Habitat distribution modelling to identify areas of high conservation value under climate change for Mangifera sylvatica Roxb. of Bangladesh

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Habitat distribution modeling to identify areas of high conservation value under climate change for *Mangifera sylvatica* Roxb. of Bangladesh

Abstract

The impact of climate change on ecosystems, especially at the species level, is already being observed across the world. To assess potential future climate change effects on species, scientists often use species distribution modelling (SDM). The estimation of likely changes in the distribution of species under future climate conditions is a crucial first step towards the mitigation and management of future species losses or habitat shifts. Considering this, the aim of the present study is to predict the effect of climate change on a valuable threatened tree species, *Mangifera sylvatica* Roxb., of Bangladesh using Maximum Entropy. The current potential distribution as by the model suggests that around 5% of the study area is highly suitable wild mango habitat, with between 6% and 11% being moderately suitable. Under the RCP 4.5 scenario, the net decrease in suitable habitat is predicted to be 7% by 2070. Under the RCP 8.5 scenario, the model predicts that the total area suitable for mango will reduce by 12% by 2050, disappearing altogether by 2070. Therefore, urgent measures are required for the conservation of *M. sylvatica* in Bangladesh. The application of the species distribution model may provide policymakers and conservationists with a useful tool for the prediction of future distribution (at both local and regional scales); of poorly known species with high preservation concerns. The approach used in this study can provide a rapid assessment of the future conservation status of other important forest tree species in Bangladesh to improve our understanding of the vulnerability under changing climate.

Keywords: Threatened species, MaxEnt, Geographic distribution, Habitat suitability, Conservation

1. Introduction

Global climate change is occurring at an unprecedented rate. Average temperatures have increased by 0.85ºC in the last century and are predicted to continue to increase by a minimum of 0.3ºC–1.7ºC to a maximum of 2.6ºC–4.8ºC by 2100 (IPCC, 2013). There are known effects of this change on ecosystems, species and biodiversity (IPCC, 2015; CBD, 2010; Hansen et al., 2001). Effects include changes in phenology, habitat range shifts and extinction risk in one-fifth of plant species (Brummitt and Bachman, 2010; Lenoir et al., 2008; Fischlin et al., 2007; Hickling et al., 2006, Parmesan, 2003). Hence, it is important to understand the impacts of climate change on the future habitat distribution and suitability of species. Bangladesh is a biodiversity hotspot zone because of its geographical and climatic traits. It supports species numbers of at least 5,000 angiosperms, five gymnosperms, 113 mammals, 628 birds, 126 reptiles, 22 amphibians, 708 fish, 2,493 insects, 66 corals, 168 algae and 15 crabs (MoEF, 2001; IUCN, 2000; Ahmed and Ali, 1996). This rich biodiversity is highly vulnerable to climate change. According to the GOB (2005), the average increase in temperature would be between 1.4ºC and 2.4ºC; predicted increases in rainfall are 6% and 10% for the two projection years 2050 and 2100, respectively. The consequences of climate change are already felt in Bangladesh. There has been an increase in the frequency and intensity of floods, cyclones and droughts. Together with a rise in sea levels, these pose an increasing threat to the livelihoods of people (Ahmed, 2006). Unfortunately, very few studies have been conducted yet on the impact of climate change on forest ecosystems and biodiversity in Bangladesh (Alamgir et al., 2015; Sohel et al., 2016). Yet, for conservation planning, knowledge of species' potential distribution under current and future climates is imperative. For example, species re-introduction is a common strategy for recovery of depleted species as well as restoration of degraded habitats and ecosystems (Polak and Saltz, 2011; Rodríguez-Salinas et al., 2010; Nazeri et al., 2010; Ren et al., 2009). To ensure the long-term success of re-introduction strategies, a detailed knowledge of the current distribution of the species is required as well as its potential distribution under future climates (Adhikari et al., 2012). Here, species distribution modelling (SDM) is an effective tool to predict potential distribution and habitat suitability of target species, which can be used to design proper conservation plans.

In Bangladesh, there are 59 edible wild forest fruits available (Das, 1986), an important one of which is the wild mango species, *M. sylvatica*. According to IUCN, the species is in the category of 'lower risk/least concern'. However, this status is based on the data from 1998, and therefore needs updating (World Conservation Monitoring Centre, 1998). The species is threatened in Bangladesh (BFRI, 2013; Dutta et al., 2016) and India (Jiji, 2015). *M. sylvatica* is one of the most important species in the hilly region of Bangladesh, not only for its fruits but also because of its role in carbon storage. Alamgir and Al-Amin (2007) found that M. sylvatica has the second highest mean value in above-ground, below-ground and total organic carbon (2.78, 0.42 and 3.20 t/tree) in the CHTs of Bangladesh. Moreover, they also state that *M. sylvatica* has the fifth highest total organic carbon storage (2.00 t/ha) among the species available in hilly regions. Unfortunately, this species is declining at an alarming rate due to various factors. Dewan (2009) found that the important Value Index (IVI) of *M. sylvatica* in the CHTs is very low in comparison to other plant species. According to Dewan (2009), the reason behind the depletion is legal or illegal logging as well as shifting cultivation. Forest fires associated with clearance for shifting cultivation have a further negative impact on the natural regeneration of this species. Moreover, in Bangladesh, this species is used mainly in the plywood industries for making tea chests, internal decoration of buses, aircraft, cabinet making, house building and sports goods. In Bangladesh, there are approximately 25 factories producing commercial plywood; the majorities are located in Chittagong and the CHTs and one of the major raw materials used is *M. sylvatica*. The Bangladesh Standards and Testing Institution recommends 16 timber species for plywood production and *M. sylvatica* is one of them (Sattar, 2006). In Bangladesh, the young leaves of *M. sylvatica* are used as vegetables and the fruits are consumed (fresh and processed) by the tribes in the CHTs (Jalil and Chowdhury, 2000). Therefore, a decline in the *M. sylvatica* population will have a negative impact on the socio-environmental aspect. Bangladesh Forest Research Institute (BFRI) has undertaken initiatives to conserve the species. It has initiated two projects: 'Ex-situ conservation of threatened forest tree species in different agro-ecological regions of Bangladesh' and 'Conservation of threatened plant species through domestication', which started in 2006–7 and 2003–4, respectively. Under these two projects, the BFRI raised 17.5 ha and 0.2 ha of conservation plots from seed, together with eight and ten other threatened species as gene banks (BFRI 2013). Over time, *M. sylvatica's* habitat has shrunk due to an ever-increasing demand on land for cultivation, industry, human habitation, over exploitation, illegal logging and encroachment. An important first step in the conservation of this valuable species is to provide information on its potential habitat extent for re-introduction and restoration. Without this, it is difficult to plan and implement strategies for species conservation, including re-introduction in areas where it has disappeared. The present study aims to fill this gap by modelling the potential distribution under current climate conditions and to use these models to assess the potential effects of projected climate changes on the future habitat suitability and distribution of this species. We thereby considered three research questions. Firstly, which bioclimatic variables most influence the predicted distribution of *M. sylvatica*? Secondly, to what extent is the potential distribution of this species expected to change under projected future climate changes?

2. Materials and Methods

2.1. Study area

The study area (Figure 1) is located in eastern part of Bangladesh in Sylhet, Chittagong, Chittagong Hill Tracts (CHTs) and Cox's Bazar. The natural vegetation in this region is hill forest (evergreen to semi evergreen forest) and is considered one of the most biodiversity rich hotspots in the country (Sohel et al., 2015; Akhter et al., 2013; Sohel et al., 2010; Biswas and Choudhury, 2007; Mukul et al., 2014). It receives a mean annual precipitation of 2540 mm. Mean annual temperature ranges from 22^{o}-25^{o}C. Mean annual humidity ranges from 75 - 83%. In the last decades there has been a trend of increasing mean annual temperature and rainfall from 1989 - 2009 in the north-eastern part of Bangladesh (Akhter et al., 2013), including our study area.

"Figure 1 here"

2.2. Studied species

The investigated species for this study is *M. sylvatica* Roxb, a wild mango species, which belongs to the Anacardiaceae family. The species has several different local names in Bangladesh and we will hence forward refer to this species as Uriam. Uriam is mainly distributed in the tropical forests and subtropical rainforests of the Indo-Malayan biogeographic region (Udvardy, 1975), in India, Bangladesh, Thailand, Cambodia, Nepal, China and Myanmar (Figure 1). In Bangladesh, the species is distributed in the hilly areas such as Chittagong, Cox's Bazar, the Chittagong Hill Tracts and Sylhet (Figure 1). The species prefers 'Brown Hill Soils', which are found in the hilly regions and vary from brown sandy loam to clay loam (FRA, 2000). A recent study showed that the kernel of this species can be used as a cocoa butter alternative (Akhter et al., 2016) and has the potential to be incorporated into small-scale forestry programmes (Baul et al., 2016).

2.3. *M. sylvatica* occurrence data collection

As the species is locally threatened, to gain information on the species location, key informant interviews were conducted. Key informants were considered based on: a) their familiarity with the forest area, and b) an adequate background on the status of *M. sylvatica* in the study area. Selected respondents included: local forest department officials, forest product collectors, and indigenous group leaders living within and outside of the forest area. 253 trees (134 trees from Cox's Bazar, 95 trees from Sylhet, 23 trees from Chittagong and 1 tree in Banderban) were located in the study area and their positions recorded using Global Positioning System coordinates (Figure 1).

2.4. Spatial modelling

MaxEnt (version 3.3.3k) was used to model the distribution of the species under present climate conditions and project the potential distribution under future climates. MaxEnt is a widely used species distribution model that can be used to predict the probable distribution of a species based on biophysical and bioclimatic parameters (Phillips et al., 2006). It needs only presence data points (Phillips et al., 2006) and performs relatively well with small sample sizes compared to other modelling methods (Kumar and Stohlgren, 2009; Wisz et al., 2008; Pearson et al., 2007; Papers and Gaubert, 2007; Elith et al., 2006; Weber, 2011). MaxEnt generates an estimate of habitat suitability for the species that varies from 0 (lowest suitability) to 1 (highest suitability). The strong attributes of MaxEnt are: i) it has strong mathematical definition; ii) it gives a continuous probabilistic output; iii) it can handle both continuous and categorical environmental data; iv) it can investigate variable importance; v) it has the capacity to handle low sample sizes; and vi) it has simplicity for model interpretation (Elith et al., 2011; Pearson et al., 2007; Phillips et al., 2006).

Models were created using the default parameters and based on present climate conditions. As calibration data, we used a 75% random selection of the presence points and 10,000 random selected background points, and the other 25% presence points were used to evaluate the model's goodness-of-fit using the Area Under the Receiving Operator Curve (AUC) as the evaluation statistic. To validate the model robustness, we executed 10 replicated model runs for the species. To find out which variables were most important, the jackknife procedure of the MaxEnt model was used. We used the average of 10 model runs to create potential distribution maps under current conditions. We used the same approach, but using the future bioclimatic data as input, to create potential distribution maps under projected future climate conditions. We did this for all four combinations of the two RCPs (RCP 4.5 and RCP 8.5) and years (2050 and 2070). The 0 to 1 suitability values of the resulting species suitability distribution maps were aggregated into four classes of potential habitats following the method by Yang et al. (2013), viz. ‘high potential’ (> 0.6), ‘good potential’ (0.4–0.6), ‘moderate potential’ (0.2–0.4) and ‘least potential’ (< 0.2).

"Table 1 here"

2.5. Bioclimatic variables

We used 19 climatic variables (Table 1) as potential predictors of *M. sylvatica’s* habitat distribution. Bioclimatic variables (Hijmans et al., 2005) are biologically more meaningful to define the eco-physiological tolerances of a species than simple rainfall or temperature (Graham and Hijmans, 2006). They are, therefore, frequently used in modelling species distributions (Yang et al., 2013; Garcia et al., 2013; Adhikari et al., 2012). Data layers for these bioclimatic variables were downloaded from the WorldClim database, with 30 arc seconds (~1 km) spatial resolution. To project the future distribution and habitat suitability due to climate change, we used projected climatic data for 2050 and 2070 based on the IPCC fifth assessment report available from www.worldclim.com. Among four future greenhouse gas concentration trajectories (also known as representative concentration pathways or RCPs) two GHG concentration trajectories, RCP 4.5 and RCP 8.5, were considered for the two time periods. RCP 4.5 represents a stable scenario where GHG will be stabilised due to green technologies and the radiative force will reach up to 4.5 W/m^2 by 2100 (Wise et al., 2009; Clarke et al., 2007; Smith and Wigley, 2006; Guisan and Thuiller, 2005). RCP 8.5 represents a relatively extreme scenario where GHG will continuously increase throughout 2100, at which time radiative force will reach 8.5 W/m^2 (Meinshausen et al., 2011; Riahi et al., 2007). A widely used global circulation model, HadGEM2-CC (Hadley Global Environment Model 2 Carbon Cycle) was used in this study because of its well-known acceptability (Shrestha and Bawa, 2014). This model has been used to perform all of CMIP5 (Coupled Model Inter Comparison Project Phase 5) and was also used by the IPCC in its fifth Assessment Report (Shrestha and Bawa, 2014).

The bioclimatic variables and the species presence data were extracted and prepared using ArcGIS 10. To minimise multi-collinearity, we used a step-wise variance inflation factor (Graham, 2003) selection procedure, whereby we first computed the VIF using all bioclim variables. The variable with the highest VIF was removed and VIF was computed for the remaining variables. This was repeated until the VIF was below 10 for all remaining variables. The remaining eight bioclimatic variables (Table 1, Supplementary Table 1) were used in our model.

3. Results

3.1. Model evaluation

The model calibration test for *M. sylvatica* yielded satisfactory results (AUCtrain = 0.92 ± 0.002 and AUCtest = 0.89±0.02). This indicates that the bioclimatic variables used for the model explained the predicted distribution very well. Amongst the input variables, mean diurnal range (BIO 2) contributed 29.2% and precipitation seasonality (BIO 15) contributed 22%. BIO 2, BIO 15, BIO 14 and BIO 18 together contributed 83% to the model. Maximum temperature of warmest month (BIO 5) is the lowest contributed climatic variable. The jackknife test showed that mean diurnal range (BIO 2) has the highest training gain when considered alone (Figure 2).

"Figure 2 here"

3.2. Species response and habitat suitability under present and future climatic conditions

Response curves showed changes in the logistic prediction when each predictor variable changed by keeping all other variables at their average sample value. Responses of the species to the changes of bioclimatic variables are shown in Figure 3. The response curves showed that the distribution of *M. sylvatica* is highly controlled by both temperature and precipitation. The probability of presence is high when mean diurnal temperature (BIO 2) is above 10^{o}C. The probabilities of increasing the presence of the studied species increased with increased temperature and were found to be highest between 32^{o}C and 33^{o}C. The mean temperature of the warmest quarter (BIO 10) provides the mean temperatures during the warmest three months of the year, which can be useful for examining how such environmental factors may affect species seasonal distributions. The species, however, started to decline when the temperature exceeded more than 28^{o}C during the warmest month. The maximum temperature of warmest month (BIO 5) is useful when examining whether species distributions are affected by warm temperature anomalies throughout the year. Precipitation seasonality (BIO 15) provides a percentage of precipitation variability where larger percentages represent greater variability of precipitation. The results showed that the study species was able to tolerate higher variability (ranges from 98% to 115%) of rain. Precipitation of the coldest quarter (BIO 19) provides total precipitation during the coldest three months of the year. The study species showed a higher probability of presence in the winter season when rainfall ranges between 30mm to 36mm (Figure 3). Precipitation of the warmest quarter (BIO 18) provides total precipitation during the warmest three months of the year and the model showed that this species prefers moderately high amounts of rain in the range of 800–1200 mm.

The predicted current distribution of *M. sylvatica* under current climatic conditions is shown in Figure 4. Based on our model, about 4.58% of the study area is ‘highly suitable’ for wild mango habitat, followed by ‘good potential’ at 6.53% and ‘moderate potential’ at 10.71%, while 78.19% of the area is ‘least suitable’ or ‘unsuitable’ for this species (Table 2). Current suitable habitats for *M. sylvatica* were predicted in the north-eastern and south-eastern parts of Bangladesh (Figure 3). The concentration of pixels with highly suitable, good potential and moderate potential is observed in the CHTs, Cox’s Bazar, and the Maulvibazar and Habiganj districts when the current predicted distribution habitat map is overlaid with the district map of Bangladesh.

"Figure 3 here"
"Figure 4 here"
"Figure 5 here"

According to the results of the MaxEnt modelling, the predicted future ranges of habitat are likely to be negatively affected by future climate. The predicted distribution and habitat change of wild mango in future climate scenarios are shown in Figure 5 and Table 2. The maximum expansion (16.05% addition to the current potential suitable area considering high, good and moderately suitable areas) would occur under RCP 4.5 by 2050, whereas the total loss of habitat was predicted for the year 2070 for RCP 8.5. Most of the expansion was observed in the CHTs and Cox's Bazar and in RCP 4.5 during 2050. In RCP 4.5 during 2070, a 7.82% reduction of suitable habitat was observed compared to the present distribution. However, a decline in habitat was observed for RCP 8.5 during both 2050 and 2070, and by 2070 the species will be completely lost. Wild mango habitat will be completely lost from the north-eastern part of the country under all scenarios.

"Table 2 here"

4. Discussion and Conclusion

This study is the first attempt to look into the impact of climate change on the distribution and range of suitable habitat of a threatened wild mango species of Bangladesh. The study findings show that the distribution of the threatened wild mango species is partly controlled by precipitation-related bioclimatic variables (Figure 2 and Figure 3), with the most important explanatory variables being mean diurnal temperature, precipitation seasonality, precipitation of the warmest quarter and precipitation of the driest period. Especially under the RCP 8.5 scenario, these factors are projected to show considerable changes, causing large parts of the current distribution area to become unsuitable by 2050, while the whole study region is projected to become unsuitable by 2070. It should be noted that RCP 8.5 represents a more extreme scenario. On the other hand, rainfall patterns are expected to become more erratic in many parts of the world, while extended dry spells may become more frequent; factors that we did not include in our models. Recent climate data analysis for the period 1961–2010 shows that temperature is increasing slowly and the total amount of annual precipitation is increasing along with increasing trends in consecutive dry days (CDD) (Islam et al., 2014). In light of the potential importance of rainfall patterns for *M. sylvatica*, these extreme climate events in future may cause more stress to the existing populations and prevent expansion to areas that would be considered suitable when considering average conditions only.

Given that a number of bioclimatic variables, highly correlated to currently used variables, were excluded from our analysis, more analyses are needed to determine the sensitivity of the species considering more environmental and climatic variables. It is important to notice that we only employed one GCM and two RCP scenarios. For a more reliable assessment of future changes, we need to consider a wider range of GCMs and all four RCP scenarios (RCP 2.5, RCP 4.5, RCP 6.0, RCP 8.5) for better understanding of the vulnerability and sensitivity of the studied species to climate change. Moreover, although our models were based on climate data only, we were able to capture the observed distribution well, but the need remains to consider other biophysical factors, such as soil characteristics, land cover and geology (Alamgir et al., 2015), to obtain more reliable and relevant predictions of where the species will be able to grow in the next decades. Such data with higher resolution is currently scantily available for Bangladesh. For example, new global data sets such as the http://soilgrids.org/ are being developed, but currently still have a limited thematic (wide confidence limits) and spatial accuracy (Hengl et al., 2014). In the case of land cover data, the land use classification of freely available global-scale data from http://www.eea.europa.eu/data-and-maps/data/global-land-cover-250m does not cover the detailed land use of the study area. However, better resolution satellite images were not analysed in this study due to funding limitations. Moreover, the addition of regional/local climate change models may give considerably more reliable predictions of climate change effects. However, in light of the limitations of only one GCM and two RCP scenarios (RCP 4.5 and RCP 8.5), and as regional models were not used, our study provides a preliminary assessment of the effects of climate change on the species, and is useful to highlight the most vulnerable areas.

The predicted potential distribution of *M. sylvatica* was largely in agreement with what we know about the distribution of this species, with the species' major habitats to be the forests in the CHTs, Cox's Bazar, and the Maulvibazar and Habigang districts. Our results confirm that future climate changes may result in a major decline in the potential distribution of this species, especially under the scenario in which GHG will continue to increase at the current pace throughout 2100. In contrast, under the stable climate change scenario (RCP 4.5), the potential distribution of the species may even show a modest increase in the south-eastern part of our study area by 2070. Restoration of depleted populations may, therefore, be an option in these parts of the country if humanity manages to limit the increase in radiative force to less than 4.5 W/m^2.

The future for the species is considerably bleaker in the north-east. Our model results suggest that, under both climate change scenarios, conditions are likely to become unsuitable for the species. Other studies in different locations also show both reduction, expansion and complete habitat loss due to climate change (Barrett et al., 2013; Molloy et al., 2013; Dullinger et al., 2012; Dawson et al., 2011; Loarie et al., 2008; Bakkenes et al., 2002). *M. sylvatica* seems to have shifted upwards little, which may have also caused the local extinction of wild mango from north-eastern regions under all climate scenarios. These results might be a useful guide for government and NGOs responsible for the conservation and management of forest resources. There is still a major knowledge and research gap about how forests respond to climate change at local scales and what adaptation strategies can be taken in such contexts (Kaeslin et al., 2012). Here, Species Distribution Modelling (SDM) can be a helpful tool that can provide information on the effect of climate change on species' geographic distribution and habitat suitability. This information can facilitate better management and conservation of those species, especially for threatened and rare species. Protection of threatened species' habitat is an important step. Here, protected areas can play a significant role. Apart from declaring protected areas, landscape connectivity between non-protected areas should also be taken into account (Hannah et al. 2002). Additionally, the active participation of the local, forest-dependent people is fundamental, especially in developing countries, as successful forest conservation is not possible without their active participation (Sohel et al., 2010). To engage the local people in the decision-making process of conserving forests, a participatory approach or co-management system should be introduced (Mukul et al., 2012). Apart from this, establishing non-timber forest product facilities in buffer zones around the protected areas will help reduce the pressure on the protected areas for forest-based livelihood activities (Mukul et al., 2016). The government of Bangladesh has prioritised the above mentioned issues, so most of the protected areas of

Bangladesh are now under a co-management system. Finally, an awareness programme should also be prioritised to address climate change issues and protect the valuable forest resources of Bangladesh for future generations (Sohel et al., 2016). From the present study, the area identified from the predicted potential current distribution can be used for the re-introduction of wild mango trees. This will help restoration of the forest as well as improve the overall conservation status of the species. This pioneer study can act as an early warning for climate change effects on valuable threatened tree species of the forest ecosystems of Bangladesh. Taking this into consideration, conservation managers could start to think of adapting policy that can reduce the extinction risk of this valuable species. The method and approach used in this research can be applied to other forest tree species of Bangladesh to see how they respond to climate change impact in order to better inform conservation decisions.

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Tables

Table 1. Environmental variables used in the study

Code	Climatic variables	Unit

BIO 1	Annual mean temperature	°C
BIO 2	**Mean diurnal range (mean of monthly max. and min. temp.)**	**°C**
BIO 3	**Isothermality ((Bio2/Bio7) × 100)**	
BIO 4	Temperature seasonality (standard deviation × 100)	C of V
BIO 5	**Maximum temperature of warmest month**	**°C**
BIO 6	Minimum temperature of coldest month	°C
BIO 7	Temperature annual range (Bio5–Bio6)	°C
BIO 8	Mean temperature of wettest quarter	°C
BIO 9	Mean temperature of driest quarter	°C
BIO 10	**Mean temperature of warmest quarter**	**°C**
BIO 11	Mean temperature of coldest quarter	°C
BIO 12	Annual precipitation	mm
BIO 13	Precipitation of wettest period	mm
BIO 14	**Precipitation of driest period**	**mm**
BIO 15	**Precipitation seasonality (CV)**	**C of V**
BIO 16	Precipitation of wettest quarter	mm
BIO 17	Precipitation of driest quarter	mm
BIO 18	**Precipitation of warmest quarter**	**mm**
BIO 19	**Precipitation of coldest quarter**	**mm**

N.B. Variable with bold were used for final model run. The other variables removed because of high V (supplementary table 3.1).

Table 2. Changes in habitat class of *M. sylvatica* under current and future climate scenarios

Suitability	Area (km^2)

class	Current	RCP 4.5 2050	Area change	RCP 4.5 2070	Area change	RCP 8.5 2050	Area change	RCP 8.5 2070	Area change
Least potential	28116	22347	-5769	30929	2813	32603	4487	0	-28116
Moderate potential	3851	5280	1429	1971	-1880	2363	-1488	0	-3851
Good potential	2347	3584	1237	1637	-710	877	-1470	0	-2347
High potential	1646	4749	3103	1423	-223	117	-1529	0	-1646

Supplementary Table 1: Multi-Collinearity test by using VIF analysis among environmental variables

Variables	VIF Scores	
bio_2	9.50	Variables with VIF Score ≥ 10 were excluded for further analysis
bio_3	4.52	
bio_5	6.23	
bio_10	4.26	
bio_14	2.05	
bio_15	6.75	
bio_18	4.08	
bio_19	6.07	