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Will climate change impact distribution of bats in Nepal Himalayas? A case study of five species

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ABSTRACT

Nepal Himalayas combine Oriental and Sino-Japanese zoogeographic realms as well as those of the eastern and western Himalayas. Physiography coupled with the diverse local climates has enriched the biodiversity of the Nepal Himalayas. The order Chiroptera constitutes more than 25% of the mammalian fauna and forms the most speciose group of mammals in Nepal, where bats are recorded within a wide range of elevations from 64m to 4154m. Climate variation in the past has been observed and projected change has been predicted, and an evaluation of the climate change impact on biodiversity and habitats has been initiated. However, none of the studies has assessed the impact of climate change on bats in the Himalayan range including Nepal, despite bats represent the largest mammalian group in the country. Through Species Distribution Modelling (SDM), we describe the present distribution range for five common species, further assess their response to future climatic changes. Specifically, the occurrence of bats against 10 environmental variables were projected under different climate scenarios; present, Representative Concentration Pathways (RCPs) 4.5 and 8.5 for 2050 and 2070 deploying maximum entropy modeling (MaxEnt). We prepared predicted distribution range maps and estimated area using Arc GIS 10.7.1. Among 10 uncorrelated bioclimatic variables, six contribute to the SDM significantly. Annual precipitation (bio12) is the most common variable for all five species. Two species shows wider present distribution ranges compared to other three. Under the climate change scenarios, although predictions varied among species, similar trends of the range shifting toward northern latitudes and higher elevations are observed. Since the larger part of the current potential distribution range lies outside protected areas, a landscape level conservation approach prioritizing bat conservation is needed. Future surveys should target ground truthing in the western region of the country.

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1. Introduction

The diverse local climates have bestowed the Himalayas with enriched biodiversity and the range qualifies as the biodiversity hotspot (N. Myers et al., 2000). Oriental and Sino-Japanese terrestrial zoogeographic realms (Holt et al., 2013) as well as the eastern and western Himalayas are brought together in Nepal. With about 0.1% of global land area, Nepal harbors 11 eco-regions (Olson and Dinerstein, 2002), 118 ecosystems, more than 3.2% and 1.1% of known flora and fauna (MoFSC, 2014).

The impact of climate change on biodiversity and habitats in Nepal and in the Himalayas has been documented (Song et al., 2004; Chettri et al., 2010; Forrest et al., 2012; Shrestha et al., 2012; Ferrarini et al., 2014; Gaire et al., 2014; Salick et al., 2014; Shrestha and Bawa, 2014; Shah et al., 2015; Bhattacharjee et al., 2017; Thapa et al., 2017; Lamsal et al., 2018; Kanagaraj et al., 2019). However, no studies assessed the impact of climate change on bats in the Himalayan region including Nepal. Habitat suitability models for bats have been deployed to predict the response of species towards land use change and level of effect due to habitat change in tea and coffee plantations in the Western Ghats (Wordley et al., 2015). The potential distribution of bat diversity in the eastern parts of the Eastern Ghats has been mapped deploying MaxEnt modelling (Debata et al., 2019). Closer to the Himalayan region, the effect of climatic and vegetation changes on the distribution and diversity of bats has been predicted for South East Asia. Hughes et al. (2012) predicted that 3–9% species would suffer loss of all currently suitable niches. On the top of that, 2–6% of species may lose suitable niche space in 2050–2080. The coupled effect from potential vegetation and climate change is predicted to change the predicted ranges for 99% of species by 2050. Besides, some species will expand the current ranges, but there exist potential barriers to species especially those with poor dispersal ability (Hughes et al., 2012).

The order Chiroptera forms the most speciose group of Mammalia in Nepal and constitutes more than 25% of the mammalian fauna (Thapa, 2014). Bats are recorded within an elevation range of 64m asl at Taghandubba, Jhapa District (*Pteropus giganteus*, *Megaderma lyra* and *Scotophilus heathii*) to 4154m asl at Mukot, Dolpa District (*Murina aurata*) (Bates and Harrison, 1997; Acharya et al., 2010; Pearch, 2011). In Nepal, Bats provide ecosystem services such as pollination (Acharya et al., 2010) and pest control (Acharya et al., 2010; Pokhrel and Budha, 2014) but face several threats (Acharya et al., 2010) including climate change.

Although the Himalayan range act as a geographical barrier for the dispersal of species and populations, the southern flank consists of glacial refugia (Brandon-Jones, 1996; Jablonski and Whitfort, 1999; Fuchs et al., 2008; Patou et al., 2010; Morgan et al., 2011; Gao et al., 2012) facilitating species endemism (Lin et al., 2014). Since, topographical elevation causes geographic isolation, limiting and confining species ranges, the Himalayas and the fate of its biodiversity is particularly vulnerable to the global climate change (Chettri et al., 2010; Srinivasan et al., 2013; Bhattacharjee et al., 2017).

The climate in Nepal varies with topography and is influenced by monsoon and westerly circulations. According to the recent classification system, there are seven major climates in Nepal (Karki et al., 2016). During 1975–2014, the annual maximum temperature has increased at the rate of 0.056 °C per year while minimum temperature has increased at the rate of 0.02 °C per year. Warm days and nights have significantly increased (DHM, 2017). In between 1981 and 2010, precipitation during the monsoon has increased in the western Middle and High Mountains and central High Himalayas (Karki et al., 2017; MoFE, 2019). Future climate models project the increase in average annual mean temperature up to 1.82 °C under RCP 8.5 for 2036–2065. The temperature is likely to increase in the western compared to the eastern region of the country. High Mountains and High Himalayas will record slightly higher temperatures. The average annual precipitation is projected to increase up to 12.1% under RCP 8.5 for 2036–2065. The central and western region of the country will receive more precipitation than the eastern (MoFE, 2019).

Climate change will cause redistributions of species (Jetz et al., 2007; García-Valdés et al., 2015) directly through (a) changes in temperature and water availability, indirectly through (b) further habitat modification and additionally (c) through feedback loops between climate and vegetation, agricultural practices and land use (Vander Wal et al., 2014; Tsarouchi and Buytaert, 2018). Redistribution will affect biogeography, phylogeography, phenology and other attributes and species interactions (Walther et al., 2002). It will lead to changes in biogeography such as migration (Lundy et al., 2010) and northward range expansion (Humphries et al., 2002; Rebelo et al., 2010). An area previously unsuitable for bats is projected to convert later in to a more suitable area in Australia, Europe and Africa and Neotropical savannah (Parris and Hazell, 2005; Sherwin et al., 2012; Aguiar et al., 2016). Bat assemblages in more northerly latitudes are at risk due to climate change. They are likely to lead to movement of species towards new locations or refugia (Rebelo et al., 2010). Close to Nepal, mass die-offs in *Pteropus giganteus* (56 individuals) has been reported from Purulia District, West Bengal, India caused by soaring temperature (up to 48 °C) triggered by heat waves and consequent drought (Dey et al., 2015).

Species Distribution Modeling (SDM) can help to identify the potential distribution range of the species (Razgour et al., 2016) and guide future surveys and conservation management (Hernandez et al., 2008; Sánchez-Fernández et al., 2011). The present study has three objectives; 1) distinguishing important climatic factors influencing current distribution of five common bats species in Nepal, 2) assessing the current distribution range of bats and 3) predicting their response to future climate change.

2. Methods

2.1. Study area

Nepal, a landlocked country between India and China stretches approximately 800 km east to west and 150 km−250 km north to south and covers an area of 147,181 km^2. It encompasses diverse landscapes from the northern rim of the Gangetic plain to the world's highest mountain Mount Everest (Sagarmatha in Nepali) within an elevation range of 59 m−8848 m asl. It can be broadly divided into five physiographic regions; Tarai (plain), Siwalik (Chure in Nepal) range, Middle Mountains (Mahabharat range and Midlands with sub-tropical valleys and elevated plains), High Mountains (with subtropical valleys) and High Himalayas (Shrestha et al., 2013) as well as Dun valleys (Inner Tarai) and Trans-Himalayas (Fig. S1). This diverse physiography supports six climate zones along the elevation gradient south to north; Subtropical (below 2,000 m), Temperate (2,000 m −3,000 m), Subalpine (3,000 m-4,000 m), Alpine (4,000 m-5,000 m), Nival (above 5,000 m) and Trans-Himalayan (rainshadow). Overall, a monsoon climate predominates, and the amount of annual precipitation decreases from east to west (2,500 mm-1,000 mm) as the distance from the Bay of Bengal increases. In contrast, the southern slope of the Annapurna Himalaya, in the central part of Nepal receives the highest amount (5,500 mm) (Barnekow Lillesø et al., 2005). Altogether there are 6000 rivers (cumulative length of 45,000 km), rivulets and tributaries originating from glaciers and glacial lakes in the High Himalayas, the Mahabharat and Churia ranges, and a few originating in Tibet, are channeled into three major river systems: Sapta Koshi, Gandaki and Karnali (east-west)(WECS, 2011).Although 75% of its population is engaged in agriculture (Barrueto et al., 2018), forest (5.83 million ha) is the dominant land cover of Nepal (MoFSC, 2016). The physiography and climate bestow 37 types of vegetation and forest (Barnekow Lillesø et al., 2005), largely occupied by broadleaved open and closed forests (Uddin et al., 2015).

2.2. Bats occurrence data and species selection

We collated 578 occurrence records (coordinates) for 51 bat species from the available literature. These were mainly from secondary sources such as Bates and Harrison (1997), Csorba et al. (1999), P. Myers et al. (2000), Acharya et al. (2010) and Pearch (2011).

We selected five representative species from different families and with different feeding habit (Table 1) from the list of 51 species (Table S1). We removed duplicate records and the presence points outside the range of Nepal and the final occurrence matrix contained 232 occurrences coordinates of five species for further modelling. To avoid spatial auto-correlation between the presence points, we effectively removed every presence location within 10 km. A study in a landscape with similar environmental heterogeneity with respect to altitude showed the distance window suitable for the analysis (Boria et al., 2014). We created a kernel density based bias file to be used for background point selection. Spatial filtering (Boria et al., 2014) and bias file for background point selection (Brown, 2014) can effectively remove sampling bias for presence only models like MaxEnt. We used SDM Toolbox 2.4 (Brown et al., 2017) for spatial filtering and bias file preparation.

2.3. Environmental and projection layers

We downloaded 19 bioclimatic variables (raster) with the highest resolution (30 arc-seconds (~1 km)) from WorldClim (version 1.4) for current conditions (~1960−1999). We also downloaded 19 bioclimatic variables (30 s spatial resolution raster) for future climate downscaled $IPCC_5$ ($CMIP_5$) projections from Global Climate Models (GCMs). We selected two representative concentration pathways (RCPs) 4.5 and 8.5 for the years 2050 and 2070 (Hijmans et al., 2005).

Table 1
List of selected species and brief details on criteria of selection.

S.N.	Species Common name	Species Scientific name	Family	Habitat	Distribution known	Feeding Habit	Location (# points)	Recorded elevation range (m asl)
1	Greater Short-nosed Fruit Bat	*Cynopterus sphinx*	Pteropodidae	trees, vegetation	Tarai, Churia range range, Inner Tarai, Middle Mountain	Frugivorous	86	60−2300
2	Great Himalayan Leaf-nosed Bat	*Hipposideros armiger*	Hipposideridae	cave	Inner Tarai, Middle Mountain	Insectivorous	62	390−2100
3	Intermediate Horseshoe Bat	*Rhinolophus affinis*	Rhinolophidae	cave/ abandoned house	Inner Tarai, Middle Mountain, High Mountain	Insectivorous	31	396−2172
4	Leschenault's Rousette	*Rousettus leschenaultii*	Pteropodidae	cave	Inner Tarai, Middle Mountain, High Mountain	Frugivorous	26	390−2000
5	Greater False Vampire	*Megaderma lyra*	Megadermatidiae	Cave/ abandoned house	Tarai, Churia range, Inner Tarai, Middle Mountain	Carnivorous	27	60−1574

Source: Acharya et al. (2010).

For each of five species multi-collinearity test (Pearson Correlation Coefficient) of these 19 bioclimatic variables were performed to reduce highly correlated variables ($r > 0.75$). The final set of variables to be used for a species was reduced to four for one species and six to seven for the remaining four species (Table 4). Biological interpretation and importance of a variable for the particular species was considered when removing or selecting a variable in case of collinearity between two variables. All collinearity tests were performed using the package stats (R Core Team, 2019).

2.4. Model Building

We deployed Species Distribution Modeling (SDM) to predict the current and future distribution ranges of five species of bats, using MaxEnt version 3.4.1 (Phillips et al., 2006). The model is a robust and widely used tool predicting species distribution for small sample sizes, irregularly sampled presence-only data even with minor location errors (Elith et al, 2006, 2011; Pearson et al., 2007; Wisz et al., 2008a, 2008b; Kumar and Stohlgren, 2009; Kramer-Schadt et al., 2013; Merow et al., 2013).

We used two different approaches to build a model and validate it based on the number of presence points available for modelling purpose. For species with presence points more than 25, we subsampled 70% of the available presence points for model training and used the rest for validation purpose (Fielding and Bell, 1997). For a species with presence points less or equal to 25, we used the leave-one-out cross validation method where the data is divided in n (number of presence location) subsets and one subset (one presence location) used for model validation (Pearson et al., 2007). We ran 10 replicates of the model using auto features, 10000 background points and all the settings at default to predict the distribution of the species and project them on to one of the future scenarios at a time.

2.5. Output evaluation

Predictions were evaluated based on higher Area Under Curve of ROC (AUC) values and further accepted after visual inspection of the prediction result based on the known occurrence of the species. The predicting model outperforms the random prediction (AUC value = 0.5 or nearer) if the AUC value is closer to 1.0 and indicates high probability suitability for AUC value > 0.70 towards 1.0 (DeLeo, 1993). To convert the continuous predicted output probability to binary response of presence and absence, we used Maximum test sensitivity plus specificity, a threshold approach considered suitable for the purpose (Liu et al., 2005). We used the Jackknife procedure implemented in MaxEnt (Phillips et al., 2006) to assess the contribution of variables. The procedure compares the gain of the model using a single variable, excluding the variable and all the variables to predict the importance of a particular variable (Torres et al., 2010).

3. Results

3.1. Potential distribution five bat species in present climate scenario

Models predict the distribution of five bat species with better accuracy (Table 2). Area of distribution range for all bats species *Hipposideros armiger* followed by *Cynopterus sphinx* occupies the largest distribution range (Fig. 1) covering 40.84% and 40.69% of the total area of the country (Table 3). Distribution is also predicted for the hitherto unsurveyed western Middle Mountains. The distribution is finely predicted for *Rhinolophus affinis* and shows a low probability of its occurrence in lowland Tarai. *Megaderma lyra*, *R. leschenaultii* and R. *affinis* have comparatively small distribution ranges (Fig. 1; Table 3) covering 22%, 21.5% and 18.4% of country's area.

3.2. Influencing predictors

Among the uncorrelated 10 predictor bioclimatic variables (Table 4), altogether six variables: annual mean temperature (bio1), Isothermality (bio3), minimum temperature of the coldest month (bio6), mean temperature of the coldest quarter (bio11), annual precipitation (bio12) and precipitation seasonality (bio15) are influential (Table 4). However, the contribution of predictors varies with species (Fig. 2; Table 4). Among six variables, annual precipitation (bio12) was a common variable from our SDM for all five species. However, bio1 was important for *M. lyra*, *C. sphinx* and *R. leschenaultii*. Similarly, Isothermality (bio3) was important for three species; *C. sphinx*, *H. armiger* and *R. leschenaultii*. The other three variables; bio6,

Table 2
AUC values for model validation for bat species.

Species	AUC
C. sphinx	0.77
H. armiger	0.77
R. affinis	0.79
R. leschenaultii	0.77
M. lyra	0.78

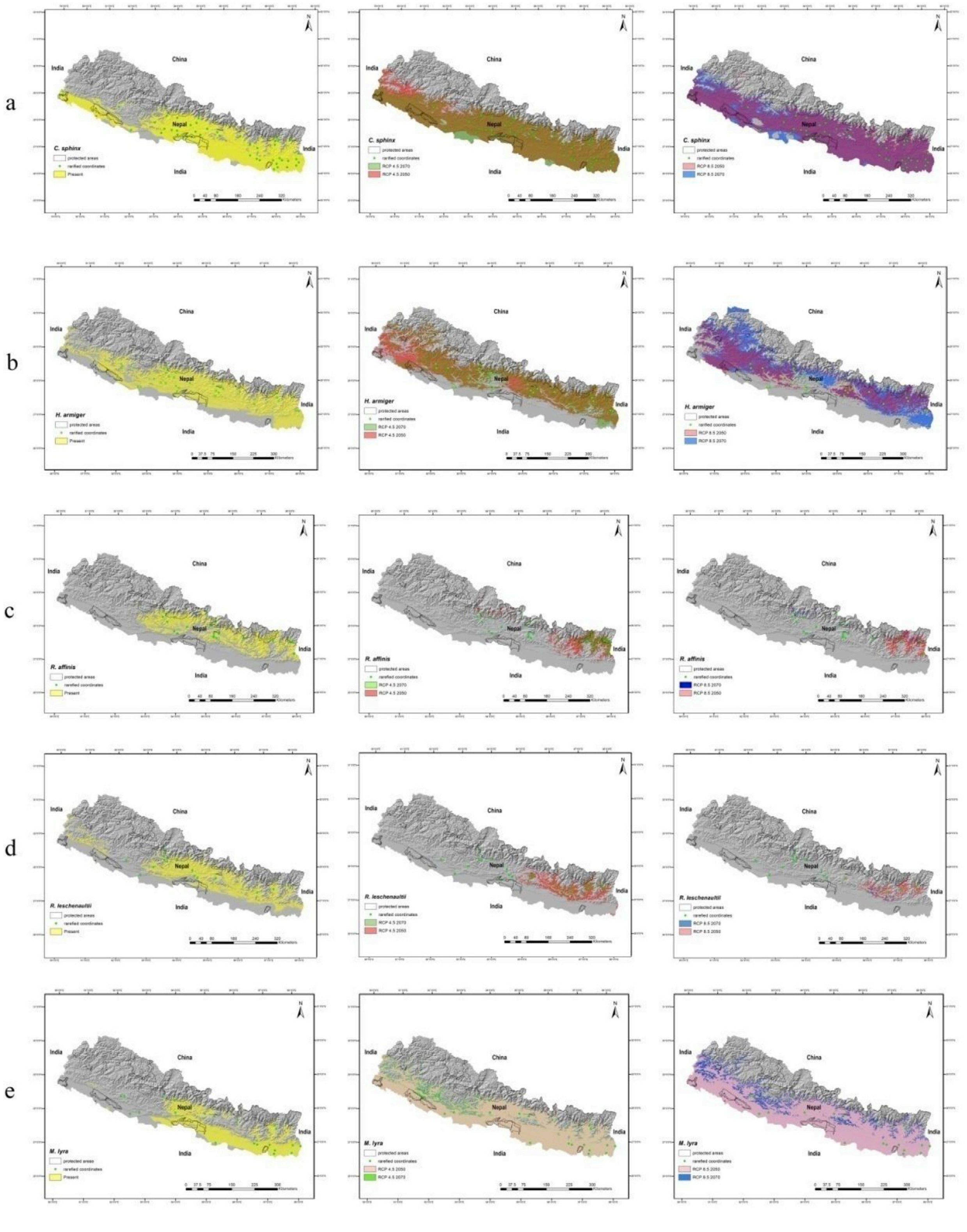

Fig. 1. Projected distributions for a) *C. sphinx*, b) *H. armiger*, c) *R. affinis*, d) *R. leschenaultii*, e) *M. lyra* in Nepal according to various climate change emission scenarios A1: Present, A2: RCP 4.5 and Year 2050 and 2070, A3: RCP 8.5 and Year 2050 and 2070, as predicted by MaxEnt Model.

Table 3
Estimated potential distribution range area change in percentages compared to total area of the country for five species.

species	Estimated potential distribution range area in %						
	present	proj_RCP 4.5		proj RCP 8.5		Avg. of all future scenarios	present-Avg. of all future scenarios
		2050	2070	2050	2070		
C. Sphinx	40.69	56.2	54.82	54.03	58.85	55.975	15.285
H. armiger	40.84	39.64	35.48	28.2	43.08	36.6	−4.24
R. affinis	18.42	5.69	2.53	3.68	0.24	3.035	−15.385
R. leschenaultii	21.55	6.74	2.39	2.95	0.33	3.1025	−18.4475
M. lyra	21.98	46.61	50.12	50.8	59.15	51.67	29.69

Table 4
Predictor and its contribution in SDM for bat species using Jack-knife procedure implemented in MaxEnt.

Variable	Species				
	C. sphinx	H. armiger	R. affinis	R. leschenaultii	M. lyra
bio1	43.6	0	0	26.3	67.3
bio12	31.3	55.7	30.1	37.6	20.5
bio3	11.9	26.4	4.3	25.2	6.2
bio17	7.9	5.5	7.7	2.8	0
bio14	1.9	0	0	2.6	0
bio2	0.8	0	0	1.3	0
bio15	2.7	0.2	17.6	4.2	0
bio6	0	10.6	0	0	0
bio4	0	1.4	12	0	6
bio11	0	0	28.2	0	0

bio11 and bio15 were important for single species so that bio6 was important for *H. armiger* and bio11 and bio15 were important for *R. affinis*.

The response curves for predictors (bioclimatic variables) for all five species are presented in Fig. 2. For *C. sphinx*, model prediction fits well with increase in annual mean temperature, annual precipitation, isothermality and precipitation in the driest quarter, and less well with increase in mean diurnal range, precipitation in the driest month and precipitation seasonality. For *H. armiger*, distribution prediction fits better with increase in annual precipitation and minimum temperature of the coldest month, but is less well fitted with increase in isothermality, precipitation in the driest quarter and temperature seasonality. For *R. affinis*, distribution predictions fit better with increase in annual precipitation and isothermality but fit less well with increase in mean temperature of the coldest quarter, precipitation seasonality, temperature seasonality and precipitation in the driest quarter. For *R. leschenaultii*, model prediction fits better with increase in annual precipitation, annual mean temperature, isothermality and mean diurnal range, but less well with increase in precipitation seasonality, precipitation in the driest quarter and precipitation in the driest month. For *M. lyra*, distribution model fits better with increase in annual mean temperature, annual precipitation and isothermality but less well with temperature seasonality which is not highly variable.

3.3. *Future climate projections*

We projected the MaxEnt models with future climate projections under two climatic scenarios RCPs 4.5 and 8.5 for the years 2050 and 2070, respectively. The projections from MaxEnt models showed all five species respond to climate change in different ways (Fig. 1; Tables 3 and 5). All bats are projected to expand its range slightly towards north and higher elevations and significantly in western region of the country. Two species, *M. lyra* and *C. sphinx* are likely to experience range expansion in most parts of the country. *Hipposideros armiger*, however, shows a slight range contraction but expands slightly in RCP 8.5 2070 compared to present scenario. The decline in range is likely to be significant in both the cave roosting bats, *R. leschenaultii* and *R. affinis*. The future potential distribution range for *M. lyra* and *C. sphinx* are projected to expand by an average of 30% and 15%, respectively while that for *R. leschenaultii*, *R. affinis* and *H. armiger* is projected to contract by an average of more than 18%, 15% and 4%, respectively (Fig. 1; Table 3).

In *C. sphinx*, the range will expand towards the northern latitude and higher elevation prominently in the western region. For *H. armiger* the southern and central range will contract slightly while the north western range will expand to reach the Trans-Himalayan range. For *M. lyra*, the distribution range will expand towards the west and the north. Dramatic reductions in distribution range will occur in the central part for *R. affinis* which will become confined to the eastern part. Similarly, the projected range compared to the present scenario will be isolated into two strictly narrow ranges. The range for *R. leschenaultii* will contract in the western and central part and become confined to a narrow range in the Middle Mountains of the eastern region (Fig. 1).

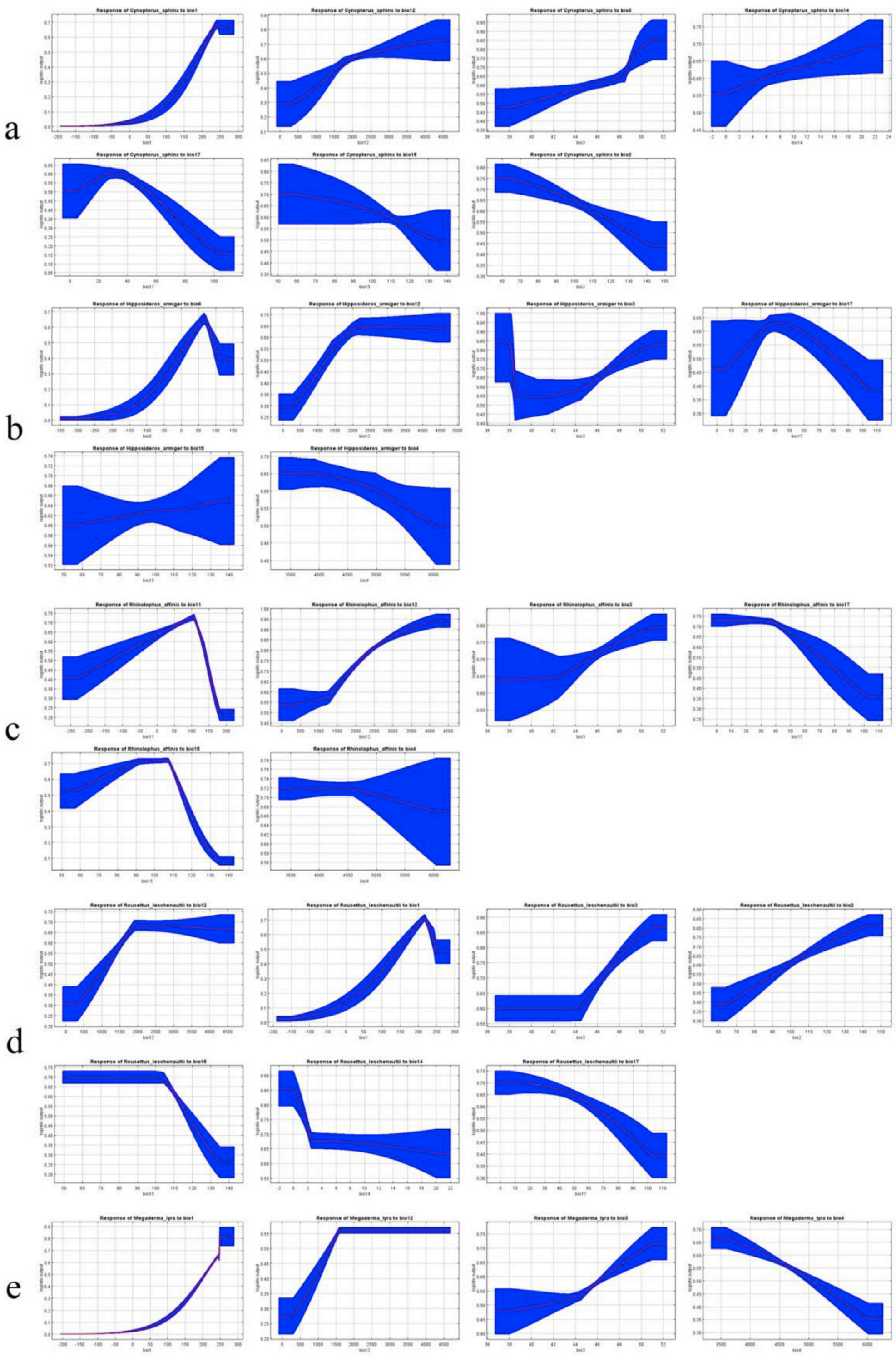

Fig. 2. Response curves of predictor variables for bats species a) *C. sphinx*, b) *H. armiger*, c) *R. affinis*, d) *R. leschenaultii*, e) *M. lyra*.

Table 5
Estimated distribution area in sq. km in different climate scenarios for five species.

Species	Estimated distribution Area in Sq. Km				
	present	proj_RCP 4.5		proj RCP 8.5	
		2050	2070	2050	2070
C. Sphinx	59897	82723	80691	79520	86618
H. armiger	60112	58342	52224	41511	63404
R. affinis	27105	8380	3726	5421	353
R. leschenaultii	31725	9925	3522	4350	486
M. lyra	32353	68607	73766	74772	87056

The distribution range of five species under future climate scenarios is likely to extend to higher elevations and contract in lower elevations compared to the present distribution range (Fig. 3). Under the RCP 8.5 2070 scenario, *H. armiger* is projected to extend surprisingly to higher elevation up to 6000 m asl. In the same scenario the range of *R. affinis*, however, will contract and it is most probably become restricted within a new range below and around 3000 m asl. In future climate scenarios there is high probability of loss in range below 1000 m asl for *R. leschenaultii*. Similarly, *M. lyra* also shows range expansion above 2000 m asl. The most preferred altitude for *C. sphinx*, *H. armiger* and *M. lyra* will decrease as a result of climate change. An upland shift of the most preferred altitude was shown to a slight extent in *R. leschenaultii*, but more extensively in *R. affinis* (Fig. 3).

4. Discussion

4.1. Present scenario potential distribution of five species and the influencing predictors

Altogether, 51 species of bats occur in Nepal (Table S1) belonging to seven families. However, due to their heterogeneity of the distribution records and a focus on general distribution pattern of bats, five species with wide distribution were selected in our modeling. Their occurrences and present scenario potential distribution area overlap with each other (Fig. 1). Amongst them, *C. sphinx* and *H. armiger* occupy the largest distribution in our SDM. The potential present scenario distribution range for *C. sphinx*, *H. armiger* and *R. leschenaultii*, extends to western region, from where there has been no record hitherto (Fig. 1). Meanwhile, the potential occurrence of *H. armiger* in eastern Tarai region also needs to be verified. The distribution area of *R. affinis* ranges from Middle Mountains, High Mountains to the High Himalayas in eastern and central Nepal (Fig. 1). The potential distribution range of *M. lyra* is concentrated in eastern and central Nepal, and excludes very few known occurrences from western region (Fig. 1), which needs to be verified in future surveys.

Collinearity among environmental variables deployed in SDMs is expected to increase model uncertainty (De Marco and Nóbrega, 2018). One of the common approaches to variable selection is reduction of number of collinear bioclimatic variables (Porfirio et al., 2014). Six non collinear variables were used herein, some of which have been verified as the determinate climatic variables in chiropteran distribution pattern and SDMs (Bradie and Leung, 2017; Debata et al., 2019).

Although selected species are widely distributed across different elevation gradients and in different types of habitats, annual precipitation (bio12) predominately contributes to the distribution of all the five species (Table 4). For *M. lyra* and *C. sphinx*, the variable with the greatest contribution is annual mean temperature (bio 1). For the remaining three species, bio12 has the greatest influence (Table 4). Isothermality is another common but less contributing predictor for all five species. Predictors other than annual precipitation and isothermality influence range contraction in *R. affinis* and *R. leschenaultii*.

Climate would determine the species distribution through its direct or indirect influence on local availability of food resources (Frick et al., 2010) and habitat. Changes in temperature and precipitation affect phenology (seasonal flowering and fruiting) of plants, which may affect the foraging behavior in fruit bats. Precipitation is also associated with delays in reproduction and later parturition in bats (Grindal et al., 1992). This consequently, affects the colony structure, productivity and juvenile survival (Richter and Cumming, 2008). Precipitation and temperature during spring affects the growth rate of *Rhinolophus ferrumequinum* in the UK (Froidevaux et al., 2017). These changes affect differently among bat species because of their ecological variations such as in foraging, habitat and reproduction (Ciechanowski et al., 2007). Several factors supplement the niche establishment for the species (Sherwin et al., 2012).

4.2. Response to future climate change

The responses of the five common bats in Nepal to global climate changes are inconsistent: *R. affinis* and *R. leschenaultii* reveal a dramatic contraction from their present distribution range, while *M. lyra* and *C. sphinx* shows a tendency to biogeographic expansion (Fig. 1).Such phenomena are common in chiropteran SDMs as revealed by Costa et al. (2018) and Hayes and Piaggio (2018), because climate change can benefit some species by making the area more inhabitable for those species, whereas others are affected detrimentally (Bellard et al., 2013).The area of the distribution range exponentially increases for two species and decreases sharply for the other two (Table 5). Our projections for five species consistently show a

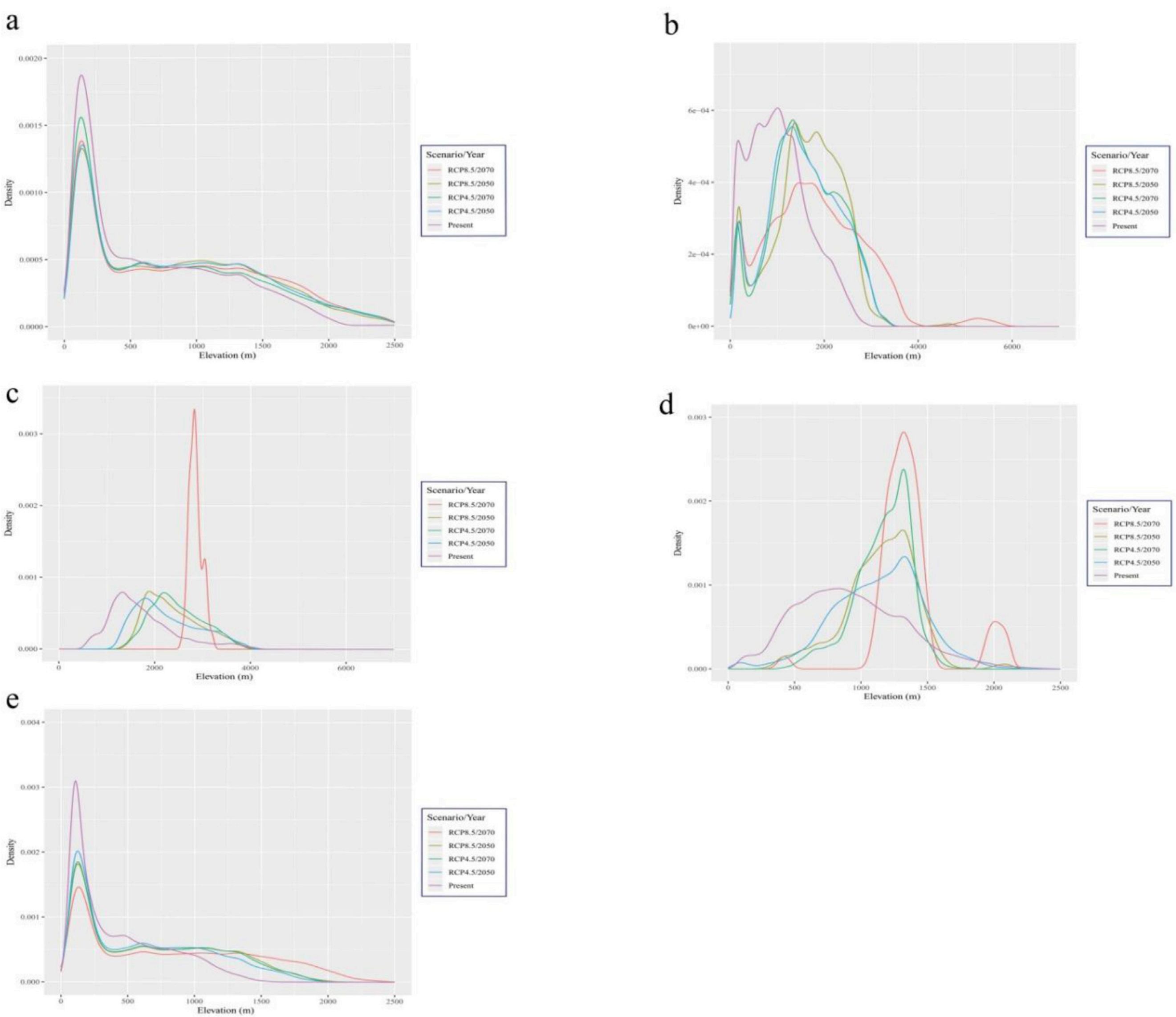

Fig. 3. Probability density function of bats species a) *C. sphinx*, b) *H. armiger*, c) *R. affinis*, d) *R. leschenaultii*, e) *M. lyra* presence predicted by Maxent across elevational gradient.

northward shift (around 30° N) and to higher elevations (Fig. 3), which have been observed in the bats in different parts of the northern hemisphere (Humphries et al., 2002; Parmesan and Yohe, 2003; Araújo et al., 2006; Hickling et al., 2006; Huntley et al., 2008; Lenoir et al., 2008; Rebelo et al., 2010) and in South East Asia (Hughes et al., 2011, 2012). However, the projection from the current study is different to the projections for South-east Asia, where most of bat species will be at risk under projections IPCC climate scenarios A2 and B1 (Hughes et al., 2012). The extreme gradient of elevations in Nepal seems to provide ecological corridors and/or refuges for montane bats.

The impact of climate change can be detrimental for bats (Park et al., 2000; Dunbar and Tomasi, 2006; Turbill, 2008; Jones et al., 2009; Rebelo et al., 2010). Two cave roosting bats (*R. affinis* and *R. leschenaultii*) in the current study reveal a significant decline in range while another, for *H. armiger* which will have a slight change in area (Table 5). The range will be fragmented and isolated to the eastern and the central High Mountains and High Himalayas in the former while the latter will be confined to a narrow range in the eastern Middle Mountains. The distribution range of frugivorous, tree and foliage roosting bats such as *C. sphinx* is projected to expand, whereas the projected future distribution range of *R. leschenaultii*, which is also frugivorous but cave roosting will dramatically contract (Fig. 1). This implies that there could be an impact on the ecological niche (specifically micro-climate and foraging habitat) of some species.

Moreover, shifts in range due to rapid climatic changes could further influence inter/intra specific genetic structure (Excoffier et al., 2009; Arenas et al., 2012) and local ecological function, thus the consequence is unpredictable. Such phenomena may be worse because of a lack of studies regarding the genetic background or assessment of the ecological role of bats in Nepal. It is urgent to conduct the related evaluations on those species that are affected by rapid climate change including relatedness among populations, population structure, and identification of conservation units because they may be genetically isolated or locally extinct. In addition even if a species such as *M. lyra* and *C. sphinx* in this study may benefit through expansion of their ranges, their entries into previously unoccupied areas will impact the previously occurring species, local community structure and ecosystem dynamics (Rebelo et al., 2010). More sensitive species will contract their range causing population decline and increasing the risk of extinction (Thomas et al., 2004). Simulation reveals populations of forest specialist bats that will experience drastic decline in future climate projections for 2086 in North America (Hayes and Adams, 2017). Species with small ranges are likely to be more vulnerable to environmental change since their overall range including refugia may collapse (Colles et al., 2009). It can be inferred that, the threatened and endemic species with scattered and confined distribution ranges such as *Myotis sicarius* may also be impacted by climate change.

The changing pattern of bats in Nepal under global climatic changes (Fig. 1; Tables 3 and 5) coincides with the predictions of future climate scenarios in Nepal (MoFE, 2019). Increase in average annual mean temperature and average annual precipitation in the western region of the country and along the northern region and higher elevations is likely to support the future climate distribution range at higher elevations and towards western region of the country specially for *C.sphinx*, *H. armiger* and *M. lyra*. Higher temperatures at lower elevations may be unfavourable for *R. affinis* and *R. leschenaultii* and, therefore, the distribution range is likely to contract (Figs. 1 and 3). In future climate scenarios the distribution range for *H. armiger* is projected to transcend to the Trans-Himalayan range. This indicates that the barrier effect of the Himalayas will be weakened, and potentially become a new refuge for species in the Anthropocene. On the other hand, the Himalayas still restrict gene flow in other species. This is similar to some species such as *Barbastella barbastellus*, which have transcended the Alps and Pyrenees mountains while spreading to the UK from a refugium located in today's Italy (Rebelo et al., 2010) while for some such as *Myotis myotis* the Alps and Pyrenees mountains still acts as barriers to gene flow (Ruedi et al., 2008).

4.3. Conservation implication

The species considered in this study are all assessed as Least Concern globally and nationally (Jnawali et al., 2011). Two species; *R. affinis* and *R. leschenaultii* are projected to contract their distribution range under future climate scenarios (Fig. 1). The threatened and endemic species with scattered and confined distribution ranges and habitat specialist species may largely be impacted by climate change. Both current and future predictions reveal the potential occurrences within unexplored area, and further indicate the urgency of bats protection and targeted investigation. Hitherto, bat surveys have not been initiated in the western region of the country or in protected areas, with the exception of a few surveys in Chitwan National Park (P. Myers et al., 2000); Annapurna Conservation Area (Csorba et al., 1999); Shivapuri Nagarjun National Park (Bates and Harrison, 1997; Pearch, 2011; Thapa et al., 2012a), and rarely in Koshi Tappu Wildlife Reserve (Thapa et al., 2012b). A landscape conservation approach is imperative to ensure long term conservation of bats as higher bat assemblages have been recorded outside the Protected Area (PA) systems. Although global and local conservation approaches aim to protect and conserve larger proportion of the biodiversity (Eken et al., 2004), bats are yet to be included as a national priority. Despite their important role in ecosystem regulation through pollination, seed dispersal and pest control (Fujita and Turtle, 1991; Jones et al., 2009; Kunz et al., 2011), bats are neglected in the current discourses of conservation at protected areas, ecosystems and landscape levels in Nepal.

In response to global warming, 3700 endemic vertebrate species may be lost from the Indo-Burmese region, unless the species are able to migrate annually (Malcolm et al., 2006). In South East Asia for 2050 IPCC climate scenario B1 when vegetation cover change is also considered, 17% of the species' original range is projected to increase over 100%, however, the lack of landscape connectivity may not support this expansion (Hughes et al., 2012). The paradigm shift in conservation strategy approach from species to ecosystem and more recently to landscape level conservation approaches is expected to support bat conservation. Conservation landscapes such as the Sacred Himalayan, Chitwan-Annapurna, Tarai Arc, Kailash and

Kanchenjunga has been initiated and established (MoFSC, 2016). However, this approach has yet to prioritize bats as most colonies lie outside protected areas (Figs. S5–8). More than 82% of total forests lie outside the protected areas (DFRS, 2015). Community forests occupy 38.5% of total forests (Pathak et al., 2017) and about 15% of the total land. The Community Forestry Program in Nepal so far has supported biodiversity conservation (Luintel et al., 2018) but its management is primarily focused on timber and non-timber Forest Products (NTFPs). Despite the ecological role and ecosystem services of bats, these have not been prioritized in forest management. However, most of these landscapes except the Chitwan-Annapurna are established as a connection link between East-West corridors and with limited North-South linkage (Fig. S4). The study made it apparent that North-South linkage is more important to conserve bats. Bat conservation should be prioritized in forest management including community forestry.

4.4. Limitation to our modelling and way forward

The current modelling selected five different species representing different families and feeding habit (Table 1). However, all the species selected are widely distributed common species in the country. Occurrences of all five selected species for this study overlap (Figs. S5 and S6), range extension in some species might not have resulted in contraction in others. Rather, other habitat specialist and other species with narrow and restricted ranges may be affected (Safi and Kerth, 2004).

It is not clear about the response of habitat specialist species and other species with limited distribution range, and more species should be included in future surveys. The other limitation in our study is using only climatic variables. It is well-known that vegetation, land use, land cover and human disturbance will alter distributions of bats (Hughes et al., 2012; Oliver and Morecroft, 2014; Heer et al., 2015; de Oliveira et al., 2017; Alpízar et al., 2019). Future modeling should incorporate future land use scenarios datasets (Verburg et al., 2004; Van Asselen and Verburg, 2013; Smith et al., 2016). We suggest this research would be a reference for future conservation strategy instead of conclusive work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2021.e01483.

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