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Impact of Climate Change on Distribution of Caterpillar Fungus, *Ophiocordyceps sinensis* in Sikkim Himalaya, India

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ABSTRACT

MaxEnt modelling has been used to predict the present and future distributions of caterpillar fungus, *Ophiocordyceps sinensis* in Sikkim Himalaya in four future climate change trajectories (viz. RCP 2.6, RCP 4.5, RCP 6.0 and RCP_8.5) for the year 2050. The result predicted an area of 311 km^2 (4.77 % of total area) to be suitable under current climatic condition. Under future climate change scenario the suitable habitat of caterpillar fungus would get drastically reduced (RCP_2.6, RCP_4.5 and RCP_8.5) with a minor expansion (i.e. ~71 km^2) in addition to current potential suitable habitat under scenario RCP_6.0. Niche overlap analysis resulted in more than 90 % niche overlap among current and future distribution of species. The existing protected areas (PAs) accounts for only 0.54 % (~35 km^2) of the total area of state of Sikkim and 1.64 % of the total area of PAs and shows variability in suitable habitat under climate change scenario. Therefore the establishment of new PAs especially towards Far-East and North-East region of Sikkim could be an alternative measure for the conservation of suitable habitat of caterpillar fungus. Alternatively, trans-boundary conservation programs connecting country like Bhutan in the West, Nepal in the East and Tibet in the North of Sikkim could be a feasible long term alternative plan for conservation of species.

Key words: Niche Modelling, *Ophiocordyceps sinensis*, Protected Area, Sikkim, *Yartsha-gumbu*

INTRODUCTION

Ecological Niche Modelling (ENM) has a variety of applications in conservation biology. One such application is an estimation of present and future suitable habitat of threatened species through identification of protected area for conservation of such species (Pradhan and Chettri, 2017; Chettri *et al*., 2018). The future distribution of species due to climate change depends on a variety of biotic and abiotic factors leading to change in distribution patterns (Hellmann *et al*., 2008). Even though the interactions between species and climate have been widely considered in conservation of species, the effect of climate change can produce shifts in species distribution (Mawdsley *et al*., 2009). In the last 25 years (1982-2006) the Himalaya has warmed up by about 1.5º C, which is three times more than that of the global average (Shrestha *et al*., 2012). Like other Himalayan states of India, climate in Sikkim is changing rapidly and that more changes are at the forefront leading to loss in Biodiversity, human health, local livelihoods, agriculture and water availability (Bawa and Ingty, 2012).

Ophiocordyceps sinensis locally known as *Yartsha-gumbu* in Sikkim, is a fungal parasite of larvae (caterpillars), hence also known as Caterpillar Fungus (CF). The CF has patchy distribution and known to occur in the Tibetan plateau, Bhutan, China, Nepal and India (Namgyel & Tshitila, 2003; Pegler *et al*., 1994; Winkler, 2005; Sharma, 2004; Devkota, 2006).

In the present study, we used presence record of CF in Sikkim Himalaya (Figure 1), with the following two objectives: (1) to predict and identify protected areas suitable for CF in Sikkim Himalaya (2) to compare the future (2050) predicted distribution of CF with present climate scenario.

MATERIALS AND METHODS

Occurrence data, Niche Modelling and Climate data

Due to a narrow geographic range of CF in Sikkim Himalaya, we collected five occurrence data, i.e. geographic coordinates from Northern and Eastern District of Sikkim (Supplementary material 1). We used MaxEnt (maximum entropy) model to predict the current and future habitat distribution of CF in Sikkim Himalaya. MaxEnt model is one of the most widely used software package for environmental niche modelling and can achieve high predictive accuracies even with the low presence only data (Phillips and Dudík, 2008). MaxEnt have been previously used to predict the impact of climate change on the distribution of CF in Nepal Himalaya (Shrestha and Bawa 2014). The climate data for current and future climate change scenario (2050) were obtained from the Worldclim data base (www.worldclim.org) at the resolution of 30 arc Sec (~1 km^2). The 19 bioclimatic variables were subjected to a correlation test using ENM Tools 3.3. (Warren *et al*., 2010) and therefore out of 19 variables 13 variables were found to be highly correlated (r^2>0.90) leaving six variable for modelling (Table 1).

Model evaluation and validation

The performance of the model was evaluated based on area under the curve (AUC) metric. The AUC value of

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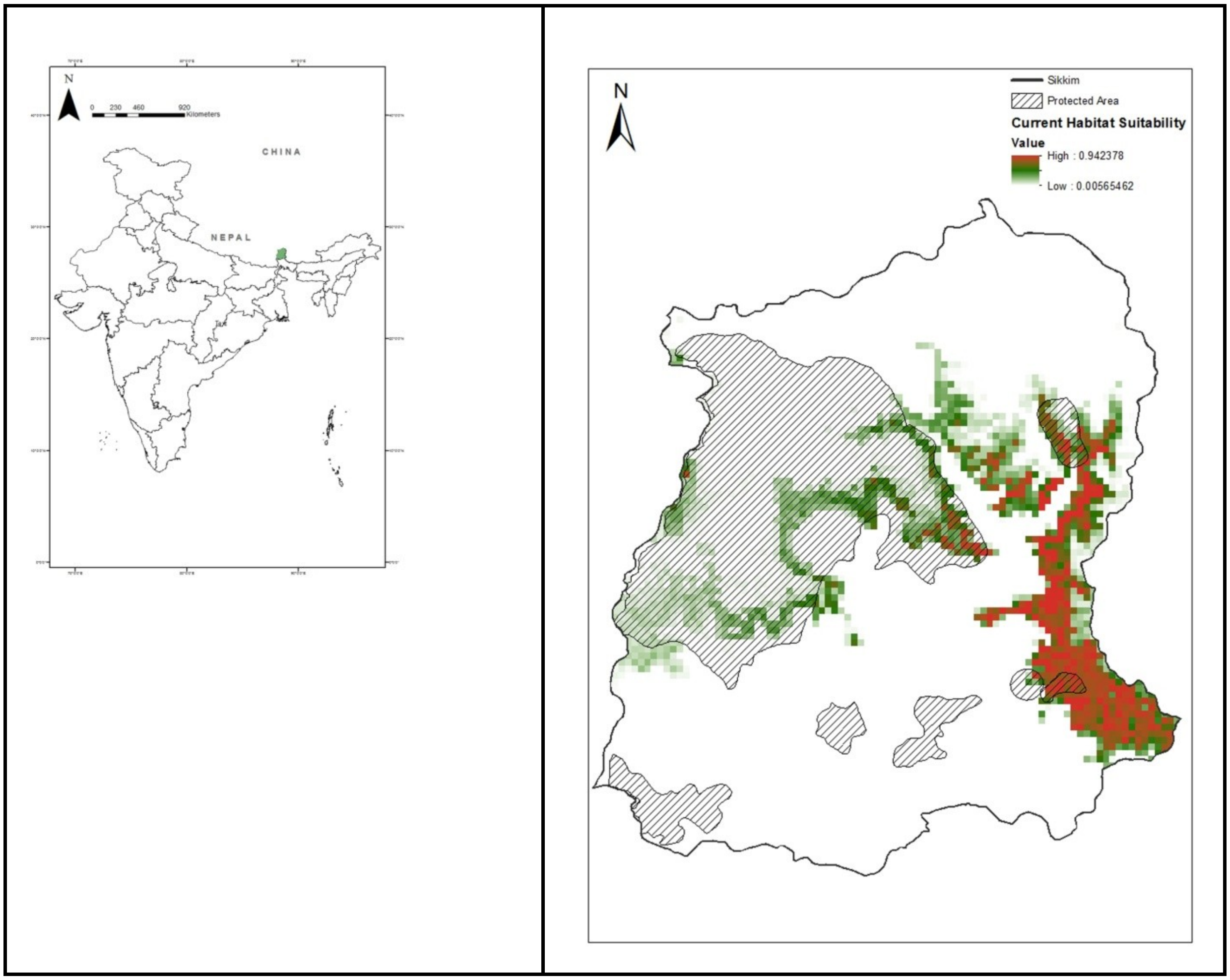

Figure 1. Habitat distribution of *O. sinensis* under current climate

Table 1. The relative contribution of six bioclimatic variables used in MaxEnt modelling

Variables code	Description	Units	Average % contribution
BIO 15	Precipitation seasonality (Coefficient of variation)	mm	40.5
BIO 1	Annual mean temperature	º C	39.2
BIO 12	Annual precipitation	mm	11.5
BIO 3	Isothermality (bio2/bio7)*100	-	6.3
BIO 2	Mean diurnal temperature range	º C	2.2
BIO 19	Precipitation of Coldest Quarter	mm	0.3

<0.5 indicates poor model as the model could not perform better than random where as the value above 0.75 are normally considered useful (Elith, 2000). The partial AUC metric was also used for model evaluation (Lobo *et al*., 2008; Peterson, 2008). Partial AUC was estimated using Niche Toolbox available online at http://shiny.conabio.gob.mx:3838/nichetoolb2/. The tool was used to calculate the ratio of AUC_{random} (at 0.5 level) and AUC_{actual} using the occurrence data and the output model developed. We executed 500 bootstrap iterations with 5 % omission to obtain the distribution curves for AUC_{random} and AUC_{actual}.

RESULTS

Ecological Niche Modelling under current climatic condition

Out of 6 bioclimatic variables used, Precipitation seasonality (BIO 15) had the highest contribution (40.5 %) to the model followed by Annual mean temperature (BIO 1) and Annual precipitation (BIO 12). The contribution of above mentioned 3 variables together accounts for 91.2 % of the model prediction (Table 2). The Area under the Curve (AUC) values of 0.999 shows a high level of accuracy in predicting the distribution of *O. sinensis* in Sikkim Himalaya. At 10 % training presence logistic

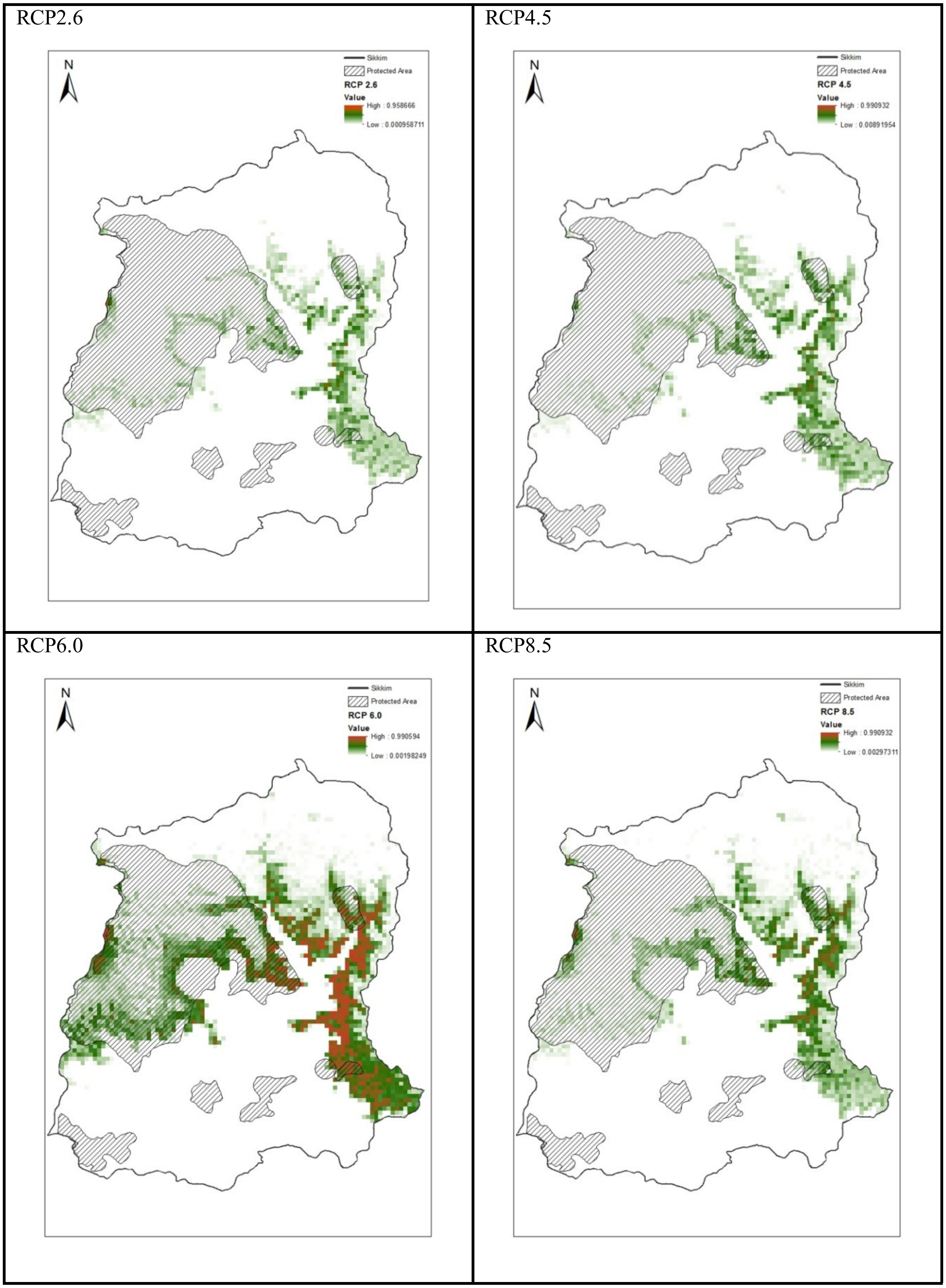

Figure 2. Habitat distribution of *O. sinensis* under future climate change scenario 2050

threshold value (i.e. 0.634) the current suitable habitat was estimated to be 311 km2, which accounts for only 4.77 % of the total area of Sikkim Himalaya.

Distribution under climate change scenario (2050)

The potential suitable habitat of CF showed drastic reduction in comparison to current climatic condition (Figure 2), however there has been considerable increase in suitable habitat under climate change scenario RCP6.0 (Figure 3). The predicted potential areas of CF have also been showed to increase under climate change scenario in Nepal Himalaya (Shrestha and Bawa, 2014).

Habitat suitability within PAs and Niche Overlap

A total of approximately 35 km^2 areas was predicted to be suitable under current climatic condition within PAs,

Table 2. Results of final MaxEnt model for current and future distribution of *O. sinensis*

Variables	AUC at 0.5 levels (mean ± SD)	AUC at 0.05 levels (mean ± SD)	AUC ratio (mean ± SD)
Current (1960-1990)	0.5±1.79927E-11	0.99±0.0002	1.99±0.0004
RCP 2.6 (2041-2060)	0.5±3.43864E-13	0.99±0.0074	1.99±0.0149
RCP 4.5 (2041-2060)	0.49±1.51358E-06	0.96±0.0255	1.92±0.0511
RCP 6.0 (2041-2060)	0.49±6.30808E-08	0.98±0.0082	1.97±0.0165
RCP 8.5 (2041-2060)	0.49±8.31817E-08	0.97±0.0244	1.94±0.0489

Table 3. Current and future suitable habitat for *O. sinensis* within protected areas of Sikkim Himalaya

Protected area (PAs)	Current (km^2)	RCP 2.6 (km^2)	RCP 4.5 (km^2)	RCP 6.0 (km^2)	RCP 8.5 (km^2)
Khangchendzonga National Park	14	0 (-)	0 (-)	70 (+)	6 (-)
Fambong Lho Wildlife Sanctuary	0	0 (*)	0 (*)	0 (*)	0 (*)
Kyongnosla Alpine Sanctuary	11	0 (-)	0 (-)	9 (-)	0 (-)
Maenam Wildlife Sanctuary	0	0 (*)	0 (*)	0 (*)	0 (*)
Kyongnosla extension	1	0 (-)	0 (-)	2 (+)	0 (-)
Singba Rhododendron Sanctuary	9	0 (-)	0 (-)	19 (+)	0 (-)
Barsey Rhododendron Sanctuary	0	0 (*)	0 (*)	0 (*)	0 (*)
Total	35	0	0	100	6

Note: (+) sign denotes increase in suitable habitat; (-) sign denotes decrease in suitable habitat and (*) denotes no change in habitat suitability within PAs compared to current climatic condition

which accounts for only 0.54 % of the total area of the state of Sikkim and 1.64 % of the total area of PAs. Moreover, considerable declines in suitable habitats were estimated under RCP2.6, RCP4.5 and RCP8.5 within PAs. However, increases in habitat suitability were estimated in the Khangchendzonga National Park, Kyongnosla extension and Singba Rhododendron Sanctuary under RCP6.0 (Table 3).

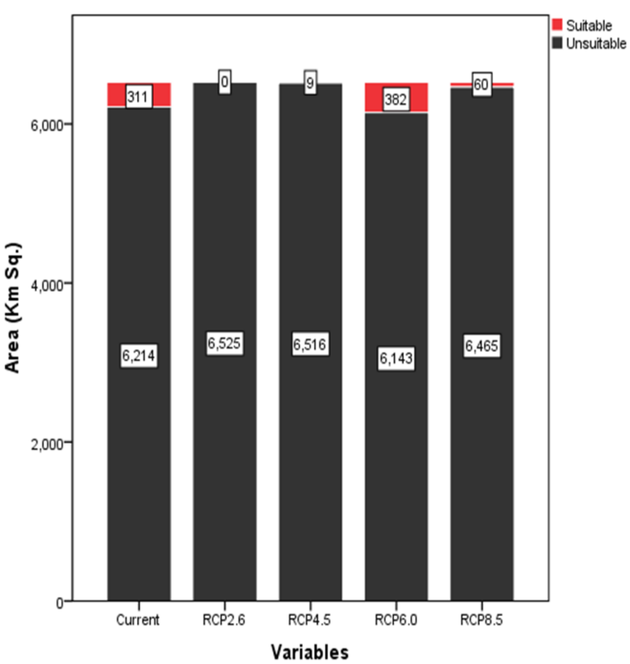

Figure 3. Habitat suitability under current and future climate change scenario (2050) (*at 10 percent training presence logistic threshold value*).

DISCUSSION

The present study is the first attempt to model the distribution of CF in Sikkim Himalaya under climate change scenarios for the year 2050. This rare combination of CF is found at an altitude above 3800 m and is popular among the local community of Lachung and Lachen valley of North Sikkim (Panda and Swain, 2011). The distribution of CF is mostly confined to the far East and Northeastern part of Sikkim. Precipitation seasonality (BIO15) and Annual mean temperature (BIO1) were the top two bioclimatic variables which govern the distribution of CF in Sikkim Himalaya. The present study is in line with that of Shrestha and Bawa (2014), where they observe seasonality of precipitation affecting the distribution of CF in Nepal.

Our model predicted reduction in potential suitable habitat of CF under climate change scenarios (RCP2.6, RCP4.5 and RCP8.5). However, on a positive note increase in suitable habitat (~71 km^2 increase) were estimated under RCP6.0 compared to current condition.

Similarly, the existing PAs network also showed less suitability for CF under present and future climate change scenario (Table 3). The habitat suitability across seven PAs is not consistent, and this may be due to variation in climate across different elevation gradients in PAs (Lamsal *et al*., 2018). Compared to overall habitat suitability under current climatic condition only 11.25 % area (~35 km^2) is estimated to be suitable within PAs resulting in more than 88 % suitable area falling outside PAs. Therefore the establishment of new PAs especially towards far east and northeast region of Sikkim could be an alternative measure for the conservation of suitable habitat of CF. Alternatively trans-boundary conservation programs connecting country like Bhutan in the West, Nepal in the East and Tibet in the North of Sikkim could be a viable long term alternative plan for conservation of species.

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