STUDY POTENTIAL HABITAT DISTRIBUTION OF RED PANDA *AILURUS F. FULGENS* AND THEIR CONNECTIVITY IN SAKTENG WILDLIFE SANCTUARY USING MAXENT AND LINKAGE MAPPER

SONAM TOBGAY

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Geographic Information Science)
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By SONAM TOBGAY

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Geographic Information Science of Naresuan University

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Title	STUDY POTENTIAL HABITAT DISTRIBUTION OF RED PANDA *AILURUS F. FULGENS* AND THEIR CONNECTIVITY IN SAKTENG WILDLIFE SANCTUARY USING MAXENT AND LINKAGE MAPPER
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ABSTRACT

In the current era, habitat degradation and fragmentations are a severe threat to the survival of the species in natural habitats. It is caused by ever-growing anthropogenic activities leading to an unprecedented rate of climate change. The red panda as an endangered species is no exception. However, limited studies have been done in the context of the spatial distribution of habitats for red panda and their habitat connectivity in Sakteng Wildlife Sanctuary. Lack of such information remains a challenge while implementing effective and holistic conservation initiatives. Therefore, this study attempts to identify the distribution of potential habitats and their connectivity under different climate scenarios using the maxent and linkage mapper algorithms respectively. The model predicted 260km^2 of potential habitat (fundamental niche) under the current climate scenario which is unequally distributed across Merak (54.5%), Sakteng (33.4%) and Joenkhar (12.2%) ranges connected by a least-cost corridor (length µ= 2.91 km) with several pinch points in it. Out of the total predicted habitat, more than 75% falls outside the designated core zones where the likelihood of anthropogenic disturbance is relatively high. With climate change, it is predicted that there will be an expansion in suitable habitat (up to ca. 26.5 percent) towards relatively

higher elevation. However, predicted expansion is likely to make red panda more vulnerable to disturbances from seminomadic communities who practice extensive grazing in the higher elevation during the summer season. Climate change is predicted to increase the number of habitat fragmentations (up to ca. 13%) and linkages (up to ca. 29%). However; there won't be much impact on the quality and functionality of the predicted connectivity, except change in the centrality scores of few habitats. This indicates that connectivity with current climate scenarios will potentially facilitate the movement of red panda and will be also useful in the event of future climate change. Therefore, the current conservation initiatives should not be restricted to only habitats where the red panda occurs today but should be also extended to predicted future potential habitats. Such initiatives would enhance the capability of the red panda to adapt to future climate change; ensuring their long term persistence.

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This work would be impossible without data. Therefore, I am also thankful to the management of Sakteng Wildlife Sanctuary and selflessly dedicated scientist of worldclim.org for making the data available without any cost and restriction.

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SONAM TOBGAY

TABLE OF CONTENTS

Page

List of Tables

Page

List of Figures

Page

ABBREVIATIONS

AICc	=	Corrected Akaike's Criteria
ASCII	=	American Standard Code for Information Interchange
AR5	=	Fifth Assessment Report
AUC	=	Area Under Curve
BAM	=	Biotic, Abiotic, Movement
CCSM	=	Community Climate System Model
CH	=	Core Habitats
CITES	=	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMIP5	=	Coupled Model Inter-comparison Project 5
CSV	=	Comma Separated Values
CWD	=	Cost-weighted Distance
DEM	=	Digital Elevation Model
ENM	=	Ecological Niche Model
EucD	=	Euclidean Distances
GCM	=	Global Climate Model
GHG	=	Greenhouse Gas
GIS	=	Geographic Information System/Science
GPS	=	Global Positioning System
ICDP	=	Integrated Conservation and Development Porject
IPPC	=	Intergovernmental Panel on Climate Change
IUCN	=	International Union for Conservation of Nature
Km	=	Kilometer
LCD	=	Least-cost Distance
LCP	=	Least Cost Path
LQH	=	Linear, Quadratic, Hinge
m	=	Meter
Maxent	=	Maximum Entropy Modelling
NCHM	=	National Center for Hydrology and Meteorology
RCP	=	Representative Concentration Pathways

RGOB	=	Royal Government of Bhutan
RM	=	Regularization Multiplier
ROC	=	Receiver Operating Characteristic
SDE	=	Standard Deviational Ellipse
SDM	=	Species Distribution Model
SWS	=	Sakteng Wildlife Sanctuary
TSS		True Skill Statistics
WCRP	=	World Climate Research Program
WWF	=	World Wide Fund for Nature

CHAPTER I

INTRODUCTION

This chapter is divided into several sections consisting of the significance, threat and challenges, an overview of the modeling approach, habitat and connectivity status in Bhutan, research problems, research questions, objectives, expected outcome, scope, limitations and study area.

Significance of habitat and connectivity

The dynamics of habitat, connectivity and their influence on survival of the species is an inevitable component of wildlife ecology (Morrison et al., 2012). Wildlife habitat is an area in the landscape that can support a viable population of the specific species. It fulfills the fundamental needs of an individual or the population to reproduce, occupy, protect, interact and survive by providing basic resources such as food, shelter, water and climatic or environmental conditions in favor of the species (Morrison et al., 2012). However, a healthy viable population of wildlife is dependent on a mosaic of heterogeneous habitat across the landscape (Grebner et al., 2013) with good connectivity (Fahrig & Merriam, 1994).

Habitat connectivity is the extent to which species can move between the fragmented landscape (Taylor et al., 1993). Connectivity is critical for facilitating effective dispersal of the species across the landscape, uninterrupted seasonal migration, population persistence, range expansion and maintain prey-predator dynamics (Cross et al., 2013; Kareiva & Wennergren, 1995; Stephens & Krebs, 1986; Taylor et al., 1993). Connectedness helps in the maintenance of ecosystem functionality and biodiversity in the landscape. Broadly, landscape connectivity can be defined based on structural and functional connectivity. Structural connectivity represents spatial relationship (continuity and adjacency) between the habitat patch while functional connectivity takes into account of permeability of the landscape features for the movement of the species(Taylor et al., 2006). In structural connectivity like the corridor, species are expected to move through defined linear pathways while in later case defuse movement of the species depends on the permeability (resistance) of the landscape (Cross et al., 2013).

Threats and Challenges

The climate change, increasing human footprint with extensive manufacturing, infrastructure development and land use change have fragmented the habitat and their connectivity. The ability to access available resources and maintain genetic diversity via dispersal in the landscape will be challenged by fragmentation and barriers, ultimately threatening the survival of the species (Crist, 2015). In an isolated fragmented landscape with poor connectivity, species are susceptible to extinction due to a reduced potential of colonization from the adjacent habitat (Newmark, 1987) while connecting landscape has been observed to support increased species population persistence and more diversity with greater genetic exchange (Hilty et al., 2012). Fragmentation will undermine the role of connectivity to facilitate a restructuring of the species distribution related to an expected shift in habitat range of the species in response to climate change (Warren et al., 2001).

Management and restoration of habitat and their connectivity have become an important priority in the field of wildlife conservation which is challenging with growing human footprint. The success of the management and restoration depends on the dynamics of the conservation plan, calling for a need for reliable and efficient tools that can help to understand the habitat and identify their connectivity in the landscape.

Habitat and connectivity modeling approach

There are numerous species distribution modeling (henceforth referred to as SDM) and connectivity tools developed that are extensively discussed elsewhere (Drew et al., 2010; Guisan & Zimmermann, 2000). Climate envelope modeling, habitat modeling, and environmental or ecological niche-modelling (ENM) are some of the synonyms used to represent SDM. Nevertheless, measurement of the species-environment relationship is the basis for every predictive habitat modeling in ecology which functions based on the influence of environmental factors on the spatial distribution of the species (Guisan & Zimmermann, 2000). They use occurrence (presence or presence and absence) record of the species and the environmental variables (Sinclair et al., 2010). Suitability of any habitat to the species is predicted by classifying grid cells according to the degree in which it is suitable or unsuitable for the species based on the input set of the environmental predictors (Guisan & Thuiller, 2005).

SDM is wildly applied to study species in the context of geographic space related to the impact of climate change (Dobrowski et al., 2011), habitat exploration (Hernandez et al., 2008; Williams et al., 2009), invasive species (Ficetola et al., 2007), endemism (Pearson et al., 2007), and conservation planning (Wilson et al., 2011).

The combination of the physical characteristics of the landscape with species response to that physical characteristics forms the theoretical concept of the landscape connectivity model. Connectivity modeling tools are prominently used in identifying corridor connection between patches of higher habitat suitability, identification of important patch or stepping stone which can facilitate restoration and management of the networks of habitat for the persistence of the species (Correa Ayram et al., 2016).

However, in this study, the maxent (Maximum Entropy) species distribution model and the hybrid of least cost path (LCP) and circuitscape in linkage mapper will be used for habitat and connectivity modeling respectively. Habitat and landscape connectivity will be modeled in context to the ecological need of endangered red panda as a focal species.

Habitat and connectivity in Bhutan

In Bhutan, connectivity between (inter-connectivity) protected areas are maintained with biological corridors. However, there is no identified corridor or connectivity within (intra-connectivity) the landscape of the protected areas despite the problem of habitat degradation and fragmentation. Lack of designated connectivity within the protected area may impede effective dispersal of the species; threatening the survival besides the implementation of various conservation measures.

Research Problem

The Sakteng Wildlife Sanctuary (henceforth referred to as SWS) is home to indigenous semi-nomadic people known as Brokpa, a group of yak and cattle herder. More than 85 percent of the inhabitants' livelihood is dependent on a huge population of yak and cattle rearing (SWS, 2019). They practice open grazing in meadows of the mountain and deep inside the forest based on the season. Their winter rangeland overlaps with the primary habitat of the red panda. Increasing herd size to maximize the livestock product and their more dependence on usage of forest and natural resources have further degraded the wild habitats, thus increasing the threat (Dorjee, 2009).

Of lately, settlements in SWS are connected with farm roads. Forest degradation, overuse of land for grazing, geological disturbances from excavation to construct roads and other climate factors have led to a major landslide in and around the potential habitats of the red panda, creating the fragmentation. Timber requirements for construction and fuelwood for the settlement within and periphery of the SWS are also met from this forest. The existing trend of timber extraction and increasing demand will also result in habitat fragmentation and degradation (SWS, 2019). Recent studies in Bhutan predicted an increase in temperature and rainfall by up to more than 3.2^0C and 30 percent respectively at the end of the century (NCHM, 2019) which in turn increases the vulnerability of forest to climate change. Therefore, climate change, resources demand by huge livestock population and increasing timber need by the inhabitant exerts intense pressure on a forest in SWS which is also an important habitat for the endangered red panda.

Although the endangered red panda is identified as the flagship species of SWS, information regarding the distribution of the potential habitat and their connectivity are very sparse in spite of threats and challenges. Lack of reliable potential habitat and connectivity map for the red panda in SWS remains a challenge while implementing effective and holistic conservation initiatives. Thus, there is a need to study habitat distribution and their connectivity within the landscape of SWS to ensure the long-term survival of the species

Research Questions

This study is expected to answer following questions:

- How are the potential habitats of the red panda spatially distributed within the landscape of Sakteng Wildlife Sanctuary?
- How will climate change impact the predicted habitat of a red panda?
- How are the predicted habitats of the red panda connected to ensure the mobility of the species in the landscape of Sakteng Wildlife Sanctuary?
- Where should Sakteng Wildlife Sanctuary focus to ensure long term persistence of the red panda within the landscape?

Objectives of the Research

The core purpose of this study is to identify the distribution of potential habitat (fundamental niche) for endangered red panda and their connectivity within (intra-connectivity) the landscape of SWS to ensure the long-term persistence of the species.

The specific objectives of this study are:

- To predict potential habitat of red panda using bioclimatic and environmental variables in maxent
- To predict the potential impact of climate change to the predicted habitat of red panda using different climate scenarios
- To investigate landscape connectivity among the predicted habitat of red panda applying linkage mapper

Research Scope and Limitations

This study was conducted in the landscape of SWS in Bhutan which harbors a good habitat for the endangered red panda. It enables to understand the distribution and identification of red panda habitat and their connectivity between the habitats within the SWS under different climate scenarios. Such findings can contribute towards providing some valuable information on the distribution of potential red panda habitat and their connectivity along with the predicted impact of climate change. This can help in the formulation of dynamic conservation plan to ensure the long-term persistence of the red panda and other associated species in the landscape. Moreover, climate change is inevitable phenomenon and outcomes from this study could be also useful to policymakers and conservation managers for strategic planning of species towards climate resilience.

However, this study is also likely to suffer from the following limitations:

- Model in the study does not consider the influence of the biotic interaction like competition and pest and diseases. Failure to include such factors might introduce uncertainty in the model projection.
- In the model, restriction of the species distribution by the political boundary may underrepresent the actual potential distribution (that area located outside the political boundary) of the species in response to climate change.
- Certain level of the uncertainty in model output is also expected due to the use of coarse resolution climate data and uncertainty associated with climate projections.
- Although land use can influence the distribution of the potential habitat, it is not used in the model because it is subjected to change in the future with climate change. Hence using current land use may not represent the actual land use scenario of the future while modeling the potential habitat using future climate scenarios.

Study Area

Location

The Sakteng Wildlife Sanctuary (SWS) is one of the tenth protected areas in Bhutan. It was established in the year 2003 with the mandate to conserve the representative ecosystem of the eastern Himalaya along with the unique culture of the seminomadic inhabitants.

Geopolitically it is located (extent: 91.70603^0 – 92.12468^0E, 27.136012^0 - 27.486256^0N) within the jurisdiction of Merak and Sakteng gewog in eastern Bhutan and covers an area of 740.60 km² that is likely to be increased to ca. 938.02 km² after boundary re-demarcation [for this study 938.02km^2 is used]. It is managed under three range offices comprising of Merak, Sakteng and Joenkhar range (Figure 1).

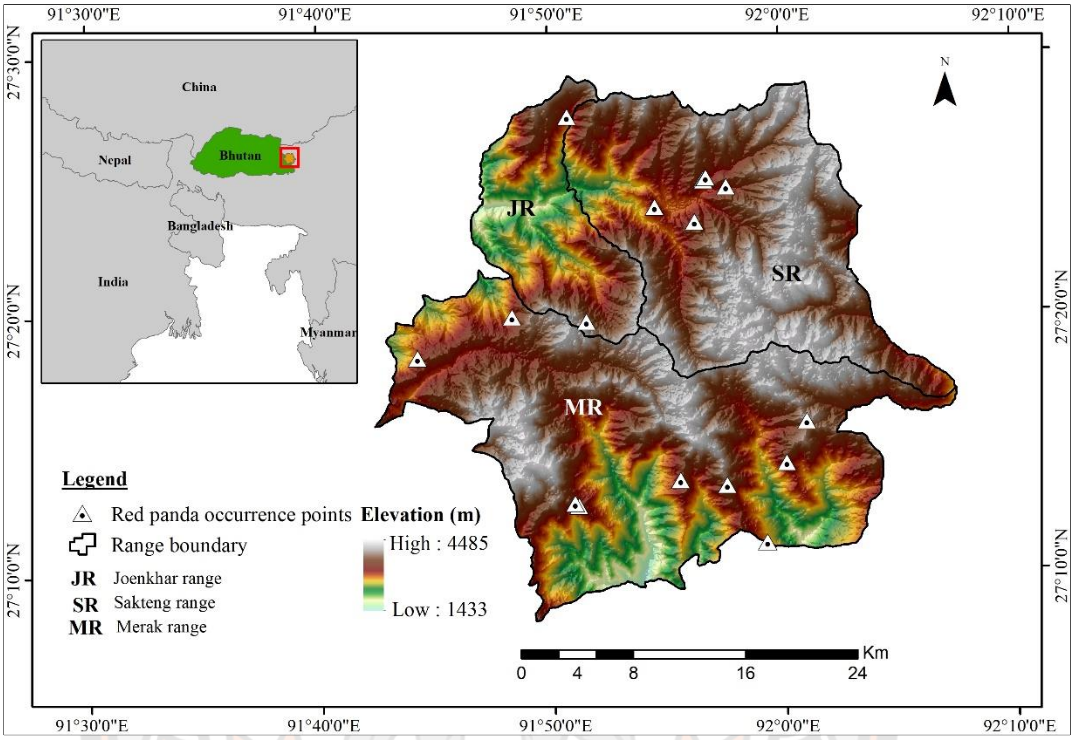

Figure 1 The map showing the location of Sakteng Wildlife Sanctuary (study area) with red panda occurrence records

Climate

Majority of the SWS experiences temperate climate characterized by cold winter and warm summer. Sporadic rainfall starts from late April to early October with peak rainfall in June and July. Generally, snowfall occurs from late October to early April leading to extremely cold winter. According to the climatic data from the meteorological station of Sakteng for the past seven years (2012 -2018), the average annual rainfall recorded was 129.3 mm with more than 75 percent rainfall from May to August and minimum during October to February. The highest mean annual rainfall of 364.5 mm was recorded during July with corresponding to the highest average annual atmospheric temperature. No rainfall was recorded in January and corresponds to the lowest atmospheric temperature. The mean annual temperature ranges from 4^{o}C to 14.6^{o}C with an average of 9.1^{o}C. The respective mean of high and minimum temperature was 17.2^{0}C and minus (-) 4.13^{0}C. Mean annual relative humidity exhibits narrow variation that ranges from 48 percent to 71 percent with the annual average of 61 percent, which resulted in a moderately humid environment in SWS (Figure 2).

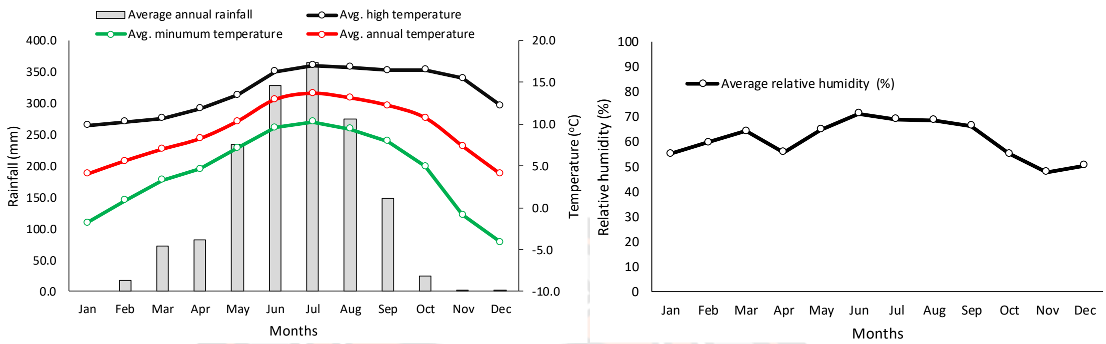

Figure 2 The climatic condition of the SWS for the year 2012-2018

Biodiversity

A rich diversity of flora and fauna are recorded in SWS within the elevation ranging from ca. 1500 m in lower valleys to 4500 m in the peaks of the mountain. The broadleaf forest is a dominant habitat type in the lower elevation which is gradually replaced by mixed conifer, fir and alpine meadows with the gain in elevation (Figure.3 and Table 1).

Recent surveys have recorded the presence of 37 mammal species despite its small area in comparison to other protected areas. Globally endangered royal bengal tiger, red panda, and musk deer are some of the species recorded among others which signifies the importance of the SWS as a protected area. The red panda is considered a flagship species of SWS.

Management practices

SWS is further managed under different zones according to their specific use. These zones consist of a core ($146km^2$), multiple-use ($585.62km^2$) and buffer ($206.4km^2$). The core zone is strictly designated for conservation whereby activities other than research and conservation works are prohibited.

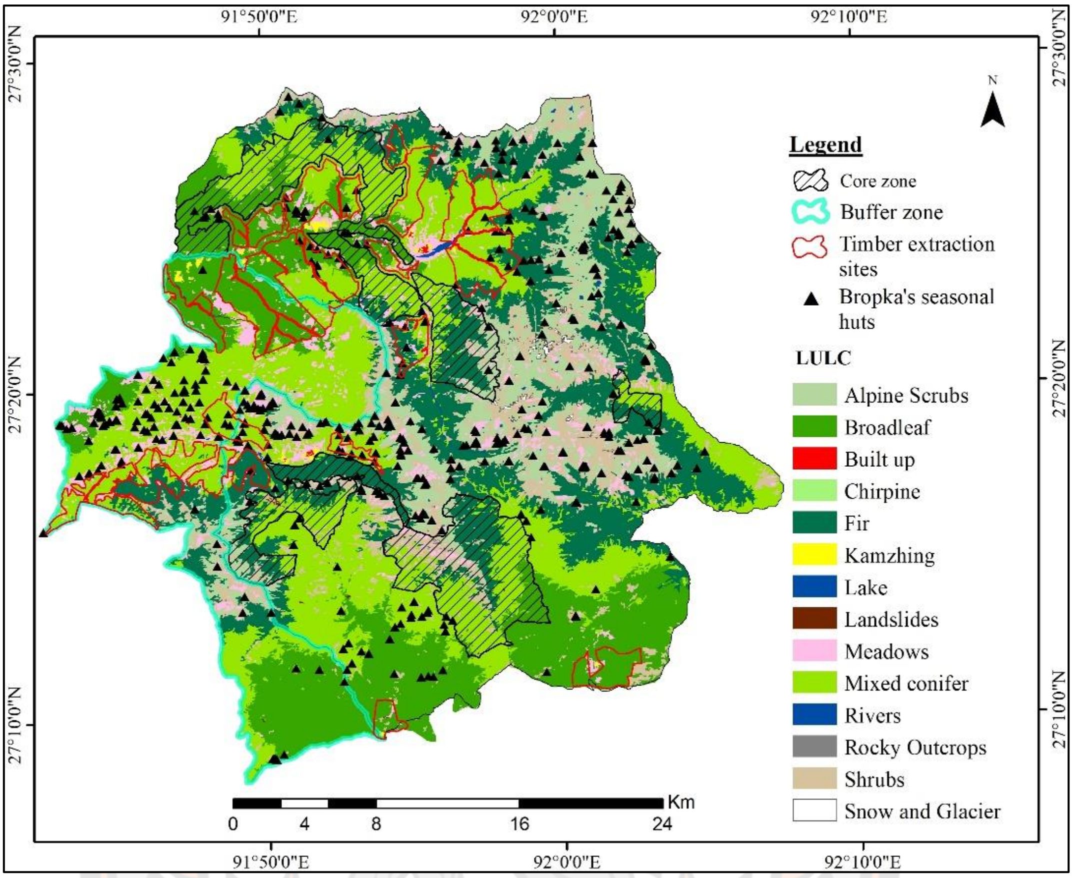

Figure 3 Existing land use/land cover and their management in SWS

Table 1 Land use/Land cover type in SWS according to LULC 2016

Land use/Land cover types	Area(km^2)	Coverage (%)
Mixed conifer forest	291.907	31.136
Fir forest	196.086	20.915
Broadleaf forest	195.311	20.832
Shrubs	96.143	10.255
Alpine Scrubs	93.355	9.958
Meadows	56.674	6.045
Water bodies	2.258	0.241
Snow and Glacier	2.010	0.214
Kamzhing (Dry agriculture land)	1.941	0.207
Landslides	0.713	0.076
Built up	0.476	0.051
Rocky Outcrops	0.357	0.038
Chirpine forest	0.279	0.030

The buffer zone is designated as the cushion or transition zone between the area within SWS and outside to minimize the undesirable impact from outsiders. In between the buffer and core lies the multiple-use zone intended to cater to all types of goods and services obtained from nature that contribute to local people's livelihood on a sustainable basis with little restrictions (WWF & SWS, 2011). Timber extraction sites are designated within the multiple-use and buffer zone (Figure 3).

Challenges

Native inhabitants of SWS are known as Brokpa (ethnic group) and are transhumant by profession. Approximately, 5000 Brokpas reside within SWS. More than 85 percent of inhabitant's livelihood is dependent on livestock who practice open grazing in an alpine meadow in summer and inside the forest in winter. Their seasonal huts are spread across the landscape since 75 percent of the area is accessible to grazing with varying intensity. As of the year 2016, an estimated population of 16,941 cattle was known to graze within the landscape which translates to 35.5 cattle/km^2 in comparison to 11.2 cattle/km^2 of national grazing density (SWS, 2019). Timber for construction and fuelwood for the settlements within and peripheries is also met from the forest of SWS. Meeting the resources demand of huge livestock population and timber need by the inhabitant exerts intense pressure on a forest in SWS which is also home to the endangered red panda.

CHAPTER II

LITERATURE REVIEW

This chapter is divided into four sections. They are described in the order of species distribution model, habitat connectivity model, ecology of focal species and climate scenarios.

Habitat modeling concepts

Species distribution modelling

Over the year, predicting species distribution has become an important aspect of effective conservation planning. Species distribution modelling is extensively used to model species geographic distribution based on associations between the environmental condition of the sites of known occurrence and occurrence record to identify the suitable areas where species can survive and reproduce (Phillips et al., 2006). Species distribution models (SDMs) are developed within the concept of ecological niche theory. SDMs enables a deeper understanding of environmental parameters influencing species distribution through temporal and spatial prediction (Thuiller et al., 2005). The suitable environment in favour of the species can be predicted through a mechanistic or correlative approach. The former approach tries to integrate physiologically limiting mechanisms in a species' tolerance to environmental conditions while correlative predicts based on the correlation of known species' occurrence records with sets of environmental variables that are expected to affect the physiology and prospect of the persistence of the species (Pearson, 2010). However, correlative SDM will be used in this study and outline of the main steps involved are presented in figure 4.

In ecology, a niche is explained as a relational position and role of the species within the ecosystem (Polechová & Storch, 2008). Niche is characterized by interactions of species with abiotic and biotic factors. The heuristic BAM diagram provides a holistic understanding of the niche (Figure 5).

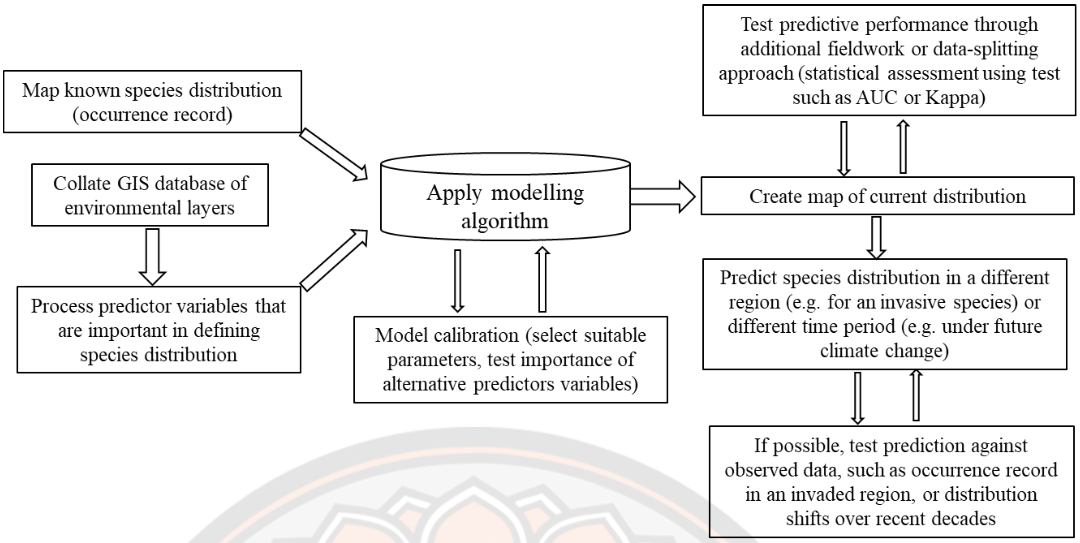

Figure 4 Main steps involved in building and validating a correlative SDM

Source: Pearson, (2010)

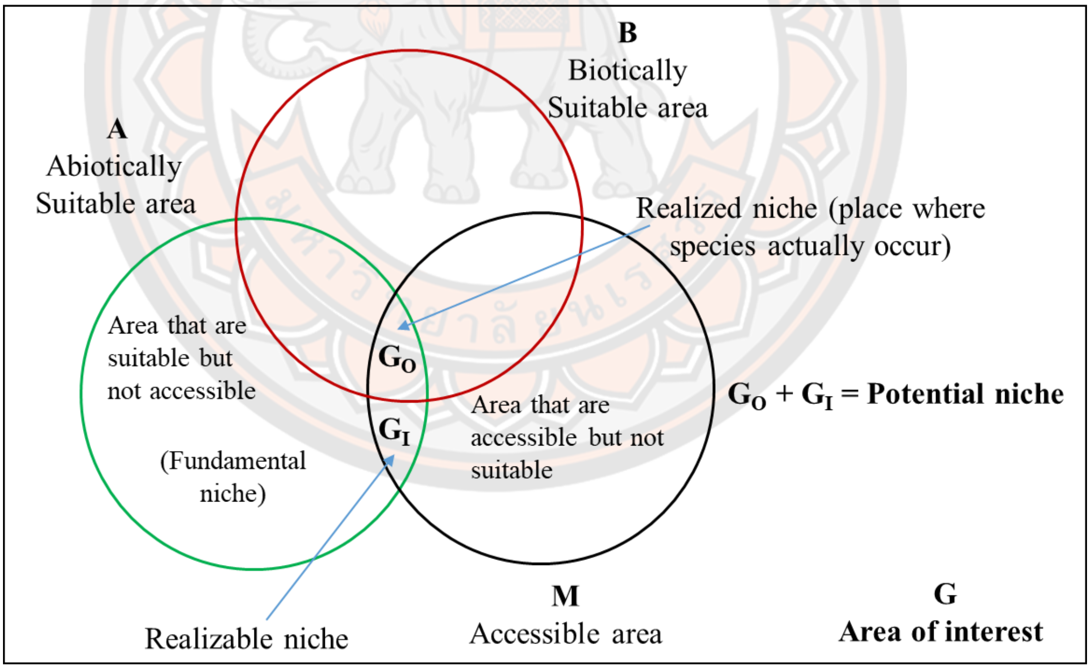

Figure 5 The BAM diagram illustrating the influence of biotic, abiotic and mobility factors to the species' geographic distribution

Source : Peterson et at., (2016).

However, biotic interaction comprising of interspecific and intraspecific in the form of competition, mutualism, commensalism, predation, and parasitism are practically difficult to handle in existing SDMs. In essence, existing correlative models extrapolate from relations between occurrences point and abiotic data sets to identify areas of predicted presence on the map.

The algorithm only finds places that resemble characteristics of the occurrence point location in the input layer. It should be understood that predicted output from the model is those areas that have relatively similar characteristics to the point occurrence data. Therefore, the occurrence points of the species are assumed to meet an optimum ecological need of the species.

SDMs are frequently embraced by the researcher in the field of biogeography, ecology, conservation biology and biodiversity to assist decision-making process in conservation area planning, study impact of climate change, management of invasive species, epidemiology and other related fields (Pearson, 2010; Phillips et al., 2006)

Theoretical framework of maxent.

Maxent is a presence-only species distribution model where the probability distribution is defined on the pixels of the study area. The pixels with known species occurrence records form the sample points and features are input environmental predictors and functions thereof (Phillips et al., 2006). It predicts the probability of species distribution in unknown geographic space based on the probability distribution of maximum entropy (Phillips et al., 2006). The presence location of the species is assumed to meet an optimum ecological need of the species (Figure 6).

It is unaffected by small sample size and uses environmental factors as the constraints to generate an acceptable species distribution model. Maxent is one of the extensively used SDM tools to study invasive species, habitat distribution and the response of the species to climate change because of its better prediction ability with the only-presence record, environmental predictors and small sample size (Phillips et al., 2006).

It works based on Gibbs probability distributions of the maximum entropy given the constraints.

$$q\lambda(X) = e\lambda.f(x)$$

where x is pixel in the study area, λ is vector of coefficient (feature weights), and f is vector of all features.

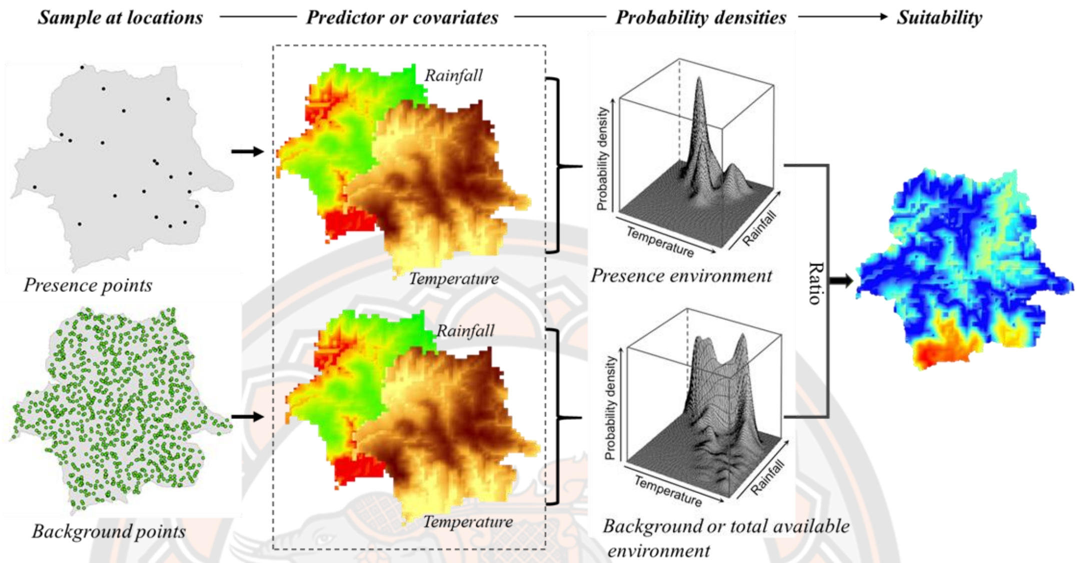

Figure 6 A diagrammatic representation of maxent probability densities. Two steps are involved in calculation of potential distribution of species in maxent: (i) calculate probability densities for all presence points (PDPPs), (ii) calculated probability densities for background points (PDBPs) across the entire study region. PDBPs characterizes the available environment within the study region, whereas the PDPPs characterizes the environment of where a species has been found. Maxent then calculates the ratio between PDPPs and PDBPs, which gives the relative environmental suitability for presence of a species for each point in the study area.

Source: Adapted from a statistical explanation of maxent for ecologist (Elith et al., 2011)

Ecological application of maxent

Understanding the spatial distribution of species and their relationship with the surrounding environment is one of the important statistics essential for efficient conservation planning (Macdonald & Rushton, 2003). However; the gathering of such statistic for endangered species is both time and resource extensive due to the rarity of the species in the wild. Moreover, studying endangered small mammals like the red panda is challenging since they are small in size, elusive, territorial and solitary with crepuscular behavior which inhabits forested mountainous regions relatively inaccessible to the researcher (Wei & Zhang, 2011). Thus; maxent as an SDM tool can identify the environmental variables related to species occurrence and project across the area of interest (Pearson et al., 2007; Phillips et al., 2006). Prediction can help conservationist and policymaker to make an informed decision through the identification of spatial distribution pattern, priority conservation site, suitable habitat for rare species (Rebelo & Jones, 2010), or for species that are distributed across a wide or challenging landscape that prohibit detailed survey (Newbold et al., 2010).

Recently, modelling of the potential red panda habitat distribution across the range countries was made using maxent (Thapa et al., 2018). The model satisfactorily predicted an estimated area of 1,34,975 km^2 as the potential habitat of which 72.07 percent is likely to receive relatively low legal protection since they fall outside the existing protected area network. The study recommended initiation of field survey in newly predicted places, establish and strengthen community conservation sites outside the protected areas, pledge transboundary conservation, identify conservation priority sites and biological corridor to facilitate dispersal to secure the population of endangered red panda in wild (Thapa et al., 2018).

Similarly, initial modelling of the potential habitat of red panda in Bhutan was also initiated by using maxent (Dorji, 2011). According to study 21 percent of the total geographic area was predicted to have suitable potential habitat. Though 46 percent of this predicted habitat are known to occur within the cluster of protected areas, a large population of human settlement and their livestock overlapped in the same habitat, in turn, increasing resource competition. Diversification of livelihood option, insertion of predicted nearby potential habitat into Sakteng Wildlife Sanctuary’s jurisdiction via boundary extension and initiation of transboundary conservation with Indian counterpart was also recommended. Transboundary conservation is expected to maintain landscape connectivity between the potential red panda habitat in two countries, ultimately contributing to the long term persistence of the species and other associated wildlife beyond geopolitical boundaries (Dorji, 2011).

Maxent has also extensively contributed to study potential response of species to climate change (Loarie et al., 2008; Shrestha & Bawa, 2014; Songer et al., 2012), conservation effectiveness of protected areas (Xu et al., 2014), spatial distribution of species (Knowles et al., 2016; Matawa et al., 2012; Phillips et al., 2006), management priorities for mammal (Trisurat et al., 2012) , effects of landscape restoration to conservation (Angelieri et al., 2016).

Landscape connectivity modelling concepts

Landscape connectivity and modelling

In the current era; habitat degradation and loss is the major challenge and threat to the conservation, resulting in fragmentation of the habitat. Risk and incidence of extirpation increase with a fragmented population, whereby, the ability of the species to recolonize the patches that experienced extirpation is important for the regional survival of species in fragmented landscape (Fahrig & Merriam, 1994; Henderson et al., 1985). In essence, the maintenance of a good network of resource patches with adequate connectivity for dispersing individuals is likely to support species persistence (Fahrig & Merriam, 1994) (Figure 7). However, the success of recolonization is dependent on the availability of adequate individuals of dispersing population, their behavior, landscape spatial structure and permeability of the landscape to facilitate the movement of the species in between the resource patches known as landscape connectivity (Fahrig & Merriam, 1994). Thus, landscape connectivity according to (Taylor et al., 1993) is defined as “the degree to which the landscape facilitates or impedes movement among the resource patches”.

In the landscape, connectivity can be measured based on the probability of the movement of species between resource patches, whose distribution is influenced by landscape physiognomy and composition (Taylor et al., 1993).

Landscape connectivity can be broadly assessed under two categories viz. structural and functional connectivity. Former is defined based on landscape structure ignoring the species movement behaviour, while, later is defined incorporating the species’ behavioural responses to landscape elements and spatial structure of the entire landscape(Taylor et al., 2006). Structural connectivity can be further subcategorized based on; distance, contagion or percolation, amount of habitat, dispersal success, searching time for new habitat, immigration rate, presence or absence of corridors, graph theory, movement probability and re-observation of displaced individuals (Kindlmann & Burel, 2008). Functional connectivity can be measured based on the probability of movement between patches, immigration rates and landscape matrix permeability (Kindlmann & Burel, 2008). However, landscape connectivity in this study will be determined using landscape matrix permeability with the help of a least-cost path in combination with circuitscape.

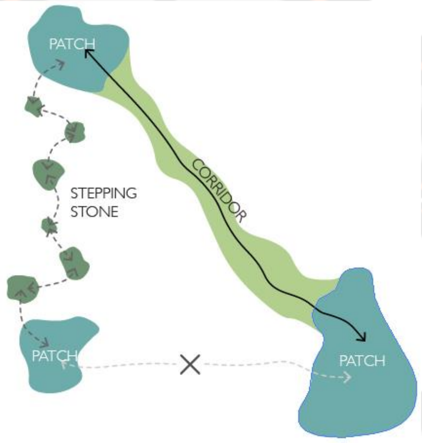

Figure 7 Illustration of the landscape connectivity with corridor

Source: Adopted from an introduction to habitat connectivity (Crain, 2015).

Theoretical framework of Least Cost Path

The least-cost path (LCP) is one of the prominently used tools to study landscape connectivity in ecology. It provides the measure of connectivity between pairs of locations by integrating the function of distance traveled and traversed cost across the landscape represented by the cost-surface (Etherington, 2016). LCP measure proximity of the place to identify the best travel route in the landscape with varying travel cost which is more convincing than the Euclidian distance measured in a straight line (Etherington & Holland, 2013). Per unit distance cost associated with traversing different parts of the landscape is represented by the values within a cost surface. The product of cost and distance traversed results in accumulated cost (Etherington, 2016).

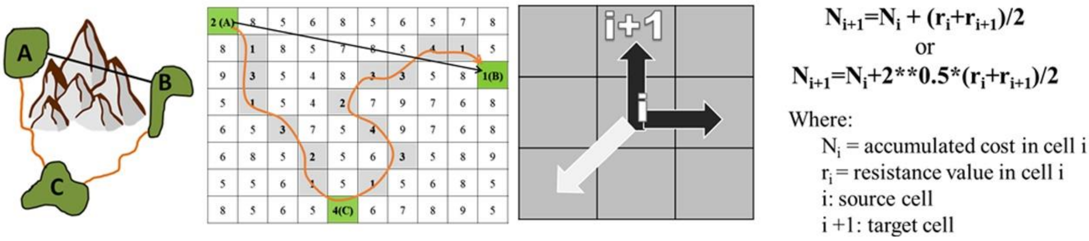

Figure 8 Diagrammatic illustration of least cost model

Least cost path:(left) real geographic scenario and (center and left) raster cost surface. To travel from point A to point B, straight black line represents Euclidian distance which does not consider the cost and curvy orange line represent least cost path that take into account of cost represented by lower values.

Cells with greater cost represent factors that hinder the movement of the species in the landscape. Least cost path works with a simple algorithm; for any given movement in the landscape from cell Ni to cell Ni+1, the cost to reach cell Ni plus the average cost to move through cell Ni and Ni+1 make a cumulative cost. Diagonal movement along the cells is realized using the 8-neighbor cell algorithm. The longer distance traversed upon diagonal movement between the cell is compensated by multiplying with a square root of 2 (Adriaensen et al., 2003) (Figure 8).

Theoretical framework of Circuitscape

In circuitscape, connectivity in a heterogeneous landscape is modelled using electrical circuit theory. In electrical connectivity between two electrical nodes, the greater current flow is known to occur through multiple or broader conductors than the conductors that are single or narrow. Likewise, multiple and broader width corridor connecting habitat patches or dispersal population facilitates greater movement in the landscape between the habitat patches. This conceptual resemblance enables the application of circuit theory (circuitscape) to handle the ecological problem (Figure 9 B and C). Further, voltage, current, conductance and resistance in circuit theory can be interpreted in terms of movement in landscape ecology since circuit theory is closely connected to random walk theories (McRae et al., 2008).

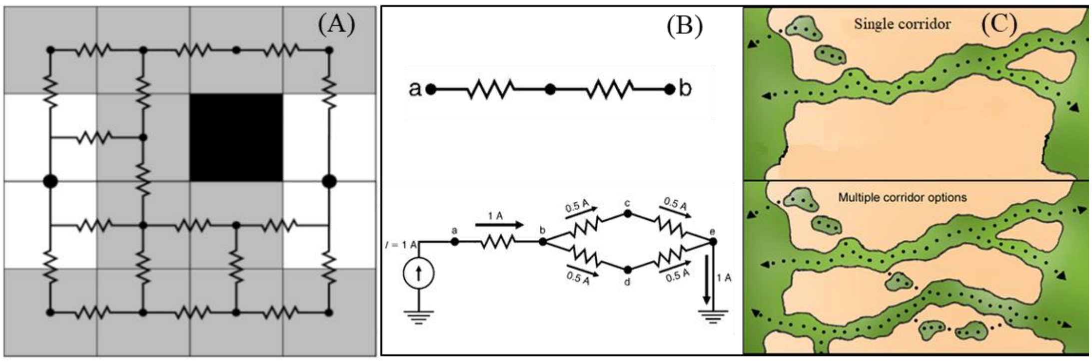

Figure 9 Illustrations of the data type used by circuitscape
Though raster grid cells can have any resistance value, here for illustration purpose, cells shown in white represents zero resistance ("short-circuit regions," used to represent contiguous habitat patches), gray represent resistance value 1 and black with infinite resistance [coded as NODATA. (A) When Raster grids are converted to electrical networks. Each cell becomes a node (represented by a dot), and adjacent cells are connected to their four or eight neighbors by resistors. Here, the two short-circuit regions have each been collapsed into a single node. The infinite resistance cell is dropped entirely from the network. (B) and (C) Pictorial illustration of conceptual resemblance of circuit theory and animal movement.

Source: McRae et al., (2008)

In circuitscape, landscape function as the conductive surface where the landscape matrix that facilitates individual movement with better permeability is assigned with low resistance value and movement barrier with high resistance value. Movement of the individual species and genetic dispersal across the landscape is interpreted from current flow, effective resistances, and voltages calculated across the landscapes (McRae et al., 2008) (Figure 9 A).

Ecological application of Least Cost Path and Circuitscape

In the landscape ecology; connectivity maintains ecological dynamics in and among the habitats which promote species persistence through dispersal, demographic rescue, gene flow and shift in response to climate change (Collinge, 1996; Heller &

Zavaleta, 2009; Henderson et al., 1985). Lack of connectivity in the fragmented landscape may limit the recolonization of species through restricted species dispersal, resulting in reduced genetic exchange which is an undesirable phenomenon (Henderson et al., 1985). The identification of suitable connectivity or corridor in the large landscape through the detailed survey is time and resource extensive. Thus; the least cost path and circuitscape can enable identification of suitable connectivity based on known ecology of the species and available landscape information, involving minimum time and resource. Such findings can be a guide for investments targeted to promote and improve landscape connectivity.

Though there is no specific study ever attempted to identify landscape connectivity in context to red panda as the focal species, least cost model in complement with circuitscape is extensively used to identify potential connectivity (corridor) for other species. Least cost path and circuitscape together have greatly contributed to the field of conservation by identifying landscape connectivity for endangered Bornean banteng in Malaysia (Lim et al., 2019), European bison in Europe (Ziółkowska et al., 2012), corridor restoration between giant panda reserves in China (Wang et al., 2014), dispersal routes in the California tiger salamander (Wang et al., 2009), potential corridors for cougars dispersal in North America (LaRue & Nielsen, 2008), translocation cost of invasive common brushtail possum in New Zealand (Etherington et al., 2014), and movement route for royal bengal tiger in central India (Dutta et al., 2015).

Red panda

Ecology of the red panda

Red panda is the only living species in the family of Ailuridae (Duszynski et al., 2018) which has adapted to the herbivore way of living despite being a carnivore. Based on the morphology and geographic barriers, red panda is reported to have two subspecies (*Ailurus f.fulgens* and *Ailurus f. styani*). *Ailurus f. styani* is restricted to Sichuan and part of Yunan province and known as the Chinese subspecies while *Ailurus f.fulgens* is referred as Himalayan subspecies distributed across the Himalayan range (Glatston, 2011; Wei et al., 1999). However, latest genomic evidence revealed that they are two different species (Hu et al., 2020) and this study deals with Himalayan species *Ailurus f. fulgens*. Across the range countries, the red panda population is estimated at less than 10,000 matured individuals with a likely decline over the years (Wang et al., 2008).

Recently, red panda is upgraded to an endangered category in the IUCN red list of threatened species due to the estimated decline in population and natural habitat which is projected to continue and probably intensify over coming years (Glatston et al., 2015).

Young leaves and shoots of the bamboo comprise the primary diet of the red panda though it also feeds on fruit, roots, succulent grasses, acorns, lichens and occasionally birds eggs, insects and grubs (Yonzon & Hunter, 1991). It is mostly arboreal and has specialized habitat niche requirements related to forest types, elevation, availability of fallen logs and stumps, proximity to water sources and disturbances (Yonzon & Hunter, 1991).

Distribution of the red panda

The red panda is endemic to eastern Himalaya (Roberts & Gittleman, 1984). Their distribution stretches from Nepal in the west through Sikkim and Darjeeling in India, Bhutan, Arunachal Pradesh (India), Myanmar, and southern China in the east (Choudhury, 2001; Roberts & Gittleman, 1984) (Figure 10).

Generally, they prefer elevation within the range of 2800m to 3900m (Yonzon & Hunter, 1991), yet some incidences of species sighting at an elevation of 1525 m (Prater, 1965) and 4325m are reported (Dorjee et al., 2014). Though there is no recent evidence of red panda sighting in Meghalaya (Ghose & Dutta, 2011), the presence of the disjoint population of the red panda was also reported in a tropical forest of Meghalaya plateau at an elevation of 700m to 1400m (Choudhury, 1997).

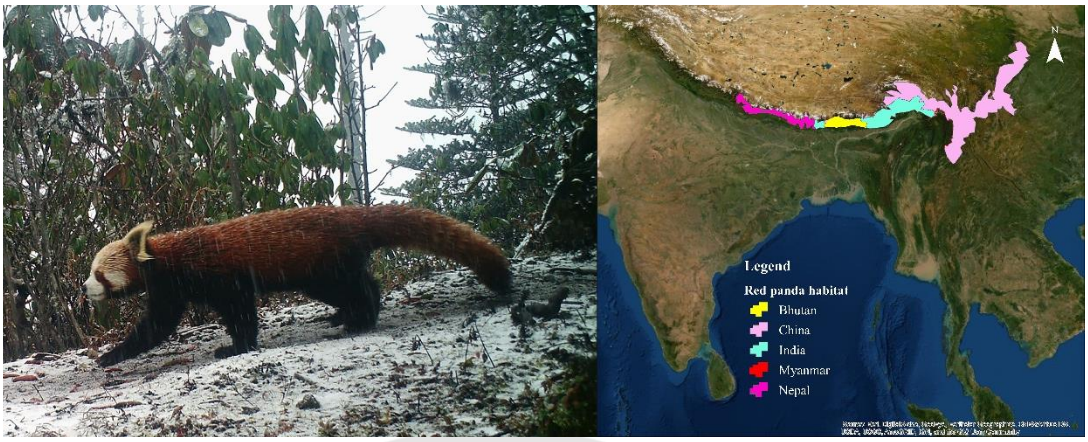

Figure 10 The red panda (left) and their global distribution map(right).

Source: The red panda photograph was obtained through camera traps in Sakteng Wildlife Sanctuary and their distribution map was adapted from the IUCN website.

Within the confirmed habitat of 592.39 km^2 across 24 districts, Nepal is expected to have an estimated population of 317 red panda (Bista & Paudel, 2014). The occurrence of the species in Bhutan was confirmed from 13 districts by then (now 17 districts) within the elevation range of 2400m to 3700m (Dorji et al., 2012). Earlier, in China red panda was also known to occur in the province Guizhou, Gausu, Shaanxi and Qinghai however at present species occurs only in the provinces of Sichuan, Yunnan, and Tibet (Wei et al., 1999). Despite the availability of 2900km^2 potential habitat was predicted, not much is known about the red panda in Myanmar. Recent modeling by Thapa et al. (2018) predicted 1,34,975 km^2 of suitable red panda habitat across the range; 62% occurs in China, Nepal (15%), Myanmar (9%), Bhutan (9%), and India (5%). However, most of the habitats are known to occur outside the protected area across its range countries (Thapa et al., 2018).

Benefits from the red panda conservation

The red panda is considered as an indicator species of temperate ecosystems (Williams, 2006) and is chiefly associated with matured temperate forest with dense bamboo thicket understory (Roberts & Gittleman, 1984; Yonzon & Hunter, 1991). Since; they prefer temperate forests for ensuring its viable population, their presence can be an appropriate indicator for monitoring the intactness of the Eastern Himalayan Broadleaf and Conifer Eco-region (Dorji et al., 2012).

It is also considered as flagship species of Himalaya. Their habitat in eastern Himalaya is stretch across huge landmass with relatively intact forest cover from Nepal to southwest China. This stretch of the intact forest directly contributes to climate regulation, clean air and water to a large number of people (Glatston & Gebauer, 2011) besides substantial contribution to the economy. In Bhutan, all major river systems have tributaries and catchments originating from most preferred red panda habitat. Protection of watershed catchments maintains a continuous flow of water which is essential for sustainable agriculture production and revenue generation. As a flagship species; the red panda plays a significant role in the functioning of an ecosystem of temperate forest in eastern Himalaya, influencing the health of other wildlife and diverse bird species that are endemic to the region (Mallick, 2015). In essence, the presence of red panda ensures the health of the forest and the quality of the overall environment.

The red panda conservation efforts

The red panda is highly protected as Appendix I species under the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) (www.checklist.cites.org). It is also legally protected by the government of all the habitat range countries (Bista & Paudel, 2014; Ghose & Dutta, 2011; Wei et al., 1999), as a result hunting of red panda is illegal across the range (Glatston et al., 2015).

Besides legal protection across the habitat range, red panda habitat is also managed in some areas through community participatory-based conservation, which empowers the community and provides sustainable livelihood benefits through community-based ecotourism and ecosystem services. Reduction in fuelwood consumption by up to 35 percent per households (Ghose & Dutta, 2011), management of solid waste and free-ranging dog populations to reduce the impact of waste and outbreak of disease from dog to the red panda are also initiated (Ghose & Dutta, 2011). In Bhutan, under integrated conservation and development programs (ICDP), shingle and bamboo mat roofing are replaced with a metallic sheet to reduce Fir and Bamboo extraction from the valuable habitat of the red panda. Under the same initiatives, communities are provided with sustainable livelihood options by promoting community-based ecotourism and other benefits (Dorjee, 2009).

The red panda conservation threats and challenges

Though red panda is legally protected in all the range countries; unfortunately, it's population is still unstable because of rapid fragmentation and loss of habitat. It is resulted from resource exploitation by ever-increasing human populations and other threats such as accidental killing, illegal poaching, diseases, free-ranging dogs, climate change, mass flowering of bamboo, habitat encroachment and resource competition throughout the red panda habitat range (Bista et al., 2017; Dendup et al., 2016; Dorji et al., 2012; Glatston et al., 2015; Wei et al., 1999; Yonzon & Hunter, 1991). These threats have accelerated the decline in the population of the red panda in the wild promoting its status to the endangered category of IUCN (Glatston et al., 2015).

The red panda conservation in Bhutan

Generally, red panda in Bhutan is known to occur within the elevation range of 2400 to 3700 m in cool broadleaf to fir forest with profuse bamboo undergrowth near the water sources (Dorji et al., 2012). Although in 2011 red panda was reported to be present only in 13 districts (Dorji et al., 2012), recently their distribution in 17 out of 20 districts were confirmed. Out of 10 protected areas and 9 biological corridors, the presence of red panda is documented from 7 parks and 8 biological corridors. Bhutan is predicted to harbour an estimated area of 12,407km^2 of potential habitat for the red panda, of which 43.52 percent are within the network of protected areas. In term of habitat suitability, 32.93 percent and 12.31 percent falls within the category of moderate and highly suitable respectively (Thapa et al., 2018).

Considering the average density of one red panda per 4.4 km^2 (Yonzon & Hunter, 1991); under the ideal situation, Bhutan is likely to have an estimated population of 1275 individuals of red panda within the moderate to highly suitable habitats. However; according to (Dorji, 2011), only 21 percent (8062.74km^2) of the total geographic area of the country is predicted as the potential habitat which is relatively lower than 32.3 percent estimated habitat by Thapa et al., (2018). Thapa's prediction was based on data obtained from entire range countries while Dorji's model was based on data confined to Bhutan, such dissimilarity might have resulted in difference in a percent of predicted areas. The difference in conservation modalities, disturbances pattern and culture across the range countries could also affect the distribution of red panda, thus introducing biases in data collection and difference in model prediction.

The red panda has been listed as a Schedule I species in the Forest and Nature Conservation Act of Bhutan under which it receives the highest legal protection (RGOB, 1995). Although it is legally protected and majority of the potential habitat in Bhutan falls within the network of park and biological corridors, red panda is known to experience threat from the huge population of humans residing in same elevation range, timber and fuelwood extraction, construction of roads, growth in tourism sector, people dependency on natural resource, extensive livestock grazing, accidental poaching and predation by dogs (Dendup et al., 2016; Dorjee, 2009; Dorji et al., 2012). Nevertheless, relevant stakeholders, policymakers and conservationist are constantly working towards reducing the threat by diversifying people's livelihood option through implementation of ICDP initiatives, improvement of rangelands, restoration of degraded habitats, advocacy, research, preparation of conservation action plan and management of stray dog population (Dorjee, 2009; Dorji et al., 2012; Millar, nd; NCD, 2019).

Climate scenarios

Theoretical framework of the Representative Concentration Pathways (RCPs) as future climate scenarios

Climate change is anticipated to be triggered by anthropogenic activities related to elevated greenhouse gas (GHG) emission due to the increasing population, economic activity, consumption pattern, energy use, land use patterns, technology, and climate policy. Changes manifested through elevated GHG concentration can be reported by the additional amount of energy trapped within the atmosphere in the units of Watts/m^2 (W/m^2). The Representative Concentration Pathways (RCPs) are first used to summarize these future change scenarios in the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change. The RCPs describe four different 21st century pathway of GHG emissions which are used for making projection based on aforementioned factors(IPCC, 2014).

"The name "representative concentration pathways" or RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest, but also the trajectory that is taken over time to reach that outcome. They are representative in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics"(Wayne, 2013).

Based on the GHG mitigation scenarios, RCPs are classified as stringent mitigation scenario (RCP2.6), intermediate (RCP4.5 and RCP6.0) and extreme or very high GHG emission (RCP8.5). Pathways ranging between RCP6.5 and RCP8.5 is assumed to occur if no extra efforts to limit GHG emission takes place (IPCC, 2014).

RCP2.6 is a "peak-and-decline" scenario where radiative forcing level returns to 2.9 W/m^2 by 2100 with peak of ca.3.1W/m^2 by midcentury. Decline in radiative forcing level after midcentury is assumed to achieve with substantial reduction in GHG emission over time(van Vuuren et al., 2007). RCP4.5 assumes that total radiative forcing will be stabilized shortly after 2100 at 4.5W/m^2 without overshooting that value, thus it is considered as stabilization scenario which will peak at midcentury (Meinshausen et al., 2011; Thomson et al., 2011). RCP6.0 is also a stabilization scenario where radiative forcing will peak at 2060 and will stabilize at 6.0W/m^2 after 2100 without overshoot, by reducing GHG emission with application of technologies and strategies(Hijioka et al., 2008; Masui et al., 2011). Unlike the other three RCPs, the increasing GHG emission scenario over time is represented by RCP8.5. It assumes the high energy demand, GHG emission and absence of climate change policies as a result of high population and slow income growth, little change in technologies and energy intensity improvement (Meinshausen et al., 2011; Riahi et al., 2011).

By the end of the 21st century, the global surface temperature change is predicted to exceed 1.5^{0}C relative to 1850-1900 for all the RCPs except RCP2.6. With RCP4.5 it is unlikely that it will exceed 2^{0}C while RCP6.0 and RCP8.5 are likely to exceed 2^0C. Change in surface temperature is predicted to be within the range of 0.3 to 4.8^0C towards the end of the 21^{st} century under different RCP scenarios(IPCC, 2014).

Ecological application of climate scenarios

Scenarios of different rates and magnitude with identifiable thresholds facilitate the assessment of the risk of climate change. They enable a better understanding of uncertainties and alternative futures, rather than predicting the future and describe likely trajectories of different aspects of the future that are built to investigate the potential impact of anthropogenic climate change(IPCC, 2014; Moss et al., 2008). Scenarios represent many of the major driving forces that are important for informing climate change policy including processes, impacts (physical, ecological, and socioeconomic), and potential responses. Thus it provides an option to consider how robust different decisions may be under range of future climate possibilities(Moss et al., 2008).

Climate scenarios are widely used for studying the potential impact of climate change to the distribution of species (de Oliveira et al., 2019; Loarie et al., 2008; Shrestha & Bawa, 2014; Songer et al., 2012)

CHAPTER III

RESEARCH METHODOLOGY

Conceptual framework

This section mainly discusses the data collection process, data characteristics, processing and modelling techniques that are involved in conducting this study. The methods used in this study is adopted from the literature review of similar studies conducted elsewhere (Figure 11).

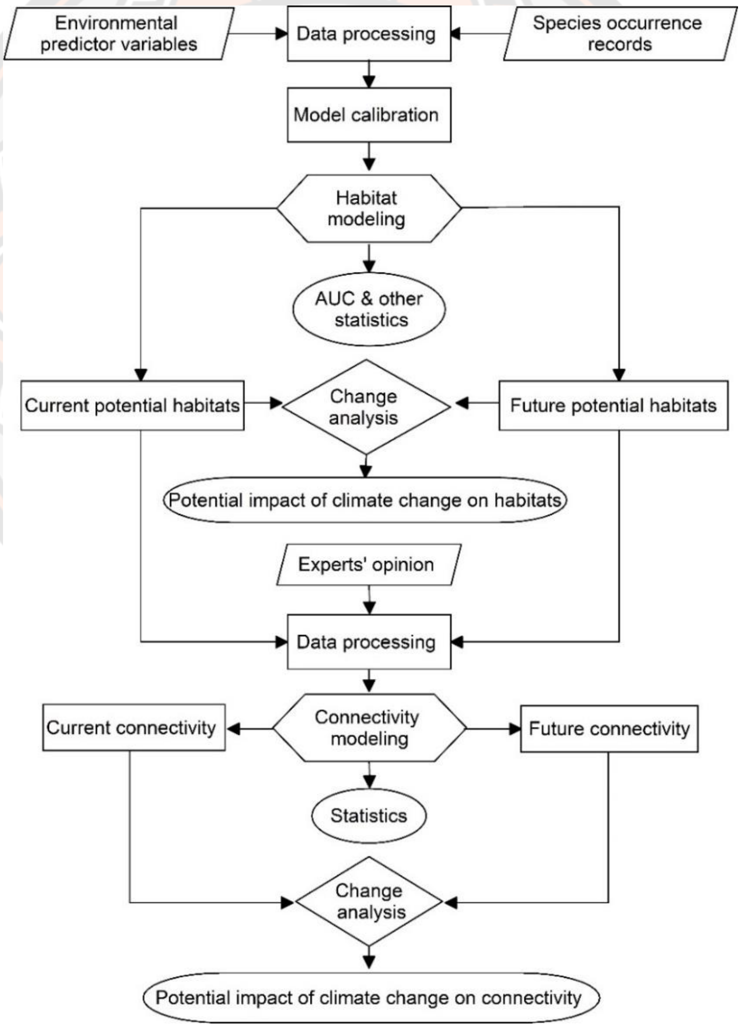

Figure 11 The overall conceptual framework

Data and software

The following list of data and software given in table 2 are used in this study. They are elaborated in the subsequent sections in this chapter.

Table 2 A list of data and software used in this study

Name	Type	Source	Purpose	Resolution
Red panda occurrence points	Georeferenced coordinates	Collected using handheld GPS during the survey	Sample	-
Bioclimatic variable	Raster file	https://www.worldclim.org/	Predictor layers	30 arc-sec resampled to 30 m
Environmental layer	Raster file	Aster DEM	Predictor layers	30 m
ArcMap 10.4.1	Software	ESRI@ India	Data processing	-
Maxent 3.4.1	Software	https://biodiversityinformatics.amnh.org/open_source/maxent/	Habitat modeling	-
Linkage mapper 2.0.0	Software	https://circuitscape.org/linkagemapper/	Connectivity modeling	-
Garmin eTrex 30	GPS	-	Data collection	
Camera traps	-	-	Data collection	-
R3.4.4	Software	https://cran.r-project.org/bin/windows/base/old/3.4.4/	Data processing	-

Species occurrence data and their collection methods

The red panda occurrence data are acquired from the database maintained in the office of SWS collected using handheld GPS during the survey from 2014-2018. Those data are collected during several field surveys: national tiger survey (2014-2015), biodiversity survey (2015), musk deer camera trapping exercise (2017), sustainable forest management plan survey (2018) and regular field patrolling by the field staffs. Species is identified based on photographs captured by motion sensor camera traps, scats and feeding characteristics of the red panda. Red panda occurrence coordinates were collected using handheld GPS Garmin Etrex 30x. Systematic national tiger survey was conducted by the installation of a pair of camera traps in every 5km x 5km grid. Biodiversity survey in 108 circular plots (12.62m radius) followed the stratified random sampling and the musk deer survey used an opportunistic sampling method using motion sensor camera traps. Sustainable forest management plan survey adopted a systematic survey that was confined within potential resource extraction sites. Data collected during patrolling doesn't follow any defined survey method; however, extensive patrolling is regularly conducted across the landscape of SWS. After an extensive search and screening, 18 numbers of georeferenced points were obtained for this study (Figure 12).

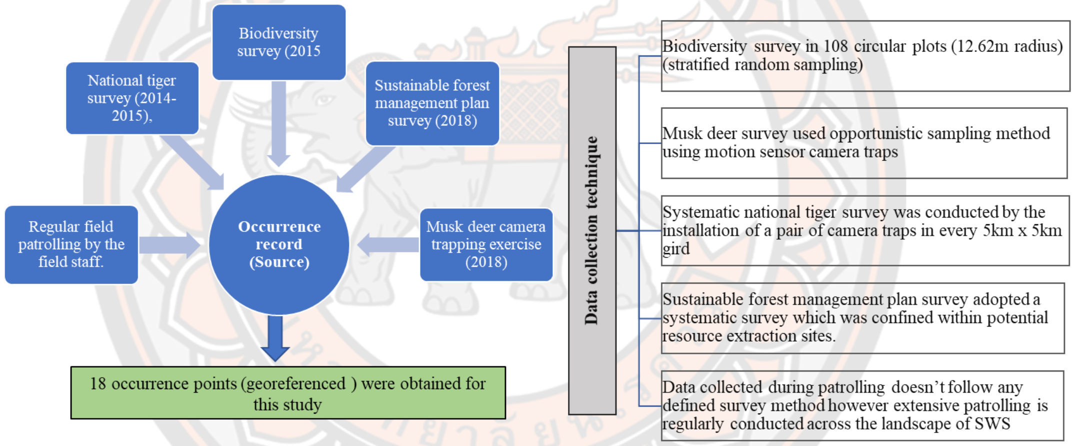

Figure 12 Data collection methods

Predictor variables and their source

The slope in degree and aspect are prepared using 30 m aster DEM. Bioclimatic variables are downloaded from worldclim version 1.4 (http://www.worldclim.org/). It is a set of 1km^2 spatial resolution global climate layers (gridded climate data). Data restricted from 1950 to 2000 gathered from the different sources across the globe were used to generated worldclim version 1.4 climate layer through interpolation. The interpolation process was executed in the ANUSPLIN package following a thin-plate smoothing spline algorithm, using latitude, longitude, and elevation as independent variables (Hijmans et al., 2005). It consists of 19 bioclimatic variables representing annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters) (Table 3). A quarter is 1/4 of the year. The highest spatial resolution climate data available for the download is 30 arc-seconds (~1 km) which is very coarse to represent the climate of the small study area. However; for this study, ~1 km was resampled to 30 m resolution adopting a bilinear resampling technique in ArcGIS.

Table 3 A list of 19 bio-climatic variables downloaded from worldclim version 1

Code	Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temp. Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Source: Hijmans et al., (2005)

The downscaled and calibrated global climate model (GCM) data for the year 2050 from World Climate Research Programme's (WCRP) Coupled Model Inter-comparison Project 5 (CMIP5) of Intergovernmental Panel on Climate Change's (IPPC) Fifth Assessment (AR5) was used as a future climate scenario. The climate scenario for the year 2050 (average of 2041 to 2060) modelled by Community Climate

System Model Version 4 (CCSM 4.0) was used to model future climate. CCSM4.0 is a general circulation climate model consisting of atmosphere, land, ocean, and sea ice components that are linked through a coupler that exchanges state information and fluxes between the components (Gent et al., 2011).

Out of four Representative Concentration Pathways (RCP), only RCP4.5 and RCP8.5 are used in this study. RCP4.5 is selected because it is a stabilization scenarios corresponding to policies that approximate GHG emission mitigation efforts proposed at the COP21. While RCP 8.5 is selected since it represents the worst case GHG emission scenario over other RCPs (Barredo et al., 2017).

Global mean surface temperature for the year 2046-2065 is projected to change by 1.4^{o}C and 2^{o}C under the scenario of RCP 4.5 and RCP 8.5 respectively (IPCC, 2014). RCP 4.5 can be considered as optimistic and RCP 8.5 as the pessimistic climate scenario.

Data analysis

Data analysis involves following steps mentioned in the figure 13. Habitat modeling was executed in maxent software while connectivity modeling was achieved with linkage mapper. Change and other analysis are done using ArcGIS.

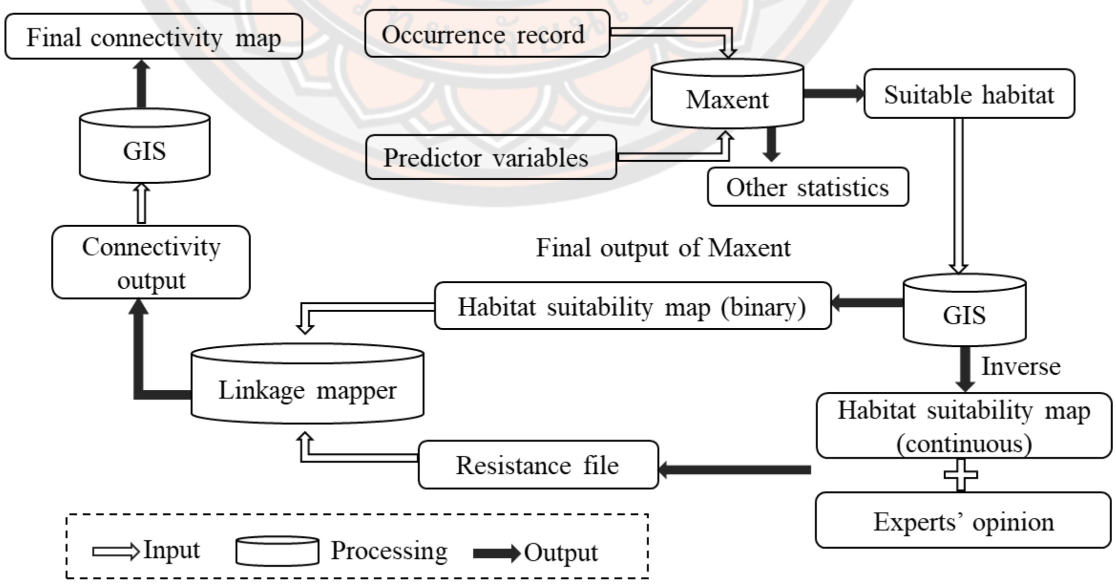

Figure 13 A framework of data analysis

Maxent species distribution model

The Maxent accepts only .ascii and .csv file format. All environmental layers are converted to .ascii in ArcGIS and the presence data are recorded in a .csv file. All environmental layers are converted to the same coordinate system, cell size, and extent. The maxent is one of the robust SDM tools for presence-only records, however, there are two schools of thought regarding the treatment of predictor variable's collinearity. One suggests that the maxent model is not affected by collinearity (Elith et al., 2011; Phillips & Dudík, 2008), while the other argues the need to minimize collinearity (Merow et al., 2013). In this study, a preliminary test run with and without treatment of collinearity amongst the predictor variables exhibited different results. Though there was no visible difference in result with the current climate, future climate scenario's results were contrasting for with and without collinearity treatment. Hence, this study is based on the model run after treating the collinearity.

Multi-collinearity among the predictor variables were minimized by selecting only variables with Pearson's correlation threshold $r < 0.7$. Finally, six statistically and ecologically significant predictor variables were selected to model the potential habitat distribution. Background sample points (pseudo absences) were restricted within the 4km buffer of actual points of species occurrence record to reduce the sampling bias. Area within the buffer of 4km seems reasonable for approximating the assumptions of background selection by not including large areas that the species does not reside because of limitations to dispersal or biotic interactions and less than $4km^2$ home- range size of red panda (Elith et al., 2011). Model was fine-tuned with help of ENMeval package in R with given settings: method = "randomkfold" (where kfolds=5), RMvalues=seq (0.5,4,0.5) and fc = c ("L", "LQ", "H", "LQH"). LQH feature class was selected based on the recommendation by Elith et al., (2011). Model with lower corrected Akaikes's criteria (AIC_c) values with less over fitting was used to determine the best fit model. AICc accounts balance between the goodness of fit and number of the model parameters enabling selection of model with optimal complexity (Warren & Seifert, 2011).

Model was trained and tested with 80% and 20% of the occurrence points respectively. The output format was set to logistic, which results in each grid cell in the map having values ranging continuously from 0 (least suitable) to 1 (most suitable) The maximum True Skill Statistics (TSS) value (0.66) was selected as a decision threshold to distinguish between suitable and unsuitable habitats. The pixels with values equal to or higher than the threshold (maximum TSS) are considered suitable habitats, yielding a binary prediction map. This maximum TSS is independent of prevalence (Somodi et al., 2017) and their use as decision threshold minimizes the risk of choosing unsuitable habitat (Pearce & Ferrier, 2000). Relative importance of individual predictor variables was determined with jackknife procedure. The model was executed in maxent version 3.4.1 using dismo package in R v3.4.0.

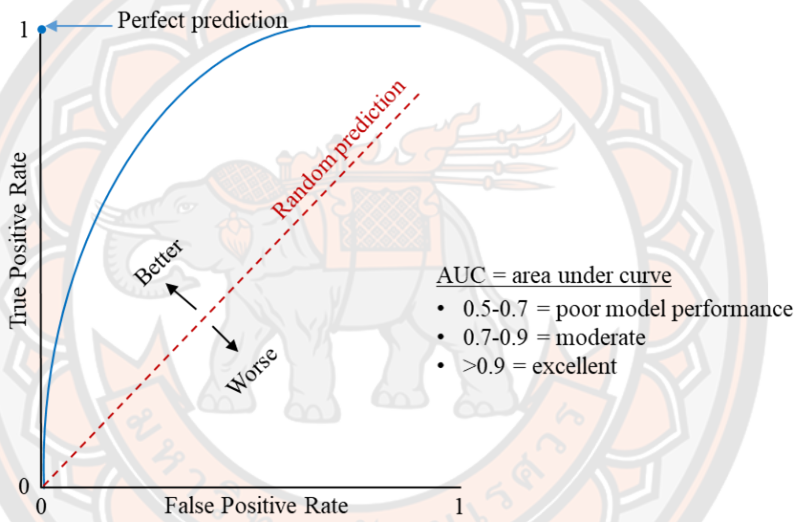

Figure 14 Visual representation of Relative Operating Characteristic (ROC).

Source: Adapted from ROC Curve, a Complete Introduction (Bagheri, 2019)

Model performance was assessed based on the area under curve (AUC) of the receiver operating characteristic (ROC) plot. It measures the distinguishing capability of the classification model where ROC represents the probability curve and AUC as the measure of separability. AUC-ROC tells how much the model is capable of discriminating between the classes. The AUC threshold ranges from 0 to 1 where value higher than 0.5 is considered as a good model with better discriminatory capability, while a model with 0.5 is believed to be the result of random sampling below which model is considered to be unfit or useless as shown in figure 14 (Jiménez-Valverde, 2012; Phillips et al., 2006).

The ROC curve is plotted with sensitivity (y-axis) against commission error (x-axis). Sensitivity (true positive rate) is the proportion of presence correctly identified as presence and commission error is the proportion of absence wrongly identified as a presence which is represented by 1 – specificity, where specificity (true negative rate) is the proportion of absences correctly identified as absence (Jiménez-Valverde, 2012). Further, Kappa statistics was also used to assess the performance of the model. The value of the Kappa statistic ranges from minus (-) 1 to plus (+) 1, where values close to +1 indicates better performance and values =<0 indicate a poor performance (no better than random prediction) (Cohen, 1960).

Directional distribution (standard deviational ellipse) summarises the dispersion or direction of the features to understand the spatial distribution trend. Standard deviational ellipse (SDE) was calibrated at 1standard deviation which will incorporate c. 68% of all input feature centroids (Mitchell, 2005). Systematic grids of 1000m x 1000m was plotted over the predicted habitat and the centre points of respective gird within the habitat were selected as sample point for SDE analysis. Such systematic sampling helps to minimize the unnecessary sampling bias.

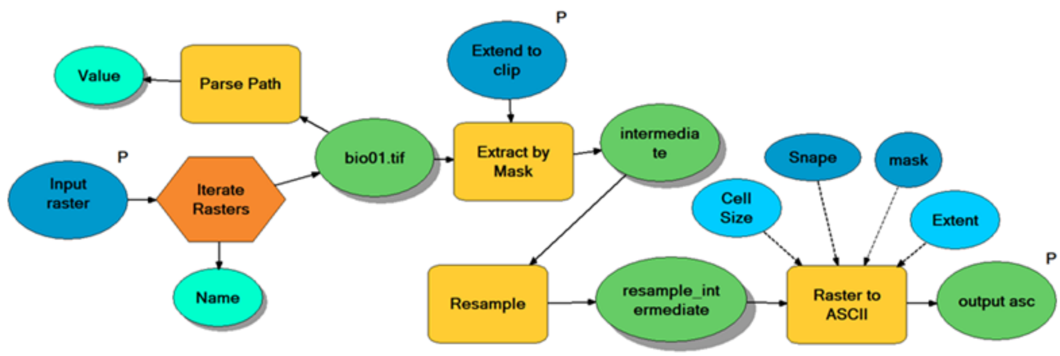

Figure 15 The model builder used in data preparation for maxent. Some of the geo-processing tools like extraction, resampling, conversion, and iterators are used to build the model.

Least Cost Path and Circuitscape in Linkage mapper to model habitat connectivity

The raster resistance or cost file and vector core habitat file are both extracted from a habitat suitability map produced by the maxent model. Final resistance map was formed as the hybrid of inverted habitat suitability map from maxent and the resistance map produced based on expert's opinion. The inverted habitat suitability map was added with reclassified normalized land use map with resistance value to form resistance surface. It represents relative cost required to pass over gridded mapped surface representing the landscape. The following equation was used to invert the habitat suitability map:

*Float ((“Raster layer” – Highest cell value) * - 1) + Lowest cell value*

From the habitat suitability map; cells with the values equal to and more than the corresponding value of maximum TSS was selected as suitable habitats. Core habitat used in connectivity model was prepared by removing non-forested areas, settlements and timber extractions sites from suitable habitats of maxent output.

Using resistance and core habitat as input files, linkage mapper version 2.0.0 is executed to map least cost corridors and least cost paths between the pairs of core habitats. Linkage mapper identifies the adjacent core habitats, creates a network of core habitats using distance and adjacency data, calculates cost-weighted distance (CWD) and least cost path (LCP) and generates maps of least cost corridors between them. Later it combines all individual corridors to from normalized composite map of corridors (Dutta et al., 2015) calculated as follows.

$$CWD_A + CWD_B - LCD_{AB}$$

Where CWD_A is CWD from core habitat A, CWD_B is CWD from core habitat B and LCD_{AB} is the cost weighted distance accumulated moving along the LCP.

Least cost corridors identifies the swath of habitat expected to provide the best route for the movement of animal between the patch of habitats. CWD denote the least accumulative cost required to traverse between a cell and a specified source which is equal to the resistance value of individual cell's to be traversed multiplied by the cell size. The LCP is the single path generated with the minimum CWD between the core habitats (Adriaensen et al., 2003). After least cost corridors are mapped, pinch point (bottleneck or chokepoints) and current flow centrality was determined.

The pinch point represents an area within the corridor that functions as the bottleneck without much alternative route for the movement(McRae, 2012a). Even small loss of areas in identified pinch points would result in compromise of the connectivity. Thus, pinch points play pivotal role in keeping the connectivity intact(Castilho et al., 2015). Current flow centrality helps to measure the importance of a respective linkage in maintaining the overall connectivity in the landscape (McRae, 2012b). During the process least cost corridor act as the surface through which current will flow between the habitats and amount of flow is dependent on resistance of individual cells within it. Pinch point mapper and centrality mapper in linkage mapper was used to determine pinch point and current flow centrality. Both uses circuit theory by calling Circuitscape in linkage mapper(McRae et al., 2008).

Random choice of CWD cut-off width delineates what area to include within the predicted corridor. However, due to lack of empirical data on optimum width of CDW for red panda corridor, existing model was executed with 500m corridor cut-off width. This cut-off figure was derived based on ca. 14 percent (twice the core area) of red panda’s home range size since their core area constituted of only 7.6 percent of the home range (Johnson et al., 1988).

Corridors are analysed and compared based on cost weighted ratio metrics. The two metrics are computed by means of the ratio of CWD to the euclidean distances (EucD) separating each pair of core habitats and CWD to the length of LCP. The higher ratio value for first metric indicates more difficulties to move between the habitat pairs relative to how close they are or after accounting the Euclidean distance. Second metrics describes average resistance animal has to encountered while moving along the LCP identified as the optimal or least resistance path. In both cases, optimum quality linkage will have the ratio equals to one (Dutta et al., 2015).

CHAPTER IV

RESULTS

This chapter is described in two sections. The first section is presented with the results of habitat modelling and the second section describes the findings of the connectivity model

Habitat modelling

Model selection, performance and influencing predictor variables

From the 32 candidate models, the best fit model was assessed with the lower AICc values with higher mean test AUC. The best fit model has an AICc value of 443.66(RM values = LQH3.0). It exhibited higher mean training AUC (0.79) and test AUC (0.74), meaning the selected model performs better than random (AUC > 0.5) in predicting potential red panda habitat distribution (Figure 16). The higher kappa (train = 0.749 and test=0.739) also suggests the better discriminatory capability of the model.

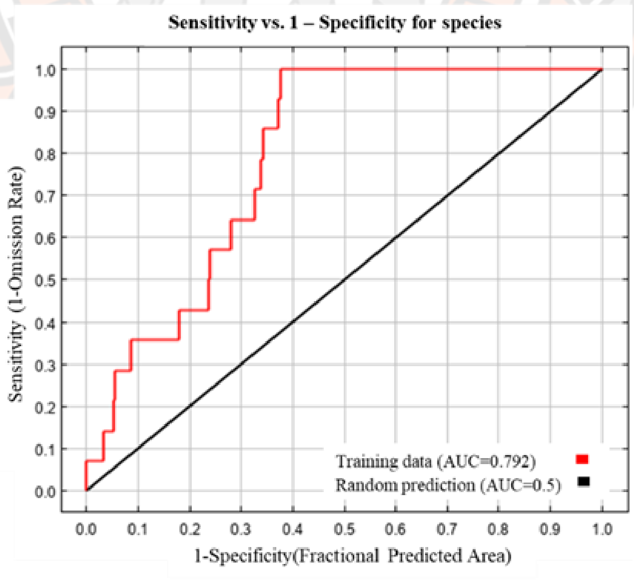

Figure 16 Area under the curve (AUC) plot.
Curve red line indicates the AUC of training data and straight black line indicates random prediction.

Of 21 predictor variables (19 bioclimatic and 2 environmental), only six were not correlated (r<0.7) and are used for model execution. The bio13 (Precipitation of Wettest Month) contributed 67 percent to model building followed by bio15 (33%) (Precipitation Seasonality (Coefficient of Variation)). Remaining predictor variables consisting of bio4 (Temperature Seasonality (standard deviation *100)), bio7 (Temperature Annual Range (bio5-bio6)), slope and aspect did not contribute to the model (Figure 17). Overall, variables related to precipitation exhibited significant influence in predicting potential habitat distribution of red panda in SWS.

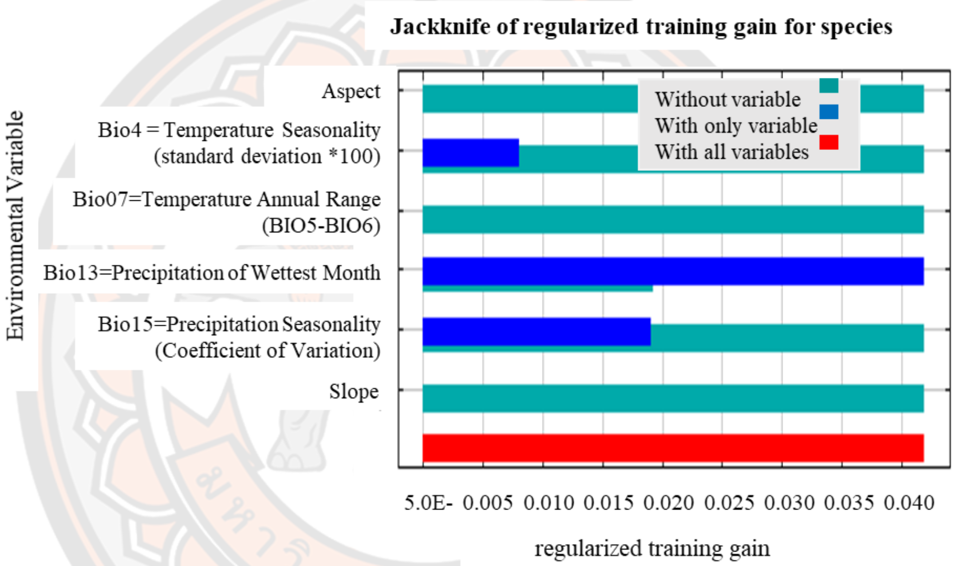

Figure 17 The jackknife test result showing the relative contribution of predictor variables for potential habitat distribution under current climate scenario

Potential habitat for Red panda under current and future climate

The maxent model predicted that Sakteng Wildlife Sanctuary is likely to have 260 km^2 of potential habitat for red panda with current climate scenario. This accounts for 27.7 percent of the total area under SWS. Of the total predicted potential habitat, the maximum predicted habitat occurs under the jurisdiction of Merak range (54.5%) followed by Sakteng (33.4%) and least in Joenkhar (12.2%).

Although Joenkhar has a small patch of potential habitat, it serves as an important link between the larger habitats of Merak and Sakteng (Figure 18). Mixed conifer (60%) and Fir (20.8%) comprise of major forest types within the predicted habitats under the current climate scenario.

With RCP4.5 and RCP8.5 scenarios, 35.1 and 34.1 percent of the SWS is predicted as the potential habitat for red panda respectively. They are relatively more than the potential habitat predicted under current climate scenario.

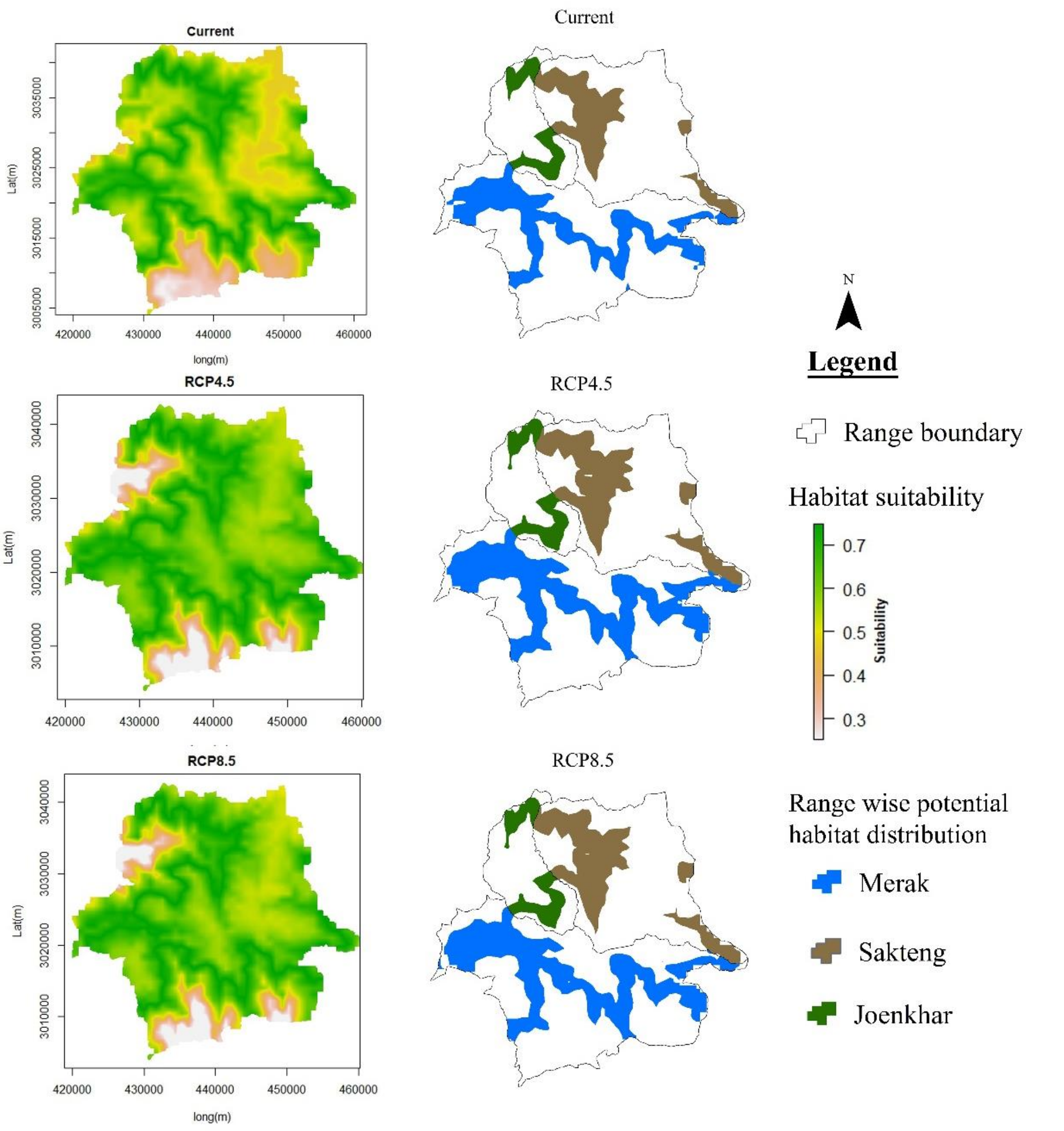

Figure 18 The availability of potential habitats for red panda in SWS under current and future climate (RCP4.5 and RCP8.5).

Habitat suitability (left row) is illustrated in the color gradient where white indicates the lowest and dark green the highest suitability and (right row) maps indicate potential habitats in binary distributed across different range.

Potential impact of climate change on habitat distribution

The potential impact of climate change on the red panda habitat is studied from two different aspects consisting of (1) change in habitat size and (2) shift in elevation. Overall, the model predicted that potential habitat in SWS is likely to experience gain and shift to relatively higher elevation by the year 2050. With RCP4.5 it is likely that there will be gain in potential habitat by up to 26.5 percent which is slightly higher in comparison to the predicted 23.1 percent with RCP8.5. The maximum gain in potential habitat is predicted with RCP4.5 which is approximately 3.4% more than RCP8.5 (Figure 19).

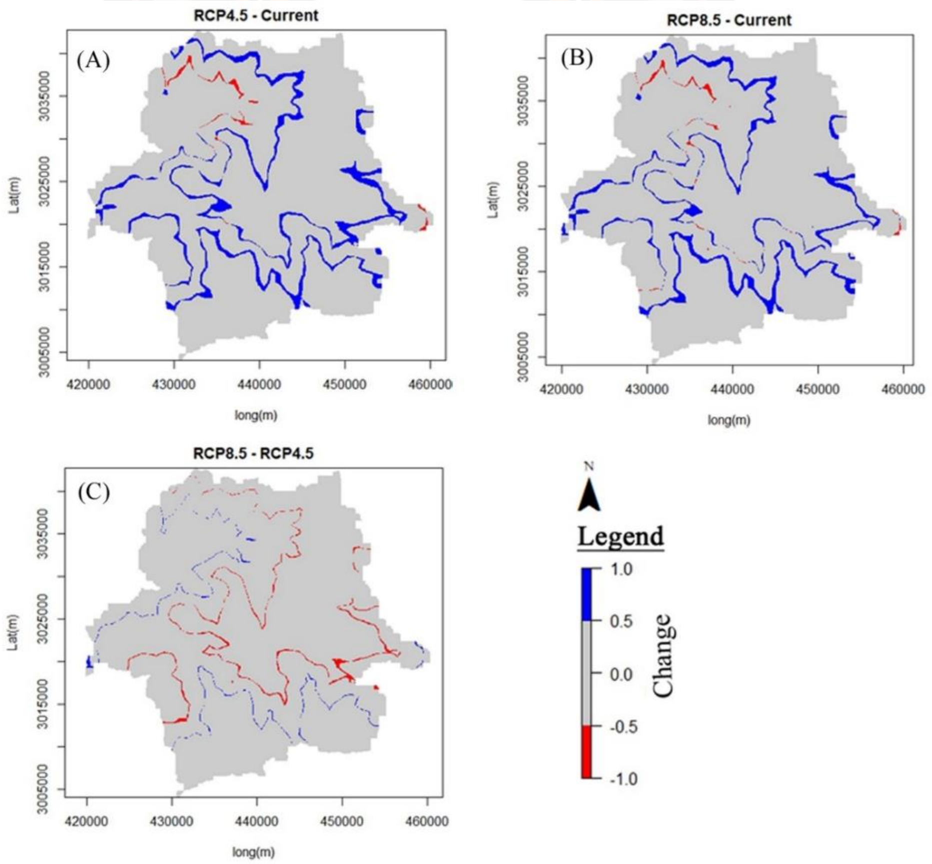

Figure 19 The model based potential impact of climate change in area coverage of the potential habitats of red panda in SWS.
(A) RCP4.5 minus Current (B) RCP8.5 minus Current and (C) RCP8.5 minus RCP4.5. Positive (blue) and negative (red) indicates gain and loss in habitats respectively. Gray color indicates no change or no impact.

Based on the jurisdiction of the respective range, the model has predicted that area under Merak range is likely to experience maximum gain in potential habitats followed by Sakteng and least in Joenkhar irrespective of climate scenarios (Table 4).

Table 4 The potential habitat distribution with different climate scenarios under respective range

Range	Potential habitat under current climate scenario (km^2)	% Gain in habitat in comparison to current	
		RCP4.5	RCP8.5
Merak	141.30	30.93	44.69
Sakteng	86.60	25.87	21.25
Jonekher	31.60	10.76	3.93

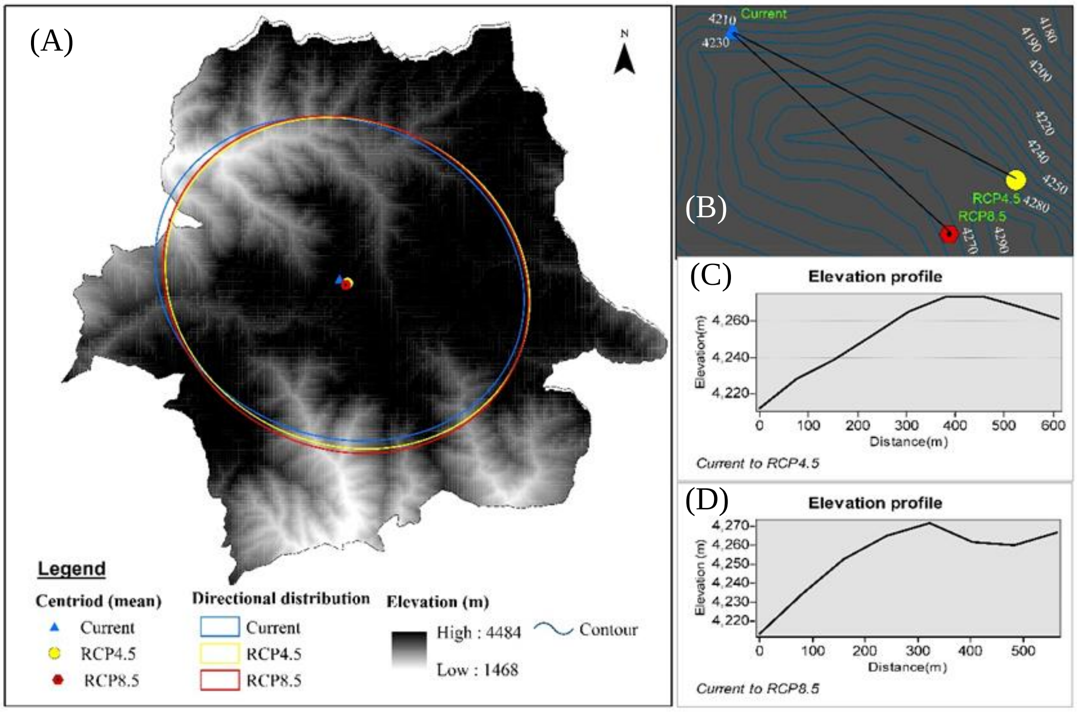

Figure 20 The potential impact of climate change on predicted habitats. Directional distribution (SDE) indicates the direction of gain in potential habitats. (A)The centroid mean (B) and elevation profile (C) and (D) indicates that there is a shift in the habitat towards relatively higher elevation with predicted gain.

According to the location of the mean centre and direction of the standard deviational ellipse, it is likely that habitat will shift towards relatively higher elevation as a result of a gain in potential habitat with climate change (Figure 20). With RCP4.5. the model predicted that gain in potential habitats are likely to occur in places with relatively higher elevation located in central, south and southwest region of the SWS. However, in the case of RCP8.5, it is predicted that the south and northwest regions with relatively higher elevation are like to experience the gain (Figure 19)

Conservation status of the predicted potential habitats

Landscape within the SWS is managed under different management regimes divided in to different zones based on their prime functionality. The core zones are designated for strict conservation where activities other than conservation works and research are prohibited. The buffer zones are transition zone between the area within SWS and outside which functions as the cushion against potential pressure from outside. In between the two zones lies a multiple-use zone designated for multipurpose use with few restrictions (WWF & SWS, 2011). The timber extraction sites are the area designated for extraction of timber resource from the SWS to meet the growing demand for timber for local use (SWS, 2019). It is a part of the multiple-use zone. The area under timber extraction sites, buffer and multiple-use zones are likely to experience a relatively higher frequency of disturbances from human-related activities.

Out of 260km^2 of potential habitats predicted under the current climate scenarios; only 24.42 percent falls within core zone and remaining 75.58 percent are known to occur in other zones comprising of buffer (23.88%), multiple use (32.31%) and timber extraction sites (19.38%). In the case of RCP4.5 scenarios, 35.81% occurs within the multiple-use zone followed by core (24.26%), buffer (22.37%) and timber extraction site (17.57%). Similarly, with RCP8.5, the distribution of potential habitat occurs more in the multiple-use zone (35.02%) followed by a core zone (24.38%) then buffer zone (22.84%) and 17.72% in timber extraction sites (Figure 21).

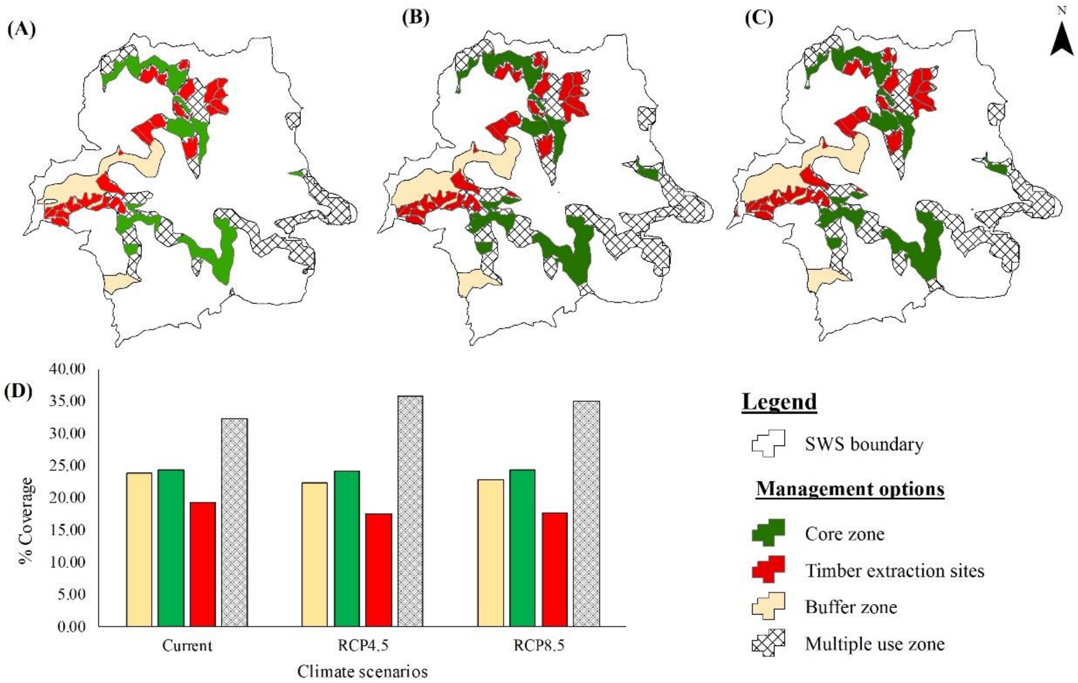

Figure 21 Distribution of habitats under different management options. (A) Current, (B) RCP4.5, (C) RCP8.5 and (D) graphical illustration of habitat distribution under different climate scenarios. More than 75% of the potential habitats are predicted outside designated core zones where likelihood of anthropogenic disturbance is relatively high.

Connectivity modelling

Potential habitat connectivity under current climate scenario

Under the current climate scenario, 15 individual core habitats (hereafter core habitat will be referred to as CH) are identified with an area ranging from 0.3 to 43.3km^2 (μ= 11.5, σ = 13.1). The sum of the CH area is 173.2km^2 which is 33.4 percent less than total potential habitats predicted by the maxent model with the current climate scenario. This deficit accounts for an area those are predicted as suitable but falls within non-forested, settlements and timber extraction sites that are removed from CH used for connectivity analysis.

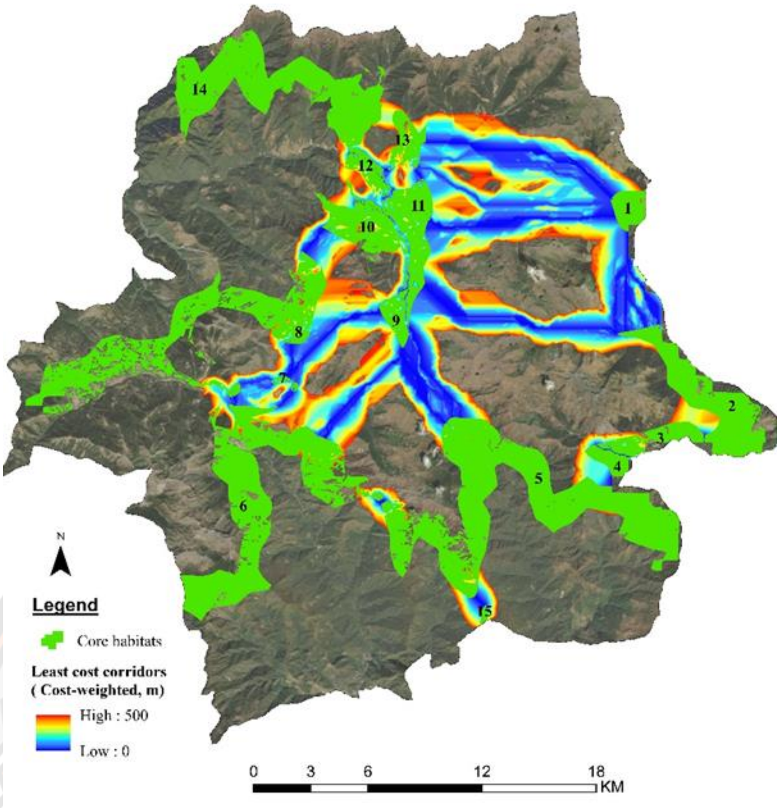

Figure 22 Map showing the least cost corridors with current climate scenario clipped at cost weighted distance of 500m.
The cost weighted distance is illustrated in the color gradient where blue indicates the lowest cost path and red the highest cost path.

The connectivity model identified and mapped 24 active linkages across the landscape which can help to maintain connectivity between different pairs of CH (Figure 22). The Euclidean distance (EucD) ranged from 0.01 to 10.45 km (μ= 2.65, σ = 3.34), cost weighted distance (CWD) ranged from 0.01 to 6.1km (μ= 1.43, σ = 1.92) and least cost path (LCP) ranged from 0.03 to 11.24 km (μ= 2.91, σ = 3.37). The highest value of EucD (10.45km), CWD (6.10km) and LCP (11.24km) was recorded for CH2-CH11, while CH9-CH11, CH12-CH14 and CH10-CH11 exhibited lowest EucD (0.01km), CWD (0.01km) and LCP(0.03km).

Table 5 The characteristics of 24 mapped active linkages between 15 core habitats in the landscape of SWS.

Linkages are sorted with decreasing current flow centrality scores to illustrate their importance in keeping the landscape connected.

Core habitats (CH)		EucD (km)	CWD (km)	LCP, (km)	CWD: EucD	CWD: LCP	Current flow centrality (Amps)
From	To						
5	6	0.18	0.14	0.21	0.82	0.67	38.77
4	5	0.53	0.19	0.55	0.36	0.35	38.11
11	12	0.05	0.05	0.09	0.96	0.57	32.97
3	4	0.03	0.04	0.08	1.43	0.51	32.23
10	11	0.01	0.01	0.03	0.59	0.26	26.70
12	14	0.01	0.01	0.03	0.78	0.32	24.78
2	3	0.02	0.02	0.06	1.08	0.34	24.70
9	11	0.01	0.01	0.03	0.62	0.27	24.25
6	8	0.34	0.20	0.54	0.60	0.38	23.65
8	10	1.62	0.68	1.72	0.42	0.40	23.20
13	14	0.22	0.17	0.24	0.80	0.71	14.94
5	15	0.71	0.26	0.75	0.37	0.35	14.00
6	7	1.01	0.41	1.14	0.41	0.36	13.61
1	2	5.07	2.49	5.35	0.49	0.47	11.77
5	9	4.45	2.07	4.96	0.47	0.42	9.67
5	11	5.30	2.47	5.77	0.47	0.43	8.12
7	8	1.63	0.74	1.91	0.45	0.38	7.00
7	9	5.67	3.03	6.41	0.53	0.47	6.19
1	11	9.34	5.33	10.34	0.57	0.52	5.79
1	13	10.17	5.70	11.08	0.56	0.51	5.73
11	13	0.57	0.63	0.65	1.12	0.98	5.64
9	10	0.03	0.03	0.06	0.97	0.48	5.61
6	9	6.10	3.50	6.67	0.57	0.53	5.01
2	11	10.45	6.10	11.24	0.58	0.54	4.22

The mean CWD:EuCD and CWD:LCP was 0.67 ($\sigma = 0.27$) and 0.47 ($\sigma = 0.15$) respectively. The highest CWD:EuCD (1.43) was recorded for CH3-CH4 which indicates that the cost of species movement between CH3-CH4 is relatively higher than other pairs of CH despite having the same EuCD. The linkage between CH4-CH5 exhibited the highest quality illustrated by lowest CWD:EucD (0.36). The highest resistance to movement along the optimal path was recorded in between CH11-CH13 which is indicated by the highest CWD:LCP (0.98). The lowest CWD:LCP (0.26) occurred in between CH10-CH11 demonstrating lowest resistance to movement along an optimal path (Table 5).

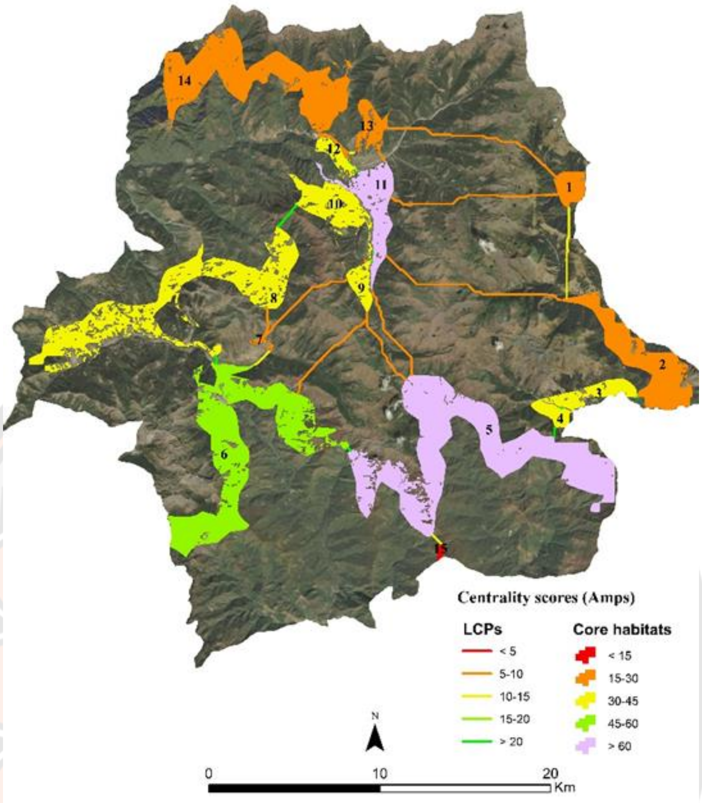

Figure 23 Current scenario centrality core habitats and linkages in SWS. Core habitats and linkages are color graded according to their centrality scores.

Centrality scores varied among the CH and linkages. The high centrality score was recorded for CH5, CH11, CH6 and CH4 while lower scores were observed for CH15, CH7, CH1, and CH13. The highest centrality scores for CH5 (61.3) and CH11(60.8) indicates their importance in keeping the overall red panda habitats within SWS connected. However, the area corrected centrality scores unveiled that CH7(59.4) [highest centrality scores] will play an extremely important role in maintaining the connectively in SWS in comparison with size of the CH (Table 6 and Figure 23). The centrality score for linkages between CH5-CH6 (38.77) and CH4-CH5 (38.22) was recorded to be highest, revealing the importance of the CH5 landscape in maintaining the overall connectivity. On the other hand, the lowest centrality score was recorded for the linkage between CH2-CH11(4.22) indicating its minimum role in overall connectivity within SWS (Table 5).

Table 6 The characteristics of 15 core habitats with their respective centrality scores and area corrected centrality scores.

Core habitats (CH)	Area (Km^2)	Centrality scores (amps)	Area corrected centrality scores
5	43.30	61.34	1.42
11	8.34	60.85	7.30
6	31.01	47.52	1.53
4	1.95	42.17	21.64
12	1.83	35.88	19.59
3	3.98	35.47	8.91
10	7.31	34.75	4.76
8	25.61	33.92	1.32
9	2.37	32.37	13.64
2	14.15	27.35	1.93
14	26.69	26.86	1.01
7	0.34	20.40	59.39
13	3.05	20.15	6.62
1	2.90	18.65	6.43
15	0.30	14.00	46.87

The model exhibited the presence of several pinch points in the corridors being mapped. The pairwise analysis revealed the occurrence of pinch points in between almost every pair of CH while there were only a few pinch points in terms of all pairs analysis. Pairwise pinch points indicate the constriction in movement pathways in between the two CH which is illustrated by areas with higher current flow. On the other hand, all pairs analysis shows the pinch points in the connectivity that illustrates part of corridors that is essential in keeping an entire network of habitat connected. The linkages between CH5-CH9, CH7-CH8, CH8-CH10, CH4-CH5, CH2-CH3 and CH1-CH2 has a higher all pairs pinch points, signifying that these are important linkages to keep the entire network of red panda habitat connected in SWS (Figure 24).

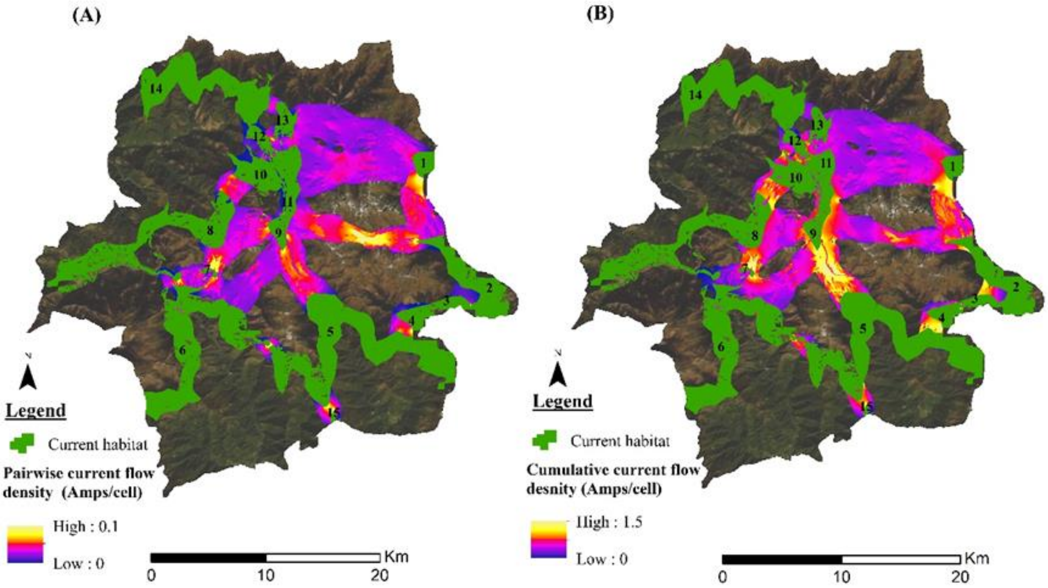

Figure 24 Pinch points (A) pairwise and (B) all pairs mapped in SWS. Shades of yellowish indicate areas with highly restricted current flow (A) between adjacent core habitats and (B) Cumulative current flow in the landscape.

Potential habitat connectivity under future climate scenarios

Under the RCP4.5 climate scenario, 16 individual CH are identified with an area ranging from 0.1 to 63.3km^2 (μ= 14.1, σ = 18.2). Similarly, 17 individual CH with an area ranging from 0.1 to 59.2 km^2 (μ= 13, σ = 17) are identified with RCP8.5 scenarios. The respective sum of CH areas under RCP4.5 and RCP8.5 was predicted to be 30.4% and 27.1% higher than the CH under the current climate scenario. An increase in the number of CH indicates higher likelihood of habitat fragmentation with future climate scenarios. Meanwhile, the larger mean value of future climate scenarios suggests that some of the small fragmented CH under current climate scenarios will be connected to form single larger CH. For instance, small habitats like CH2 and CH3, CH4, CH5 and CH15 from the current scenario will be connected to form larger-sized CH2 and CH3 respectively with the RCP4.5 climate scenario. In the case of RCP8.5, CH3 and CH4 (current scenario) will be connected to from CH3(RCP8.5) and CH5 and CH15 (current scenario) will be connected to form CH4 (RCP8.5). However, there will be also a formation of new fragmented CH (CH14, CH15, CH16 and CH17) which will increase the overall number of CH in both the future climate scenarios.

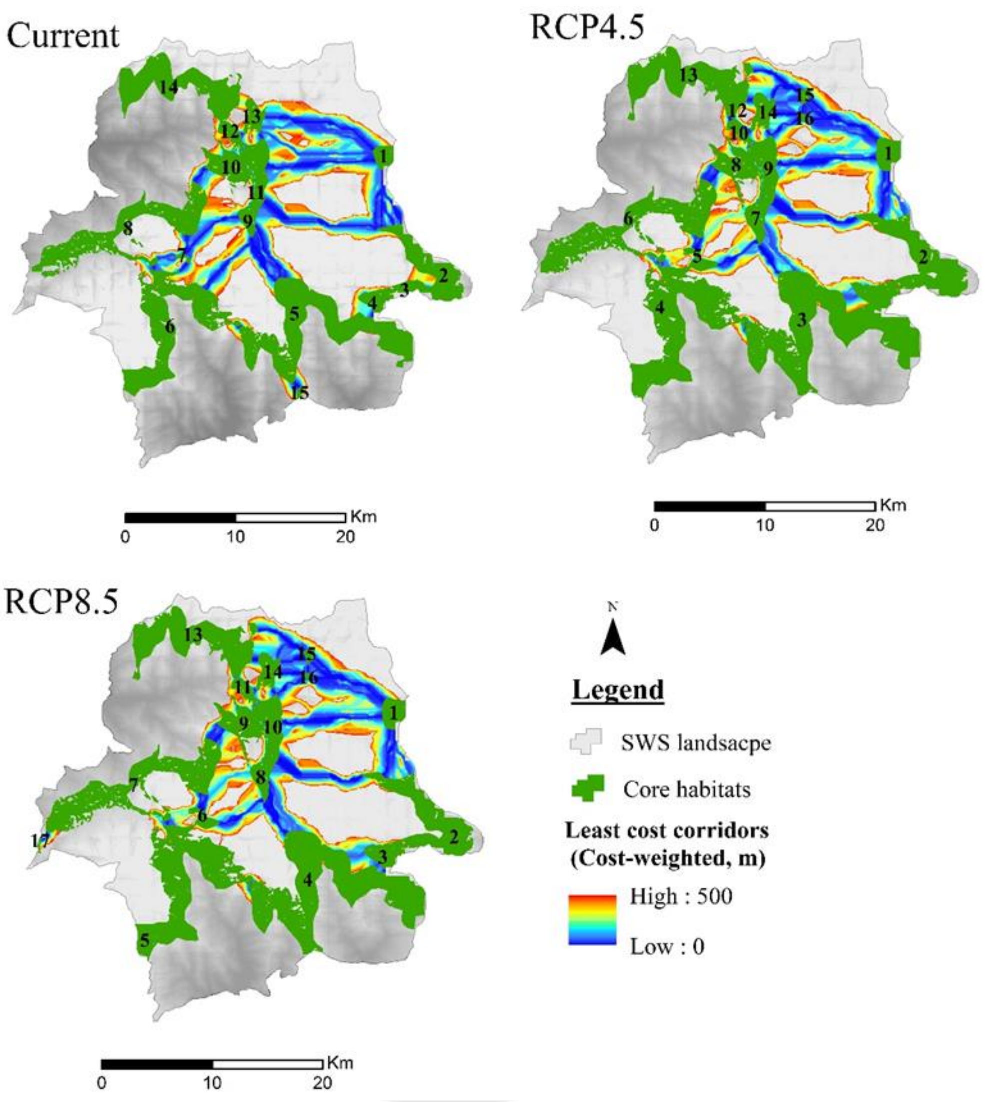

Figure 25 Comparative map showing the least cost corridors under current and future climate scenarios (RCP4.5 and RCP8.5) clipped at CWD 500m. The cost weighted distance is illustrated in the color gradient where blue indicates the lowest cost path and red indicates the highest cost path.

RCP4.5

The model identified and mapped 30 active linkages under RCP4.5 (Figure 25). The EucD ranged from 0.01 to 8.89 km (μ= 1.96, σ = 2.58), CWD ranged from 0.01 to

4.4km (μ= 1.04, σ = 1.34) and LCP ranged from 0.03 to 9.39 km (μ= 2.19, σ = 2.81). The highest value of EucD/CWD/LCP was recorded for CH1-CH9 (8.89/4.44/9.39km), while CH8-CH9, CH7-CH9, CH10-CH11, CH10-CH12, CH4-CH5 exhibited lowest EucD/CWD/LCP (0.01/0.01/0.03 km).

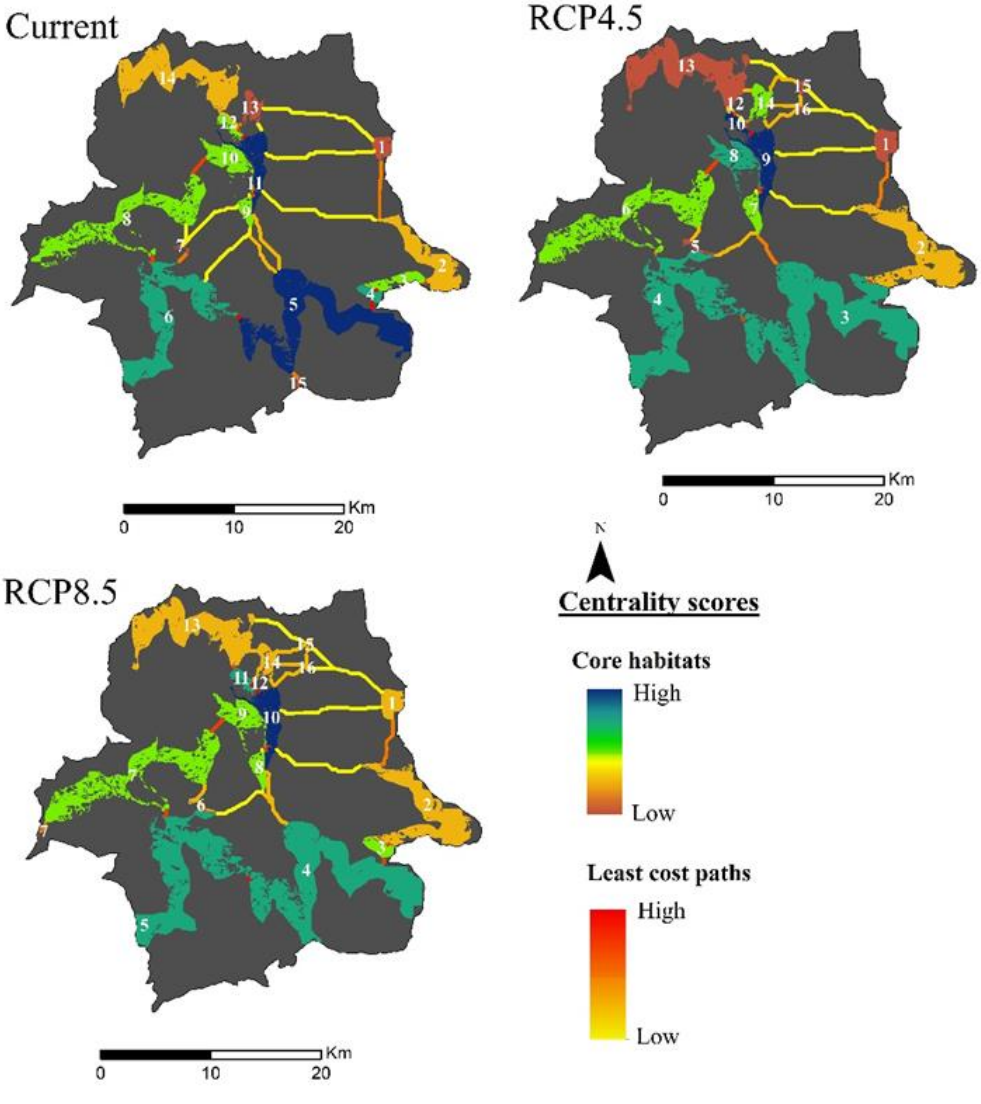

Figure 26 Comparative map showing the centrality core habitats and linkages under different current and future climate scenarios (RCP4.5 and RCP8.5). Core habitats and linkages are color graded according to their centrality scores.

The mean CWD:EuCD and CWD:LCP for RCP4.5 was 0.74 (σ = 0.34) and 0.50 (σ = 0.16) respectively. The highest CWD:EuCD (1.89) was recorded for CH10-CH12 which indicates that the cost of species movement between CH10-CH12 is relatively higher than other pairs of CH despite having the same EuCD. The linkage between CH5-CH6 exhibited the highest quality illustrated by lowest CWD:EucD (0.41). The highest resistance to movement along the optimal path was recorded in between CH9-CH14 which is indicated by the highest CWD:LCP (1.01). The lowest CWD:LCP (0.25) occurred in between CH7-CH9 demonstrating the lowest resistance to movement along an optimal path (Table 7).

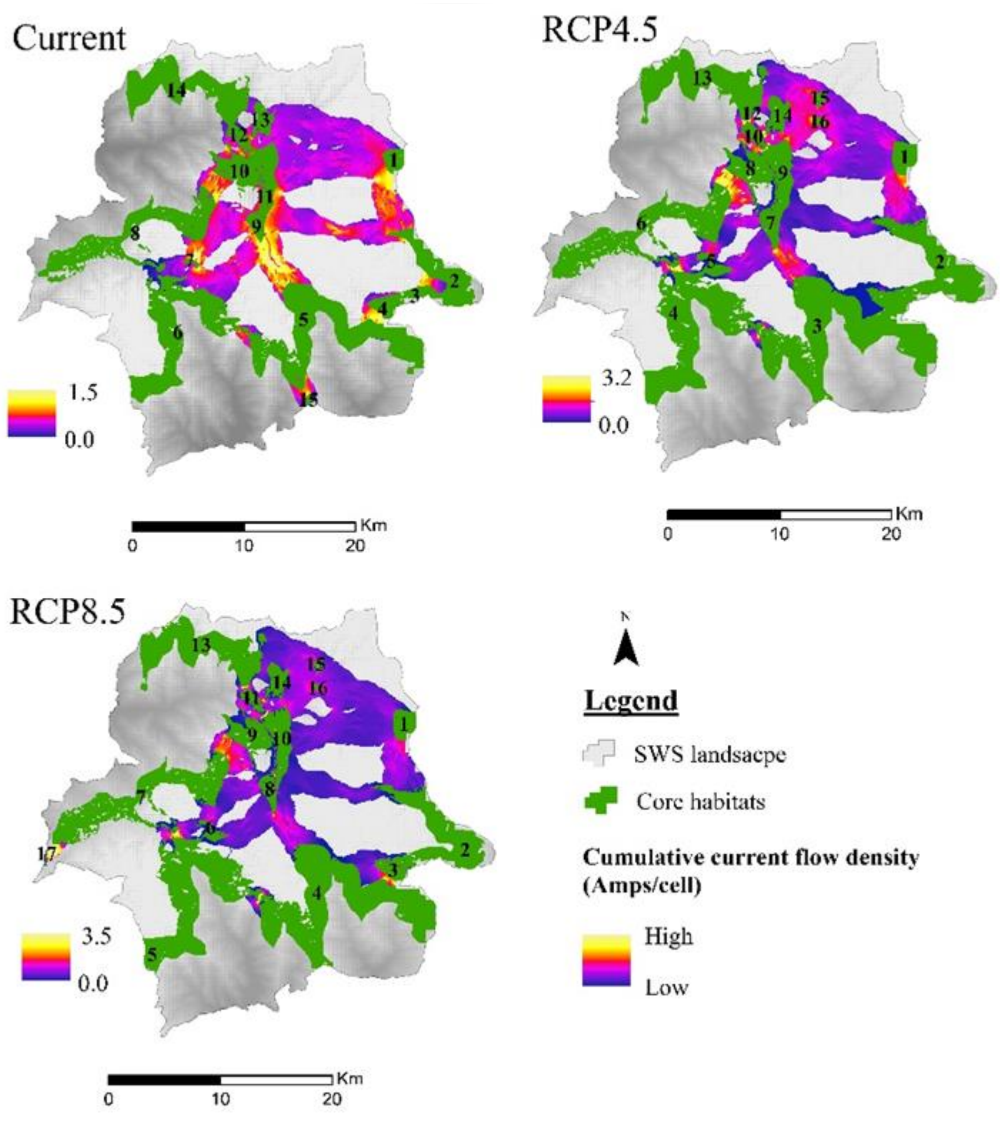

Figure 27 Comparative map showing the pairwise pinch points mapped in SWS under current and future climate scenarios (RCP4.5 and RCP8.5) Shades of yellowish indicate areas with highly restricted current flow .

Table 7 The characteristics of 30 mapped active linkages between 16 core habitats under RCP4.5.

Linkages are sorted with decreasing current flow centrality scores to illustrate their importance in keeping the landscape connected

Core habitats (CH) From	Core habitats (CH) To	EucD (km)	CWD (km)	LCP, (km)	CWD: EucD	CWD: LCP	Current flow centrality (Amps)
9	10	0.05	0.05	0.09	0.97	0.58	52.28
8	9	0.01	0.01	0.03	0.59	0.27	33.37
3	4	0.09	0.08	0.12	0.87	0.67	33.32
7	9	0.01	0.01	0.03	0.58	0.25	30.38
6	8	1.37	0.60	1.44	0.44	0.42	27.17
10	11	0.01	0.01	0.03	1.22	0.33	26.21
2	3	0.03	0.05	0.08	1.50	0.54	26.06
10	12	0.01	0.01	0.03	1.89	0.46	24.08
4	5	0.01	0.01	0.03	0.77	0.31	21.70
4	6	0.17	0.18	0.22	1.06	0.81	21.39
11	14	0.22	0.18	0.24	0.82	0.73	17.81
12	13	0.11	0.09	0.15	0.87	0.62	15.63
3	7	3.09	1.30	3.31	0.42	0.39	14.20
1	2	3.88	1.80	4.63	0.46	0.39	13.69
15	16	0.73	0.54	0.83	0.74	0.65	11.17
14	15	2.26	1.36	3.42	0.60	0.40	9.31
14	16	2.26	1.37	2.35	0.60	0.58	9.19
9	16	3.00	1.61	3.41	0.54	0.47	8.42
13	14	0.59	0.38	0.60	0.64	0.63	8.33
5	6	1.13	0.46	1.29	0.41	0.36	8.19
10	13	0.36	0.20	0.41	0.56	0.49	7.76
5	7	4.11	2.42	4.48	0.59	0.54	7.54
9	14	0.57	0.65	0.65	1.14	1.01	7.37
1	16	6.41	3.24	6.96	0.51	0.47	6.91
13	15	4.48	2.08	4.94	0.46	0.42	6.76
1	15	7.21	3.64	7.80	0.51	0.47	6.33
7	8	0.03	0.03	0.06	0.99	0.49	6.01
1	9	8.89	4.44	9.39	0.50	0.47	4.73
11	12	0.20	0.09	0.25	0.43	0.34	4.32
2	9	7.54	4.44	8.51	0.59	0.52	4.24

From the centrality analysis, it is found that CH9 (77.9) and CH10 (62.67) have the highest centrality scores and will play a vital role in keeping an overall network of the habitat connected under RCP4.5 scenarios. However, the area corrected centrality scores suggested that CH11(240) [highest centrality scores] will play a significant role in maintaining the connectively irrespective of size (Table 8 and figure 26). In terms of linkages, the centrality score was found to be highest in linkage connecting CH9-CH10 (52.28) further supporting the importance of CH9 and CH10 landscape in maintaining the overall connectivity. The lowest centrality score was recorded for the linkage between CH2-CH9 (4.24), indicating its minimum role in overall connectivity (Table 7).

The linkages between CH9-CH10, CH11-CH14, CH12-CH13, CH3-CH4, CH4-CH6 and CH6-CH8 has a higher all pairs pinch points, indicating that these linkages have a narrow passage and are important in keeping the entire CH network connected under RCP4.5 (Figure 28).

Table 8 The characteristics of 16 core habitats with their respective centrality scores and area corrected centrality scores under RCP4.5

Core habitats (CH)	Area (Km^2)	Centrality scores (amps)	Area corrected centrality scores
9	9.84	77.90	7.92
10	1.68	62.67	37.40
4	42.49	45.71	1.08
3	63.31	44.29	0.70
8	7.66	40.78	5.32
7	3.69	36.57	9.91
6	31.06	35.87	1.15
14	3.93	33.50	8.52
11	0.13	31.67	240.45
12	0.20	29.52	144.17
2	25.71	29.49	1.15
13	28.83	26.74	0.93
5	1.01	26.21	26.05
16	0.51	25.34	49.96
15	0.84	24.28	28.83
1	4.94	23.33	4.72

RCP8.5

Model with RCP8.5 identified and mapped 31 active linkages which is highest amongst three scenarios (Figure 25). The mean EucD, CWD and LCP for 31 different linkages was 2.29km ($\sigma = 2.65$), 1.22km ($\sigma = 1.39$) and 2.54km ($\sigma = 2.89$) respectively.

The linkage between CH1-CH10 exhibited the highest EucD/CWD/LCP (9.05/4.59/9.55km), while the lowest EucD/CWD/LCP (0.01/0.01/0.03km) was observed in linkages between CH9-CH10,CH5-CH6 and CH8-CH10. The mean CWD:EuCD and CWD:LCP for RC8.5 was 0.69 ($\sigma = 0.23$) and 0.47 ($\sigma = 0.15$) respectively. The cost of species movement in between CH2-CH3 is found to be relatively higher than other linkages owing to highest CWD:EucD (1.41), while linkages between CH3-CH4 has the lowest CWD:EucD (0.38) representing the highest quality linkage in RCP8.5.

Table 9 The characteristics of 17 core habitats with their respective centrality scores and area corrected centrality scores under RCP8.5

Core habitats (CH)	Area (Km^2)	Centrality scores (amps)	Area corrected centrality scores
10	9.47	86.53	9.14
4	59.21	59.40	1.00
5	41.46	59.30	1.43
11	1.77	58.02	32.70
12	0.42	53.00	127.38
7	31.06	48.50	1.56
9	7.76	42.75	5.51
8	3.24	41.46	12.79
3	2.96	40.84	13.78
14	3.83	35.41	9.24
2	23.82	32.00	1.34
6	0.77	28.41	36.68
13	28.76	27.84	0.97
16	0.38	27.27	72.17
15	0.71	25.84	36.18
1	4.45	25.00	5.62
17	0.11	16.00	144.29

Table 10 The characteristics of 31 mapped active linkages between 17 core habitats under RCP8.5.

Linkages are sorted with decreasing current flow centrality scores to illustrate their importance in keeping the landscape connected.

Core habitat (CH)		EucD (km)	CWD (km)	LCP (km)	CWD: EucD	CWD: LCP	Current flow centrality (Amps)
From	To						
10	11	0.05	0.05	0.09	0.96	0.57	52.74
11	12	0.02	0.01	0.03	0.64	0.33	47.29
4	5	0.08	0.06	0.13	0.74	0.49	44.24
3	4	0.30	0.11	0.33	0.38	0.35	37.12
9	10	0.01	0.01	0.03	0.58	0.26	34.81
8	10	0.01	0.01	0.03	0.59	0.26	33.44
2	3	0.03	0.04	0.08	1.41	0.50	28.55
7	9	1.47	0.65	1.55	0.44	0.42	28.07
5	7	0.28	0.20	0.52	0.72	0.39	27.25
12	13	0.07	0.06	0.10	0.87	0.59	24.27
5	6	0.01	0.01	0.03	0.94	0.31	24.03
12	14	0.22	0.17	0.24	0.81	0.73	18.43
7	17	0.75	0.61	1.10	0.81	0.55	16.00
1	2	4.05	1.90	4.78	0.47	0.40	14.80
4	8	3.45	1.49	3.77	0.43	0.39	12.66
15	16	0.74	0.55	0.80	0.74	0.68	11.96
14	16	2.25	1.36	2.32	0.60	0.59	9.96
14	15	2.26	1.40	2.46	0.62	0.57	9.84
6	7	1.38	0.56	1.55	0.41	0.36	9.67
10	16	3.00	1.61	3.41	0.54	0.47	9.30
4	10	4.96	2.15	5.65	0.43	0.38	8.78
13	14	0.59	0.39	0.63	0.65	0.61	8.32
10	14	0.56	0.65	0.65	1.15	1.00	8.27
1	16	6.76	3.44	7.34	0.51	0.47	7.31
6	8	4.43	2.62	4.88	0.59	0.54	7.12
13	15	4.54	2.13	5.01	0.47	0.43	7.08
5	8	4.47	2.63	4.91	0.59	0.54	7.07
1	15	7.46	3.81	8.07	0.51	0.47	6.81
8	9	0.03	0.03	0.06	0.98	0.49	6.62
1	10	9.05	4.59	9.55	0.51	0.48	5.07
2	10	7.64	4.59	8.66	0.60	0.53	4.64

The resistance to the movement along the optimal path is illustrated by the CWD:LCP scores; where a higher value indicates higher resistance and vice versa. The highest CWD:LCP (1) was observed in the optimal path connecting CH10-CH14 and least (0.26) in CH9-CH10 and CH8-CH10 (Table 10).

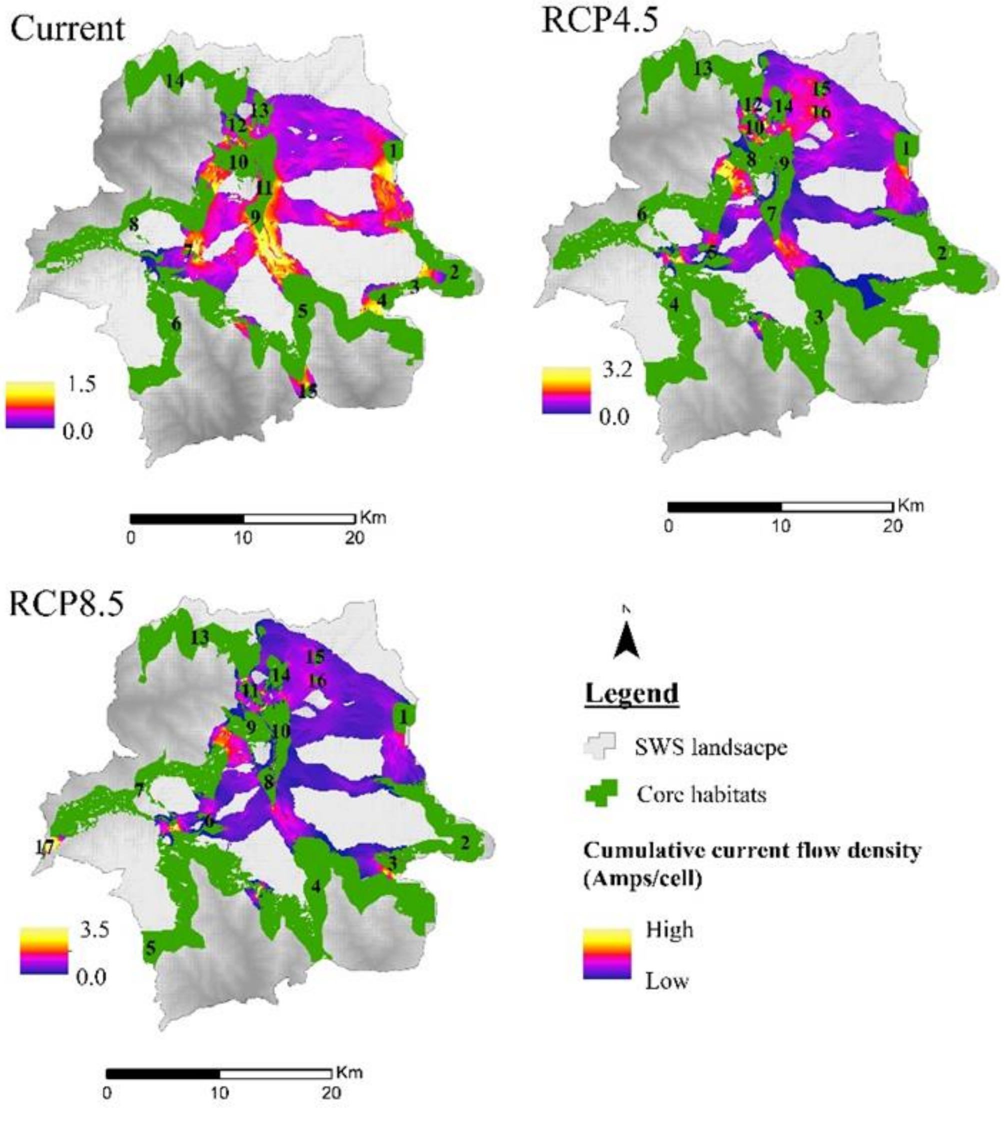

Figure 28 Comparative map showing all pairs pinch points under current and future climate scenarios (RCP4.5 and RCP8.5).
Shades of yellowish indicate areas where the current flow is highly restricted.

Centrality result suggested that CH10 with the highest centrality score [same CH which is assigned as CH9 in RCP4.5] will function as the important CH in keeping the landscape connected. However, CH17 has the highest area corrected centrality score

(144.29) suggesting its importance in maintaining the connectively irrespective of size (Table 9 and figure 26). Linkage connecting CH10-CH11 exhibited the highest centrality score (52.74) amongst other linkages; thus supporting the importance of CH10 landscape in maintaining the overall connectivity. The lowest centrality score was recorded for the linkage between CH2-CH10 (4.64), indicating its minimum role in overall connectivity (Table 10).

With RCP8.5, the higher all pairs pinch points were observed in between the linkages connecting CH7-CH17, CH10-CH11, CH11-CH13, CH4-CH5, CH5-CH7, CH3-CH4 and CH7-CH9 (Figure 28). It indicates that these linkages have a narrow passage and are important in keeping the entire HC network connected.

CHAPTER V

DISCUSSION AND CONCLUSION

This chapter is illustrated under different section comprising of discussion, conclusion and recommendations.

Discussion

Influence of predictor variables on habitat model

Potential habitats predicted by the model in this study corresponds to anecdotally known and methodically confirmed distribution of the red panda in SWS (Dorjee, 2009). However, actual distribution of species might be smaller because influence of only climate related variables in present model may not be the only determinant of habitat suitability in reality. Other factors like land use, edaphic, competition and anthropogenic disturbances that are not incorporated in the model might limit the actual distribution despite suitable climate (Ranjitkar et al., 2014; Wang et al., 2018). Maxent model has been widely embraced in studying potential habitat distribution of diverse group of taxa with respect to both current and future climate scenarios (Li et al., 2015; Loarie et al., 2008; Songer et al., 2012; Thapa et al., 2018). Yet, maxent model has its own shortcomings which can be improved by species specific model tuning (Radosavljevic & Anderson, 2014). Use of only AUC as the evaluation statistics has been criticized (Peterson et al., 2008) and default setting is likely to result in model over-fit(Radosavljevic & Anderson, 2014). In this study the limitation of the model is minimized by fine tuning of model with regularization multiplier and adopting more robust model evaluation statistics (Kappa and AICc) in addition to AUC. Further, model was correct for sampling biased by determining the background sample points from within the 4km buffer of the actual species occurrence records (Elith et al., 2011).

In the mountainous topography, numerous seasonal spring flow emerges during the monsoon as a result of precipitation. Accessibility to seasonal spring flow could influence the dispersal of the red panda, since, earlier studies reported that red panda has a high affinity to water accessibility (Wei & Zhang, 2011; Yonzon & Hunter, 1991). Further, precipitation is one of the important factors that regulate the growth and development of bamboo. The significant contribution of precipitation related predictors bio13 (67%) and bio15 (33%) in the present model may correspond to its influence to water accessibility and regeneration of the bamboo (Thapa et al., 2018) which is a primary diet of the red panda (Yonzon & Hunter, 1991).

In this study the topographic factors of slope and aspect did not contribute to the model building unlike in the findings of Thapa et al., (2018). Non contribution of the topographic factors (slope) was also reported in previous studies where the microhabitat features like fallen logs and tree stumps are found as more important factors over topographic factors. This is adopted to aid feeding strategies because of their small body size (Zhang et al., 2006). Generally, the elevation is considered as one of the determining factors for the distribution of species and may affect the habitat distribution of red panda. However, it is not used in the present model since the inclusion of elevation is known to result in a conservative prediction of species habitat distribution range (Hof et al., 2012).

Distribution of potential habitats and their implications

According to the SWS (2019), Sakteng has the highest livestock population which indicate the likelihood of relatively high competition for same resources leading to distribution of poor quality habitat in comparison to Merak and Jonekhar. Similar findings were reported in the earlier studies in Phrumsengla National Park (Dendup et al., 2016) and Langthang National Park (Yonzon & Hunter, 1991). Merak range with maximum predicted potential habitats and lower livestock population is expected to have habitats with better quality. However, the annual consumption of fuelwood is comparatively higher (40% - 80%) than Sakteng and Joenkhar because of its extremely cold weather (SWS, 2019). Requirements of this fuelwoods and timber are met from the nearby forest which indicate that habitat degradation from resource harvesting could be the issue in Merak range similar to the findings of Dorji et al., (2012).

In all the climate scenarios, as shown in figure 21 more than 75 percent of the potential habitats for red panda in SWS were predicted outside the core zone where the frequency of anthropogenic disturbances is relatively high. Approximately, 39 percent of the SWS is an open pasture where extensive grazing is in practice and another 36 percent are accessible to livestock with varying grazing intensity (SWS, 2019). Moreover, the increasing demand for livestock products has resulted in increased livestock population (SWS, 2019). Widespread herders and livestock are always accompanied by dogs which are known to carry canine distemper that is contagious to red pandas through contact with faeces and urine or a bite from infected dogs (Deem et al., 2000). The free-roaming dog population is increasing in SWS due to the abandonment of old dogs by herder communities and the high birth-rate of dogs. Incidences of dog hunting the red panda were reported in the studies elsewhere (Dorji et al., 2012; Yonzon & Hunter, 1991). Increasing population of livestock and free roaming dogs could be a severe threat to the red panda in SWS with more than 75 percent of the predicted potential habitats occurring outside the core zone.

Though the model predicted 260km² of potential habitat (fundamental niche) for red panda under the current climate scenario, actual habitat (realized niche) is likely to be less since the correlative species distribution model (maxent) predicts fundamental niche which is relatively larger than the realize niche(Polechová & Storch, 2019). Based on the assumption that all predicted suitable habitat will be usable, inferring the average density of 1 adult/4.4km^2 (Yonzon & Hunter, 1991) and 260 km^2 of predicted fundamental niche, SWS is likely to support ca. 59 individuals of the red panda. However, the actual red panda density in realized niche was found to be ca. 34 percent (1adult/2.9km^2) less than the observed density with fundamental niche (Yonzon & Hunter, 1991). Therefore, the actual population of red panda in SWS is expected to be approximately 39 individuals.

Potential impact of climate change to the predicted habitats

According to the NCHM (2019), Bhutan is predicted to experience an increase in temperature (> 3.2^{0}C) and rainfall (>30%) by the end of the 21st century. Predicted change is expected to directly affect vegetation patterns and will significantly influence the distribution, structure, and ecology of forests (Sharma et al., 2009) in addition to the upward range expansion (Kullman, 2002; Parmesan & Yohe, 2003). Subsequently, the model predicted that the climate change will have a noticeable impact on the distribution of the red panda habitat in SWS with a net gain in the suitable habitat up to ca. 26.5 percent towards higher elevation. The phenomenon of predicted range expansion will alter the availability of food and shelter in the existing habitat, influencing the future upward distribution of the red panda as predicted in the model. The model prediction agree with upward shift in elevation in response to climate change observed elsewhere in birds (Peh, 2006), mammals (Payette, 2011), plants (Kullman, 2002) and various other taxa (Parmesan & Yohe, 2003).

However, the predicted expansion/gain in red panda habitat contradicts with most of the studies in which wildlife habitats are predicted to shrink with future climate change (Li et al., 2015; Songer et al., 2012). The studies on impact of climate change on forest predicted increase in boreal needle leaved evergreen forest in European mountains (Wolf et al., 2008) and temperate forest in northern high latitudes (Jiang et al., 2012) due to positive climate feedback (Chapin et al., 2005) from reduced surface albedo associated with expansion to higher elevation (Thompson et al., 2004). Since, red panda depends on forest for food, shelter and habitat, predicted expansion in habitat with future climate change is not unlikely.

Livestock rearing is the main economy for the semi-nomadic inhabitants of SWS. They practice open grazing in higher elevation meadows on an extensive scale. The predicted upward shift and expansion of the habitats to a relatively higher elevation will result in distribution of red panda closer to grazing grounds, ultimately increasing the rate of an anthropogenic disturbance despite suitable habitats. Similar findings were observed in earlier studies where the abundance of red panda is known to reduces in the areas accessible to livestock grazing due to disturbances (Dendup et al., 2016; Dorji et al., 2012; Sharma et al., 2014) and reduced bamboo growth to an optimum height to be fed by a red panda (Yonzon & Hunter, 1991).

However, our model is based on the assumption that the forest of SWS will shift to a relatively higher elevation in response to climate change (Wangdi et al., 2019) and livelihood option of Brokpas will remain as usual. This assumption may not hold if forest fails to migrate to higher elevation and occupation of Brokpa changes from semi-nomads to the agriculturist. Hence, findings in this study may be a conservative estimate of the impact of climate change on a red panda in SWS.

Landscape connectivity among the predicted habitats

While movement information of red panda is lacking in Bhutan, the study in China using radio telemetry found that red panda travels ca. 500m per day within the home range of 3.4km^2 (Johnson et al., 1988). This perhaps will consume a considerable amount of time and energy to traverse between isolated habitat patches where the average length of predicted least-cost corridors are more than 2.5km under various current climate scenarios. According to Johnson et al., (1988), red panda avoids open space and consumes 63 percent of the day resting during the frequent interspaced activity, each resting period lasting <= 2hours. Some of the longest predicted least corridors (highest 10.54km), at some points it doesn’t pass through the vegetated area as required by the species. Thus; for red panda which has specialized habitat need and narrow dispersal ability, identification and management of relatively small habitat patches (stepping stone) along the predicted corridor will facilitate the movement. Although; sufficient size, suitable location and quality stepping stone can increase the network of habitat connectivity and dispersal, poor quality may distract species from successfully colonizing the intended larger suitable patches resulting in reduced colonization success (Kramer-Schadt et al., 2011; Saura et al., 2014).

Though feasibility and functionality of predicted corridors are not tested in the ground, linkage quality metrics suggested that quality and significance of respective linkages varied from each other. The quality of the linkages is inversely proportional to the value of CWD:EucD and CWD:LCP; meaning higher value indicates lower quality. In the first case, quality is interpreted based on difficulty to move between habitat patches relative to how close they are and later talks about average resistance along the identified optimal paths (Dutta et al., 2015). The close inspection of the least cost corridor overlaid on the base map revealed that poor quality linkages occur between those core habitats isolated by rivers and unsuitable landuse types. This could be attributed to the very fundamental concept that cost distance increases in proportion to the increase in resistance along the landscape; in this case river and unsuitable landuse types exhibit relatively higher resistance or cost amongst others.

With the current climate scenario, the highest centrality score was detected in CH5 and CH11. CH5 is centrally located amongst the habitats in the southern region and CH11(assigned as CH9 and CH10 in future climate scenarios) represents the center of northern habitats, thus, indicating their importance in maintaining overall connectivity within SWS. However, CH5 is predicted to lose its centrality score since current CH patches in southern regions are predicted to get connected with future climate scenarios. This doesn’t mean that CH located in the peripheries with lower centrality score are not important for red panda conservation. It could be equally important in facilitating the movement in the context of larger landscapes adjacent to SWS which are outside the delineated study area but are home to the red panda. Thus, habitats located in the eastern region with relatively low centrality scores (CH1, CH2 and CH3) can play an equally important role as the connecting link to enable transboundary movement of the species between red panda rich Indian state of Arunachal Pradesh in east and SWS in the west. The need for transboundary landscape connectivity in this region was also recommended in earlier studies (Dorji, 2011; Thapa et al., 2018). Overall, SWS can play a critical role as a connecting link between the larger landscape of Bhutan and Arunachal Pradesh towards the conservation of red panda that exhibits narrow dispersal with special habitat needs. Transboundary landscape connectivity will not only facilitate the genetic dispersal across geopolitical boundaries but also prepare for uninterrupted movement of species (both red panda and other associated species) in the event of habitat shift or expansion owing to future climate change (Rüter et al., 2014).

Pinch points were observed in all most all pairs of CH suggesting that predicted linkages in SWS possess some kind of bottleneck in the movement of the red panda, which can be a critical section of the linkage for maintenance of a network of connectivity. Such pinch points could be the result of one or a combination of several factors that must be evaluated via a detailed field survey. Understanding the detailed cause of pinch points and exploring potential mitigation and restoration measures will help in improving the existing network of connectivity (Dutta et al., 2015). With a visual inspection, most of the pinch points seem to be caused by natural features though the actual ground survey might reveal otherwise. However, there is a pending proposal for the construction of hydropower plant in the Gamri river that flows through the landscape of Sakteng and Joenkhar range. Such man-made infrastructures could result in collateral damage to the network of connectivity, leading to an increasing number of pinch points and fragmentations.

Future climate change is likely to have both positive and negative impacts on overall connectivity. It is predicted that CH and linkage numbers will increase with climate change indicating more fragmentation of habitats. However, climate change will also help to extend the connection between some of the currently fragmented habitats thus offsetting an overall number of fragmented CH. It is predicted that more fragmentation is likely to occur in the northern region and vice versa in the southern region. The position of the majority of the predicted linkages remains the same for all the climate scenarios, except change in centrality position for some CH. This indicates that linkages with current climate scenarios will potentially facilitate the movement of red panda and will be useful in the event of future climate change.

The red panda will need landscape connectivity to cope with potential losses of habitat distribution with predicted gain/expansion in areas adjacent to their present distribution limit. Therefore, the current conservation initiatives should not be restricted to only habitats where the red panda occurs today but should be also extended to predicted future potential habitats. Such initiatives would enhance the capability of the red panda to adapt to future climate uncertainty; ensuring their long term persistence.

Conclusion

This thesis aimed to identify the distribution of potential habitat for endangered red panda and their habitat connectivity within the landscape of SWS under different climate scenarios. Based on the maxent and linkage mapper model output, 260km^2 of potential red panda habitats are predicted to be randomly distributed across Merak (54.5%), Sakteng (33.4%) and Joenkhar (12.2%) range and will experience the net gain or expansion up to ca. 26.5% towards relatively higher elevation due to climate change. As a consequence, there will be reduction in mean distance of leas cost corridors by ca. 11% to 21% and increase in the number of habitat patches up to ca. 13% and linkages up to ca. 29%. Though potential habitats under current and future climate scenarios are predicted to occupy 27% to 35% of the total SWS area, more than 75% of the predicted habitat falls outside core zones. Based on centrality scores, CH5 and CH11 (CH11 is assigned as CH9 and CH10 in future climate scenarios) are inferred as the important habitat patch to maintain overall connectivity within SWS. However, CH with lower centrality located in the eastern part also play equally important in maintaining connectivity in the wider landscape.

Therefore, it is concluded that predicted red panda habitats in SWS is unequally distributed across three range with high frequency of disturbances. By the year 2050, climate change will have positive impact leading to habitat expansion towards higher elevation, yet, they will experience a high rate of anthropogenic disturbances. The predicted linkages are not only important to maintain connectivity within the SWS but can also function as the important linkage in maintaining the transboundary movement of the red panda in the larger landscape of Bhutan(west) and Arunachal Pradesh, India (east).

Recommendations

Taking into account of the findings from this study, following recommendations are suggested.

- Conduct future study using a fine-scale climatic dataset which could improve the model accuracy.
- Initiate radio-collaring of the red panda to understand their behavior and movement in the landscape to evaluate the functionality of the predicted habitat and least cost corridors. This can also help the management of SWS to understand the precise interaction between huge livestock population, herder’s dog or increasing stray dog population and red panda dwelling in the same landscape.
- Explore the feasibility of transboundary conservation initiative with adjacent Indian state of Arunachal Pradesh to facilitate genetic dispersal of the species in a broader landscape. Such initiatives could also help in empowering the minor communities residing within and nearby the landscape, thus, involving the communities towards conservation of the species.

- More than 75% of the predicted habitats in all the climate scenarios falls outside the designated core zone where likelihood of anthropogenic disturbances is relatively high. Therefore, SWS need to reconsider the existing management options and practices to reduce the impact of anticipated disturbances to red panda

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GLOSSARY

Brokpa	:	A native inhabitant (ethnic group) of Merak and Sakteng valley who are transhumant by profession.
Buffer zone	:	This is a transition zone between the area within the sanctuary and area outside the sanctuary. This is supposed to function as the cushion zone between the area under divisional forest and protected areas.
Core habitat	:	Predicted habitats from which the non-forested areas, timber extraction sites and settlements are removed. Habitat connectivity are modelled to connect this core habitats
Core zone	:	These are the zones designated as the totally protected areas within the sanctuary owing to their ecological importance. Except the research and management work, other activities are prohibited.
Gewog	:	It refers to an administrative division composing a group of villages also called as block
Kamzhing	:	It refers to cultivated rain-fed areas (dry land)
Multiple use zone	:	These are the areas within the sanctuary where regulated activities area permitted with some restriction. Timber extraction zones occur in this zone.
Timber extraction sites	:	These sites are the area designated for extraction of timbers to meet the local demand. However, commercial loggings are prohibited.
Wildlife Sanctuary	:	Area declared as the protected area under Forest and Nature Conservation Act of Bhutan 1995 for the preservation of areas of natural beauty of national importance, protection of biological diversity, management of wildlife and related purpose

APPENDIX

Table 11 Expert's opinion on resistance cause by the different land use types. It ranges from 0 -1, where 0 is indicates least and 1 is the highest resistance

Land use	**Experts rating**				**Mean resistance**
	I	**II**	**III**	**IV**	
Alpine Scrubs	0.8	0.1	0.5	0.6	0.5
Broadleaf	0.1	0.2	0.2	0.2	0.2
Built up	1.0	1.0	1.0	1.0	1.0
Chirpine	1.0	1.0	0.5	1.0	0.9
Fir	0.1	0.1	0.1	0.1	0.1
Kamzhing (dry agricultural land)	0.8	0.6	1.0	1.0	0.9
Lake	1.0	0.4	1.0	1.0	0.9
Landslides	1.0	0.4	1.0	1.0	0.9
Meadows	0.9	0.2	0.3	0.5	0.5
Mixed conifer	0.1	0.1	0.2	0.1	0.1
Rivers	1.0	0.8	1.0	1.0	1.0
Rocky Outcrops	1.0	0.1	0.5	1.0	0.7
Shrubs	0.7	0.3	0.5	0.5	0.5
Snow and Glacier	1.0	0.5	1.0	0.8	0.8
Timber extraction sites (zone)	0.3	0.2	0.4	0.5	0.4