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Future climate and habitat distribution of Himalayan Musk Deer (*Moschus chrysogaster*)

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ABSTRACT

Change in future climate will either expand, contract or shift the climatic niche of many species and this could lead to shifting of their geographical ranges. Species distribution models identify habitat over a specified area that may have similar ecological characteristics of a species in question. We modelled current and future distribution of endangered Himalayan Musk Deer (*Moschus chrysogaster*), referred here as HMD, in Nepal Himalaya based on two representative concentration pathways (RCP4.5 and RCP8.5) for the year 2050 and 2070 using MaxEnt and MIROC5 global climate models (GCM). Annual mean temperature, altitude, isothermality and land cover were the major contributing variables to the model with area under ROC (Receiver Operating Characteristic) curve (AUC) being 0.975. Almost 7.7% (11,342 km^2) area of the country is currently suitable for HMD. The model shows that a majority of current suitable habitat will remain stable under both RCPs in the future though 29.47% of the current suitability will be decreased by 2070 under RCP4.5, mostly in the western and far western regions. Overall, the shift of habitat shows a longitudinal pattern. Existing protected areas (PAs) account for 52.6% of the total suitable habitat area, and shows variability of changes in suitability under both RCPs in the future. Initiation of trans-boundary conservation programs could offset the likely climate change impact on HMD habitat in Nepal and adjoining native Himalayan ranges.

1. Introduction

Anthropogenic climate change (CC) has become a major threat to global biodiversity and has affected natural ecosystems in numerous regions around the world. The earth has warmed up by 0.74 °C in the 20th century, and global mean temperatures are projected to increase further by 4.3 ± 0.7 °C by 2100 (IPCC, 2013). Changes in future climate will either expand, contract or shift the climatic niche of many species and this could lead to shifting of their geographical ranges. Of the global 976 species studied, Wiens (2016) found that almost 47% are locally extinct due to range contraction even within current modest temperature rises, and that animals suffered the most (50%) compared to plants (39%). Terrestrial ecosystems have seen widespread changes in its climate in the past (Alley et al., 2003; Diffenbaugh and Field, 2013), and as a result, animal habitat ranges have shifted both in latitude and altitude (Chen et al., 2011; Hickling et al., 2006). Warren et al. (2013) projected that approximately 27% of common and widespread animal species at current time could lose half of their climatic range by 2080.

Around 96% of the Global 200 Ecoregions, identified by World Wildlife Fund (WWF) as priority eco-regions, are likely to experience moderate to pronounced climatic impact by the end of the 21st century (Li et al., 2013). Wildlife, especially mammalian species, in this context could lose substantial amounts of their habitat range at a global scale with future warming climate. Thuiller et al. (2006) projected that 20% of African mammalian species with migration capacity and 40% without migration capacity could fall either within critically endangered or extinct category as a consequences of habitat change by 2080. Likewise, Levinsky et al. (2007) estimated that almost up to 9% of European mammalian species without migration capacity risk extinction while 78% of them risks for severely threatened by 2100. Around 9% of locally found mammals in American continents would likely be unable to keep pace with future climate while 80% could have reduced range size (Schloss et al., 2012).

High species richness and endemism characterizes the Himalayan region due to climate variations, exposure effect and habitat diversity (Aryal et al., 2014; Pandit et al., 2014; Xu et al., 2009). This region however has recently been reported to be warming at a greater rate

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Fig. 1. Himalayan Musk Deer (*Moschus chrysogaster*) foraging in its natural habitat in Mt. Everest region, eastern Nepal.

than the global average, for instance, the global average for the last 100 years was 0.74 °C (IPCC, 2013) while it was 1.5 °C for the Himalayas from 1982 to 2006 (Shrestha et al., 2012). Rapid glacier melt in the Himalaya in recent times is a compelling evidence of such warming (Shrestha and Aryal, 2011). Warming impacts to species, for instance, vegetation range shift and plant composition changes have been documented for western Himalaya (Lamsal et al., 2018; Padma, 2014; Rashid et al., 2015), central Himalaya (Gaire et al., 2014; Chhetri and Cairns, 2015; Lamsal et al., 2017a), eastern Himalaya (Manish et al., 2016; Telwala et al., 2013), southern Tibetan belt (Xiaodan et al., 2011; Zhao et al., 2011) as well as the whole Himalayas and Tibetan Plateau (Lamsal et al., 2017b). Similarly, around 30% of snow leopard (*Panthera uncia*) habitat is projected to be lost in the whole Himalayan region by 2050, of which 40% could disappear from Nepal alone (Forrest et al., 2012). Aryal et al. (2016) also predicted decreased habitat for snow leopard and blue sheep (*Pseudois nayaur*) for Nepal with future climate. All these evidences suggest that climatic change drives species to alter their geographic distribution in every region, including the Himalayas.

Himalayan Musk Deer (*Moschus chrysogaster*) (Fig. 1) is distributed throughout the Himalayan range. In Nepal, two species of HMD are mentioned in the literature, *Moschus chrysogaster* and *M. leucogaster*, of which this study concentrates on *M. chrysogaster* because of the field data availability. HMD has been under the IUCN endangered category since 2008, Appendix I of CITES list and is also protected by the Government of Nepal under the National Park and Wildlife Conservation Act, 1973. HMD is one of the six deer species found in Nepal, and prefers alpine forest habitat of the Himalaya between 2200 and 4300 m. It is native to Nepal, India, Bhutan and China but also reported in Afghanistan, Pakistan and Myanmar (Green, 1986). HMD is solitary and territorial in nature, and is a concentrate feeder with an ability to adapt to poorer diets when high quality food is in short supply (Green, 1987).

The population size of HMD for Nepal and other native regions is unknown. However, it has been decreasing in the last few decades due to anthropogenic activities (such as illegal poaching for musk gland and habitat fragmentation) in China (Yang et al., 2003), India (Syed and Ilyas, 2016), Pakistan (Khan et al., 2006), and Nepal (Aryal et al., 2010; Aryal and Subedi, 2011; Khadka et al., 2017). Such anthropogenic activities, together with ongoing and projected CC, could exacerbate their survival through impacting on their habitat. As stated earlier, many studies have reported habitat shift of species in the Himalaya region. We found no studies on impact of CC on Musk deer and its habitat in Nepal, therefore, this study attempted to investigate (i) current distributional range of HMD (ii) future climate effects on the spatial distribution of HMD, and (iii) climatic variables explaining future spatial distribution of potential habitat of HMD. This study accounted for such distributional change both inside and outside of the protected areas (PAs) of Nepal.

2. Material and methods

2.1. Study area

The study area covered the entire hilly and mountainous region from east to west of Nepal where the habitat of HMD currently exists (Fig. 2). Nepal is an agrarian-economy-based mountainous country

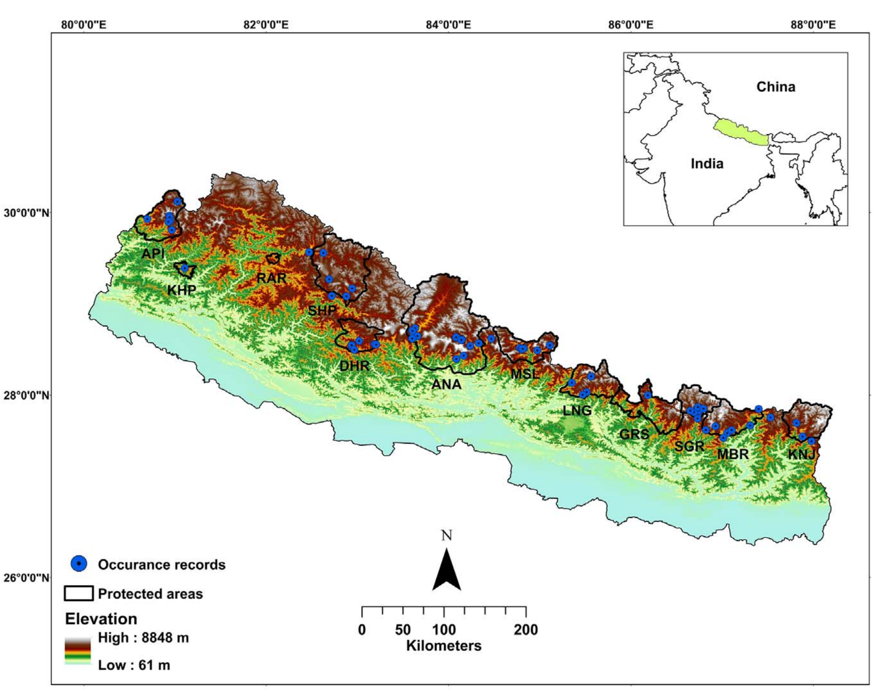

Fig. 2. Study area showing location of occurrence records, protected areas and elevation gradient [API = Api Nampa CA; KHP = Khaptad NP; RAR = Rara NP; SHP = Shey Phoksundo NP; DHR = Dhorpatan HR; ANA = Annapurna CA; MSL = Manaslu CA; LNG = Langtang NP; GRS = Gaurishankar CA; SGR = Sagarmatha NP; MBR = Makalu Barun NP; KNJ = Kanchanjunga NP].

situated in the central Himalaya of South Asia. The agriculture sector contributes almost 35% to national gross domestic product (GDP) and employs around 76% of the population (CBS, 2011). The most dominant climate of the country is temperate with dry winter and hot summer (Karki et al., 2015). However, the altitudinal range varies from 60 m amsl with tropical and subtropical climate in the southern plains to 8848 m amsl with temperate, sub-alpine, alpine and tundra climate in the northern highlands that harbour 118 ecosystems, 75 vegetation types and 35 forest types (MoE, 2012). Mountain highland, a preferred habitable range of HMD, accounts for 24% of the country's total area and contains two thirds of the PAs available in the country (Shrestha et al., 2010). These PAs harbour many endangered flora and fauna of global importance.

2.2. MaxEnt, occurrence data, and model variables

We used maximum entropy (MaxEnt) model to predict the current and future suitable habitat for HMD in Nepal Himalaya. The MaxEnt model is a correlative approach that uses species occurrence data and environmental data in order to make a correlative model of the environmental conditions that satisfy species ecological requirements and finally predict relative suitability of habitats (Phillips et al., 2006; Warren and Seifert, 2011). It is one of the most widely used software package for environmental niche modelling and can achieve high predictive accuracies even with low presence only data (Pacifici et al., 2015; Phillips and Dudík, 2008). MaxEnt has been used for either single or multiple mammalian species in Nepal (Aryal et al., 2016) as well as other geographic regions including Denmark (Flojgaard et al., 2009), Spain (Morueta-Holme et al., 2010), South Africa (Jackson and Robertson, 2011), South America (Marino et al., 2011), Northern Europe (Hof et al., 2012), Malaysia (Nazeri et al., 2012), Bangladesh (Alamgir et al., 2015), and China (Hu and Jiang, 2010; Su et al., 2015).

A total of 80 (from a total of 192, after removing multiple presences within a 1 km^2 raster grid cell) distribution points of HMD within the territory of Nepal were used for processing in MaxEnt software, sourced from different literature (Aryal et al., 2010; Aryal and Subedi, 2011; Chalise, 2012; Subedi et al., 2012). Most of the presence data from Annapurna Conservation Area, Mt. Everest National Park and Dhorpatan Hunting Reserve were collected between 2005 and 2010 by one of the co-authors. We believe the 80 locations that we used in the model were extensive enough for a good result as it covers the whole current spatial location of the species in Nepal from the eastern to western sections that also represents different altitude, temperature and habitat types along that stretch. To model the distribution of HMD, we downloaded 19 grid based bioclimatic variables from Worldclim dataset (www.worldclim.org). Similarly, current global land cover data at 300 m spatial resolution for Nepal was obtained from the European Space Agency (http://due.esrin.esa.int/page_globcover.php) while elevation data with similar resolution to bioclimatic variables (30 arcsec) was obtained from global multiresolution terrain elevation data 2010 (https://lta.cr.usgs.gov/GMTED2010). Slope and aspect were derived from the elevation data. All the above raster layers were resampled to 30 arcsec (~1 km) resolution to make them equivalent to Worldclim bioclimatic data. We removed highly correlated variables before MaxEnt analysis. Thereafter, values of each bioclimatic, environmental and topographic variable used in the modelling were extracted using ArcGIS 10.2 and PCA analysis was undertaken to investigate the correlation among those variables. Altogether, twelve variables out of 22 were found highly correlated ($R^2 \geq 0.75$), leaving ten variables suitable for final MaxEnt analysis (Table 1, Supplementary 1).

Using logistic threshold value (equal training sensitivity and specificity), an inbuilt functionality of MaxEnt, current and projected habitat suitability maps for 2050 and 2070 were prepared using ArcGIS 10.2 along with the calculation of habitat loss and gain. *Equal training sensitivity and specificity* threshold refers to a model that has an equal probability of being sensitive (i.e. predicting true presences) as it does of being specific (i.e. predicting true absences) (Freeman and Moisen, 2008; Jimenez-Valverde and Lobo, 2007). The model performance was evaluated using a metric called AUC. Sub sampling procedure available in MaxEnt was used for model validation. 70% of the occurrence records were allocated for training whereas 30% for testing the model. The relative contribution of different bioclimatic predictors to the distribution model was evaluated through MaxEnt outcome such as percent variable contribution and jackknife procedures (Elith et al., 2011).

Table 1
Predictor variables used for Himalayan Musk Deer habitat assessment.

Variables	Description	Source	Data type
Climate		Worldclim	Continuous
	BIO 1 = annual mean temperature		
	BIO 2 = mean diurnal range (mean of monthly (max temp − min temp))		
	BIO 3 = isothermality (Bio2/Bio7)		
	BIO 4 = temperature seasonality (St. Dev × 100)		
	BIO 12 = annual precipitation		
	BIO 14 = precipitation of driest month		
	BIO 15 = precipitation seasonality (coefficient of variation)		
	BIO 19 = precipitation of coldest quarter		
Elevation		GMTED	Continuous
	Altitude (reclassified at 100 m interval)	Calculated from DEM data	
	Aspect (eastness and northness)		
Land cover	25 land cover categories	European Space Agency	Categorical

We used Model for Interdisciplinary Research on Climate (MIROC5), the latest version of global climate change (GCM) (Watanabe et al., 2010) to predict the distribution of HMD. Mishra et al. (2014) and Sharmila et al. (2015) reported that MIROC5 captures various observed features of future climate very well, especially for the South Asian region, and some studies (Aryal et al., 2016; Su et al., 2015) have used it to predict species distribution for Nepal Himalaya. Two medium and extreme future climate scenarios, namely RCP4.5 and RCP8.5 for two periods (2050 and 2070) were downloaded from the Worldclim database (www.worldclim.org). RCP4.5 is supposed to be a medium carbon emission scenario that peaks around 2040 – total radiative forcing could reach +4.5 W/m^2 (~650 ppm CO_2 equivalent) by the end of the 21st century and stabilizes thereafter, whereas RCP8.5 is an extreme carbon emission scenario that continue to rise throughout the 21st century with radiative forcing reaching +8.5 W/m^2 (~935 ppm CO_2 equivalent) (IPCC, 2013).

3. Results

3.1. Distribution model

Of the eleven predictor variables used, the contribution of the four variables, annual mean temperature, altitude, isothermality and land cover, accounted for almost 85% of the model prediction (Fig. 3). Annual mean temperature highly influenced the potential habitat of HMD by contributing 47.3% to the model, while altitude, isothermality and land cover contributed 16.4%, 14.4% and 7.3% respectively. Likewise, precipitation of the driest month, aspect and annual precipitation contributed 5.9%, 4.8% and 2.4% respectively. The jackknife test also showed that annual mean temperature, altitude, isothermality and landcover were the four main variables (Supplementary 2). Model training area under ROC curve (AUC) values above 0.75 are normally considered useful (Elith, 2000); our model provided training AUC value of 0.975, suggesting the selected variables described the current

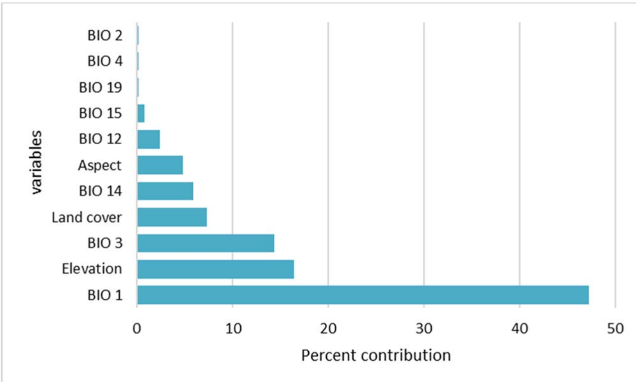

Fig. 3. Variables contribution for modelling.

distribution of HMD very well.

Response curves (Supplementary 3) showed how each environmental variable used in this modelling responded to the predicted suitability of HMD, both on each variable and its correlation with other variables. The result demonstrated that annual mean temperature (BIO 1) is the most influential factor controlling the distribution of HMD. The HMD prefers to stay in habitats where mean annual temperature ranges between −2 °C to 14 °C. Similarly, HMD avoids areas where annual precipitation (BIO 12) is lower than 500 mm and higher than 2400 mm. Land cover having dense vegetation, belonging to needle and broad leaved evergreen and deciduous forest cover, and shrubs seems ideal. The preferred altitude ranges between 1800 m–5200 m. Closed needle leaved evergreen to open broadleaved evergreen or semi-deciduous forest followed by a mosaic of forest and shrub land are the preferred land cover.

3.2. Habitat suitability dynamics

The current predicted suitable habitat of HMD is approximately 11,342 km^2 which represents 7.7% of the total country area. Similarly, Fig. 4 and Table 2 depict dynamism of HMD habitat by showing expansion in suitable areas, area remaining as stable at current time or decrease in suitable area under RCP4.5 and RCP8.5 by 2050 and 2070 in Nepal. The majority of current suitable areas of the species will remain as stable under all RCPs in the future.

Likewise, RCP4.5 by 2070 will result in maximum reduction in suitable area (29.47%) where as RCP8.5 by 2070 will result in maximum expansion in suitability (14.61%). Almost 77% area that is currently suitable will remain stable under RCP8.5 by 2050 (Table 2).

3.3. Habitat suitability dynamics within PAs

The total suitable habitat within PAs at current time as predicted by our model is approximately 5966 km^2, which is 23.88% of the total PAs (Table 3) and 52.60% of the total countrywide suitable area. Compared to current within PAs habitat suitability, the year 2050 under RCP4.5 will have 0.58% increment whereas such suitability decreases by almost 5.42% in 2070 under RCP4.5, 0.65% in 2050 and 0.37% in 2070 under RCP8.5 respectively (Table 3).

Interestingly, the expansion and contraction of HMD habitat suitability shows no pattern across PAs networks (Table 3). For instance, Annapurna, Rara and Api Nampa will have decreased suitability under all RCPs in the future while Manaslu and Khaptad will have decreased suitability in all RCPs except in 2070 under RCP8.5. All PAs will have decreasing habitat suitability by 2070 under RCP4.5 whereas nine PAs will have increasing habitat suitability by 2070 under RCP8.5.

3.4. Elevation shift in suitability

Our results show a longitudinal shift of habitat rather than latitudinal shift (Fig. 4), suggesting HMD habitat does not shift to higher altitude drastically in the future from climate change but rather it will expand in the longitudinal direction. Suitable habitat will continually expand between 2600 and 4600 m elevations after which it will be reduced.

4. Discussion and conclusions

This study is the first to investigate CC impact on the HMD habitat distribution under two IPCC scenarios focussing on Nepal Himalaya. HMD are an endangered animal and its population has been continually decreasing in its native regions owing to various human induced anthropogenic threats, mainly habitat fragmentation and illegal hunting (Harris, 2016). Further, wild ungulates such as HMD are considered as an indicator of environmental integrity and play a vital role in the maintenance of Himalayan ecosystem, and therefore its conservation is of utmost importance in the context of future projected warming climate in the Himalaya.

Our model obtained an AUC value of 0.975, suggesting that it described HMD habitat very well with high levels of accuracy. Our current habitat suitability prediction totally matched with the existing occurrence records used in the analysis (Fig. 2). HMD prefers high altitude regions above 2500 m on average and are found mostly in the central and eastern parts of the country. Temperature is the most influential variable in the distribution of HMD in Nepal Himalaya as annual mean temperature (BIO 1) and isothermality (BIO 3) are two of the top three contributors to the model. This is in line with Khadka et al. (2017) who also reported temperature as the highest contributing variable for the distribution of other species *Moschus leucogaster* found in the same region in the Himalaya. Similarly, altitude is the other influential variable to predict the HMD habitat. Our model demonstrated that HMD mostly preferred elevation from 2200 to 4600 m (Fig. 5). This finding is supported by Green (1986) who reported similar elevation range as the suitable habitat for HMD in Nepal and other native neighbouring countries. A recent study (Ilyas, 2015) found HMD mostly within a range of 2500 to 4200 m in western Himalaya of India. Closed needle-leaved evergreen to open broadleaved evergreen or semi-deciduous forests followed by mosaic of forest and shrub land are the preferred land cover for HMD distribution in Nepal Himalaya. Khadka and James (2016) found similar land cover having temperate forest with dense canopy (> 42%) was preferred by HMD in central Nepal. Qamar et al. (2008) and Qureshi et al. (2013) also reported woody high elevation moist temperate forest as the major HMD habitat followed by mosaic of forest-shrub land in northern Pakistan, while conifer and broadleaved temperate tree species overlapped by shrub and meadows characterise HMD habitat in western Himalaya of India (Ilyas, 2015; Syed and Ilyas, 2016).

The existing total suitable habitat of HMD in Nepal as per our model is 11,342 km^2. This data, however, is in sharp contrast to the only available study of Aryal and Subedi (2011) who reported it at 30177 km^2. This suitability variation could be due to the nature of methodology employed, as the later study was mainly based on key informants in the selection of HMD suitable vegetation belts, and therefore could have easily overestimated the area. The model showed 29.47% decrease in suitable area for 2070 under RCP4.5, most noticeably in the existing Annapurna Conservation Area of Mustang district in the western region and Bajhang and Bajura district in the far western region (Fig. 4b). Likewise, most of the current suitable areas of the HMD will remain stable (72% area in average) under both RCPs in the future. Similarly, existing PAs network that are mostly situated in the mountain regions incorporate more than half of the countrywide HMD suitable area predicted for current time. This is obvious as more than two thirds (68%) of the total area of PAs in Nepal lies within

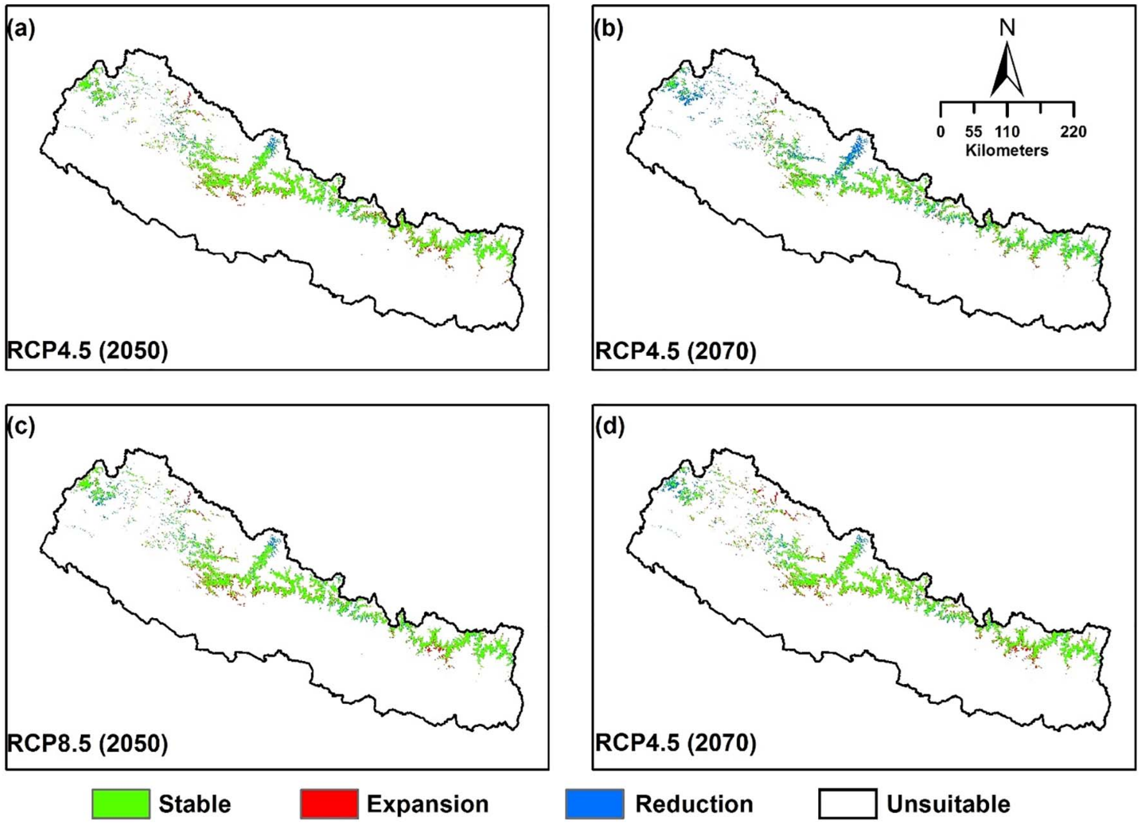

Fig. 4. Projected distribution map of Himalayan Musk Deer showing likely stable, expansion and reduction area under RCP4.5 and RCP8.5 in 2050 and 2070 with respect to the current time period.

mountain regions (Shrestha et al., 2010) where HMD exists. On the other hand, 5376 km^2 or 47.4% of current HMD suitable area still lies outside PAs.

The changes in suitability range across twelve PAs are not consistent (Table 3), and could be an effect of topoclimate, a spatial variation of climates with topographic position in the landscape mainly as a result of differentiation in elevational gradient within PAs. Elevation is considered as a proxy for temperature (Fang and Yoda, 1988; Racoviteanu et al., 2015), and a major contributor giving rise to such topoclimate. In the Himalayas, especially Nepal, there is a sharp temperature gradient as elevation tends to incline from southern belts towards the north. Korner (2007) argued that the changes in elevational ranges, such as seen in PAs of Nepal (Fig. 2, Table 3), could have a significant effect on vegetation of the high altitudinal areas, and thereby to an overall habitat, mainly through decline in air temperature and availability of land area per bioclimatic belt. The undulating terrain of the country has diverse topography that has given rise to numerous such topoclimates, which are the effects of aspect, slope, relative elevation, and surrounding terrain on solar exposure, wind, and cold air drainage within 0.1–1 km range (Ackerly et al., 2010). The presence of such topoclimate could have a pronounced effect on the variation in habitat suitability across PAs as predicted by the model.

Elevation is one of the most important variables for the distribution of HMD. This is confirmed by our model as elevation is the second highest contributor (Fig. 3) and is in concordance with Ilyas (2015) and Khadka and James (2016), who reported altitude as one of the significant variables of HMD habitat that differentiates it from other ungulates. Our analysis showed no such striking changes in the altitudinal ranges of HMD habitat suitability under different projections; however the range between 3000 and 3800 m amsl is the most preferable elevation for its habitat as maximum area of suitable habitat lies in this range (Fig. 5). Our finding supports Khadka and James (2016) who reported upper mid-hill to high-mountain (above 2800 m amsl) as the preferable habitat for HMD in Nepal. The majority of the HMD habitat will overlap while only a small area will be shifted in the future under both RCP scenarios. The model further depicts that such future shift of habitat in terms of elevation will mostly lean towards longitudinal rather than latitudinal direction. This supports the fact that HMD is sedentary in nature and remains within a defined home range throughout the year (Green, 1986). A similar trend is seen for most of the PAs within the country where the future shifts are all towards longitudinal directions (Supplementary 4).

Table 2
Changes in the suitability area of the Himalayan Musk Deer under RCP4.5 and RCP8.5 in the year 2050 and 2070.

Area suitability	RCP4.5				RCP8.5			
	Year 2050		Year 2070		Year 2050		Year 2070	
	Area (km^2)	% change	Area (km^2)	% change	Area (km^2)	% change	Area (km^2)	% change
Stable	10048.08	76.54	7721.26	62.76	9902.66	76.91	9819.90	73.89
Expansion	1780.47	13.56	955.31	7.76	1528.99	11.87	1941.96	14.61
Reduction	1299.20	9.9	3626.02	29.47	1444.62	11.22	1527.38	11.49

Table 3
Current and future Himalayan Musk Deer suitable habitat within protected areas of Nepal.

Protected areas (PAs)	Elevation (m)	Areas (km^2)	Current	RCP4.5 2050	RCP4.5 2070	RCP8.5 2050	RCP8.5 2070
Annapurna CA (ANA)	790–8090	7629	1902	1842 (−)	1156 (−)	1787 (−)	1853 (−)
Api Nampa CA (API)	539–7132	1903	606	544 (−)	345 (−)	562 (−)	318 (−)
Dhorpatan HR (DHR)	2850–5500	1325	574	655 (+)	573 (−)	648 (+)	603 (+)
Gaurishankar CA (GRS)	2130–6885	2179	625	787 (+)	599 (−)	630 (+)	674 (+)
Kanchanjunga CA (KNJ)	1200–8586	2035	311	313 (+)	244 (−)	296 (−)	321 (+)
Khaptad NP (KHP)	1400–3300	225	19	10 (−)	2 (−)	6 (−)	26 (+)
Langtang NP (LNG)	845–7245	1710	525	569 (+)	460 (−)	448 (−)	530 (+)
Makalu Barun NP (MBR)	435–8463	1500	627	607 (−)	514 (−)	642 (+)	637 (+)
Manaslu CA (MSL)	1400–8156	1663	482	453(−)	462 (−)	450 (−)	525 (+)
Rara NP (RAR)	1800–4039	106	10	3 (−)	2 (−)	5 (−)	7 (−)
Sagarmatha NP (SGR)	2845–8848	1148	125	134 (+)	116 (−)	125 (+)	140 (+)
Shey Phoksundo NP (SHP)	2130–6883	3555	161	194 (+)	136 (−)	206 (+)	240 (+)
Total Area		24,978	5966	6110 (+)	4611 (−)	5804 (−)	5874 (−)

Note: CA = Conservation Area, NP = National Park, HR = Hunting Reserve; + ve sign indicates increase in suitable area and − ve sign indicates decrease in suitable area within PAs compared to the current time.

As half of the HMD suitable area is still outside of the PAs network at current time, efforts should be geared towards either establishment of new PAs, especially in the mid and far western Nepal that lacks continuous PA network, or expansion of the existing PAs. This will help to accommodate more HMD suitable area within PA networks. However, just expanding PAs would not help species to track future suitable climate if current and future PA networks do not overlap (Araujo et al., 2011; Hannah et al., 2005). This suggests that future PAs management strategy should consider suitable corridor policy for making PA networks better respond to future unstable climate through facilitating species movement. Though our model predicted a majority of current suitable area to remain as stable in the future, there is still likely an overall loss if we consider individual scenarios. For instance, there will be a reduction of 29.47% HMD habitat by 2070 under RCP4.5, and therefore establishment of new PAs and linking them with the corridor concept looks of utmost importance. This also acts as a justifiable measure to compensate habitat loss that is predicted for within PA networks in the future (Table 3). Most importantly, future climatic uncertainty must be acknowledged and incorporated into PA decision framework and interventions (Dickinson et al., 2015).

On the other hand, if the establishment or expansion of existing PAs is not feasible due to economic, political or social constraints, then we argue that collaborative HMD habitat conservation programs with the support of grass root people should be designed and implemented in such climatic vulnerable regions. Nepal is considered a leader in people oriented conservation practice in the global arena through some exemplary efforts, such as community forestry programs. Forest cover is the primary habitat of HMD and such collaborative programs aiming at conservation of forest will expand the HMD habitat outside PA networks and help HMD to escape the projected future warming effects. This helps not only HMD but also other wildlife in the regions that are equally vulnerable and could lose their habitat from such unexpected warming. The application of socio-ecological frameworks for landscape level planning and conservation that links human, their socio-culture, and ecological systems (Berkes et al., 2003; Lamsal et al., 2017c; Martin-Lopez et al., 2017; Virapongse et al., 2016) could be an ideal strategy in this context.

The geography of Nepal extends from 60 m amsl in the south to 8848 m amsl in the northern Himalaya, giving rise to numerous heterogeneous landscapes and climatic contrasts within a very narrow latitudinal band. This could be an opportunity to respond to future warming. For instance, Ackerly et al. (2010) reported that protecting and connecting climatically heterogeneous landscapes and regions could buffer the grave impact of climate change on species populations and also enhance species adaptation ability. This could be a viable approach to existing mountain PAs in the country that populate HMD as most of the PAs contain wide elevation ranges possessing multiple climates. Therefore an approach to detect, conserve and link such model-predicted suitable areas with elevation gradient with existing PA networks through corridor concept is a good adaptation alternative, as protection of large scale elevation gradients retains diversity by allowing species to migrate in response to climate and vegetation change (Moritz et al., 2008).

Uncertainty exists in species distribution modelling, mainly due to several inherent model assumptions and doubts prevailing in future GHG emission trends. It should be noted that though MaxEnt is effective

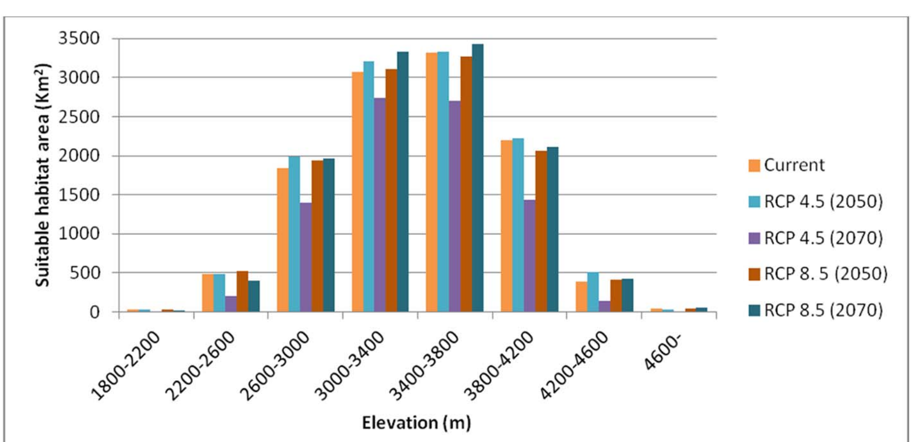

Fig. 5. Habitat suitability for Himalayan Musk Deer with respect to elevation for current and future time period under RCP4.5 and RCP8.5.

in habitat niche modelling of species with low occurrence data and limited ecological information, the climatic variables used in this model may not sufficiently explain the species distribution. Non-climatic variables such as biotic interaction, dispersal mode and abilities of a species, future land-cover changes and other anthropogenic disturbances were not employed in the model that could affect the outcome, and is a limitation of this study. Though having many assumptions and uncertainties, such species distribution models still remain a critical data source for future suitability prediction in order to formulate scientific adaptation strategies for offsetting future warming impact on biota at species, community and ecosystem levels (Ackerly et al., 2010; Wiens et al., 2009).

In conclusion, this study provides current modelled and future potential suitable habitat of HMD in the context of IPCC's latest projected climate change scenarios through a well-accepted species distribution model. It is obvious that future uncertain climate creates confusion among PAs management authority in a resource deficient country, such as Nepal, where the model shows variation in suitability ranges. It is anticipated that the outcome of this study could be a good resource base for PAs authorities of Nepal in planning future conservation and habitat management of HMD. We believe trans-boundary conservation programs connecting both climatic and landscape-wise divergent PAs and non-PA networks that contain current and future HMD suitable areas in its native Himalayan ranges, especially Afghanistan in the east to Myanmar in the west, could be a viable long term alternative plan. Only strengthening PA networks as a corridor management policy as discussed earlier to tackle future climate however is deemed not sufficient unless ongoing poaching and other anthropogenic disturbances against this endangered species is fully controlled in all existing PAs and non-PA networks.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoinf.2018.02.004.

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