distribution of Tossa via the EdGCM prediction in Bangladesh.

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Bangladesh is susceptible due to the worst state of climate change. Maxent flourished the precise distributions of *Tossa* using RCP4.5 scenarios based on its presence data and the effective environmental factors used in the current study. MaxEnt (RCP8.5) predicted that *Tossa* will decline much under the RCP8.5 scenario by the end of the 21st century due mostly to intensifying temperatures resulting in precipitation inconsistency and extreme drought conditions. This also may affect the morphological development of *Tossa*. Additionally, Maxent identified elevation, N, temperature and precipitation as the prime determinants of *Tossa* distribution, which was controlled by both edaphic and climatic factors. In the case of EdGCM, the results are comparable to the MaxEnt to predict the habitat suitability of *Tossa*. The results indicated that the most alarming issue was the intensified mean annual temperature of >4°C which may cause precipitation variability and extreme drought condition ensuing decline of the *Tossa* habitat in Bangladesh.

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