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Modelling spatial distribution of critically endangered Asian elephant and Hoolock gibbon in Bangladesh forest ecosystems under a changing climate

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ABSTRACT

The Asian elephant (*Elephas maximus*) and Hoolock gibbon (*Hoolock hoolock*) are two globally endangered wildlife species limited to only tropical Asian forests. In Bangladesh both species are critically endangered and distributed mainly in the northeast and southeast hilly regions bordering neighboring India and Myanmar. Using existing distribution data, land-use/land cover, elevation and bio-climatic variables, we modeled the likely distribution of Asian elephant and Hoolock gibbon in Bangladesh for 2050 and 2070. We used the IPCC's Representative Concentration Pathways (RCPs) – RCP6.0 and RCP8.5 and Maximum Entropy algorithm for our modelling. Our study indicated that the Asian elephant will be more resilient to climate change compared with the Hoolock gibbon. Habitat loss for the Asian elephant is also expected to remain constant (i.e. 38%) throughout the period, whilst Hoolock gibbon habitat will be more sensitive to climatic variations, with the species predicted to be extirpated from the country by 2070. Being highly exposed to climate change with ever increasing land use pressures, we believe our study in Bangladesh can be used to enhance our understanding of future vulnerabilities of wildlife in a rapidly changing climate. A trans-boundary conservation program with greater attention to the species that are less resilient to climate change is also essential.

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Introduction

Rapid biodiversity loss and species extinction are amongst the major environmental issues affecting the structure and functions of ecosystems and human well-being (Alamgir, Pert, & Turton, 2014; Kaeslin, Redmond, & Dudley, 2012; Sachs et al., 2009; Sohel, Mukul, & Burkhard, 2014). According to the latest edition of the Living Planet Report, wildlife populations have declined globally by 52% since 1970 (McLellan, Iyengar, Jeffries, & Oerlemans, 2014). Apart from land-use/land cover (LULC) change, dramatic changes in local and regional climate are responsible for this rapid loss in biodiversity (Faleiro, Machado, & Loyola, 2013; Feeley, Malhi, Zelazowski, & Silman, 2012; Ordonez, Martinuzzi, Radelo, & Williams, 2014; Stanton, Shoemaker, Pearson, & Resitakcakaya, 2014; Thomas et al., 2004). In the tropics, species will lose suitable habitats faster than other regions due to climate change and will therefore be affected more adversely (Loarie et al., 2009; Thuiller, 2007; Wright, Muller-Landau, & Schipper, 2009). With climate change and related extreme events likely to increase over the coming decades, biodiversity and ecosystems are likely to suffer additional stresses in tropical regions, creating a need for integrated assessments and planning for effective conservation (IPCC., 2014; Ordonez et al., 2014; Stanton et al., 2014; Feeley et al., 2012; Kaeslin et al., 2012).

The Asian elephant (*Elephas maximus*) and Western Hoolock gibbon (*Hoolock hoolock*) are two species of global conservation importance that are limited to only tropical Asian forests (Fig. 1; IUCN., 2014). The elephant is the largest living land animal in Asia

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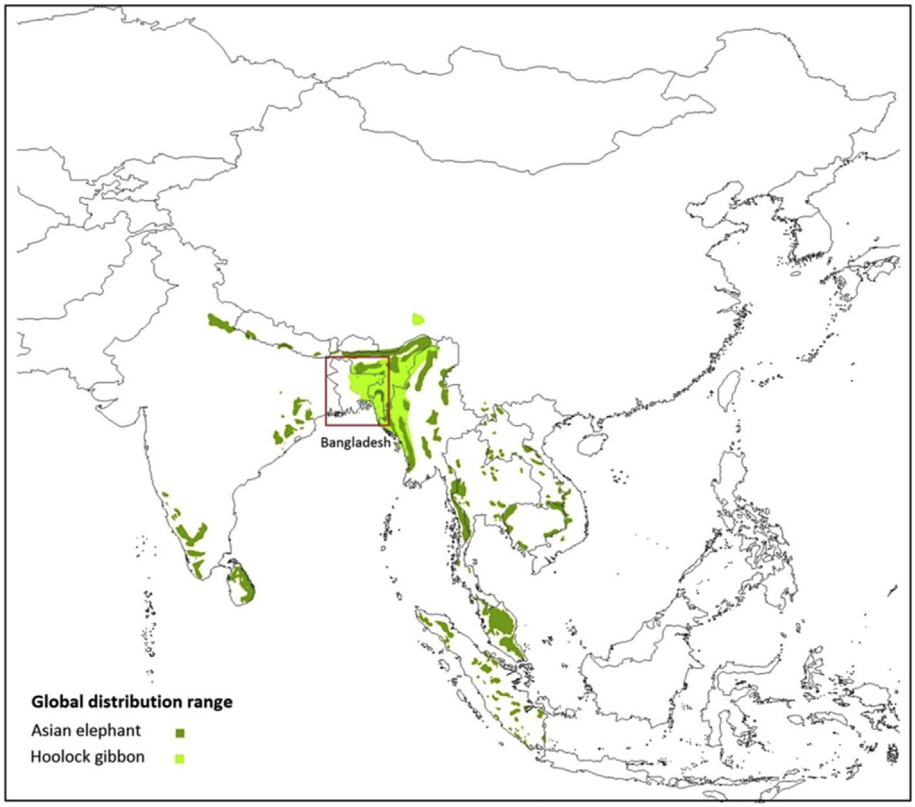

Fig. 1. Global distribution of Asian elephant and Hoolock gibbon.
Source: IUCN.

and has always been an important part of culture and religions here (Mukul, Rashid, & Uddin, 2012; FAO., 2002; Olivier, 1978). Hoolock gibbons, though not as familar as the Asian elephant, are considered to be one of the 25 most endangered primate species in the world (Mittermeier et al., 2009). Populations of both species have declined drastically in recent years due to habitat loss, forest fragmentation, illegal hunting and poaching (Mittermeier et al., 2009; Sukumar, 1989).

Bangladesh is located at 21^0–26^0 north of the equator and has one of the wettest climates in the world (McSweeney, New, & Lizcano, 2010). Due to its geo-climatic location, the country has already experienced substantial changes in local and regional climates and is highly susceptible to any future changes (Alamgir & Turton, 2014; Mukul et al., 2014; MoEF 2008). Both the Asian elephant and Hoolock gibbon were once abundant in most forests in the country, but are now listed locally as critically endangered (Fig. 2; IUCN, 2000). Whilst most wildlife is protected in Bangladesh under the Wildlife Conservation (Amendment) Act of 1974 (Mukul, Uddin, Uddin, Khan, & Marzan, 2008), the population of both species has dropped enormously in recent years (Table 1; Gain, 1998). For instance, the Hoolock gibbon population has declined by more than 50% in the country between 1986 and 2006 (McLellan et al., 2014; Muzaffar et al., 2007).

In recent years, the development and application of species distribution models (SDMs) have benefited the conservation of biodiversity through influencing science, policy and practice (McShea, 2014). SDMs are used as an adaptive management tool to understand the complex landscapes that are undergoing short and long term changes, with models that have evolved to provide future scenarios based on known and projected climatic and environmental parameters (Elith et al., 2011; Elith & Leathwick, 2009). SDM is widely used to determine species distribution patterns at spatial scales (Elith et al., 2011), and produces spatially explicit maps that are useful for identifying areas where conservation efforts should be prioritized (Zhang et al., 2012). Whilst a combination of climate change, deforestation and forest

Fig. 2. Asian elephant roaming around Fashiakhali forests near Chittagong in southeast Bangladesh (left); the endangered Hoolock gibbon in Satchari forests in the northeast Bangladesh (right) (Photo credits: Sayam U. Chowdhury).

Table 1
Profile of the wildlife species in this study.

Species	Conservation status		Population range	
	Bangladesh[a]	Global[b]	Bangladesh[c]	Global
Asian elephant *Elephas maximus*	Critically endangered	Endangered	300–350 (~1%)	25,600–32,750
Western Hoolock gibbon *Hoolock hoolock*	Critically endangered	Endangered	~300 (~10%)	~2800

[a] As per IUCN. (2000).
[b] As per IUCN. (2014).
[c] Values in the parenthesis indicate the percentage of global population.

degradation are widely considered to be the most significant threats to tropical biodiversity (Brodie, Post, & Laurance, 2012; Malhi et al., 2008; Struebig et al., 2015), few studies have made explicit predictions on their potential impact on wildlife species, and there is no study that has focused on either the Asian elephant or Hoolock gibbon.

Using current distribution data bioclimatic and environmental variables, we modelled the present and likely future distributions of Asian elephant and Hoolock gibbon in Bangladesh in 2050 and 2070. We used two greenhouse gas concentration trajectories, i.e. Representative Concentration Pathways (RCPs) – developed by the Intergovernmental Panel on Climate Change (IPCC., 2014) – RCP6.0 and RCP8.5 (Moss et al. 2010). Both RCPs are based on plausible ranges of greenhouse gas concentration pathways, where RCP8.5 is a substantially rising pathway and RCP6.0 is an intermediate pathway (Makino et al., 2014). In tropical regions, effective biodiversity conservation in the future will largely depend on conservation strategies that acknowledge the potential impacts of climate change on species distributions and incorporate appropriate mitigation measures in conservation planning (Keppel et al., 2012; Mukul, 2014; Stanton et al., 2014). We believe our study on two globally endangered wildlife species in Bangladesh, a country which is highly vulnerable to climate change, will improve our understanding of the distribution of species that are in critical need of conservation and could potentially be used to develop strategies to minimize the adverse effects of climate change on wildlife.

Material and methods

Wildlife data

Islam, Mohsanin, et al. (2011) and Islam, Muzaffar, et al. (2011) and Muzaffar et al., (2007) provided comprehensive information on the distribution and population status of Asian elephant and Hoolock gibbon in Bangladesh's forests based on intensive field survey data. For the present study, we used spatial abundance data of Asian elephant and Hoolock gibbon respectively from Islam, Mohsanin, et al. (2011) and Islam, Muzaffar, et al. (2011) and Muzaffar et al., (2007). We used 13 location points for the Asian elephant and 15 location points for the Hoolock gibbon in Bangladesh (Supplementary material 1). Fig. 3 shows the current distribution of both wildlife species based on information provided in Islam, Mohsanin, et al. (2011) and Islam, Muzaffar, et al. (2011) and Muzaffar et al., (2007).

Bioclimatic and environmental variables

The WorldClim data provided 19 bioclimatic variables including 11 temperature and eight precipitation metrics (see Table 2 for details). We used the bioclimatic variables provided in the

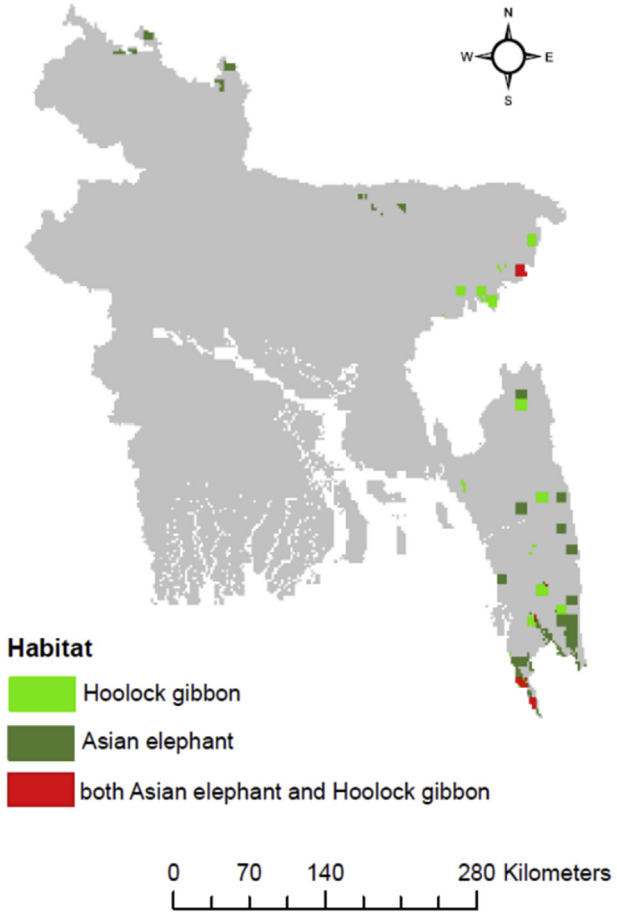

Fig. 3. Current distribution of the Asian elephant and Hoolock gibbon in Bangladesh. Source: Islam, Mohsanin, et al. (2011) and Islam, Muzaffar, et al. (2011) and Muzaffar et al. (2007).

WorldClim (2014) database together with land-use/land cover and elevation. For modeling the future distribution of wildlife we integrated IPCC's RCP6.0 and RCP8.5 pathways for the years 2050 and 2070 in our model. We used projected averaged climate data for 2041–2060 for 2050 and for 2070 we used averaged data for 2061–2080 from HadGEM2-AO Global Circulation Model (GCM) as provided in WorldClim 1.4. at 30 s (~1 km) spatial resolution (WorldClim, 2014). Heterogeneity in LULC and elevation can greatly affect the distributions of wildlife by influencing their accessibility and movement capabilities to different microclimates (Paudel & Heinen, 2015; Struebig et al., 2015; Turner, 2005). We used current LULC information for Bangladesh from the global land cover map of 2009 available at 300 m spatial resolution from the European Space Agency (http://due.esrin.esa.int/globcover/). Elevation data were collected as the same spatial resolution as the bioclimatic variables (i.e. 30 s) from the Digital Eleveation Map (DEM) available from NASA's SRTM (Shuttle Radar Topography Mission; http://www2.jpl.nasa.gov/srtm/). We processed all spatial data in ArcGIS 10.2 interface.

Variable selection

We applied Principal Component Analysis (PCA) to our data, using all 19 bioclimatic variables obtained from the WorldClim 1.4. database. In our correlation matrix derived after performing the PCA, nine bioclimatic variables (i.e. mean diurnal range (BIO2), temperature seasonality (BIO4), maximum temperature of warmest month (BIO5), mean temperature of wettest quarter (BIO8),

Table 2
Bioclimatic and environmental variables used in the preliminary and final MaxEnt model.

Variable	Description	Final model	
		Yes	No
BIO1	Annual Mean Temperature	✗	
BIO2	Mean Diurnal Range (Mean of monthly (max temp − min temp)		✗
BIO3	Isothermality (BIO2/BIO7) (*100)	✗	
BIO4	Temperature Seasonality (standard deviation*100)		✗
BIO5	Max Temperature of Warmest Month		✗
BIO6	Min Temperature of Coldest Month	✗	
BIO7	Temperature Annual Range (BIO5-BIO6)	✗	
BIO8	Mean Temperature of Wettest Quarter		✗
BIO9	Mean Temperature of Driest Quarter		✗
BIO10	Mean Temperature of Warmest Quarter	✗	
BIO11	Mean Temperature of Coldest Quarter		✗
BIO12	Annual Precipitation	✗	
BIO13	Precipitation of Wettest Month		✗
BIO14	Precipitation of Driest Month	✗	
BIO15	Precipitation Seasonality (Coefficient of Variation)	✗	
BIO16	Precipitation of Wettest Quarter		✗
BIO17	Precipitation of Driest Quarter	✗	
BIO18	Precipitation of Warmest Quarter	✗	
BIO19	Precipitation of Coldest Quarter		✗
ENV1	Elevation	✗	
ENV2	Land-use/Land cover (LULC)	✗	

mean temperature of driest quarter (BIO9), mean temperature of coldest quarter (BIO11), precipitation of wettest month (BIO13), precipitation of wettest quarter (BIO16), precipitation of coldest quarter (BIO19)) showed a strong positive correlation ($p < 0.05$; see Annex 1 for details). To avoid spatial autocorrelation among these variables, we excluded them from the final model. Consequently, 10 bioclimatic variables out of 19 were selected and used in the final species distribution modelling, together with the two environmental variables (Table 2).

Modelling species distribution

We used Maximum Entropy algorithm ran in MaxEnt (version: 3.3.3k; www.cs.princeton.edu/~schapire/maxent/) to obtain the current and projected habitat distribution of the Asian elephant and Hoolock gibbon for 2050 and 2070, incorporating the IPCC's RCP6.0 and RCP8.5 pathways (Phillips, Anderson, & Schapire, 2006). MaxEnt was exclusively developed to model the distributions of species using presence-only data, especially when few occurence records are available, and it is also the least affected by location errors in the occurrence (Elith, Kearney, & Phillips, 2010; Merow, Smith, & Silander, 2013; Phillips et al., 2006; Wilting et al., 2010). MaxEnt has been shown to perform the best amongst available species distribution modeling algorithms (Graham et al., 2007; Zhang et al., 2012). MaxEnt models were fitted using cross-validation (500 iterations) after adding the selected bioclimatic and environmental variables (Table 2). In the case of the Asian elephant the model converged after 340 iterations, and in case of the Hoolock gibbon it converged after 380 iterations. In the advanced setting of the model we applied an omission error of 10 percent threshold as suggested in Pearson, Raxworthy, Nakamura, and Peterson (2007). Therefore, only those areas with parameters which were within 90% of presences were recorded and designated as suitable habitat (Elith et al., 2011; Merow et al., 2013). Using the threshold raster layer we prepared current and projected habitat suitability maps for 2050 and 2070 for RCP6.0 and RCP8.5 and calculated the percentage of habitat loss using ArcGIS 10.2.

Results

Our model indicated that LULC provided the highest contribution to explaining the present distribution of Asian elephant and Hoolock gibbon in Bangladesh (Fig. 4). LULC has explained 65.4% and 70.2% of the variation in current distribution of the Asian elephant and Hoolock gibbon respectively (Table 3). Annual temperature range (BIO7) explained 33.1% of the variation in the distribution pattern of the Asian elephant. Other variables that contributed in the model were precipitation in the warmest month (BIO18), mean temperature of the warmest quarter (BIO10), precipitation of the driest month (BIO14) and elevation (ENV1). In the case of Hoolock gibbon, isothermality (BIO3), annual rainfall (BIO12), elevation (ENV1) and mean temperature of the warmest quarter (BIO10) explained the most variation in the current distribution. Several bioclimatic variables, including annual mean temperature (BIO1), minimum temperature of the coldest month (BIO6), precipitation seasonality (BIO15), and precipitation of the

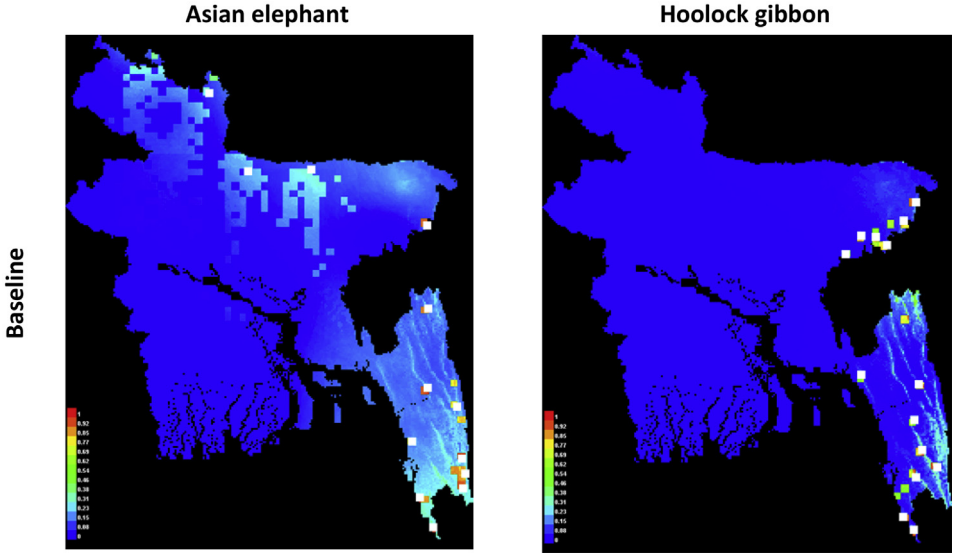

Fig. 4. MaxEnt models showing the likely present distribution of the Asian elephant and Hoolock gibbon in Bangladesh (the white pixels within the maps indicates the current location point of the respective wildlife species used in MaxEnt modelling).

Table 3
Relative contribution of selected bioclimatic and environmental variables in the final MaxEnt model.

Variable	Description	Contribution (%)	
		E. maximux	*H. hoolock*
BIO1	Annual Mean Temperature	0	0
BIO3	Isothermality (BIO2/BIO7) (*100)	0	18.9
BIO6	Min Temperature of Coldest Month	0	0
BIO7	Temperature Annual Range (BIO5-BIO6)	33.1	0
BIO10	Mean Temperature of Warmest Quarter	0.2	1.8
BIO12	Annual Precipitation	0	4.6
BIO14	Precipitation of Driest Month	0.2	0
BIO15	Precipitation Seasonality (Coefficient of Variation)	0	0
BIO17	Precipitation of Driest Quarter	0	0
BIO18	Precipitation of Warmest Quarter	1	0
ENV1	Elevation	0.1	4.5
ENV2	Land-use/Land cover (LULC)	65.4	70.2

driest quarter (BIO17) appeared to have no significant contribution in the final model. However, bioclimatic variable BIO3 and BIO7 were influenced by other variables (i.e. BIO2 and BIO5) that were not included in final model.

Fig. 5 and Fig. 6 below show the likely future distributions of the Asian elephant and Hoolock gibbon in Bangladesh's forests, as determined by the IPCC's RCP6.0 and RCP8.5 pathway projections for 2050 and 2070 respectively. The warm colors (i.e. colors closest to red) represent suitable habitats, and therefore a greater chance of the presence of the Asian elephant and Hoolock gibbon in the area, whilst the cooler colours indicate unsuitable habitat. In our analysis using ArcGIS 10.2 it appeared that the habitat loss of the Asian elephant in both projected years (i.e. 2050 and 2070) and with both climate scenarios (i.e. RCP6.0 and RCP8.5) is likely to remain the same, while Hoolock gibbon is likely to be extinct by 2070 if climate change continues to follow the higher emission RCP8.5 pathway (Table 4).

Discussion

Our current habitat suitability predictions for both species using Maximum Entropy algorithm and MaxEnt is in accordance with the information provided in Islam, Mohsanin, et al. (2011) and Islam, Muzaffar, et al. (2011) and Muzaffar et al., (2007) (Figs. 3 and 4). In Bangladesh, the Asian elephant is currently only present in the southeast part of the country, i.e. Chittagong Hill Tracts (CHT), Chittagong and Cox's Bazar forest divisions (Islam, 2006). Up to 30% of the wild Asian elephant population of the country is transient, and may be found in the northeast and southeast forests bordering the neighboring India and Myanmar (Islam, Mohsanin, et al., 2011; Islam, Muzaffar, et al., 2011). Muzaffar et al., (2007), Islam, Feeroz, Muzaffar, Kabir, and Begum (2006; 2011) reported 12 sites in the northeast and 25 sites in southeast Bangladesh where Hoolock gibbon is present. It is possible that there are an additional 50–100 individuals located in remote areas in southeast Bangladesh (i.e.

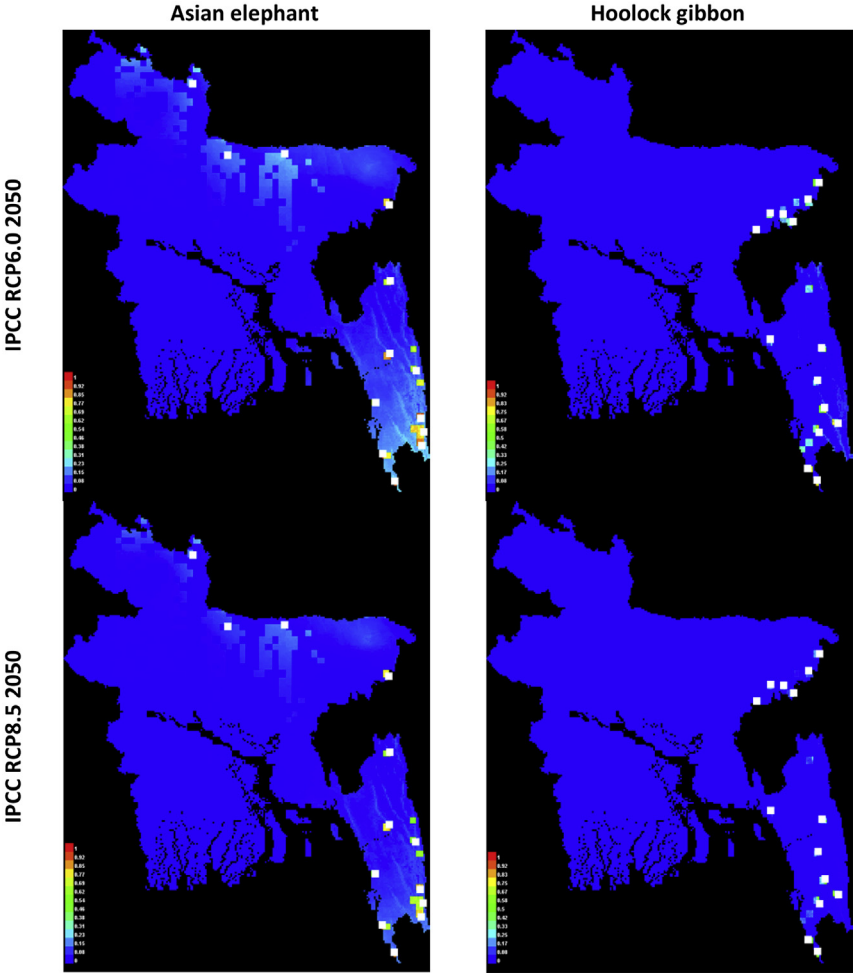

Fig. 5. MaxEnt models showing the likely distribution of the Asian elephant and Hoolock gibbon in 2050 in Bangladesh with IPCC's RCP6.0 and 8.5 RCP projections (the white pixels within the maps indicates the current location point of the respective wildlife species used in MaxEnt modelling).

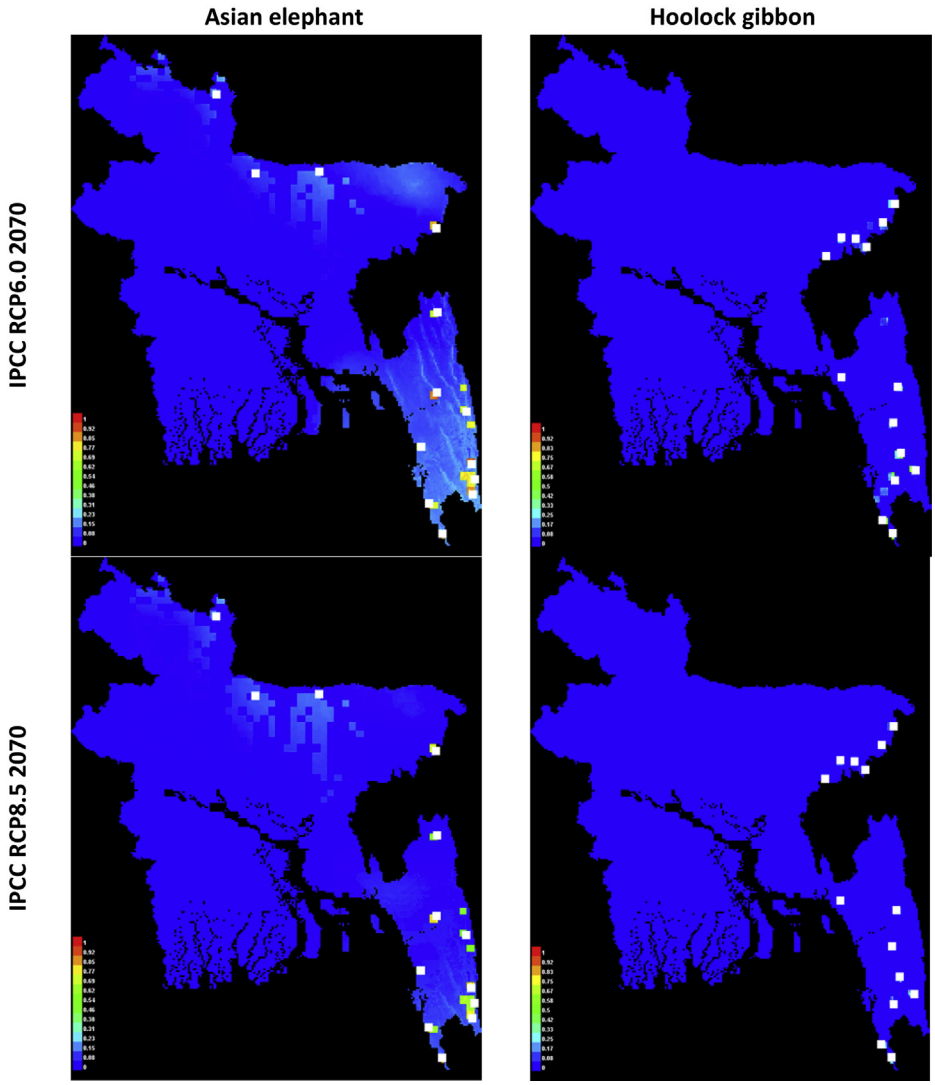

Fig. 6. MaxEnt models showing the likely distribution of the Asian elephant and Hoolock gibbon in 2070 in Bangladesh with IPCC's RCP6.0 and RCP8.5 RCP projections (the white pixels within the maps indicates the current location point of the respective wildlife species used in MaxEnt modelling).

CHT) which has not been confirmed by field surveys due to inaccessibility and political insurgency (Muzaffar et al., 2007).

The future of many wildlife species will depend on the ability of a given species to tolerate or adapt to a wide range of conditions, e.g. limited or heavy rainfall, a change in temperatures, etc. (Feeley et al., 2012; Loucks, Barber-Meyer, Hossain, Barlow, & Chowdhury, 2010; Ramirez-Villegas et al., 2014). Among our bioclimatic variables, five temperature metrics (out of 11) and five perecipitation metrics (out of 8) were finally included in the model. However, in the case of the Asian elephant only two of the temperature metrics (i.e. temperature annual range (BIO7) and mean temperature of warmest quarter (BIO10)) and two of the precipitation metrics (i.e. precipitation of driest month (BIO14) and precipitation of warmest quarter (BIO18)) contributed respectively 33.1%, 0.2%, 0.2% and 1% in the final model. In the case of the Hoolock gibbon only two of the temperature metrics (i.e. insothermality (BIO3) and mean temperature of the warmest quarter (BIO10)) and one precipitaion metrics (i.e. annual precipitation (BIO12)) explained respectively 18.9%, 1.8% and 4.6% of the model. These may be attributed to the relatively high demand of water by Asian elephant and the need for a good canopy condition for the survival of Hoolock gibbon (Muzaffar et al., 2007; Sukumar, 1989).

Table 4
Likely habitat loss for the Asian elephant and Hoolock gibbon due to projected climate change in 2050 and 2070, as determined by the IPCC's RCP6.0 and RCP 8.5 emission pathways.

IPCC scenario	Year	Habitat loss (%)	
		E. maximus	*H. hoolock*
RCP6.0	2050	38	82
	2070	38	97
RCP8.5	2050	38	99
	2070	38	100

Our future habitat suitability modeling using the IPCC's RCP6.0 and RCPP8.5 pathways for 2050 and 2070 showed an alarming future decline in the percentage of suitable habitat for both the Asian elephant and Hoolock gibbon (Fig. 7, Fig. 8, Table 4). Quite expectedly, the likely habitat loss with the RCP8.5 emission pathway – which is a substantially rising climate change pathway – is larger than that in RCP6.0 pathway –an intermediate pathway (Makino et al., 2014; Table 4). Interestingly, the loss of available habitat for the Asian elephant is likely to remain constant throughout the period, whilst the Hoolock gibbon is likely to be extirpated from the country by 2070 if climate change follows the RCP8.5 pathway. Such a phenomenon may also be explained by the comparatively high resilience of the Asian elephant in the wild to a

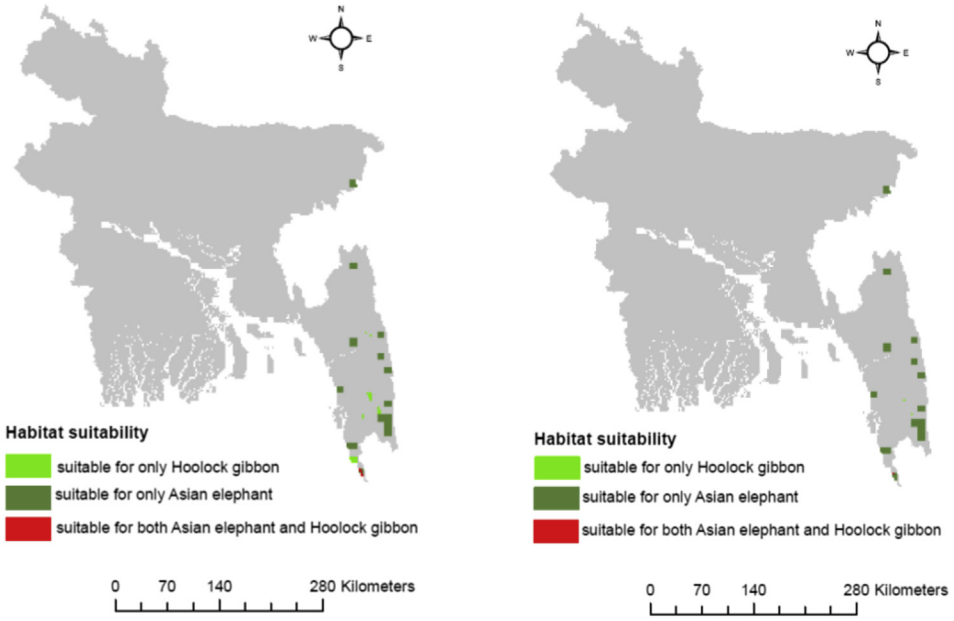

Fig. 7. Likely distribution of the Asian elephant and Hoolock gibbon in 2050 under IPCC's RCP6.0 and RCP8.5 emission pathways in Bangladesh.

wide range of climatic extremes (WWF, 2014). On the other hand, the population of Hoolock gibbon will severely decline, as their existence is strongly associated with the availability of contiguous canopy coverage and broad-leaved forests (Mittermeier et al., 2009; Muzaffar et al., 2007). It is also possible, that a decline in forest quality affecting the canopy cover and fruit trees available in forests will be a contributing factor to their sudden population decline (Chowdhury et al., 2011).

In addition to climate change, forest loss and degradation will also significantly affect the quality of wildlife habitat that will remain in the future (Feeley & Silman, 2010; Uddin, Steinbauer, Jentsch, Mukul, & Beierkuhnlein, 2013). In the wild, the Asian elephant has very few predators due to their large body size (Sukumar, 1989). Illegal hunting by humans for ivory trade is presently the main threat to their existence. In contrast, the Hoolock gibbon is affected by many human activities and their population has declined globally by almost 90% over the last thirty years (Mittermeier et al., 2009). The most significant threats to the survival of Hoolock gibbon, not in an order of importance, are – habitat loss due to encroachment, forest clearance, shifting cultivation, wild hunting and/or capture for medicinal and dietary use (Fig. 9) (Mittermeier et al., 2009). These factors were, however, not included in our modelling due to data scarcity and incompatibility with our present focus with climate change.

Conclusion

Our habitat suitability modeling using present distribution data, bioclimatic and environmental variables and IPCC's RCP6.0 and RCP8.5 emission pathways for 2050 and 2070 showed a steady but rapid decline in the availability of suitable habitats for the Hoolock gibbon in the forests of Bangladesh, and a relatively stable habitat

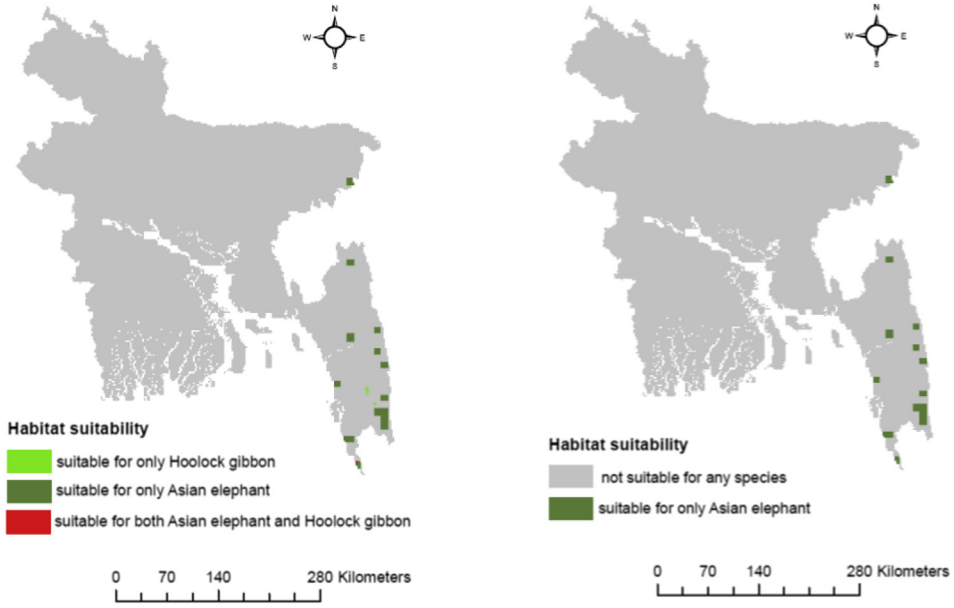

Fig. 8. Likely distribution of the Asian elephant and Hoolock gibbon in 2070 under IPCC's RCP6.0 and RCP 8.5 emission pathway in Bangladesh.

Fig. 9. Eaten to extinction! The mother of this baby Hoolock gibbon was killed by Mro huntsmen for subsistence in Chittagong Hill Trcats in southeast Bangladesh (Photo credit: Shahriar Caesar Rahman).

range available for the Asian elephant after reaching a plateau. In the wild, the Asian elephant requires a large amount of plant matter to reach its dietary requirements, and about 150–300 L of water every day for drinking. Their population can therefore be impacted by the availability of plant species on which they feed, and changes in precipitation and other related climatic events like droughts and floods. In the case of Hoolock gibbon, lush forests and canopy cover with fruiting trees are a prerequisite for their survival in the wild, which are likely to be highly impacted by land use pressure and climatic events that influence tree phenology. Enrichment of degraded forests and fresh water sources in areas that are susceptible to droughts could help both the Asian elephant and Hoolock gibbon to survive in a changing climate. Most of the forests in the country are fragmented, offering isolated habitats to the wildlife. Creating corridors between such isolated habitats could provide wildlife with access to more food and better habitats, if necessary. Also since both of the species share their habitat with neighboring countries, a transboundary conservation and joint monitoring program with these countries could help minimize the adverse effects of climate change on the survival and availability of suitable habitat for both wildlife species.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2015.03.001.

Annex 1. Correlation matrix between bioclimatic variables

Variable	BIO1	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO11	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	BIO18	BIO19
BIO1	1.000	−0.152	−0.584	0.000	0.582	0.429	0.149	0.541	0.599	0.717	0.631	−0.491	−0.451	0.322	−0.192	−0.433	0.124	−0.757	0.100
BIO2	−0.152	1.000	−0.022	**0.882***	0.585	−0.893	**0.885***	0.612	−0.710	0.467	−0.781	−0.532	−0.571	−0.496	−0.199	−0.602	−0.267	−0.087	−0.229
BIO3	−0.584	−0.022	1.000	−0.388	−0.707	0.017	−0.480	−0.565	−0.077	−0.636	−0.069	0.667	0.611	−0.025	0.061	0.591	0.209	0.661	0.220
BIO4	0.000	**0.882***	−0.388	1.000	0.708	−0.862	**0.950***	0.795	−0.673	0.652	−0.773	−0.679	−0.691	−0.461	−0.118	−0.715	−0.389	−0.209	−0.351
BIO5	0.582	0.585	−0.707	0.708	1.000	−0.337	**0.853***	**0.827***	−0.123	**0.861***	−0.178	−0.883	−0.848	−0.210	−0.155	−0.838	−0.251	−0.733	−0.240
BIO6	0.429	−0.893	0.017	−0.862	−0.337	1.000	−0.779	−0.448	**0.890***	−0.250	**0.944***	0.349	0.407	0.500	0.178	0.446	0.286	−0.161	0.250
BIO7	0.149	**0.885***	−0.480	**0.950***	**0.853***	−0.779	1.000	0.799	−0.576	0.712	−0.642	−0.782	−0.790	−0.417	−0.202	−0.806	−0.326	−0.399	−0.298
BIO8	0.541	0.612	−0.565	0.795	**0.827***	−0.448	0.799	1.000	−0.186	**0.901***	−0.271	−0.767	−0.760	−0.282	−0.187	−0.780	−0.320	−0.466	−0.304
BIO9	0.599	−0.710	−0.077	−0.673	−0.123	**0.890***	−0.576	−0.186	1.000	−0.002	**0.910***	0.143	0.233	0.422	0.219	0.267	0.160	−0.282	0.145
BIO10	0.717	0.467	−0.636	0.652	**0.861***	−0.250	0.712	**0.901***	−0.002	1.000	−0.043	−0.717	−0.693	0.000	−0.155	−0.695	−0.099	−0.647	−0.087
BIO11	0.631	−0.781	−0.069	−0.773	−0.155	−0.178	−0.642	−0.187	−0.282	−0.155	−0.006	0.203	0.423	−0.228	1.000	0.441	−0.520	0.209	−0.496
BIO12	−0.491	−0.532	0.667	0.349	−0.782	−0.767	0.143	0.233	0.259	0.962	0.221	1.000	0.222	1.000	−0.228	0.250	0.233	0.677	−0.023
BIO13	−0.451	−0.571	0.611	−0.691	−0.848	0.407	−0.790	−0.760	0.233	−0.693	0.259	0.962	1.000	0.222	0.209	0.677	−0.032	1.000	0.231
BIO14	0.322	−0.496	−0.025	−0.461	−0.210	0.500	−0.417	−0.282	0.422	0.000	0.555	0.279	0.222	1.000	−0.228	0.250	0.725	−0.182	0.709
BIO15	−0.192	−0.199	0.061	−0.118	−0.155	0.178	−0.202	−0.187	0.219	−0.155	−0.006	0.203	0.423	−0.228	1.000	0.441	−0.520	0.209	−0.496
BIO16	−0.433	−0.602	0.591	−0.715	−0.838	0.446	−0.806	−0.780	0.267	−0.695	0.290	**0.960***	**0.992***	0.250	0.441	1.000	0.233	0.233	0.225
BIO17	0.124	−0.267	0.209	−0.389	−0.251	0.286	−0.326	−0.320	0.160	−0.099	0.369	0.378	0.238	0.725	−0.520	0.233	1.000	−0.032	**0.993***
BIO18	−0.757	−0.087	0.661	−0.209	−0.733	−0.161	−0.399	−0.466	−0.282	−0.647	−0.312	0.753	0.701	−0.182	0.209	0.677	−0.032	1.000	−0.023
BIO19	0.100	−0.229	0.220	−0.351	−0.240	0.250	−0.298	−0.304	0.145	−0.087	0.326	0.367	0.231	0.709	−0.496	0.225	**0.993***	−0.023	1.000

*Correlation significant at $p < 0.05$ level in bold.

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