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Predicting the Impact of Climate Change on Vulnerable Species in Gandaki River Basin, Central Himalayas

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Abstract: Gandaki River Basin (GRB) is an important part of the central Himalayan region, which provides habitat for numerous wild species. However, climatic changes are making the habitat in this basin more vulnerable. This paper aims to assess the potential impacts of climate change on the spatial distributions of habitat changes for two vulnerable species, Himalayan black bear (*Ursus thibetanus laniger*) and common leopard (*Panthera pardus fusca*), using the maximum entropy (MaxEnt) species distribution model. Species occurrence locations were used along with several bioclimatic and topographic variables (elevation, slope and aspect) to fit the model and predict the potential distributions (current and future) of the species. The results show that the highly suitable area of Himalayan black bear within the GRB currently encompasses around 1642 km^2 (5.01% area of the basin), which is predicted to increase by 51 km^2 in the future (2050). Similarly, the habitat of common leopard is estimated as 3999 km^2 (12.19% of the GRB area), which is likely to increase to 4806 km^2 in 2050. Spatially, the habitat of Himalayan black bear is predicted to increase in the eastern part (Baseri, Tatopani and north from Bhainse) and to decrease in the eastern (Somdang, Chhekampar), western (Burtibang and Bobang) and northern (Sangboche, Manang, Chhekampar) parts of the study area. Similarly, the habitat of common leopard is projected to decrease particularly in the eastern, western and southern parts of the basin, although it is estimated to be extended in the southeastern (Bhainse), western (Harichaur and northern Sandhikhark) and north-western (Sangboche) parts of the basin. To determine the habitat impact, the environmental variables such as elevation, Bio 15 (precipitation seasonality) and Bio 16 (precipitation of wettest quarter) highly contribute to habitat change of Himalayan black bear; while Bio 13 (precipitation of wettest month) and Bio 15 are the main contributors for common leopard. Overall, this study predicted that the suitable habitat areas of both species are likely to be impacted by climate change at different altitudes in the future, and these are the areas that need more attention in order to protect these species.

Key words: climate change; habitat change; Himalayan black bear (*Ursus thibetanus laniger*); common leopard (*Panthera pardus fusca*); Gandaki River Basin

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1 Introduction

Since historical periods, changes in climatic patterns have been shaping the habitat distributions of wild species (Pielke et al., 2002; Yu et al., 2017). Rapid climate changes and habitat loss are the main threats driving the global loss of biodiversity (Travis, 2003; Mantyka-pringle et al., 2012). According to the International Panel on Climate Change (IPCC), the temperature is expected to rise globally by around 1.5 ℃ between 2030 and 2052 (IPCC, 2018). Therefore, global climate change is already known to be a major threat to conservation and it can be assumed that the historical range of a species no longer remains suitable (McCarty, 2001). Climate change, mainly the rise in temperature, along with illegal activities involving wildlife have profound influence on the habitats of numerous important key protected species on the earth's surface (Jnawali et al., 2011). Overall, the current and future climate changes are key factors determining habitat loss, fragmentation, and geographic regionalization (Mantyka-pringle et al., 2012). Climate change scenarios can, therefore, be used as components of studies which predict the future habitat changes and provide a foundation to aid decision-makers in developing policies (Geary et al., 2015).

The effects of climate change on species habitats at local and global scales are so great that many taxa are likely to go extinct, even as their present geographic ranges increase in elevation (Pimm, 2008, 2009). The upward shifting of vegetation due to increasing temperature is also a key threat to high altitude endemic faunas, snails and beetles; for example, suitable habitats for these species are likely to be reduced by 77% in 2100 in the Austrian Alps (Dirnböck et al., 2011). Climate change and treeline shifts are also influencing the distributions of species and causing habitat loss in the Himalaya region (Zhang et al., 2011; Forrest et al., 2012; Chhetri et al., 2018). Likewise, the effect of future climate change has been estimated as the greatest threat to the Asiatic black bear, which will likely migrate to more northern and western areas with higher elevations, where the area of decrease in the future (2070) would be higher than the increase in Iran (Farashi and Erfani, 2018). Jetz et al. (2007) have also projected that climate change and anthropogenic factors in the tropical region will cause the extinction of around 400 species of land birds out of a total of 8750 by the year 2050 (Jetz et al., 2007). The Asian tropical region is, therefore, of immediate conservation concern because of decreasing habitats (Sodhi et al., 2004; Sodhi et al., 2010). Globally, decreasing forest cover and increasing agricultural land are also reducing the quality of habitat and increasing habitat fragmentation, particularly in Southeast Asia (Jacobson et al., 2016), which has resulted in human-wildlife conflicts and adversely impacted the habitats of many wild species (Acharya et al., 2017). In this context, more studies are needed to assess future climate changes based on current changing patterns in order to protect habitats from further losses (Geary et al., 2015; Liu et al., 2017).

Due to variations in altitude, climate and topography, the Himalayan region provides habitats for many unique flora and fauna species (Sun et al., 2012; Liu et al., 2017; Nie et al., 2017), although the changing climate has negatively impacted the habitats of many wild species (Thuiller, 2003; Jetz et al., 2007; Hofmeister et al., 2010). The specific effects on biodiversity in the Himalayan environment remain poorly understood (Grimmett et al., 2016). The warming is more pronounced in the higher Himalayas and middle mountain regions compared to the lower elevations. The warming trend was 0.06 to 0.128 ℃ per year during 1977–1994 in Nepal (Shrestha et al., 1999), while the maximum temperature increased by 0.045 ℃ and the minimum temperature by 0.009 ℃ per year in the country during 1976–2015 (Thakuri et al., 2019). Likewise, Aryal et al. (2013) have also observed a higher annual temperature increase (by 0.13 ℃ yr^{-1}) than in other parts of the Himalayas, particularly in the Upper Mustang of the trans-Himalaya region. As a result, snow/glacier melting, upward shifting of tree lines and the rapid degradation of alpine grasslands have all led to habitat range contractions of the Snow leopard in the southern Himalayan ranges, although habitat expansion is predicted in the northern ranges (Farrington and Li, 2016). The increasing temperature has adversely impacted higher elevation habitats in Nepal, especially in the Himalayas (Shrestha and Aryal, 2011), whereas species habitat distributions have already been shifting upward in this area because of the warming temperature (Karki et al., 2009).

Climate change, forest cover depletion and human-wildlife conflicts are the primary threats leading to declining wild species and habitat in Nepal (Jnawali et al., 2011; DNPWC, 2017; Liu et al., 2017). The common leopard is one of the top predators and a keystone species in terms of the food web and functioning ecosystems (Friedmann and Traylor-Holzer, 2008; Gavashelishvili and Lukarevskiy, 2008). However, humans have had a negative impact on the leopard due to economic losses and attacks on humans and livestock (Jnawali et al., 2011). The Mountain, high Himalayas and Hill are important regions for several wild species, including the Himalayan black bear. However, due to poaching for body parts and the decline in forest cover, the bear habitat is declining in Nepal (Jnawali et al., 2011). People used to hunt the bear illegally for its bile and other parts for medicinal purposes (Garshelis and Steinmetz, 2016); therefore, the species is at risk (Jnawali et al., 2011; Bista and Aryal, 2013; Bista et al., 2018). Besides, the human-wildlife conflict also has generated major issues regarding habitat degradation (Jnawali et al., 2011; Garshelis and Steinmetz, 2016). Due to frequent crop-raiding and livestock killing by two bears, Himalayan black bear and brown bear, they are known as pest animals in Manaslu Conservation Area (Chetri, 2013). However, studies concerning the potential impact of climate change on the future habitat distribution of vulnerable species such as the Himalayan black bear and common leopard are lacking. These two species are listed as vulnerable by the International Union for the Conservation of Nature (IUCN). While both species are valued from the conservation perspective, they have impacted the livelihood of the local people through crop-raiding, livestock depredation and attacking humans. Therefore, for long-term conservation, harmonious circumstances must be maintained. This study predicts the potential impact of climate change on the future distribution of these two globally protected species, along with relevant topography, within the Gandaki River Basin of the central Himalaya region.

2 Materials and methods

2.1 Study area

Geographically, the Gandaki River Basin (GRB) is a part of the Himalayan region located in central Nepal. It extends between 28.35°N–29.33°N and 82.87°E–85.80°E. This basin encompasses about 32810 km^2 in area at elevation ranging between 94 m and 8167 m above sea level (masl) (Fig. 1). The sum of annual precipitation in the basin has been recorded as ranging from 285 mm (driest region) to 5160 mm (wettest region), and the average temperature varied from 6.12 ℃ to 32.35 ℃ in 2014 (MoPE, 2018). The basin is rich in various land cover types, ecosystems and habitats for various wild species (Rai et al., 2018; Rai et al., 2020).

According to the IUCN red-data list, GRB harbors 12 Critically Endangered, 16 Endangered, 41 Vulnerable and 55 Near-threatened species. This basin includes six nationally protected areas (Annapurna, Manaslu, Chitwan, Langtang, Shivapuri-Nagarjun, Parsa) (DNPWC, 2018). The nationally protected Annapurna Conservation Area (ACA) contains 105 species of mammals, 519 species of birds, 40 species of reptiles and 23 species of amphibians (DNPWC, 2018). Similarly, Chitwan National Park (CNP) was the first National Park established in the country and has also been listed as an UNESCO World Heritage Site, which contains more than 57 species of mammals, including common leopard, Royal Bengal tiger, One-horned Rhino, and Asian Elephant and many more key protected species (DNPWC, 2018). The Himalayan black bear is distributed mainly in the northern parts at the high altitudes, while the common leopard has been found all across the lower and higher elevations of the GRB (Fig. 1).

2.2 Datasets

2.2.1 Species occurrence

This study focuses on two species, the Himalayan black bear and common leopard, which are both listed on the appendix of Convention on International Trade in Endangered Species (CITES). CITES Appendix I lists species of conservation concern, and 32 mammals from Nepal are listed,

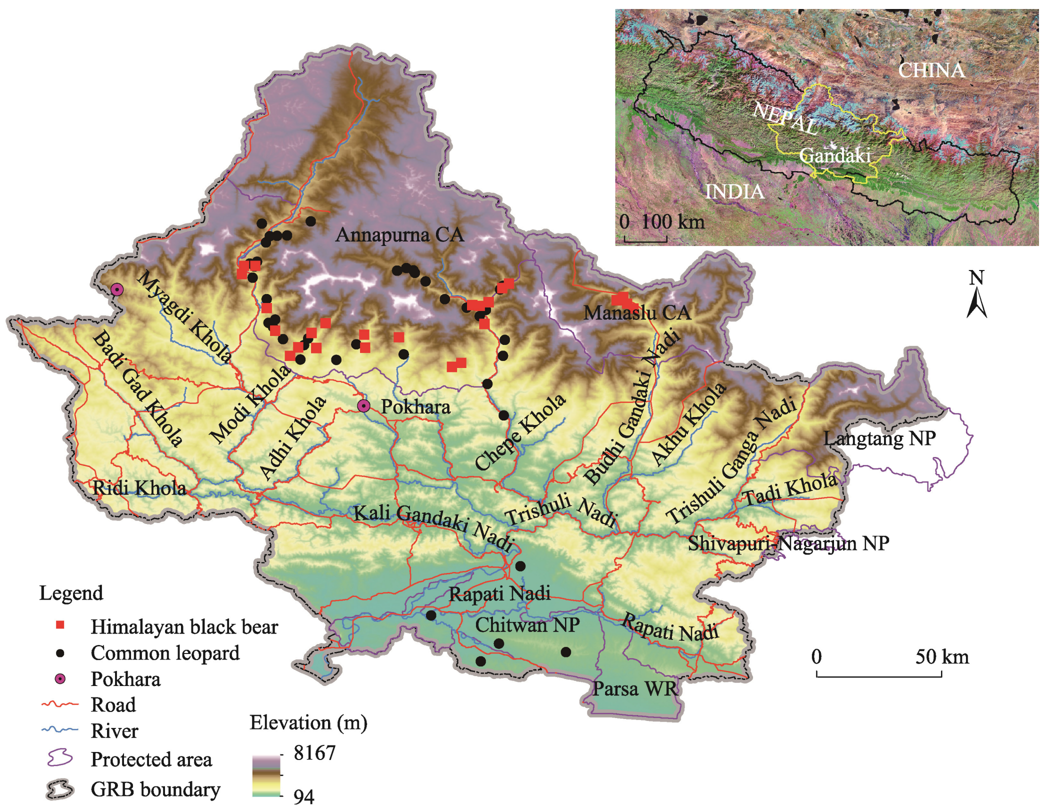

Fig. 1 Location of GRB and species occurrences

Note: CA-Conservation Area; NP-National Park; WR-Wildlife Reserve.

including the Himalayan black bear and common leopard (MoFE, 2018). Information regarding the locations of occurrence for these species (25 points for Himalayan black bear and 42 for common leopard) was obtained from the National Trust for Nature Conservation (NTNC). The NTNC, an organization which has been working on wildlife research and conservation in the country since 1982. It was established by the special act "National Trust for Nature Conservation Act 1982" and is an authorized organization for wildlife research and conservation. The NTNC conducts regular monitoring of many wild species and human-wildlife conflicts.

2.2.2 Bioclimatic and topographic variables

A total of 19 bioclimatic variables at 30 arc-second spatial resolution were downloaded from version 2 of the WorldClim geoportal (http://www.worldclim.org/) (Table 1). These bioclimatic variables encompass annual trends in mean temperature and mean precipitation, as well as extreme or limiting environmental factors for the coldest and warmest months and precipitation in the wet and dry quarters (Fick and Hijmans, 2017). The WorldClim current data layer was generated by interpolation of the average monthly climate data annually for the period between 1970 and 2000 on a 30 arc-second resolution grid (Rai et al., 2020).

In this study, future projected climate data from IPPC5-Global Climate Models (GCM) were used for four representative concentration pathways (RCPs). The GCM climate projections used in this study were published in the Fifth Assessment IPCC report (Fick and Hijmans, 2017). The future climatic data of 2050 were the downscaled Coupled Model Intercomparison Project phase 5 (CMIP5) data at 30 arc-second resolution based on Representative Concentration Pathways (RCP) 4.5 and the Community Climate System Model version 4 (CCSM4). The simulated climate data (CMIP5) includes four different RCP scenarios for the 20^{th} and 21^{st} centuries and the pattern of future temperature in CCSM4 agrees with previous results (Meehl et al., 2012). The RCP45 model was based on a medium carbon emission scenario (IPCC, 2013). All bioclimatic variables (current and future) were resampled into 30 m spatial resolution. The Digital elevation model (DEM)/elevation at 30 m spatial resolution was obtained from the United States Geological Survey Earth Explorer and used to prepare slope and aspect maps using ArcGIS software. In addition to bio-climatic and DEM data, land use and land cover data also include important variables for habitat modelling (Liu et al., 2017), but in this study, we have used only bio-climatic and topographic data (elevation, slope and aspect) for the MaxEnt modelling.

To address the multicollinearity problem of bio-climatic data, Pearson correlation analysis was performed based on the values for each climatic variable corresponding to the species occurrence locations. Highly correlated variables, i.e., those with a threshold greater than 0.65 for Himalayan black bear and 0.75 for common leopard, were dropped and only the less correlated variables were retained. Due to the species occurrences and very high inter-correlations among the climatic variables, the coefficient values which were removed differed.

Table 1 Environmental variables used in this study and their descriptions

Variable		Description	Himalayan black bear	Common leopard
Climate	Bio 1	Annual mean temperature	√	×
	Bio 2	Mean diurnal range	√	×
	Bio 3	Isothermality	√	×
	Bio 4	Temperature seasonality	×	×
	Bio 5	Max temperature of warmest month	×	×
	Bio 6	Min temperature of coldest month	√	√
	Bio 7	Temperature annual range (Bio 5, 6)	×	×
	Bio 8	Mean temperature of wettest quarter	×	×
	Bio 9	Mean temperature of driest quarter	√	√
	Bio 10	Mean temperature of warmest quarter	×	√
	Bio 11	Mean temperature of coldest quarter	√	√
	Bio 12	Annual precipitation	×	√
	Bio 13	Precipitation of wettest month	√	√
	Bio 14	Precipitation of driest month	√	√
	Bio 15	Precipitation seasonality	√	√
	Bio 16	Precipitation of wettest quarter	√	√
	Bio 17	Precipitation of driest quarter	√	√
	Bio 18	Precipitation of warmest quarter	√	×
	Bio 19	Precipitation of coldest quarter	√	×
Topography		Elevation, slope, aspect	√	√

Note: √– retained; ×– excluded

2.3 Maximum Entropy (MaxEnt) model and suitability analysis

MaxEnt version 3.4.1 was used to model and map the current and future distributions of suitable habitats for the two selected species. MaxEnt calculates the probability of suitable conditions occurring for a species rather than the likelihood of its presence (Phillips et al., 2004). The purpose of this model is to identify wild species environmental requirements and the geographical distributions of the conditions that meet those requirements (Phillips et al., 2006; Baldwin, 2009). MaxEnt has been widely used in estimating the present and future geographic distributions of various species, such as predicting the distribution of Himalayan Monal (Rai et al., 2020), habitat changes of *Stipa purpurea* in the Tibetan Plateau (Hu et al., 2015), habitat changes for key protected species in Koshi Basin (Liu et al., 2017), assessing the potential distribution of the Chinese caterpillar fungus in Nepal (Shrestha and Bawa, 2014), and mapping the present and future dengue fever suitability areas in Nepal (Acharya et al., 2018). In the MaxEnt analysis, 75% of species occurrence locations were randomly assigned for training the model, while the remaining 25% were used for testing. Ten-fold cross validation (de Groot et al., 2012) was used to assess model accuracy.

The MaxEnt results were imported into ArcGIS 10.5 for further analysis and mapping and to examine the possible suitable habitat changes of the key protected species. The continuous probability maps were reclassified into five classes of very high suitability (greater than 70% probability); high suitability (between 50% and 70% probability); medium suitability (between 30% and 50% probability); low suitability (between 10% and 30% probability); and very low suitability (less than 10% of habitat suitability) (Liu et al., 2017; Rai et al., 2020). Finally, the habitat changes were also assessed along with altitudinal ranges in every 250 m interval, and areas were considered to be highly suitable habitat area (i.e., either very high or high suitability), which includes all areas with a prediction probability of more than 50%.

3 Results

3.1 The model evaluation

Figure 2 shows the model evaluation based on the receiver operating characteristic of the randomly selected training and test data for the habitat predictions of Himalayan black bear and common leopard. The diagonal straight black lines show the level (0.5) that would be expected if the model performed no better than random. This study found that the MaxEnt model distinguished between suitable and unsuitable habitat for the selected species because the area under the curve (AUC) for the training data, as well as the AUC for the test data, are both greater than the random prediction line (0.5). The AUC values for the training data are 0.982 and 0.944, while for the test data they are 0.973 and 0.868, respectively, for Himalayan black bear and common leopard. The overall accuracy of the model indicates that the distributions provide close estimates for the real-world distribution probabilities.

3.2 Variable contributions

Based on the input bio-climatic and topographic variables, the most important variables are elevation, Bio 15 (precipitation seasonality) and Bio 16 (precipitation of driest quarter), which contributed 37%, 19% and 17% for Himalayan black bear distribution modeling, respectively (Table 2 and Fig. 3). Similarly, the variables of Bio 13 (precipitation of wettest month), Bio 15 and elevation are highly contributing variables for common leopard distribution, accounting for 40%, 27% and 14%, respectively (Table 2 and Fig. 3). Other environmental variables and topography are also important, but they showed less importance for determining the suitable habitat of the selected species within the study area. Likewise, some other variables with less than 1% (Table 2) are far less significant or almost insignificant for determining the habitat of the species.

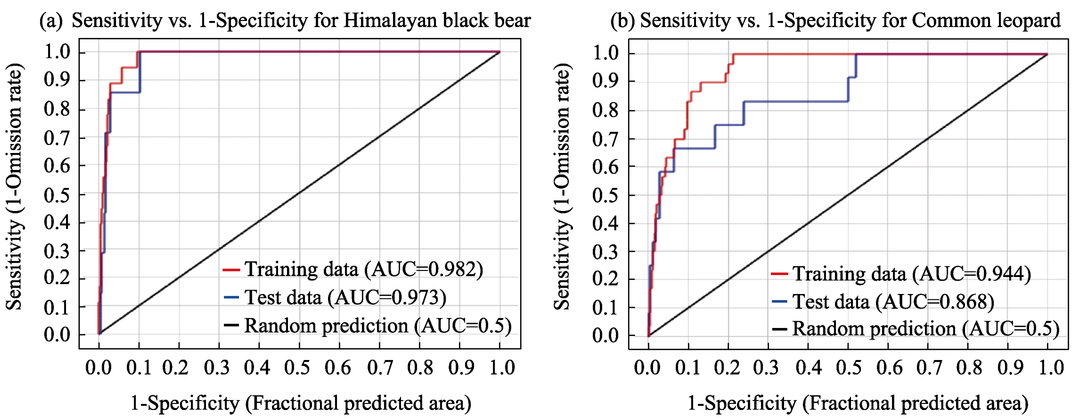

Fig. 2 The AUC of habitat prediction (the training and test data are denoted by red and blue lines, respectively)

Table 2 Environmental variables and their contributions (%) to the species habitats

Variables	Species	
	Himalayan black bear	Common leopard
Bio 1	0	×
Bio 2	0.5	×
Bio 3	0.7	×
Bio 6	6.6	2.3
Bio 9	0	4.3
Bio 10	×	1.5
Bio 11	0	0
Bio 12	×	1.4
Bio 13	0.5	39.8
Bio 14	0	4.6
Bio 15	19.1	26.8
Bio 16	17.3	1.3
Bio 17	1.3	0.2
Bio 18	0	×
Bio 19	11.5	×
Elevation	36.8	14.3
Slope	0.1	2.6
Aspect	5.7	1.0

Note: × – excluded

To obtain alternate predictions of which variables are most important in the model, a jackknife test was also conducted. In this test, a model is created using each variable in isolation (Phillips, 2005). The AUC plot (Fig. 3) shows that Bio 15 is the most effective variable for predicting the distribution of the occurrence data for Himalayan black bear.

3.3 The potential impact on habitat

This study analyzed the overall habitat changes of the species within the GRB. The habitat of Himalayan black bear is expected to increase 1035 km^2 of newly suitable areas in the future, particularly in the eastern part (Baseri, Tatopani and norther from Bhainse) (Fig. 4). About 1046 km^2 of the current Himalayan black bear habitat is likely to be decreased in the future in the eastern (Somdang, Chhekampar) western (Burtibang and Bobang) and northern (Sangboche, Manang, Chhekampar) parts, while about 1985 km^2 of the current area is projected to remain stable. Similarly, the habitat of common leopard is projected to increase 3894 km^2 of new areas in the future, with corresponding areas for this species of 1257 km^2 being lost and 4505 km^2 remaining stable (Table 3). Spatially, the decreasing habitat is expected mostly in the eastern, western and southern parts of the basin. The habitat is estimated to be extended in the southeastern (Bhainse), western (Harichaur and northern Sandhikhark), and north-western (Sangboche) parts of the basin (Fig. 4). Overall, the net changes are estimated as 1975 km^2 and 7142 km^2 for the Himalayan black bear and common leopard, respectively (Table 3).

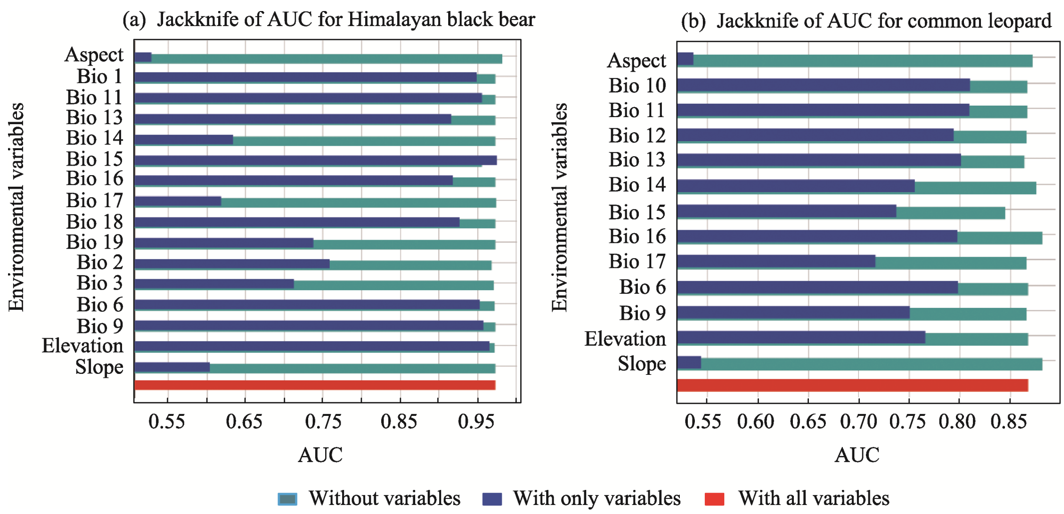

Fig. 3 Jackknife AUC of the different environmental variables

Table 3 Habitat status within the GRB (Unit: km^2)

Habitat change	Himalayan black bear	Common leopard
Increase	1035.05	3894.33
Decrease	1045.86	1257.37
Stable	1985.56	4504.81
Net change	1974.75	7141.78

3.3.1 Current and future habitat distribution

The very high suitability category of current habitat of Himalayan black bear is expected to increase by around 76 km^2 in 2050 under the RCP4.5 scenario (Table 4 and Fig. 5). However, the high suitability area is likely to decrease by 26 km^2 at the same time. Overall, the highly suitable area with more than 50% prediction probability (i.e., both very high

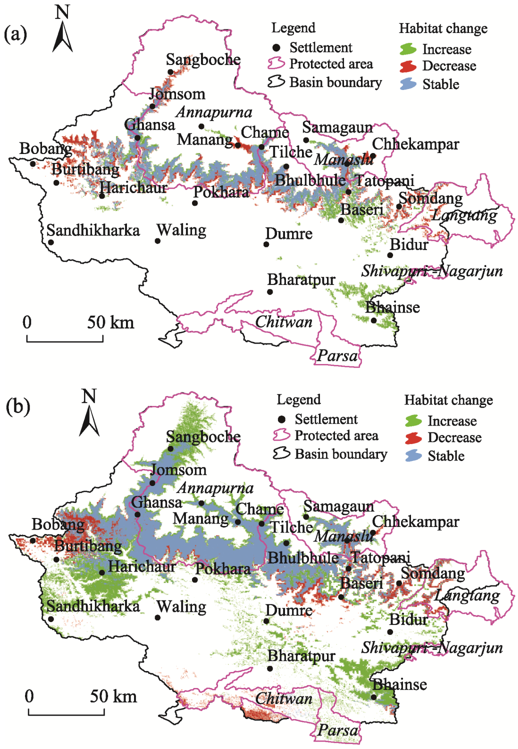

Fig. 4 Predicting the changes in the habitat suitability within the GRB for the Himalayan black bear (a) and common leopard (b)

and high) is likely to increase by 50 km^2 within the GRB. Likewise, the suitable habitat of common leopard is expected to decrease from 1974 km^2 to 1888 km^2 (Table 4 and Fig. 5). However, the highly suitable habitat is likely to increase by 893 km^2 in the GRB. Therefore, the overall highly suitable area is likely to increase by 807 km^2 within the GRB. The medium and low suitability habitats of both species are likely to increase in the future based on climatic and topographic variables.

Table 4 Current and future predicted habitat in the GRB

(Unit: km^2)

Habitat suitability	Himalayan black bear		Common leopard	
	Current	Future	Current	Future
Very high	616.38	692.35	1973.62	1888.06
High	1025.76	1000.15	2024.99	2917.51
Medium	1482.78	1565.61	2731.43	4600.69
Low	2459.98	2814.51	7671.67	8603.56
Very low	27222.90	26734.50	18407.00	14797.42

3.3.2 Habitat changes along the altitudinal gradient

This study also mapped the highly suitable habitat with greater than 50% prediction probability (i.e., very high and high) based on altitudinal ranges in the future. This analysis predicts that the habitat of the Himalayan black bear will experience a large gain of 384 km^2 at elevations between 2500 m and 2750 m along with losses of 43 km^2 between 2000 m and 2250 m elevations in the future (Table 5 and Fig. 6). However, the habitat of the Himalayan black bear is likely to increase at the elevation ranges from 2250 m to 3000 m and decrease from 1750 m to 2250 m. Likewise, common leopard habitat is predicted to decrease at elevations between 3000 m and 3250 m, while it is likely to increase at the 1750 m to 2000 m elevation range across the GRB. In the GRB, the highly probable suitable habitat area is found at the elevation ranges from 1250 m to 2500 m, while a greater loss area is predicted within the 2250 m to 3500 m elevation areas of the basin.

4 Discussion

4.1 MaxEnt modeling for habitat predictions

Different environmental variables can play an important role in explaining whether or not a species exists in a particular niche. Thus, if any environmental layer provides a higher contribution, those variables have a higher impact on habitat prediction (Rai et al., 2020). Traditionally, species distribution modeling was carried out with presence-absence data, which made it challenging to project potential habitat; recently, a new approach has been developed to utilize only presence locations to assess potential habitat changes (Baldwin, 2009). A study has also utilized this approach (MaxEnt) to predict the potential habitat distribution of rhinoceros in the Chitwan National Park, Nepal, with climatic variables and land cover data as input variables (Kafley et al., 2009). Another study by Liu et al. (2017) also adopted the MaxEnt model and found receiver operating characteristic (ROC) values between 0.905 and 0.998 for habitat changes in the Koshi basin. Likewise, a recent study also used MaxEnt modeling to predict the habitat change of Himalayan Monal in GRB with an AUC value of 0.920 (Rai et al., 2020). It is assumed that a higher AUC (closer to 1.0) implies a high correlation between the true distribution and environmental variables (Hanley and McNeil, 1982; Merow et al., 2013). A higher AUC represents better model performance (Bista et al., 2018). An AUC <0.7 means poor model performance, while 0.7–0.9 means moderately useful model performance, and >0.9 means excellent model performance (Pearce and Ferrier, 2000). The AUC of the results of this study is close to 1, which indicates good model performance.

4.2 The possible impact of climate change and threats on species habitat

Himalayan black bear: The changes in climate and topography are important environmental variables that can influence the habitat of the wild species (Liu et al., 2017). Climate change as well as human-wildlife conflict and hunting have been identified as the main causes of the declining habitat of Himalayan black bear, which is already in

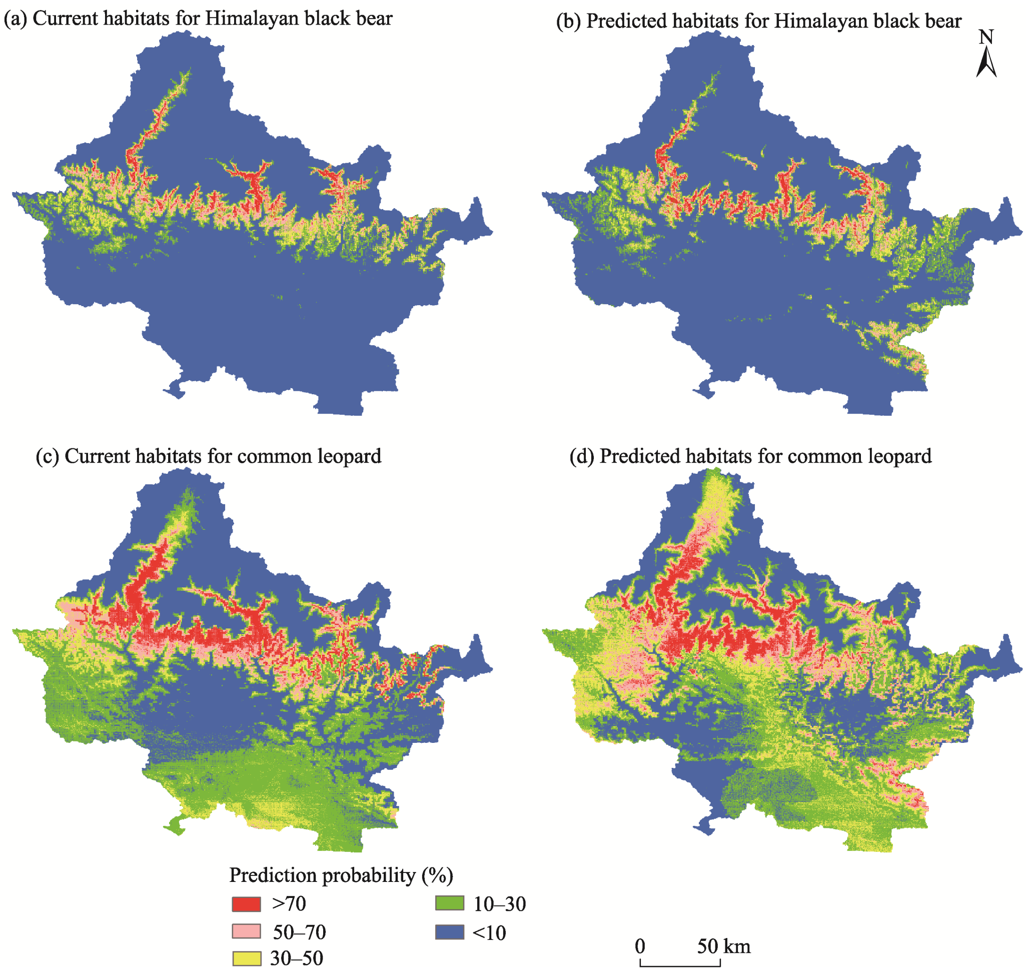

Fig. 5 Current and future predicted habitats of the Himalayan black bear (a, b); and common leopard (c, d)

Table 5 Predicting habitat changes along the altitudinal gradient (Unit: km^2)

Elevation (m)	Species and habitat				Gain and loss	
	Himalayan black bear (HBB)		Common leopard (CL)			
	Current	Future	Current	Future	HBB	CL
250–500			0.00	10.71		10.71
500–750			0.62	6.58		5.96
750–1000			6.35	2.09		–4.26
1000–1250	0.36	1.56	52.85	30.48	1.20	–22.37
1250–1500	9.98	21.32	165.85	202.38	11.34	36.54
1500–1750	46.89	67.72	220.20	495.32	20.82	275.12
1750–2000	118.19	87.98	268.65	561.90	–30.21	293.26
2000—2250	210.71	167.38	348.68	459.18	–43.34	110.50
2250–2500	282.01	301.02	384.52	394.12	19.01	9.59
2500—2750	331.46	384.46	418.93	411.71	53.00	–7.23
2750–3000	295.66	331.31	483.83	449.92	35.65	–33.91
3000—3250	244.07	221.63	612.11	487.54	–22.43	–124.57
3250–3500	96.30	86.45	555.95	487.36	–9.85	–68.59
3500–3750	6.49	17.91	341.66	448.69	11.41	107.02
3750–4000	0.00	3.43	115.23	286.02	3.43	170.79
4000–4250	0.00	0.30	21.09	67.05	0.30	45.96
4250–4500			1.45	3.61		2.16
4500–4750			0.63	0.00		–0.63

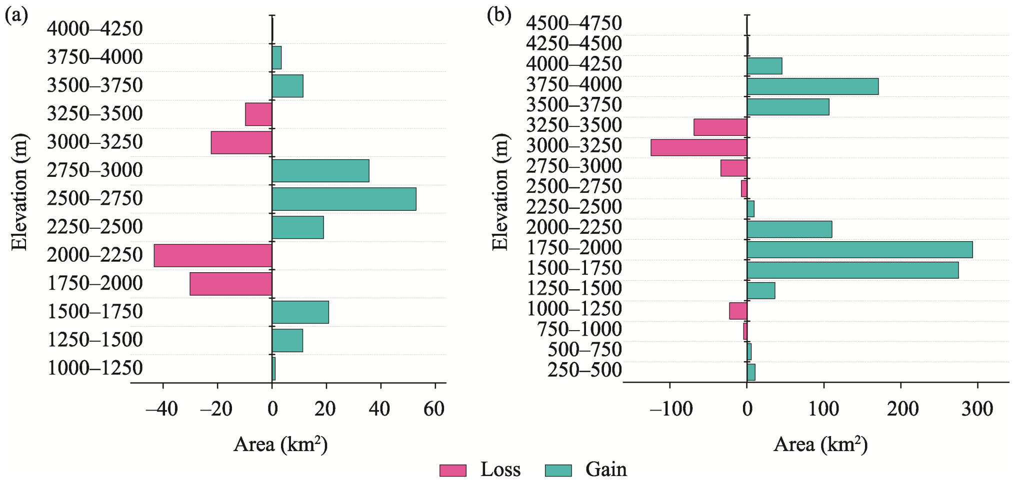

Fig. 6 Potential changes in the highly suitable (i.e., very high and high probability) habitat of the species at the different elevation ranges for Himalayan black bear (a) and common leopard (b)

a declining trend and an approximate 30% reduction of suitable habitat over the past 10 years has been observed in Nepal (Jnawali et al., 2011). The habitat losses of Himalayan black bear were estimated not only at the national level, but a remarkable decreasing trend was also reported at the global level, i.e., in Vietnam and Bangladesh (Garshelis and Steinmetz, 2016), India (Sathyakumar, 2001; Garshelis and Steinmetz, 2016) and China (Liu et al., 2009). Among the various Asian countries, Vietnam and Bangladesh have reported much loss of Asian black bear, which declined by approximately more than 60% over the past 30 years (Garshelis and Steinmetz, 2016). The loss of the geographic range of Himalayan black bear was estimated to be around 31% over the past 30 years and it would likely decline by 20% to 30% in the future globally (Garshelis and Steinmetz, 2016).

Common leopard: The common leopard is distributed at elevations below 4400 m and is well-known as a killer of livestock as well as humans (Aryal and Kreigenhofer, 2009; Jnawali et al., 2011). Although the total population of common leopard in Nepal is unknown, the estimated figure is fewer than 1000 across the country (Jnawali et al., 2011). One study found that due to climate change and an increase of forest cover in higher elevations, the common leopard habitat is also increasing, particularly in the Mountain regions of the world (Lovari et al., 2013). Liu et al. (2017) studied eight protected species, including the leopard in the Koshi basin. Land cover (vegetation change), Bio 6, Bio 12, and elevation were found to be the major factors influencing habitat distribution in the Koshi basin. This present study also found the elevation is the third-highest factor affecting common leopard in the GRB. The differences in the factors affecting distribution could be due to location or the adoption of different sets of bioclimatic variables. In the case of the south-west Mountain region of China, climate change is resulting in the increase in common leopard habitat where there have already been occurrences of common leopards recorded by camera trap survey at high elevation (3000 to 4500 m) (Buzzard et al., 2017). This study also expected an increase at the higher elevations (up to 4500 m).

The upward shifting of the habitat could be due to high habitat and diet overlaps in the lower elevations. One study found that leopard habitat has been significantly affected by tiger habitat in Chitwan National Park, Nepal, where the tiger density was found at 3.84 per 100 km^2 versus 3.18 per 100 km^2 for leopards with the same prey chital (*Axis axis*) within the park (Lamichhane et al., 2018a). The decrease in prey (*chital*) resulted in the tiger becoming aggressive towards the leopard, which is also the determinant of the coexistence of tiger and leopard in the wild (Odden et al., 2010).

It has also been stated that common leopards are ecologically flexible (Lovari et al., 2013) and show a positive relationship with landscape heterogeneity (Acharya et al., 2017). Our results also show that elevation and slope are not highly significant factors in shaping the current and future habitat distributions of common leopards. However, a study has found that the distribution of common leopard is highly affected by elevation in Golestan National Park (GNP), Iran (Abdollahi, 2015). This contradiction in the results could be due to the different climatic conditions between GBR and GNP. The annual rainfall ranges between 284 mm and 5160 mm in GRB compared to 400 mm in GNP in 2014. Similarly, the temperature is almost the same in the whole year in GNP (between 10.6 ℃ to 12.0 ℃) while GRB experiences a wider range between 6.12 ℃ and 32.35 ℃ in a year. This study found that the precipitation of wettest month (Bio 13) and precipitation seasonality (Bio 15) are the most important variables in common leopard habitat. In some cases, the selection of environmental variables for modeling also shows different results. The proximate causes, such as distance from settlement area to habitat, were predicted as the highest impact factors for common leopard in Shivapuri Nagarjun National Park, Nepal (Maharjan et al., 2017). In contrast, a study in Gorkha district has observed that the common leopard occupies habitat close to human settlements and frequently visits the settlement area searching for domestic animals as their prey instead of wild prey species (Gurung and Dahal, 2017). These dissimilarities in the results are due to the selection of varying methods in the studies; Maharjan et al. (2017) have used proximate causes (i.e., settlement, road) and land cover for the MaxEnt model which resulted in the highest impacted variable being distance from residences to habitat, while the Gurung and Dahal (2017) study was based on a field survey.

4.3 Other factors affecting habitat loss

Despite the various climatic and topographic factors, human-wildlife conflict, illegal trade on wildlife and land cover change are also major determinants of habitat loss for both species around the world (Sathyakumar, 2001; Aryal and Kreigenhofer, 2009; Jnawali et al., 2011; Lovari et al., 2015; Garshelis and Steinmetz, 2016). The habitats of Himalayan black bear have been destructed by reductions of forest cover by fire and tree felling, especially spectabilis and pine *(Pinus wallichiana)* for fuelwood, building construction, fencing, and other local uses in Darchula district, western Nepal. The local people used to burn fire to produce good quality grass but the habitats are declining and fragmenting in that district (Phuyal, 2018). During the insurgency period, the hunters were controlled on the one hand, and the conservation offices/posts were destroyed by Maoist in many protected areas in Nepal (Stubblefield and Shrestha, 2007). Moreover, both species frequently enter the villages and agricultural lands due to the availability of livestock prey as well as to attack humans. The Himalayan black bear is highly dependent on crops and also damages large cultivated areas, particularly in ACA, Nepal (Bista and Aryal, 2013). In addition to crop-raiding, it also attacks humans and livestock. During 2017–2018, Himalayan black bear attacked and caused serious injuries to four people in Chitwan Annapurna area of the GRB (Adhikari et al., 2018). Similarly, six human injuries and 55 livestock deaths were recorded due to bear attack in the Manaslu Conservation Area during 2009–2012 (Chetri, 2013).

Likewise, human-leopard conflict is also a serious cause of habitat degradation and the decrease in its population (Shrestha, 2016; Lamichhane et al., 2018b; Ruda et al., 2018). For example, a total of 424 livestock were killed during 2007–2016 in CNP (Dhungana et al., 2019), and 53 people were injured all over the country between 2010 and 2014 (Acharya et al., 2017). One study also revealed that common leopard uses livestock for prey more significantly than the tiger (Lovari et al., 2015). Not only the livestock, but humans have also been attacked by leopards in various parts of the country. A total of five human attacks were recorded, including one fatality and four injuries in the Annapurna Conservation Area (Adhikari et al., 2018). One study has reported that 51 common leopards died between 2006 and 2013 as the result of human-induced (i.e., poaching, retaliation, road accident, lethal control) and natural causes across Nepal (Thapa, 2015). Among the causes, the highest mortality (around 65% of leopard mortality) was due to poaching, retaliation, road accidents and lethal control in Nepal (Thapa, 2015). Also, anthropogenic activities such as deforestation are serious threats to the remaining habitat of common leopards in the case of Banpale forest of Pokhara (Bist et al., 2017).

5 Conclusions

This study assessed the current and future habitat distributions of Himalayan black bear and common leopard, two vulnerable species of Gandaki River Basin, based on the species occurrence locations and a set of climatic and topographic variables using MaxEnt modeling. Bio-climatic and topographic variables were found to be highly influential variables determining the overall habitat distribution in the basin. To determine the habitat changes, the elevation showed the greatest contribution to Himalayan black bear and variations in precipitation of the wettest month was highly influential for common leopard. The results of this study reveal that the habitat area of common leopard is likely to be decreased due to climate change. Therefore, efforts should be made to protect the habitat of the common leopard for the future. Geographically, the eastern region (Baseri, Tatopani and north from Bhainse) of the basin is the highly suitable area with a high probability for human-wildlife conflict. However, the habitat is likely to be lost in the eastern (Somdang, Chhekampar), western (Burtibang and Bobang), and northern parts (Sangboche, Manang, Chhekampar). The decreasing habitat of common leopard has been projected, particularly in the eastern, western and southern parts of the basin. However, the increase is estimated to be extended in southeastern (Bhainse), western (Harichaur and northern Sandhikhark), and north-western (Sangboche) parts of the basin. Therefore, these above-named villages could be important locations where more attention should be paid, especially concerning the minimization of human-wildlife conflict, illegal wildlife trade and land cover (forest cover, grassland and shrubland), to protect the bear and leopard habitats.

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气候变化对喜马拉雅中部甘达基河流域濒危物种的影响预测

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摘　要：甘达基河流域位于喜马拉雅山脉中部，是众多濒危野生物种的重要栖息地。然而气候变化使该流域的生态环境变得愈发脆弱。本研究利用最大熵物种分布模型（MaxEnt）评估气候变化对喜马拉雅黑熊（*Ursus thibetanus laniger*）和印度花豹（*Panthera pardus fusca*）等濒危物种空间分布变化的潜在影响。研究基于物种出没地点、生物气候和地形（海拔、坡度和坡向）等数据拟合模拟并预测物种在目前与未来的潜在分布情况。研究结果显示，目前喜马拉雅黑熊的高度适宜区面积约为 1642 km^2，占流域面积的 5.01%，预计至 2050 年，其高度适宜区面积在甘达基河流域内将会增加约 51 km^2；印度花豹的高度适宜区面积约为 3999 km^2，占流域面积的 12.19%，预计至 2050 年可能会增加到 4806 km^2。喜马拉雅黑熊的栖息地面积可能会在研究区域的东部（伯塞里、塔托潘尼和班塞以北）增加，而在东部（颂当、切坎帕）、西部（布尔提邦和波邦）和北部（桑波切、玛南、切坎帕）减少；印度花豹的栖息地面积则将在研究区域东南部（班塞）、西部部分地区（赫里乔尔和桑迪哈克北部）和西北部（桑波切）增加，而在研究区域的东部、南部和其他西部地区减少。研究同时指出，海拔、Bio 15（季节性降水变化）和 Bio 16（最湿润季度降水量）等环境因素对喜马拉雅黑熊的栖息地变化影响较大，而 Bio 13（最湿润月降水量）和 Bio 15（季节性降水变化）对印度花豹的栖息地变化影响较大。总之，这两个物种的栖息地在不同海拔下均会受到气候变化的影响，需要加强对该区域内濒危物种的保护力度。

关键词：气候变化；物种栖息地变化；喜马拉雅黑熊（*Ursus thibetanus laniger*）；印度花豹（*Panthera pardus fusca*）；甘达基河流域