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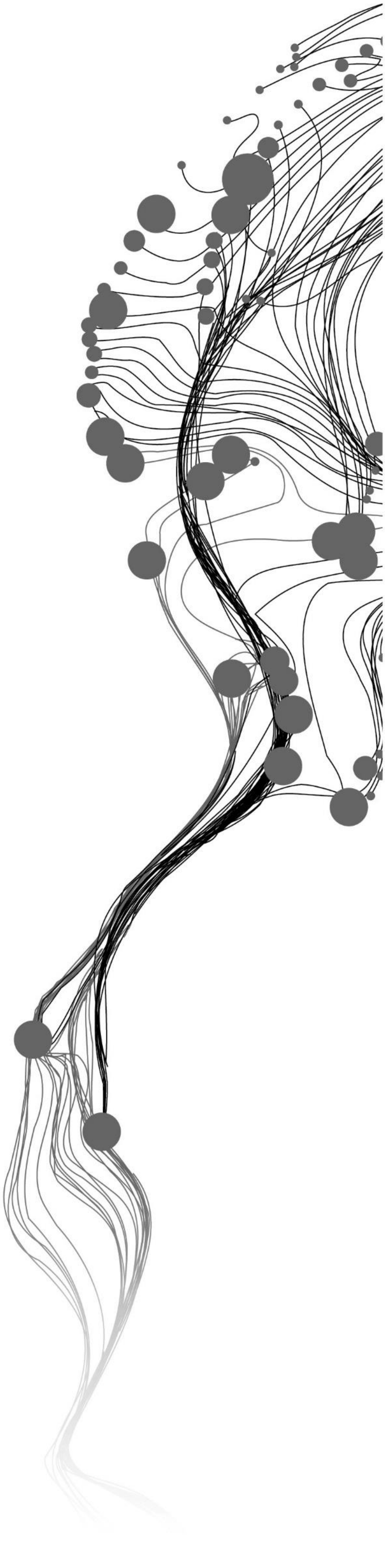

PREDICTING CURRENT AND FUTURE HABITAT SUITABILITY FOR RED PANDAS IN NEPAL

SAROJ PANTHI
Enschede, The Netherlands, February 2018

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Natural Resources Management

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ABSTRACT

The red panda is an endangered species. Although they are protected by national laws in their range countries, its population continues to decline due to habitat loss and fragmentation. Estimating and mapping suitable habitat plays a critical role in red panda conservation planning and policy. In this study, the red panda habitat in Nepal was predicted using a Maximum Entropy Model based on red panda occurrence data and environmental variables (including climatic, topographic, vegetation-related, and anthropogenic variables) under current and future climate and land use and land cover change scenarios. The study results indicated that approximately 13,800 km^2 area was identified as the current suitable habitat for red pandas, with 40% of the habitat being covered by the existing protected area system. The largest habitat in Nepal was located in the Solukhumbu district and mainly covered by the Langtang National Park. About 75% of the habitat was distributed between 2400 m and 3800 m. It was found that the mean annual temperature, distance from human paths and livestock density were important variables to the prediction of current suitable habitat for red pandas in Nepal. The model suggested that the future suitable habitat for red pandas in Nepal will be increased by 6.5% under the future climate change scenario. However, the suitable habitat will be reduced by 0.5% due to the combined effects of future climate and land use and land cover changes. This is the first study that attempts to use comprehensive environmental and anthropogenic variables for predicting habitat suitability for the red pandas at a national level. The suitable habitat identified by this study is important and could serve as a baseline for the development of conservation strategy for the red panda in Nepal. The study recommends that the Department of National Parks and Wildlife Conservation should coordinate with the Department of Livestock Services and the Department of Tourism to mitigate the impacts of livestock and tourist routes on red panda. In addition, the study recommends that Nepalese government should pay more attention to the land use planning in the future in order to mitigate the potential economic impact on red panda as well as other endangered species in Nepal.

Key words: Climate change; Conservation; Habitat suitability; Red panda; Suitable habitat

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Saroj Panthi
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1. INTRODUCTION

1.1. Background

Humans depend on biodiversity in myriad ways, yet species are being rapidly lost due to anthropogenic activities (Gascon et al., 2015). Biodiversity is an important economic asset. For example, biodiversity helps to improve the productivity of ecosystems (Wilsey and Potvin, 2000). Unfortunately, the global biodiversity resource has been declining continuously over the last several decades mainly due to increasing anthropogenic interferences (Tittensor et al., 2014). The species extinction rate is about 1000 times more than the likely background rate, and future rates are poised to increase (Pimm et al., 2014). Over-exploitation of the biological resources and agricultural activities such as crop production and livestock farming are identified as major causes of global biodiversity loss (Maxwell et al., 2016). In other words for wildlife conservation, habitat fragmentation (Bentley et al., 2000) and the impact of domesticated animals are major challenges (Loss et al., 2013). Furthermore, climate change is becoming a severe threat to biodiversity (González-Orozco et al., 2016). Often species react to climate change by shifting distribution to follow changing the environmental situation, by adapting to changing conditions in location, or, if unable to do either, by remaining in isolated pockets of the unchanged environment or, more likely, becoming extinct (Holt, 1990). Similar to climate change, the land use change is also becoming the emerging threat to conserve the biodiversity and may lead the greater species loss in tropics (Jetz et al., 2007). The conservation of biological resources and their habitats are directly influenced by the socio-political situation of the country (Barnes et al., 2016). Less developed countries are focusing on the production of food and management of shelter for their people. Due to the poverty (Adams et al., 2004), human-wildlife conflict (Acharya et al., 2016), overexploitation of biological resources and tourism pressure on protected areas (Bhattarai et al., 2017), people's dependency on forests and consequent deforestation and forest fragmentation (Uddin et al., 2015) developing countries are facing more difficulties for biodiversity conservation.

Large mammals, considering as flagship species are indicators of stable and rich biodiversity (Simberloff, 1998). For example, the presence of tiger is an indication of the existence of small mammals and vegetation. They are consumers and maintaining the ecological system from high trophic level; therefore conservation of flagship species leads to conservation of overall biodiversity in the region (Williemas et al., 2000). Due to the requirement of large habitat patches and a large number of feeding resources, the conservation of large mammals is more challenging. Some species like giant panda do not prefer the small patches of fragmented habitats (Wang et al., 2010). In addition, the human-wildlife conflict is major conservation challenge to conserve the large mammals because of their aggressive behaviour to human fatalities (Acharya et al., 2016).

The red panda is a charismatic animal, making it an ideal flagship species for harnessing public support for prudent biodiversity conservation. It is solitary small sized (weight is 3 to 6.2 kg and length from head to body is 50 to 64 cm, and the tail is 28 to 59 cm) herbivorous carnivore (Roberts and Gittleman, 1984). This species is native to five countries of Asia: Bhutan, China, India, Myanmar and Nepal (Glatston et al., 2015) (Figure 1). The presence of red panda is confirmed from 13 districts of Bhutan (Dorji et al., 2012), three provinces of China (Sichuan, Yunnan and Tibet), three states of India (Sikkim, West Bengal and Arunachal Pradesh), and Northern Kachin province of Myanmar (Glatston et al., 2015). Although the published location data are not available, the presence of red panda has been confirmed from 24 districts of the high mountain region of Nepal (Jnawali et al., 2010). The home range of the red panda is 94-111 ha (Reid et al., 1991). Although the altitudinal range of the red panda distribution is 2200 m – 4800 m (Roberts and Gittleman, 1984), the preferred altitudinal range is 2900 m – 3400 m (Bhatta et al., 2014; Panthi et al., 2012). Red pandas live around the steeper slope with a higher density of fallen logs, shrubs, and bamboo culms (Wei et al., 2000) and prefer steep to moderate slope gradients (36° - 45°)(Bhatta et al., 2014; Panthi et al., 2012). The red panda is a habitat specialist, and it prefers the temperate forests with bamboo ground cover (Bhatta et al., 2014; Chakraborty et al., 2015; Dorji et al., 2011; Panthi et al., 2012; Pradhan et al., 2001; Roberts and Gittleman, 1984). The leaves and shoots of understory bamboo are major foods of this animal (Fei et al., 2017; Hu et al., 2017; Panthi et al., 2015, 2012; Sharma et al., 2014b; Thapa and Basnet, 2015; Wei et al., 1999).

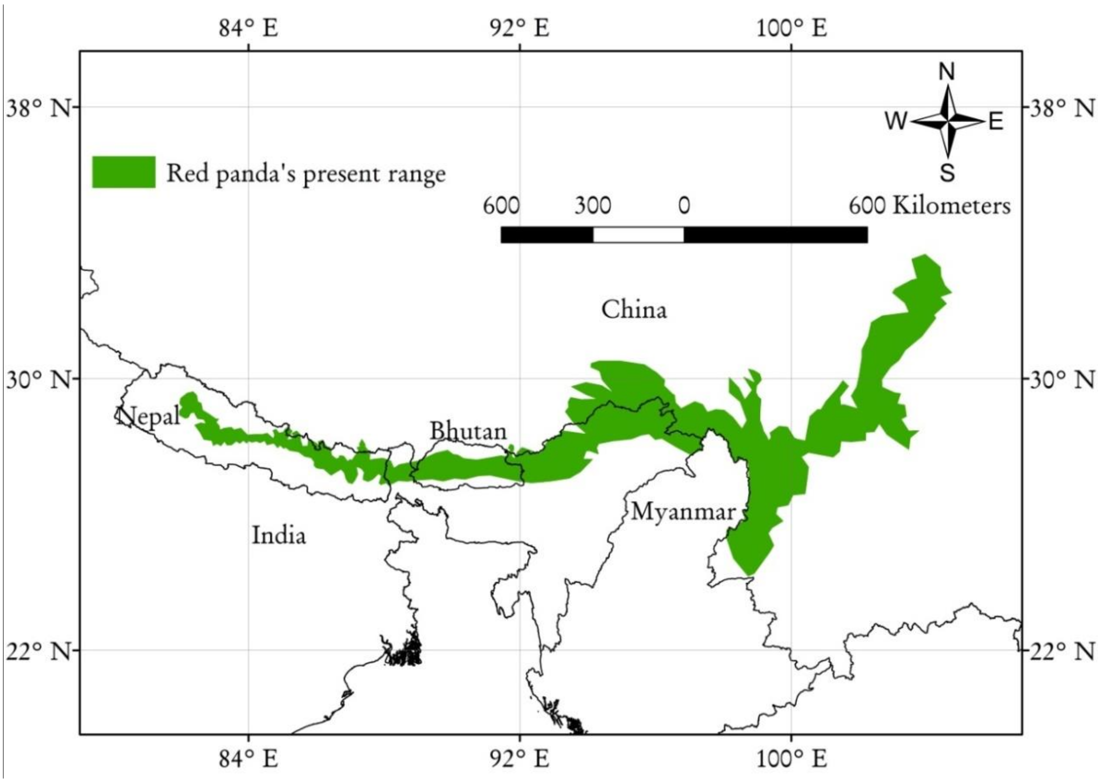

Figure 1: The global distribution of red pandas (Source: IUCN, 2017)

The conservation status of the red panda is endangered on the red list of the International Union for Conservation of Nature (IUCN) (Glatston et al., 2015) and included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (CITES, 2017). This animal is also protected by Nepal's National Parks and Wildlife Conservation

Act, 1973 and has a provision of fine of NRs 40,000 to 75,000 and/or imprisonment of 1 to 10 years for any people who kill, sell and buy its body parts (GoN, 1973).

Although the red panda is protected by international conventions (CITES, 2017) and national law (GoN, 1973), it is facing the several threats. Due to anthropogenic pressures on it and fragmentation of natural habitats, its population continues to decline (Glatston et al., 2015). The anthropogenic impact on its habitats has been identified as major threats to the conservation of this species in its distribution range (Dendup et al., 2017; Dorji et al., 2012; Panthi et al., 2017; Sharma et al., 2014a). Large numbers of cattle, herders, and their guard dogs were responsible for disturbance to the red pandas and their habitats (Yonzon and Hunter, 1991a). On another hand, the climate change is becoming an emerging threat to biodiversity conservation. Due to the more than average impact of climate change in Himalaya (IPCC, 2007), the Himalayan biodiversity is facing more threats to their ecology.

The development of predictive habitat distribution models has rapidly increased in ecology, with the rise of new powerful statistical techniques and GIS tools (Guisan and Zimmermann, 2000). A wide range of models (e.g. BIOCLIM, BRT, DOMAIN, GARP, GLM, and MaxEnt) has been developed to cover aspects as diverse as biogeography, biology, climate change, conservation, research, and habitat management. These models have been used to predict the distribution of plants, birds, reptiles, and mammals (Gillespie and Walter, 2001; Guisan et al., 1998; Pearce and Ferrier, 2000; Phillips et al., 2006). These species distribution models are also using to predict the risk of fires (Renard et al., 2012), landslides (Goetz et al., 2011), diseases (Murray et al., 2011), and accidents (Maher and Summersgill, 1996). Modelling the distribution of the species is crucial to understand the spatial ecology of these species and to manage them for mutual benefit for human and nature. Due to the chance of not recording the observation at the time of researcher's field work, the recording of the true absence data points is a challenging task. Collection of lots of data for rare species is also another challenge in research. Therefore species distribution model which needs only presence data from the field is becoming more popular among the species distribution models.

1.2 Problem statement

A species cannot be conserved without knowing where it is. To conserve the habitat of red panda the managers should have the geographic information of its habitats. Because of its "endangered" conservation status (Glatston et al., 2015), it is imperative to pay more attention to its effective conservation. Accurate, reliable and timely information about the suitable habitat and distribution of red pandas in Nepal are still missing. Due to lack of reliable information on the habitat of the red panda, conservation partners such as the government of Nepal, World Wildlife Fund, National Trust for Nature Conservation and Red Panda Network couldn't prepare effective plans and strategies for the conservation of the red panda in Nepal.

Several studies related to habitats, conservation threats and diet of red pandas were conducted in small landscapes of Nepal (Bhatta et al., 2014; Panthi et al., 2017; Sharma et al., 2014a; Thapa and Basnet, 2015; Yonzon and Hunter, 1991b). There is only one study has been conducted to investigate the habitat and the distribution of this species at regional scale covering Nepal (Kandel et al., 2015). That regional level study only used topographical and bio-climatic variables to model the distribution of red panda. Bamboo is the main food and habitat characteristic of the red panda throughout its distribution range (Fei et al., 2017; Hu et al., 2017; Panthi et al., 2015, 2012; Sharma et al., 2014b; Thapa and Basnet, 2015; Wei et al., 1999). The bamboo information was effective to quantify the distribution of the similar species: giant panda (Linderman et al., 2005). The previous study didn't include this crucial variable at the time of red panda habitat modelling (Kandel et al., 2015). The habitat modelling of red panda may not be reliable without using this important bamboo information. In addition, many studies were alarming that red panda is facing the anthropogenic pressure (Glatston et al., 2015; Panthi et al., 2017; Sharma et al., 2014a). However, the previous study did not include any anthropogenic variables for modelling the habitat of this species. Therefore, findings of the previous study may not be reliable, which need to be updated by including vegetation-related and anthropogenic variables to estimate the suitable habitat for red pandas.

Moreover, the climate and land use and land cover change are becoming emerging and challenging issues in the field of biodiversity conservation. The climatic condition is directly responsible for determining the daily activities of animals so their habitat may shift under climate change in future (Holt, 1990). If conservationists do not know about the impact of climate and land use and land cover change on the habitat of the red panda in future, they cannot think to tackle the future situation to conserve the species in its natural habitat. How the future climate and land use and land cover change will affect the habitat of the red panda is also to be answered for effective conservation planning.

1.3 Research objectives

The overall objective of this study was to predict current and future habitat suitability for red pandas in Nepal. Specific objectives of the study were as follows:

- To predict current habitat suitability for red pandas in Nepal
- To assess the distribution pattern and the conservation status of current red panda habitat in Nepal
- To investigate the impact of different variables that determine the current habitat suitability for red pandas in Nepal
- To model the impacts of future climate and land use and land cover change on the distribution of the red panda habitat in Nepal

1.4 Research questions

- What is the area of suitable habitat currently available for red pandas in Nepal?
- What is the geographical distribution pattern of predicted suitable habitat for red pandas in Nepal?
- Which predictor variables are important for determining the current habitat suitability for red pandas in Nepal?
- What are the impacts of future climate and land use and land cover change on the distribution of red panda habitat in Nepal?

1.5 Research hypotheses

Hypothesis 1

H_0: There is no statistically significant difference in accuracy between the two models with and without the use of vegetation-related variables for red panda habitat suitability modelling.

H_1: Adding vegetation-related variables to the model can significantly improve the prediction accuracy for the red panda habitat suitability modelling.

Hypothesis 2

H_0: There is no statistically significant difference in accuracy between the two models with and without the use of anthropogenic variables for the red panda habitat suitability modelling.

H_1: Adding the anthropogenic variables to the model can significantly improve the prediction accuracy for the red panda habitat suitability modelling.

Hypothesis 3

H_0: The predicted suitable habitat for red pandas is fully covered by the existing protected areas in Nepal.

H_1: The existing protected areas do not cover the entire predicted suitable habitat for red pandas in Nepal.

Hypothesis 4

H_0: The future climate and land use and land cover change does not reduce the amount of current suitable habitat as well as alter the geographical distribution patterns of red panda habitat in Nepal.

H_1: The future climate and land use and land cover change will reduce the amount of current suitable habitat. The future suitable habitat for red pandas in Nepal will shift to the higher mountains.

2. MATERIALS AND METHODS

2.1 Study area

Nepal is situated in the central part of the Himalaya (26^{o}22' - 30^{o}27' N, 80^{o}04' - 88^{o}12' E), covering an area of 147,181 km^2 and an elevation ranges from 67 m to 8848 m. Nepal has diverse climates due to the large variation in elevation. The climate varies from humid tropical type in the tropical lowlands in the south to alpine cold semi-desert type in the trans-Himalayan zone (Ohsawa et al., 1986). Nepal's forest ecosystems can be categorized into 10 major groups on the basis of climatic conditions: (1) tropical, (2) subtropical broad-leaved, (3) subtropical conifer, (4) lower temperate broad-leaved, (5) lower temperate mixed broad-leaved, (6) upper temperate broadleaved, (7) upper temperate mixed broadleaved, (8) temperate coniferous, (9) subalpine, and (10) alpine scrub (Stainton, 1972). The average annual rainfall is around 1000 – 2000 mm, but sometimes it exceeds to 3000 mm in some lower parts of the country (Ichiyanagi et al., 2007). Nepal has diverse geography that ranges from permanently snow and ice covered very rugged Himalayan Mountains in the north to the tropical alluvial plains in the south. Due to variation in climate and topography, Nepal is classified into five physiographic zones (i.e., Terai, Siwalik, middle Mountain, high Mountain and Himalaya) (Barnekow Lillesø et al., 2005; Shrestha et al., 2010).

In spite of the poor economic condition, the government of Nepal has established 20 protected areas: 12 national parks, six conservation areas, one wildlife reserve and one hunting reserve (Figure 2) (DNPWC, 2017). Around all national parks and wildlife reserves, buffer zones are declared for intensive management of the human-wildlife conflict. Out of total protected areas, six national parks, five conservation areas, and one hunting reserve are established in the Himalayan region, one national park is in middle Mountain region, and rest are in Terai and Siwalik region (DNPWC, 2017). These protected areas are providing the natural habitat for the elephant, musk deer, red panda, rhino, snow leopard, tiger, wild buffalo, wild dog and other threatened wildlife by covering 23.23 % of the total land of the country (Bhattarai et al., 2017).

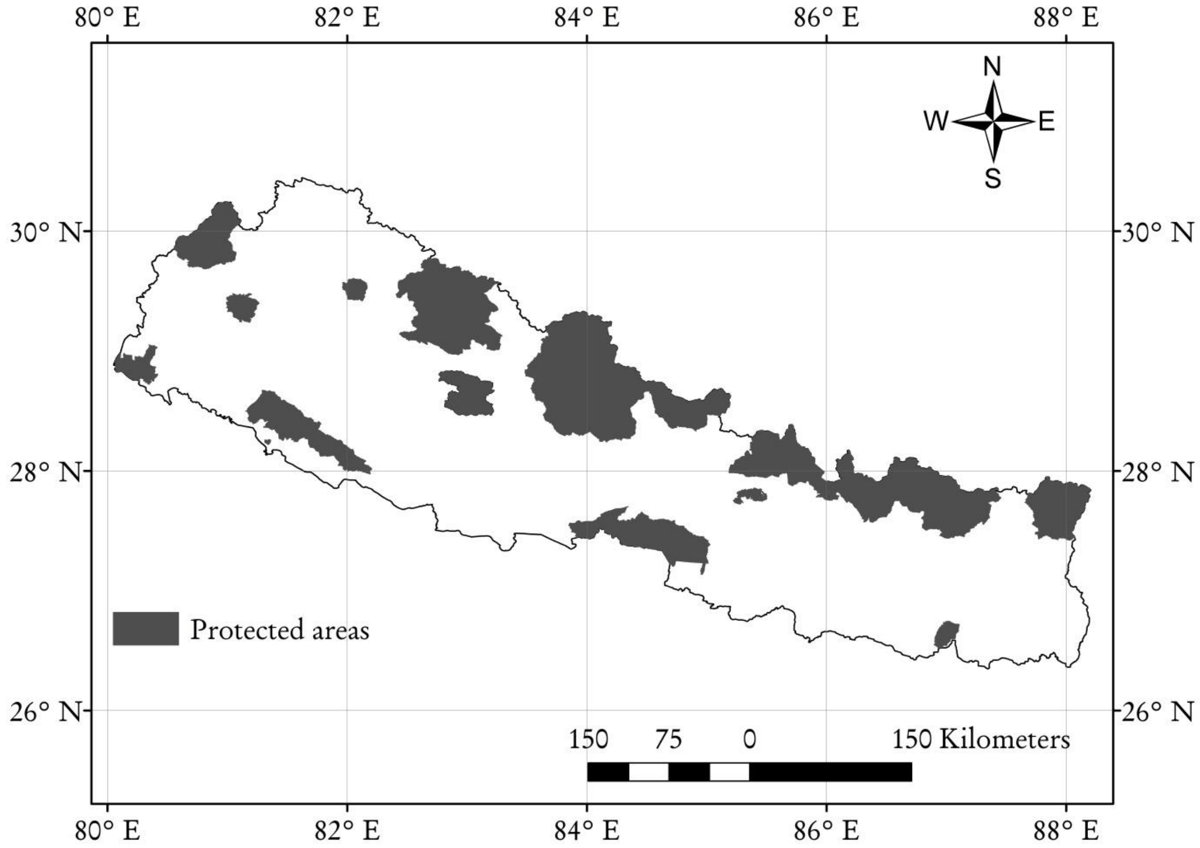

Figure 2: The geographical distribution of protected areas in Nepal

2.2 Data collection

2.2.1 Collection of secondary red panda occurrence data

The secondary red panda occurrence data observed during 2009 to 2016 were collected and compiled from published and unpublished research reports and reports of the government of Nepal (Figure 3). All these secondary data were collected using Global Positioning System (GPS) receivers. The sources of these secondary red panda occurrence data were listed in Table 1.

Table 1: Sources of secondary red panda occurrence data

Location	Number of red panda presence points	Source
Whole Nepal	22	Kandel et al., 2015
Rara National Park	73	Sharma, 2013
Jumla district	9	Bhatta et al., 2014
Dhorpatan Hunting Reserve	117	Panthi, 2011
Manang district	5	Paudel, 2009
Langtang National Park	14	Chalise, 2013
Langtang National Park	30	Kathayat, 2016

Gaurishankar Conservation Area	9	Thapa, 2016
Makalu-Barun National Park	15	MBNP, 2016
Ilam district	1	Chalise, 2009
Total	295	

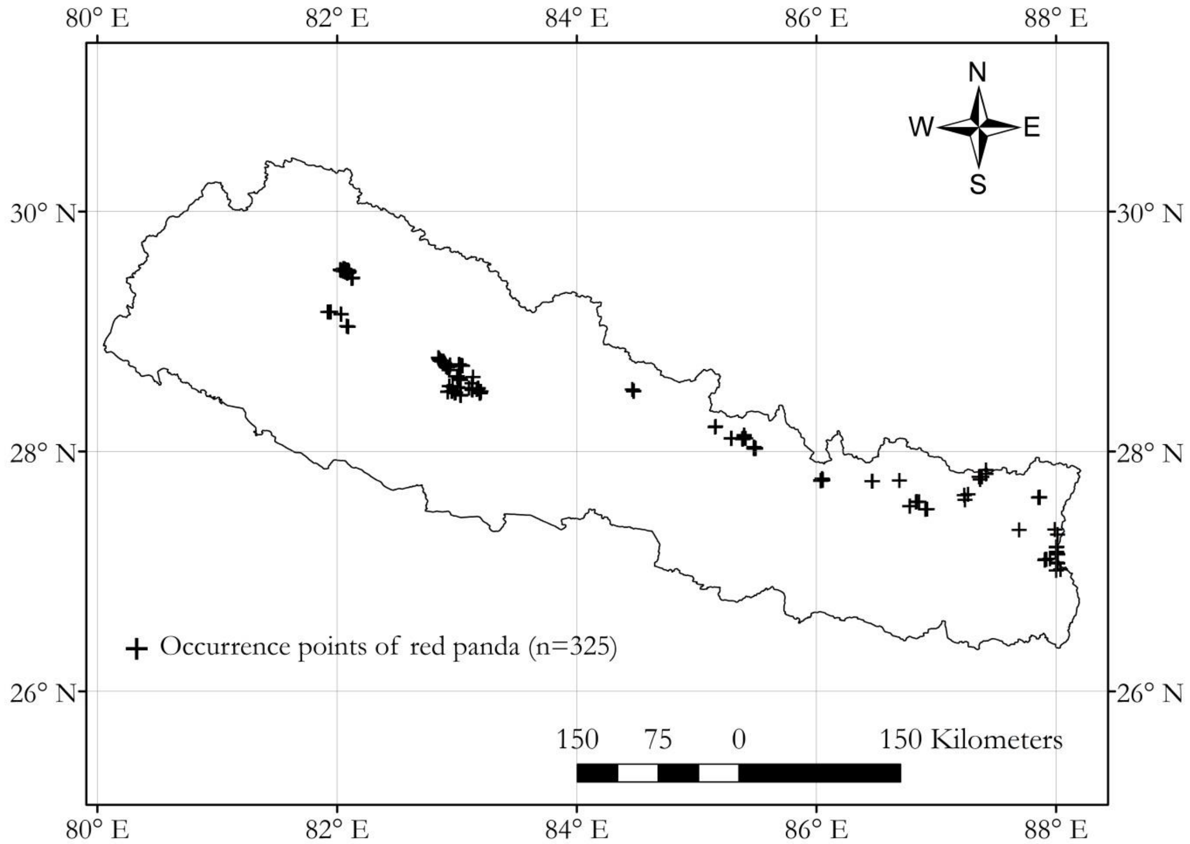

Figure 3: The geographical distribution of red panda occurrence points used for the study

2.2.2 Collection of primary red panda occurrence data

Based on the spatial distribution of the secondary red panda occurrence data, a number of red panda experts and local rangers were interviewed further in order to identify other potential red panda habitats for primary red panda occurrence data collection. The field survey was carried out between 11th September and 7th October 2017 in Langtang National Park, Ilam, Panchthar, and Dhading districts of Nepal. Due to the nature of the study, specifically the rugged mountainous characteristics of the field, data were collected by adopting a purposive sampling. In the field, the direct and indirect signs of red pandas (i.e., droppings) were recorded using a GPS. As a result, 30 primary data of red panda presence points were collected with a spatial accuracy of less than 50 meters.

2.2.3 Environmental variables

The environmental variables were downloaded from freely available sources (**Table 2**) and pre-processed in ArcGIS (ESRI, 2017) to make appropriate format (ASCII) and same spatial resolution (1 km). Some variables with vector features (i.e. point and line) were also converted into raster format having the same resolution (1 km). The environmental variables were divided into four categories as follows.

2.2.3.1 Bio-climatic variables

Every living being is sensitive to the climate. The bio-climatic variables are biologically meaningful variables for characterising species distribution at continent-scale (Blach-Overgaard et al., 2015) as well as at regional scale (Kandel et al., 2015). Bio-climatic variables were downloaded from the WorldClim database (http://worldclim.org/). The WorldClim database (version 2) is a set of global climate layers that derived from over 4000 weather stations between 1950 and 2000, including annual time series with annual means, seasonality, and extreme or limiting temperature and precipitation data (Hijmans et al., 2005). In this study, 19 bio-climatic layers with a spatial resolution of 1 km were used (Table 2).

2.2.3.2 Topographical variables

The topographical variables are major influential factors for the distribution of the animals. Elevation, aspect, and slope are most important topographical factors regarding selection of habitat by red panda (Bhatta et al., 2014; Dorji et al., 2011). These variables were used for the habitat modelling of the species since the beginning (Osborne et al., 2001). Topographical variables were already used to model the habitat of red panda (Kandel et al., 2015) and giant panda, a similar species of red panda (Sun, 2011; Wang et al., 2010). Digital Elevation Model (DEM) of 1 km resolution was downloaded from USGS website (https://earthexplorer.usgs.gov/), and slope and aspect were calculated from the DEM using ArcGIS software (ESRI, 2017).

2.2.3.3 Vegetation-related variables

Vegetation-related variables are major variables responsible for the distribution of the terrestrial animals (Andersen et al., 2000). The red panda is a herbivorous animal (Roberts and Gittleman, 1984), so the inclusion of vegetation-related variables to the model is a prerequisite for the robust habitat modelling. Normalized Difference Vegetation Index (NDVI) is a commonly used vegetation index for ecological research. The NDVI has been used to map the understory bamboo (Fava and Colombo, 2017; Shang et al., 2013; Wang et al., 2009), and it is significantly correlated with the distribution of understory bamboo (Wang et al., 2009). Therefore, the time series of NDVI was used as a surrogate of understory bamboo which was supposed to be a very important environmental variable to model the habitat of the red panda. Since most of the secondary red panda occurrence data were collected between 2009 and 2013, atmospherically corrected 10-day composite NDVI images of 1 km resolution over the period from 2009 to 2013 acquired by SPOT4 and SPOT5 Vegetation (VGT) sensor were downloaded (1800 images, three images per month) from website of European Space Agency product distribution portal (http://www.vito-eodata.be). These NDVI images were smoothed using an adaptive Savitzky-Golay filter in TIMESAT program (Jönsson and Eklundh, 2004). The seasonal characteristics of five full phonological cycles were constructed based on the five years' time series NDVI data and statistical products (i.e., maximum, mean, minimum, standard deviation and amplitude) of time series of the resulting smoothed data were used as environmental variables (Jiang et al., 2014).

The red pandas are living inside the forests and resting on horizontal branches and trunks of the trees (Roberts and Gittleman, 1984). Therefore, forest cover and canopy height were recognized as important variables for the habitat modelling of the red panda. The forests cover of Advance Land Observing Satellite (http://www.eorc.jaxa.jp/ALOS/en) and the forest canopy height of EARTH DATA/ NASA (Spatial data access tool) (https://webmap.ornl.gov/ogc) having 1 km spatial resolution were downloaded for input of the models (Simard et al., 2011).

2.2.3.4 Anthropogenic variables

The red panda is facing anthropogenic pressure (Glatston et al., 2015; Panthi et al., 2017; Yonzon and Hunter, 1991b). During the primary data collection also, human influences were realized as major threats to the red panda. Therefore, anthropogenic variables were added for robust modelling. Variable related to the population density having 1 km spatial resolution was downloaded from the socio-economic data and application centre (http://sedac.ciesin.columbia.edu) (CIESIN, 2016). The livestock density having 1 km spatial resolution was obtained from the website of livestock geo-wiki (https://livestock.geo-wiki.org) (Robinson et al., 2014). The road and path networks were downloaded from the website of Geofabrik (http://download.geofabrik.de/asia/nepal.html). The settlement points throughout Nepal were obtained from the Department of Survey, Nepal. The distance raster files of roads, paths, and settlements were created in ArcGIS (ESRI, 2017). The land use and land cover having 1 km spatial resolution was obtained from the website of fine resolution observation and monitoring global land cover (FROM-GLC) (http://data.ess.tsinghua.edu.cn) (Li et al., 2016).

2.3 Collinearity analysis

Removing the highly correlated variables for species distribution models is recommended for reliable and unbiased output (Braunisch et al., 2013). The values of the environmental variables of presence points were extracted from sample tool of ArcGIS (ESRI, 2017), and the collinearity between environmental variables was tested with the help of R software (Appendix I)(R Core Team, 2013). Very highly correlated ($|r| > 0.70$) variables were removed to obtain the reliable result (Dormann et al., 2013), although multicollinearity has very low (2-3%) impact on model performance (Merow et al., 2013). Important variables were identified based on the existing literature, field experiences, and expert knowledge. Finally, highly correlated and the less important variables (not bolded in Table 2) were removed from the dataset before the modelling.

Table 2: Environmental variables used for the current models

Data Sources	Categories	Variables	Abbreviation	Units
WorldClim	Bio-climatic (version 2)	**Annual mean temperature**	**bio1**	**◦ C**
		Mean diurnal range (mean of monthly (max temp – min temp))	**bio2**	**◦ C**
		Isothermality (BIO2/BIO7)	bio3	Dimensionless
		Temperature seasonality (standard deviation)	**bio4**	**◦ C**
		Max temperature of warmest month	bio5	◦ C
		Min temperature of coldest month	bio6	◦ C
		Temperature annual range (BIO5-BIO6)	bio7	◦ C
		Mean temperature of wettest quarter	bio8	◦ C
		Mean temperature of driest quarter	bio9	◦ C
		Mean temperature of warmest quarter	bio10	◦ C
		Mean temperature of coldest quarter	bio11	◦ C
		Annual precipitation	**bio12**	**mm**
		Precipitation of wettest month	bio13	mm
		Precipitation of driest month	**bio14**	**mm**
		Precipitation seasonality (coefficient of variation)	bio15	Dimensionless
		Precipitation of wettest quarter	bio16	mm
		Precipitation of driest quarter	bio17	mm
		Precipitation of warmest quarter	bio18	mm
		Precipitation of coldest quarter	bio19	mm
USGS GTOPO30	Topographic	Elevation	elevation	m
		Aspect	**aspect**	**Degree**
		Slope	**slope**	**Degree**
SPOT	Vegetation-related	**Annual minimum NDVI**	**ndvi_min**	**Dimensionless**
		Annual mean NDVI	ndvi_mean	Dimensionless
		Annual maximum NDVI	ndvi_max	Dimensionless
		Amplitude (difference of max and min) NDVI	ndvi_amp	Dimensionless
		Standard deviation NDVI	**ndvi_sd**	**Dimensionless**

ALOS Japan		**Forest cover**	**forestcover**	**Dimensionless**
NASA/ Earth data		**Forest canopy height**	**canopyheight**	**Dimensionless**
FROM-GLC	Anthropogenic	**Land use land cover**	**lulc**	**Dimensionless**
SEDAC		**Population density**	**pop_density**	**Population per square km**
GE OF AB RIK		**Distance to motor road**	**motorroad_dist**	**km**
		Distance to path	**path_dist**	**km**
Survey Dept. Nepal		**Distance to settlement**	**settle_dist**	**km**
Livestock Geo-wiki		**Livestock density**	**livestock_den**	**per square km**

Note: The variables without bold font were less important and highly correlated (|r| > 0.70) with other variables. Only bolded variables were used in models.

2.4 Habitat modelling

The Maximum Entropy (MaxEnt) Model was used to predict the habitat of the red panda by using the species occurrence points and environmental variables (Phillips et al., 2006). MaxEnt needs only presence data from the field, and it generates the pseudo-absence, so this model is becoming more popular among the species distribution models. Careful selection of extent of the background of environmental layers can minimise the sampling bias (Merow et al., 2013). In this study, no any primary and secondary data of red panda occurrence points were available from two physiographical regions of Nepal: Terai and Siwalik. Therefore, the extents of environmental variables were limiting to exclude these two physiographic regions to reduce the sampling bias. Sun (2011) adopted a distance of more than 3 km between presence points of the giant panda to reduce the spatial autocorrelation. During the field work of primary data collection of this study, it is realized there were different characteristics (slope, elevation, forests density, land use and land cover and so on) of environmental variables after one-kilometre distance due to undulating terrain of mountains. Therefore removing the duplicate presence points was realized sufficient action (only one presence points were used in one grid) to lessen the spatial autocorrelation. The 10,000 background points, 10 replicates, and 1000 maximum iteration were selected for the fine and reliable result (Barbet-Massin et al., 2013).

2.5 Model scenarios, evaluation, and statistical analysis

Models were run in three different scenarios to investigate the impact of specific variables as follows

1. Using only bio-climatic and topographical variables
2. Using only bio-climatic, topographical and vegetation-related variables
3. Using all bio-climatic, topographical, vegetation-related and anthropogenic variables

Assessment of the accuracy is essential to validate the models and to understand the performance of the models. Total 50 % of the species occurrence points were allocated for the training dataset, and 50 % were used as testing /validation dataset for all models. The models were evaluated by the two methods. One method was threshold independent, and another was threshold dependent. In threshold independent method, the area under the receiver-operator curve (AUC) of models were reported (Phillips et al., 2006; Wiley et al., 2003). The higher AUC, the higher the model performance was. The AUC <0.7 denotes poor model performance, 0.7–0.9 denotes moderately useful model performance, and >0.9 denotes excellent model performance (Pearce and Ferrier, 2000). Although AUC is classical and widely used model evaluation parameter, it is criticised by some researchers (Lobo et al., 2008). Therefore, threshold dependent accuracy assessment: True Skill Statistic (TSS) was also performed for the model evaluation (Merow et al., 2013). TSS was calculated for all model outputs (0-9 replications), and final TSS was averaged of all 10 replications (Jiang et al., 2014). The accuracies of 10 replicates were normally distributed for all models (Shapiro-Wilk test, $p=0.05$) so the accuracies of models were compared using t-test (5% level of significance) to find out the importance vegetation-related and anthropogenic variables to the red panda habitat suitability models.

The maximum sum of sensitivity and specificity (MaxSSS) threshold is appropriate to convert the continuous probability map to binary map when only presence data are available from the field (Liu et al., 2013). Therefore, this threshold was used to produce the habitat distribution map of the red panda in Nepal. The habitat distribution of red pandas was identified by three models. The outcome obtained from the most accurate model was realised as the suitable habitat of red panda in Nepal.

2.6 Assessment of impacts of climate change on red panda habitat

The future projection of suitable habitat for red pandas was modelled by the MaxEnt. The MaxEnt is widely used and established functionality for projecting the future habitat of the species under the climate and land cover change based on current species-environment relationships (Aguilar et al., 2015; Aryal et al., 2016; Fuller et al., 2008; Holt et al., 2009; Pickles et al., 2013; Rödder and Weinsheimer, 2009). The topographical variables were not changed within simulation period (2070). The version 1.4 of bio-climatic variables (Hijmans et al., 2005) and land use and land cover of FROM-GLC (Li et al., 2016) are available for the future projection. Vegetation-related and other anthropogenic variables may be changed, but future projections of these variables are not available. Titeux et al. (2017) suggested integrating the climatic variables and land use change scenario to explore the possible futures for biodiversity. Therefore, models were run using topographic variables, current bio-climatic variables as well as land use and land cover (Table 3), and then projected onto the future climate and land use and land cover.

The representative concentration pathways (RCP) 4.5 is the more realistic carbon emission scenario and provides the common platform for future climate change (Thomson et al., 2011). Therefore, RCP 4.5 of 2070 was used for the future prediction of suitable habitat for red pandas. Model for Interdisciplinary Research on Climate (MIROC5) global climate model (GCM) was selected because it is the latest model and recommended for interdisciplinary research on climate changes (Watanabe et al., 2010).

The data acquisition, exploration, processing, modelling, and validation were done as described in the previous sections of the methodology part of this thesis. Less important and highly correlated ($|r| > 0.70$) variables were excluded at the time of modelling (Appendix II). Finally, percentage of loss or surplus and range shifting situation of red panda habitat due to climate and land use and land cover change were identified by comparing the outputs of current and future models.

Model with bio-climatic and topographical variables only was run for comparison to explore the importance of land use and land cover variables. All accuracies of two models except the AUC of model using land use and land cover, bio-climatic and topographical variables were normally distributed (Shapiro-Wilk test, $p=0.05$); therefore t-test (5% level of significance) was performed to explore the significant impact of land use and land cover by comparing the accuracies of both model scenarios.

Table 3: Environmental variables used for future models

Data Sources	Categories	Variables	Abbreviation	Units
WorldClim	Bio-climatic	**Annual mean temperature**	**bio1**	◦ C
		Mean diurnal range (mean of monthly (max temp – min temp))	**bio2**	◦ C
		Isothermality (BIO2/BIO7)	**bio3**	**Dimensionless**
		Temperature seasonality (standard deviation)	bio4	◦ C
		Max temperature of warmest month	bio5	◦ C
		Min temperature of coldest month	bio6	◦ C
		Temperature annual range (BIO5-BIO6)	bio7	◦ C

		Mean temperature of wettest quarter	bio8	◦ C
		Mean temperature of driest quarter	bio9	◦ C
		Mean temperature of warmest quarter	bio10	◦ C
		Mean temperature of coldest quarter	bio11	◦ C
		Annual precipitation	**bio12**	**mm**
		Precipitation of wettest month	bio13	mm
		Precipitation of driest month	**bio14**	**mm**
		Precipitation seasonality (coefficient of variation)	**bio15**	**Dimensionless**
		Precipitation of wettest quarter	bio16	mm
		Precipitation of driest quarter	bio17	mm
		Precipitation of warmest quarter	bio18	mm
		Precipitation of coldest quarter	bio19	mm
USGS GTOPO30	Topographic	Elevation	elevation	m
		Aspect	**aspect**	**Degree**
		Slope	**slope**	**Degree**
FROM-GLC	Anthropogenic	**Land use and land cover**	**lulc**	**Dimensionless**

The variables without bold font were less important and highly correlated ($|r| > 0.70$) with other variables. Only bolded variables were used in the model as environmental variables.

3. RESULTS

3.1 Current suitable habitat for red pandas in Nepal

3.1.1 Predicted current suitable habitat for red pandas using the bio-climatic and topographical variables

The model was run by using only the bio-climatic and topographical variables as described in Table 2. A total of 20,178 km^2 is identified as suitable habitat for red pandas (Figure 4). This area is equal to the 13.71 % of the total area of Nepal. The threshold 0.201 was used to convert the continuous map (habitat suitability) to binary map. The AUC and TSS of the model are 0.9191 and 0.7366 respectively.

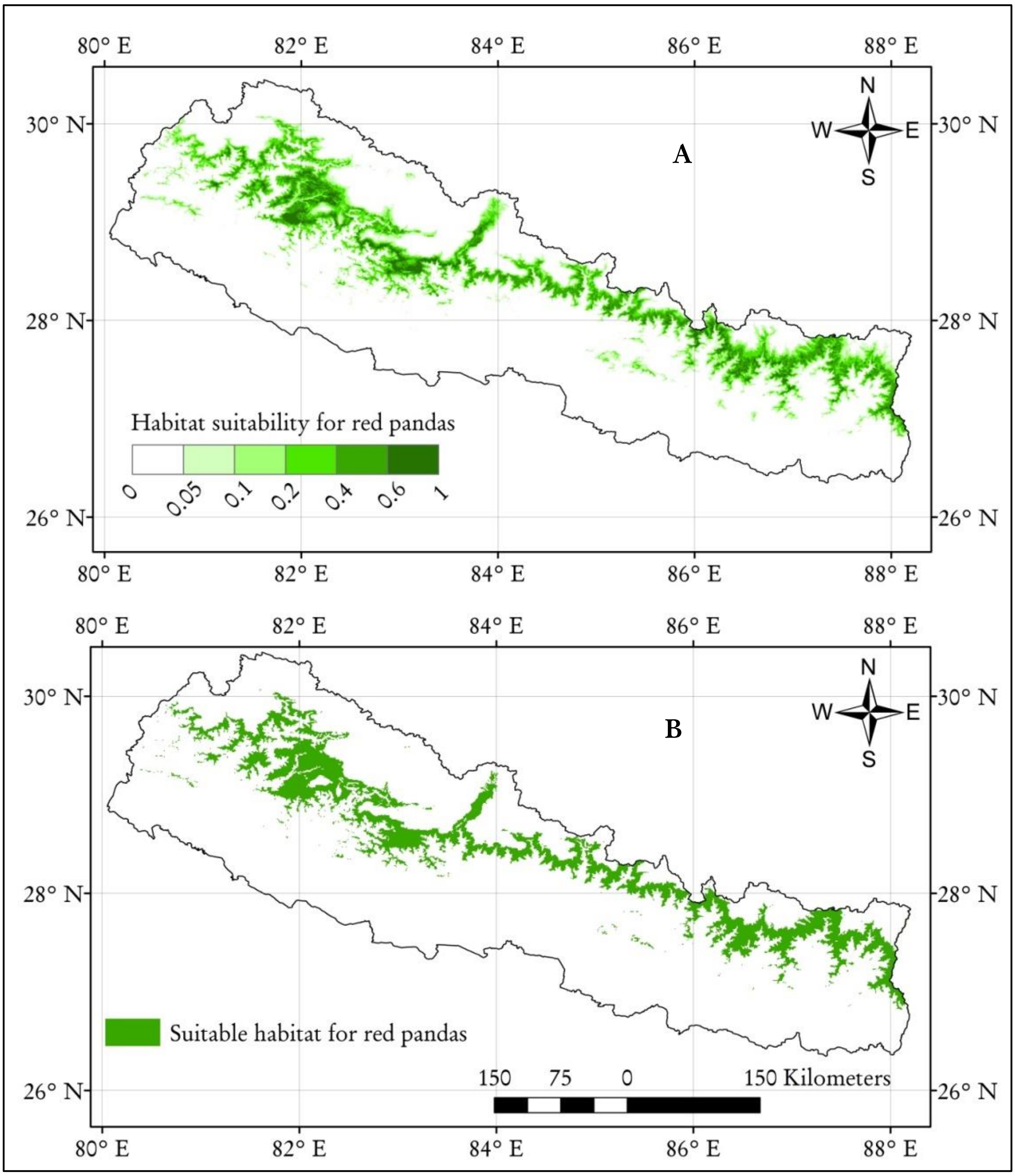

Figure 4: Predicted red panda habitat based on the inputs of bio-climatic and topographical variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

3.1.2 Predicted current suitable habitat for red pandas using the bio-climatic, topographical and vegetation-related variables

The model was run by using bio-climatic, topographical and vegetation-related variables as described in Table 2. A total of 18,193 km^2 is identified as suitable habitat for red pandas in Nepal (Figure 5). This area is equivalent to 12.36 % of total area of Nepal. The threshold 0.116 was used to convert the continuous map (habitat suitability) to binary map. The AUC and TSS of the model are 0.9300 and 0.7485 respectively.

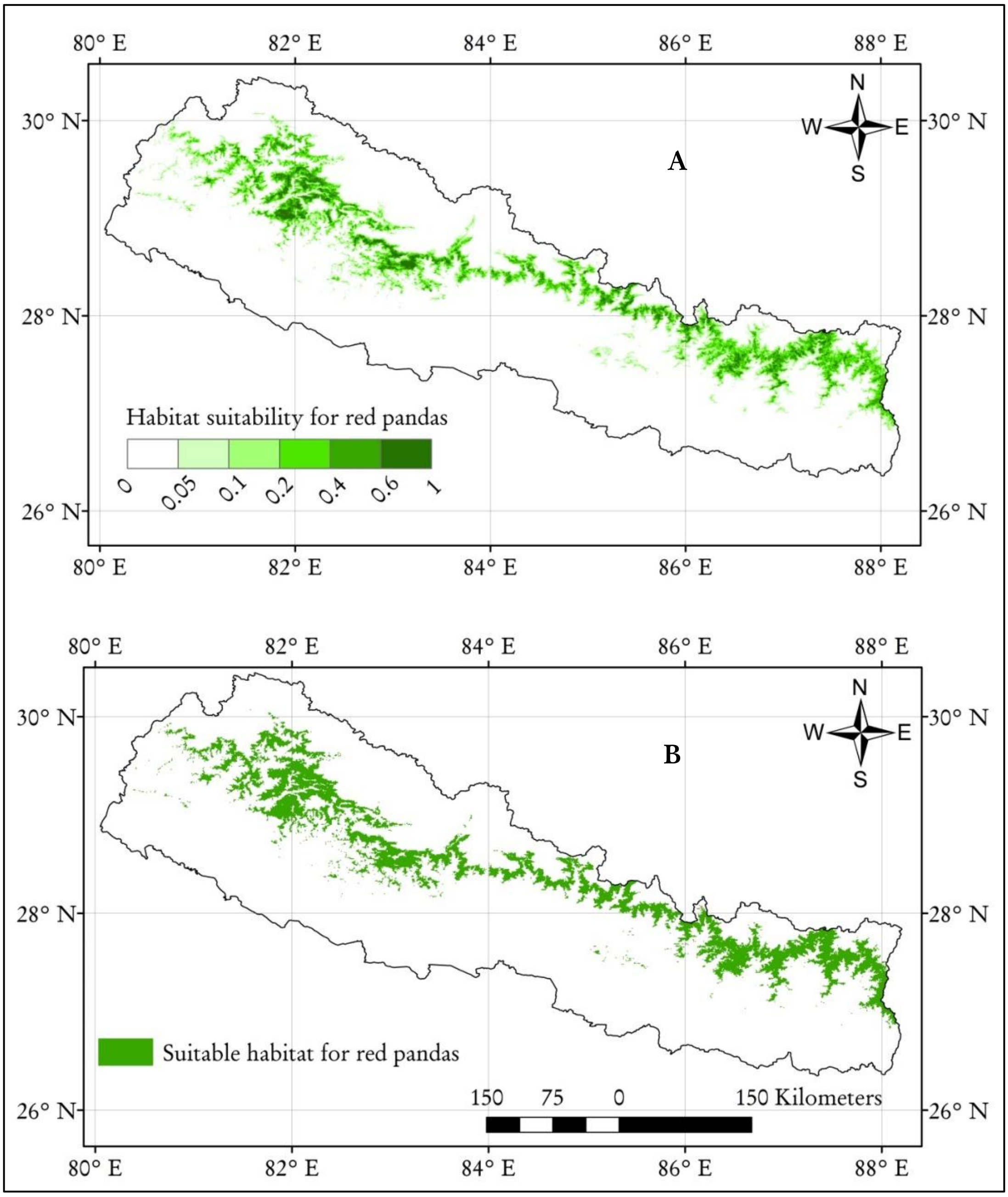

Figure 5: Predicted red panda habitat based on the inputs of bio-climatic topographical and vegetation-related variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

3.1.3 Predicted current suitable habitat for red pandas using bio-climatic, topographical, vegetation-related and anthropogenic variables

In this model, all bio-climatic, topographical, vegetation-related, and anthropogenic variables were used as environmental variables for modelling purpose. A total of 13,781 km^2 is identified as suitable habitat for red pandas throughout Nepal (Figure 6). This amount is approximately 9.36 % land of the total area of Nepal. The threshold 0.102 was used to convert the continuous map (habitat suitability) to binary map. The AUC and TSS of the model are 0.9454and 0.7676 respectively.

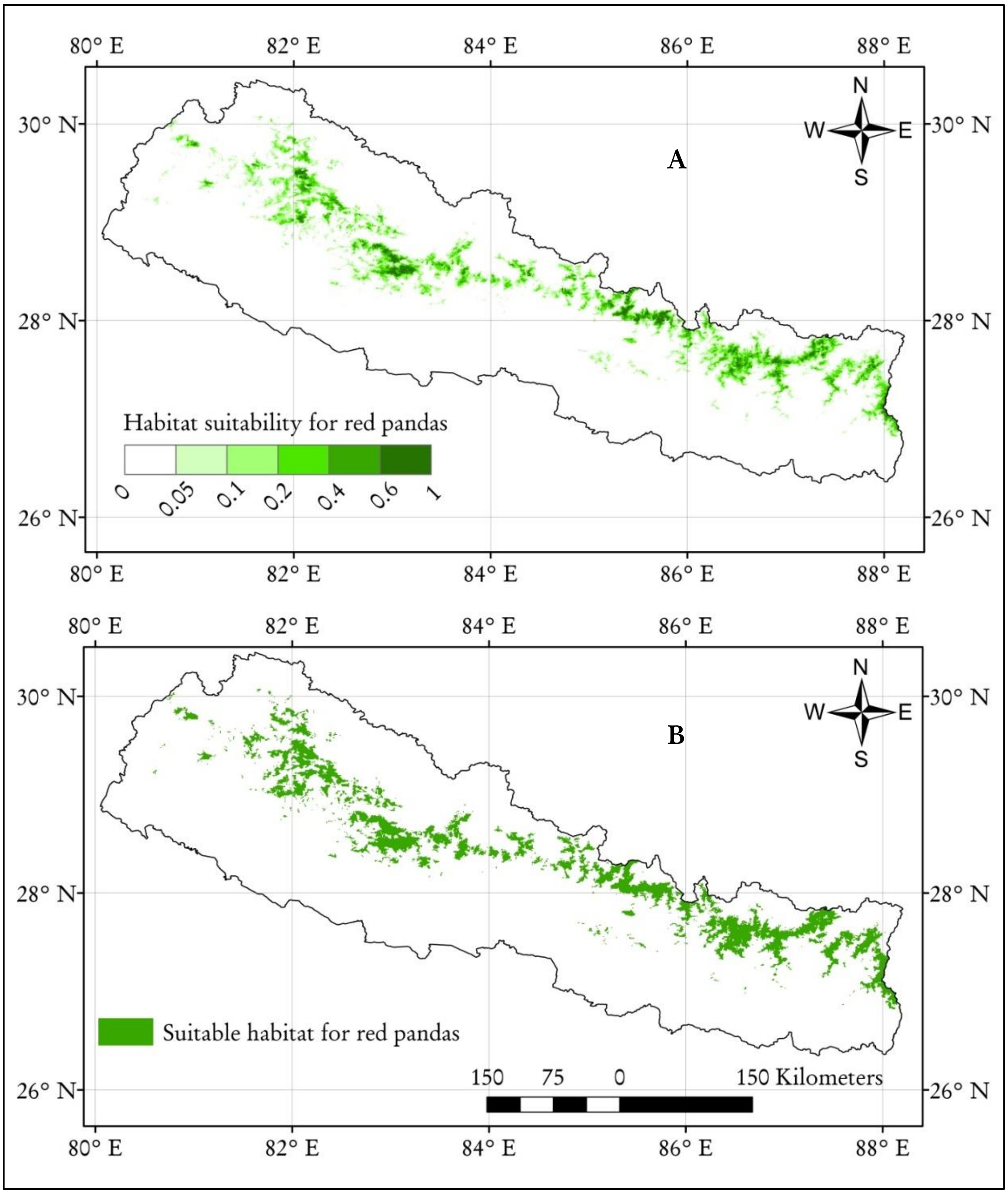

Figure 6: Predicted red panda habitat based on the inputs of bio-climatic, topographical, vegetation-related and anthropogenic variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

3.2 Accuracy comparison between three different model scenarios for the prediction of current suitable red panda habitat

One objective of this study was to investigate the impact of different types of variables when modelling the suitable habitat for red pandas. At first, one model was run by using only the bio-climatic and topographical variables. When the vegetation-related variables were added to the model, the AUC was significantly improved ($p<0.05$) (Table 4). Again vegetation-related and anthropogenic variables were added to the model then TSS and AUC were improved significantly ($p< 0.05$).

Table 4: Performance of models to predict the current suitable habitat for red pandas
Different superscript letters denotes the significant different at $p=0.05$

Model	AUC		TSS	
	Mean	SD	Mean	SD
Bioclim-topo	0.9191^{a}	0.0082	0.7366^{a}	0.0337
Bioclim-topo+veg	0.9300^{b}	0.0067	0.7485^{ac}	0.0236
Bioclim-topo+veg+anthro	0.9454^{c}	0.0103	0.7676^{bc}	0.0295

3.3 Distribution and abundance of the predicted current red panda habitat

3.3.1 Habitat distribution in relation to protected areas

Approximately three-fifth of the red panda habitat is located outside the existing protected areas of Nepal. Out of 13,781 km^2 red panda habitat, 5,578 km^2 (Table 5) is located inside the existing 13 protected areas of Mountain region of Nepal (Figure 7). The remaining 8,203 km^2 habitat is located outside the protected areas. Langtang National Park is the most important for red panda which covers the largest amount of the red panda habitat among the protected areas. Its core zone and buffer zone cover 784 km^2 and 170 km^2 suitable habitat for red panda respectively. The Khaptad National Park and its buffer zone cover only 31 km^2 habitat of red panda which is the smallest proportion of the suitable habitat for red panda among all protected areas of the high Mountain region of Nepal.

Table 5: Predicted red panda habitat covered by existing protected areas in Nepal

	Name of Protected Area	Area of red panda habitat (km^2)		
		Core Zone	Buffer Zone	Total Area
A	Api Nampa Conservation Area			159
B	Khaptad National Park	27	4	31
C	Rara National Park	99	84	183
D	Shey-Phoksundo National Park	47	110	157
E	Dhorpatan Hunting Reserve			733
F	Annapurna Conservation Area			907

G	Manaslu Conservation Area			233
H	Langtang National Park	784	170	954
I	Shivapuri Nagarjun National Park	54	2	56
J	Gaurishankar Conservation Area			917
K	Sagarmatha National Park	43	95	138
L	Makalu-Barun National Park	388	412	800
M	Kanchanjungha Conservation Area			310
	Total	1442	877	5578

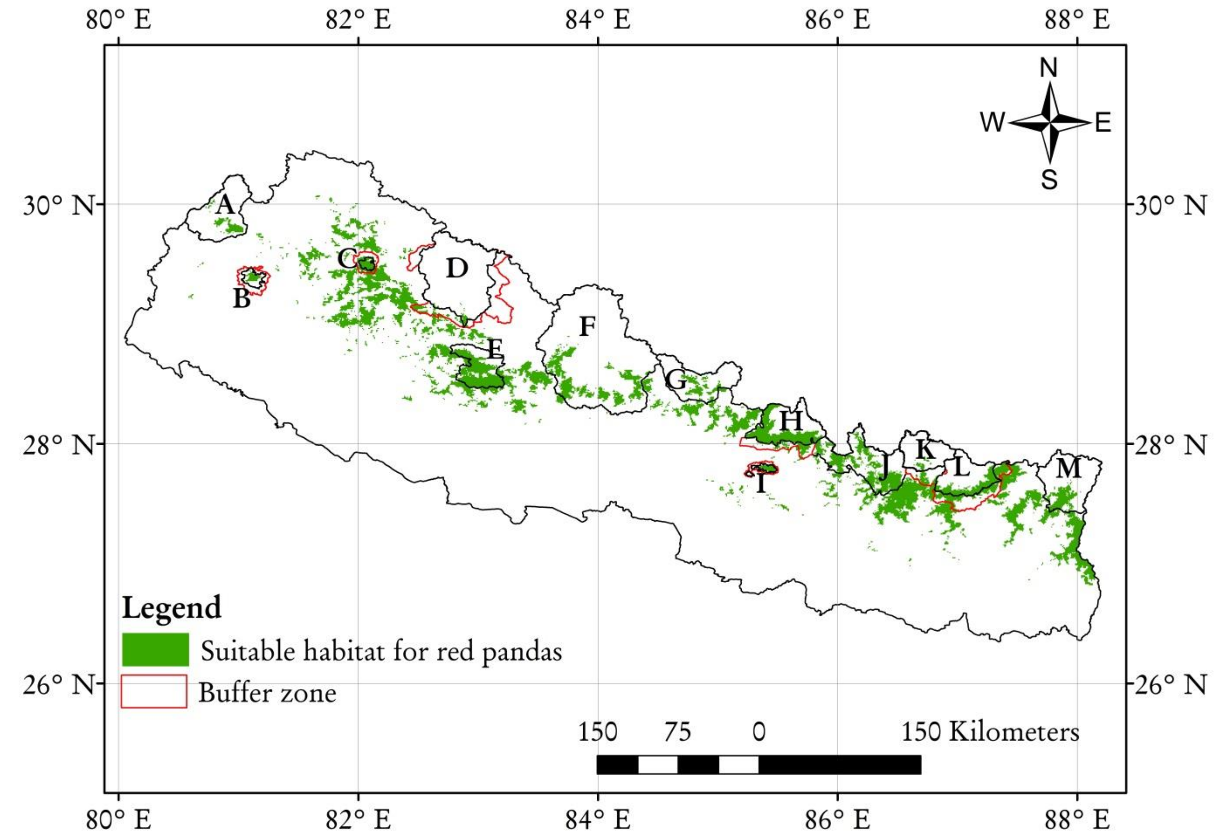

Figure 7: The distribution of current predicted red panda habitat inside and outside the protected areas

(A) Api Nampa Conservation Areas (B) Khaptad National Park and its Buffer Zone (C) Rara National Park and its Buffer Zone (D) Shey-Phoksundo National Park and its Buffer Zone (E) Dhorpatan Hunting Reserve, (F) Annapurna Conservation Area (G) Manaslu Conservation Area (H) Langtang National Park and its Buffer Zone, (I) Shivapuri Nagarjun National Park and its Buffer Zone (J) Gaurishankar Conservation Area (K) Sagarmatha National Park and its Buffer Zone, (L) Makalu Barun National Park and its Buffer Zone, (M) Kanchanjungha Conservation Area

3.3.2 Habitat distribution in relation to political boundaries

The Solukhumbu district where Mount Everest is located covers the highest amount of red panda habitat. This district covers the Sagarmatha National Park and some part of Makalu-Barun National Park. Including Solukhumbu, Jumla, Sankhuwasabha, Taplejung, and Rukum are top 5 districts which cover the suitable habitat for red pandas in Nepal (Table 6).

Table 6: Predicted red panda habitat covered by different districts in Nepal

S.N.	Name of district	Area (km^2)
1	Solukhumbu	1219
2	Jumla	1073
3	Sankhuwasabha	1041
4	Taplejung	865
5	Rukum	792
6	Sindhupalchok	782
7	Myagdi	687
8	Baglung	607
9	Dolakha	575
10	Rasuwa	560
11	Gorkha	535
12	Dolpa	442
13	Kalikot	397
14	Mugu	367
15	Humla	323
16	Ramechhap	307
17	Ilam	306
18	Kaski	292
19	Panchthar	272
20	Bajura	251
21	Mustang	236
22	Manang	213
23	Dhading	200
24	Okhaldhunga	184
25	Lamjung	168
26	Jajarkot	167
27	Darchula	159
28	Rolpa	129
29	Khotang	113
30	Nuwakot	109
31	Bhojpur	89
32	Bajhang	56
33	Makawanpur	50
34	Kathmandu	47
35	Doti	40
36	Kavre	31
37	Parbat	24
38	Pyuthan	20
39	Tehrathum	15
40	Sindhuli	8

41	Dadeldhura	8
42	Udayapur	6
43	Baitadi	5
44	Achham	5
45	Dailekh	3
46	Lalitpur	2
47	Dhankuta	2
48	Slyan	1
49	Gulmi	1
Total		13781

3.3.3 Habitat distribution along the elevation gradients

Most (75%) of the predicted suitable red panda habitat is situated between 2400 m- 3800 m in Nepal. The suitable habitats are decreasing towards the upper and lower elevations (Figure 8). Very little area of predicted suitable red panda habitat (2%) is located below 1600 m and above 4600 m.

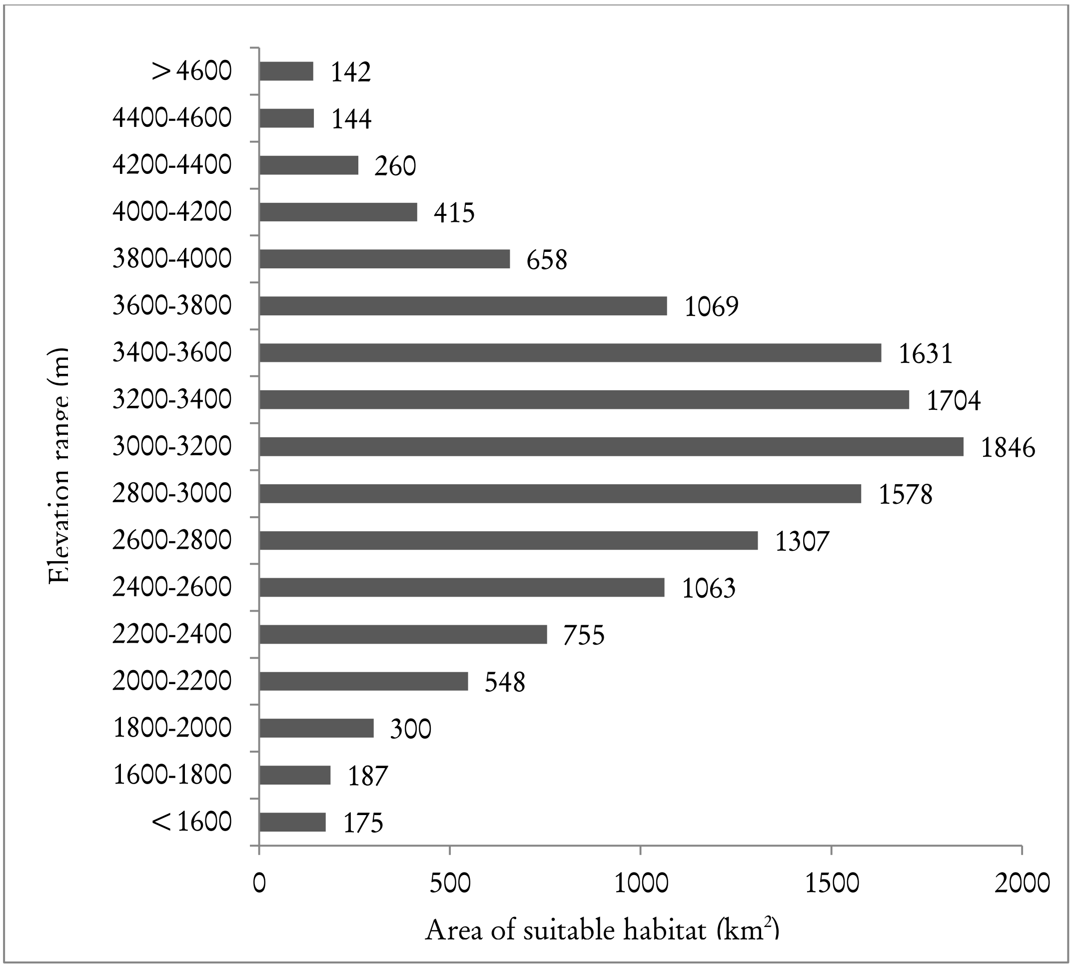

Figure 8: Predicted suitable habitat for red pandas along the elevation gradients in Nepal

3.4 Variable importance to the prediction of current suitable habitat for red pandas

The importance of variables to the prediction of suitable red panda habitat is shown in Figure 9. It indicates that topographic variables (e.g. slope and aspect) barely useful to the prediction of suitable habitat for red pandas. Of the climatic variables, annual mean temperature (Bio 1) and mean monthly diurnal temperature range (Bio 2) are more useful to the prediction of suitable habitat for red pandas. Of the vegetation-related variables, forest cover, canopy height, and minimum NDVI are more useful to the prediction of suitable habitat for red pandas. Of the anthropogenic variables, distance from paths, livestock density, and population density are more useful to the prediction of suitable habitat for red pandas. Among all input predictor variables, annual mean temperature, distance from paths and livestock density are most important to the prediction of red panda habitat in Nepal.

In **Figure 9,** the regularised gain of the model without Bio1 was lesser than that of the model using without other single variables, so the Bio1 is a more useful variable to the model. Similarly the regularised gain of the models without distance from paths, livestock density, population density and minimum NDVI are less so these variables are useful to model the habitat of red panda.

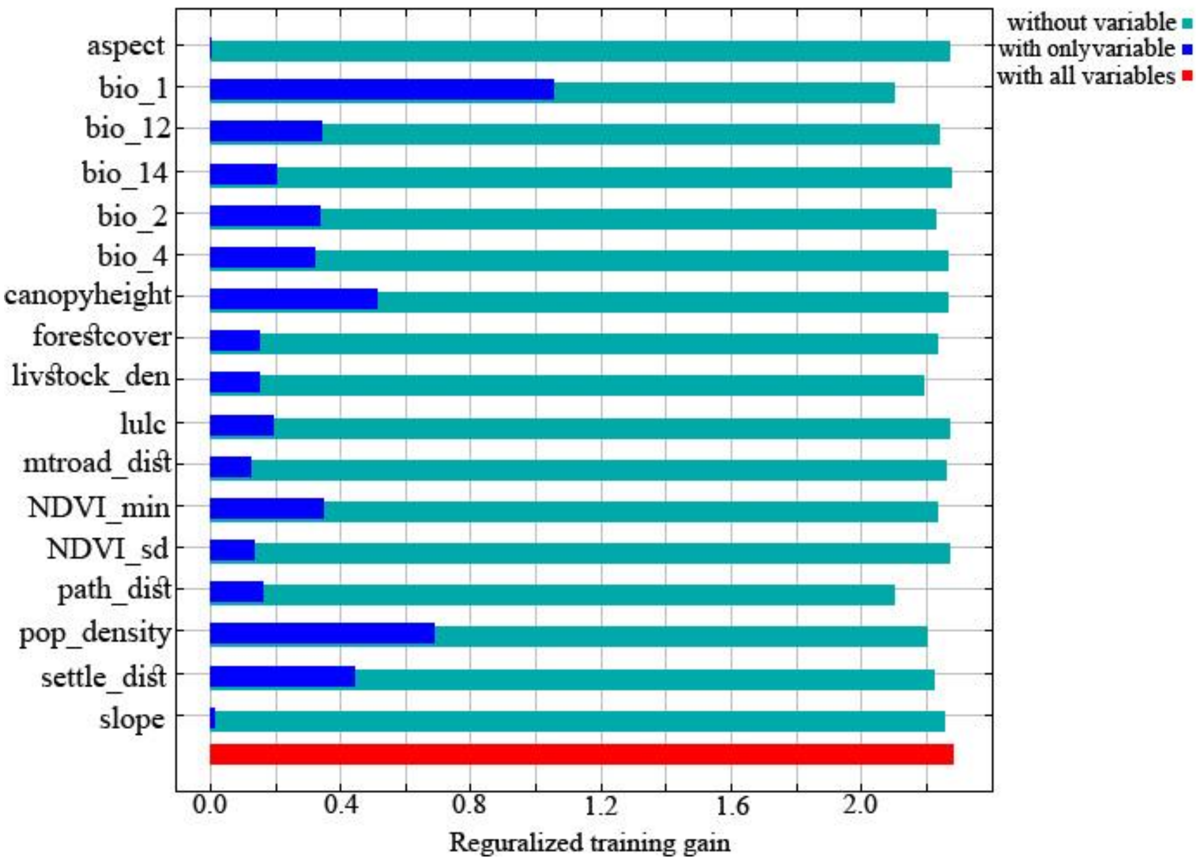

Figure 9: Importance of environmental variables in modelling the current suitable habitat for red pandas in Nepal

Note: The regularised training gain explain how much better the model distribution fits the presence data compared to a uniform distribution. "Without variable" denotes the effect of removing that single variable from the mode and "with only variable" denotes the results of the model when an only that variable is run. "With all variables" indicates the results of the model when all variables are run (Phillips, 2017). See Table 2 for full variable names and descriptions.

Response curves are useful to interpret the limiting environmental factors of suitable habitat for red pandas. Response curves illustrate the probability of suitable red panda habitat to the predictor variable. These curves show how the response changes for a particular variable (Phillips, 2017). The response curves of Figure 10 were derived from the model using all four categories of variables (i.e., bio-climatic, topographic, vegetation-related, and anthropogenic variables) in the model.

Responses of the important variables for prediction of suitable habitat for red pandas are presented in Figure 10. Red panda habitat is limiting to a certain range of the annual mean temperature (Bio1) and mean monthly diurnal temperature range (Bio 2). The habitat of red pandas is located between five and 10-degree centigrade mean annual temperature and zero to 10-degree centigrade mean monthly diurnal temperature range. Habitat which is located at the higher and lower temperatures from this range is not suitable for red pandas. The higher canopy height and the denser forests are an indication of suitable habitat for red pandas (Figure 10). The probability of the presence of suitable habitat for red pandas is higher in medium (around 0) but lower in very low and very high minimum NDVI. The presence of suitable habitat for red pandas has a negative response to the higher livestock density and higher population density. The suitable habitat for red pandas is facing the large anthropogenic pressure regarding forests paths. There are lots of paths near to the red panda habitat. The probability of distribution the red panda habitat is higher near to the paths and trails (Figure 10).

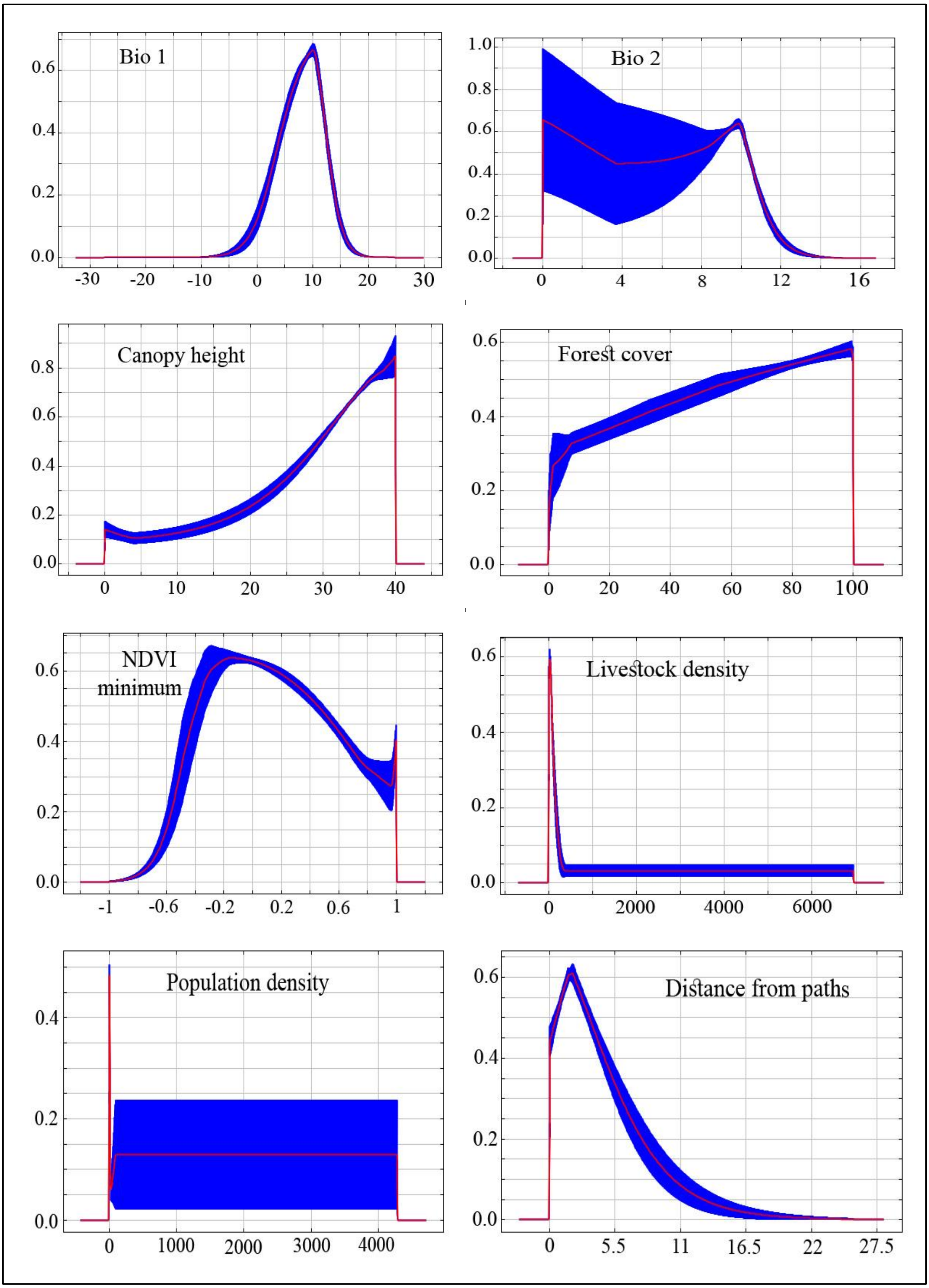

Figure 10: Response of variables to the distribution of the red panda habitat

3.5 Future suitable habitat for red pandas in Nepal

3.5.1 Predicted future suitable habitat for red pandas using bio-climatic and topographical variables

The model was run to find the current and future suitable habitat (2070) for red pandas by using bio-climatic (version 1.4) and topographical variables. A total of 16,920 km^2 of habitat is identified as current suitable habitat for red pandas in Nepal (Figure 11), but that will be 18,019 km^2 in 2070 due to climate change (Figure 12). Suitable habitat for red pandas will be increased by 6.5% in 2070 due to climate change. The threshold 0.202 was used to convert the continuous map (habitat suitability) to binary map. The AUC and TSS of the model are 0.9174 and 0.7303 respectively.

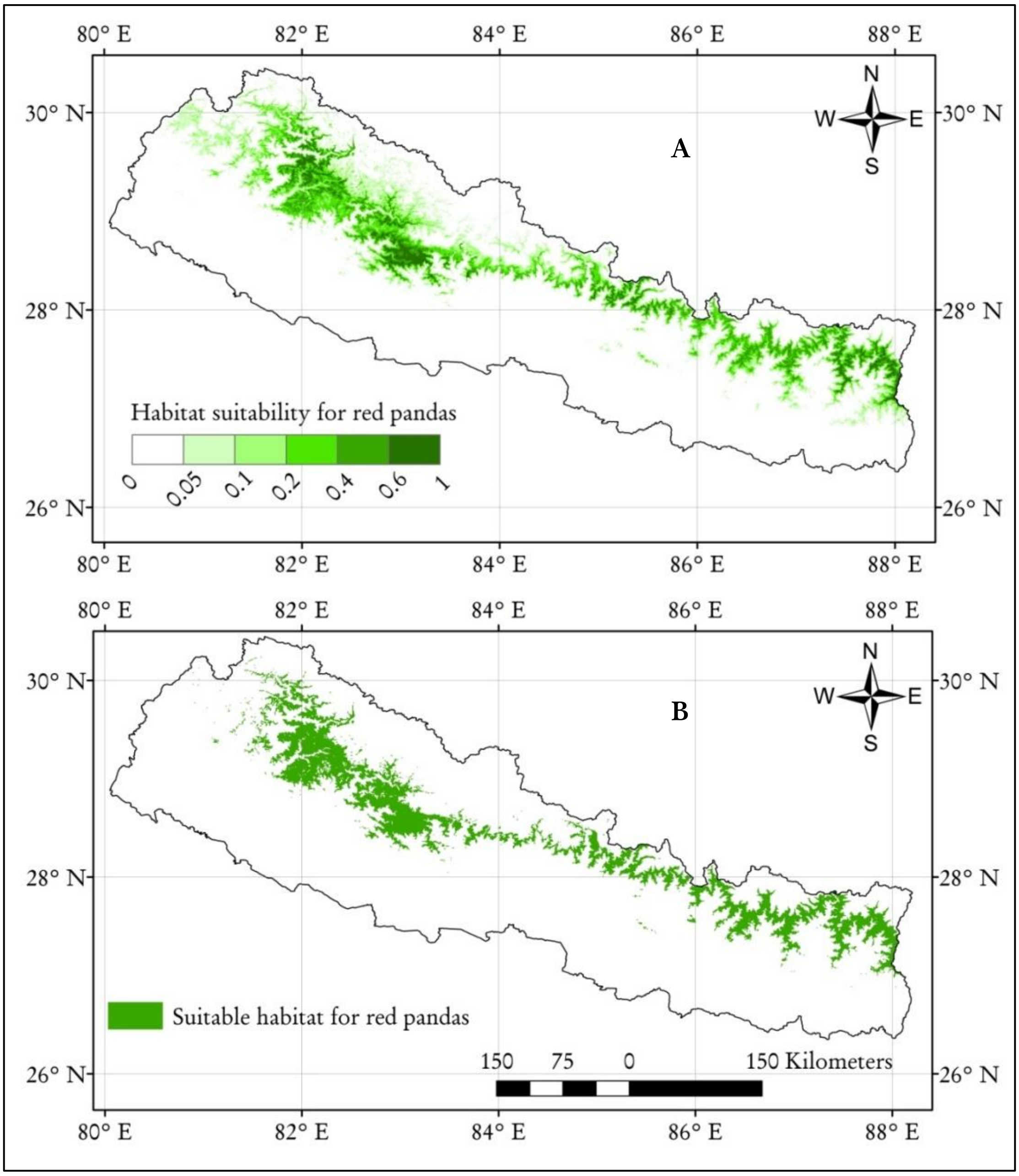

Figure 11: Predicted current red panda habitat based on the inputs of bio-climatic (version 1.4) and topographical variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

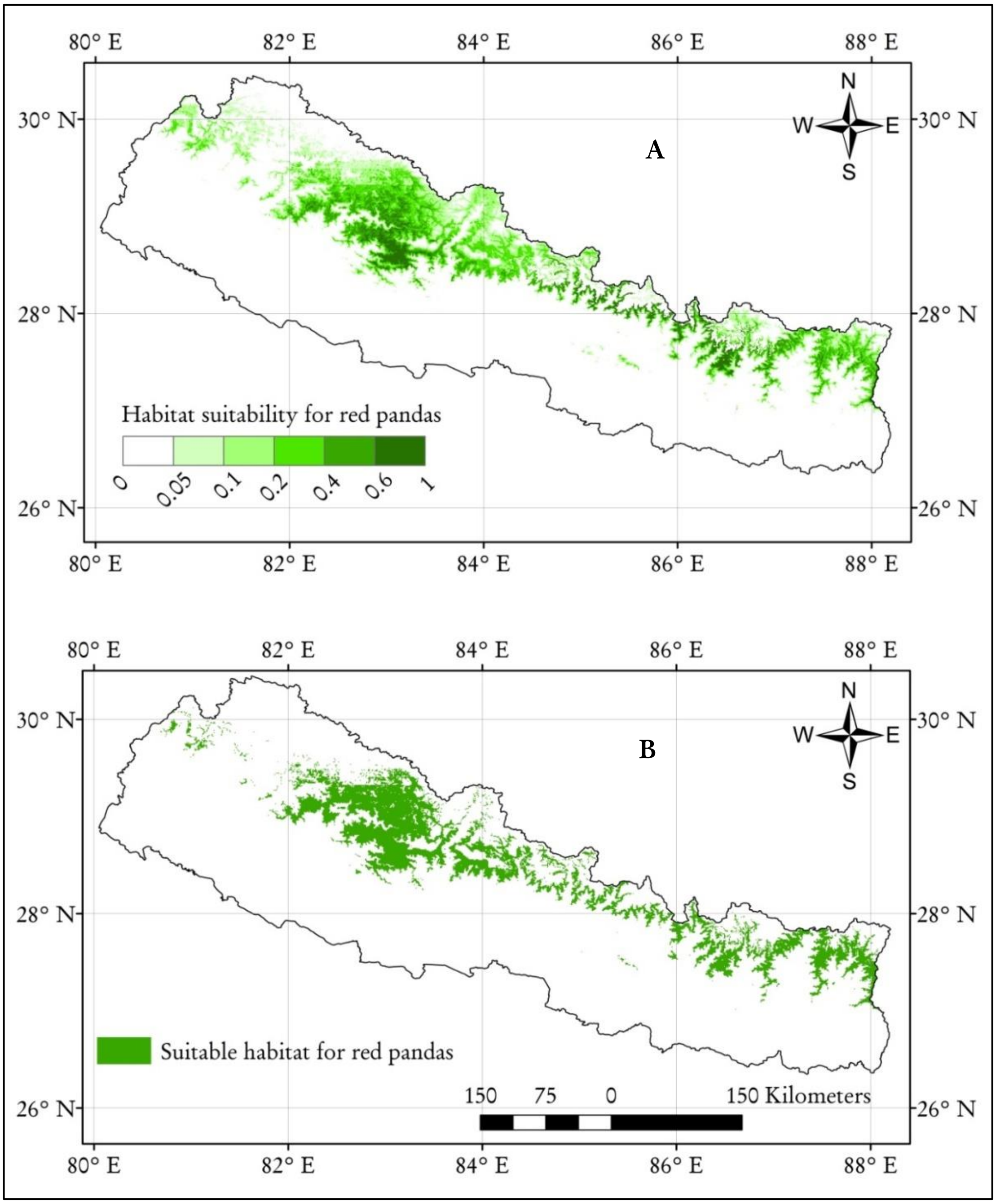

Figure 12: Predicted future (2070) red panda habitat based on the inputs of bio-climatic (version 1.4) and topographical variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

3.5.2 Predicted future suitable habitat for red pandas using land use and land cover, bio-climatic and topographical variables

The model was run by using land use and land cover, bio-climatic and topographical variables. A total of 16,725 km^2 of habitat is identified as current suitable habitat for red pandas in Nepal (Figure 13), but that will be 16,649 km^2 in 2070 due to climate and land use and land cover change (Figure

14). Suitable habitat for red pandas will be reduced by 0.5% in 2070 due combined effect of climate, and land use and land cover change (Figure 15). The threshold 0.220 was used to convert the continuous map (habitat suitability) to binary map. The AUC and TSS of the model are 0.9256 and 0.7436 respectively.

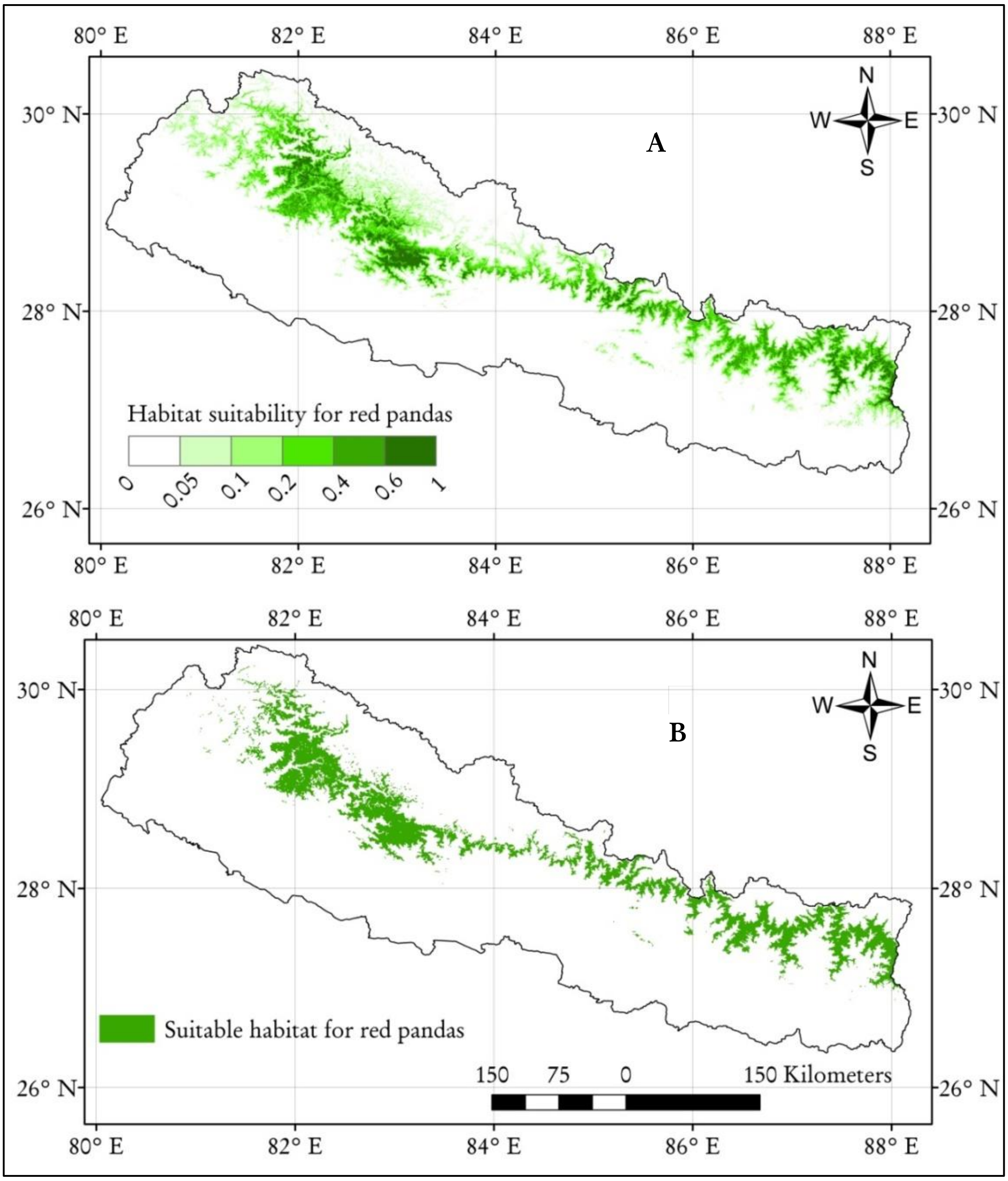

Figure 13: Predicted current red panda habitat based on the inputs of land use and land cover, bio-climatic (version 1.4) and topographical variables (A) Habitat suitability of red panda (B) Suitable habitat for red pandas

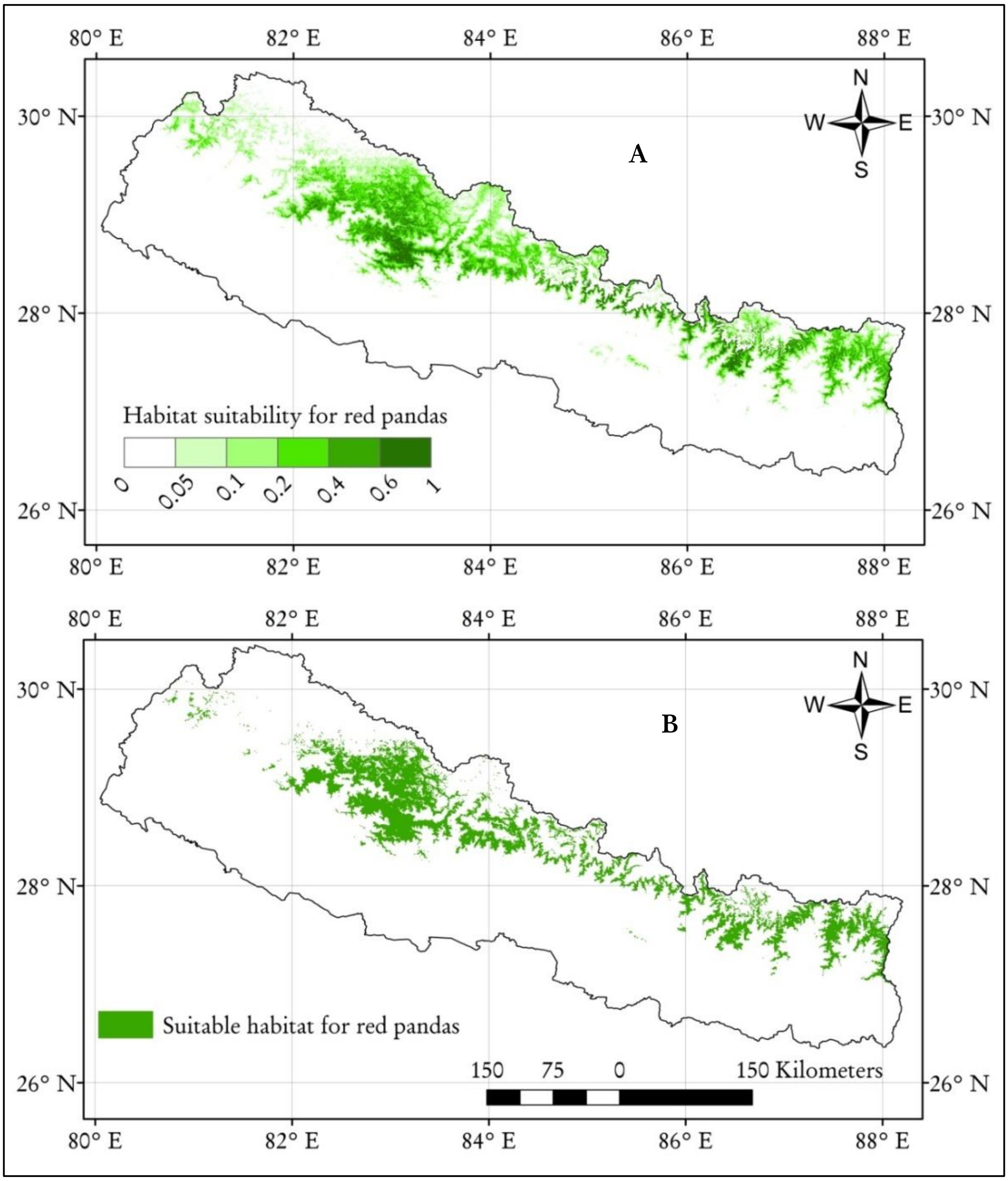

Figure 14: Predicted future (2070) red panda habitat based on the inputs of land use and land cover, bio-climatic (version 1.4) and topographical variables (A)Habitat suitability of red panda (B) Suitable habitat for red pandas

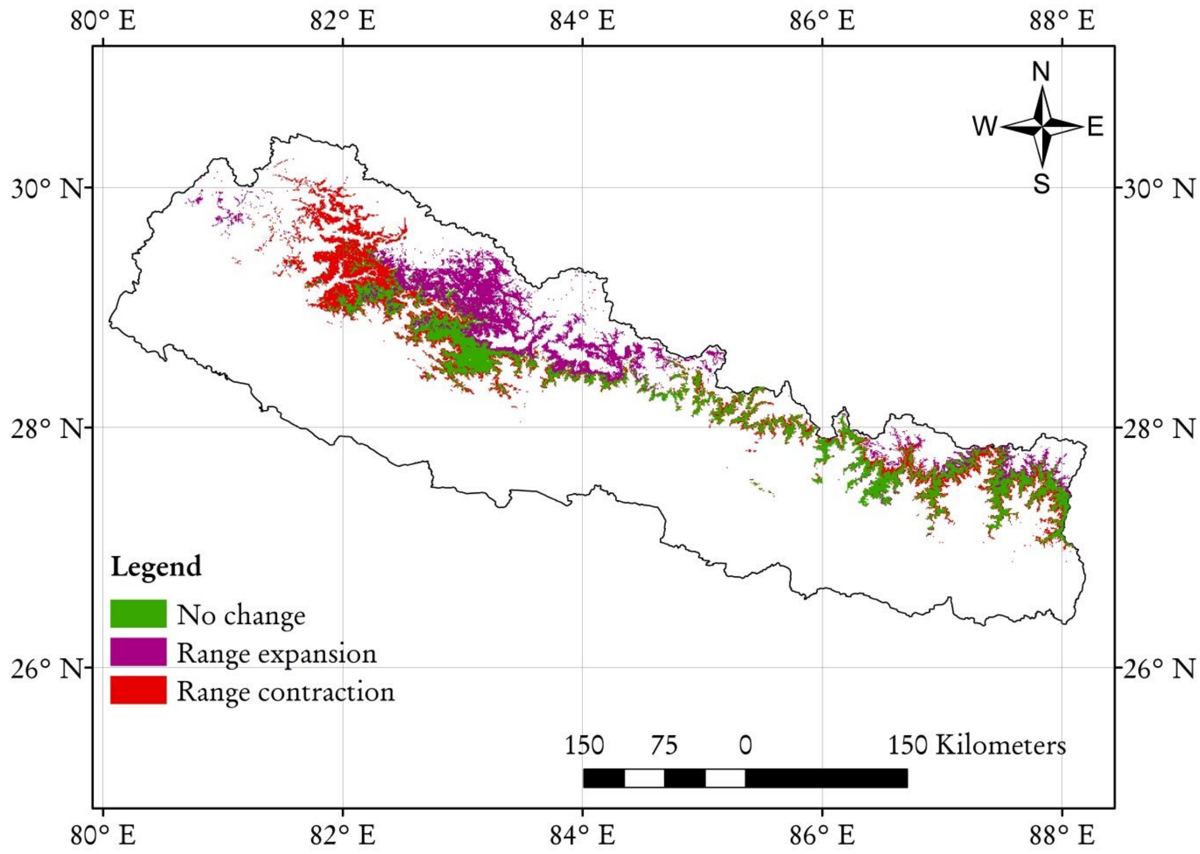

Figure 15: The change detection of predicted current and future (2070) red panda habitat

3.6 Comparison of future model scenarios

As described in the methods and results sections, two models were run to explore the future suitable habitat (2070) for red pandas in Nepal. One was model which used only bio-climatic and topographical variables, and other was used land use and land cover, bio-climatic and topographical variables. When the land use and land cover was added to the model, AUC was significantly improved ($p < 0.05$) (Table 7).

Table 7: Performance of models to predict the future suitable habitat for red pandas
Different superscript letters denotes the significant different at $p = 0.05$

Model	AUC		TSS	
	Mean	SD	Mean	SD
Bioclim-topo	0.9174[a]	0.0084	0.7303[a]	0.0172
Bioclim-topo+lulc	0.9256[b]	0.0081	0.7436[a]	0.0243

The model which used land use and land cover, bio-climatic and topographical variables is highly accurate than the model which used bioclimatic and topographical variables. Therefore the area identified by the model which used land use and land cover, bio-climatic and topographical variables model is realised as the habitat of red panda in future (2070). The findings of this model were used for further discussion.

4. DISCUSSION

4.1 Distribution and abundance of current suitable habitat for red pandas in Nepal

This study was designed to model the suitable habitat for red pandas in Nepal. Kandel et al. (2015) identified an area of 17,400 km^2 as red panda habitat in Nepal but in this study, approximately 13, 800 km^2 is identified as a suitable habitat of red pandas in Nepal. That study used only bio-climatic and topographical variables as environmental variables. The red panda prefers to live in forest with understory bamboo (Panthi et al., 2012; Roberts and Gittleman, 1984) and it is facing the serious anthropogenic pressures since the 1980s (Glatston et al., 2015; Panthi et al., 2017; Yonzon and Hunter, 1991b) but Kandel et al. (2015) ignored the anthropogenic vegetation-related variables to model the suitable habitat for red pandas. In this study, the vegetation-related and anthropogenic variables (Table 1) were added to achieve the reliable result.

The red panda presence is previously confirmed in seven protected areas of Nepal: Kanchanjungha Conservation Area (Kandel et al., 2015), Makalu Barun National Park (MBNP, 2016), Sagarmatha National Park (Mahato, 2004), Gaurishankar Conservation Area (Kandel et al., 2015), Langtang National Park (Thapa and Basnet, 2015; Yonzon and Hunter, 1991a, 1991b), Dhorpatan Hunting Reserve (Panthi et al., 2012) and Rara National Park, Nepal (Sharma et al., 2014b). In this study, red panda habitat has been identified inside the 13 Mountain protected areas of Nepal (Figure 7). Although the government of Nepal established 13 protected areas so far in the high Mountain and Himalayan region of the country, only 40 % of identified red panda habitat is covered by the existing protected areas of Nepal. Most of the red panda habitat is located outside the protected areas. The red panda habitat is distributed in the high Mountain region from east to west continuously, but the protected areas are not established continuously to cover this habitat. The habitat between Kanchanjungha Conservation Area and Makalu-Barun National Park, Langtang National Park and Manaslu Conservation Area, Annapurna Conservation Area and Dhorpatan Hunting Reserve and habitats around the Rara National Park is still unprotected (Figure 7). Although, department of forests (DoF) has a responsibility to manage and protect the wildlife and their habitats outside the protected areas, the major focus of this department is timber production. DoF could not conserve the wildlife as effectively as protected areas. Although the presences of red panda were scientifically confirmed from most part of the suitable habitat for red pandas identified by this study, the presence of red panda is not confirmed by literature and personal communication from Khaptad National Park, Shivapuri Nagarjung National Park, Api Nampa Conservation Area and Manaslu Conservation Area (Figure 7). These protected areas can be a suitable destination for red panda translocation to reduce the risk of red panda extinction. The Shivapuri Nagarjung National Park is a nearest protected area from Kathmandu, the capital city of Nepal. The study identified 55 km^2 areas as the habitat of red panda in this national park. This area is suitable to translocate the red panda. The government of Nepal can translocate the red panda in this national park and attract the wildlife tourist to the nearest accessible destination. This area can also be suitable for red panda breeding centre.

The presence of red panda was already confirmed from Julma, Mugu, Rolpa, Rukum, Baglung, Myagdi, Manang, Rasuwa, Nuwakot, Dolakha, Ramechhap, Solukhumbu, Sankhuwasabha, Ilam, Panchthar and Taplejung districts (Bhatta et al., 2014; Chalise, 2013, 2009; Kandel et al., 2015; Kathayat, 2016; Lama et al., 2015; MBNP, 2016; Panthi et al., 2012; Paudel, 2009; Sharma, 2013; Thapa, 2016). During the primary data collection of this study, red panda occurrence points were collected from Dhading, Rasuwa, Ilam and Panchthar districts. Similar to the findings of previous studies and field survey of this study, Solukhumbu, Jumla, Sankhuwasabha, Taplejung, Rukum, Sindhupalchok, Myagdi, Baglung, Dolakha and Rasuwa are the top 10 districts of Nepal which cover the suitable habitat for red pandas (Table 6). Jnawali et al. (2010) identified the 36 districts of Nepal as possible red panda presence districts through experts' consultation. More or less similar to that study, this study identified suitable habitat for red pandas from 48 districts including these 36 districts of Nepal. In contrast to Jnawali et al. (2010), this study has modelled the habitat of the red panda by MaxEnt at a spatial resolution of 1 km identifying even smaller patches of habitat with more precise locations. Sindhuli, Dadeldhura, Udayapur, Baitadi, Achham, Dailekh, Lalitpur, Dhankuta, Slyan and Gulmi districts cover less than 10 km^2 of suitable for habitat red pandas (**Table 6**). Previous literature and informal communication did not confirm the presence of red panda from these districts. This amount of habitat is too little for a viable population of the red panda.

The altitudinal range of red panda distribution was reported between 2200 m – 4800 m (Roberts and Gittleman, 1984). In this study, approximately 1200 km^2 habitat is identified below 2200 m, but only 60 km^2 habitat is identified above 4800 m elevation. The preferred range is 2900 m – 3400 m (Bhatta et al., 2014; Panthi et al., 2012). Similar to these studies, 3000 m - 3200 m elevation range covers the large proportion of habitat in comparison to the other ranges of the 200 m interval (**Figure 8**). The suitable habitat for red pandas is decreasing towards both sides from that elevation range. The red panda is herbivorous, so this animal needs vegetation for food, and it doesn't prefer very high elevation where plants are not surviving.

4.2 Variables affecting the habitat of red pandas in Nepal

In the previous study (Kandel et al., 2015), the temperature related variables (i.e. temperature annual range and temperature seasonality) were identified as most important to the modelling of suitable habitat for red pandas. The red panda occupies an elevation range 2200 m - 4800 m (Roberts and Gittleman, 1984) because this species preferring the temperature range depend on this range in elevation (Kandel et al., 2015). Similarly to the previous findings, the variables related to the temperature such as mean annual temperature and mean monthly diurnal temperature range were identified as most influencing variables to the red panda habitat suitability model (Figure 9). The red panda prefers the 5-10°C annual mean temperature and around 10°C monthly diurnal temperature range (Figure 10).

The bamboo is the principal food of this animal (Fei et al., 2017; Hu et al., 2017; Panthi et al., 2015, 2012; Sharma et al., 2014b; Thapa and Basnet, 2015; Wei et al., 1999). It prefers the temperate forests with bamboo ground cover (Bhatta et al., 2014; Chakraborty et al., 2015; Dorji et al., 2011; Panthi et al., 2012; Pradhan et al., 2001; Roberts and Gittleman, 1984). Similar to the findings of these studies, this study found the significant contribution of the vegetation-related variables to the red panda habitat suitability model. When the vegetation-related variables of Table 2 were added to the model which used the bio-climatic and topographical variables, the AUC was significantly improved (Table 4). Canopy height, forest cover and minimum NDVI were crucial to model the suitable habitat for red pandas (Figure 9). The red panda prefers the denser forest cover with higher canopy height (Figure 10). Winter NDVI was significantly correlated with understory bamboo (Wang et al., 2009) so this study used minimum NDVI as a surrogate of understory bamboo which is the major food and habitat indicator of the red panda. The red panda prefers the medium to high minimum NDVI (Figure 10).

Though several studies indicated that the red pandas were facing the serious anthropogenic impacts (Glatston et al., 2015; Panthi et al., 2017; Sharma et al., 2014a; Yonzon and Hunter, 1991b), the previous study related to the modelling ignored the anthropogenic variables to model the suitable habitat for this species (Kandel et al., 2015). This study used and identified the anthropogenic variables as the significant contributor to model the suitable habitat for red pandas. Distance from the human paths, livestock density, and population density were most important variables to model the suitable habitat for red pandas (Figure 9). Red pandas are living in forests, so their suitable habitat was almost zero with a high density of livestock and population (Figure 10). Distance from the motor road is less useful but distance from paths is more useful to explain the suitable habitat for red pandas. Therefore, the impact of paths is higher than the impact of the motor road to the suitable habitat for red pandas (Figure 10). Peoples are living in very high mountains of Nepal, and they are managing the facilities for tourists. These local people are using the paths of the forest for daily movement and visitors are using path for recreation trekking.

4.3 Impacts of future climate and land use and land cover change on red panda habitat

Due to the high impact of climate change in Himalaya (IPCC, 2007), the mountain biodiversity is facing the more threats. The habitat of the giant panda, a similar species to red panda will be reduced up to 62 % in 2070 in Qinling Mountains of China (Fan et al., 2014). Although the further effect is uncertain, the climate change can be favourable for some species. The habitat of Chinese caterpillar fungus *(Ophiocordyceps sinensis)* will be expanded a little bit in Nepalese Himalaya (Shrestha and Bawa, 2014). This study also found that the habitat of red panda will be expanded by 6.5 % in 2070 (Figure 11 & 12). The habitat of the red panda is in middle part of the mountain. If the temperature is increased due to global warming, the red panda has still space to move upwards till a specified period (2070). Besides the climate change, the land use and land cover change is another emerging challenge in the biodiversity conservation. Titeux et al. (2017) suggested integrating the climatic variables and land use and land cover to understand the future situation of biodiversity. Some wild animals of Alti Mountain of China will lose their distribution range due to the combined effect of climate and land cover change (Ye et al., 2018). In Nepal, the red panda is facing the anthropogenic pressure since 1985 (Glatston et al., 2015; Panthi et al., 2017; Sharma et al., 2014a; Yonzon and Hunter, 1991b). This study also found the negative impact of the combined effect of climate and land use and land cover change on red panda habitat. Even though the loss percentage is small (0.5%), the trend is negative. The rapid loss may happen after 2070. Due to combined effect of climate and land use and land cover change, the habitat of red panda will be shifted upwards and eastwards remarkably (Figure15).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study predicted current habitat suitability for the red pandas in Nepal. In addition, this study also modelled the impacts of projected future climate change and land use and land cover change on red panda habitat. The main conclusions that can be drawn from this study are (a) in total, approximately 13800 km^2 current suitable red panda habitat has been predicted in Nepal. Of which approximately 40% of suitable habitat is covered by the existing protected areas and remaining are located outside the protected areas. Most of the suitable red panda habitat (75%) is situated between 2400 m and 3800 m. The Solukhumbu district covers the highest proportion of suitable habitat in comparison with other districts. In addition, the Langtang National Park covers the highest proportion of suitable red panda habitat in comparison to other existing protected areas; (b) The most important environmental and anthropogenic variables to the prediction of current suitable habitat for red pandas is the mean annual temperature (Bio 1), mean monthly diurnal temperature range (Bio 2), forest cover, forest canopy height, distance from paths, livestock density and human population density. Of these six variables, the annual mean temperature and the distance from paths are most important; (c) The potential suitable habitat for red pandas will be increased approximately 6.5 % in 2070 under the projected future climate change, but it will be decreased by 0.5% due to combined effects of climate and land use and land cover change. Therefore it can be concluded that the land use and land cover change and anthropogenic impact are the major threats to red pandas in the next 50 years.

5.2 Recommendations

Conserving biodiversity and wildlife habitat outside the protected areas are essential to tackle the biodiversity loss (Cox and Underwood, 2011). In-situ conservation is the most appropriate method for biodiversity conservation. This study identified suitable habitat for red pandas in Nepal. This is the first study that attempts to use comprehensive environmental variables (i.e. bio-climatic, topographic, vegetation-related and anthropogenic) for predicting habitat suitability for the red pandas at a national level. The suitable habitat identified by this study is important and could serve as a baseline for the development of conservation strategy for the red panda in Nepal. This study revealed that a large amount of suitable red panda habitat is located outside the existing protected areas. For example, the habitat between the Kanchanjungha Conservation Area and the Makalu-Barun National Park, the Langtang National Park and the Manaslu Conservation Area, the Annapurna Conservation Area and Dhorpatan Hunting Reserve as well as the habitat around the Rara National Park. This study suggests that this habitat should be protected by establishing new protected areas or expanding the existing protected areas. In case of difficulties to establish or expand the protected areas immediately, the identified suitable habitat for red panda should be designed as future priority conservation areas by the Department of Forests, which has the responsibility to conserve the natural resources outside the protected areas. Before the establishment of new protected areas for red pandas, the community level conservation groups such as community forests users groups and mothers groups should be empowered to conserve the identified suitable habitat for red pandas outside the protected areas. Moreover, this study also found that the suitable habitat for red pandas is facing a variety of anthropogenic pressures such as the development of rural tourism routes (paths) and livestock. We recommend that the Department of National Parks and Wildlife Conservation should coordinate with the Department of Livestock Services and the Department of Tourism to mitigate the impacts of livestock and tourist routes on red panda. This study found that the impact of projected future climate change on red panda habitat is positive. However, this study also found that the impacts of projected future land use and land cover change on red panda are negative. Therefore, this study recommends that Nepalese government should pay more attention to the land use planning in order to mitigate the economic impact on red panda as well as other endangered species in Nepal.

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Appendix I: Multicollinearity analysis of variables used in current models

	aspect	bio_1	bio_10	bio_11	bio_12	bio_13	bio_14	bio_15	bio_16	bio_17	bio_18	bio_19	bio_2	bio_3	bio_4	bio_5
aspect	1															
bio_1	-0.13	1														
bio_10	-0.17	**0.99**	1													
bio_11	-0.13	**0.98**	**0.94**	1												
bio_12	0.01	0.51	0.42	0.56												
bio_13	-0.02	0.64	0.57	0.68	**0.96**	1										
bio_14	0.07	-0.28	-0.26	-0.33	-0.15	-0.12	1									
bio_15	-0.14	0.82	0.81	0.83	0.52	0.69	-0.26	1								
bio_16	-0.01	0.59	0.51	0.64	**0.99**	**0.99**	-0.17	0.63								
bio_17	-0.04	-0.27	-0.20	-0.34	-0.44	-0.39	**0.73**	-0.37	-0.47	1						
bio_18	0.02	0.56	0.47	0.61	**0.99**	**0.98**	-0.18	0.60	**1.00**	-0.49	1					
bio_19	-0.16	-0.36	-0.26	-0.42	-0.68	-0.63	0.49	-0.41	-0.70	**0.89**	**-0.72**	1				
bio_2	-0.16	-0.07	-0.07	-0.06	-0.34	-0.32	-0.38	-0.03	-0.30	-0.18	-0.31	0.07	1			
bio_3	0.05	-0.05	-0.17	0.12	0.33	0.28	-0.36	0.08	0.34	-0.52	0.37	-0.53	0.37	1		
bio_4	-0.10	-0.11	0.04	-0.29	-0.47	-0.42	0.21	-0.14	-0.46	0.41	-0.50	0.51	0.04	**-0.83**	1	
bio_5	-0.20	**0.96**	**0.98**	**0.92**	0.37	0.51	-0.32	**0.79**	0.45	-0.21	0.41	-0.22	0.10	-0.15	0.06	1
bio_6	-0.10	**0.95**	**0.91**	**0.97**	0.67	**0.77**	-0.28	**0.81**	**0.73**	-0.34	**0.71**	-0.48	-0.25	0.11	-0.32	**0.86**
bio_7	-0.19	-0.02	0.09	-0.14	-0.59	-0.52	-0.07	-0.08	-0.55	0.26	-0.58	0.50	0.64	-0.47	**0.72**	0.23
bio_8	-0.15	**0.99**	**0.99**	**0.95**	0.49	0.62	-0.26	**0.82**	0.57	-0.23	0.53	-0.31	-0.12	-0.14	0.00	**0.97**
bio_9	-0.25	**0.85**	**0.86**	**0.85**	0.34	0.49	-0.36	**0.78**	0.43	-0.20	0.40	-0.14	0.07	-0.04	-0.08	**0.87**

bio_18	bio_17	bio_16	bio_15	bio_14	bio_13	bio_12	bio_11	bio_10	bio_1	aspect	
0.02	-0.17	0.02	0.03	-0.05	0.00	0.02	0.12	0.11	0.13	0.16	canopyheig
-0.61	0.53	-0.62	-0.63	0.45	-0.63	-0.57	**-0.81**	**-0.75**	**-0.80**	-0.04	elevation
0.17	-0.08	0.19	0.25	-0.14	0.20	0.18	0.32	0.40	0.35	-0.20	forest
0.52	-0.07	0.53	0.33	0.12	0.56	0.54	0.19	0.11	0.16	0.01	livestock_den
-0.02	0.33	-0.03	-0.25	0.33	-0.02	0.03	-0.25	-0.21	-0.23	0.04	motoroad_dist
0.30	-0.33	0.27	-0.10	-0.03	0.22	0.31	-0.24	-0.38	-0.32	-0.04	ndvi_amp
0.40	-0.35	0.43	0.59	-0.34	0.45	0.38	0.69	**0.72**	**0.71**	-0.03	ndvi_max
0.22	-0.23	0.25	0.52	-0.34	0.28	0.20	0.67	**0.73**	**0.71**	-0.02	ndvi_mean
-0.04	0.09	-0.01	0.38	-0.15	0.05	-0.06	0.55	0.68	0.62	0.02	ndvi_min
0.44	-0.47	0.41	0.04	-0.12	0.36	0.44	-0.04	-0.17	-0.11	-0.04	ndvi_sd
-0.03	0.15	-0.02	-0.15	0.09	-0.02	0.00	-0.28	-0.24	-0.26	-0.11	path_dist
0.39	-0.42	0.38	0.23	-0.22	0.36	0.36	0.20	0.09	0.15	0.05	pop_densi
-0.18	0.57	-0.18	-0.34	0.40	-0.16	-0.13	-0.37	-0.34	-0.36	0.10	settle_dist
0.20	-0.14	0.19	-0.10	0.06	0.16	0.22	-0.09	-0.16	-0.13	0.00	slope

bio_9	bio_8	bio_7	bio_6
			1
		1	-0.31
	1	0.01	**0.93**
1	**0.84**	0.10	**0.80**

ndvi_amp	motoroad_dist	livestock_den	forest	elevation	canopyheight	bio_9	bio_8	bio_7	bio_6	bio_5	bio_4	bio_3	bio_2	bio_19
					1	0.01	0.11	0.06	0.10	0.13	-0.05	-0.01	0.04	-0.16
				1	-0.20	-0.60	**-0.77**	0.19	**-0.81**	**-0.73**	0.27	-0.18	0.06	0.61
			1	-0.20	0.14	0.30	0.39	0.15	0.32	0.40	0.18	-0.23	-0.05	-0.04
		1	0.07	-0.10	-0.26	0.09	0.16	-0.48	0.29	0.04	-0.26	0.12	-0.42	-0.26
	1	-0.06	-0.12	0.26	-0.15	-0.20	-0.18	-0.07	-0.20	-0.24	0.09	-0.13	-0.19	0.21
1	-0.01	0.28	-0.21	0.10	0.03	-0.28	-0.33	-0.57	-0.12	-0.43	-0.37	0.37	-0.28	-0.37
-0.09	-0.29	0.07	0.49	-0.61	0.34	0.61	**0.72**	0.01	0.68	**0.71**	0.00	-0.13	-0.11	-0.35
-0.43	-0.30	-0.06	0.54	-0.57	0.30	0.61	**0.72**	0.22	0.61	**0.75**	0.12	-0.22	0.03	-0.18
-0.86	-0.14	-0.19	0.42	-0.39	0.15	0.54	0.63	0.47	0.45	**0.71**	0.30	-0.36	0.17	0.12
0.93	-0.10	0.30	-0.07	-0.12	0.13	-0.15	-0.12	-0.58	0.08	-0.23	-0.39	0.35	-0.31	-0.52
0.06	0.36	0.06	-0.07	0.34	-0.22	-0.12	-0.23	0.12	-0.28	-0.22	0.20	-0.09	0.06	0.20
0.38	-0.38	0.38	0.07	-0.30	0.06	0.10	0.11	-0.38	0.25	0.05	-0.32	0.18	-0.25	-0.44
-0.05	0.41	-0.03	-0.13	0.39	-0.20	-0.33	-0.33	-0.02	-0.32	-0.34	0.10	-0.08	-0.09	0.41
0.27	0.18	0.18	-0.23	0.03	-0.18	-0.14	-0.13	-0.40	-0.01	-0.23	-0.20	0.18	-0.27	-0.25

slope	settle_dist	pop_den	path_dist	ndvi_sd	ndvi_min	ndvi_mean	ndvi_max
							1
						1	**0.90**
					1	**0.81**	0.58
				1	-0.68	-0.19	0.15
			1	-0.03	-0.17	-0.19	-0.23
		1	-0.13	0.47	-0.21	0.07	0.20
	1	-0.35	0.16	-0.19	-0.18	-0.35	-0.43
1	0.18	0.06	0.14	0.22	-0.29	-0.16	-0.14

Appendix II: Multicollinearity analysis of variables used in future models

	aspect	bio_1	bio_10	bio_11	bio_12	bio_13	bio_14	bio_15	bio_16	bio_17	bio_18	bio_19	bio_2	bio_3	bio_4
aspect	1														
bio_1	0.06	1													
bio_10	0.12	**0.89**	1												
bio_11	0.13	**0.90**	**0.99**	1											
bio_12	0.09	0.57	0.52	0.59	1										
bio_13	0.12	0.58	0.54	0.61	**0.98**	1									
bio_14	0.11	0.21	0.17	0.20	0.51	0.40	1								
bio_15	0.17	0.15	0.20	0.21	0.31	0.44	-0.45	1							
bio_16	0.12	0.57	0.52	0.59	**0.99**	**1.00**	0.39	0.45	1						
bio_17	-0.14	0.14	0.14	0.14	-0.01	-0.13	0.62	**-0.89**	-0.16	1					
bio_18	0.13	0.56	0.51	0.58	**0.98**	1.00	0.39	0.47	**1.00**	-0.18	1				
bio_19	-0.19	0.04	0.02	0.01	-0.22	-0.34	0.40	**-0.93**	-0.36	**0.95**	-0.39	1			
bio_2	-0.01	-0.41	-0.41	-0.51	-0.67	-0.62	-0.43	0.18	-0.59	-0.39	-0.58	-0.25	1		
bio_3	0.14	-0.24	-0.31	-0.32	-0.13	-0.07	-0.23	0.58	-0.03	-0.67	0.00	-0.64	0.69	1	
bio_4	-0.15	-0.37	-0.31	-0.44	**-0.76**	**-0.76**	-0.34	-0.24	**-0.75**	0.04	**-0.75**	0.17	**0.77**	0.09	1
bio_5	0.01	**0.82**	**0.94**	**0.90**	0.24	0.25	0.02	0.03	0.24	0.25	0.21	0.20	-0.25	-0.39	-0.04
bio_6	0.06	**0.87**	**0.97**	**0.98**	0.53	0.54	0.18	0.08	0.52	0.26	0.50	0.15	-0.58	-0.47	-0.42
bio_7	-0.11	-0.39	-0.36	-0.48	**-0.80**	**-0.78**	-0.40	-0.13	**-0.77**	-0.08	**-0.77**	0.08	**0.91**	0.33	**0.95**
bio_8	0.15	**0.90**	**0.99**	**0.99**	0.60	0.62	0.19	-0.27	0.61	0.07	0.60	-0.07	-0.49	-0.25	-0.38
bio_9	0.03	**0.81**	**0.89**	**0.90**	0.46	0.44	0.36	-0.16	0.41	0.47	0.39	0.36	-0.54	-0.49	-0.35
elevation	-0.04	**-0.76**	**-0.76**	**-0.76**	0.62	0.63	0.28	0.28	0.63	-0.01	0.62	-0.17	-0.36	0.14	-0.34
slope	0.01	0.11	0.20	0.17	0.21	0.21	0.18	0.12	0.21	0.11	0.22	0.15	0.01	0.19	0.17

slope	elevation	bio_9	bio_8	bio_7	bio_6	bio_5
						1
					1	**0.92**
				1	-0.49	-0.10
			1	-0.43	**0.95**	**0.89**
		1	**0.86**	-0.41	**0.92**	**0.86**
	1	-0.63	**-0.79**	-0.40	**-0.71**	-0.62
1	0.03	0.20	0.15	0.13	0.23	0.32