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Research article

Impact of climate change on distribution of common leopard (*Panthera pardus*) and its implication on conservation and conflict in Nepal

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ABSTRACT

Climate change is projected to create alterations in species distributions over the planet. The common leopard (*Panthera pardus*) serves an important ecological function as a member of the big carnivore guild, but little is known about how climate change may affect their distribution. In this study, we use MaxEnt to simulate the geographic distributions by illustrating potential present and future ranges of common leopard by utilizing presence records alongside important topographic and bioclimatic variables based on two shared socioeconomic pathways (SSP2-4.5 and SSP5-8.5) scenarios. The goals of this study was to look into possible distribution ranges of common leopards due to climate change, as well as explore the implications for conservation and potential conflict with humans. At present, 4% of Nepal was found to be highly suitable for common leopards, 43% suitable, 19% marginally suitable, and 34% unsuitable. A large portion of the climatically suitable habitat was confined to non-protected areas, and the majority of the highly suitable habitat was encompassed by forest land, followed by agricultural areas. Elevation, mean temperature of driest quarter, annual precipitation, and precipitation seasonality were the variables influencing habitat suitability for the common leopard. A significant increase in marginally suitable habitat was observed in the high mountain region, indicating a shift of habitat in upper elevation areas due to the effects of climate change. We recommend timely management of these potential habitats to expand the range of this vulnerable species. At the same time, a combination of expanding new habitats and poor management practices could escalate human-leopard conflict. Therefore, further study on the impact of climate change on the distribution of prey species and proper habitat management techniques should be prioritized to mitigate conflicts.

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1. Introduction

One of the largest issues conservationists face today is the degradation of the integrity of the ecosystem due to loss of biodiversity [1–4]. This problem has been exacerbated by the effects of climate change [2,5]. Climate change is projected to alter species distributions over the planet, putting their survival at risk owing to reduced ranges [6,7]. Such changes in species distributions, as well as range reduction or fragmentation, can lead to population reductions, putting endemic and habitat-specific species at risk [5,8–11].

Climate change will have dire effects on biodiversity [12], with extinction rates likely to skyrocket [5,13]. Climate change's cascading effects will have negative consequences for ecosystems, affecting a wide range of trophic levels and species interactions [14-16]. Habitat shift is one of the most well-documented reactions of species to climate change [5,17,18] Because many species disperse at a slower rate than climate change and environmental factors limit their range-shift capacity, it is difficult for specialist species to adapt to changing conditions in a timely manner [16,19,20], and they may be driven to extinction [21-23]. Large animals with a restricted range of climate adaptations are particularly sensitive to these changes [24,25].

Studying correlations between climatic conditions and the current ranges of species can help predict the future distribution of these species [24,26]. With the help of the Intergovernmental Panel on Climate Change (IPCC), the climate modeling community created the Shared Socioeconomic Pathways (SSPs). A group of scenarios (SSP1-2.6, SSP2-4.5, SSP4-6.0, and SSP5-8.5) were developed to show a range of different climate change outcomes by the end of the century. Shared socioeconomic paths (SSPs) are narratives that outline many socioeconomic possibilities related to the population, urbanization, and GDP of a country (per capita). SSPs, which provide predictions of expected global socioeconomic patterns until the year 2100, are frequently used to develop scenarios for greenhouse gas emissions (GHG) under different climate policies [27,28]. Temperature, rainfall, and humidity are all dynamic bioclimatic factors that are linked to species distribution and play an essential role in determining appropriate habitats [29,30].

To understand and minimize the effects of climate change on biodiversity, several methods for detecting risks and ranges of species distribution have been developed [2,3]. Species distribution models, including maximum entropy modeling (Maxent) (SDMs), have been widely used to estimate, forecast, and simulate the geographic distributions of species through time [30]; Peterson et al., 2007; [29,31,32]. Maxent is frequently used to illustrate present and future distributions of a specific species by utilizing presence records and a collection of important environmental factors based on climatic scenarios [30,33,34]. Maxent is particularly well suited to modeling presence-only data; it accurately predicts the distribution and even has better performance than other SDM algorithms [31, 35].

Big carnivores perform an important ecological function and their extinction can trigger trophic cascades, resulting in a rise in herbivore populations and habitat deterioration or alteration [36,37]. The common leopard, as an apex predator of the mid-hill ecosystem of Nepal, performs a similar function [38-41]. Despite their importance, little is known about how climate change may affect their distribution. Research on the impacts of climate change on predators such as common leopards and their suitable habitat under climate change scenarios in the Himalayan area is crucial for future conservation [42] as well as predicting their interaction and conflict with humans [39,43]. Assessment of current suitable habitat according to the land use categories could also provide important insights regarding range of species distribution and its potential association with conflict [44]. Such information is important for

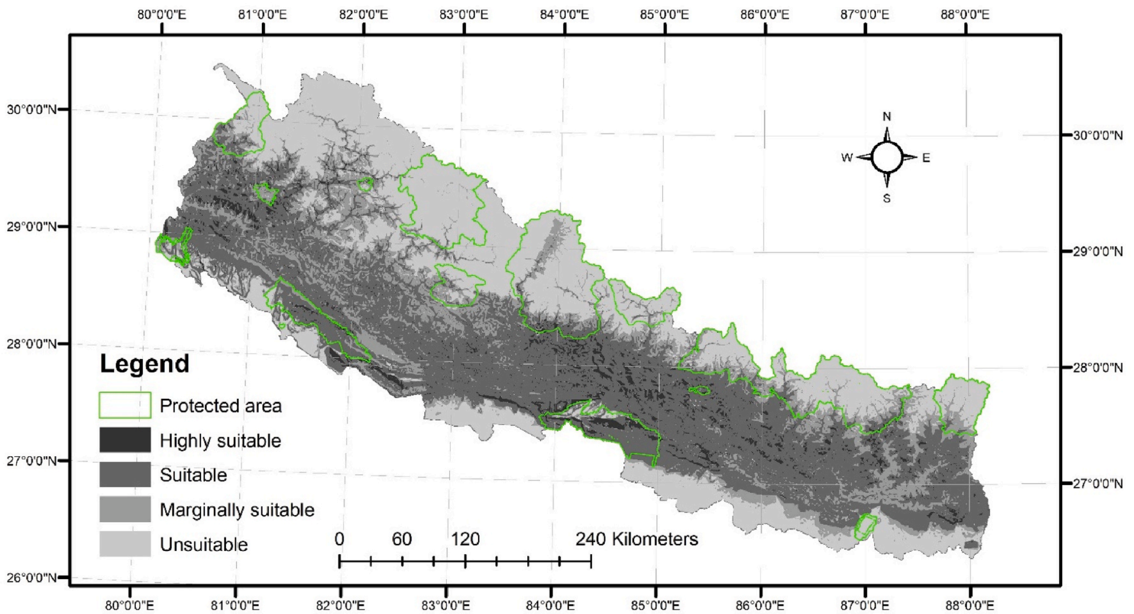

Fig. 1. Present distribution of common leopard in Nepal, with green boundary representing protected areas and the darker color representing the highly suitable areas and the lighter color represents low suitable areas.

formulating and implementing sound conservation strategies, taking into account human as well as wildlife well-being [45]. The goals of this study were to learn about the current distribution ranges of common leopard from a climatic standpoint and to find out its implications for conservation of common leopard and its interaction and conflict with humans. The study also aimed to analyze the key climatic variables that regulate or restrict its dispersion. Under the assumption that climate change modifies common leopard habitats in Nepal, the current work seeks to generate a distributional maps of common leopard habitats and estimate the expected habitat shift in future climate change scenarios.

2. Materials and methods

2.1. Study area

This study was conducted in Nepal and used location data of common leopards collected throughout the country. Nepal lies in the central Himalaya region (28.3949° N, 84.1240° E) (Fig. 1). Despite the small land area (147,181 km^2), Nepal has high altitudinal variations ranging from 70 m to 8848.8 m from mean sea level (Mt. Everest) [46]. The country is classified into five disparate physiographic zones, namely the High Himalayas (above 5000 m s l.), High Mountains (3000–5000 m m.s.l), Middle Mountains (1000–3000 m m.s.l), Siwaliks (500–1000 m m.s.l)and Terai (below 500 m m.s.l) [46] (Table 1). With a rich biological diversity, due to the heterogonous physiography, a total of 118 ecosystems have been reported in Nepal, including 112 forest ecosystems (Majupuria and Majupuria, 2006; [46-49]. There are 12 national parks, one wildlife reserve, one hunting reserve and six conservation areas covering 23.23% of the total land area of the country. The total population of the country is 26.5 million, out of which 64% of people primarily depend on agriculture and animal husbandry to sustain their livelihood [50].

The climate also varies from the alpine cold semi-desert type in the *trans*-Himalayan zone to the tropical humid type in the Terai lowlands [51]; Labh & Shakya, 2016). Six distinct climate zones, from tropical in the southern lowlands to tundra/nival in the far north with year125 round snowfall, best describe the climate of Nepal. The subtropical climate with a wet season in the southern flat strip, the temperate temperature in the low mountains, and lastly, the frigid mountain climate in the summits of the Himalayas, all have varied climates according to elevation. Rainfall is plentiful throughout the summer monsoon season (June to early October). Both the maximum and lowest temperatures in Nepal were found to be rising by 0.03 °C per year and 0.05 °C per year, respectively. While the trajectory of precipitation in Nepal is not as obvious as that of temperature, most research has determined that monsoon precipitation will increase in the years to come.

2.2. Data collection

The location data of common leopard presence was collected throughout Nepal between 2018 and 2020. We visited the division forest offices of each district and protected area offices to collect the records of common leopard sightings in the area. We verified the location of leopard sightings by consultation with local people and recorded the signs of common leopard presence, which included scat, pugmark, scrape, and kill sites. A total of 343 locations of leopard presence were recorded throughout the study area within the timeframe.

We downloaded 19 bioclimatic variables (Table 2) of current and future climate conditions (2050 and 2070) from Worldclim (https://www.worldclim.org/) [52] at a spatial resolution of 30 arc seconds (1 km × 1 km). To model response of leopard to future climatic scenarios, we used bioclimatic variables from Models for Interdisciplinary Research on Climate (MIROC), specifically MIROC6, as it is the most recent upgrade to MIROC5 [53], and even has greater overall reproducibility of mean climate and internal variability compared to the previous version [54]. Though there are uncertainties in prediction of global climate change models [55, 56], the MIROC5 global circulation model (GCM) has consistently predicted rainfall for the Indian subcontinent [57] and has simulated extreme and summer precipitation better than other GCMs for the South Asian region [58]. Moreover, the temperature distribution and variations in the Indian subcontinent area can also be captured using MIROC5 [59]. For this reason we acquired MIROC6 based bioclimatic variables for two scenarios (SSP2-4.5 and SSP5-8.5) for the years 2050 and 2070 for the analysis. SSP2-4.5 denotes an intermediate level of greenhouse gas emissions, in which CO2 emissions will decline after 2050 but not reach net zero by 2100. SSP5-8.5, on the other hand, has extremely high GHG emissions and triples CO2 emissions by 2075. Because SSP2-4.5 is considered to

Table 1
The description of the five physiographic regions in Nepal.

Physiographic regions	Characters
Terai	14% of the country area, (60–200) m.a.s.l, covers, sub-tropical climate, reasonably hotter summer and mild winter, Most of the rainfalls are concentrated in monsoon season.
Siwalik	13% of the country area, (up to 1800) m.a.s.l. Subtropical climate.
Middle mountain	29% of the country area. (1000–2500) m.a.s.l. Sub-tropical climate at the bottom of the hills but gradually cooler, experiences warm temperate climate toward higher elevation with some higher elevation experiencing occasional snowfall during winter season.
High Mountain	20% of the country area, 2000–4000 m.a.s.l. cold temperate climate, some higher elevation often remains below freezing point for 5 months in a year.
High Himalayas	24% of country areas, above 4000 m.a.s.l. and reaches to the highest point in the earth at 8848 m.a.s.l. alpine to tundra climate, most of the parts are under permafrost, snow or glaciers throughout the year.

Table 2
Bioclimatic variables used for modeling habitat of common leopard.

Variables Name	Code
Annual Mean Temperature	BIO 1
Mean Diurnal Range [Mean of monthly (Max Temperature - Min Temperature)]	BIO 2
Isothermality (BIO 2/BIO 7) (*100)	BIO 3
Temperature Seasonality (Standard Deviation × 100)	BIO 4
Max Temperature of Warmest Month	BIO 5
Min Temperature of Coldest Month	BIO 6
Temperature Annual Range (BIO 5-BIO 6)	BIO 7
Mean Temperature of Wettest Quarter	BIO 8
Mean Temperature of Driest Quarter	BIO 9
Mean Temperature of Warmest Quarter	BIO 10
Mean Temperature of Coldest Quarter	BIO 11
Annual Precipitation	BIO 12
Precipitation of Wettest Month	BIO 13
Precipitation of Driest Month	BIO 14
Precipitation Seasonality (Coefficient of Variation)	BIO15
Precipitation of Wettest Quarter	BIO 16
Precipitation of Driest Quarter	BIO 17
Precipitation of Warmest Quarter	BIO 18
Precipitation of Coldest Quarter	BIO 19

Table 3
Average threshold and accuracy (AUC and TSS) of the model.

S·N	Accuracy	Average	Std
1	Threshold	0.424	0.039
2	TSS	0.646	0.044
3	AUC	0.782	0.010

be a moderate and very plausible scenario [60], and SSP5-8.5 is the most extreme scenario but also the best match to the cumulative emissions from 2005 to 2020, we utilized these two specific scenarios [61]. Slope, aspect, and elevation were calculated using a 30 m resolution digital elevation model (DEM) acquired from the USGS website (https://www.usgs.gov/). We used all 19 bioclimatic variables and three topographic variables for the study. All the variables were downloaded at 1 km × 1 km to match the spatial resolution.

2.3. Modeling the distribution of leopard

To reduce spatial autocorrelation and type I error, the geo-referenced location data were spatially filtered, and any location with a distance of less than 1 km to the closest location was removed. Out of 343 occurrence records of the common leopard, 206 presence points were retained after filtering. In order to reduce the multicollinearity among the variables, a variance inflation factor (VIF) test was conducted in R software [62] by systematically excluding the variables with VIF>5. Among the ten environmental variables, i.e. isothermality, aspect, precipitation of driest month, mean diurnal range, precipitation of coldest quarter, slope, precipitation seasonality, annual precipitation, mean temperature of driest quarter, and elevation, were retained to be used for further analysis in Maxent after accounting for correlation among variables.

For this study, Maxent SDM was used for modeling the distribution of leopards. The optimal MaxEnt model was chosen by using maximum training sensitivity plus specificity threshold and the 10-fold cross-validation approach to build binary maps. A total of 48 alternative models were examined for this, with multiple combinations of six feature classes (H, L, LQ, LQH, LQHP, and LQHPT, where L = Linear, Q = Quadratic, H = Hinge, P = Product, T = Threshold) and eight regularization multiplier (RM) values (0.5–4, 0.5). The maximum number of iterations was set to 1000, and 70% of the presence points were used to train the model, with the remaining data used to test it [63].

The jackknife test was used to evaluate the dominant environmental variables and their permutation importance for the generation of a model [64]. Also, the response curves were created to scrutinize the association between environmental variables and habitat suitability. Assessment of accuracy was conducted by both threshold-independent and threshold184 dependent methods. In the threshold independent method, the AUC-ROC value was used, which ranges from 0 to 1. AUC 0.7 indicates poor model performance, 0.7–0.9 indicates average model performance, and 0.9 indicates excellent model performance [65]. For the threshold dependent model, true skill statistics (TSS) were evaluated, which utilize the maximum sum of sensitivity and specificity. The TSS = Sensitivity + Specificity −1, which has a range from 0 to 1, in which 1 indicates perfect fit and 0 represents random performance. Using the R software [62], the final TSS was obtained by averaging the TSS of models generated from 10 replications.

We classified the continuous probability map obtained from the Maxent model into four habitat class categories; unsuitable (0–0.2), marginally suitable (0.2–0.5), suitable (0.5–0.7) and highly suitable (0.7–1) [66,67] to better understand the climatic distribution of the species. A digital polygon data of national parks and protected areas of Nepal (created using Topographic Zonal Map of 250,000 scale; published by Department of Survey Nepal), a digital polygon of physiographic region of Nepal, and annual land cover data of Nepal created through the National Land Cover Monitoring System (NLCMS) for Nepal were obtained from ICIMOD website (https://www.icimod.org/). To generate information on the distribution of common leopards according to the current land use, physiographic zones, and protected areas, the corresponding shape files were overlaid and intersected with suitable area categories.

3. Results

3.1. Present distribution of common leopard

At present, from a climatic perspective, out of the total area of Nepal, 4% of land was found to be highly suitable for common leopard, whereas 43% resulted as suitable, 19% as marginally suitable and 34% was deemed unsuitable (Fig. 1). The majority of the area in the high Himalayas (93% of this region) was deemed unsuitable for the common leopard. The largest proportion (45%) of the High Mountain region was classified as marginally suitable. 79% of total land within the middle mountains and 75% of total land of the Siwalik region was suitable for the common leopard, whereas the Terai constituted mostly unsuitable habitat (69%).

Out of four habitat classes, 13% of highly suitable habitat, 10% of suitable habitat, and 21% of marginally suitable habitat were inside protected areas (PAs), and a large portion of the climatically suitable habitat were in non-protected areas (Fig. 2). Forest land covered the majority of the highly suitable habitat (58%), followed by agriculture land (35%). Similarly, suitable habitat consists of 60% forest land and 34% agriculture area. The majority of marginally suitable habitats was forest (59%) followed by agriculture (24%) and grassland (8%), while the majority of unsuitable habitats constituted snow and glacier (24%), grassland (22%), and barren land (21%) (see Fig. 3).

3.2. Importance of variables and response curves of important variable

Out of 10 variables used in the model, the jackknife test (Fig. 4) of regularized training gain indicated that elevation, mean temperature of driest quarter, annual precipitation, and precipitation seasonality were the variables affecting habitat suitability for leopards. Response curves (Fig. 5) indicate that common leopards prefer elevations around 1000 m. There is a gradual decrease in the probability of occurrence with lower or higher elevations. It also indicated that common leopards prefer the mean temperature of the driest quarter range from 10 to 15° Celsius. Annual precipitation above 3500 mm and a precipitation seasonality value of 70 (which indicates a low coefficient of variation in precipitation) was found to be the most suitable for common leopard.

3.3. Future distribution of common leopard in Nepal

At both SSP2-4.5 and SSP5-8.5 scenarios, suitable and highly suitable habitat were relatively more stable than marginally suitable and unsuitable habitat (Figs. 6 and 7). The unsuitable habitat decreased by 7% in the SSP2-4.5 scenario, while the marginally suitable habitat increased by 10% by 2070. Similarly, in the SSP5-8.5 scenario, unsuitable habitat decreased by 6%, whereas marginally suitable habitat increased by 9% by the year 2070. In both scenarios, there are fairly similar trends of change in the highly suitable and suitable habitat categories across all physiographic zones (Fig. 8).

3.4. Accuracy assessment of the model

The average accuracy of the replications using AUC-ROC was 0.782 ± 0.01. The average threshold used to maximize the sum of sensitivity and specificity was 0.424 ± 0.03 and the average TSS generated from the replications was 0.646 ± 0.04 (Table 3).

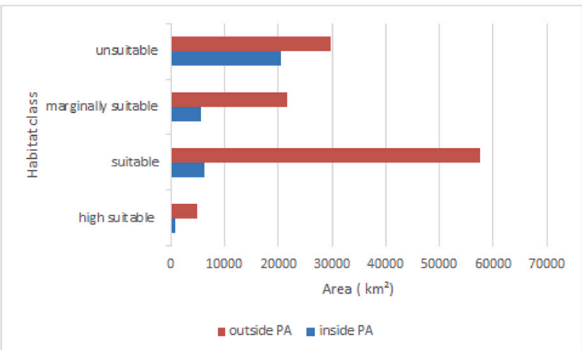

Fig. 2. Two categories of protected areas and non-protected areas in Nepal (X axis) and four habitat class (Y axis) for common leopard. Most of the suitable habitat encompassed in non-protected regions (outside PA).

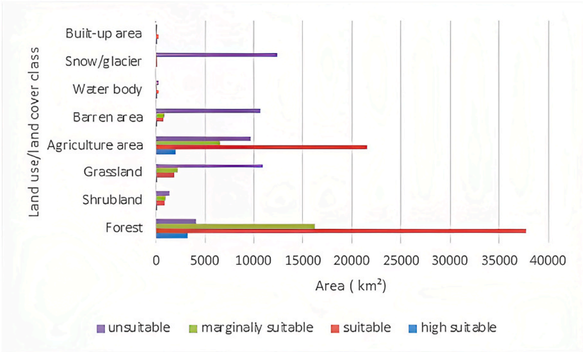

Fig. 3. Eight categories of land use (Y axis) and corresponding distribution of suitable habitat among four habitat class (X axis).

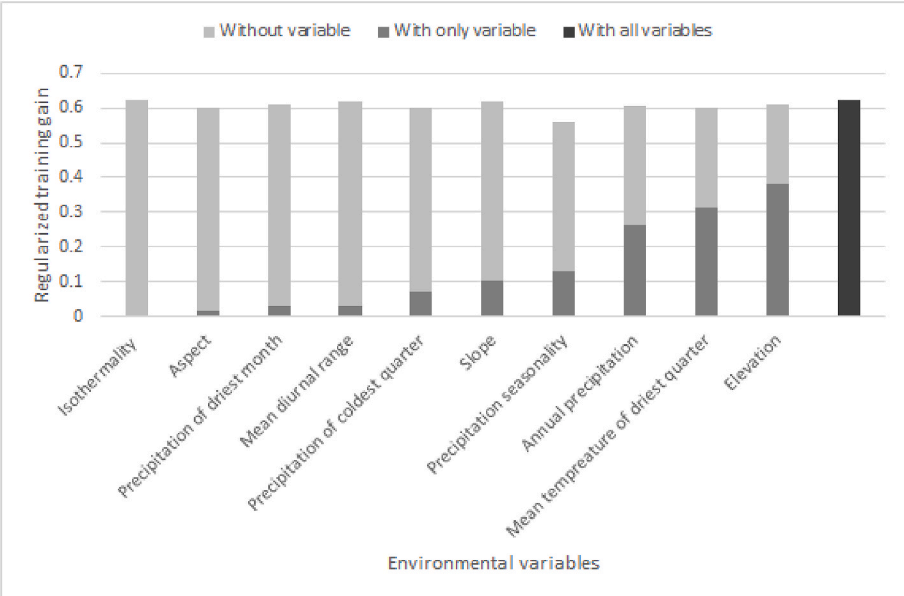

Fig. 4. Jackknife regularized training gain for assessing the importance of variables for predicting the distribution of common leopard. The X axis includes 10 variables and the Y axis depicts the value of regularized training gain. The shades represent values of training gain without variable, with only variable and with all variables.

4. Discussion

Our study explored an important component of common leopard conservation, the effect of climate on habitat suitability, and assessed the potential changes in habitat due to changing climate. We mapped the current suitable habitat of the common leopard and categorized them into four habitat classes. We revealed a drastic increase in marginally suitable habitat and a decrease in unsuitable habitat, indicating the potential expansion of common leopard habitat in the Himalayan region in coming years.

Our study shows that a large proportion of suitable and highly suitable habitats for the common leopard are incorporated within outside protected areas (PAs) in Nepal. The expansion of the forest area and wildlife habitat outside PA could be attributed to the success of the community (CF) forest program, an effective forest management strategy to restore ecosystem services such as biodiversity and carbon sequestration [68]). The CF program in the last 3 decades has increased forest cover and thereby expanded wildlife habitats [68]. On the other hand, the mid-hill physiography of Nepal is underrepresented in the PA system [69], as most of the PA areas are located in the high Himalayan region or the flatlands of the Terai region. Nepal's Landsat satellite images reveal that the forest cover increased from 36% in 2000 to 45% in 2015 [70]. Due to the continuous increase in the forest land in the mid-hills region, the habitat of leopards outside PAs, the leopard population is predicted to increase, resulting in the high chances of encounter of people with leopards [71]. A large proportion (67%) of the human-wildlife conflicts in the last five years happened outside PAs [72].

Our data showed that at present context, the agricultural land is the second most suitable habitat for leopards, followed by the forest areas. This may be due to the increase in agricultural land abandonment in Nepal [73]. Abandonment of agricultural practices is due to emigration of people from the villages in mountain areas to cities and flatlands for jobs and other better lifestyle opportunities

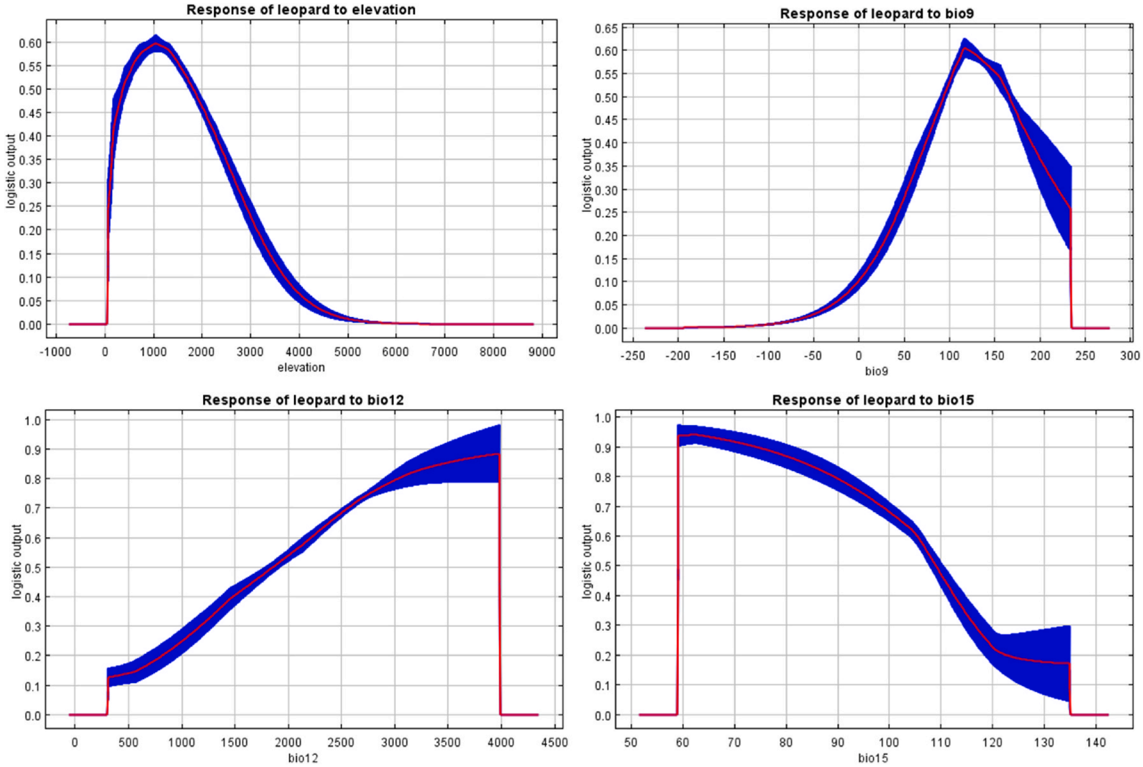

Fig. 5. The response curve of four most important variables governing habitat suitability of common leopard. Bio 9 indicates mean temperature of driest quarter (suitability peaks at around 10–15 °C), bio 12 indicates annual precipitation (suitability peaks at higher precipitation >3500 mm), and bio 15 represents precipitation seasonality (suitability peaks around the value < 70).

[71,74–76]. Forest succession in such abandoned agricultural lands has extended the habitat of wildlife. Human leopard conflicts in human-dominated landscapes may increase as the common leopard habitat expands into agricultural land [77].

A high proportion of the high Himalayas is unsuitable for common leopards, whereas a large proportion of the high mountain regions is marginally suitable for common leopard habitat. The majority of suitable and highly suitable habitats for the common leopard are included in the middle mountain and Siwalik regions. As the tiger (*Panthera tigris*) is the apex predator in the flatland Terai ecosystem [78] and the snow leopard (*Panthera uncia*) is the apex predator in the high Himalayan region [79], common leopards generally occupy mid-hill forest ecosystem [80]. Moreover, leopards' preferred prey are medium-sized ungulates such as barking deer (*Muntiacus muntjak*) and wild boar (*Sus scrofa*) [81] and the mid-hills region, with dense sub-tropical forest, is one of the most favorable habitats for barking deer [82], thereby facilitating the niche partition between apex predators.

In the context of Nepal, winter is the driest quarter with the least amount of precipitation [83,84]. The majority of parts of the mid hills of Nepal experience a mean temperature of 10–15° Celsius in the winter season. The response curves generated in our study also indicated that habitat suitability peaked at 10–15° Celsius. Our study indicated high habitat suitability for leopards in areas where average annual rainfall is more than 3500 mm. Areas with low precipitation seasonality; coefficient of variation in precipitation (less than 70) were discovered to be more favorable for common leopard distribution. As a result, the higher annual precipitation value and low variation in precipitation provide suitable habitat for the common leopard. The districts of Tanahun, Kaski, Syanjga, Kathmandu, Argakahchi, Parbat, Ilam, and Dhankuta, with an annual average rainfall of 3500–4425 mm (DHM, 2018), represent good leopard habitat in the midhills of Nepal. These areas have a high level of human-leopard conflicts [72], indicating high leopard density.

Since the common leopard is a generalist species, occupying a wide range of habitats [85], shift in habitats due to climate change could affect them less compared to other habitat specialist species. Nevertheless, a steady increase in the highly suitable habitat of the leopard in the middle mountain range within both climatic scenarios (SSP2-4.5 and SSP5-8.5) could signify the enlargement of suitable habitats in this range, mainly due to the conversion of unfavorable conditions towards favorable conditions (mean temperature of driest quarter, annual precipitation, and precipitation seasonality) in future. Similarly, according to our findings, the marginally suitable and unsuitable habitats are expected to experience a significant fluctuation under the current rate of climate change. Previous studies also have suggested that the high Himalayan and high mountain ranges will experience the most adverse effects of climate change [86-89]. Our study also suggests change in habitat suitability of common leopards in the high Himalayan region, resulting an expansion of common leopard's habitat. Moreover, the downward shift of snow leopard habitat due to climate change [42] and the upward shift of common leopard habitat might as well as create competition between these two species for prey and space, thereby disrupting ecological cascade and increasing conflicts with human.

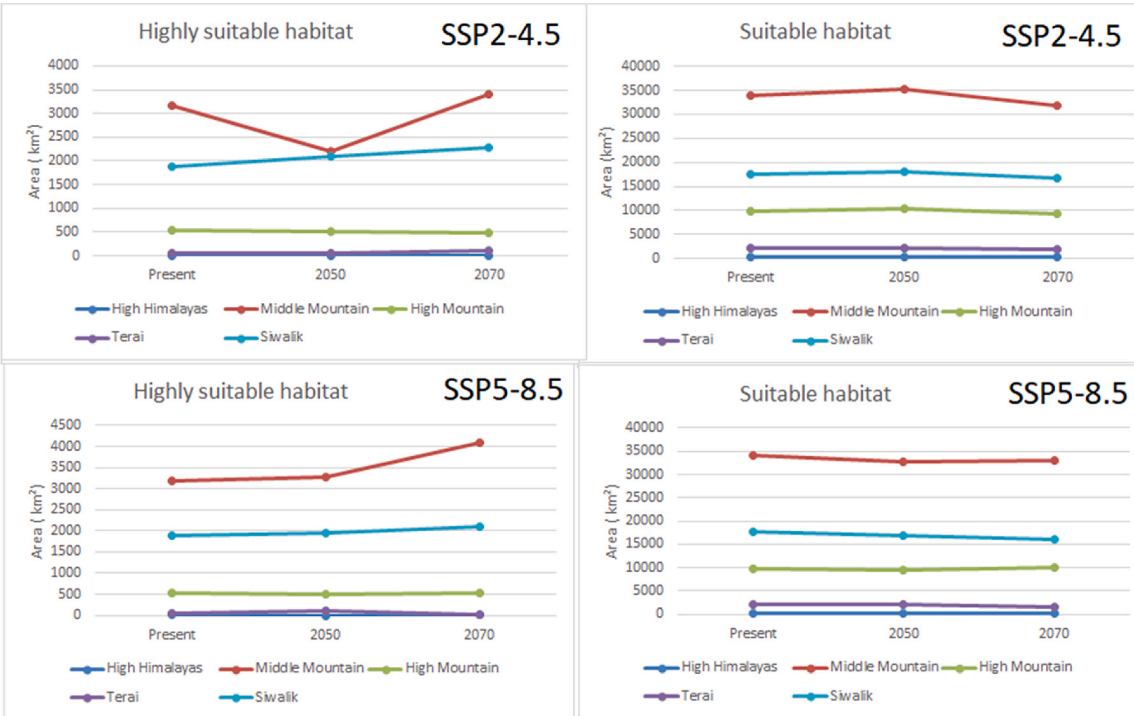

Fig. 6. Areas corresponding to two categories (Highly suitable and Suitable) habitat for common leopard in under present condition and two climate change scenarios (SSP2-4.5 and SSP5-8.5) for the year 2050 and 2070. The x axis represents area, y axis represents the year and the lines represent the corresponding physiographic zones (high Himalayas, High Mountain, Middle Mountain, Siwalik and Terai).

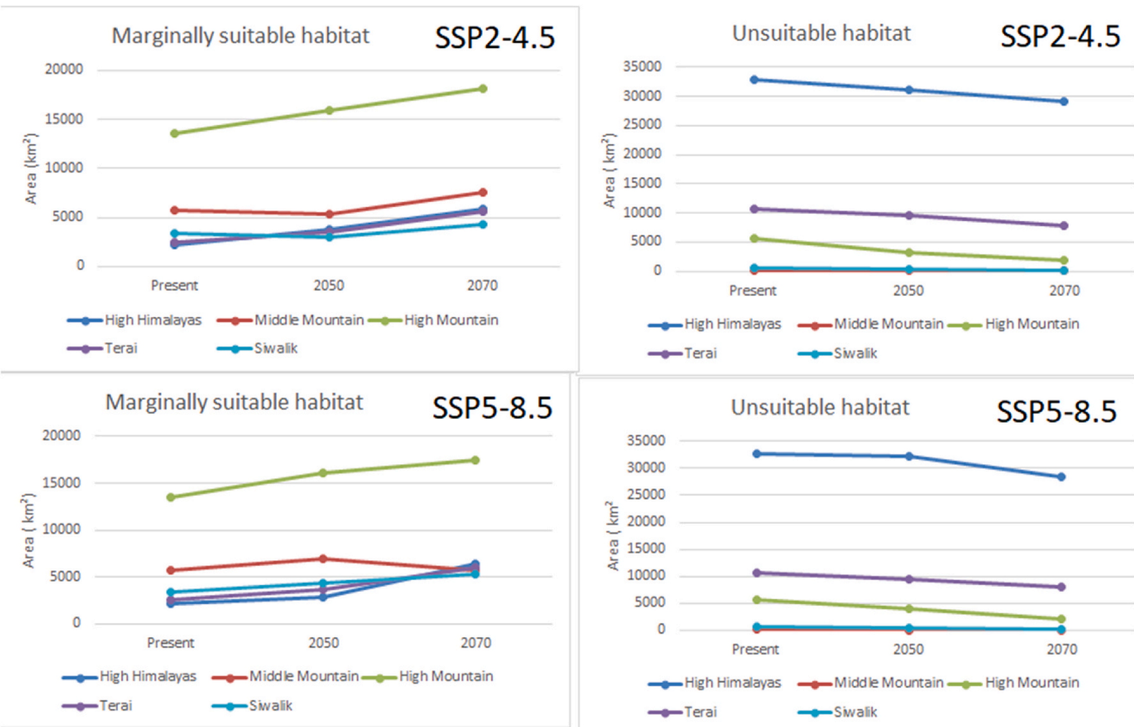

Fig. 7. Areas corresponding to two categories (Marginally suitable and Unsuitable) habitat for common leopard in under present condition and two climate change scenarios (SSP2-4.5 and SSP5-8.5) for the year 2050 and 2070. The x axis represents area, y axis represents the year and the lines represent the corresponding physiographic zones (high Himalayas, High Mountain, Middle Mountain, Siwalik and Terai).

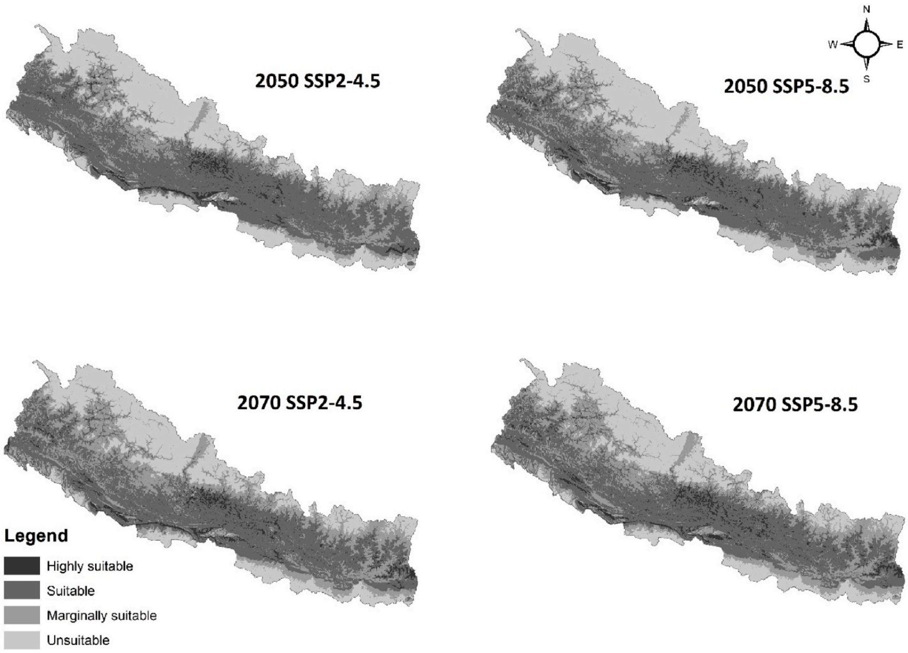

Fig. 8. Future distribution (2050 and 2070) of common leopard in Nepal in SSP2- 4.5 and SSP5- 8.5 scenarios, where the darker color represents the highly suitable areas and the lighter color represents low suitable areas.

5. Conclusion and implication on conservation and human wildlife conflict

The changing climate is expected to result in the expansion of common leopard habitats in the high Himalayas and high mountain regions. This scenario presents us with opportunities as well as challenges for the conservation of vulnerable leopards. Opportunities in a sense that, with proper management, the expansion of new climatically suitable habitat will help to increase the distribution of species, thereby decreasing the extinction risk. However, if potential climatically suitable habitats are not well managed, the risk of human-leopard conflict may escalate in future. Moreover, as the distribution of species is not only governed by climatic and topographic variables, a detailed study incorporating anthropogenic variables such as future land use scenarios is highly recommended. Similarly, expansion of PAs in mid-hill regions and formulation of efficient policies and programs to address the effects of climate change should be the foremost priority of the federal and provincial governments of Nepal. At the same time, studies focusing on assessing the impact of climate change on the prey species of common leopard are highly essential for management of expanding habitats, sustainable conservation of this species, and managing conflict between people and common leopard.

Data availability statement

The data associated with this manuscript will be available from corresponding author upon request.

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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