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Change in the Distribution of National Bird (Himalayan Monal) Habitat in Gandaki River Basin, Central Himalayas

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Abstract: Gandaki River Basin (GRB) is part of the central Himalayan region, which provides habitat for numerous wild species. However, due to changes in climate and land cover, the habitats of many protected species are at risk. Based on the maximum entropy (MaxEnt) model, coupled with bioclimatic layers, land cover and DEM data, the impacts of environmental factors on habitat suitability of Himalayan Monal *(Lophophorus impejanus),* a national bird of Nepal, was quantified. This study further assessed the present and future habitat and distribution of the Himalayan Monal in the context of climate and land cover changes. The results of this study show that the highly suitable habitat of Himalayan Monal presently occupies around 749 km^2 within the northern, eastern and western parts, particularly protected areas such as Langtang National Park, Manaslu Conservation Area and Annapurna Conservation Area, while it is likely to decrease to 561 km^2 by 2050, primarily in the northern and northwestern parts (i.e., Chhyo, Tatopani, Humde and Chame). These expected changes indicate increasing risk for Himalayan Monal due to a decline in its suitable habitat area.

Key words: climate change; land cover; Himalayan Monal; habitat change; Gandaki River Basin

1 Introduction

The International Panel on Climate Change (IPCC) has reported that the global temperature is likely to increase by about 1.5℃ between 2030 and 2052 (IPCC, 2018). This global increase in temperature will obviously have impacts on many wild species of the Nepal Himalayas. A study has revealed that species habitats are gradually migrating northward due to in the rising temperatures in Nepal (Karki et al., 2009). In addition to climate change, land cover changes also affect many protected species globally (Thuiller, 2003; Jetz et al., 2007; Hofmeister et al., 2010; Grimmett et al., 2016). The increasing temperature has resulted in the shifting of vegetation to higher elevations which poses threats to high altitude endemic species that are likely to be reduced by around 77% by 2100 in the Austrian Alps (Dirnböck et al., 2011) and the Himalayan region (Forrest et al., 2012; Chhetri et al., 2018). In addition to climate change, declining forest cover is also a fundamental cause of habitat losses and one study has projected that around 42% of forest is likely to be impacted in the Asian tropical region by 2100 (Sodhi et al., 2004). Thus, this region is likely to experience impacts on many native habitats in the future which will need conservation efforts in due time (Sodhi et al., 2004; Sodhi et al., 2010). A previous study has predicted that many Mountain species might be threatened with large ecological range reductions in the future, due to natural and anthropogenic factors (del Rosario Avalos and Hernández, 2015).

The changes in climate have exacerbated habitat loss and fragmentation in different ecological regions globally; and these changes have already impacted 54% of important terrestrial species during the 21st century (Segan et al., 2016).

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One study has projected a reduction between 91% and 100% in the geographic distributions of endemic Andean bird species that currently extend from central Bolivia to southern Peru (del Rosario Avalos and Hernández, 2015). Likewise, a previous study has estimated that land cover dynamics are likely to affect around 400 species of land birds, out of the total of 8750 species, by the year 2050 in the tropical regions of the world (Jetz et al., 2007). Since historical periods, land cover dynamics have been known as a fundamental component of environmental change (Ganasri et al., 2013; Li et al., 2016), and they also play crucial roles in climate change (Pielke et al., 2002). Climate change will impact other important birds and their potential habitat distributions in future. For example, black woodpecker and boreal, tawny and Ural owls are all likely to change their geographic distributions due to changes in climate and forest cover (Brambilla et al., 2020). The changing patterns in climate and land cover, mainly decreases in vegetation, as well as illegal hunting, are already noted as the main threats to habitat protection in Mountain regions (Bhattacharya et al., 2009; Jnawali et al., 2011; Liu et al., 2017).

The Himalayan region is a shelter for numerous species (Liu et al., 2017; Nie et al., 2017). Gandaki River Basin (GRB) is a part of the central Himalayan region located in central Nepal that provides habitat for many kinds of birds, including the national bird: Himalayan Monal (HM). Among the various birds of Nepal, the HM is well-known to the Nepalese people. It is legally protected by the government and is also listed on CITES Appendix I, nationally categorized as near threatened (Inskipp et al., 2016) and listed in IUCN's least concern category (Inskipp and Baral, 2013). In addition, the HM was the first species recorded by Colonel Fitzpatrick in Nepal in 1793 (Inskipp and Baral, 2013). The higher Himalayan region, including the northern part of Gandaki Basin, has been experiencing a greater rate of temperature increase and a consequent change in the habitat of many threatened birds, including HM. However, the change in the distribution of suitable habitat for HM in the context of climate and land cover change is poorly understood. In order to address this research gap, this study assesses the current distribution and potential impacts of climate and land cover changes on the suitable habitat of HM within the GRB.

2 Materials and methods

2.1 Selection of the study area

GRB is located between 28.35°N and 29.33°N and between 82.87°E and 85.80°E. The basin covers around 32807 km^2 of the central Himalayan region (Fig. 1). The elevation ranges from 94 m above mean sea level (amsl) in the south to 8167 m amsl in the north. The sum of annual precipitation in GRB was recorded in 2014 as 285 mm (driest region) and 5160 mm (wettest region), and the average temperature was between 6.12 ℃ (lowest) and 32.35 ℃ (highest) (MPE, 2018). Due to heterogeneous landforms and altitudinal variations, the GRB contains various land covers and ecosystems (Rai et al., 2018). The predominant land covers are agricultural land and forest cover, which are mainly distributed in the central and southern parts of the GRB. The Annapurna Conservation Area, Manaslu Conservation Area, Chitwan National Park, Shivapuri Nagarjuna and Parsa Wildlife are located within the GRB, where large numbers

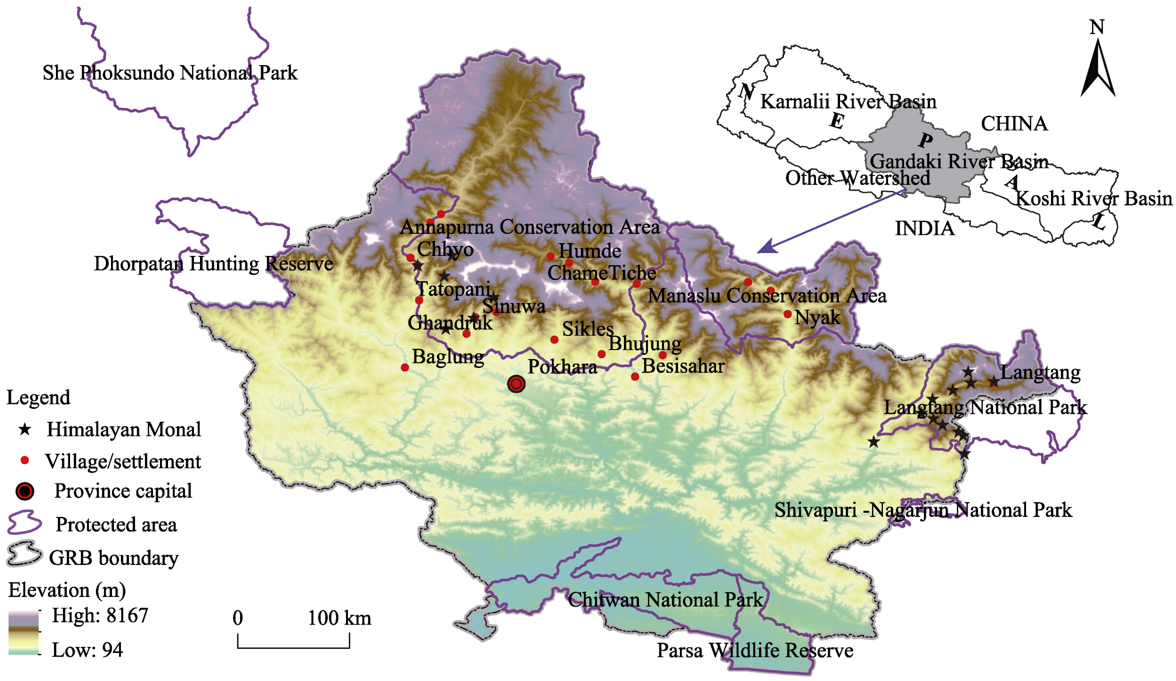

Fig. 1 Location of the GRB and species occurrences

of mammals, birds, and reptiles are found (DNPWC, 2018). The Himalayan Monal, also called Danfe, is the national bird of Nepal which has given it a very high profile (DNPWC and BCN, 2018), and it is distributed in higher elevations, particularly in Langtang National Park, Manaslu Conservation Area and Annapurna Conservation Area in the GRB (BirdLife International, 2016). According to the National Parks and Wildlife Conservation Act 1973, HM is included with eight other species of birds as protected species (Baral, 2009).

2.2 Datasets

2.2.1 Species occurrence

The points of known HM occurrences were extracted from the Global Biodiversity Information Facility (GBIF) portal (http://www.gbif.org/), a platform which provides more than 280 million records of different species observations worldwide (Telenius, 2011). GBIF is the largest global databank of biodiversity for scientific research (Beck et al., 2013; Robertson et al., 2014; Liu et al., 2017).

2.2.2 Bioclimatic variables

The bioclimatic variables (at 30 arc-second spatial resolution) were extracted from WorldClim: http://www.worldclim.org/ (Table 1). The current WorldClim data layer was generated by the interpolation of average monthly climate data annually for the period between 1970 and 2000 on a 30 arc-second resolution grid. The future climatic model used was the IPPC5-Global Climate Models (GCM) for four representative concentration pathways (RCP). 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) for 2050, were used in this study. Values for each climatic variable were extracted for the corresponding species occurrence locations and used to perform the correlation analysis. Highly correlated variables were removed according to their Pearson correlation coefficients. Variables with a coefficient greater than 0.60 were excluded from the modeling.

Table 1 Environmental variables and their descriptions

Variable		Description	Retained or excluded
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	√
Land cover		Land cover data at 30 m spatial resolution	√

Note: Abbreviations: √ means retained; × means excluded.

2.2.3 Land cover data

National land cover data for 1990 were download from the International Centre for Integrated Mountain Development (ICIMOD) (http://rds.icimod.org). Similarly, land cover data for 2010 were extracted from Uddin et al. (2015). Based on the 1990 and 2010 data, land cover data for 2050 were simulated using a Cellular Automata (CA) Markov model in TerraSet version 18.21. The Markov model is often used for projecting future land cover changes (Mandal, 2014; Mondal et al., 2016). The Markov model was introduced by Brown (1963) for the projection of future land use change (Mandal, 2014). Since the model was introduced, numerous scholars have used it at different spatio-temporal scales for the prediction of land use changes. The CA-Markov model can predict both spatial and temporal changes in land use and land cover over an area (Ye and Bai, 2008; Zhao et al., 2017). It is a convenient tool for simulating land use and land cover changes (LUCC), which describes the LUCC from one period to another (in this case 1990 to 2010) and uses this as the basis for projecting future changes (in this case 2050) (Kumar et al., 2014). A digital elevation model (DEM) at 30 m spatial resolution was download from the United States Geological Survey Earth Explorer. The slope map was prepared from the DEM using ArcGIS tools.

2.3 Maximum Entropy (MaxEnt) model

The freely available MaxEnt version 3.4.1 software was used in this study. This model identifies wild species' environmental requirements and geographical distributions (Phillips et al., 2006; Baldwin, 2009) which are then used to estimate current and future distributions (Phillips et al., 2004; Phillips et al., 2006). The MaxEnt model is a simple and precise mathematical formulation that incorporates a number of features for estimating the geographic distribution of suitable habitat for a given species (Phillips et al., 2006). This approach has been applied across many disciplines including studies of cropland changes (Heumann et al., 2011; Gu et al., 2018) and infectious disease habitat suitability (Mweya et al., 2016; Acharya et al., 2018). Indeed, more than 1000 studies have applied this model since 2006 because of its high predictive performance (Merow et al., 2013). Several existing studies also have recommended this model for predicting the future habitat of protected species under different environmental scenarios (Kumar and Stohlgren, 2009; Larson et al., 2010; Zhang et al., 2011; Remya et al., 2015; Liu et al., 2017). Species occurrences, climatic variables, land cover, DEM and slope were used as the source input data for the model. The results from the MaxEnt model were imported to ArcGIS to analyze the current and future habitat distribution of HM.

This study categorized habitat suitability by defining five classes: Very high suitability (greater than 70% probability); High suitability (from 50% to 70% probability); Medium suitability (from 30% to 50% probability); Low suitability (from 10% and 30% probability); and Very low suitability (less than 10% probability) (Liu et al., 2017).

3 Results

3.1 Land cover changes

Based on land cover data for 1990 and 2010, the CA Markov model was used to predict land cover data for 2050. This model predicts that agricultural land, shrubland and built-up areas are likely to increase in the future, while forest cover, grassland, barren land and water body area would decrease by 2050 (Table 2). It further predicts that largely occupied forest cover is likely to decrease from 40% to 35% between 2010 and 2050, while shrubland and agricultural land are likely to increase by about 1% and 2%, respectively (Table 2 and Fig. 2).

The results show that the predominant forest cover is likely to decrease in each of the elevation ranges, while the shrubland is likely to increase at elevations up to 3750 m (Fig. 3). Likewise, the grassland is likely to decrease between 3500 m and 6500 m elevation ranges, while the agricultural land is more likely to increase in each of the elevation ranges from 250 m to 3250 m within the GRB (Fig. 3).

Table 2 Current (2010) and projected (2050) land use and land cover (LULC) types

LULC types	2010		2050	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Forest	13174	40.15	11344	34.58
Shrubland	821	2.50	1072	3.27
Grassland	3798	11.58	3366	10.26
Agricultural land	7574	23.09	8379	25.54
Barren land	3284	10.01	3147	9.59
Water body	168	0.51	115	0.35
Snow/Glacier	3887	11.85	5218	15.91
Built-up area	101	0.31	166	0.51
Total	32807	100	32807	100

3.2 Model evaluation and analysis of variables

In setting-up the MaxEnt model, 25% of the occurrence locations were used for testing and the remaining randomly selected 75% were used to train the model. This process found the area under the Receiver Operating Characteristics (ROC) curve, or mean Area Under ROC (AUC) test set data, to be 0.920. The overall accuracy of the model performance was high, which indicates that the distributions generated provide close estimations for the real-world distribution probabilities.

The environmental variables are fundamental to MaxEnt modeling and each one contributes to the spatial distribution of habitat. Different environmental variables play important roles in explaining whether or not the species exists in a particular area. Thus, if any environmental layer provides a higher contribution, then it represents a higher impact of the variables on the habitat prediction. The result shows that climatic layer Bio 8 (mean temperature of wettest quarter) provided the highest contribution to the HM, corresponding to 29%. Two others, Bio 14 (precipitation of driest month)

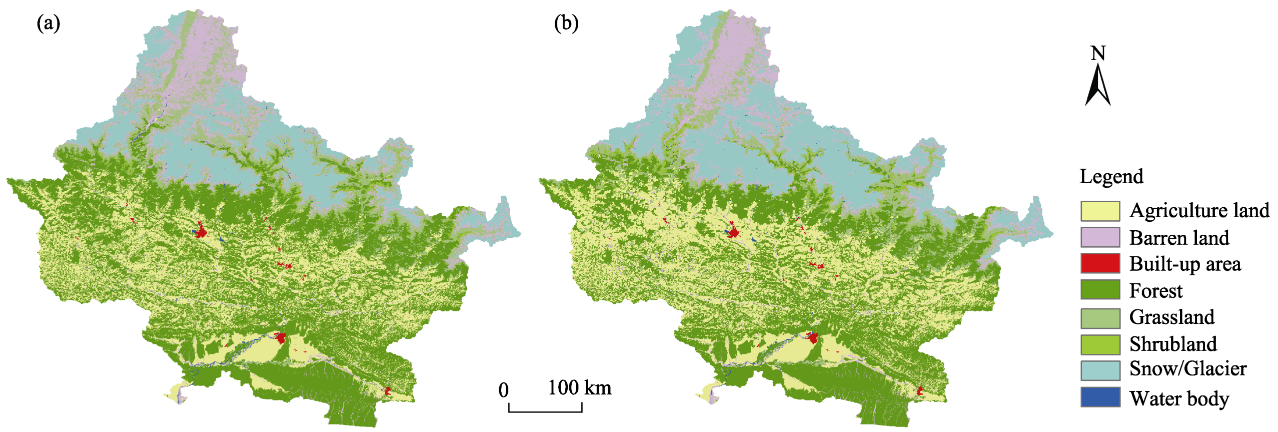

Fig. 2 Current (a, 2010) and projected (b, 2050) LULC

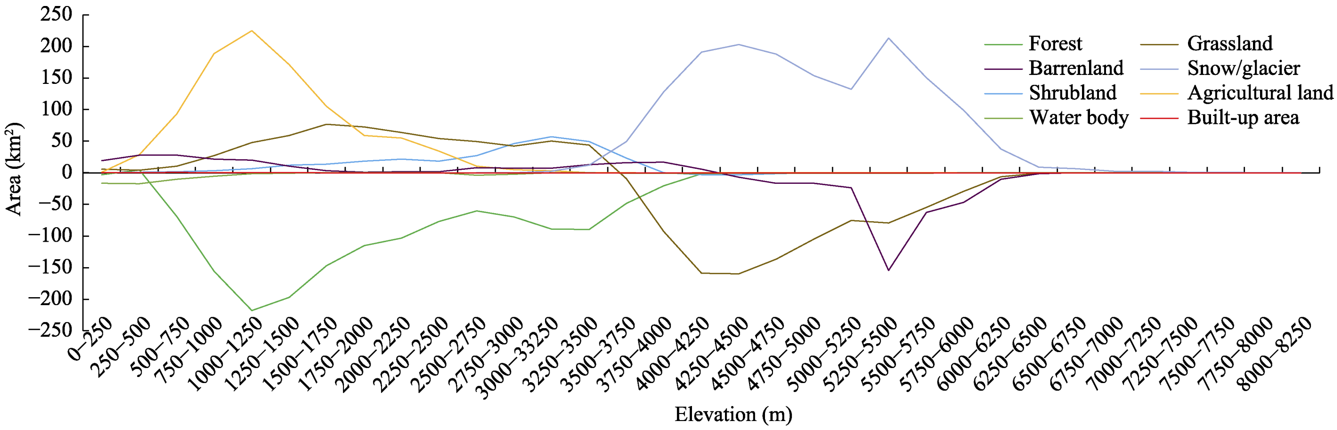

Fig. 3 Land cover changes along the altitudinal gradient

(12%) and elevation (9%) were also found to be important variables contributing to the habitat of HM (Fig. 4).

3.3 Habitat status and future distributions

Under the appropriate conditions of the climatic variables, topography and land cover, the modeling results reveal the suitable habitat across the GRB. The total area of HM habitat is projected to increase by 695 km^2 in the future, with corresponding decreases and stable areas projected to be 3177 km^2 and 995 km^2, respectively, in the future (Fig. 5).

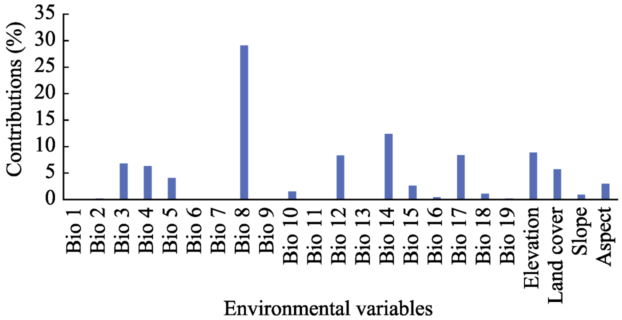

Fig. 4 Environmental variables and contributions

Note: See Table 1 for descriptions of the variables.

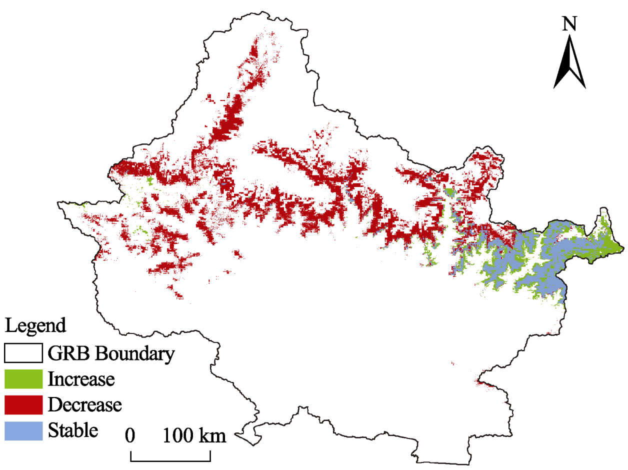

Fig. 5 Projected habitat changes of HM within the GRB in the future (by 2050)

Most of the suitable habitat increase would be in the eastern parts such as Nyak, Langtang National Park and Manaslu Conservation Area, while in many places in the central and western parts such as Chame, Chhyo, Tatopani, and Humde, habitat areas are likely to decrease by 2050.

This study assessed the habitat suitability according to five classes: very high suitability (>70% probability); high suitability (50%–70% probability); medium suitability (30%–50% probability); low suitability (10%–30% probability); and very low suitability (<10% of probability) (Liu et al., 2017). The very high suitability habitat of the species is projected to decrease in the future at different spatial scales, while the high suitability habitat is likely to decrease around 188 km^2 in the future. Similarly, medium suitability habitats are also predicted to decrease in total area (Table 3 and Fig. 6).

3.4 Habitat changes along the altitudinal gradient

This study assessed the very high suitability area of greater than 70% prediction probability as it was mapped at different altitudes in the future. The habitat of HM is likely to decrease at elevations between 1750 m and 3750 m, and between 4500 m and 5500 m, while at elevation ranges from 3750 to 4500 m it will likely increase in the future. Overall, the projections found around 186 km^2 of total area loss within these elevation ranges (Fig. 7).

4 Discussion: The potential impact of climate and land cover changes on habitat of HM

Currently, the HM is estimated to occur within less than 20000 km^2 area globally, including Nepal, India, Bhutan, Afghanistan, Pakistan, Tibet and Myanmar (Baral, 2009;

Table 3 The suitability status of current and predicted future habitat areas (km^2)

Habitat suitability	Current	Future
Very high	748.50	560.54
High	1532.99	846.76
Medium	2625.70	1849.90
Low	4520.88	9201.65
Very low	23379.74	20349.06

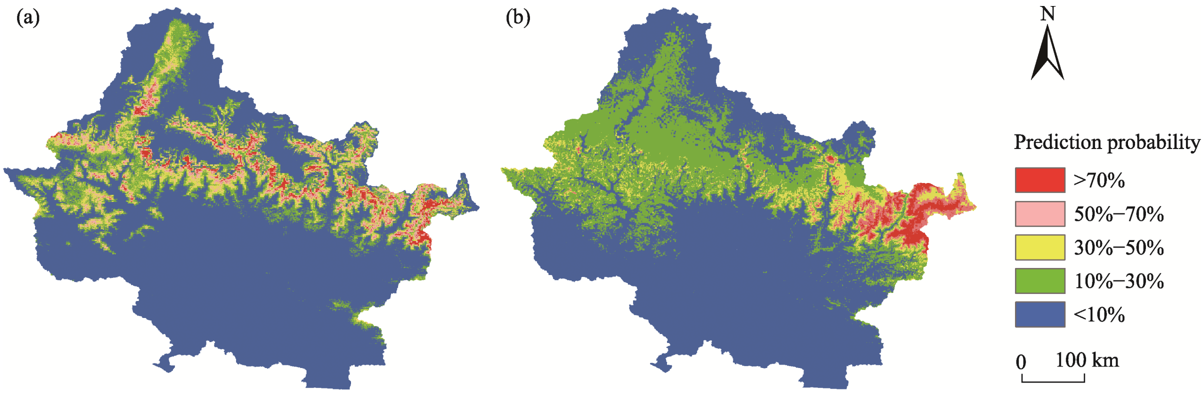

Fig. 6 Current (a) and predicted (b) habitat distributions in the GRB

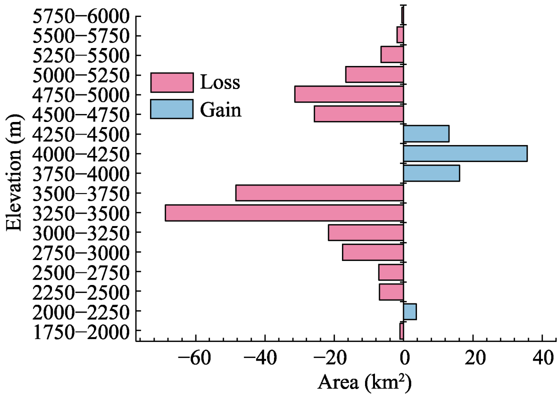

Fig. 7 Changes in very high suitability habitat at different elevation ranges in the GRB

Miller, 2010; BirdLife International, 2016). It is found at high altitudes, in places with steep slopes, rocky slopes, cliffs, grasslands and wood patches (Inskipp et al., 2016; Inskipp and Inskipp, 1991). The total global population has not been calculated, though in Nepal it is estimated at around 3500 to 5000 individuals (Inskipp et al., 2016). Still, the total population within the GRB is unknown, though one previous study reported 26 individuals in winter and 51 in spring within the Annapurna Conservation Area (BCN, 2013). However, hunting and trapping have been heavily practiced by local hunters, herders and medicinal plant collectors in the Mountain region of the country for many years (Baral, 2009; Miller, 2010; Inskipp and Baral, 2013; Inskipp et al., 2016). This bird tends to move into surrounding farmlands where people kill it for its crest feathers as well as its meat, which reaches a high price (Kaul et al., 2004; Ma et al., 2011; Inskipp et al., 2016). Changes in forest cover, grassland, and human activities, as well as illegal activities, threaten the continuing presence of this bird in Nepal (BCN and DNPWC, 2011; Inskipp et al., 2016). The grassland area has a declining trend due to overgrazing and burning, such that no significant area remains outside of the protected areas in the country (Inskipp et al., 2016). The human disturbance, particularly livestock grazing, and natural disturbances were also noted as the key causes of declining habitat in the Great Himalayan National Park, India (Miller, 2010). One recent study has observed that due to livestock grazing and large-scale collection of Mushrooms from the forest, many species are experiencing degraded situations in the western Himalayan region of Pakistan (Ahmad et al., 2019). The results of this study also project a decrease in the forest area by approximately 5% between 2010 and 2050. Nationally, the forest cover has shown a decreasing trend between 1930 to 2014, and a net loss of 37318 km^2 across the country has been observed (Reddy et al., 2018). Decreases in forest cover and grasslands are likely to reduce the habitat for HM within the GRB.

The habitat of HM is also projected to decrease at elevations between 1750 m and 3750 m, and to increase at elevations between 3750 m and 4500 m. Past studies also found the suitable habitat ranges between 2500 m and 4750 m in barren land and open forest of the Nepal Himalayan regions (BCN, 2013). The model used in this study found that a suitable habitat range might be at elevations between 3750 m and 4500 m. These elevation ranges encompass estimated decreases in forest cover, grassland and shrubland, which could influence these habitat ranges in the future. Land cover and changing climatic patterns determine future habitat changes for this species. Highly significant climatic variables, as well as elevation, are expected to be favorable for HM in the northeastern region. Habitat is projected to likely increase in the eastern part of LNP and ACA buffer zones, as well as in the MCA and surrounding protected areas that are especially close to agricultural land.

This species undergoes fluctuations with altitudinal and seasonal migrations (Inskipp et al., 2016). This study has projected a small increase in the elevation range between 2000 m and 2250 m, and the increase in this range could be due to the seasonal migration of HM. This species migrates with seasons mainly during winter, and moves to lower elevations, around 2500 m (Baral, 2009), bringing it close to human habitations and people hunting it for local consumption in the western Himalaya, India (WII, 2016). Similarly, during the spring and autumn seasons, the Himalayan

Monal shares habitat with herded livestock, which is also associated with negative factors for species occurrence, mainly shepherd dogs and human disturbances which have negatively impacted the MH in the western Himalayan region, India (Bhattacharya et al., 2009). During the summer season, the HM shifts up to 4300 m elevation and digs roots by using its strong bill (Ma et al., 2011). Therefore, this study has estimated that the mean temperature of wettest seasons will have a high impact on habitat suitability of the HM in the future within the GRB.

5 Conclusions

This study assessed the current and future distributions of the habitat of the nationally protected bird, Himalayan Monal, within the GRB using the MaxEnt model. Under the conditions of changing climatic variables, land cover changes were found likely to impact the habitat of the Himalayan Monal in 2050. The highly suitable habitat of the Himalayan Monal is likely to decrease by around 188 km^2 in the future, particularly in the northern and northwestern parts (i.e., Chhyo, Tatopani, Humde and Chame). For the most part, the suitable habitat would increase in the eastern parts such as Nyak, Langtang, Langtang National Park and Manaslu Conservation Area in 2050. This study highlights the fact that more attention should be given to HM, in terms of future habitat protection. This species is expected to experience considerable decreases in suitable habitat areas in the future. The northeast parts are particularly important regions and more attention should be paid to them, especially with regard to forest cover, grassland, and shrubland to protect the remaining habitat of HM.

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喜马拉雅中部甘达基河流域尼泊尔国鸟（棕尾虹雉）生境分布变化

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摘　要：甘达基河流域（Gandaki River Basin，GRB）是喜马拉雅中部地区的一部分，该地区栖息着许多珍稀的野生动物。由于气候和人类活动的影响，许多珍稀保护物种的生境处于危险之中。本研究基于最大熵（MaxEnt）模型，运用生物气候、土地覆被和 DEM 数据，分析各环境要素对棕尾虹雉（*Lophophorus impejanus*）的生境适宜性的影响，评估棕尾虹雉现在状况和未来栖息地分布的变化。研究表明，目前棕尾虹雉的高度适宜栖息地面积约为 749 km^2，主要分布在流域北部、东部和西部，尤其是郎塘国家公园、马纳斯卢峰自然保护区和安纳布尔纳峰自然保护区等保护区内。到 2050 年，棕尾虹雉的高度适宜栖息地面积将减少至 561 km^2，主要在流域北部和西北部（即 Chhyo，Tatopani，Humde 和 Chame 地区）。未来环境变化的模拟表明，由于适宜栖息地面积的减少，棕尾虹雉面临的生存风险将增加。

关键词：气候变化；土地覆被；棕尾虹雉；生境变化；甘达基河流域