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Research article

Impacts of climate, land use, and land cover change on the distribution of squirrels in Nepal

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Abstract

Squirrels are one of the least studied mammalian faunas in south Asia. Squirrels are habitat-specialists and therefore are sensitive to changes in climate and land cover. Therefore, it is necessary to understand the impact and conservation implications of climate and land cover change. We used species distribution modelling to predict the distribution of species in suitable habitats and the impacts of future climate change. Three species of squirrels that prefer heterogeneous arboreal habitat and have high occurrence records were assessed through maximum entropy modelling. Eight uncorrelated bioclimatic variables and six Euclidean distances of land used and land cover change were used for MaxEnt modelling under current and four different scenarios of climate change. For two species (*Callosciurus pygerythrus* and *Petaurista magnificus*) the maximum and minimum possible areas of habitat suitability under the current climatic scenario were predicted in Nepal. The distribution of suitable habitats for all representative species of squirrels was predicted from eastern to central Nepal, due to no record of baseline data. Habitat suitability of three species of squirrels is projected to change by 2050 and 2070 under SSP4.5 and SSP8.5 scenarios, contingent on climate and land used and land cover change. In the future, suitable distribution range of the habitat of *C. pygerythrus* is predicted to shrink, whereas the distribution ranges of suitable habitat of *Dremomys lokriah* and *P. magnificus* predicted to expand. This is the first study targeted the distribution modeling of squirrels in Nepal. The results from this study inform future surveys and highlight the importance of monitoring needs for the conservation of squirrels throughout Nepal.

Keywords: Climate change; Distribution; Habitat suitability; MaxEnt; Modelling

1 | Introduction

Widespread taxa can serve as helpful indicators of global climate change. As the climate changes, the taxa may exhibit shifts in their suitable habitat ranges, moving towards areas that continue to meet their ecological requirements (Siddig et al. 2016). Rodentia is the most species-rich mammalian order in the world (Burgin et al. 2018) and the second largest order of mammals in Nepal (Thapa 2014; Thapa et al. 2016). Sciuridae, the second largest family of the Rodentia, includes 11 species of squirrels in Nepal (Thapa 2014; Thapa et al. 2016). Squirrels inhabit forested and urban areas and are found within and outside protected areas in all physiographic regions of Nepal from the Terai to the Trans Himalayas (Thapa et al. 2016; Thapamagar et al. 2020; Perodaskalaki et al. 2023; Rawat et al. 2023). Squirrels are common mammals of urban parks, zoos, green spaces and gardens and contribute to ecosystem services such as seed dispersal and eco-engineers of the ecosystems (Steiner & Huettmann 2023) and as the prey of birds and mammals (Bizhanova et al. 2022). Due to the rapid spread and development of the human population, ecofriendly natural infrastructure and human settlements are converting into expanses of concrete groundcover and buildings, which reduce the habitat of squirrels (Wang et al. 2019). Squirrels have been proposed as important indicators of global change (Koprowski & Rajamani 2008; Steiner & Huetterman 2023).

Climate and land cover changes are adversely affecting the survival rate, hibernation behavior, phenological mismatch between sexes, and yearling female breeding propensity of ground squirrels (Kucheravy et al. 2021) and are one of the major factors influencing the distribution of squirrels (Malekian & Sadeghi 2019). Little evidence of climate change impacts on phenological characteristics of American red squirrel (*Tamiasciurus hudsonicus*) in Canada has been reported (Lane et al. 2018). Climate change is responsible for shifts of the vegetation that affect the nesting behavior of flying squirrels (Selonen et al. 2020) and cause habitat loss and the drastic decline in the population of Siberian flying squirrel (*Pteromys volans*) in western Finland (Koskimaki et al. 2014). Adverse impacts of climate and land cover changes in Nepal are reported on some species of wild animals, such as the greater one-horned rhinoceros (*Rhinoceros unicornis*) (Pant et al. 2021), fishing cat (*Prionailurus viverrinus*) (Mishra et al. 2022), golden monitor lizard (*Varanus flavescens*) (Baral et al. 2023), and 11 species of bats (Thapa et al. 2021; Dahal et al. 2024) has been predicted. The habitat suitability models also predict an increase in potential habitat for the leopard (*Panthera pardus*) (Baral et al., 2023) and some alien invasive plant species in Nepal (Shrestha et al., 2018) but the impact on squirrels is unknown.

Maximum entropy (MaxEnt) modelling (Phillips et al. 2006) is a common method that performs well, especially with small sample sizes (Elith et al. 2006; Pearson et al. 2007; Merow et al. 2013). Species distribution modelling (SDM) is a popular spatial technique that predicts the distribution of a species in a large area by using environmental data and known geographic coordinates of distribution of a species (Guisan et al. 2017). An SDM is a Geographic Information System (GIS)-based program designed to produce high-resolution maps using species occurrence coordinates and bioclimatic variables (Villero et al. 2016). These types of models are mainly used for the study of broad patterns of species distribution and identification of habitat suitability at a fine scale (Fernandez et al. 2003). Prediction of the distribution of suitable habitat for species under future climate change is important for conservation planning and mutual coexistence. This study aims to predict impact of climate and land use land cover (LULC) change in Nepal. This prediction can be applicable to future management and conservation actions in Nepal and across southern Asia, the areas of the highest diversity but lowest knowledge of squirrels (Molur et al. 2005; Thapa et al. 2016; Thapamagar et al. 2020).

2 | Materials and methods

2.1 | Study area

Nepal (Fig. 1) covers a total area of 147181 km^2. From the southern plain to the northern Himalayas including Mount Everest, Nepal has a diverse topography. Nepal can be broadly split into five physiographic regions: Terai (Plain), Siwalik (Chure Range), Mid Hills (Mahabharat Range, Midland Valleys, and Elevated Plain), High Mountain (Subtropical Valleys), and High Himalaya (Karki et al. 2016).

2.2 | Occurrence coordinates and selection of species

Total of 257 geographic coordinates for occurrences of 11 species of squirrels in Nepal were collected from published literature (Thapa et al. 2016; Katuwal et al. 2018; Thapamagar et al. 2020; Perodaskalaki et al. 2023). Three species of squirrels (*Petaurista magnificus*, *Callosciurus pygerythrus* and *Dremomys lokriah*) have a sufficient number of occurrence records throughout the country and were selected as representative species for the modelling (SDM). *P. magnificus* is a large flying squirrel, whereas *C. pygerythrus* and *D. lokriah* are small-sized tree squirrels with different habits and habitats (Annex 1). Hodgson's giant flying squirrel *P. magnificus* is one of the largest flying squirrels of Nepal and generally is a nocturnal forest dweller and has been recorded from tropical and subtropical broad leaf forests of Nepal (Thapa et al. 2016). *C. pygerythrus* and *D. lokriah* are small, diurnal and arboreal species of squirrels. The former is distributed in tropical, subtropical, moist forest and suburban areas from lowlands to the Mid Hills, but *D. lokriah* is distributed in subtropical broad leaf forest of Mid Hills and is a forest dweller (Thapa et al. 2016). Duplicated occurrence coordinates were removed, and a total of 134 references coordinates were prepared. We also removed the presence of locations < 1 km to avoid spatial autocorrelation. Similar environmental heterogeneity with respect to elevation shows the distance window responsible for the concurrent analysis (Boria et al. 2014). The kernel density was created based on the bias file used for background point selection. Sampling bias was effectively removed by spatial filtering and bias file background point selection (Boria et al. 2014).

2.3 | Selection of environmental and projection layers

We downloaded 19 bioclimatic variables with the highest resolution (30 arc-second or ~ 1 km) from WorldClim (version 2) for current conditions (1970-2000). We also downloaded 19 bioclimatic variables (30 sec spatial resolution raster) for future prediction from the Coupled Model Intercomparison Project Phase 6 (CMIP6) for the

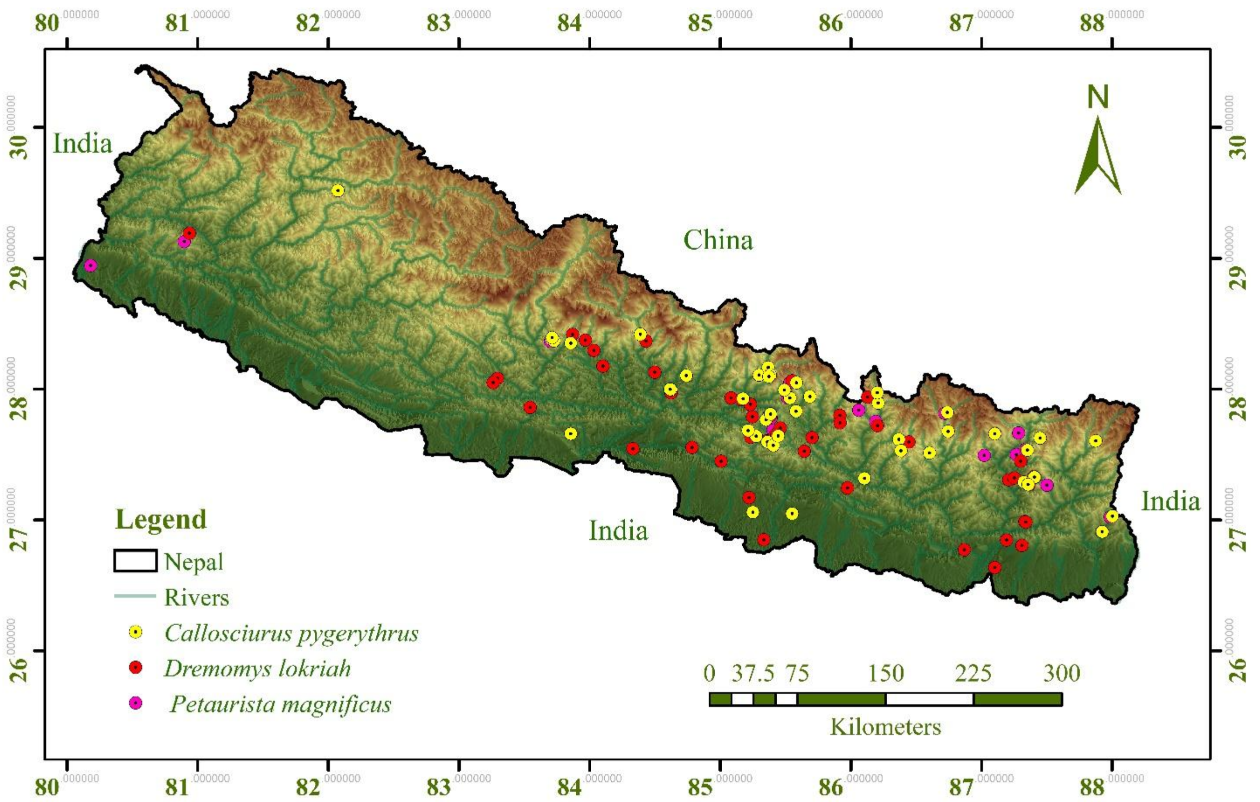

Figure 1. Map of Nepal with reference occurrence coordinates of three representative species of squirrels included in this study.

Table 1. AUC and TSS values for model validation of species distribution of squirrels in current scenarios for Nepal

Representative species	AUC value	Mean TSS value ± SD
Callosciurus pygerythrus	0.792 ± 0.017	0.5357 ± 0.026
Dremomys lokriah	0.866 ± 0.009	0.714 ± 0.031
Petaurista magnificus	0.798 ± 0.028	0.8061 ± 0.022

projection of global multiple climate model (GCMS) (Fick & Hijmans 2017). We downloaded the Moderate Resolution of Imaging Spectroradiometer (MODIS) annual land use and land cover (LULC) data (MCDI12Q1V006; Li et al. 2021)for the year 2021from Google Earth Engine (GEE). These layers of agriculture land, forest, grassland, water, urban land and unused land were extracted from data and created raster layers of Euclidean distance from nearest layers of the study area (Baral et al. 2023).

We selected two shared socioeconomic pathways (SSP) 4.5 and 8.5 for the years 2050 and 2070 for 19 bioclimatic variables (Hijmans et al. 2005). The scenario SSP 4.5 represents the state with higher values of carbon dioxide emission, whereas SSP 8.5 represents the highest value (~ 20%) of carbon dioxide emission. Both values represent the heating of the Earth's surface as functions of the concentration of greenhouse gases (Bourdeau-Goulet & Hassanzadeh 2021). We also used two scenarios for LULC, via the B2 (beginning of high emission) scenario and the A2 (higher emission) scenario (Nakicenovic et al. 2000; Riahi et al. 2017). SSP 4.5 was combined with B2 LULC scenarios and SSP 8.5 was combined with A2 LULC scenarios. LULC data for the year of 2050 were used for both models (2050 and 2070) because data for 2070 were not available. For each of three representative species of squirrels in SDM, a multicollinearity test (Pearson correlation coefficient) of 19 bioclimatic variables and six distances from LULC data were performed to reduce highly correlated variables (r > 0.75). The final set of noncorrelated variables were used for the SDMs of species (Annex 1).

2.4 | Species distribution modelling

The final set of non-correlated bioclimatic variables and distance from LULC were used for the species distribution modelling. The maximum entropy model, MaxEnt 3.4.3 (Phillips et al. 2006) was used to predict the current and future distribution ranges of the three representative species of squirrels. The selected model of species distribution is a robust and widely used model for small sample sizes and also accepts irregular data presence even with few locations (Pearson et al. 2007; Salinas-Ramos et al. 2021; Thapa et al. 2021). The selected model has superior predictive power, which can handle the relationship between predictor and response variables (Elith et al. 2006; Wisz et al. 2008). For each species of the squirrel, the presence occurrence points for modelling are more than 25, and the subsample is 70 % of those available for modelling. Each model of the species was run in raw data format with 25 replicates, a 10% random test and 10,000 background points. MaxEnt models using the subsample method in logistic output with other settings set as the default (Chatterjee et al. 2020; Lah et al. 2021; Thapa et al. 2021; Gur 2022).

2.5 | Evaluation of the models

The MaxEnt models were evaluated using the area under the receiver operator curve (AUC) and true skill statistics (TSS) (Jimenez-Valverde 2012; Ahmadi et al. 2023) and by visual inspection of the predicted result based on the known occurrences of each species (Thapa et al. 2021). The models with the highest raw AUC and TSS values (>0.5) resemble the fit of models and are used for prediction of habitat suitability (Allouche et al. 2006; Bradsworth et al. 2017). AUC and TSS values closer to 1 (AUC value > 0.70, TSS value > 0.5) indicate a high probability best fit of models (DeLeo 1993; Ahmadi et al. 2023). We converted the continuous predicted output probability to a binary response of presence or absence of species by reduction of 10 percentile training presence logistic threshold (Liu et al. 2005). The contribution of the variables can be predicted by the jackknife response curve implemented in MaxEnt (Elith et al. 2006). The shifting of squirrels along the elevation gradient in future climatic scenarios was represented by a density function (Thapa et al. 2021).

3 | Results

3.1 | Current species distribution modelling

The models of three representative species of squirrels performed with good accuracy producing AUC values that were more than 0.792 and TSS values greater than 0.5357 (Table 1).

The current coverage areas of three representative species of squirrel are 9.50 % to 36.09 % of the total area of Nepal. The hoary-bellied squirrel *C. pygerythrus* has the largest current potential distribution (53118.269 km^2) whereas *P. magnificus* has the smallest current potential distribution (13983.185 km^2) (Table 2). The predicted current potential distribution of *C. pygerythrus* includes different physiographic ranges from the Chure to Higher Himalayas in eastern Nepal and the Chure to Mid Hills in central Nepal. On the other hand, the predicted current potential distribution for *D. lokriah* and *P. magnificus* ranges from the Mid Hills to Higher Himalayas throughout eastern and central Nepal (Fig. 2).

3.2 | Influence of predictors

We found 10 bioclimatic variables and six distances from LULC data that influenced the potential current distribution of the three species of squirrels (Table 3). Precipitation of the warmest quarter (bio18) is a major contributing variable for *C. pygerythrus*, likewise isothermality (Bio 3) is the major contributing variable for *D. lokriah* whereas temperature annual range (Bio 7) is the major contributing variable for *P. magnificus*. All six distances of LULC contribute for the three squirrels, including major contributors such as distance from agriculture land, urban land and forest (Table 3). The response curve of influential variables for three species of squirrels (Fig. 3), isothermality (bio3), distance from unused land and grassland are predicted to respond positively, whereas mean diurnal range (bio2) is predicted to negatively influence the distribution of all species of squirrels.

Table 2. Estimated areas of predicted potential distribution of three representative species of squirrels in different climatic scenarios in Nepal.

Representative species	Area (km^2)				
	Current scenario	Future scenarios			
		SSP 4.5		SSP 8.5	
		2050	2070	2050	2070
Callosciurus pygerythrus	53118.269	53387.168	52752.7015	50427.526	48373.917
Dremomys lokriah	27268.176	22980.187	25421.052	30126.839	28223.474
Petaurista magnificus	13983.185	13312.3079	11578.4699	14642.012	14648.439

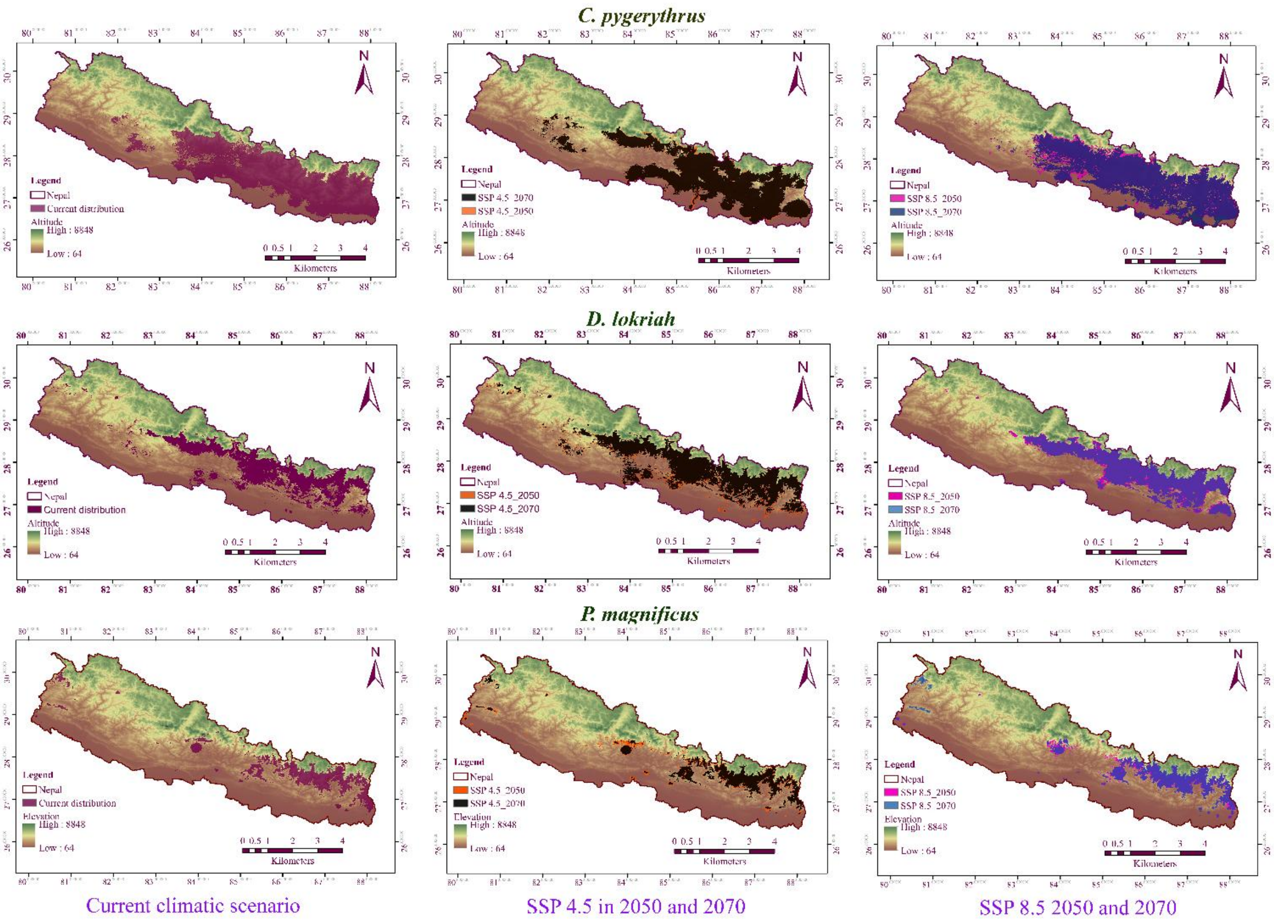

Figure 2. Projected distribution for *C. pygerythrus*, *D. lokriah* and *P. magnificus* in various climatic scenarios in Nepal: Current climatic scenario, higher value of carbon dioxide emission (shared socioeconomic pathway 4.5 in the year of 2050 and 2070) and highest value carbon dioxide emission (shared socioeconomic pathway 8.5 in the year of 2050 and 2070) as predicted by Maximum Entropy model version 3.4.3

For *D. lokriah* the model predicts that the isothermality (bio3) expresses a positive response for habitat suitability, mean temperature of warmest quarter (bio10), annual precipitation (bio12) and distances from grass land, unused land, sources of water and agriculture land but with decrease in mean diurnal range (bio2), temperature seasonality (bio4), mean temperature of driest quarter (bio9), precipitation of driest month (bio14) and distance from urban land and forest. For *C. pygerythrus* the model predicts the best fit with increase of isothermality (bio3), temperature seasonality (bio4) and the distance from grassland and unused land but with decrease in mean diurnal range (bio2), precipitation of warmest quarter (18) and precipitation of coldest quarter (bio19) and the distance from agriculture land, urban land sources of water.

Table 3. Bioclimatic and LULC variables and its predicted contribution in species distribution in current climatic scenarios for Nepal.

S. N.	Name of contributed variables	Representative species of squirrels and amount of contribution		
		Callosciurus pygerythrus	*Dremomys lokriah*	*Pataurista magnificus*
1	Mean diurnal range (bio2)	1.8	1.9	0.7
2	Isothermality (bio3)	15.8	24.3	1
3	Temperature seasonality (bio4)	4	17	-
4	Temperature annual range (bio7)	-	-	39.3
5	Mean temperature of driest quarter (bio9)	-	2.8	7
6	Mean temperature of warmest quarter (bio10)	-	3.6	-
7	Annual precipitation (bio12)	-	10.2	20.1
8	Precipitation of driest month (bio14)	-	0.2	8.1
9	Precipitation of warmest quarter (bio18)	38.7	-	-
10	Precipitation of coldest quarter (bio19)	4.7	-	0.8
11	Distance from agriculture land	8.5	9.5	5.9
12	Distance from forest	2.2	4.8	2.2
13	Distance from grass land	1.6	3	1.7
14	Distance from sources of water	0.7	1.3	2.6
15	Distance from urban land	14.6	4.7	4.8
16	Distance from unused land	7.3	16.7	5.9

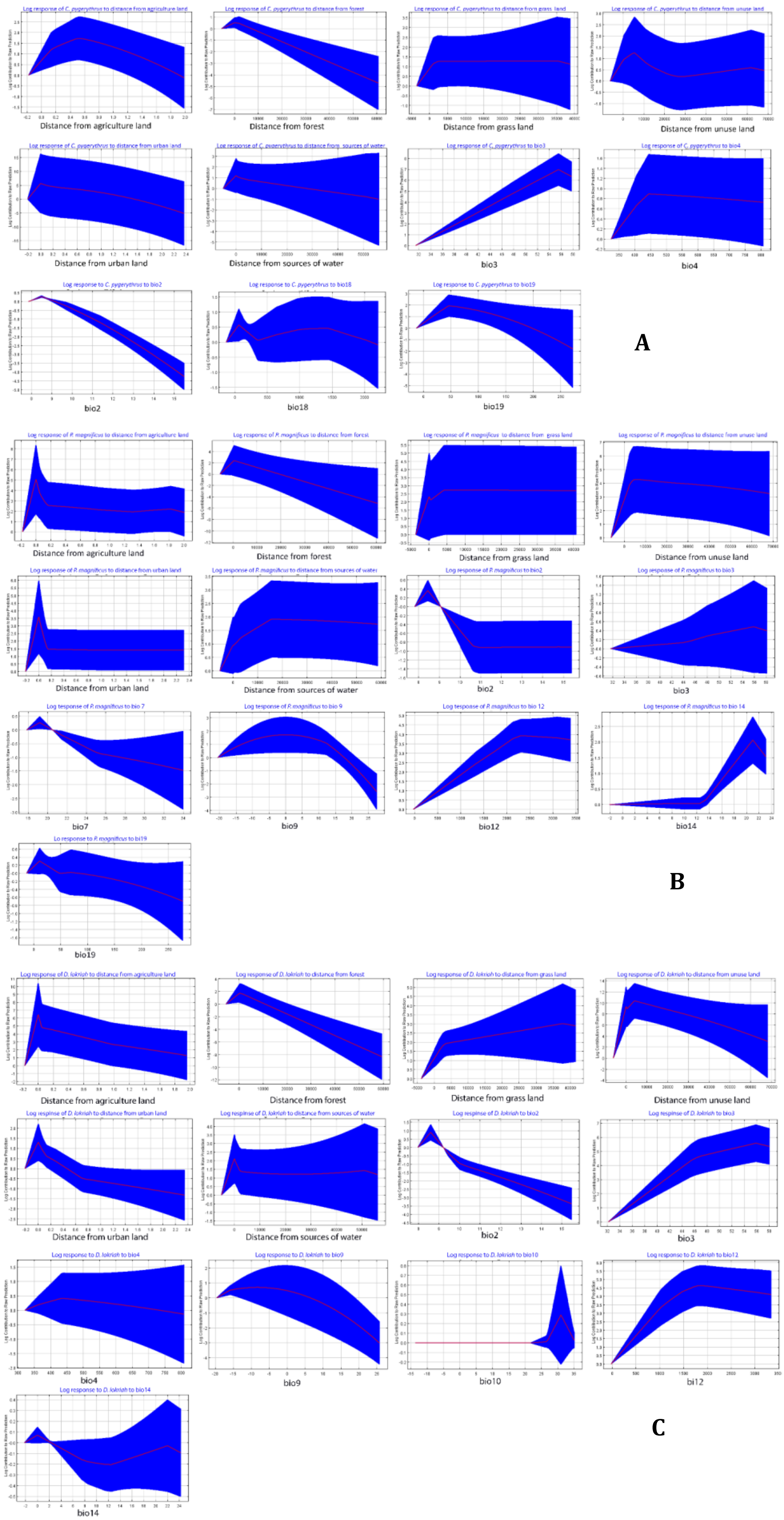

Figure 3. The response curves of predictor variables for three representative species of squirrels (A: represent the *C. pygerythrus*, B: represent the *P. magnificus*, C: represent the *D. lokhriah*)

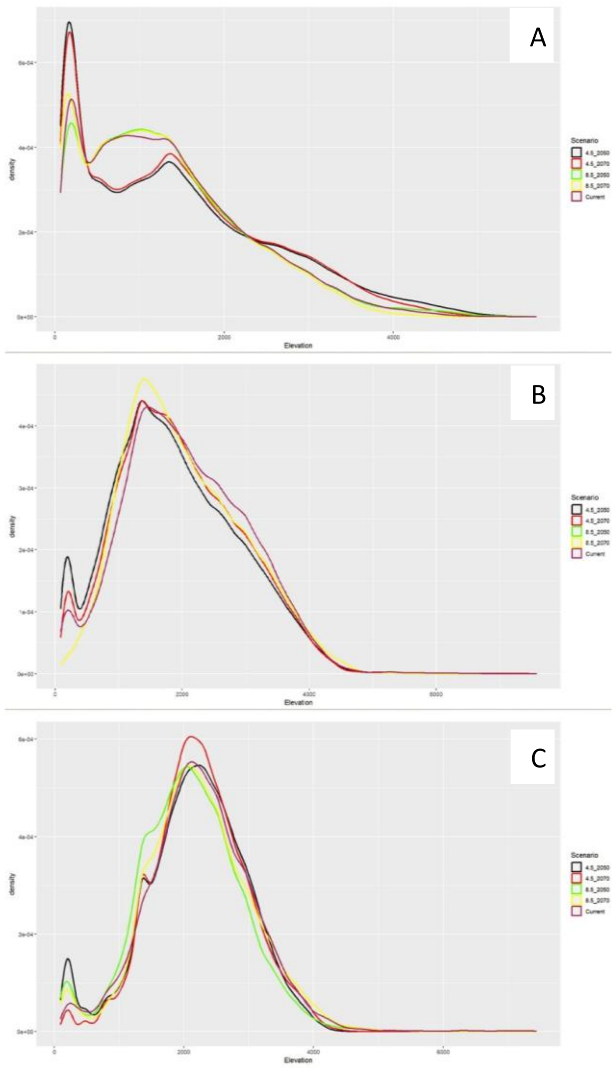

Figure 4. The density function of three species of squirrel presence in elevation gradient across Nepal predicted by MaxEnt modelling, A- *C. pygithrus*; B- *D. lokriah*; and C- *P. magnificus*

agriculture land, grassland, water, unused land, urban land, isothermality (bio3), annual precipitation (bio12) and precipitation of driest month (bio14) but decreases the fit with forest, mean diurnal range (bio2), temperature annual range (bio7), mean temperature of driest quarter (bio9) and precipitation of coldest quarter (bio19) (Fig. 3).

3.3 | Prediction of future species distribution

We projected MaxEnt models with future climatic forecasting under higher carbon dioxide emission (SSP 4.5) and highest value of carbon dioxide emission (SSP8.5) for the years of 2050 and 2070, respectively. The projections from the MaxEnt models with respect to current climatic and land use conditions for four different scenarios of climate and land use change demonstrate subtle differences among the species (Fig. 2, Table 2). *C. pygerythrus* is predicted to experience shrinkage of suitable habitat under SSP 4.5, 2050 and 2070 across eastern Nepal and expansion toward the northwest region of country whereas in the SSP 8.5 suitable habitat shrinks from western Nepal and slightly expands toward the Chure Range of Nepal (Fig. 2).

The future distribution of *D. lokriah* under the SSP 4.5, 2050 and 2070 is predicted to expand to the west and south and shifts towards the Higher Himalayas under the SSP 8.5, 2050 and 2070 (Fig. 4).

In contrast, the predicted distribution of *P. magnificus* under SSP 4.5 and 8.5 in 2050 and 2070 suggest general similarity in distribution range and position of suitable habitats (Fig. 2). In comparison to the other two species, *C. pygerythrus* is more sensitive to changes of future climatic scenarios because its suitable habitat range is predicted to shrink (Table 2). Whereas, *D. lokriah* and *P. magnificus* suitable habitat is predicted to slightly expand in future climate change (Table 2). No significant shifting of squirrels in elevation range are seen under the scenarios of future climate and landcover change (Fig. 4)

4 | Discussion

4.1 | Distribution modelling of squirrels under current climatic scenario

Our models are the first disstribution model for squirrels in Nepal and predicted the effect of climate and land use change in different climate scenarios using a robust approach in MaxEnt. Current distribution models of three species of squirrels predict the low distribution of suitable habitat in western Nepal due to the lack of surveys and occurrence coordinates (Thapa et al. 2016). The potential coverage of habitat suitability for *C. pygerythrus* and *P. magnificus* under the current climatic scenario is predicted to be maximum and minimum, respectively. The potential distribution of *C. pygerythrus* covers physiogeographic regions range from the Chure to Higher Himalayas in eastern and the central Nepal. Only a few small patches of suitable habitats are predicted in western region of the Nepal (Fig. 2), which must be verified by the future surveys in west. The prediction of the current potential distribution range of *D. lokriah* covers the Mahabharat to Himalayas in eastern and central Nepal. The predicted distribution range of *P. magnificus* covers higher elevations in the Mahabharat range to Higher Himalayas in eastern to central Nepal.

Due to deforestation and fragmentation of habitat, squirrels in South Asia are facing a high risk of extinction (Koprowski & Nandini 2008). Climate and land use change also promote invasion of alien species and losses of suitable habitat and corridors for squirrels (Di Febbraro et al. 2018). Isothermality (bio3), temperature annual range (bio7) and precipitation of warmest quarter (bio18) are major climatic variables and distance from forest, agriculture land and unuse land are major landcover variables that we found to influence the distribution of squirrels. Forest and unused lands are important habitats (Chatterjee et al. 2020). Temperature and precipitation are important climatic variables for hibernation, reproductive rate, litter size and juvenile survival rate of squirrels (Goldberg & Conway 2021; Kucheravy et al. 2021).

4.2 | Species distribution modelling under future climatic scenarios

Changes of climate and landcover are predicted to reduce the corridors and suitable habitats of squirrels and constrict distributions. Climate change is projected to expand habitat suitability for species such as the grey squirrel, potentially exacerbating their invasive impact on other squirrel species. Such invasions have been observed in Italy (Di Febbraro et al. 2018). Climate change causes adverse effects on hibernation, phenological mismatch, breeding and survival rate of squirrels (Goldberg & Conway 2021; Kucheravy et al. 2021). Our study shows the effect of future climate and landcover change on the distribution of *C. pygerythrus*. Nearly 13% of its suitable habitat range is predicted to be lost under the SSP 4.5 (Table 1). Precipitation of warmest quarter (bio18), isothermality (bio3) and distance from urban land are major contributing variables. Distance from urban land and bio18 show negative contribution whereas bio3 shows positive contribution to the model. Due to climate change, precipitation increases in the warmest months. The occurrence of squirrels near human settlements (Almazroui et al. 2020) but urban areas of

Mid Hills and Higher Himalayas are now expanding into the valleys and plains (Rimal et al. 2020). No study has been conducted to understand the impact of climate and landcover changes on *C. pygerythrus*. However, reduction of suitable habitat and corridors has been predicted in the congeneric, *C. finlaysonii* in Iran (Febbraro et al. 2018). On the other hand, *C. pygerythrus* is recorded from small and moist forest patches near the human settlements and agriculture land in between Low Land to Mid Hills of south Asia, southeast Asia and south China (Molur et al. 2005). Shifts of agriculture land, clear cutting of small patches of forest, and forest fires are the major current threats to the survival of this species; shifting of forest patches and increase in competition with invasive species will increase due to the future climate change (Vanderwel & Purves 2013; Thapa et al. 2016).

In *D. lokriah* suitable habitat is predicted to increase in future scenarios of climate and landcover change, and under the SSP 4.5 in 2050 the maximum increase (33.302 %) is likely to occur and slight rise is predicted to occur under 8.5 in 2070 (3.495 %; Table 1). This species is found in a wide elevation ranges and varieties of forests across south Asia, southeast Asia and south China (Molur 2016). Orange-bellied squirrels also tolerate some habitat disturbance and sometimes can be observed near human settlements near forests (Molur 2016; Thapa et al. 2016). Isothermality (bio3), temperature seasonality (bio4) and distance from unused land are the major contributors to distribution models. Distance from unused land and bio4 show negative contribution and bio3 show positive contribution to our models. Isothermality (bio3) is predicted to rise in climate change (Almazroui et al. 2020). Due to migration from rural areas, unused land has been increasing in the mountains of Nepal (Rimal et al. 2020). This may facilitate increase in suitable habitats of orange-bellied squirrels in Nepal.

For *P. magnificus*, the prediction of habitat suitability in future climate, land use and landcover change are different from that of the two other species in all scenarios. The coverage area of suitable habitat is predicted to slightly reduce under the SSP 4.5 in 2070 whereas predict to expand under the 4.5 scenario for the year 2050 and the 8.5 scenario for the year 2050 and 2070. Temperature annual range (bio7), annual precipitation (bio12) and precipitation of direst month (bio14) are the major contributors to the SDMs. Flying squirrels including *P. magnificus* has been facing threats such as reduction of habitat (habitat loss and fragmentation) in India (Koli 2016). Although no study has occurred on SDM of Hodgson's giant flying squirrel, distribution modelling of *P. philippenis* in India (Koli et al. 2023) predicted that the future climate change affects the dispersal and colonization of the species.

5 | Conclusions

This study confirms the presence of *Lycodon gammiei* in Nepal. The available reference coordinates of these modelling were colonized toward eastern Nepal because very few survey were conducted behind central Nepal (Thapa et al. 2016; Katuwal et al. 2018; Thapamagar et al. 2020). The current distribution model predicted the deviation of *C. pygerythrus* toward western Nepal and which covered Dang Valley and river basin of Babai and West Rapti but no reference coordinates are available (Fig 2). Again, future distribution modes predicted western deviation were lost from SSP 4.5 to 8.5. Detail survey and monitoring on possible predicted range for confirmation of presence and design the corridors with suitable habitat for future conservation. The possible distribution of *D. lokriah* expand from Gorkha to Rukum out of reference coordinates and the expansion remain constant in all conditions of future models. The prediction of current distribution model may useful for conformation of evidence in site of expansion by detail survey. If the occurrence of species is confirmed, upgrading of possible corridors, increased connectivity, and improvement of habitat and public awareness for coexistence with squirrels can be important. *P. magnificus* cover narrow range of elevation from Mahabharat to Himalayas. The possible current distribution of this is expended in some region from Sindupalchok to Darchula western Nepal.

The species distribution modellings of three representative species of squirrel predict lesser degree of impacts by future climate and land cover change. But massive anthropogenic threats are a major challenge for the conservation of squirrels in Nepal like habitat loss, unregulated hunting, poaching, poisoning, road and dam construction, forest fire, dog biting, domestic keeping (Jnawali et al. 2011; Thapa et al. 2016; Thapamagar et al. 2020). This study suggests detail national survey squirrels focusing on western Nepal and public awareness highlighting the role of squirrels on ecosystem services.

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Authors' contributions

Conception, data collection, modelling, data analysis and preparation of first draft: DRD; Inputs in result, analysis and discussion: ST; Final review, suggestion and inputs: JLK

Conflicts of interest

The authors declare no conflict of interest.

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Annex 1. Details of occurrence data and predictive variables used for MaxEnt modeling

Species	***P. magnificus***	***C. pygerythrus***	***D. lokriah***
Habit	Nocturnal and arboreal	Diurnal and arboreal	Diurnal and arboreal
Habitat	Evergreen tropical and subtropical forest	Temperate, tropical and subtropical moist forest	Tropical and subtropical forest
Elevation	400 to 3000 m asl.	400 to 1500 m asl.	100 to 2900 m asl.
Numbers of reference coordinates	25	56	54
Non-correlated bioclimatic and LULC variables	Mean diurnal range (Bio 2)	Mean diurnal range (Bio 2)	Mean diurnal range (Bio 2)
	Isothermality (Bio 3)	Isothermality (Bio 3)	Isothermality (Bio 3)
	Temperature annual range (Bio 7)	Temperature seasonality (Bio 4)	Temperature annual range (Bio 7)
	Mean temperature of driest quarter (Bio 9)	Precipitation of warmest quarter (Bio 18)	Mean temperature of driest quarter (Bio 9)
	Annual precipitation (Bio 12)	Precipitation of coldest quarter (Bio 19)	Annual precipitation (Bio 12)
	Precipitation of driest month (Bio 14)	Agriculture land	Precipitation of driest month (Bio 14)
	Precipitation of coldest quarter (Bio 19)	Forest	Precipitation of coldest quarter (Bio 19)
	Agriculture land	Grass land	Agriculture land
	Forest	Water	Forest
	Grass land	Urban land	Grass land
	Water	Unused land	Water
	Urban land		Urban land
	Unused land		Unused land