LANDSCAPE CORRELATES OF LARGE MAMMAL OCCUPANCY IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL

A THESIS SUBMITTED TO THE

CENTRAL DEPARTMENT OF ZOOLOGY

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

NEPAL

FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

IN ZOOLOGY

BY

JAGAN NATH ADHIKARI

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DECLARATION

Thesis entitled **"LANDSCAPE CORRELATES OF LARGE MAMMAL OCCUPANCY IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL"** which is being submitted to the Central Department of Zoology, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by me under the supervision of Prof. Dr. Tej Bahadur Thapa and co-supervised by Asst. Prof. Dr. Bishnu Prasad Bhattarai of Central Department of Zoology, Tribhuvan University.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

[..........................]

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RECOMMENDATION

This is to recommend that **JAGAN NATH ADHIKARI** has carried out research entitled "**LANDSCAPE CORRELATES OF LARGE MAMMAL OCCUPANCY IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL**" for the award of Doctor of Philosophy (Ph.D.) in **ZOOLOGY** under our supervision. To our knowledge, this work has not been submitted for any other degree. He has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D. degree.

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On the recommendation of **Prof. Dr. Tej Bahadur Thapa /Dr. Bishnu Prasad Bhattarai**, this Ph.D. thesis submitted by **Jagan Nath Adhikari**, entitled **"LANDSCAPE CORRELATES OF LARGE MAMMAL OCCUPANCY IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL"** is forwarded by Central Department Research Committee (CDRC) to the Dean, IOST, T.U.

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Jagan Nath Adhikari

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ABSTRACT

Human activities and natural processes are causing landscape change and biodiversity loss. Large mammals are among the most threatened animals by land use and land cover change (LULCC). They are under the pressure of habitat loss and alternation, especially in the areas outside the protected area system. Chitwan Annapurna Landscape (CHAL) is a north-south linkage between Chitwan National Park and Annapurna Conservation Area in central Nepal that provide a safe passage of forest corridor for wildlife. This study attempted to: 1) characterize the spatio-temporal pattern of land use and land cover change in central part of CHAL; 2) evaluate the relative abundance of large mammals and their interaction with people; 3) examine the impacts of environmental correlates on the occupancy of large mammals, and 4) identify the landscape level connectivity for the large mammals.

The LULCC in the area was characterized by supervised classification of Landsat images for 2000, 2010 and 2020. Relative abundance of large mammals in four different blocks (A–D) of the study area was done by line-transect (n = 150, average length = 3.18 ± 0.11 km) survey. Interaction of human with large mammals were assessed through the questionnaire survey among 600 respondents. The occupancy of the large mammals was evaluated using the program PRESENCE. Potential distribution of the large mammals and their environmental correlates were identified by species distribution modelling using maximum entropy algorithm. Important landscape patches in the study area were identified and least-cost path approach with circuit theory was used to pinpoint the linkages among those patches. The Kernel density estimation method was used to identify the hotspots for the connection of isolated population of the mammals in the patches.

The LULCC results revealed that forest is dominant feature of the study area. Overall forest increased by 360.52 km^2 and cropland, grassland and barren area decreased by 329.45 km^2, 46.78 km^2 and 12.18 km^2 respectively from 2000 to 2020. A total of 18 species of large mammals were enumerated from primary field data. Chital was the most abundant species in lowland (block A) and northern red muntjac in mid-hills (blocks B, C and D). Among the carnivores, tiger was recorded only from the lowlands while leopards were reported throughout the landscape, and Himalayan black bear was reported in blocks B, C and D. Land cover types, anthropogenic disturbances, and

coverage of invasive and alien plant species (IAPS) have been identified to affect the abundance of large mammals. The human-large mammal conflict is a serious problem in this landscape with an estimated annual loss of US$ 12.02 and 74.60 per household from crop damage and livestock depredation, respectively. The highest estimated occupancy ($\psi = 0.944 \pm 0.048$) was found for leopard whereas the lowest occupancy was for Himalayan goral ($\psi = 0.038 \pm 0.011$). Species distribution model predicted 30.29% of the study area as suitable habitats for northern red muntjac, 6.45% for chital, 2.6% for sambar, 14.55% for wild pig, 15.55% for Himalayan goral, 34.88% for rhesus macaque, 34.65% for langur, 5.79% for Himalayan black bear and 29.94% for leopard. A total of 15 habitat patches were identified in the central part of CHAL on the basis of suitable habitats of mammals. The study found a poor connectivity among the patches for chital and sambar, a strong connectivity for muntjac, leopard, rhesus macaque and langur in the lowland to mid-hill and a strong connectivity for Himalayan black bear and Himalayan goral in mid-hills.

The heterogeneity and dynamics in the landscape pattern in CHAL mainly attributed forest change due to migration of people from rural to urban and lowland areas. Landscape conservation efforts in the CHAL should maintain the contiguity of forest patches. This research provides the baseline information of large mammals in the CHAL and how they are responding to changes in the landscape. It reveals the role of fragmented landscape for supporting large mammal assemblages and conserving biodiversity.

LIST OF ACRONYMS AND ABBREVIATIONS

ACA	: Annapurna Conservation Area
AIC	: Akaike's Information Criterion
AUC	: Area Under Curve
BCF	: Barandabhar Corridor Forest
BCN	: Bird Conservation Nepal
CCA	: Canonical Correspondence Analysis
CHAL	: Chitwan Annapurna Landscape
CI	: Confidence Interval
CNP	: Chitwan National Park
CWD	: Cost Weighted Distance
DCA	: Detrended Correspondence Analysis
DEM	: Digital Elevation Model
DHM	: Department of Hydrology and Metrology
DoS	: Department of Survey
ER	: Encounter Rate
ETM	: Enhanced Thematic Mapper
GIS	: Geographic Information System
GLM	: Generalized Linear Model
GPS	: Global Positioning System
HH	: House Hold
HWC	: Human Wildlife Conflict
IAPS	: Alien and Invasive Species
IBA	: Important Bird and Biodiversity Areas
ICIMOD	: International Centre for Integrated Mountain Development
IDW	: Inverse Distance Weightage
IUCN	: International Union for Conservation of Nature
LCP	: Least Cost Path
LULCC	: Land Use and Land Cover Change

MLC	: Maximum Likelihood Classification
MNDWI	: Modified Normalized Difference Water Index
MoFE	: Ministry of Forests and Environment
MoFSC	: Ministry of Forests and Soil Conservation
MoLRM	: Ministry of Land Reform and Management
NDBI	: Normalized Difference Built-up Index
NDVI	: Normalized Difference Vegetation Index
OLI	: Operational Land Imager
pGIS	: Participatory Geographic Information System
PPF	: Panchase Protected Forest
RDA	: Redundancy Analysis
ROC	: Receiver Operator Characteristic
RS	: Remote Sensing
SDM	: Species Distribution Model
SE	: Standard Error
SWIR	: Short Wave Infrared Red
TM	: Thematic Mapper
TRI	: Terrain Ruggedness Index
USGS	: United States Geological Survey
UTM	: Universal Transverse Mercator
WRS	: Worldwide Reference System
WWF	: World Wildlife Fund

LIST OF SYMBOLS

χ^2	: Chi-square
$\sum$	: Summation
κ	: Kappa
β	: Beta
ψ	: Psi (occupancy)
Isi	: Total number of individuals of a species
Nsi	: Number of species population

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CHAPTER 1

1. INTRODUCTION

1.1. Background

Mammals have a remarkable diversity of species, ecology, physiology, behavior and life history (Jones & Safi, 2011). The mammals are categorized as small and large on the basis of their weight and ecological importance (Lwin *et al.*, 2021). Body weight >5 kg is considered as large mammal (Golley *et al.*, 1975; Njoroge *et al.*, 2009; Erena, 2022). A total of 6495 species of mammals including 5341 extant and 75 extinct have been reported in the globe (Burgin *et al.*, 2018). Nepal harbors 213 species of mammals along with two endemic species (Himalayan field mouse, *Apodemus gurkha* and Csorba's mouse-eared bat, *Myots csorbai*) (Amin *et al.*, 2018; Sharma *et al.*, 2019; Bist *et al.*, 2021). Among them, 29 species of mammals are globally threatened (IUCN, 2015). The National Red List Data Book (NRDB) of Nepal listed 49 species of mammals as nationally threatened (nine critically endangered, 26 endangered and 14 vulnerable), seven species as near threatened and 83 as data deficient (Jnawali *et al.*, 2011; Amin *et al.*, 2018). Pygmy hog (*Porcula salvinia*) is listed as regionally extinct (Amin *et al.*, 2018; Bist *et al.*, 2021). Rapidly increasing human populations has created the huge pressure on wildlife of Nepal (Jnawali *et al.*, 2011; WWF, 2013a). The natural habitats of Nepal have significant role for the conservation of wildlife (MoFE, 2018).

A total of 41.69% and 13.27% of the land of Nepal is covered by forest including shrub land and grassland respectively (FRTC, 2022) but the protected area (PA) systems cover only 23.39% (DNPWC, 2022). Many threatened species including large mammals have been reported from forests and forest landscapes outside the PAs (Paudel *et al.*, 2015; Adhikari *et al.*, 2019; GPFD, 2021). The forests outside the PAs also have a vital role in the conservation (Smith *et al.*, 2020). However, these forest habitats are heavily fragmented due to unsustainable use by people for different purposes (Dinerstein *et al.*, 2007; Subedi *et al.*, 2021). These fragmented habitats in human dominated landscape not only connect the protected areas, but also provide habitats for many species (Dinerstein *et al.*, 2007).

The most recent Living Planet Report of WWF, estimates that since 1970, about 68% of all vertebrate species populations have lost (WWF, 2020). About 41% of amphibians, 25% of mammals, and 13% of birds are listed as being threatened with extinction on the IUCN Red List of Threatened Species (IUCN, 2022). Extinction of the species depends on deterministic and stochastic processes (O'Grady *et al.*, 2004; Melbourne & Hastings, 2008; IUCN, 2022). The population size of species is reduced due to human-associated factors such as habitat loss, overexploitation and pollution (Melbourne & Hastings, 2008). In addition, climate change, invasion of invasive and alien species and disease are responsible for biodiversity loss (Matters, 2022).

Fragmentation is the conversion of an intact habitat into patches with variable size and configuration whereas habitat loss is the reduction of the habitat size (Fahrig, 2003; Wilson *et al.*, 2015; Fletcher *et al.*, 2018) due to natural or anthropogenic factors (Pardini, 2018) (Figure 1). Fragmentation has both positive and negative impacts, depending upon the conditions, factors and ecology of the species (Closset-Kopp *et al.*, 2016). However, the effects of habitat loss and fragmentation have not been adequately analyzed in Nepal. Human-induced habitat fragmentation directs the biodiversity decline as it destroys habitats, interrupts community interactions, disturbs animal movement and diverts evolutionary processes (Andrén, 1997; Erb *et al.*, 2012). The fragmented habitat also acts as refugia for many surrogate species during adverse ecological conditions (Fahrig, 2003; Shrestha, 2004). With ongoing fragmentation, degradation of habitat and human encroachment, the wildlife is forced to live in close proximity to human settlements (Stanton Jr *et al.*, 2018). This leads to frequent human-wildlife interaction that evoke a negative perception of the local people in conservation (Kandel *et al.*, 2020; König *et al.*, 2020). If fragmented habitats are interlinked with each other under the ecosystem management system, they will provide an alternative habitat for the animals and also has a higher probability of their survival (Salviano *et al.*, 2021). This phenomenon has become a serious issue in the mid-hill of Nepal. Hence, conservation initiatives and researches should focus in these areas.

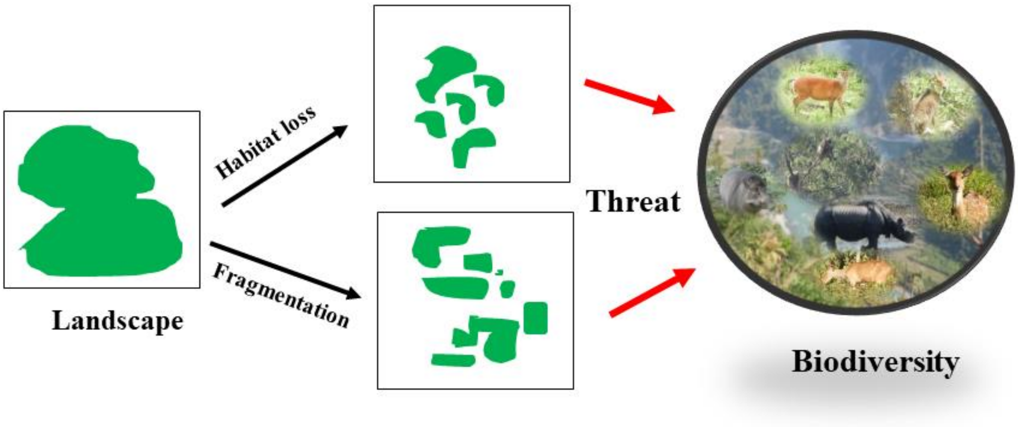


Figure 1: Habitat loss and fragmentation threaten biodiversity

1.2. Land use and land cover change

Land use and land cover dynamics strongly affect the species distribution pattern (Petrou *et al.*, 2015; Halmy *et al.*, 2020). Analysis of land cover dynamics provides the crucial information on habitat conditions and the need for restoration (Rimal *et al.*, 2019; Rather *et al.*, 2020; Wang *et al.*, 2020).

Globally, the land cover has changed drastically, 60% of the changes are associated with human activities and 40% by natural forces such as climate change and natural calamities (Song *et al.*, 2018). Major factors for land-use change are agricultural expansions, deforestation, urbanization, afforestation, increment of the forest and changes in the course of major rivers (Song *et al.*, 2018; Masiliūnas *et al.*, 2021).

The analysis of land cover dynamics from 1990 to 2015 reported that forests, wetlands, and snow are decreasing while bare lands and croplands are increasing in Nepal (Li *et al.*, 2017). Similarly, the classified images from 1930 to 2014 of Nepal also indicate 48.6% of forest loss (Reddy *et al.*, 2018). A comparative review on land use and land cover changes data have revealed an increase in croplands in Nepal (Paudel *et al.*, 2016). This study analyzed the land cover and land use change between 2000 to 2020 in the central region of Chitwan Annapurna Landscape that covered part of Chitwan (Barandabhar Corridor Forest and surrounding areas, part of Chitwan National Park), Mid-hill area of Tanahun district along Seti River basin, part of Kaski, Parbat and Syangja district (Panchase protected forest and lower part of Annapurna Conservation Area).

1.3. Mammals and their interaction with people

Conservation of mammals is a global concern as they are connected with socio-cultural and ecological values (Mainka & Trivedi, 2002; Milcu *et al.*, 2013). For the effective conservation of the mammalian species, knowledge about the abundance, distribution range, preferred habitat and response to different environmental variables are essential.

Global biodiversity loss has been increasing along with high rate of extinction. Hence, the scientists have said that "we are in the middle of a sixth mass extinction – the Anthropocene – driven by human activity" (Matters, 2022). Global extinction of species is occurring at an unpredictable rate due to anthropogenic factors (Karanth & Kudalkar, 2017; Matters, 2022). To date, about 142577 species have been evaluated, among them 29% of the species are listed as threatened (http://www.iucnredlist.org). More than 25% of the large terrestrial mammals are facing risk of extinction whereas 50% are in declining populations (Ripple *et al.*, 2017). The mammals of South Asia are facing risk and are listed in the endangered category (Karanth *et al.*, 2010; IUCN, 2022).

Human wildlife conflict (HWC) is worldwide common problem but it is more serious in the developing countries (Ogutu *et al.*, 2014). Animal husbandry and agriculture are the primary occupations of the rural people of Nepal (Cromsigt *et al.*, 2013). Habitat loss, fragmentation, agricultural expansion along with human activities inside the forests are the major governing factors of HWC (Fernando *et al.*, 2005; Mukeka *et al.*, 2019). The number and type of crop and property damaged, livestock depredation and cases of human injuries and casualties by the wildlife may vary on the basis of species, time, and availability of the food inside the forest (Acharya *et al.*, 2017; Sharma *et al.*, 2021).

HWC is the main challenge around the protected areas of Nepal. Frequent visit of the wildlife to the public areas creates the conflicts and evoke a negative perception for their conservation (Ravenelle & Nyhus, 2017; Acharya, 2018; Lamichhane *et al.*, 2019b; Baral *et al.*, 2021a). The species such as greater one-horned rhino (*Rhinoceros unicornis* Linnaeus, 1758), wild pig (*Sus scrofa* Linnaeus, 1758), chital (*Axis axis* (Erxleben, 1777)), Asian elephant (*Elephas maximus* Linnaeus, 1758) and tiger (*Panthera tigris* (Linnaeus, 1758)) in the lowland and northern red muntjac *Muntiacus vaginalis* (Boddaert, 1785), monkeys: rhesus macaque (*Macaca mulatta* (Zimmermann, 1780)) and langur (*Semnopithecus* spp.), wild pig (*Sus scrofa),* Himalayan black bear (*Ursus thibetanus* G. [Baron] Cuvier, 1823), leopard (*Panthera pardus* (Linnaeus, 1758)) in the mid-hills of Nepal are involved in crop damage, livestock depredation and human causalities (Dhungana *et al.*, 2016; Adhikari *et al.*, 2018a; Lamichhane *et al.*, 2018).

1.4. Environmental correlates and occupancy of mammals

Environmental correlates (e.g., land cover and land use dynamics, elevation, aspects, habitat heterogeneity, Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Built-up Index (NDBI), Terrain Ruggedness Index (TRI), presence of buildup/settlements areas, water resources, prey richness for carnivores and human-wildlife interactions) directly or indirectly affect the abundance, distribution, population size, range size, body size, and life history of animals in that area (Pakeman *et al.*, 2002; Chitayat *et al.*, 2021; Lwin *et al.*, 2021). Hence, describing, comparing and predicting the distribution of species and their interaction with different environmental correlates are essential for the effective conservation and management (Pimm *et al.*, 2014; Pal *et al.*, 2020).

The population dynamics and species distribution are greatly affected by extrinsic forces such as climate, geographical barriers and ecological correlates (Guisan & Thuiller, 2005). Occupancy modelling estimates the probability of occurrence and Species Distribution Model (SDM) predicts the suitable habitat for the occupancy of the animals that provides information on species-habitat relationships, species-environmental correlates relationships, realized niches and metapopulation structure (Guisan & Thuiller, 2005; Hirzel & Le Lay, 2008; Elith *et al.*, 2011; Jeon *et al.*, 2014; Lwin *et al.*, 2021). Hence, SDM is very useful for conservation planning for their long-term conservation of species (Guisan & Thuiller, 2005; Hirzel & Le Lay, 2008; Elith *et al.*, 2011).

1.5. Landscape level connectivity

The connectivity between the isolated habitat patches facilitates the movement of the species and mitigates the effects of fragmentation on biodiversity (Watson *et al.*, 2014; Closset-Kopp *et al.*, 2016). However, the scientific knowledge and tools for evaluating land cover features are very important for developing effective corridor for biodiversity conservation but they are still scarce (Closset-Kopp *et al.*, 2016; Pelletier *et al.*, 2017).

Landscape-level habitat connectivity facilitates wildlife movement, seed dispersal and various ecological services (Bennett, 2003; Almasieh *et al.*, 2019). The habitat connectivity is regarded as one of the most significant frameworks for prioritizing for biodiversity conservation (Chen, 2010). Restoration of degraded habitat and expanding the connectivity may help to link the population of core areas that further help for long-term survival of the species, e.g., leopard (*Panthera pardus*), Himalayan black bear (*Ursus thibetanus*).

1.6. Rationale

Protected Areas (PAs) have played an important role in the biodiversity conservation. But PAs are either small or isolated and are unable to hold the viable population of many wild animals (Naughton-Treves *et al.*, 2005). Hence, the forests outside the PAs are also crucial for conservation. This gap can be fulfilled by creating the community–based forest management in the bottlenecks and important corridors (Karanth *et al.*, 2010). Such corridors will also create safe zones for biodiversity mainly endangered species under the climate change and provide an alternative habitat for wildlife (WWF, 2013a, 2013b). Terai Arc Landscape (TAL) of Nepal, Chitwan Annapurna Landscape (CHAL), Sacred Himalayan Landscape (SHL), Kailash Sacred Landscape (KSL) and Kangchenjunga Landscape (KL) of Nepal are some of the responses to this conservation paradigm (WWF, 2013a). Among them, CHAL is one of the model landscapes that connects the lowland of Terai with the Himalayas through mid-hill. Mid-hill of Nepal is highly fragmented and human-dominated, but significantly covers a large number of ecosystems and biodiversity (WWF, 2013b; Paudel & Heinen, 2015). However, these areas are underrepresented in the protected area network and receive less conservation and research priority. Further, HWC is also a common phenomenon in these areas that develop a negative perception of people towards wildlife (Acharya *et al.*, 2016; Baral *et al.*, 2021a). Land cover dynamics of the landscape is very important for landscape level conservation that provides the scenario of habitat change and species distribution (Uddin *et al.*, 2015a; Li *et al.*, 2017). But the status of the habitat, land cover dynamics and species distribution in this area are poorly known. This study evaluated the land use and land cover dynamics, abundance of large mammals, their interaction with people and prediction of suitable for habitats: three carnivores- tiger, leopard and Himalayan black bear and seven prey species- northern red muntjac, chital, sambar, wild pig, Himalayan goral, rhesus macaque and langur monkey.

Developing corridors or linkages between the fragmented habitats is one of the best methods for the conservation of animals (Ramiadantsoa *et al.*, 2015). These issues demand a better understanding of the concept of corridors and their implications in biodiversity conservation through both horizontal and vertical linkages. The Himalayan Landscape of Nepal still has a large number of natural wildlife habitats, which can be linked through a web of corridors in vertical and horizontal gradients that can increase the chance of survival of wildlife species by providing better habitats with better shelter, food and refuge areas. Hence, landscape-level study is required to find out the functional corridor established between two protected areas Chitwan National Park (CNP) and Annapurna Conservation Area (ACA).

1.7. Objectives

The general objective of this study was to evaluate landscape correlates for the occupancy of the large mammals in Chitwan Annapurna Landscape, Nepal.

The specific objectives were:

1. To characterize the spatio-temporal pattern of land use and land cover
2. To evaluate the relative abundance of large mammals and their interaction with people
3. To examine the impacts of environmental correlates on the occupancy of large mammals
4. To identify the landscape level connectivity for the large mammals in the Central Part of CHAL, Nepal

1.8. Research questions

1. How do landscape patterns change through time and space along mountain and rural urban gradients?
2. How does spatio-temporal habitat attributes and anthropogenic factors influence on large mammal abundance and their interaction with human?
3. What influences do different environmental factors have on the occupancy and habitat suitability of large mammals in CHAL?
4. How can landscape attributes and species occupancy data be incorporated into habitat connectivity modeling?

1.9. Organization of the thesis

This thesis has seven chapters excluding references and appendices. Chapter–1 includes the introduction and discusses the background, land use and land cover change, mammals and their interaction with people, environmental correlates and landscape-level connectivity, rationale, research questions, objectives and organization of thesis. Four chapters (2–5) are related to the specific objectives of research and each of them is organized as abstract, introduction, materials and methods, results, discussion and conclusions. The chapter–2 deals with the spatio-temporal pattern of land use and land cover in Chitwan Annapurna Landscape, central Nepal. The chapter–3 describes the abundance of large mammals and their interaction with people, chapter–4 evaluates the impacts of environmental correlates on the occupancy of large mammals whereas the chapter–5 describes the landscape level habitat connectivity of large mammals. Chapter–6 presents overall conclusion and recommendation of the study and chapter–7 highlights the overall summary of the thesis.

CHAPTER 2

2. SPATIO-TEMPORAL PATTERN OF LAND USE AND LAND COVER IN CHITWAN ANNAPURNA LANDSCAPE, CENTRAL NEPAL

Abstract

Understanding land use and land cover dynamics are important to recognize the ecological, physical and anthropogenic processes in the landscape and are necessary for sustainable management of the landscape. The landscapes of mid-hills of Nepal are most dynamic due to anthropogenic activities since past several decades. This study evaluates spatial and temporal changes in land use and land cover in the central region of Chitwan Annapurna Landscape, Nepal. The spatio-temporal patterns of the area were evaluated through the classification of Landsat images of 2000, 2010 and 2020 using ERDAS imagine 9.2 and ArcGIS 10.8. The accuracy of classified images was evaluated on the basis of ground truthing coordinates, Google Earth and Topographic maps. The land use/land cover analysis of Landsat image 2020 revealed that the area comprised grassland (1.73%), barren area (1.76%), riverine forest (1.93%), water bodies (1.97%), buildup/settlements area (4.13%), Sal dominated forest (15.4%), cropland (28.13%), and mixed forest (44.95%) of the total area (2749.48 km^2). There was net increase of 37.46% of mixed forest, 31.34% of buildup/settlements area and 7.6% of Sal dominated forest area, decrease in riverine forest, barren area, croplands and grassland area between 2000 and 2020; overall more than 13% of the forest was increased in this landscape. The overall accuracies clearly exceed 80 percent. The substantial change in land cover over the 20-year period was the results of forest fragmentation and regeneration partially due to migration of rural people to lowland and urban area as well as resettlement of Old Padampur Village to new area and growth development of urban centers in the mountains. This result can be useful to develop a conservation strategy in human dominated landscapes.

2.1. Introduction

Land use and land cover change (LULCC) has been a universal phenomenon as a result of increasing demands of growing population as well as natural processes (Reis, 2008; Hassan *et al.*, 2016; Zhu *et al.*, 2021). This process, growing rapidly, may be the most visible effect of anthropogenic activity that has brought about drastic changes in land cover pattern around the globe (Van Asselen & Verburg, 2013). LULCC is the principal measure of environmental changes such as a change in biodiversity, habitats, landslides, floods, climate change and coverage of invasive and alien plant species (MEA, 2005; MoLRM, 2015; Paudyal *et al.*, 2019; Rimal *et al.*, 2019; Wu, 2019; Rather *et al.*, 2020). However, rapid population growth and exploitation of natural resources have significant impacts on ecosystem structure, function and dynamics (Van Asselen & Verburg, 2013; Chamling & Bera, 2020) which has made mountain environment more fragile. Therefore, it is important to identify the state of LULCC to know the drivers and their effects on ecological (e.g., forest cover) and anthropogenic processes (Chamling & Bera, 2020).

Various methods have been applied in the collection, analysis and presentation of natural resources data for analyzing the land cover dynamics. Recently, the remote sensing (RS) and geographic information system (GIS) technologies are frequently used in this process (Câmara *et al.*, 1996; Manonmani & Suganya, 2010; Petrou *et al.*, 2015). The RS provides time series data with greater spatial details and temporal frequency (Câmara *et al.*, 1996; MohanRajan *et al.*, 2020). With increased availability and improved quality of spatio-temporal data as well as efficient analytical techniques, it is now possible to monitor, analyze and map land use change in a cost-effective way (Álvarez-Martínez *et al.*, 2017; Räsänen & Virtanen, 2019; Rather *et al.*, 2020; Thapa *et al.*, 2021). The RS data are used for wildlife monitoring (Stephenson, 2019), habitat classifications (Nagendra *et al.*, 2013; Agrillo *et al.*, 2021), change in urban area (Rimal *et al.*, 2020; Wellmann *et al.*, 2020; Zhang *et al.*, 2020), land cover change detection (Zhang *et al.*, 2019; Wang *et al.*, 2020), wetland mappings (Mahdavi *et al.*, 2017; Lefebvre *et al.*, 2019) and natural disaster assessments (Bhattarai & Kondoh, 2017; Liu *et al.*, 2018). Historically, GIS and RS were used in many studies to detect LULC at different spatio-temporal scales using satellite images (Loveland *et al.*, 2000; Lee, 2005; Chen *et al.*, 2015).

The landscape is spatially heterogenous and composed of the visible feature of land (Shao & Wu, 2008; Crowley & Cardille, 2020) which represents geographic areas and their impacts on ecological, physical and anthropogenic processes. Landscape composition and habitat heterogeneity is directly or indirectly affected by biotic interactions, disturbances, natural disasters such as landslides, floods, drought formations, forest fires and ecological successions (Scheller, 2020, Siddique *et al*., 2020). Currently, the anthropogenic factor is the major driver that creates spatial heterogeneity in the landscape (Rather *et al.*, 2020; Zhu *et al.*, 2021). LULC data provide information about habitat types, ecosystems and processes which is very useful to understand land cover dynamics (Rimal *et al.*, 2019; Wang *et al.*, 2020).

Past studies showed that anthropogenic factors governed greater changes in land cover than natural causes (Thapa & Murayama, 2009; Rimal *et al.*, 2020; Wang *et al.*, 2020). More than 30% of the agricultural land of mid-hill, Nepal has already been abandoned and the people migrate to the urban and semi-urban area (Paudel *et al.*, 2012; Garrard *et al.*, 2016). This process results in increased forest in the rural areas as well as population growth, settlement expansion, roads construction and other developmental activities in the urban and semi-urban areas.

Studies related to the LULCC in Nepal have concerted mostly on the urbanization (Thapa & Murayama, 2009; Wang *et al.*, 2020), glacier fluctuations, outbursts and landslides (Huggel *et al.*, 2002; Rimal *et al.*, 2019), watershed and river systems (Rai *et al.*, 2018; Lamsal *et al.*, 2019; Paudyal *et al.*, 2019) and protected areas (Thapa, 2011; Chettri *et al.*, 2013). However, studies at landscape level land cover change analysis are insufficient and are primarily focused on areas with a high rate of urbanization (Zomer *et al.*, 2001; WWF, 2013a; Chhetri *et al.*, 2017). Therefore, this study focused on the temporal and spatial pattern of landscape dynamics in CHAL and aimed to: (i) evaluate the land use and land cover status; (ii) evaluate temporal and spatial pattern of LULCC in the central part of the Chitwan Annapurna Landscape (CHAL), Nepal. For this achievement, Landsat images of 2000, 2010 and 2020 were analyzed into eight classes (Sal dominated forest, riverine forest and mixed forest, grassland, cropland, barren land, buildup/settlements area and water bodies).

2.2. Materials and methods

2.2.1. Study area

The Chitwan Annapurna Landscape (CHAL) is located in central Nepal and covers parts of 19 districts (Dhading, Nuwakot, Rasuwa, Makawanpur, Chitwan, Nawalparasi, Tanahun, Lamjung, Gorkha, Manang, Mustang, Myagdi, Kaski, Syanja, Parbat, Baglung, Palpa, Gulmi and Argakhachi) and six protected areas (National parks- Parsa, Chitwan, Langtang; conservation areas- Annapurna, Manaslu, and hunting reserve- Dhorpatan) (WWF, 2013a) (Figure 2A and B). This landscape is drained by eight major rivers (Kali Gandaki, Seti, Madi, Marshyandi, Daraudi, Budi Gandaki, Trishuli and Rapti) and their tributaries.

This study mainly concentrated in the central part of this landscape that connects the CNP in the lowland Terai with the ACA in the high mountain. The study focused in an area of 2749.48 km^2 that covers the parts of Chitwan, Tanahun, Kaski, Syanja and Parbat districts (Figure 2C). The CHAL represents globally outstanding biodiversity including three Global 846 Ecoregions ("Terai–duar Savanna and Grasslands, Himalayan Subtropical Broadleaf forests, Himalayan Sub-tropical Pine forest") (Wikramanayake *et al.*, 2002; Dinerstein *et al.*, 2017) and two biologically important Ramsar sites (Beeshazari and associated lakes, Chitwan and lake clusters of Pokhara valley, Kaski) (NLCDC, 2020). The CHAL provides habitat for mammals, birds, herpetofauna, fish and many other micros and macroinvertebrates (Bhuju *et al.*, 2007; WWF, 2013b). Important forest patches providing potential vertical corridor in this landscape is Barandabhar Corridor Forest (BCF), forests patches along Seti River and Panchase Protected Forest (PPF) and lower parts of ACA (Figure 2C). This study was focused on the central part of CHAL as model that represents all types of ecosystems and biodiversity of entire CHAL.

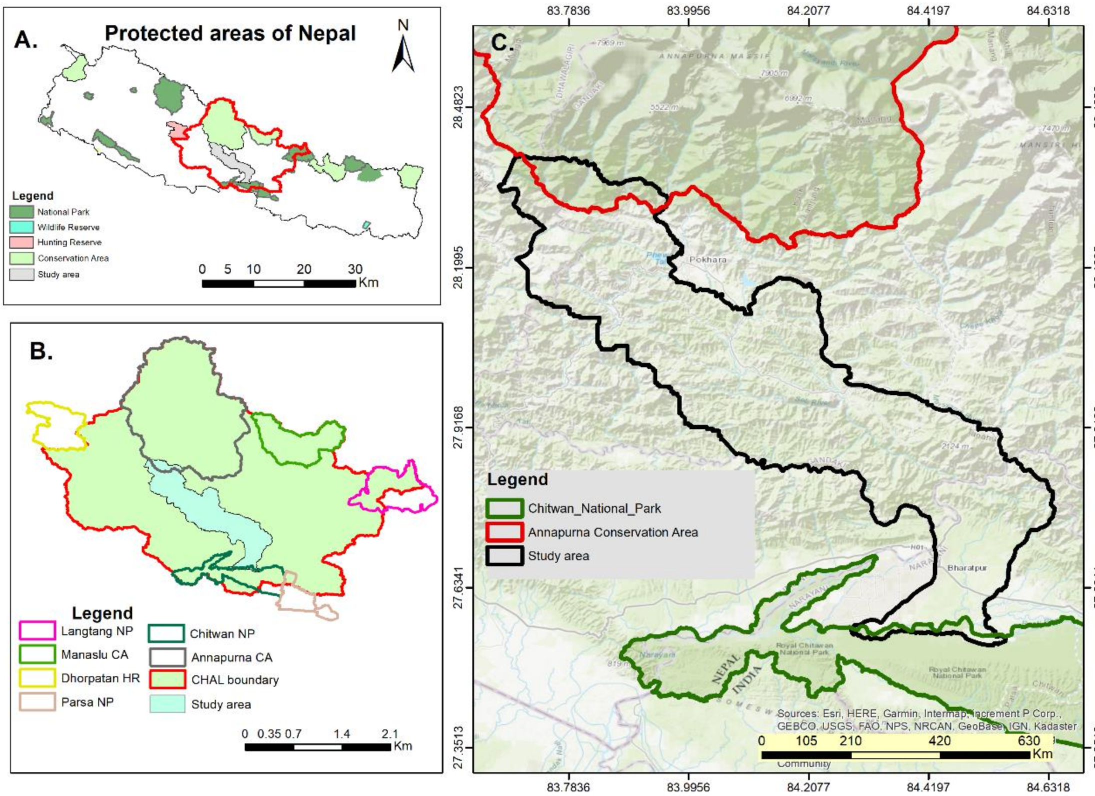


Figure 2: A. Protected Areas of Nepal and location of CHAL along with study area, B. Map showing the location of CHAL and intensive study area, C. model study area

2.2.2. Study design

For the effective study, the study area was divided into four different study blocks. These blocks were designed on the basis of river course, topography, geography, locations and accessibility, the study area was divided into four different blocks (Table 1, Figure 3).

Table 1: Detail locations of the study blocks

SN	Block	Detail locations
1	A	Barandabhar Corridor Forest (BCF) and part of Chitwan district
2	B	Devghat Rural Municipality, Anbukhaireni Rural Municipality (Gaighat area), Bandipur Rural Municipality, part of Rishing Rural Municipality and part of Vyas Municipality of Tanahun district
3	C	Part of Vyas Municipality, part of Rishing Rural Municipality, part of Ghiring Rural Municipality, Magde Rural Municipality, Bhimad Municipality, part of Shuklagandaki Municipality and part of Rupa Rural Municipality
4	D	Panchase Protected Forest, Bharatpokhari, Nirmalpokhari, Bagmara and lower part of Annapurna Conservation Area (ACA)

2.2.2.1. Location

Block A covers the BCF, part of CNP and surrounding areas of BCF (Kabilas, Jugedi, Kerabari, Chaukidanda, Simaldhap) up to Mahabharat range of Chitwan district. This block extends from 27.282°N to 27.865°N and 84.282°E to 84.574°E and covers 535.47 km^2 between the elevation ranges from 150 and 1200 m. The Ratnanagar Municipality lies on the east whereas Kalika Municipality, Ichhakamana Rural Municipality lie on the north-east, and Bharatpur Metropolitan City on the west of BCF (Figure 3). In the hilly area of this block, the human settlements are scattered and surrounded by the forest.

Block B is human-dominated mid-hill landscape along the Seti River basin. It covers Devghat, Bandipur, Abu Khairani Rural Municipalities and Vyas Municipality of Tanahun district. It is the floodplain of Seti and Trishuli River along with mid-hills. The study block extends from 27.752ºN to 28.028ºN and 84.468ºE to 84.261ºE and covers 626.19 km^2 area. The elevation ranges from 218 to 2521 m. Chimkeshwori is the highest peak of this area (2521 m asl). About 100 community forests have been established in this area (Oli, 2018). Human settlements, roads and croplands are scattered and the forests are divided into large or small patches. Part of Vyas Municipality, Bandipur, Devghat, Khairenitar, Sarangghat are the dense settlements present in this block (Figure 3).

Block C covers the Bhimad Municipality, parts of Rishing Rural Municipality, Ghiring Rural Municipality, Magde Rural Municipality and Shuklagandaki Municipality of Tanahun District and Rupa Rural Municipality of Kaski District along the Seti River basin. The Bhimad and Shuklagandaki are located on the bank of Seti River. This block is highly human-dominated and fragmented by the large cities such as Vyas, Shuklagandaki or Khairenitar and Bhimad. The forest areas surround the settlements (Figures 3 and 2B). This block extends from 27.921ºN to 28.139ºN and 84.221ºE to 83.942ºE, and covers 786.38 km^2. The elevation ranges from 280 to 2219 m. This block has more than 100 community forests (Oli, 2018).

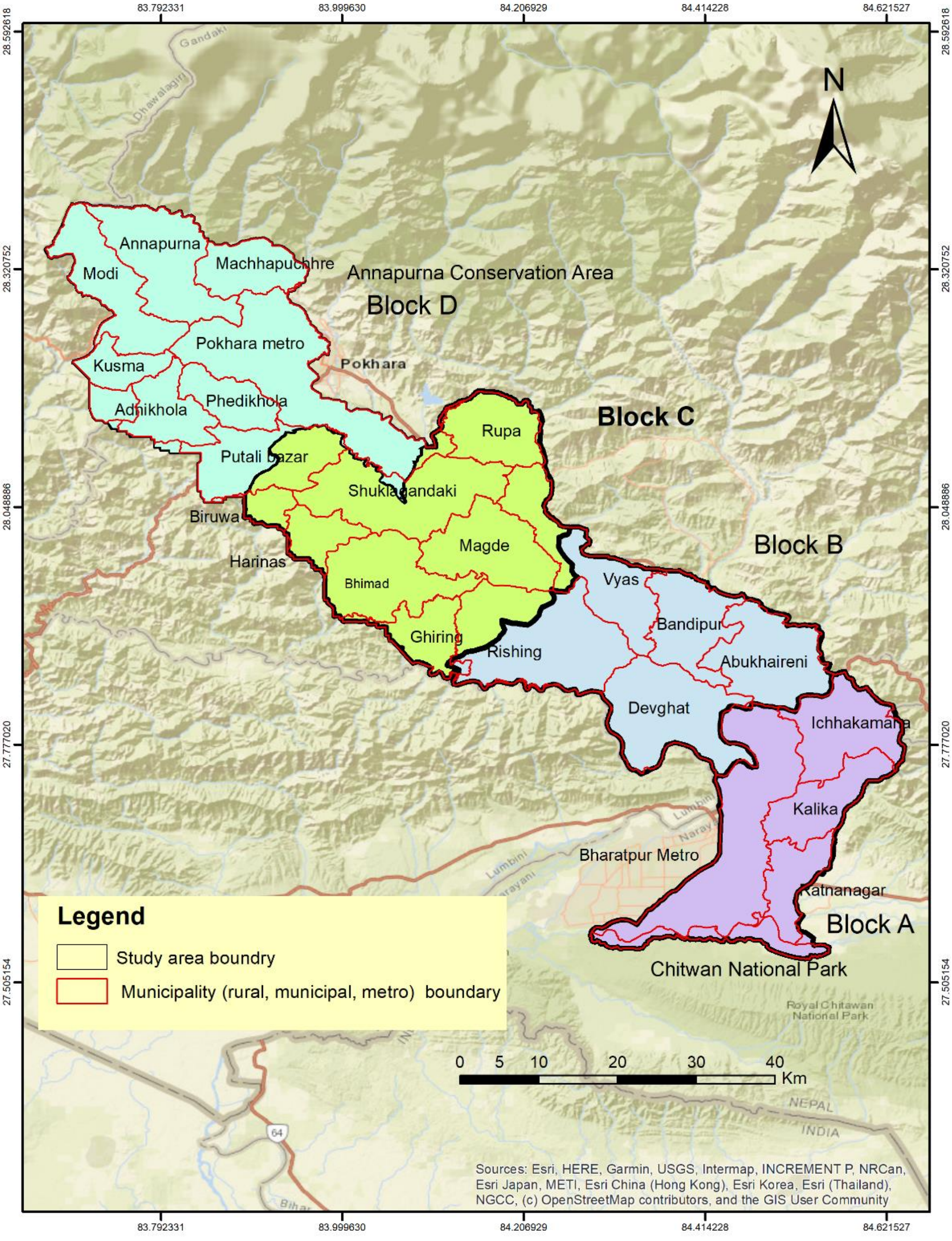


Figure 3: Map showing the intensive study area with four study blocks A–D and local administrative units

Block D covers Bharatpokhari, Nirmalpokhari, Pumdibhumdi, Panchase, Lumle, Ghandruk, Landruk, Deurali and the Australian Camp area (Figure 3). It extends from 28.064ºN to 28.405ºN and 84.066ºE to 83.677ºE and covers 801.44 km^2. The elevation ranges from 645 to 3300 m. This block has four types of forests: national forest, community forest, protected forest (Panchase) and conservation area (Annapurna).

2.2.2.2. Physiography

Based on physiography, Chitwan valley can be divided into the Terai, Siwalik hill and Mahabharat Range (Dangol & Poudel, 2004). Chitwan valley is also called inner Terai (Bhitri Madesh) which is surrounded by Mahabharat and Churia hill ranges (Malla & Karki, 2016).

The floodplain of the Chitwan valley is made by a series of ascending terraces of alluvial laid down by Narayani and Rapti River system (Dangol & Poudel, 2004). The Mahabhart range of the Chitwan valley is composed of the rocky terrain of sandstone, conglomerates, slates, limestone and quartzite. The hills' soils are mainly loam, loamy rubble with a stony surface (HMG, 1968; Dangol & Poudel, 2004).

Block B and C are situated in the mid-hill. The Seti River follows through the V-shaped deep gorge forming the alluvial floodplain in many places and joining with Trishuli River.

The valley floor is made by the rocky terrain of slates, quartzite, and dolomites but the plain and slope area of the upper mountain is composed of alluvial soil mixed with sands, gravel and rocks. Broadly, the soil of this area can be classified into three categories: alluvial, colluvial and residual (Adhikari & Tian, 2021). The alluvial soil is found in the floodplain of the Seti River Basin (Sarangghat, Vyas area, Bhimad, Khairenitar). The colluvial soil is found on the gentle slope of the mountain. The middle mountain, slope have the colluvial type of soil. Residual soils are found at the top of the mountain ranges and embedded in the bedrocks. The mountain of this block is made of slates, quartzite, limestone and dolomites. The floodplain of Rishi Patan, Vyas, Bhimad and Kharirenitar is famous for agriculture.

Block D is located in the central part of Lower Himalaya up to 3300 m elevation and is made by a thick section of para-autochthonous crystalline rock which composes of fossiliferous sedimentary and meta-sedimentary rocks such as shale, sandstone, slate, quartzite, limestone and dolomite (Dixit *et al.*, 2015). The lower slope of the area is covered by the floodplains of Seti River and Harpan River which is very useful for agriculture.

2.2.2.3. Climate

There are three different seasons: summer season (pre-monsoon), monsoon and winter (post-monsoon). Winter months (November to February) are the colder and the temperature comparatively falls in the night and morning. The average minimum temperature recorded from 1989 to 2018 was 8.29 ºC, 7.4 ºC, 8.42 ºC, 4.84 ºC and the maximum temperature was 35.48 ºC, 33.41 ºC, 33.42 ºC, 23.97 ºC respectively in blocks A, B, C and D (DHM, 2019). In the morning and the night time, the area is covered with thick fog. After that, the temperature rises to May and becomes stable for four months (June-September) after that again decreases (Appendix I).

Monsoon starts in mid-June and continues up to late September. The average annual rainfall of the Chitwan valley (Rampur station) from 1989 to 2018 was 1889.23 mm among them, 81.53% of rainfall occurred within the monsoon season (June to September). Similarly, annual rainfall in block B (Bandipur station), block C (Khairenitar station) and block D (Lumle station) was 2876.4 mm (75.53% in monsoon), 2238.08 mm (73.96% in monsoon) and 5480.19 mm (84.89% in monsoon) respectively (Appendix II). After, the monsoon, winter rainfall is very low in this valley. There is gradual increase in rainfall from March onwards and irregular thunderstorms and hailstorms occur during the pre-monsoon season.

The relative humidity is commonly high all around the year except in the dry months (March to May). The monthly average relative humidity from 1989 to 2018 was 76.6%, 71.58%, 70.29% and 82.43% respectively in blocks A, B, C and D (DHM, 2019). The average monthly relative humidity was lower from April to May and was maximum from December to January (Appendix III). The relative humidity is comparatively more in the morning time of winter days. These areas are covered with the thick fog during winter mainly nearer to the river systems. The flow of cold air from the northern Himalayas reduces the daily temperature.

2.2.2.4. Hydrology

The Chitwan valley is drained by large and medium-sized rivers originating from the high Himalayas, Mahabharat range and Churia hills. The major rivers such as Narayani and Rapti along with other rivers and streams such as Khageri, Budi Rapti, Manikhola, and Panchakanya, Amilipani Muhan, Bung Khahare Khola and Khahare Khola make areas moist and humid. BCF is also bisected by the Khageri irrigation canal which is the prime source of Beeshhazari lake (Figure 4A), one of the famous Ramsar Site of Nepal (NLCDC, 2020). Some natural and man-made lakes such as Kumal Taal, Batulpokhari, Kamal Taal, Kingfisher Taal, Panchakanya Taal, Rhino Taal, Ratmate Taal, Kaalmate Taal, Tiger Taal, Gunumandre Taal, Tikauli Taal, Chepang Taal and naturals marshy lands make the area wetter.

Figure 4: Different habitat types present in the block A: A. Bishhazari Lake, the Ramsar site, B. Sal Forest (BCF), C. Mixed forest (Jurethum area), D. Grassland and riverine forest (Rapti floodplain, Belsar area)

Block B and C are drained by rivers such as Trishuli, Kaligandaki, Madi, and Seti that follow from the high Himalayas. The Madi River joins with Seti at Damauli (Vyas area). Some perineal and temporary streams originating from the gorge of the mid-hill also make the area wet and humid. Seti River mixes with Trishuli at Gaighat (Figure 5A). This area consists of Nyagdi, Chhipchhipe Khola, Chabdi River, Mode Khola, Dharapani, Sukhaura Khola, Bagendi Khola, Bagar Khola, Pivor Khola, Wanten, Phedi Khola, Jyagdi Khola, Lima Khola and gorge of many other streams (Figure 2.5A). Most of these stream end in Seti River (NEA, 2012).

Figure 5: Landscape and habitat of mid-hill (block B): A. Gaighat area, the confluence of Trisuli and Seti River B. Sparse vegetation, at Mude area, C. Sal dominated forest, Devghat area (Raniban Community Forest) D. Landscape nearby Nagdighat area

Figure 6: Landscape and habitat type present in block C: A. Habitat types, and gorge of the stream near Magde (Mulabari area) C. Terrace farming in the human-dominated landscape of mid-hill (Manpur and Deurali area), D. Regeneration of Sal forest in Amar Jyoti C

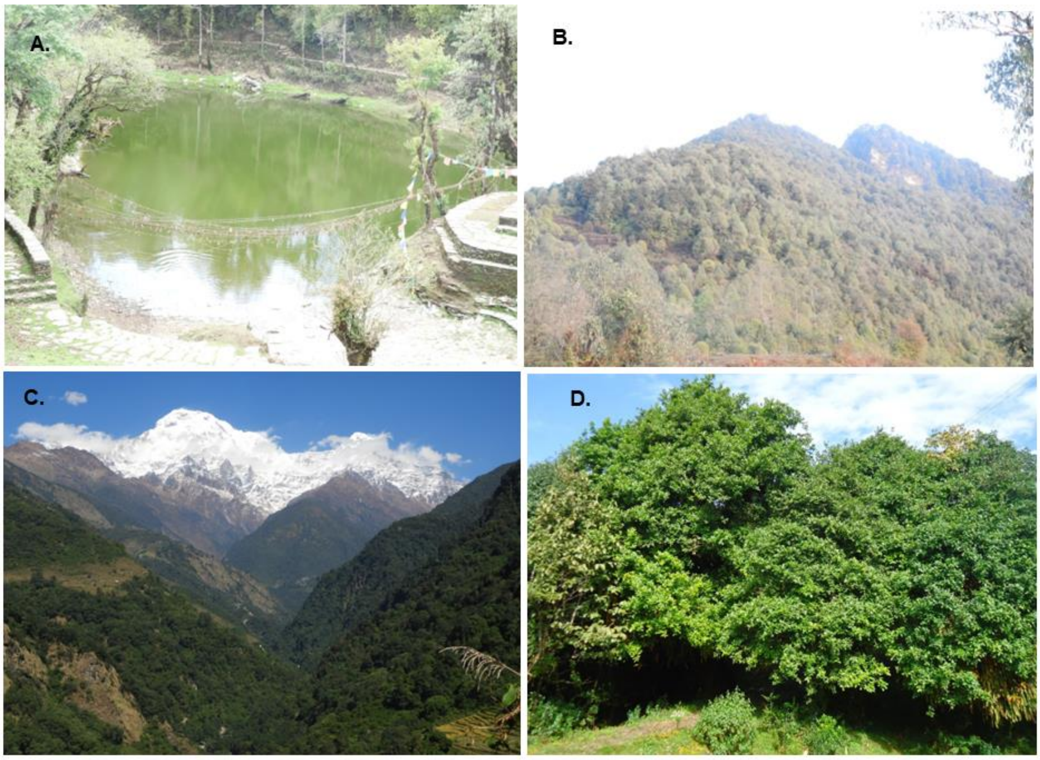


Figure 7: Landscape and habitat types in block D: A. Panchase Lake, a holy lake, perpetual source of water, Herpan River and other associate rivers are originating from this lake, B. Panchase Protected Forest showing Panchase peak, C. View of Annapurna along with Modi River Basin, D. Kharsu (Quercus semecarpefolia) forest, the dominated forest at Panchase, Forest Camp and Ghandruk area

Block D comprises three sub-watershed areas of Gandaki Basin– Upper Seti River, Modikhola and Lower Mid-Kali Gandaki. Modikhola watershed locates mainly in Parbat and Kaski districts. Seti River watershed and Lower Mid-Kali Gandaki watershed share their boundary with Kaski and Syangja respectively. This area is famous for lakes and ponds. The lake systems of Pokhara valley are listed in the Ramsar sites, the 10th Ramsar site of Nepal (NLCDC, 2020). Panchase Protected Forest (PPF) area has a holy lake named Panchase Lake which is very famous for religious pilgrimage. The Phewa Lake is fed by Herpan Khola which is originated from Panchase lake (Figure 7A). The Herpan Khola is composed of small other permanent and seasonal streams such as Khahare Khola, Thotne Khola, Lauruk Khola, Thado Khola, Betani Khola, Turung Khola and many others (Dixit *et al.*, 2015 Adhikari; *et al.*, 2018a). Seti River follows through the deep gorge in the central part of Pokhara valley and open into the Ramghat. Modi Khola basin on the way to Ghandruk drains the upper part of this study area.

2.2.2.5. Biodiversity

2.2.2.5.1. Vegetation

Vegetation of the lower part (Chitwan part) of this landscape is the sub-tropical type that links early successional floodplain vegetation community with Sal (*Shorea robusta*). The Sal is an ecologically climax community of the Terai of Nepal (Stainton & David, 1972; DFRS, 2014). The reaming vegetation types are riverine forest, grassland and mixed forest. The Sal is associated with Tatari (*Dillenia pentagyna*), Saaj (*Terminalia alata*), Kyamuna (*Cleistocalyx operculatus*), Karma (*Haldina cordifolia*), Chiraunjee (*Buchanania latifolia*), Bhalayo (*Semecarpus anacardium*), Deri (*Derris elliptica*). The riverine forest is associated with Vellar (*Trewia nudiflora*), Sisso (*Dalbergia sissoo*), Khayer (*Acacia catechu*), Simal (*Bombax ceiba*), Palas (*Butea monosperma*), Pidar (*Xeromphis uliginosa*), Datingal (*Ehretia laevis*), Peepal (*Ficus religiosa*), Kutmero (*Listea monopetala*), Madise-khirro (*Holarrhena pubescens*) (http://efloras.org). Grassland presents in the BCF and hilly area of Chiwan can be differentiated into two types. Tall grass: The tall grass is only found on the floodplain of Rapti River and Khageri (Figure 4D). The tall grasses are composed of Kaas (*Saccharum spontanium, S. bengalensis, S. munja*), Kuro (*Chrysopogon aciculatus*), Khadai (*Narenga porphyrocoma*), Siru (*Imperata cylindrica*), Ureli (*Themeda villosa*), Narkat (*Arundo domax*), *Phragmites karka*, etc. Grassland patches ranging from 0.02 to 0.3 km^2 are scattered inside the Sal forest throughout BCF (NTNC, 2003). Barmuda grass or Dubo (*Cynodon dactylon*), *Chrysopogon aciculatum, Erogrostis japonica, Clerodon viscosum* are the examples of short grasses. The hilly area of the Chitwan is covered by the mixed types (Figure 4C) of trees species such as Chiuri (*Diploknema butyracea*), Chilaune (*Schima wallichii*), Katus (*Castanopsis indica*), Khirro (*Falconeria insignis*), Pinus (*Pinus roxburghii*), Bot Dhairo (*Lagerstromia parviflora*), Jamun (*Syzygium cumini*), Siris (*Albizzia* spp.), Kusum (*Schleichera oleosa*), Aule Chaanp (*Michelia champaca*), Sindure (*Mallotus philippensis*), etc. (http://www.efloras.org).

In the mid-hill of Tanahun, Sal dominated forest (Figure 5B, 6D) is found on the gentle sloppy area of the mountain associated with Karma (*Adina cordifolia*); Saaj (*Terminalia alata*). Devghat area is mainly dominated by Sal forest (Adhikari *et al.*, 2019). Riverine forest is found on the bank of river and gorge made by the streams. Khayer (*Acacia *catechu*), Sisso (*Dalbergia sissoo*), Simal (*Bombax ceiba*), Vellar (*Trewia nudiflora*) are the major tree species of riverine forest. The riverine forest is comparatively lower in Seti River basin (Adhikari *et al.*, 2019). Most of the area of mid-hill is covered by the mixed hardwood forest including Chilaune (*Schima wallichii*), Katus (*Castanopsis indica*), Padke (*Litsea doshia*), Dhairo (*Woodfordia fruticose*), Kafal (*Myrica esculenta*), Kutmero (*Litsea monopetala*), Chaanp (*Michelia champaca*), Amaro (*Spondias pinnata*), Bot Dhairoo (*Lagerstromia parviflora*), Jamun (*Syzygium cumini*), Siris (*Albizzia* spp.), Kusum *(Schleichera oleosa*), Sindure (*Mallotus philippensis*). Chilaune (*Schima wallichii*) and Katus (*Castanopsis indica*) are the most dominant tree species; hence this type of forest is also called Schima-Castanopsis forest. Mountain gorge and moist places is dominated by Utis (*Alnus nepalensis*) (WWF, 2013b). The grassland and bushy areas are scattered within the forest patches. Babiyo (*Eulaliopsis binate*), Thakal (*Breea arvensis*), Banso (*Digitaria ciliaris*) are found in the sloppy area of the mountain whereas Siru (*Imperata cylindrica*), Khar (*Themeda* spp.), Kans (*Saccharum spontanium*) are found on the floodplain of Seti and Trisuli River. The grass patches are scattered in the forest patches.

Block D has heterogeneous forest types. The major forest type of this bock can be categorized as Sal dominated forest, Schima-Castanopsis, Lower Temperate Oak forest, Chir Pine and Broad-Leaved forest, East Himalayan Oak-Laurel forest, Alder forest and Rhododendron-*Quercus* forest. The Bharatpokhari, Nirmalpokhari areas are dominated by regenerative Sal dominated forest whereas the gorge of the river and moist area are dominated by Utis (*Alnus nepalensis*) along with Maletto (*Macaranga indica*), Paiyu (*Betula alnoides*), Kafal (*Myrica esculenta*). Patches of Chilaune (*Schima wallichii*), Katus (*Castanopsis tribuloides*) have been reported in the area of Sidhane, Lumle, Chitre, Bhadaure, Ramja, Pumdibhumdi, Kristichaur, Mattikhana area (Figures 7B and D). The area above 2000 m (Bhanjyang, Panchase hill, Ghandruk, Deurali, Australian Camp) is dominated by the Rhododendron, Kharsu (*Quercus semecarpefolia*) and Phalat (*Quercus* spp). Rakchan (*Daphniphyllum himalense*) is the main dominant tree species present in this block which replace the most of the other tree species in many parts of PPF and ACA (Maren *et al.*, 2014). PPF harbors more than 813 species of flowering plants that belong to 393 genera and 111 families (Bhandari *et al.*, 2018). The grasslands are scattered into forest patches. The major grass species are Babiyo (*Eulaliopsis binate*), Banso (*Digitaria ciliaris*), Chiraito (*Swertia* *chirayita*, the medicinal herb), Buki (*Anaphalis busua*), Satuwa (*Paris pollyphylla*, medicinal herb), Siru (*Imperata cylindrica*) and Khar (*Themeda* spp).

The national wide assessment of Invasive and Alien Plant Species (IAPS) in Nepal listed 166 species with a risk assessment of 21 IAPS (Tiwari *et al.*, 2005). Among them, 12 major species of invasive terrestrial plants have been reported from this landscape (Lamichhane *et al.*, 2016; Shrestha *et al.*, 2017). Most of the habitats such as grassland and forests of lowland and mid-hill are covered by highly notorious IAPS such as *Mikania micrantha* (Figure 8B), *Chromolaena odorata* (Figure 8A), *Lantana camara* (Figure 8C), *Ageratum conyzoides*, *Ageratum houstonianum* (Figure 8F), *Eichhornia crassipes*, *Ageratina adenophora* (Figures 8E, F) and *Parthenium hysterophorus* (Figure 8D) (Baral *et al.*, 2017; Khadka, 2017; Shrestha *et al.*, 2017).

Figure 8: Major IAPS reported from CHAL. A. *Chromolaena odorata*, the highly dominated IAPS, B. The riverine forest invaded by *Mikania micrantha*, C. *Lantana camara*, D. *Parthenium hysterophorus*. E. *Ageratina adenophora*, F. blooming of *Ageratina adenophora* and *Ageratum conyzoides*

2.2.2.5.2. Fauna

This landscape is rich in faunal diversity. This is one of the major corridors that provides the alternative habitat for the fauna of CNP and ACA, hence called the bio-corridor (NTNC, 2003). BCF, a part of this landscape supports 32 species of mammals (NTNC, 2003; Thapa, 2011; Lamichhane *et al.*, 2016; Adhikari *et al.*, 2021a) whereas ACA harbors 128 species of mammals (Baral *et al.*, 2019). The mammals reported from this landscape area are tiger (*Panthera tigris*), leopard (*Panthera pardus*), sloth bear (*Ursus ursinus*), jungle cat (*Felis chaus*), golden jackal (*Canis aureus*), large Indian civet (*Viverra zibetha*), small Indian civet (*Viverricula indica*), greater one-horned rhino (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), ungulates such as wild pig (*Sus scrofa*), chital (*Axis axis*), hog deer (*Axis porcinus*), sambar (*Rusa unicolor*), and northern red muntjac (*Muntiacus vaginalis*), Himalayan goral (*Naemorhedus goral*), Himalayan black bear (*Ursus thibetanus*), primates such as rhesus macaque (*Macaca mulatta*), Assamese macaque (*Macaca assamensis*) and langur (*Semnopithecus* spp) (NTNC, 2003; Thapa, 2011; WWF, 2013b; Lamichhane *et al.*, 2016; Adhikari *et al.*, 2019; Baral *et al.*, 2019; Adhikari *et al.*, 2021a).

BCF is one of the important bird and biodiversity areas (IBAs) among the 32 IBAs of Nepal (BCN, 2022) that supports 372 species of birds. Similarly, Seti River basin supports 267 species of birds and ACA is also another IBAs and has 518 bird species (Baral, 2018b) whereas PPF along supports 152 species (Baral, 2018a). This landscape supports critically endangered: Indian vulture (*Gyps indicus*); red-headed vulture (*Sarcogyps calvus*); slender-billed vulture (*Gyps tenuirostris*); white-rumped vulture (*Gyps bengalensis*); yellow-breasted bunting (*Emberiza aureola*), endangered: Egyptian vulture (*Neophron percnopterus*); Pallas's fish-eagle (*Haliaeetus leucoryphus*); steppe eagle (*Aquila nipalensis)*; Vulnerable: greater spotted eagle (*Clanga clanga*); Indian spotted eagle (*Clanga hastate*); common pochard (*Aythya ferina*), great hornbill (*Buceros bicornis*); lesser adjutant (*Leptoptilos javanicus*); Asian woolly-necked (*Ciconia episcopus*)*;* bristled grassbird (*Chaetornis striata*) (NTNC, 2003; Adhikari *et al.*, 2018b; GPFD, 2021; Lamichhane *et al.*, 2021a). The endemic bird spiny babbler and restricted-range bird hoary-throated barwing, White-throated tit and Spectacled finch are also reported from this landscape.

Herpetofauna are the bio-indicators and the lowland of this study area supports 31 species of herpetofauna (12 amphibians and 19 reptiles) (NTNC, 2003; Lamichhane *et al.*, 2016). The mid-hill supports 13 species of herpetofauna (Amphibia 7 and 6 reptiles) (NEA, 2012). The Ghandruk and the surrounding area support 12 species Amphibian and 13 species reptiles (Gautam *et al.*, 2020).

The Narayani and Rapti River systems support 108 species of fishes including *Tor putitora*, *T. tor*, *Wallago attu*, *Monopterus cuchia*, *Cyprinus carpio*, *Cirrhinus mrigala,* and *Notopterus notopterus* (Edds, 1989; Jha & Bhujel, 2014). Similar to other drainage such as Gandaki River Basin (Trishuli, Mardi, Marsyangdi, Madi, Kaligandaki), the Seti River supports more than 49 species of fishes (NEA, 2012).

2.2.3. Methods

2.2.3.1. Data sources

The Landsat images of 2000, 2010 and 2020 were used to detect the LULCC in CHAL. The Landsat 7-ETM (Enhanced Thematic Mapper) for 2000, Landsat 5-TM (Thematic Mapper) for 2010, and Landsat 8-OLI (Operational Land Imager) for 2020, satellite images with 30 m spatial resolutions were downloaded from the United States Geological Survey (USGS) (https://glovis.usgs.gov/app) geoportal. A total of six scenes with almost cloud free (<1%) satellite images of two from each year of same month were downloaded (Table 2).

Table 2: List of datasets used in land use and land cover analysis (source: https://glovis.usgs.gov/app)

SN	Scene	Acquisition date	Landsat Scene ID	Spacecraft ID	Spatial resolution	WRS Path/Row	UTM Zone
1	A	3-Apr-2000	LE71420402000094SGS00	L7_ETM	30 m	142/41	45
2	B	3-Apr-2000	LE71420412000094SGS00			142/40	44
3	A	18-Feb-2010	LT51420412010049KHC00	L5_TM	30 m	142/41	45
4	B	2-Feb-2010	LT51420402010033KHC00			142/40	44
5	A	17-Mar-2020	LC81420402020077LGN00	LANDSAT_8	30 m	142/41	45
6	B	17-Mar-2020	LC81420412020077LGN00			142/40	44

As a reference for verification, 1:25000 and 1:50000 scales topographic maps produced by the Government of Nepal, Department of Survey (DoS), the classified map of 2010 created by the International Centre for Integrated Mountain Development (ICIMOD) (http://rds.icimod.org) and map of Google Earth (https://earth.google.com) were used. The field level geographic coordinates were collected using a Global Positioning System (GPS) and used as ground-truthing for supervised classification and accuracy assessments of land cover (Table 2).

2.2.3.2. Image pre-processing

Each Landsat image was georeferenced to the WGS 84 datum and the Universal Transverse Mercator (UTM) Zone 44 and 45 North coordinate system using metadata. Landsat 5 TM, 7 ETM and 8 OLI images have seven, eight and 11 bands respectively (https://www.usgs.gov) (Appendix IV). Among these bands, 1 to 7 bands for Landsat 5 and 7 and 1 to 7 and 9 bands for Landsat 8 were selected for layer stacking. Different bands were combined to produce natural and false colour composites (Table 3).

Table 3: Bands combination for different ground features (Source: ESRI, 2013)

Ground features	**Band composite**	
	Landsat 5 TM/ Landsat 7 ETM	**Landsat 8 OLI**
Natural colour	Red (3), Green (2), Blue (1)	Red (4), Green (3), Blue (2)
False colour (urban)	SWIR 2 (7), SWIR1 (5), 3	SWIR 2 (7), SWIR 1 (6), 4
Colour infrared (vegetation)	NIR (4), 3, 2	NIR (5), 4, 3
Agriculture	5, 4, 1	6, 5, 2
Land/water	4, 5, 3	5, 6, 4
Vegetation analysis	5, 4, 3	6, 5, 4

ERDAS IMAGINE 9.2 was used to process the satellite images. The spectral bands of each image (2000, 2010 and 2020) were stacked. Two different scenes of a same season and year were mosaicked and then the image was masked using the AOI of the study area (Figure 9).

2.2.3.3. Ground-truthing

The field study from 2018 to 2020 gave a clear picture of the field and land cover types. The ground-truthing geographic coordinates were reported from the different land cover types using GPS (Garmin eTrex 10). The ground-truth coordinates were collected representing all land cover types along the landscape. The coordinates were taken from the center of the uniform patches of more than 30 m radius. Half of the total coordinates collected were used for supervised classification and the other half for accuracy assessment. Aside from that, topographic maps were used to locate the various land cover types as well as changes over there during participatory GIS (pGIS) techniques. pGIS provides more detailed spatial information about the place since it recognizes that the locals are accustomed to and experienced with changes in their surroundings. (Brown, 2012; Zolkafli *et al.*, 2017). Twenty focal groups (five on block A, ten on blocks B and C, and five on block D) were conducted with community forest members and senior citizens who had lived in the neighborhood for a long time and could easily feel the changes to their surroundings.

2.2.3.4. Image classification

Before image classification, the land cover scheme was determined based on published literatures (Zomer *et al.*, 2001; Thapa, 2011; MoLRM, 2015; Uddin *et al.*, 2015b; Khanal *et al.*, 2020), reports (WWF, 2013b; MoFE, 2019) and field knowledge. In this study, the land cover types were classified into eight major classes based on dominant plant association, human settlements and buildup area, landscape, water sources and agriculture (Table 4).

Table 4: Major land use and land cover types in CHAL, Nepal (Source: Adhkari et al., 2022a)

SN	Land cover types	Description
1	Water bodies	River, Lakes, ponds, marshy land, reservoirs
2	Barren area	Sand, gravel, flood plains without vegetation, landslide, snow feed area and no vegetation areas
3	Grassland	Grasslands, scattered shrub
4	Riverine forest	Simal (*Bombax ceiba*), Khair (*Acacia catechu*), Sisso (*Dalbergia sissoo*), Veller (*Trewia nudiflora*), Padke (*Litsea doshia*), Kutmero (*Litsea monopetala)* and associates plants
5	Sal dominated forest	Sal (*Shorea robusta*), Saaj (*Terminalia alata*), Karma (*Adina cordifolia)* and associates plants
6	Mixed forest	Lowland: Kyamuno (*Syzygium cumini*), Dhairo (*Woodfordia fruticose*), Amaro (*Spondias pinnata*), Mid-hill: Schima-castaopsis forest: Chilaune (*Schima wallichii*), Katus (*Castanopsis tribuloides*), Other associate species: Kafal (*Myrica esculenta*), Utis (*Alnus nepalensis*), Lapsi (*Choerospondias axillaris*), High hill: Champ (*Michelia champaca*), Paiyu (*Prunus cerasoides*), Rakchan *(Daphniphyllum himalense)*, Rhododendron and oak (*Quercus* spp), and associate plants
7	Cropland	Crop (e.g., paddy, maize, millet, mustard, wheat etc.) cultivated lands
8	Buildup/settlement area	Urban and rural settlements, commercial areas, industrial areas, hydropower project areas, roads construction, airport

Two major image classification techniques are unsupervised (calculated by software) and supervised (human-guided) (Richards & Richards, 2022). Unsupervised classification is based on the software analysis of the image without using prior knowledge of the field and user defining training field for each land cover class (Richards & Richards, 2022). The classified image obtained from this classification determine the correspondences between the spectral classes that the algorithm defines (Love, 2002). Supervised classification is the most commonly used quantitative analysis of remotely sensed image data. It is a human-guided and play a crucial role in classification (Laskov *et al.*, 2005). They specify the multispectral reflection emittance values of each land cover class or land use.

2.2.3.5. Unsupervised classification

The unsupervised classification was performed for the multi-temporal Landsat images (2000, 2010, 2020). The nearer k-means likelihood algorithms with 10 iterations were used to group the pixels having similar features (Duda & Canty, 2002). In the beginnings, images were classified into 40 categories with a convergence threshold 0.90. Then, the similar classes were merged using a recording of classes (Table 4 and Figure 9). The unsupervised classified images were used for the planning of field data collection and also used as baseline for supervised classification.

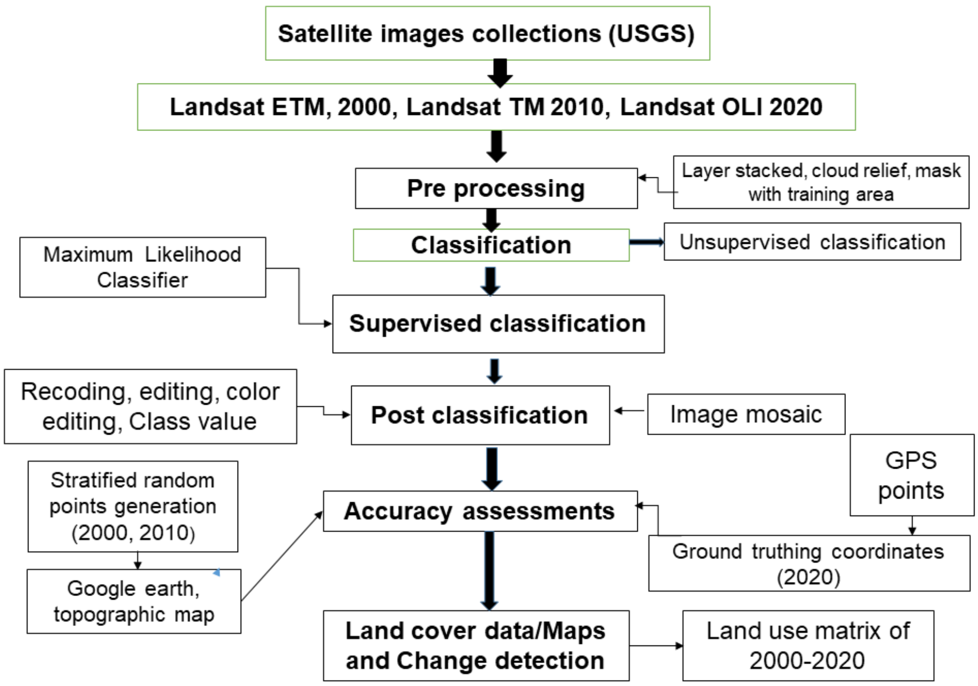


Figure 9: Flow chart: showing the process of Landsat image processing and classification (Source: Adhkari *et al.*, 2022a)

2.2.3.6. Supervised classification

The supervised classification was performed using parametric classification algorithm Maximum Likelihood Classification (MLC) as used by (Rai *et al.*, 2018; Chamling & Bera, 2020). The signature classes were generated by using ground-truth coordinates for 2020 image, Google Earth and classified map of ICIMOD for 2010 and Google Earth and topographic maps for 2000. The signature classes were used for the classification of images. Two separately classified Landsat images of each year were mosaicked into single image. In order to smooth the image and prevent misclassification mistakes, the images were finally filtered, fixing the pixels 3×3. To reduce inaccuracies, the images were recoded based on field information. Sites with heavy land cover changes (>50%) within the 20 years were identified for detail analysis.

2.2.3.7. Accuracy assessment

Accuracy assessment improves the quality of the remotely sensed data in classified thematic maps by comparing the classified image with ground truth coordinates or other references (e.g., Google earth and topographic maps) (Congalton, 2001; Song *et al.*, 2001; Thapa, 2011; Rai *et al.*, 2018; Crowley & Cardille, 2020). Ground-truthing coordinates were employed in this study as a reference for evaluating the accuracy of

2020 classified image. A total of 500 stratified random coordinates were generated for images taken between 2000 and 2010 and compared to references such as Google Earth maps and topographic maps. The confusion matrix or error matrix, as well as the Kappa coefficient, were computed during the evaluation (Congalton, 2001; Foody, 2002). The error matrix was used to determine the accuracy of user's accuracy, producer's accuracy, and overall accuracy. The user's accuracy shows the reliability that the classified pixels of the image coincide with the ground-truthing points (Equation 2), likewise, the producer's accuracy indicates the probability of accurately classified reference pixels (Equation 3). The overall accuracy was determined by dividing the correctly classified pixels in each category by the total number of reference coordinates (Equation 1) (Congalton, 2001; Foody, 2002). Measurements of the agreements between model predictions and reality are determined using the kappa coefficient ($\widehat{K}$). (Congalton, 2001). Statistically, $\widehat{K}$ is the multivariate analysis to estimate the accuracy of the classified image (Equation 4).

$$\text{Overall accuracy} = \frac{Total\ number\ of\ correctly\ classified\ pixels}{Total\ number\ of\ reference\ pixels} \times 100 \quad (1)$$

$$\text{User's accuracy} = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ that\ category\ (row\ total)} \times 100 \quad (2)$$

$$\text{Producer accuracy} = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ that\ category\ (column\ total)} \times 100 \quad (3)$$

$$\text{Kappa coefficient } (\widehat{K}) = \frac{N\left(\sum_{i=1}^{r} X_{ii}\right) - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} \times X_{+i})} \quad (4)$$

Where, r= Number of rows in the error matrix

X_{ii} = number of observations in row i and column i (on the major diagonals)

X_{i+} = Total number of observations in rows i

X_{+i} = Total number of observations in column i

N = Total number of observations included in matrix

2.3. Results

2.3.1. Land cover classes

The classification of Landsat image 2020 has yield eight different land cover classes such as water bodies, barren area, grassland, riverine forest, Sal dominated forest, mixed forest, cropland and buildup/settlements area. The human-dominated areas such as cropland and build-up/settlement areas were scattered and associated with forest patches (Table 5, Figure 10). Out of these eight classes, mixed forest covered the highest area followed by croplands, Sal dominated forest and buildup/settlement area. More than 62% of this landscape was covered by the forests (Table 5).

Table 5: Land cover classes in a central part of CHAL in 2020 (Source: Adhikari *et al*., 2022a)

SN	Land cover type	Area	
		Km^2	Percentage
1	Water body	54.04	1.97
2	Barren area	48.62	1.76
3	Grassland	47.32	1.73
4	Riverine forest	53.25	1.93
5	Sal dominated forest	423.65	15.40
6	Mixed forest	1235.90	44.95
7	Cropland	753.35	28.13
8	Buildup/settlement area	113.35	4.13
	Total area	**2749.48**	**100.00**

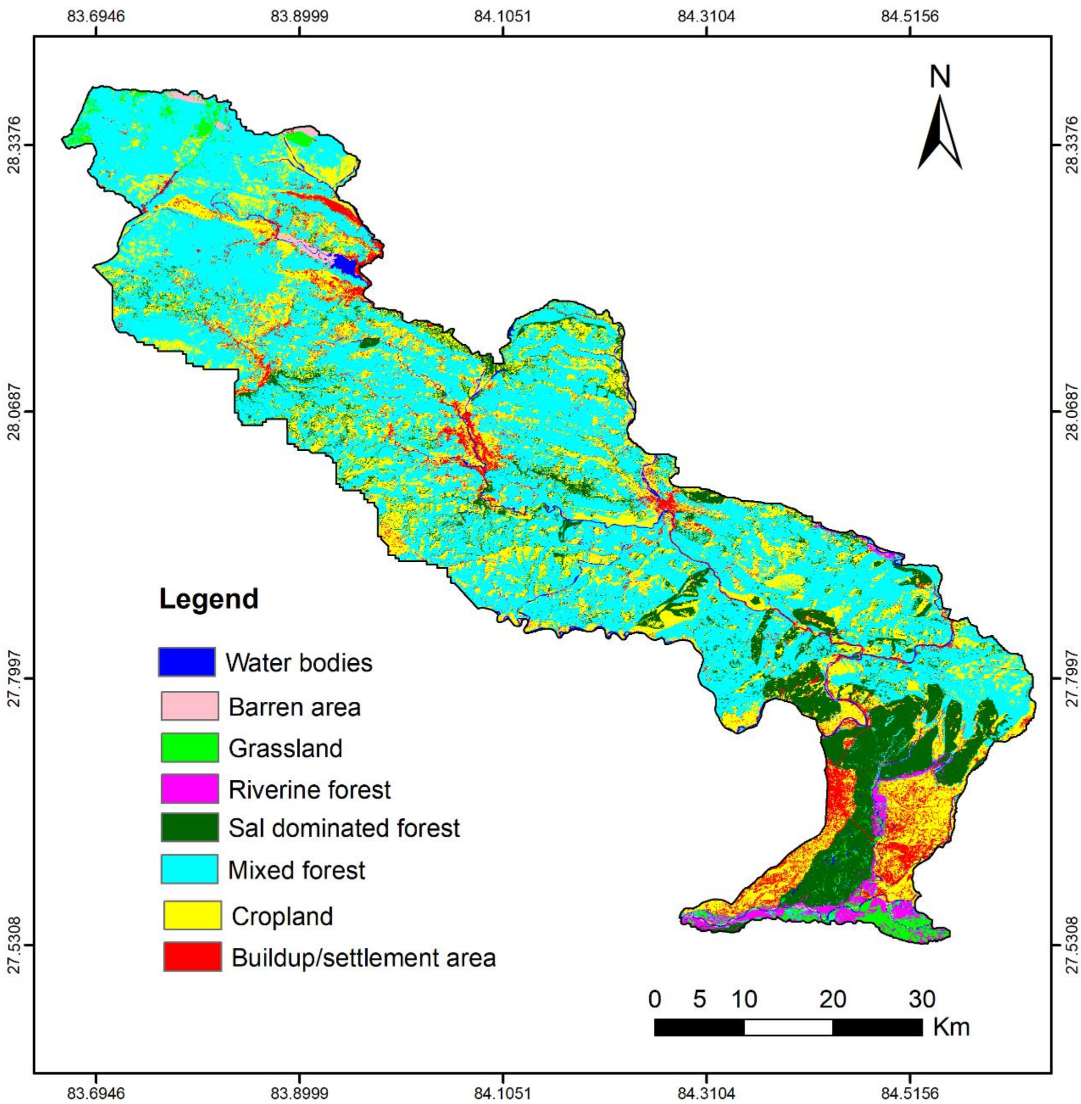


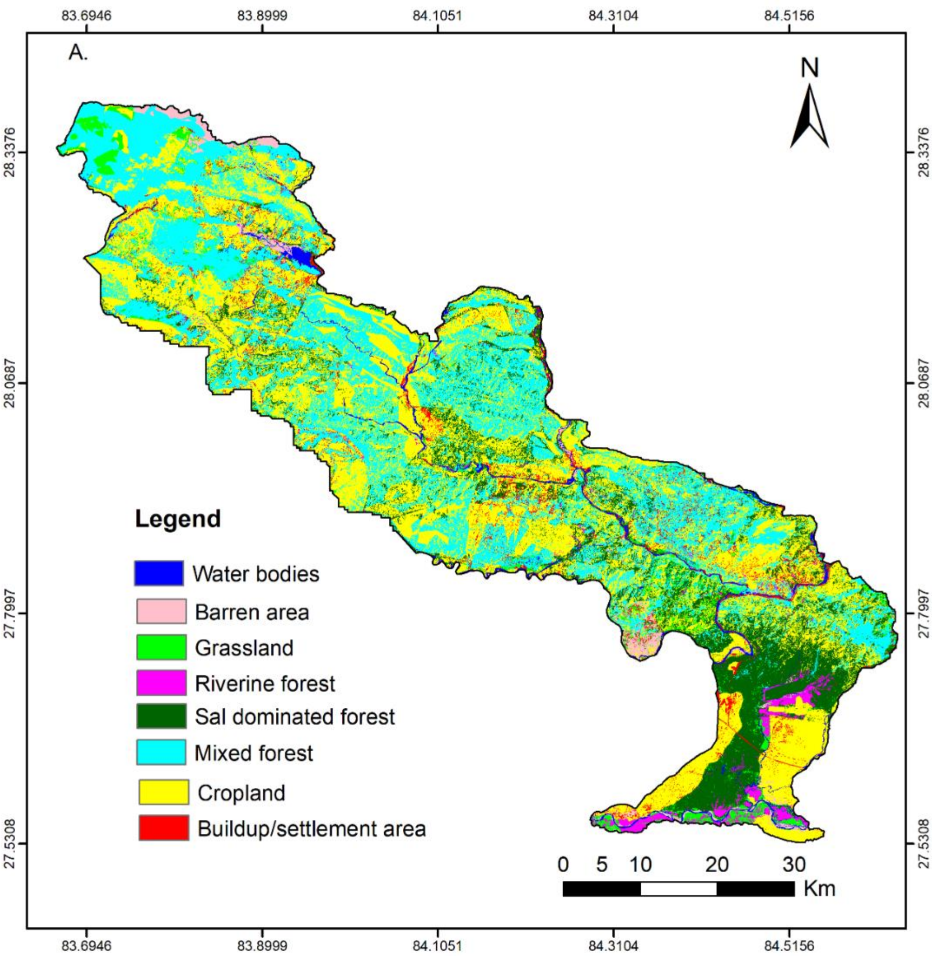
Figure 10: Land cover types of a central part of CHAL in 2020 (Source: Adhikari et al., 2022a)

2.3.2. Land cover change

The results revealed a decrease in the barren land, grassland and cropland from 2000 to 2010 whereas buildup/settlements area, Sal dominated forests and the mixed forest were increasing. Similarly, water bodies, Sal dominated forests, buildup/settlement area and mixed forests were increased from 2010 to 2020, whereas barren areas, cropland and grassland areas were decreased (Table 6, Figures 11A, B and D). Overall, from 2000 to 2020, grasslands, croplands and barren areas were decreased whereas buildup/settlement areas, mixed forests and Sal dominated forests were in increasing trend (Table 6, Figures 11A, B and C).

Table 6: Land cover changes in the study area from 2000 to 2020 (Source: Adhikari et al., 2022a)

SN	Land cover type	Land cover area (km^2)			Change 2000–2010		Change 2010–2020		Change 2000–2020	
		2000	2010	2020	km^2	%	km^2	%	km^2	%
1	Water bodies	53.20	52.70	54.04	-0.50	-0.90	1.34	2.54	0.84	1.57
2	Barren area	60.80	56.10	48.62	-4.70	-7.70	-7.48	-13.3	-12.20	-20.03
3	Grassland	94.10	88.24	47.32	-5.86	-6.20	-40.90	-46.4	-46.80	-49.71
4	Riverine forest	60.03	52.16	53.25	-7.87	-13.00	1.09	2.09	-6.78	-11.29
5	Sal dominated forest	393.15	411.30	423.65	18.15	4.62	12.40	3.00	30.50	7.76
6	Mixed forest	899.10	1062.48	1235.90	163.38	18.20	173.00	16.30	337.00	37.46
7	Cropland	1102.80	923.70	773.35	-179.10	-16.00	-150.00	-16.30	-329.00	-29.87
8	Buildup/ settlement area	86.30	102.80	113.35	16.50	19.100	10.60	10.30	27.10	31.34
	Total	**2749.48**	**2749.48**	**2749.48**						



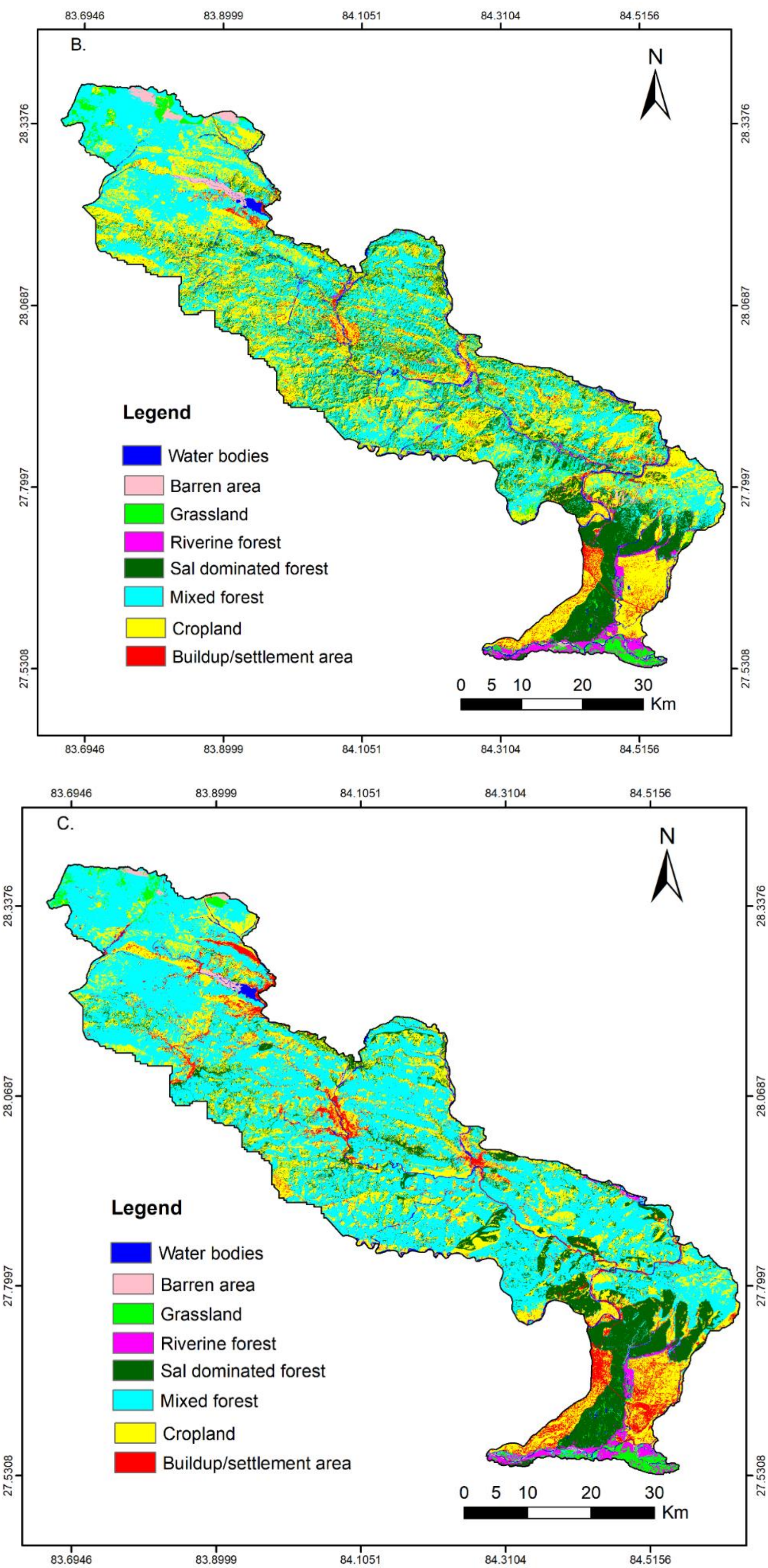


Figure 11: Land use and land cover dynamic of the study area. A. 2000, B. 2010 and C. 2020 (Source: Adhikari *et al*., 2022a)

The classification identified that five different areas where relatively higher proportions of changes occurred in land cover between 2000 and 2020.

2.3.2.1. Old Padampur, Chitwan District

More than 93% of the total cultivated lands in old Padampur and surrounding area was converted into grasslands and forest area from 2000 to 2020. Similarly, the barren area (floodplain of Rapti River) was reduced by 74.67%, but the grassland, riverine forest and mixed forest were increased by 94.45%, 91.26% and 62.50% respectively (Figures 12 and 13, Appendix V). Relatively, higher proportion of the changes were observed between 2000 to 2010 than 2010 to 2020 (Figures 12–13).

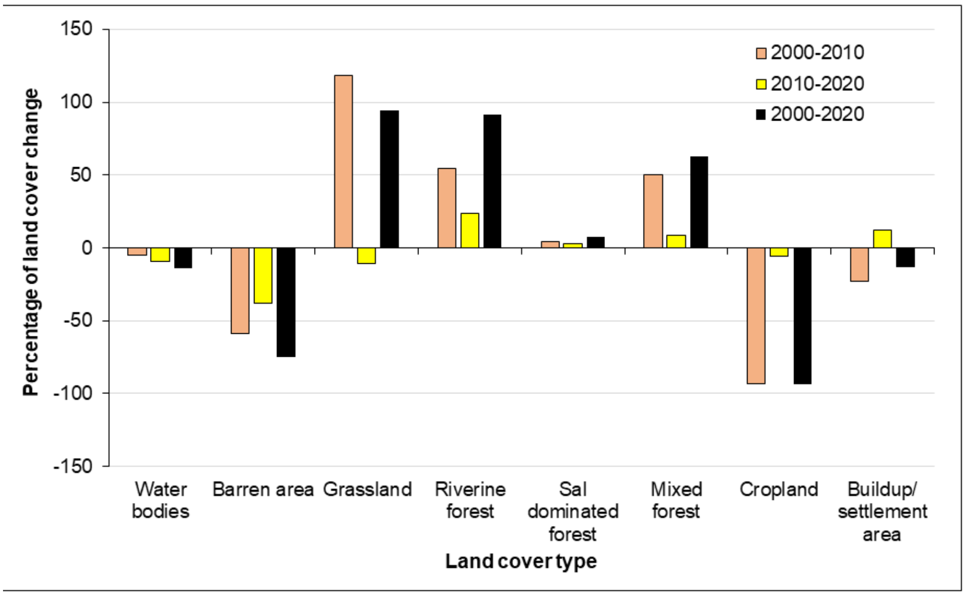


Figure 12: Percentage of land cover change Old Padampur and surrounding areas from 2000 to 2020 (Source: Adhikari *et al*., 2022a)

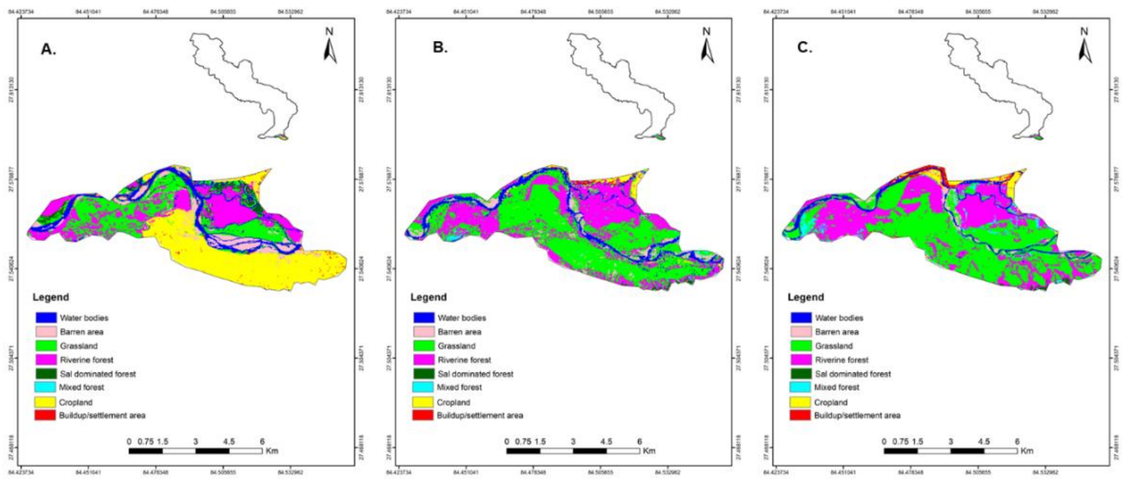


Figure 13: Land use and land cover dynamic in Old Padampur and surrounding area A. 2000, B. 2010 and C. 2020 (Source: Adhikari *et al*., 2022a)

2.3.2.2. New Padampur, Chitwan District

New Padampur area in Chitwan is an example of rapid transformation of forest into cropland and buildup area. In New Padampur area the riverine forest, Sal dominated forest and grassland were decreased by 61.21%, 54.14% and 64.88% respectively from 2000 to 2020, whereas the cropland and buildup/settlements area were increased by 88.17% and 1433.33% respectively. Relatively higher proportion of land cover changed from 2000 to 2010 than from 2010 to 2020 in this area (Figures 14 and 15, Appendix V).

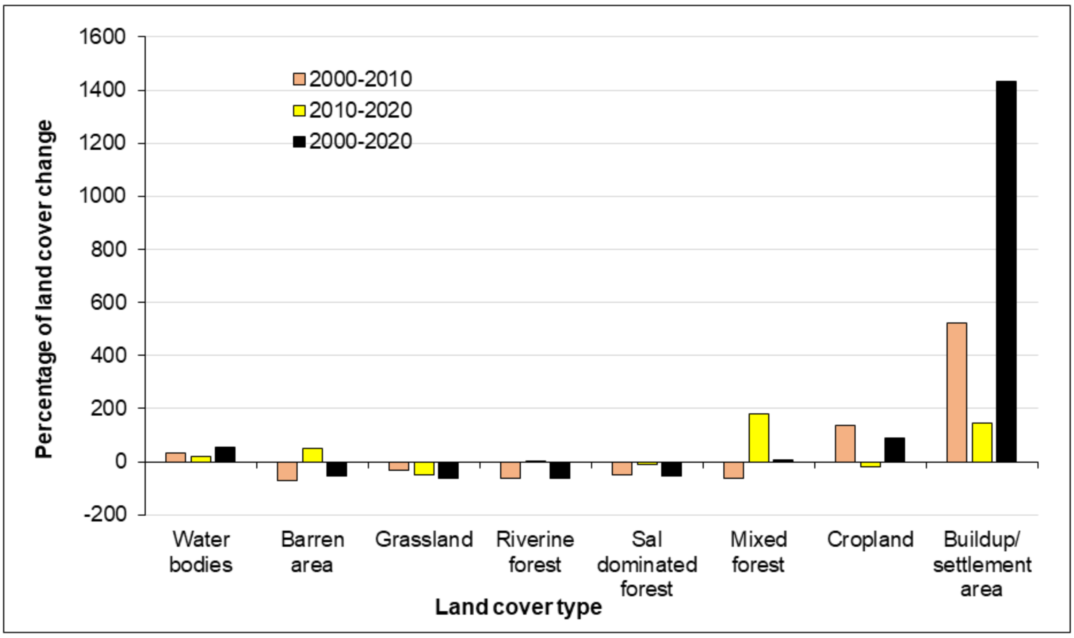


Figure 14: Percentage of land cover change New Padampur from 2000 to 2020 (Source: Adhikari *et al.*, 2022a)

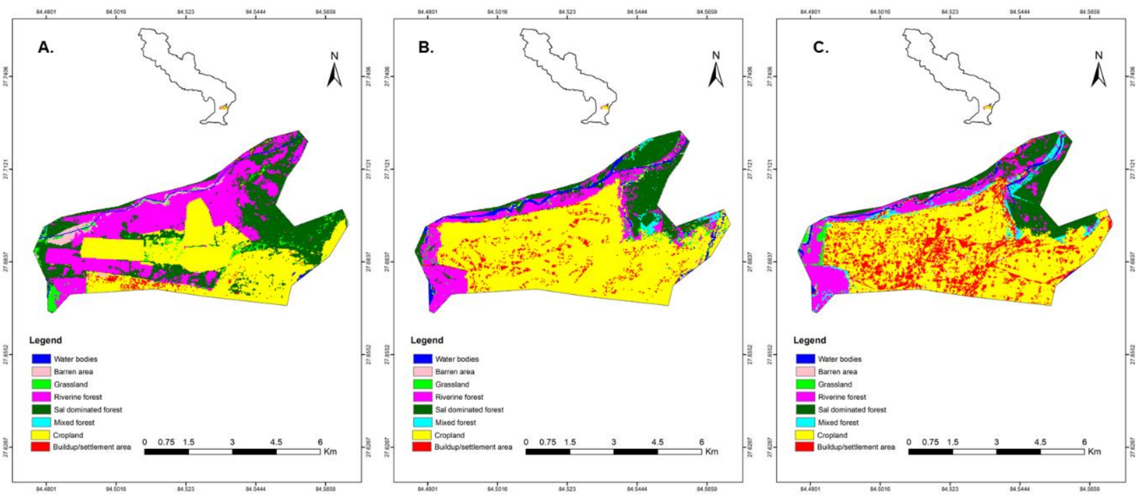


Figure 15: Land use and land cover dynamic in New Padampur A. 2000, B. 2010 and C. 2020 (Source: Adhikari *et al.*, 2022a)

2.3.2.3. Vyas Municipality, Tanahun District

Vyas Municipality is an example of rapidly urbanizing area in the mid-hill of this landscape. There was reduction of cropland by 40.86% whereas buildup/settlements area and mixed forest were increased by 86.55% and 62.14% respectively from 2000 to 2020. Comparatively, the land cover change was higher in between 2010 and 2020 than 2000 to 2010 (Figures 16 and 17, Appendix V).

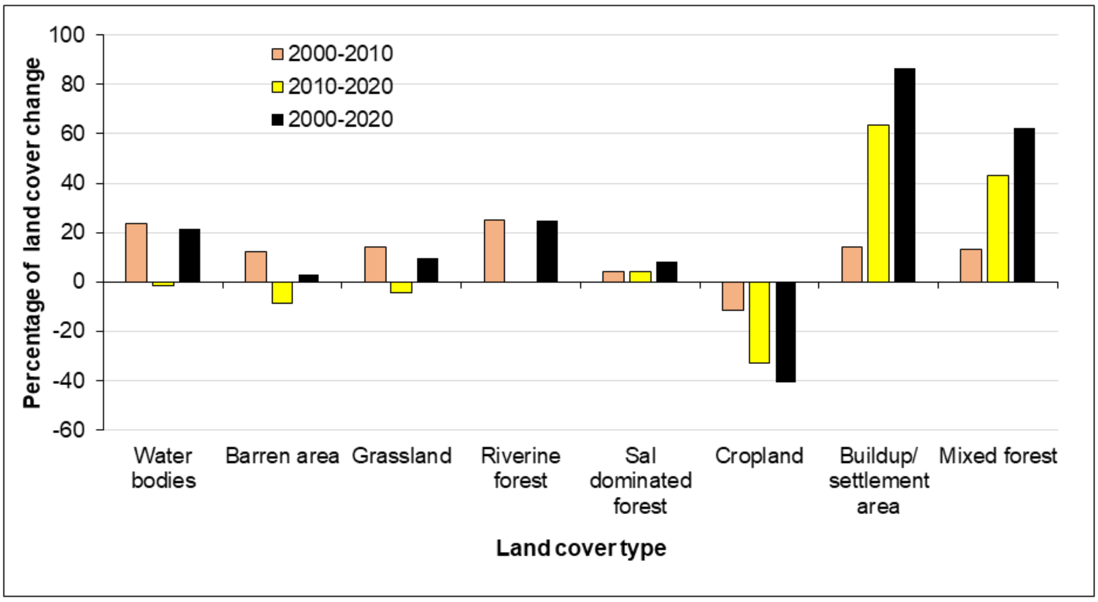


Figure 16: Percentage of land cover change of Vyas Municipality and surrounding area from 2000 to 2020 (Source: Adhikari *et al.*, 2022a)

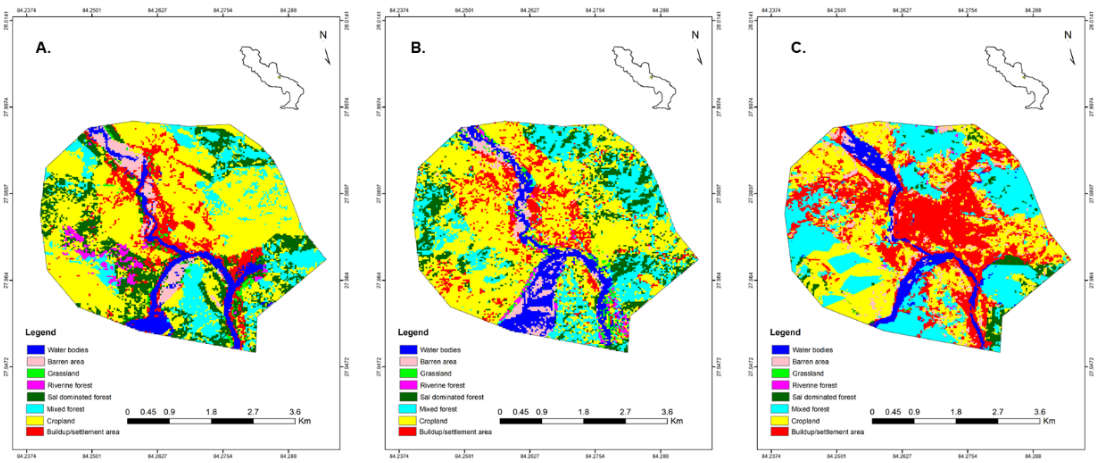


Figure 17: Land use and land cover dynamic in Vyas Municipality and surrounding area A. 2000, B. 2010 and C. 2020 (Source: Adhikari *et al.*, 2022a)

2.3.2.4. Panchase Protected Forest and surroundings

Panchase Protected Forest (PPF) and surrounding is an example of a rural area of the mid-hill that represent rapid changes cropland into forest. Land cover change analysis revealed that the cropland and grassland decreased by 51.92% and 43.22%, while mixed forest and Sal dominated forest increased by 68.1% and 23.29% respectively from 2000 to 2020 in the area (Figures 18 and 19, Appendix V). Proportionally, higher changes occurred between 2010 and 2020 than from 2000 to 2010 (Figures 18 and 19). The cropland and barren area were reduced, and mixed forest, buildup/settlement area and Sal dominated forest were increased in higher proportion between 2010 to 2020 than 2000 to 2010.

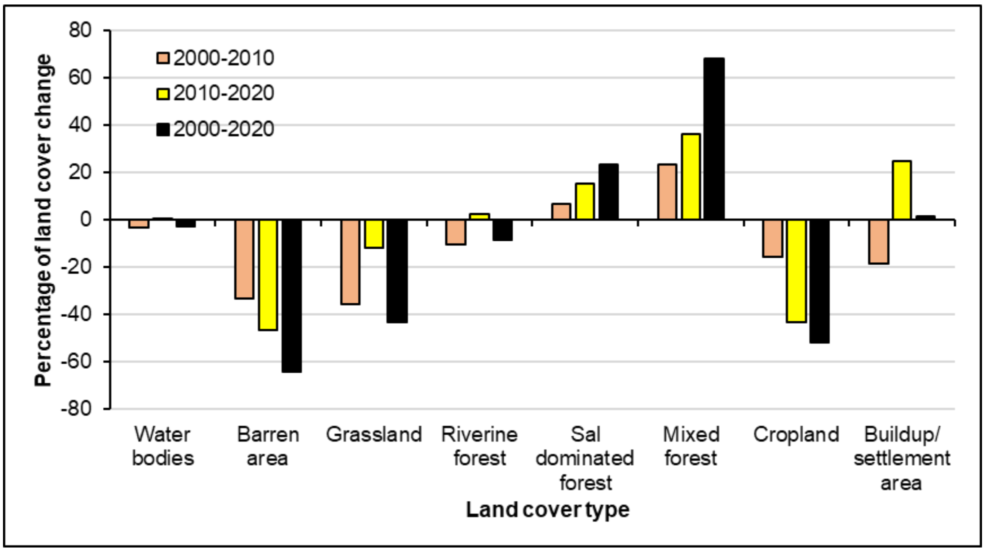


Figure 18: Percentage of land cover change of PPF and surrounding area from 2000 to 2020 (Source: Adhikari *et al*., 2022a)

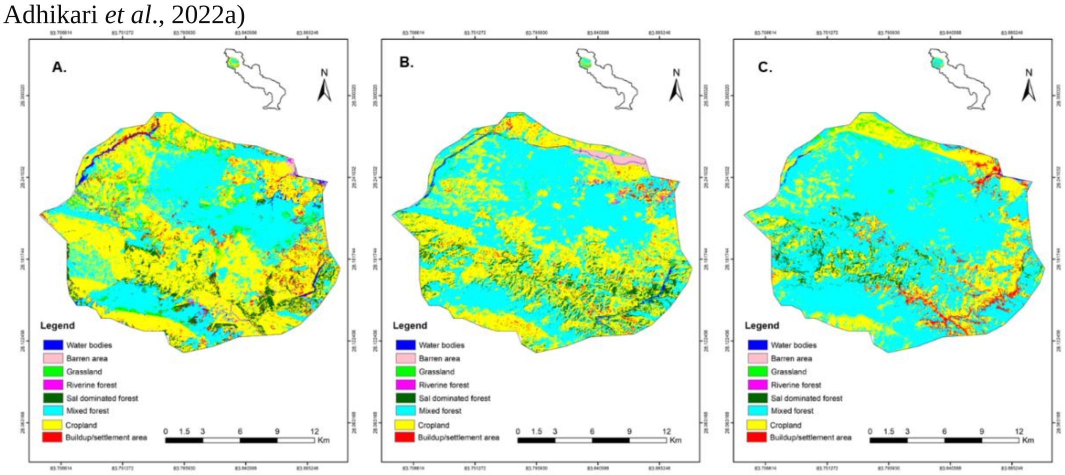


Figure 19: Land use and land cover dynamic in PPF and surrounding area A. 2000, B. 2010 and C. 2020 (Source: Adhikari *et al*., 2022a)

2.3.2.5. Lower (south-western) part of ACA

The mixed forest and buildup/settlements area increased by 14.93% and 166.66% respectively and cropland, barren area and grassland decreased by 40.97%, 24.09% and 19.94% respectively between 2000 to 2020 in lower part of ACA including Birethanti, Ghandruk, Landruk and Australian Camp area (Figures 20 and 21, Appendix V). Comparative analysis revealed that higher proportion of increment occurred in buildup/settlements area and mixed forest and higher reduction of croplands, barren area and grasslands between 2000 to 2010 than 2010 to 2020.

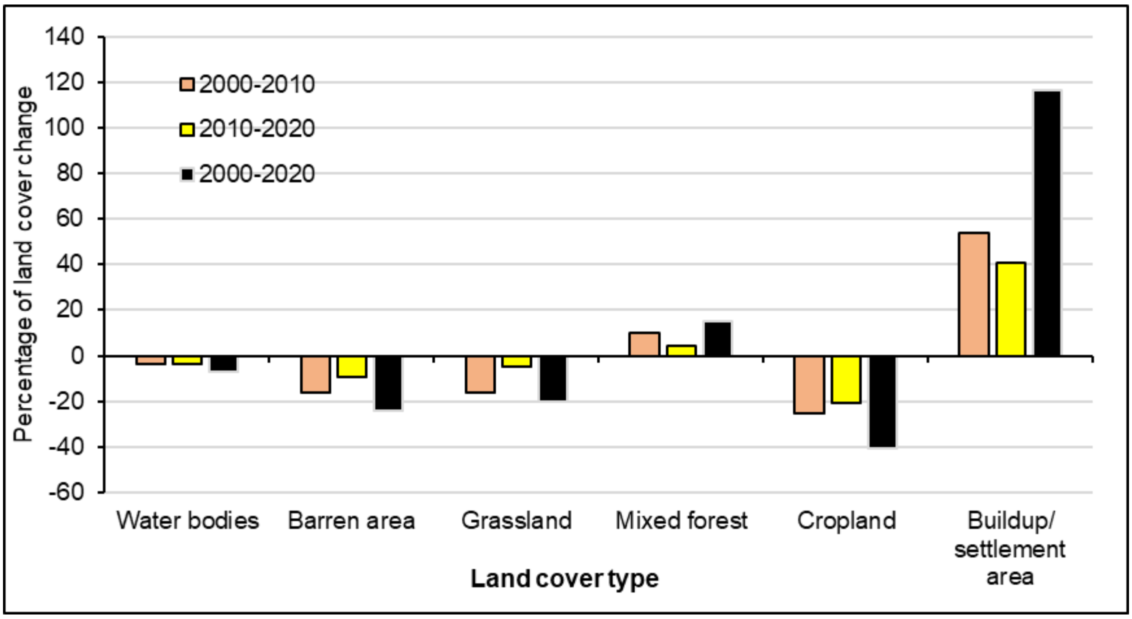


Figure 20: Percentage of land cover change in a lower south-western part of Annapurna Conservation Area from 2000 to 2020 (Source: Adhikari *et al*., 2022a)

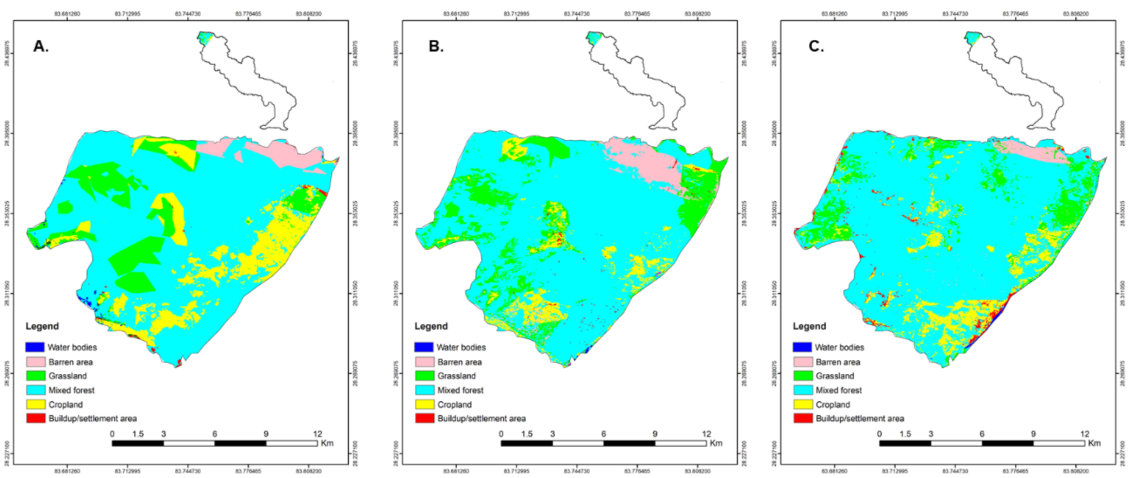


Figure 21: Land use and land cover dynamic in a lower south-western part of Annapurna Conservation Area A. 2000, B. 2010 and C. 2020 (Source: Adhikari et al., 2022a)

2.3.3. Accuracy assessment

The overall accuracy of classification of satellite images of 2000, 2010 and 2020 were >80% (Table 7). The user's accuracy ranged from 73.33% to 87.09% in 2000, 73.68% to 83.33% in 2010 and 80.26% to 90.69% in 2020. User's accuracy in barren land in 2000, in a buildup/settlement area in 2010 and in mixed forest in 2020 found comparatively lower whereas riverine forest in 2000, mixed forest in 2010 and Sal dominated forest in 2020 had the highest user accuracy (Table 7, Appendixes VI–VIII). The Kappa coefficient for the years 2000, 2010 and 2020 were 0.76, 0.79 and 0.82 respectively.

Table 7: Accuracy assessment of the classified images from 2000t to 2020 (Source: Adhikari *et al*., 2022a)

Land cover	**2000**		**2010**		**2020**	
	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy
Water bodies	81.81	90.00	76.92	76.92	90.00	81.18
Barren area	73.33	73.33	80.00	72.73	82.00	69.49
Grassland	78.37	80.50	75.00	80.00	80.95	76.11
Riverine forest	87.09	81.80	76.92	71.40	84.61	84.61
Sal dominated forest	84.21	80.00	83.11	80.00	90.69	95.90
Cropland	82.73	80.41	83.33	83.30	85.32	83.78
Buildup/settlements area	77.77	72.41	73.68	66.67	84.62	80.88
Mixed forest	78.43	83.30	83.77	86.95	80.26	89.70
Over all accuracy	81.00		81.60		84.77	
Kappa coefficient	0.76		0.79		0.82	

2.4. Discussion

Middle mountains are the most dynamic landscapes in Nepal. During last 50 years land cover changed drastic level because of urbanization and migration of people from rural to urban area and lowland Terai. Urbanization and migration have caused irregular land use/land cover dynamics. This study analyzed the spatial and temporal patterns of the land use/land cover change in the central part of Chitwan Annapurna Landscape, Nepal. The quantitative data revealed that there were irregular changes in the spatiotemporal patterns of land use/land cover classes in the study area.

Accuracy assessment results revealed that the land cover classification and changes have been assessed accurately for three different period confirmed by high overall accuracies and Kappa indices (Table 7). All the overall accuracies clearly exceed 80% and closely approached to the minimum standard of 85% stipulated by the USGS classification scheme (Anderson *et al*., 1976).

Land cover dynamics is the common phenomenon in the globe (Brown *et al.*, 2012; Lei *et al.*, 2017). Major factors, e.g., habitat fragmentation and loss, ecological succession, human activities, natural calamities habitat restoration and climate change caused LULCC (Turner, 1994, 2002). In a large and heterogenous area, different factors may become active in various areas that enhances spatial composition (Turner, 1994, 2002; Lei *et al.*, 2017).

This study categorized land cover of the central part of CHAL into eight different classes including four major forest types (e.g., Sal dominated forest, riverine forest, mixed forest and grassland). The tree species composition in the mid-hill is mixed type and highly heterogenous. Small portion of the landscape have different vegetation patterns and difficult to separate into categories, hence, classified as mixed forest. Sal dominated forest was highly abundant in BCF and part of Tanahun. The tropical and subtropical climate with high temperature and rainfall supports the Sal dominated forest (Reddy *et al.*, 2018; Adhikari *et al.*, 2019). Similarly, the floodplains of major rivers (e.g., Rapti, Narayani, Kaligandaki, Seti) support the riverine forest. Most of the area of the mid-hills are covered by the mixed forest. This analysis found that more than 62% of the total area was covered by forest (e.g., mixed forest, Sal dominated forest and riverine forest). Similar type of study in Nepal reported a total of 44.74% of total land is covered by forest, among them, mid-hill alone harbors 58% of the total forest cover (MoFE, 2018, 2019). But recent studies revealed 41.6% and 13.27% of the total land of Nepal is covered by forest and grassland respectively (FRTC, 2022). Comparatively, CHAL had higher forest cover. The river systems and the lakes found in this landscape are very important for maintaining the different ecosystems, therefore, CHAL is important for biodiversity conservation. However, this landscape is human-dominated and highly fragmented due to the scattered human settlements and croplands (WWF, 2013b).

The temporal patterns of the LULCC analysis revealed the land cover change between 2000 to 2020. Classified images clearly indicated a decrease in cropland and substantially increase in mixed forest in the central part of CHAL. The changes are the result of people migrating from the hills to the urbans in search of a better life and opportunities, as a result, the abandoned cropland and grazing areas were gradually converted into the forest area. Several studies have found an increase in forested area in the rural parts of hills and mountains. Bhandari *et al.* (2022a) reported forest coverage in Bhanu Municipality has increased from 36.57% to 40.91% and agricultural land decreased from 57.52% to 43.78% from 2000 to 2019. Similarly, Tripathi *et al.* (2020) reported forest increased from 52.59% to 61.28% and agriculture land decreased from 29.53% to 26.06% between 1991 to 2015 in Tanahun District. KC and Race (2019) reported that more than 63% of migrant people had been abandoned their agriculture land which is converted into the forest in Lamjung District of Nepal.

Growth of urban and semi urban areas from 2000 to 2020 in this landscape, proved the migration of the people from rural to urban areas. Similar type of pattern also found in the study of KC and Race (2019). The settlement density was higher in urban and plain areas in comparison to hilly areas (CBS, 2012). The rapid development of the roads, tracks and settlements in urban areas are the major factors to change urban landscape. Similarly, Tripathi *et al.* (2020) reported an increase in the barren area in Tanahun district between 1991 to 2015, but this study revealed the decrease in the barren and grassland area within the landscape because majority of these areas were replaced by the forest. The grassland on the high mountain (Panchase and part of ACA) was used by the local people as pasture as the similar reported in the study of Rai *et al.* (2018) in Gandaki River basin and Chetri and Gurung (2004) in Upper Mustang in central Nepal. Landslide, erosions and deposition of the rivers were the factors of land cover change in mid-hills and high mountains (Petley *et al.*, 2007; Budha *et al.*, 2020).

As seen in the Old Padampur area, the amount of forest within the protected areas (CNP and ACA) was also steadily growing. Cropland was converted into grassland and riverine forest following the resettlement of Padampur village (finished in 2004) to New Padampur and inclusion of it within the CNP (Dhakal *et al*., 2006). According to the analysis of land cover change, the amount of grassland in the Old Padampur area increased by more than 94% between 2000 and 2020. The Padampur settlement was moved to the New Padampur area by clearing the forest. As a result, in newly settled areas, cropland and buildup/settlement areas dramatically increased within 20 years. Similarly, the government's implementation of successful community forestry initiatives also led to an increase in the forest in the mid-hills. The results of this study were comparable to the studies conducted in Nepal's Kailash Sacred Landscape (Uddin *et al*., 2015a), Koshi River Basin (Rimal *et al*., 2019), and Mechinagar and Buddhasanti Landscape (Rijal *et al*., 2021a), but they were dissimilar from those from the Bagmati River Basin (Rijal *et al*., 2021b) as this river basin has urban areas with high population density. Regeneration of the forest inside the ACA increased in recent years. Due to low production, a scarcity of labors for agricultural activity, and a high level of human-wildlife conflict, people abandoned the marginal agricultural land; as a result, these regions were turned into forests. Similar findings were found in the investigations conducted in western Nepal by Bhandari *et al*. (2022a). My field studies revealed a similar pattern in Panchase and the neighboring districts, as residents left their productive land and migrated to the urban and semi urban area in search of a better living. As people migrated from the adjacent hills for a better quality of life, population density in the urban area (e.g., Vyas Municipality, Tanahun), increased significantly (86.55%) within 20 years. Similar increases in population were seen in the Pokhara valley from 1990 to 2013, and the Kathmandu valley between 1989 and 2016 (Ishtiaque *et al*., 2017).

According to the classified images of Nepal, 48.6% of the country's forest was lost between 1930 and 2014 (Reddy *et al*., 2018). But from 2005 to 2014, this loss was incredibly low (only 4 km^2 per year). From 2005 onwards, due to effective implementation of the community forestry programs by the government of Nepal have resulted in a decrease in the rate of deforestation (MoFSC, 2016). The Terai region has experienced significantly more forest loss in recent years as a result of development projects (Reddy *et al*., 2018). However, the CHAL area's (which covered 19 districts from Terai to high highlands) land cover change analysis between 1990 and 2010 revealed a 0.3% increase in forest area compared to a slightly decline in grassland area (WWF, 2013a). The forest in mid-hills of CHAL is increasing whereas cropland and grassland are decreasing. The land cover analysis in 2015 revealed that forests covered 48% of mid-hills, 62% of high mountains, and six percent of the high Himalayan area (MoFSC, 2015). In contrast, the mid-hills and high mountains' forest area was increasing while decreasing in croplands (MoFSC, 2015), which is similar to the findings of this study. The increasing of the forest is a sign of improvement wildlife habitats, especially for large mammals.

2. 5. Conclusions

The central part of the CHAL represent a typical mid-mountain landscape with various types of land cover and experiences dynamics of habitat degradation and regeneration at the same time. The land cover classes comprise of water bodies, barren area, grassland, riverine forest, Sal dominated forest, mixed forest, croplands, and buildup/settlements areas. The region is facing rapid changes in the land use land cover from development activities in urban and sub urban areas, and emigration of people from the rural areas to lowland and urban areas are major cause of land cover dynamics. Land cover change between 2000 and 2010 was higher in the CHAL. The temporal and spatial data on land cover provide the baseline information for the conservation of wildlife, landscape management, and sustainable development of the landscape which is useful to managers, planners, conservationists and the government.

CHAPTER 3

3. RELATIVE ABUNDANCE OF LARGE MAMMALS AND THEIR INTERACTIONS WITH PEOPLE IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL

Abstract

Large mammals face high risks of anthropogenic threats due to poaching and landscape change. Anthropogenic pressures have been most extensive in the mid-mountain ecosystem of Nepal. The human dominated landscapes connecting CNP and ACA are highly fragmented, but there is scare information available on the occurrence or abundance of mammalian species for monitoring purposes. This study evaluated the relative abundance of large mammals, factors affecting their occupancy and interaction with people. The abundance of large mammals along the habitat and disturbance gradients were determined by transect survey (n = 150) in four different blocks (A, B, C and D) and human wildlife conflicts was assessed by administering semi structure questionnaires (n = 600). The chital was the most abundant mammal in block A whereas muntjac was the most abundant in blocks B, C and D (ER = 0.34, 0.31, 0.79 respectively) but the relative abundance of rhesus macaque was comparatively higher in blocks B, C and D. Among the carnivores, tiger was recorded only in block A only whereas leopards in all blocks and the Himalayan black bear in blocks B, C and D. Habitat types, human disturbances and coverage of invasive and alien plant species were important factors affecting the abundance of large mammals. The encounter rate of the mammalian species was correlated with the level of conflicts. Rhino, wild pig and chital in lowland and monkeys, muntjac, and Himalayan black bear in mid-hills (blocks B, C and D) were the principal crop raider. The estimated average annual loss was US$ 86.62 per household. Degradation of grasslands by natural succession and invasive and alien plant species (IAPS); and human-wildlife conflicts always threaten the large mammals. The data generated by this study serve as a baseline for the researchers, conservationists, communities and concerned authorities to monitor the species and outline the research and conservation planning. The findings imply that the

threats, conflicts and IAPS threats to the habitats and population of large mammals should be highly considered when planning future conservation measures.

3.1. Introduction

The interrelations between wild animals and their environments in human-dominated landscape are the key factor in wildlife conservation. In these landscapes, both animals and human ecology are closely correlated (Schaller, 1967). Environmental factors such as habitat types, topographic features and human-wildlife interaction determine the occupancy, breeding success and survival of the animals (Laidlaw, 2000; Erb *et al.*, 2012; Oberosler *et al.*, 2017; Saisamorn *et al.*, 2019). The occupancy and abundance of the mammals are highly affected by the spatial heterogeneity than the size of the habitat (Báldi, 2008). Habitat fragmentation, loss and composition are major issues in spatial heterogeneity and affecting in a landscape that effect on the distribution and abundance of wild animals (M'Soka *et al.*, 2017; Acharya, 2018).

The habitat quality and quantity of availability of food for both prey and predators are the major determinants for their distribution and abundance (Chirima, 2009; Davis *et al.*, 2018). Large carnivores have more difficulty to obtain food comparing with herbivores due to their different predation patterns (Bubnicki *et al.*, 2019). Hence, habitat types and prey availability as well as topography, human disturbances (e.g., fodder, timber, firewood, medicinal plants collection and livestock pressure) are major determinates of their presence and abundance (Bhattarai & Kindlmann, 2012a; Kohl *et al.*, 2018; Adhikari *et al.*, 2021a). Biological invasion (e.g., Invasive and alien plant species IAPS) is another factor that alters species composition, reduce the vegetation diversity and threats the biodiversity (Davies, 2011; Bhatta *et al.*, 2020). Hence, the knowledge related to effects of IAPS on the abundance and distribution of the species is essential.

Human-wildlife interaction was common phenomena since ancient time where people and wildlife share the same landscapes and natural resources (Nyhus, 2016), but. it has been increased with increase in population of wildlife and human (Redpath *et al.*, 2015). Crop-raiding, livestock depredation, property damage and human casualties are the forms of conflicts resulting in huge monetary losses (Acharya *et al.*, 2016). Conflicts sometimes force the people to migrate from high conflict to low conflict areas (Acharya *et al.*, 2016; Baral *et al.*, 2021b). Animal husbandry and agriculture are the major occupation of most of the rural populations of developing countries (Cromsigt *et al.*, 2013). The leading factors of HWC are habitat loss, degradation and fragmentation through human activities (Acharya *et al.*, 2016; Mukeka *et al.*, 2019; Sharma *et al.*, 2021).

HWC is a common problem in majority of the PAs, protected forests, national forests and the community forests in Nepal (Adhikari *et al.*, 2018b; Baral *et al.*, 2021a; Bista & Song, 2021). On increasing the wildlife population in the forest, the trends of HWC also increases (Baral *et al.*, 2021a). The key wildlife species that governs HWC in the lowland of central Nepal (e.g., CNP and surrounding areas) are greater one-horned rhino, wild pig, Asian elephant and tiger (Dhungana *et al.*, 2016; Lamichhane *et al.*, 2018). Crop raiding by monkeys, northern red muntjac, wild pig, Himalayan black bear; livestock depredation by leopard and human injuries and casualties by leopard and Himalayan black bear are common form of HWC in mid-hills of Nepal (Dhungana *et al.*, 2016; Adhikari *et al.*, 2018b).

Knowledge of species distributions along with, environmental correlates such as habitat types and disturbances gradients could help to conserve the mammals in such areas (Rodrigues *et al.*, 2006; Pal *et al.*, 2020). Most of the research on abundance of large mammals and their interaction with people in this landscape focused either in CNP (Thapa, 2011; Bhattarai & Kindlmann, 2012a; Kafley *et al.*, 2016; Dhungana *et al.*, 2018) or in ACA (Singh *et al.*, 2018; Chetri *et al.*, 2019). Hence, this study aimed to (i) evaluate the relative abundance of mammals, (ii) analyze the abundance of mammals across habitat types, disturbance gradients and relation of mammals with IAPS cover, (iii) explore interaction of large mammals with people in the human-dominated mid-hill landscape between CNP and ACA.

3.2. Methods

3.2.1. Study area

The CHAL extends to the six protected areas including CNP and ACA and 19 districts of central Nepal. Hydrologically, CHAL is drained by eight rivers including Kali Gandaki, Seti, Madi, Marshyandi, Trishuli and Rapti. The intensive study area extends between CNP and ACA covering 2749.48 km^2 and includes Chitwan (around BCF and surrounding areas), Tanahun (Seti River Basin), Kaski and parts of Syangja and Parbat districts (Panchase and part of ACA) (Figure 22) within elevation ranges from 150 to 3300 m. The lowland of area has tropical and subtropical climate followed by temperate subalpine climate in mid-hills and in high mountain areas respectively.

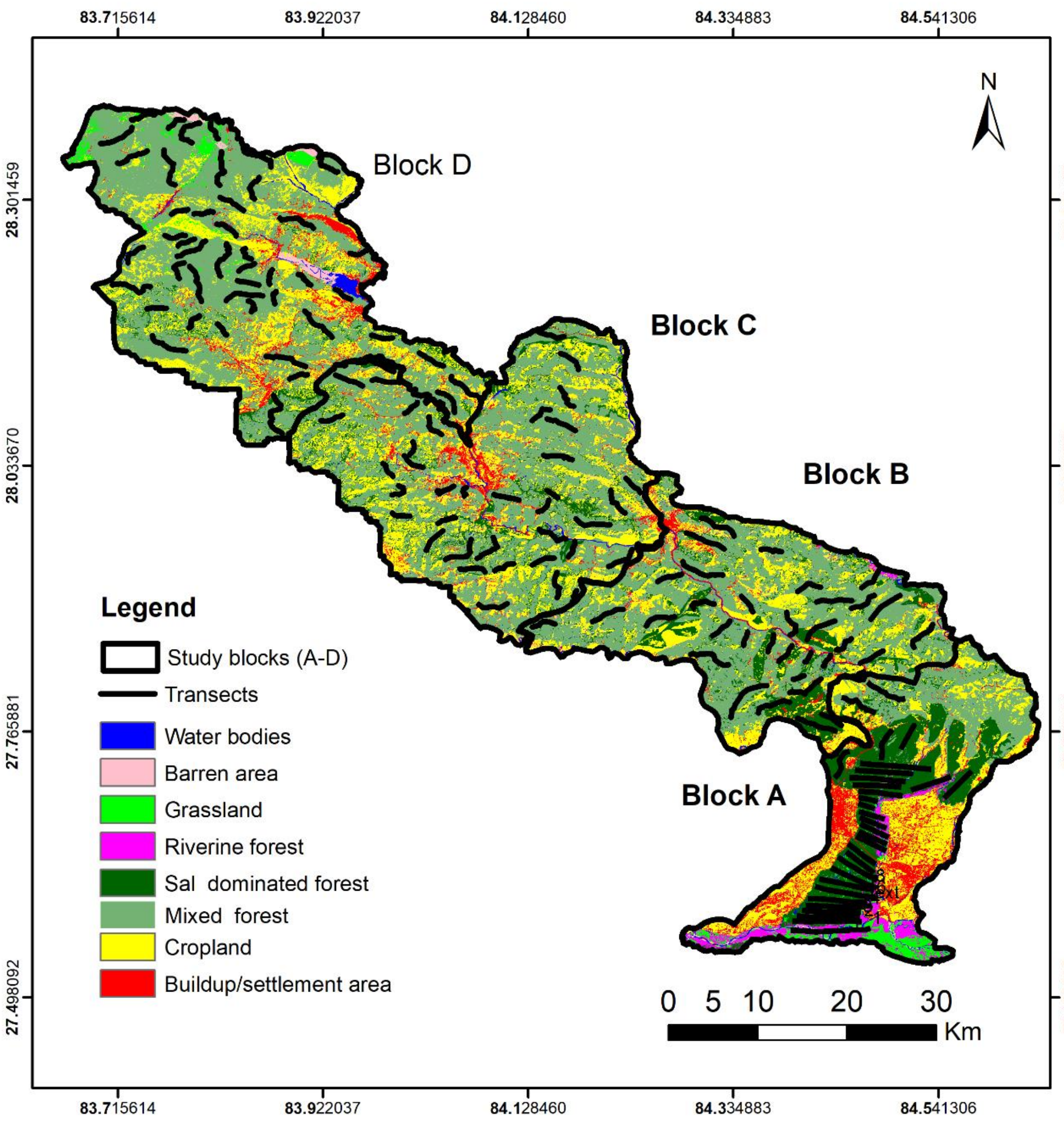


Figure 22: Design of study blocks and transects for the survey of mammals in CHAL

3.2.2. Research design

The study area was divided into four different blocks A, B, C and D based on the landscape characteristics, the major rivers courses and topography (Figure 22). The size and the length of the transects were based on size of the forest patches. First of all, the forest patches were identified using a base map/topographic map and then transects were overlaid on the base map designed. Among the designated 164 transects, only 150 transects (31 in block A, 35 in block B, 38 in block C and 46 in block D) were surveyed

(Figure 22, Appendix X). Rest of the transect (n = 14) were avoided for data collection because these were located in the inaccessible areas including deep river gorge, steep mountains, and swampy lands. The length of the transects ranged from 1.18 to 7.84 km (Appendix X). The distance between the two transects was maintained at least 500 m apart.

3.2.3. Data collection

Relative abundance data on the large mammals (body weight >5 kg) were collected by distance sampling (Wegge & Storaas, 2009, Millar *et al*., 2013, Buckland *et al*., 2015) and sign surveys (McDougal, 1999; Shrestha, 2004; Steinmetz *et al.*, 2013; MacKenzie *et al*., 2017) along the transect. Distance sampling is an appropriate method for the estimation of density and abundance of the biological population (Buckland *et al*., 2015). The relative abundance of the prey (ungulates and monkeys) was determined by the direct sighting method (Wegge & Storaas, 2009) and abundance of carnivores (tiger, leopard and Himalayan black bear), since the signs left by the animals are reliable indicators of occupancy in an area (McDougal, 1999; Shrestha, 2004; Steinmetz *et al.*, 2013).

The field surveys were carried out from November 2017 to December 2020. The mammals (direct sighting and signs) were surveyed between 06 to 10 AM and 03 to 06 PM, when mammals are relatively active. The data collection was done every 100 m, a brief stop was made to minimize the background noise and to collect the environmental correlates.

For each encounter of mammals, the sighting angle and the distance from observer to mammals were recorded by using the rangefinder (Bushnell, 7X with 500 m range). The ungulates and primates were counted through visual encounter using binoculars (Nikon, 20×50, Bushnell 8×20).

The signs of carnivores (tiger, leopard and Himalayan black bear) such as pugmarks, tracks, scat, scratch, and scrap marks were noted on five meter the either side of the transects at the interval of 100 m distance along the transects (Figure 23, Appendix XI).

The habitat types were determined on the basis of physiognomy and the dominant tree species. The environmental factors such as habitat types, canopy cover, coverage of IAPS and human disturbance indicators (i.e., number of livestock, number of cut lobed tree, medicinal plant collection, timber collection, fodder collection, fishing activities etc.) were documented within the quadrates of 10 × 10 m^2 at the interval of 100 m along the transects. Different information (habitat types, canopy cover, IAPS cover, human disturbance factors etc.) were reported from transect based sampling points (Table 8, Appendix XII).

Mammals	**Pugmark**	**Scat**	**Scrap/scratch marks**
Tiger			
Leopard			
Himalayan black bear			

Figure 23: Signs of tiger, leopard and Himalayan black bear reported during field study in CHAL

The canopy cover was evaluated by visual estimation categorized as dense: >50%, moderately dense: 20–50% and open: <20%. Similarly, IAPS cover was evaluated through visual estimation and categorized into the five categories as no invasions, very low invasion (<20%), moderate invasion (20 to 40%), high invasion (40 to 60%), very high invasions (>60%). The human disturbance status (HDS) was calculated on the basis of the disturbance parameters reported. All the disturbance parameters (Table 8) combined and categorized as 1, 2, 3, 4 or 5 indicating very low (<5), low, moderate (5–10), high (10–20) or very high (>20) disturbance respectively.

Table 8: Variables recorded during field study and codes used during analysis (Source: Adhikari *et al.* 2021a)

SN	Variables	Description and codes used in analysis
1	Mammals	a. Ungulates: chital (CH), sambar (SD), northern red muntjac (MJ), hog deer (HD), wild pig (WP), greater one-horned rhino (RH), Himalayan goral (GH)
		b. Primates: Langur (CL), rhesus (RH),
		c. Signs of carnivores: tiger (Tig), leopard (LP) and Himalayan black bear (BB)
2	Environmental variables	a. Habitats types: Sal dominated forest (SF), riverine forest (RF), grassland (GL), and mixed forest (MF)
		b. Forest cover: dense (Den) or moderately dense (MD) or open (Opn)
		c. Dominant IAPS species: *Mikania micrantha* (Mika), *Chromolaena odorata* (Chro), *Lantana camara* (Lant), *Parthenium hysterophorus* (Part) and *Ageratina adenophora* (Agir). IAPS cover: no invasions (NOI), very low invasion (LWI), moderate invasion (MI), high invasion (HI), very high invasions (VHI).
3	Disturbance variables (anthropogenic)	a. Number of the people observed inside the forest
		b. Number of lopped and logged trees and sites used for harvesting grass, fire wood and timbers
		c. Number of livestock present
		Human disturbance status (HDS): very low disturbance (VLD), low (LD), moderate (MD), high (HD) or very high (VHD) respectively.

The conflict data were collected from the nearby area of the animal sampling so that easy to judge the relation of the relative abundance of the animals with HWC. The sample size was determined by using the following equation (equation 5, Appendix XIII) (Hulley, 2007; Taherdoost, 2017).

$$n = \frac{z^2 p\,(1-p)}{d^2} \qquad (5)$$

Here, n = sample size,

z = Level of confidence at standard normal distribution (for a level of confidence of 95%, z = 1.96),

p = Estimated proportion of the population that represented the probability of characteristic (for unknown population p = 0.5),

d = Tolerated margin of error.

Respondents (n = 600, 150 from each block) were asked the semi-structured questionnaires related to crop damage, livestock depredation and human casualty and injury prepared in Nepali language (Appendix XIV). The respondents were selected based on stratified random sampling. The age, sex, ethnicity, and education of the respondents was considered during the selection of the respondents for questionnaires (Appendix XV).

The selected households were categorized into three groups on the basis of their proximity to the edges of the forest such as close (<0.5 km), medium (0.5–1 km) and far (1–1.5 km). Oral consent of respondent was taken prior to starting the questionnaires surveys. Generally, head of the house was chosen as the respondent but in the absence of the head, next member was chosen. The focal group discussion, informal interview, and key informant interview (social workers, teachers, members of community forest) were organized to gather quantitative information on HWC. Information HWC were collected from the park office, division forest offices, field staffs and community leaders.

3.2.4. Data analysis

Data collected from transect surveys were analyzed using Program DISTANCE 7.4 Release, 1 (Thomas *et al*., 2010) in case of number of group detections was adequate for particular block. The Conventional distance sampling (CDS) method with half-normal model (Buckland *et al*., 2015) was run to estimate of density (D)/km^2, cluster density (DS)/km^2, the expected value of cluster size (E(S)), and encounter rate (ER)/km for large mammal species. The standard errors, Monte Carlo confidence intervals of densities, the criterion of a minimum Akaike's Information Criterion (AIC), and chi-square goodness of fit were used to evaluate the analysis.

In the case of, lower number of detection (<30) of species distance sampling is not appropriate (Pérez *et al.*, 2015). Therefore, separate analysis was performed using relative abundance (Equation 6) and encounter rate of mammals (Equation 7).

$$\text{Relative abundance (RA)} = \frac{\text{Isi}}{\sum \text{Nsi}} \times 100 \quad (6)$$

Here, Isi = Total number of individuals of a species;

$\sum$ Nsi = Total population of species.

The encounter rate of the mammals was calculated by dividing the total number of a individuals encountered (n) by the total length of the transects (L). The signs of the carnivores such as tiger, leopard and Himalayan black bear were analyzed as sign encounter rate (Equation 7).

$$\text{Encounter rate (ER)} = \frac{\text{n}}{\text{L}} \quad (7)$$

The Detrended Correspondence Analysis (DCA) of species was performed before judging the appropriate test (Correa-Metrio *et al.*, 2014) to test the relation with the disturbance gradients, habitat types and coverage of IAPS. When the gradient length in DCA analysis was more than three, Canonical Correspondence Analysis (CCA) was used to elucidate the relationships between the species with their environmental correlates. Redundancy Analysis (RDA) was applied when the gradient length in DCA was less than three. The program CANOCO v. 4.56 (Ter Braak & Smilauer, 2012) was used to analyze DCA, CCA and RDA. In this analysis, the results are presented in a biplot (MacFaden & Capen, 2002). CCA and RDA support comparing the complex relationship between species and the environment. A Monte-Carlo permutation test (using 499 unrestricted permutations under the reduced model) was applied to detect relationship between the environmental factors and distribution of the species.

The total loss of a crop was multiplied by the crop's unit farm-get price to determine the monetary value of the total crop damage. By computing the average price reported by the district agricultural office and the local market price, the farm-get price of the various crops was established (Appendix XVI).

By computing the mean price of the district veterinary office and the local market price, the price rate of livestock was estimated. The rate of the livestock is fixed according to their age and sex (Appendix XVII). The package «pscl» was used in R software version 4.0.0 (R Core Team, 2020) for generalized linear model (GLM) (Jackman, 2020) to calculate coefficient, standard error, and p-value at 95% confidence level for all relationships between crop damage and livestock depredation with different variables such as distance to forest, distance to the farm from the house, livestock holding and land holding capacity.

The conflict hotspot mapped using geographical coordinates of the place of the interview recorded. The Inverse Distance Weighted (IDW) algorithm (Hengl, 2009) in ArcGIS 10.8 was used to interpolate values of expected conflict hotspots based on total monetary loss by crop damage and livestock depredation. IDW algorithm method of interpolation was used to evaluate the values of target variables at a new location. The weightage of the points closer to the predicted location have greater than the farther (Huang *et al.*, 2011). The conflict areas were categorized as very low, low, moderate, high and very high on the basis of monetary loss by the respondents.

3.3. Results

3.3.1. Abundance of mammals

A total of 477.77 km distance was walked along 150 transects ranges from 1.18 to 7.84 km and reported the occurrence of 18 species of mammals (Appendix IX). Among them, encounter of golden jackal, jungle cat, sloth bear, large Indian civet, Asian elephant, Assam macaque was <5, hence, excluded. Three carnivores (tiger, leopard and Himalayan black bear), one mega herbivore (greater one-horned rhino), two primates (rhesus and langur) and six ungulates (hog deer, northern red muntjac, chital, sambar, wild pig and Himalayan goral) were selected for the further analysis (Figure 24).

In block A, this study recorded seven groups comprising 20 individuals of hog deer (ER = 0.05), 12 groups with 16 individuals of rhino (ER = 0.08) and 15 groups with 231 individuals of langurs (ER = 0.11). The chital was the highest abundant (ER = 1.49) followed by wild pig (ER= 0.623), northern red muntjac (ER = 0.624), sambar (ER = 0.384) and rhesus macaque (ER = 0.28) (Table 9, Figure 24).

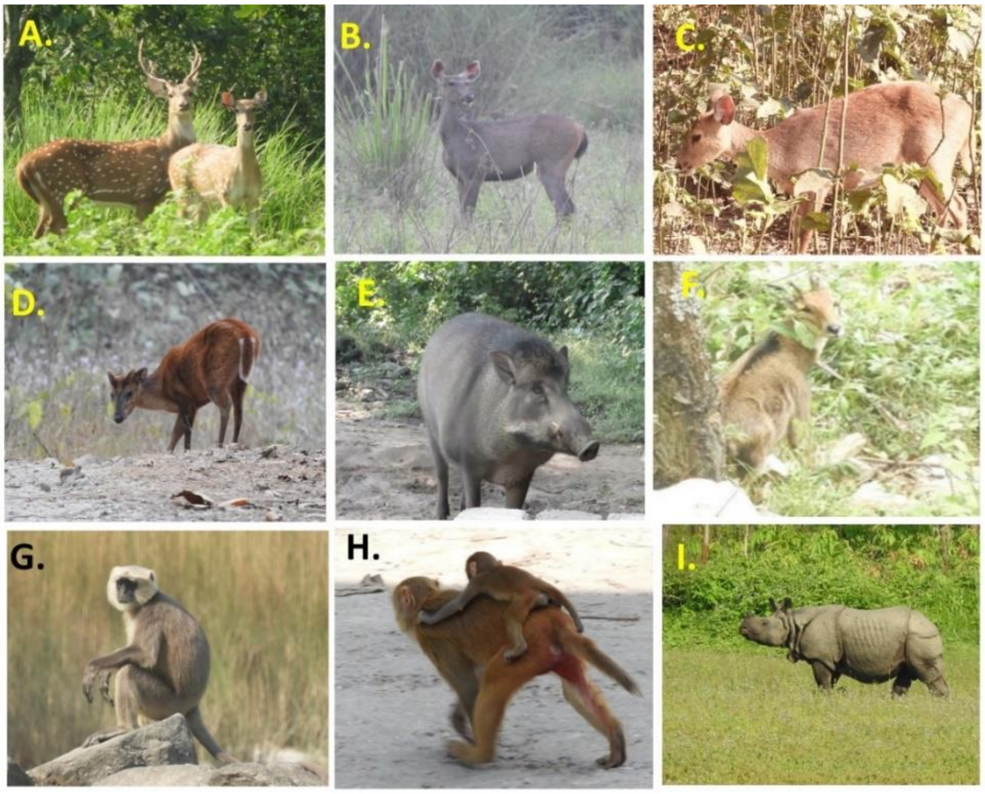


Figure 24: A. Chital, B. Sambar, C. Hog deer, D. Northern red muntjac, E. Wild pig, F. Himalayan goral (male), G. Langur monkey, H. Female rhesus macaque with infant, I. Greater one-horned rhino (Source: Adhikari *et al.* 2021b)

Table 9: Estimated prey density in block A. (Here, HN - half normal, AIC - Akaike's information criterion values, Ni - number of individuals, Ng - number of groups, Ds - density of estimate of clusters, SE - standard error, 95% CI(Ds) - 95% confidence interval of D, ES - estimate of expected value of cluster size, 95% Cl (ES) - 95% confidence interval of ES, ER - encounter rate, GOF-p - P values of chi-square goodness of fit) (Source: Adhikari *et al.* 2021b)

Parameter	Chital	Sambar	Muntajc	Wild pig	Rhesus
Model	HN	HN	HN	HN	HN
Cosines	2,3	2,3	2	2	2
AIC	1934.50	445.54	847.64	965.93	282.58
Ni	2301	99	147	425	532
Ng	219	50	101	108	32
Ds±SE	8.71±1.96	2.93±1.24	6.69±1.39	4.87±1.10	2.48±0.99
95%CI(Ds)	5.52–14.16	1.30–6.60	5,29–9.46	3.12–7.58	1.13–5.44
D±SE	83.86±19.14	5.39±2.32	9.66±2.95	14.81±3.57	38.89±16.01
95%Cl(D)	52.79–136.98	2.36–12.274	7.56–3.84	9.26–23.69	17.49–86.48
ES±SE	9.63±0.38	1.84±0.13	1.44±0.06	3.04±0.25	15.71±1.29
95% Cl (ES)	8.89–10.39	1.58–2.13	1.32–1.57	2.58–3.58	13.2718.58
Mean cluster size	10.51±0.46	1.98±0.15	1.46±0.03	3.94±0.36	16.63±1.62
Component of % of variances of ER	38.10	15.90	32.50	23.20	11.90
ER	1.49	0.384	0.624	0.623	0.28
Chi_value	45.16	18.09	20.08	33.13	13.11
GOF-p	0.0001	0.001	0.028	0.0005	0.004

The abundance of rhesus macaque and langur was higher than other mammals in blocks B, C and D. The abundance of wild pig and Himalayan goral were comparatively lower than other species (Table 10). The occurrence of chital in block B was recorded only from Devghat area. The relative abundance of the mammals was comparatively lower in block C (Table 10). The encounter rate of the wild pig in block D was lower than in other blocks B and C, but the encounter rate of the goral was higher in block D than in other blocks (B and C).

Table 10: Relative abundance of prey in block B, C and D. (Here, Ni- number of individuals, Ng- number of groups, RA (%)- relative abundance, ER/km- encounter rate of a species per km)

Block	Parameter	Chital	Wild pig	Goral	Rhesus	Langur	Muntjac
B	Ni	13	20	24	336	163	50
	Ng	3	14	10	15	12	35
	Mean cluster size (CS)	6.33±0.33	1.42±0.35	2.4±0.42	22.4±1.29	13.58±2.43	1.48±0.11
	RA (%)	2.15	3.30	3.96	55.44	26.89	8.25
	ER/km	0.03	0.14	0.09	0.14	0.12	0.34
C	Ni	0	12	12	154	108	39
	Ng	0	8	8	9	7	30
	Mean cluster size (CS)	0	1.5±0.19	1.5±0.18	17.11±1.67	15.43±0.84	1.3±0.09
	RA (%)	0	3.69	3.69	47.38	33.23	12.00
	ER/km	0	0.08	0.08	0.09	0.07	0.31
D	Ni	0	13	63	515	229	146
	Ng	0	9	35	31	15	109
	Mean cluster size	0	1.44±0.17	1.8±0.09	17.16±0.8	15.26±1.58	1.37±0.04
	RA	0	1.35	6.52	53.31	23.70	15.11
	ER/km	0	0.06	0.25	0.23	0.11	0.79

The estimated sign encounter rate of tiger and leopard in block A was 0.44 and 0.51 respectively. Similarly, sign encounter rate of the leopard and Himalayan black bear was 0.55 and 0.05 in block B, 0.39 and 0.08 in block C; and 0.89 and 0.27 in block D respectively (Figure 25).

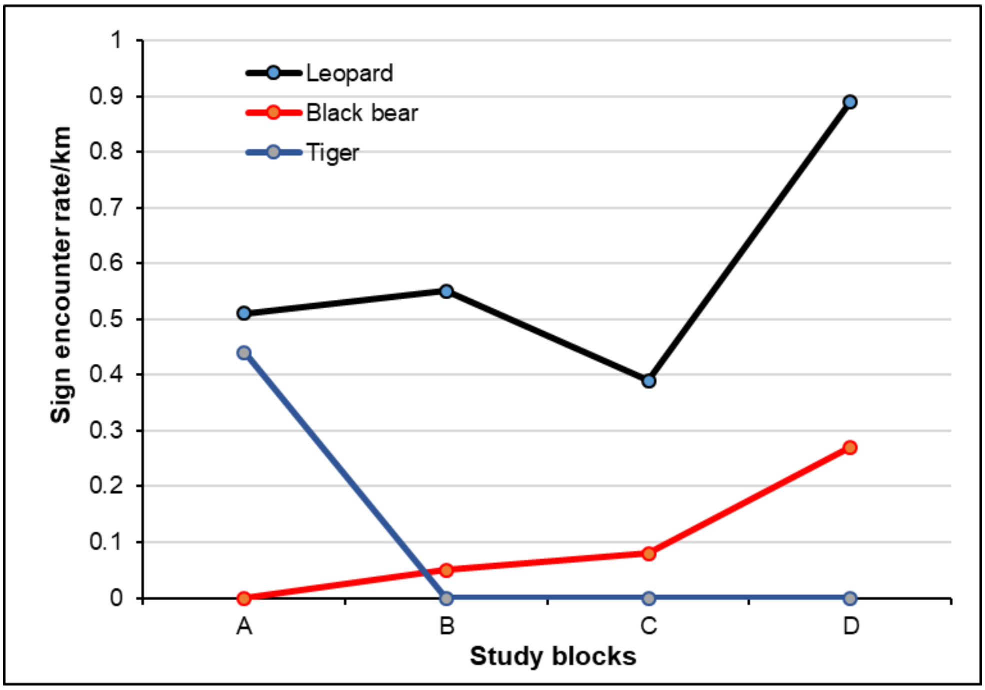


Figure 25: Sign encounter rate of carnivores found in study blocks (A–D)

3.3.2. Abundance of mammals across different habitats

The CCA ordination biplot diagram of different species of mammals recorded in block A and habitat types revealed that the abundance of hog deer, chital and rhino was significantly associated with open area grasslands of Rapti and Budi Rapti floodplains and grass patches scattered inside the forest. Chital was highly associated with grasslands (Figure 26A), but in block B, chital was observed in Sal dominated forest (Figure 26B). Northern red muntjac was a closely associated with a riverine forest in block A, mixed forest in block B, C and D (Figures 26A–C). The sambars were associated in the dense Sal Forest in block A only (Figure 26A). Wild pigs were associated with different types of habitats present in all blocks (Figures 26A–D). The abundance of langur was high in the dense and moderately dense riverine, mixed and Sal dominated forests, whereas rhesus macaque was associated in all types of the forest area, especially the mixed forests (Figures 26A–D). The open grass patches of the mid-hills (block B and C) and high-hills (block D) supported the Himalayan goral (Figures 26B–D). The signs of tiger and leopards were mostly recorded in grassland and grass patches scatted in the Sal and mixed forest in block A but the signs of leopard were also reported from the dense mixed forest of block B, all type of habitats of block C and moderately dense forest of block D. The sign of the Himalayan black bear was also observed in different habitats found in blocks B–D (Figures 26B–D).

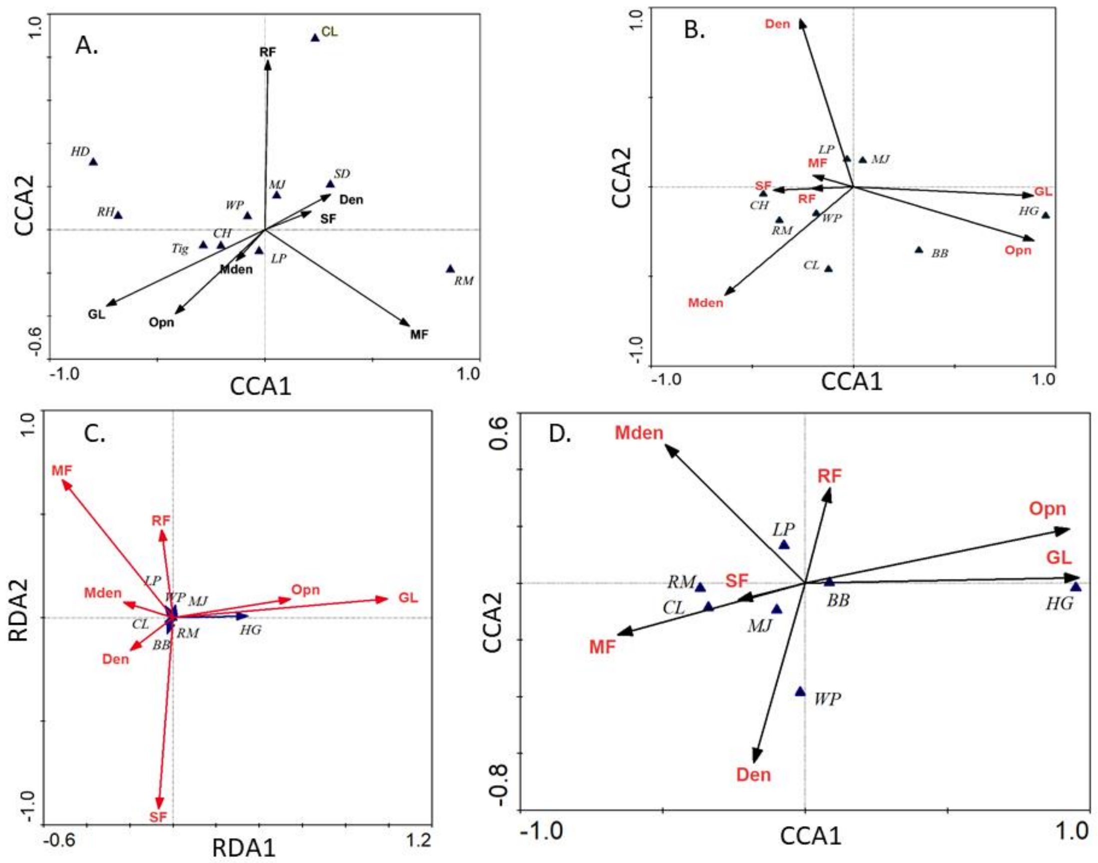


Figure 26: Ordination diagrams (biplot) showing species response to different habitats (CCA, for blocks A, B and D and RDA for block C). Monte-Carlo permutation test of significance of all canonical axes with 499 permutations under reduced model. A- Trace = 0.238, F = 2.98, p = 0.002 The first axis accounts for 58.3% and the second axis 24.3% of the variability. B- Trace = 0.43, F = 1.88, p = 0.004. The first axis accounts for 47.7% and the second axis 23.5% of the variability, C-Trace = 0.58, F = 2.25, p = 0.002. The first axis accounts for 77.2% and the second axis 16.9% of the variability, D-Trace = 0.28, F = 3.49, p = 0.002. The first axis accounts for 76.6% and the second axis 9% of the variability (Adopted from Adhikari *et al*. 2021b)

3.3.3. Abundance of mammals along disturbance gradient

The CCA result revealed the rhesus macaque had close association with highly disturbed and disturbed areas whereas the langur a close relation with moderately and less disturbed areas in all blocks (Figures 27A–D). Similarly, hog deer, sambar deer, chital, wild pig and muntjac significantly associated with very low, low, and moderately disturbed habitats in block A. Likewise, wild pigs were associated with disturbed area of block B, low and moderately disturbed area in block C and D (Figures 27B–D). The signs of the tiger have mostly been recorded from the moderately and less disturbed habitats and leopard from less disturbed area in block A. Similar type of pattern of distribution of the leopard was also seen in entire landscape (Figures 27A–D).

Himalayan gorals and Himalayan black bears were reported from the less disturbed habitats of blocks B–D (Figures 27B–D).

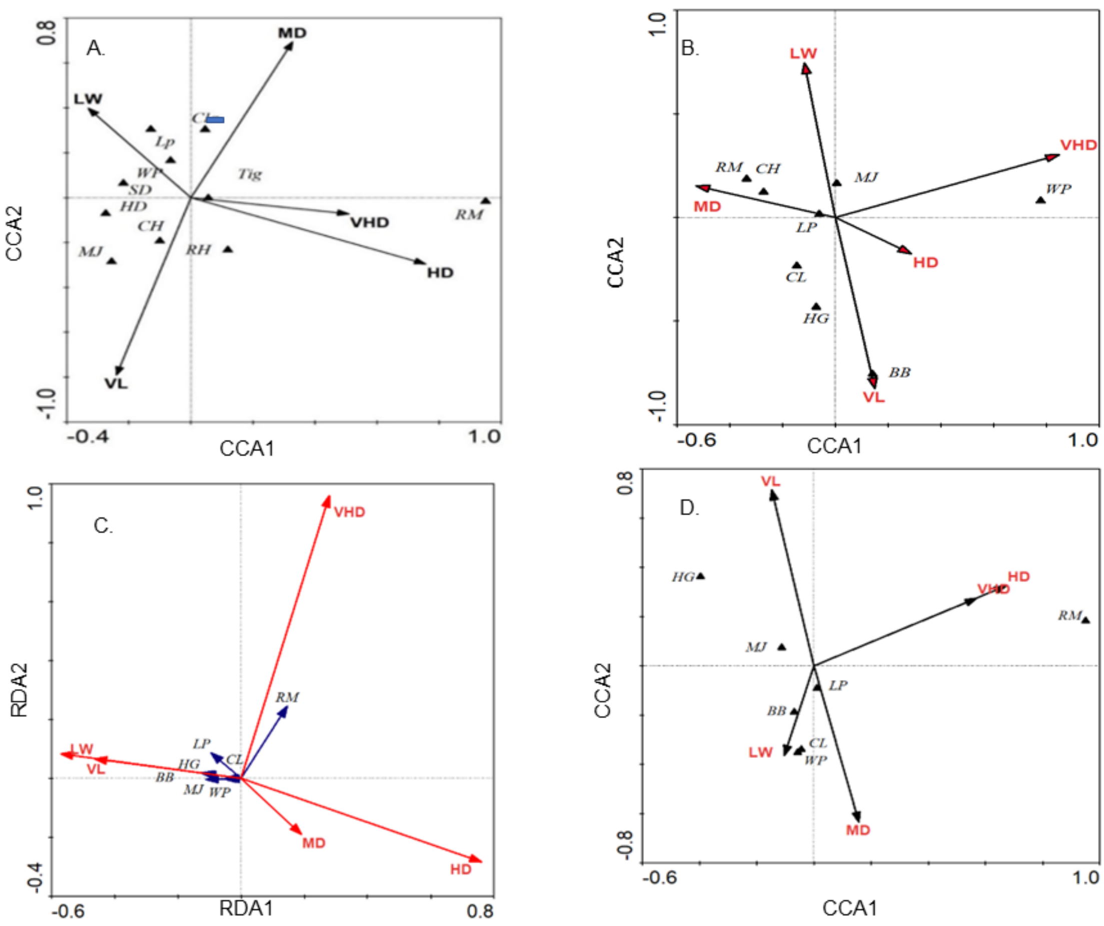


Figure 27: Ordination diagrams (biplot) showing species response with different levels of habitat disturbance status (CCA for block A, B and D and RDA for block C). Monte-Carlo permutation test with 499 permutations and significance of all canonical axes. A- Trace= 0.092, F= 8.378, p = 0.002. The first axis accounts for 84.6% and the second axis 10.2% of the variability. B- Trace = 0.135, F = 1.07, p = 0.09. The first axis accounts for 54.2% and the second axis 34.4% of the variability, C-Trace = 0.014, F = 1.563, p = 0.066. The first axis accounts for 71% and the second axis 21.1% of the variability, D-Trace = 0.258, F = 3.197, p =0.002. The first axis accounts for 72.3% and the second axis 23.9% of the variability (Adopted from Adhikari *et al*. 2021b)

3.3.4. Relationship between IAPS and large mammals

The *Mikania micrantha*, *Chromolaena odorata*, *Lantana camara and Parthenium hysterophorus* in block A, *M. micrantha*, *C. odorata*, *L. camara* and *P. hysterophorus*, *Ageratina adenophora* in block B, *C. odorata*, *L. camara* and *A. adenophora* in block C and D were the highly invaded IAPS. The abundance of the mammals was comparatively low in areas with the high IAPS cover. IAPS greatly affected the distribution of herbivores than monkeys and carnivores (Figure 28). This analysis showed that wild ungulates had the negative association with most of the IAPS ($F = 2.126$, $p = 0.002$) in block A. Here, Chital were comparatively low reported in IAPS covered area but rhino and wild pig were also found in *M. micrantha* covering habitats (Figure 28A). Similarly, sambar and leopard were reported from the *C. odorata* and *L. camara* invaded areas (Figure 28A). The relation of the IAPS and the mammals in block B was not significant, but they avoided the highly invaded area. In block C, the mammals were associated with no IAPS invaded and very low invaded areas ($F = 1.563$, $p = 0.05$). Likewise, in block D, the relation of IAPS and the mammals was not significant but Himalayan goral, langur and Himalayan black bear showed the association with no IAPS areas (Figures 28B-D).

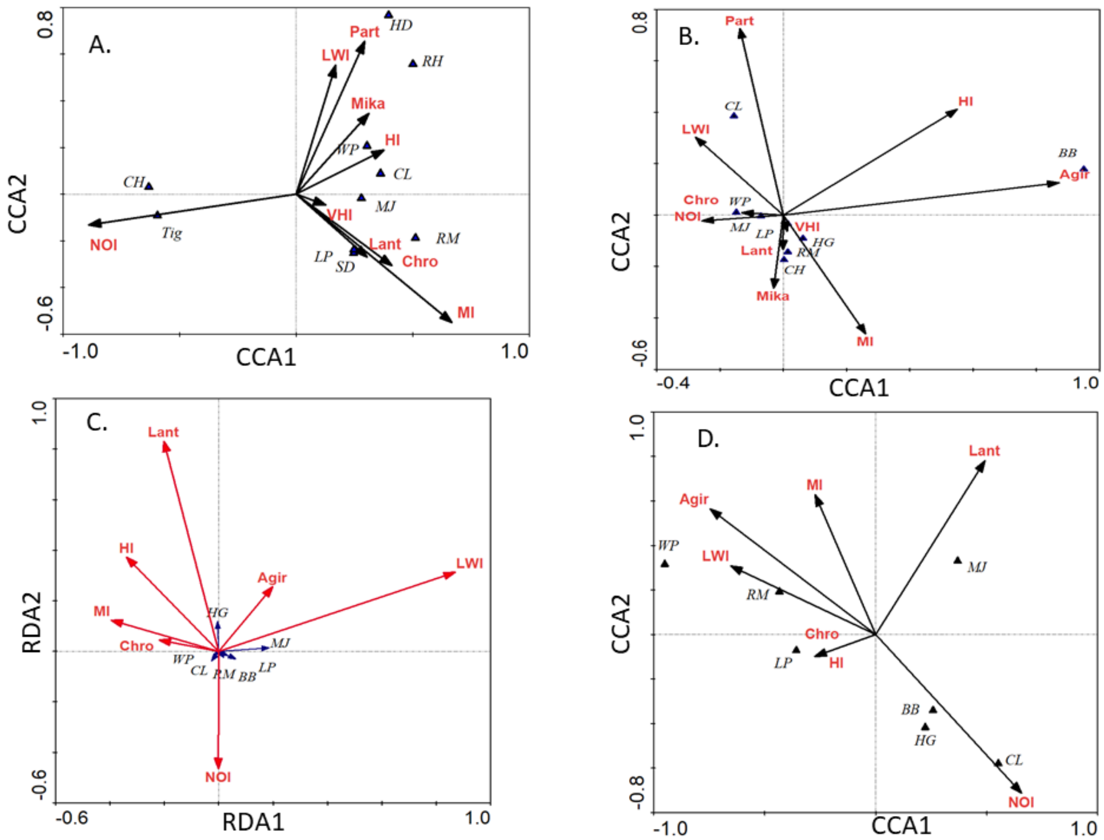


Figure 28: Ordination diagrams (biplot) showing species response with coverage of IAPS (CCA for block A, B and D and RDA for block C). Monte-Carlo permutation test with 499 permutations and significance of all canonical axes. A- Trace= 0.307, F= 2.126, p = 0.002. The first axis accounts for 65.2% and the second axis 12.2% of the variability. B- Trace = 0.51, F = 1.380, p = 0.142. The first axis accounts for 48% and the second axis 22.4% of the variability, C-Trace = 0.014, F = 1.563, p = 0.05. The first axis accounts for 78.3% and the second axis 11.6% of the variability, D-Trace = 0.065, F = 0.773, p =0.65. The first axis accounts for 49.8% and the second axis 28% of the variability (Adopted from Adhikari *et al*. 2021b)

3.3.5 Human-mammal interaction

Crop damage, livestock depredation, and human death and injury were major form of human wildlife conflict found in this landscape.

3.3.5.1. Crop damage

Respondents (n = 600, 150 from each block) reported rhino, chital, muntjac, monkeys and wild pigs were involved in crop damage in block A, whereas muntjac, monkeys, wild pigs and Himalayan black bears in blocks B–D (Figures 29A–C). The maize was the main crop damaged by ungulates, monkeys and Himalayan black bear contributed maximum crop loss (Figure 29). But in block A, the crop damage by rhino was higher than other mammals (Figure 29A). The maize was the main target crop than others (Figure 29B). The crop damage per household was significantly higher in block D followed by blocks A, B and C (χ^2 = 1378.4, p = 0.0001) (Table 11). As increasing the encounter rate of the mammals, the rate of crop damage also increased except in block A. The encounter rate of crop raider mammals was higher in block A, but the crop damage was comparatively lower than other blocks (B and D, Table 11).

Figure 29: Evidences of crop damage and livestock depredation by large mammals. A. Crop damage by Rhino, Ghatghain area, B. Crop damage by rhesus macaque, in Tanahun, C. Crop damage by rhino, in Baderni area, D. livestock depredation- goat killed by leopard in Rumsi, Tanahun, E. Cow killed by leopard, in Panchase area, F. Goat injured by the attack of leopard in Gaurigan area

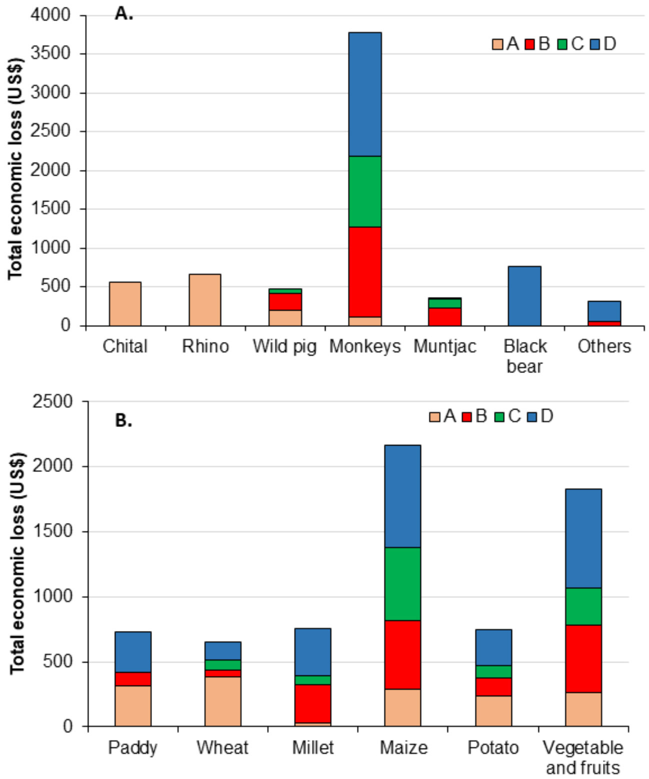


Figure 30: Crop damage by large mammals in CHAL. A. crop damage by different mammals B. damage based on crop types

Table 11: Relation between the encounter rate of the mammals (crop depredators) per km and monetary loss in US$ per household. (Here, ER= encounter rate of mammals and, 1US$ = NPR 119, exchange date 19th March 2020)

Block	ER/km	Monetary loss (US$)/HH
A	3.63	10.11
B	0.86	8.66
C	0.63	7.18
D	1.44	22.15

The monetary loss due to crop damage was significantly in area close to the forest than an area far from the forest. Similarly, the monetary loss through crop damage was significantly higher in the farms far from houses of respondents. The land holding of the respondents also showed a positive response toward crop damage (Table 12).

Table 12: Generalized Linear Model showing the relation of crop damage with different variables

Category	Estimate (β)	Std. Error	z value	p-value	Significance
(Intercept)	-1.31	0.44	-2.97	0.003	**
Distance to forest	-0.0005	0.0003	-2.04	0.04	*
Distance to farm	0.01	0.0012	11.59	<0.0001	***
Land holding (m^2)	0.00006	0.00002	2.62	0.008	**

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.3.5.2. Livestock depredation

Respondent reported that calves of the cows, young buffalo, goats and sheep were killed by the predators (Figures 29 D–F). Tiger and leopard are the major predators on lowland (block A) whereas leopards in mid-hill and high-hills (blocks B–D). A total of 263 cases were reported during 2019 in this study. Among them, block D had the highest cases (n =110) followed by block B (n = 80), C (n = 44) and A (n = 29) (Figure 31). Among the domestic animal goat and sheep killed in highest number (66.54%) followed by ox/cow (15.96%), buffalo (9.88%), dog (6.08%) and pig (1.5%) (Figure 31). The highest number of goats were killed in block B (n = 72) compared to other blocks.

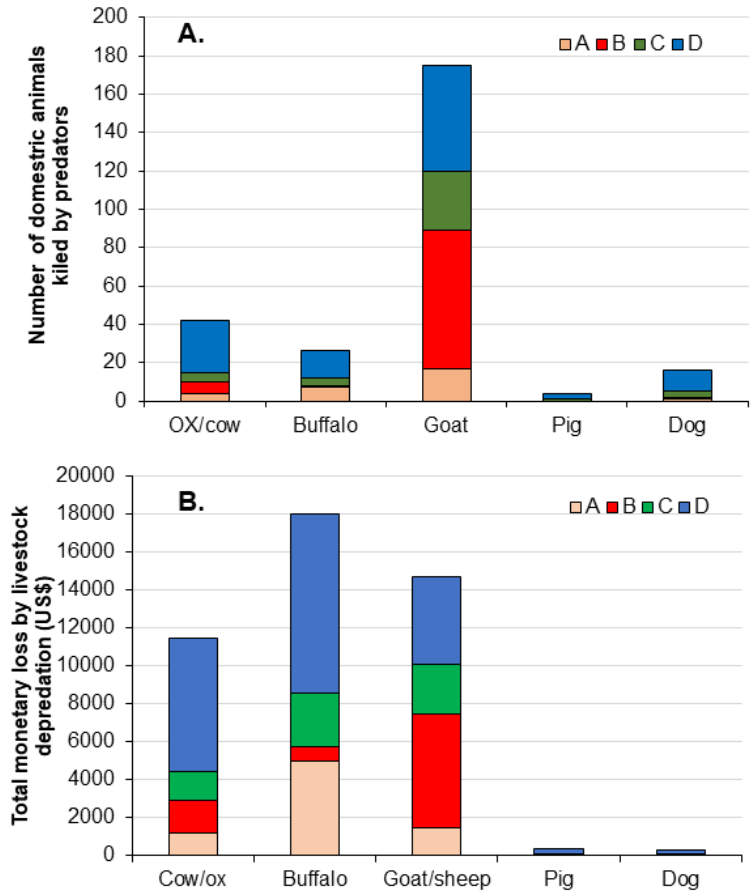


Figure 31: Livestock depredation: A. Number of livestock killed by predator, B. Total monetary loss in US$

A total of US$ 44764.71 (US$ 74.60 per HH) was lost per year. The monetary loss was higher in block D (US$ 143.52 per HH) than in other blocks. As increasing the sign encounter rate of predators, the rate of livestock depredation also increased except block A. In block A, the depredation rate was comparatively lower though the sign encounter rate of the predators was higher (Table 13).

Table 13: Relation between sign encounter rate of tiger and leopard with monetary loss in US$ per household, 1US$ = NPR 119 exchange date 19th March 2020

Block	Sign encounter of predator/km	Monetary loss (US$)/HH
A	0.95	50.81
B	0.55	56.97
C	0.39	47.11
D	0.89	143.52

Rate of livestock depredation was significantly higher in proximity of the forest. On increasing the distance from shed to house, livestock depredation was significantly increased ($z = 55.49$, $p < 0.0004$). The livestock depredation was also significantly higher on the livestock holding of the farmers (Table 14).

Table 14: Generalized Linear Model showing the relation of livestock depredation with different variables

Category	Estimate	Std. Error	z value	p-value	
Intercept	10.57	0.002	5236.01	<0.0001	***
No of livestock holding	0.0002	0.00003	6.79	<0.0001	***
Distance to forest	-0.0043	0.000003	-1391.51	<0.0003	***
Distance to shed from house	0.0001	0.000003	55.49	<0.0004	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.3.5.3. Human casualty and injury

Respondents reported tiger, rhino and wild pig in block A, leopard, Himalayan black bear, wild pig and monkeys in block B, leopard, bear and monkeys in block C and D were principal mammals that commonly attack the people. A total of 26 cases of attack (20 injuries, 6 death) were recorded along this landscape (Figures 32 and 33). The highest cases of attacks were reported in blocks C and D (n = 8). Among these cases, the Himalayan black bear alone contributed 30.76% of the total attacks followed by monkeys (26.92%), leopard (19.23%), wild pig (11.53%), rhino (7.69%) and tiger (3.84%) (Figure 32). The attack cases by tiger and rhino were only reported from block A whereas the attack cases of wild pigs were reported from block A and B (Figures 32 and 33).

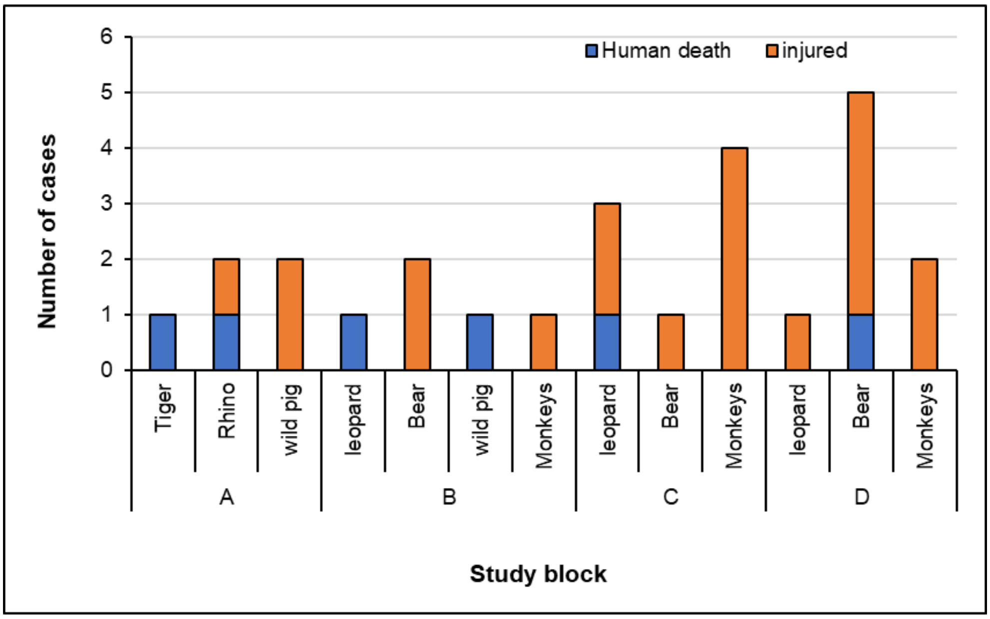


Figure 32: Human deaths and injuries caused by large mammals in the study area

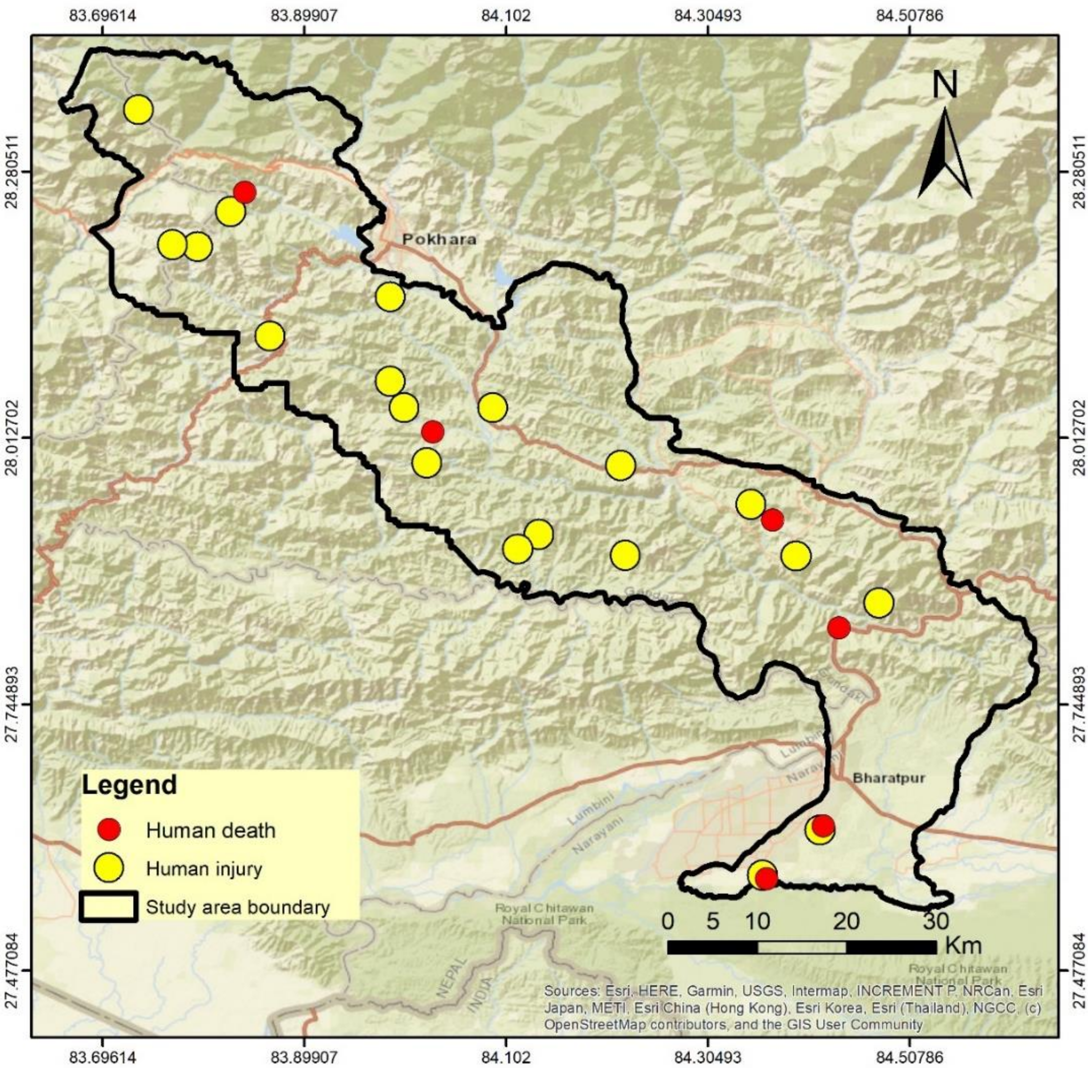


Figure 33: Locations of human death and injury due to wildlife attack in the study area

3.3.5.4. Conflict hotspots

The IDW map prepared based on monetary loss from crop damage and livestock depredation showed that the conflict was comparatively higher in mid-hills (block B and C) and high-hills (block D) than lowland (block A). Panchase and some parts of ACA had more conflict than other parts of this landscape (Figure 34).

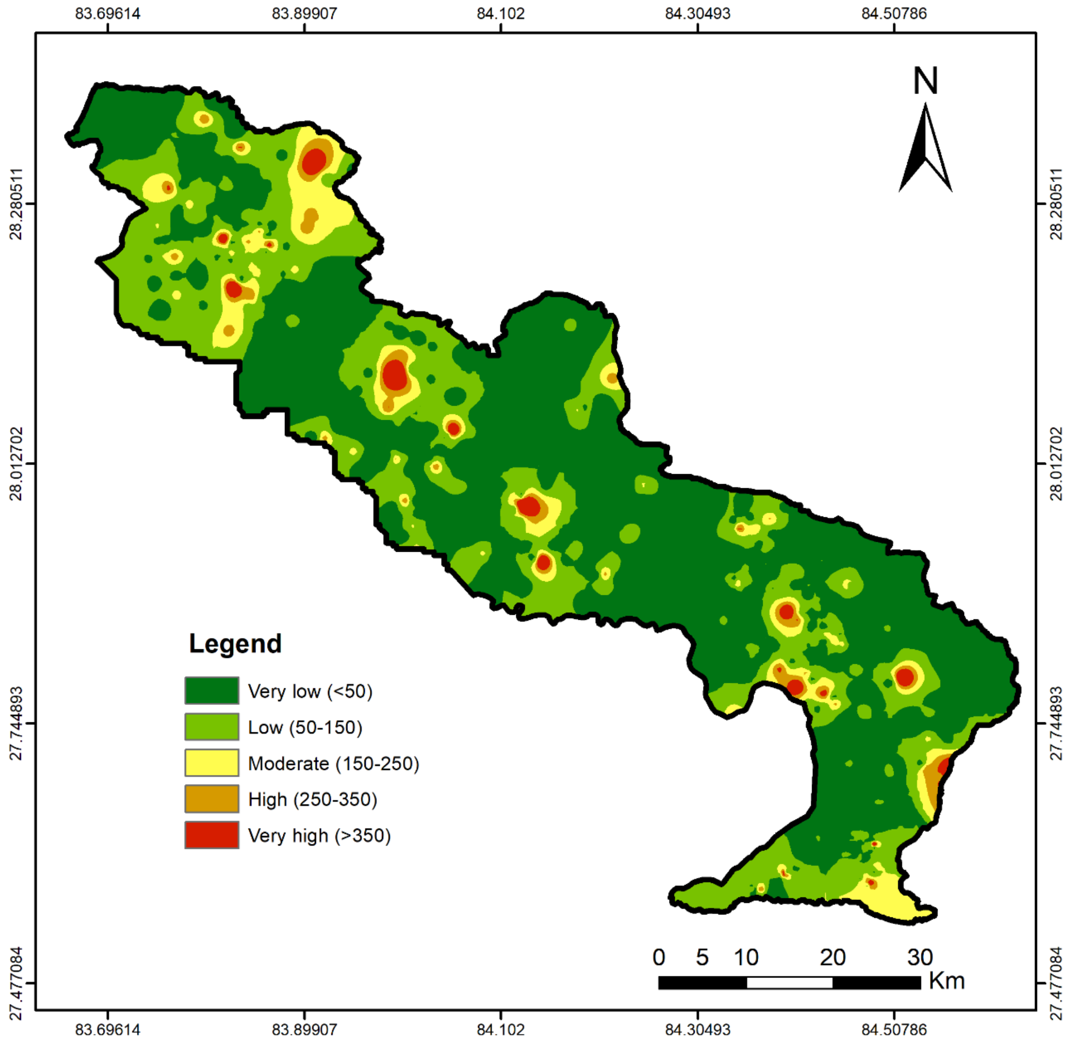


Figure 34: Conflict hotspots depicted on the basis of monetary loss (in US$) due to crop damage and livestock depredation by large mammals

3.4. Discussion

3.4.1. Abundance of mammals

Distribution and relative abundance of the mammalian species in different parts of the landscape clearly support the fact that habitat types, composition, habitat heterogeneity, connectivity, disturbances, elevation, topographic factors, management practices etc. influence on the species distribution and abundance. The abundance of mammals comparatively higher in block A (lowland) and block D than block B and C. BCF is one of the important protected forests that linked the CNP with Mahabharat range and well managed partly by CNP and partly by division forest office of Chitwan (NTNC, 2003; Adhikari *et al*., 2021b). The high habitat heterogeneity including grasslands, lakes and river/streams scattered in the forest supports high number of large mammals in BCF (NTNC, 2003; Adhikari *et al.*, 2021b). Similarly, the well managed forest in PPF and ACA (block D) supported a large population of mammals. Comparatively, lower abundance of large mammals in block B and C can be attributed to higher disturbance and smaller patches of forest scattered in the human-dominated and fragmented mid-hills. The protected forest, buffer zone forest and conservation areas are comparatively less disturbed than the community managed forests in the mid-hills (Paudel & Kindlmann, 2012). Intensive human activities, scattered croplands and human settlements disturbed the abundance and distribution of mammals. However, some wildlife species can be found in disturbed areas where predators normally avoid (Gill *et al*., 2001) hence the species can able to coexist in the disturbed area. The rhesus macaque, langur and wild pig followed this hypothesis in this landscape. However, some other ungulates including Himalayan gorals were observed in the relatively less disturbed areas, didn't follow this hypothesis. Human disturbance indicators such as number of people inside the forest and livestock pressure affect the distribution of mammals (Paudel *et al.*, 2012) in human dominated landscapes. Previous studies also reported the impacts of human disturbances on the distribution and abundance of mammals (Bhattarai & Kindlmann, 2012b; Paudel *et al.*, 2012; Fetene *et al.*, 2019).

Among the mammalian species recorded in CHAL, leopard, muntjac, wild pig, rhesus macaque and langur had wider distribution reflecting their wider range adaptive capacities. Some species have developed a wide range of adaptive capacities to survive in ranges of environmental conditions (Mishra, 1982; Tamang, 1982). For instance, the hog deer observed very restricted in the less disturbed tall grassland in the floodplains of Rapti River of BCF as previously reported by Dhungel and O'Gara (1991), Bhattarai and Kindlmann (2012a), and Thapa (2011). The occurrences of sambars only in the block A (BCF). The sambar is generalist species to use habitats in lowland (Thapa, 2011; Bhattarai & Kindlmann, 2012a) but CCA ordination diagram revealed that abundant of sambar was significantly higher in dense Sal dominated forests (Figure 27A, $F = 2.98$, $p = 0.002$), as reported by Dinerstein (1979), Thapa (2011) and Pokharel and Storch (2016) and generally occur in less disturbed habitats (F = 8.378, p = 0.002) because they are highly sensitive to human disturbances (Jnawali *et al.*, 2011; Bhattarai & Kindlmann, 2013; Yen *et al.*, 2014). Similarly, CCA ordination diagram indicated that chital was significantly found in less disturbed open and moderately dense grassland area of BCF (block A) (Figures 27A and 28A) and Devghat area (block B) as chital was closely associated with grassland (Wegge & Storaas, 2009). The grasslands scattered inside the forest of BCF and Devghat area provided the foraging grounds to chital. Similarly, northern red muntjacs have wide range of adaptive capacities and distributed varieties of habitats. Muntjac was reported from lower to higher elevation (Jnawali *et al.*, 2011) along landscape (WWF, 2013b). The CCA and RDA analysis found that the open grass patches scattered inside the forest and comparatively low disturbed moderately dense forests significantly supported the abundance of muntjac (Figures 27 and 28) but they used dense forest for shelters (Dinerstein, 1979; Wegge *et al.*, 2009; Thapa, 2011; Bhattarai & Kindlmann, 2012a). Sometimes, muntjac was also reported around the human settlements (Mishra, 1982) and also involved in crop damage.

The wild pigs recorded in the grasslands and moderately dense riverine and mixed forest along the landscape (Figures 27 and 28). Wild pigs used open area close to the wetlands for feeding and resting because such area is occupied soil invertebrates (Ferretti *et al.*, 2021). The grassland patches inside the Sal and mixed forest were the most preferred habitats of wild pigs. Sometimes they used dense forest of Sal, mixed and riverine forest for shelters (Thurfjell *et al.*, 2009). CCA analysis found that wild pigs were significantly associated with low disturbed area in block A as the habitat of block A is comparatively less disturbed, but significantly found in highly disturbed areas and moderately disturbed areas in blocks B and D as these areas are human dominated and comparatively disturbed (Figure 28). Wild pigs are generally destructive in nature; therefore, they lower the presence of other herbivores in the shared habitats (Barrios-Garcia & Ballari, 2012; Horčičková *et al.*, 2019).

The study showed the patchy distribution of the Himalayan goral in mountains and comparatively higher abundance in block D. CCA analysis showed that gorals were associated with low disturbed open grassland of blocks B–D (Figures 27 B–D and 28 B–D). The sloppy and terrain mountain covered with grassland patches of PPF and

ACA significantly supported their occurrence (Figure 27D). The rugged and steep areas have less disturbed forest due to inaccessibility of collection of resources and livestock grazing (Paudel *et al.*, 2012). These less disturbed rocky areas with grasses and mixed forests are favorable habitats for Himalayan goral (Ashraf *et al.*, 2016; Adhikari *et al.*, 2021a).

Primates used all types of habitats specially mixed forests in mid-hill which are nearer to the croplands and settlements as reported by Bhattarai and Kindlmann (2013) and Baral *et al.* (2021a). The CCA/RDA analysis indicated the occurrence of primates in the disturbed areas throughout the landscape (Figure 28). This might be due to their synanthropic nature, many rhesus macaques were observed in high disturbed areas closer to human settlements and religious places. (Engel *et al.*, 2010). Comparatively, langurs were more sensitive than rhesus macaque with human disturbances.

The occurrence and abundance of predators were associated with the occurrence of prey species. Relatively higher frequency of the signs of tiger and leopard in grassland and riverine forest of block A are partly attributed to the abundance of prey species in these habitats (Figure 27A). Similarly, the higher sign abundance of leopard in block D than B and C (Figure 27) reflects its generalist type of adaptation strategy. The abundance and distribution of tiger and leopard is correlated with abundance of ungulates and primates (Wegge & Storaas, 2009). Similar type of results reported by Bhattarai and Kindlmann (2012a) in CNP and Wegge *et al.* (2009) in Bardia National Park. The livestock pressure was comparatively lower in lowland than the mid-hill of this landscape. The abundance of prey species (e.g., wild ungulates) were negatively related to livestock abundance (Bhandari *et al.*, 2022b), hence, high livestock abundance in mid-hills lower than natural prey and increase the livestock depredation (Paudel *et al.*, 2012; Baral *et al.*, 2021a). CCA and RDA analysis also found the association of leopard with low disturbed (block A) and moderately disturbed habitat (blocks B, C and D) (Figure 28) as, prey density is comparatively lower in highly disturbed areas (Paudel *et al.*, 2012, Bhandari *et al.*, 2022b). The abundance of the Himalayan black bear was lower in the mid-hill of the Tanahun District than in Panchase and ACA. During the winter season, they reported in the lower part of the mid-hill (i.e., below 1000 m) (Chhetri, 2013).

IAPS had mostly negative but sometime deer and wild pigs utilized *Lantana camara* cover area as shade and hiding places against the predators in this study area. In general, the abundance of large mammals decreased in the IAPS covered area (Figure 28) because the IAPS reduce the food composition and quality for the herbivores by changing the quality of the grasslands and other habitats (Mack & D'Antonio, 1998; Schirmel *et al.*, 2016, Adhikari *et al*., 2022b). Invasive plants significantly affects the abundance and composition of plants, suitability of habitat and ecosystem functions, animal occupancy (Schirmel *et al.*, 2016). Much of reported effects of IAPS are negative (Vilà *et al.*, 2011) but sometimes it provides the habitat (Severns & Warren, 2008) and food resources for animals (Schirmel *et al.*, 2016). Sometimes, ungulates also used *M. micrantha* as food, even though the overall impact of *M. micrantha* was negative (Subedi, 2012; Murphy *et al.*, 2013). But the overall population of wild ungulates was lower in high *M. micrantha* invasion areas (Murphy *et al.*, 2013). The coverage of IAPS was higher in the mid-hills with lower occurrence in the higher elevations. *Ageratina adenophora* is a common IAPS in mid-hill and high-hill. Poudel *et al.* (2020) predicted that about 38% of the total area of CHAL is climatically suitable for *A. adenophora.* This indicates higher vulnerability of the mid-hill ecosystem. If not controlled, most of the native plant species and most of the grassland will disappear soon that directly impacting the population of herbivores. Furthermore, IAPS damage the grassland and grazing ground of the herbivores, hence, the animals may come to the cropland for grazing and increase the chances of human wildlife conflict.

3.4.2. Human-mammal interaction

Human-wildlife conflicts in CHAL were attributed to multiple species of mammal at varying intensities and patterns. Six herbivores and three carnivore species were reported to HWC in CHAL. Of these species, rhino, chital and wild pig in the lowland and muntjac, monkeys, Himalayan black bear, and wild pig were the top crop depredators in the mid-hill. Tiger and leopard in the lowland and leopards in the mid-hill are the main livestock depredators. Among the cases reported, the attack of Himalayan black bears on people ranked the highest. Monkeys in the mid-hills also attacked the people more than 26% of cases were contributed by monkeys. The crop damage and livestock depredation depend upon the abundance of the respective animals present in that area (Lamichhane *et al.*, 2019a). On increasing the encounter rate of crop depredator (e.g., chital, muntjac, monkey, wild pig and black bear) and the predators (e.g., tiger and leopard), the portability of the crop damage and livestock depredation also increased. But in block A (BCF and surroundings), although the encounter rate of crop depredator mammals was higher but had fewer cases of depredation. This is because BCF is well managed that provides adequate resources for both predators and prey inside the forest and the fencing controls animals exist from the forest to villages. Since proper management of forest and grassland can hold the animals inside their habitat (Lamichhane, 2019). But in the mid-hill, scattered settlements, croplands and forests increased the cases of conflict. As this study, many researchers reported that human-large carnivores' conflict, human-herbivore conflict, human-elephant conflict and human-rhino' conflict are very common in Terai. Similarly, human-bear conflicts, human-leopard conflicts, human-monkey conflicts and human herbivore conflicts are the most serious HWC in mid-hills and Himalayan area of Nepal (Srivastava & Begum, 2005; Bista & Aryal, 2013; Adhikari *et al.*, 2018). However, the majority of conflict issues that arise in human-dominated landscapes (such as mid-hills) always necessitate the proper conservation management outside the PAs (Acharya *et al.*, 2017; Lamichhane *et al.*, 2018; Baral *et al.*, 2021a; Baral *et al.*, 2021b).

Primates, the rhesus macaque and langurs share the food and space with the people in rural or urban area, hence are considered as pest. Primates are involved in suffering and monetary loss by crop-damaging and robbing, and attacking on people (Sharma *et al.*, 2020). The people of the mid-hills were commonly suffering from such type of problems from monkeys and caused high monetary loss due to crop damage. Among the ungulates, muntjac was the main crop raiders in mid-hill but rhino and chital were in the lowland (block A). The distance between the farm and forest, farm and house also play a significant role in crop damage. The farms nearer to their house, have fewer crop-raiding cases, as the people can easily guard their crops. Similar studies conducted by Baral *et al.* (2021a), in Tanahun and Kaski District reported that crop damage is the most widespread in mid-hill of Nepal.

Animal husbandry and agriculture are an important source of income for families in human-dominated mid-hills, resulting in resource competition between local communities and wildlife. Koirala *et al.* (2012) reported total monetary loss from livestock predation per household in ACA was US$ 95 in 2009 and US$ 42 in 2010, in which leopards alone contributed for 94.9% of total losses. Leopard caused heavy monetary loss to the rural people (Acharya *et al.*, 2016). But in the lowland, both tiger and leopard are responsible for the livestock depredation whereas leopard alone contributed in the mid-hills and high hills (blocks B–D). The study also reported that as increasing the sign encounter, the depredation rate also increases except in block A (lowland). Similar type of study conducted by different researchers found that increasing the tiger population in the protected areas (e.g., Chitwan National Park) is associated with increased livestock depredation by leopards outside the protected area (Harihar *et al.*, 2011). Free grazing system of the livestock, scattered settlements inside the forest, weak corals and low distance between the forest and the shed in the mid-hills are the major causes of higher depredating cases. This study indicates variations in conflict hotspot areas across central part of the CHAL. The analysis revealed that most of the conflict areas were at mid-hills than lowlands. Globally, large mammals are reported to involved in crop damage and livestock depredation (Holland *et al.*, 2018). The major conflict hotspots in this study found nearer to the human settlements in the mid-hill which coincide with the previous studies (Sharma *et al.*, 2020, Baral *et al.*, 2021b).

Among reported human attack cases, tiger, rhino and wild pigs in the lowland and Himalayan black bear, leopard, monkeys, wild pigs in the mid-hill were the contributors as these animals involved in human attacks and caused deaths and injuries. The attack cases were reported higher in the Panchase and ACA area (block D) and mid-hill (Tanahun District). Baral *et al.* (2021b) reported six deaths and 16 human injuries cases from Tanahun from 2011 to 2019. But this study reported 13 cases of attacks (3 killed and 10 injured) within one year including 5 attack cases by monkeys in Tanahun. Various studies conducted in mountain areas around the world concluded that the Himalayan black bear and leopard are the main mammals responsible for the human attacks (Sathyakumar, 2001; Charoo *et al.*, 2011; Kabir *et al.*, 2014; Constant *et al.*, 2015). The wide distribution of common leopard and Himalayan black bear cause conflicts along the entire mid-hills of Nepal which are far from the PAs (Bista & Aryal, 2013). This study concentrated solely on the issues and status of conflicts in the CHAL. This study recommends the further on the mitigation and prevention methods to reduce human-wildlife conflicts.

3.5. Conclusions

The central part of CHAL is still home to a diverse large mammal community, however, more worryingly, occurrence of many large mammal species is isolated surviving in fragmented habitats. The fragmented forests have a fundamental role in large mammal conservation in this landscape, regardless of its area or structure. Habitat types, succession, human disturbance, and invasion of IAPS are the key factors affecting occurrence and abundance of the large mammals. In addition, the ungulates and primates are responsible for crop damage, leopards for livestock depredation and leopard, Himalayan black bear, monkey, rhino, wild pig and tiger are responsible for attacking human. Crop damage and livestock depredation were significantly higher nearer the forest area. The frequency of crop damage and livestock depredation increases with the increase of encounter rate of the animals. Without management intervention, species are likely to become more threatened. Data provided from this study may be incorporated into future monitoring and the development of targeted conservation management program in study area. However, for management plans to be implemented, the factors affecting occurrence and abundance of species must be elucidated.

CHAPTER 4

4. EFFECTS OF ENVIRONMENTAL CORRELATES ON THE OCCUPANCY OF LARGE MAMMALS

Abstract

Large mammals are currently declining due to threats associated with various environmental factors. Management and conservation initiatives and planning need reliable data on species populations, their distribution and factors affecting for their occurrences. This study aimed to evaluate the influence of eco-geographic variables on the occupancy of large mammal species in CHAL. Sign data on animal presence were collected through the survey of 150 transects opportunistically to evaluate a set of environmental variables with the potential to influence occupancy (ψ) and detection (p) probabilities using program PRESENCE and predicts the habitat quality for species using the program Maxent To estimate occupancy, four spatial replicates (2 km segment) were used for each transects while for Maxent, only presence points were used. Density-based occurrence points rarefaction and performance-based variable selection was applied to improve the outputs of SDM. The model was evaluated based on the area under the curve (AUC) value of receiver operator characteristic (ROC) and analyzed as a response curve, the relative importance of variables, Jackknife test and suitability map. The detection probability was variable; high (ψ = 0.944) for common or species easy to detect (leopards), but not for species that are rare (ψ = 0.038) or difficult to detect. The detection probability can be increased by increasing the duration of the survey period and surveyed sites. The model was statistically satisfactory (mean AUC>0.7). The results showed that the nearest distance to cropland, elevation, distance to grassland, forest, water sources and settlements, Normalized Difference Built-up Index and Normalized Difference Vegetation Index were the major variables that predict occupancy of species. SDM predicated around 30% of the landscape is suitable habitat for northern red muntjac, rhesus macaque and leopard, but only small fraction of the area is suitable for other species. Hence, the outcomes of this research can be used to build the conservation and management plans for biodiversity conservation in the human dominated landscape.

4.1. Introduction

The environmental factors such as land cover and land use patterns, human-wildlife interactions, elevation, aspects, habitat heterogeneity, Normalized Difference Vegetation Index (NDVI), Terrain Ruggedness Index (TRI), presence of human settlements and buildup areas, water resource along with anthropogenic activities affect the distribution and occurrence of the animals in an area (Pakeman *et al.*, 2002; Chitayat *et al.*, 2021). The landscape correlates might be species specific and their preferred habitats (Bubnicki *et al.*, 2019). The prey richness is the major variable for the survival of carnivores (Davis *et al.*, 2018; Ferretti *et al.*, 2020).

The mid-hill landscape of Nepal is an intermediate landscape with rich biodiversity (Paudel & Bhattarai, 2012; Primack *et al.*, 2013). However, this landscape is poor representation in protected areas and the biodiversity of the mid-hill ecosystem is poorly explored (Shrestha *et al.*, 2010; DNPWC, 2022). Hence, there is very low information about the status and distribution of wildlife (WWF, 2013a).

The mid-hill landscape of Nepal is highly fragmented due to intensive human activities such as agriculture activities, livestock grazing, timber, firewood and fodder collections and environmental vulnerabilities (Paudel & Heinen, 2015; Fahrig & McGill, 2019). Many mammalian species including leopards share habitats with livestock and human, thus affecting the survival of the mammals (Mishra & Johnsingh, 1996; Acharya *et al.*, 2016; Adhikari *et al.*, 2018b).

Information on the species assemblage and distribution of the large mammals in these landscapes are sparse. In such cases, predictive models (e.g., Species Distribution Model (SDM) and occupancy models) are commonly used to evaluate the potential distribution of species (Gavish *et al.*, 2017; Gomes *et al.*, 2018). Both occupancy models and SDMs are used for predicting the species distribution and determining habitat suitability (UCT, 2022). Occupancy models estimates the probability of occurrence of species (MacKenzie *et al*., 2002; MacKenzie *et al*., 2017). Program "PRESENCE" is widely used tools for the detection of occupancy (MacKenzie *et al*., 2002; Bailey *et al*., 2007). On the other hand, the SDM is used for evaluating the suitable habitats and potential corridors (Guisan & Zimmermann, 2000; Guisan & Thuiller, 2005; Hirzel & Le Lay, 2008; Paudel & Heinen, 2015; Huang *et al.*, 2019).

SDM evaluates probability of occurrence of animals with their major environmental correlates influencing the distribution of species (Phillips & Dudík, 2008). Various algorithms e.g., Maximum Entropy Program (Maxent), Random Forests (RFs) and Boosted Regression Trees (BRTs) and the Generalized Linear Model (GLM) are used for species distribution modelling (Li & Wang, 2013; Hao *et al.*, 2019; Zurell, 2022). Maxent is one of the most widely used methods for SDM (Phillips *et al.*, 2006; Phillips, 2008, Morales *et al*., 2017) and PRESENCE for the occupancy. Several researches in Nepal used Maxent for species e.g., leopard (Maharjan *et al.*, 2017; Sarkar *et al.*, 2018; Lamichhane *et al.*, 2021b), tiger (Kanagaraj *et al.*, 2011; Battle, 2016; An *et al.*, 2021), rhino (Rimal *et al.*, 2018), ungulates (Paudel *et al.*, 2015), snow leopard (Shrestha & Kindlmann, 2020). The majority of these studies were focused on single species mostly in and around the protected areas. A few studies were done from this landscape but the studies on occupancy and species distribution modelling of mammalian species are still lacking. Hence, this study examined the environmental variables for the occupancy and developed habitat suitability maps for the large carnivores (leopard, Himalayan black bear) and prey species (chital, red northern muntjac, Himalayan goral, wild pig, rhesus macaque and, langur monkeys) in CHAL area. In this study, fine-scale habitat suitability model was applied to show the relationships of selected mammals with different environmental variables aiming to (1) investigate occupancy of mammals, (2) provide an accurate prediction of habitat suitability, and (3) compare the relation of mammals with environmental variables. The findings of this study provide the basis for further analysis on habitat patches identification, linkages among the habitat patches for mammals which is useful for effective conservation.

4.2. Materials and methods

4.2.1. Study area

Study was conducted in the central part of CHAL (2749.48 km^2), covers a part of the Chitwan, Tanahun, Kaski and a part of Syanja and Parbat districts within elevation ranges between 150 m to 3300 m (Figure 35). The climates are tropical and a sub-tropical in lowland areas, subtropical and temperate in mid-hills and subalpine in upper part of mountain (Paudel *et al.*, 2021). Heterogeneity in elevation and climate support rich flora and fauna (DFRS, 2015).

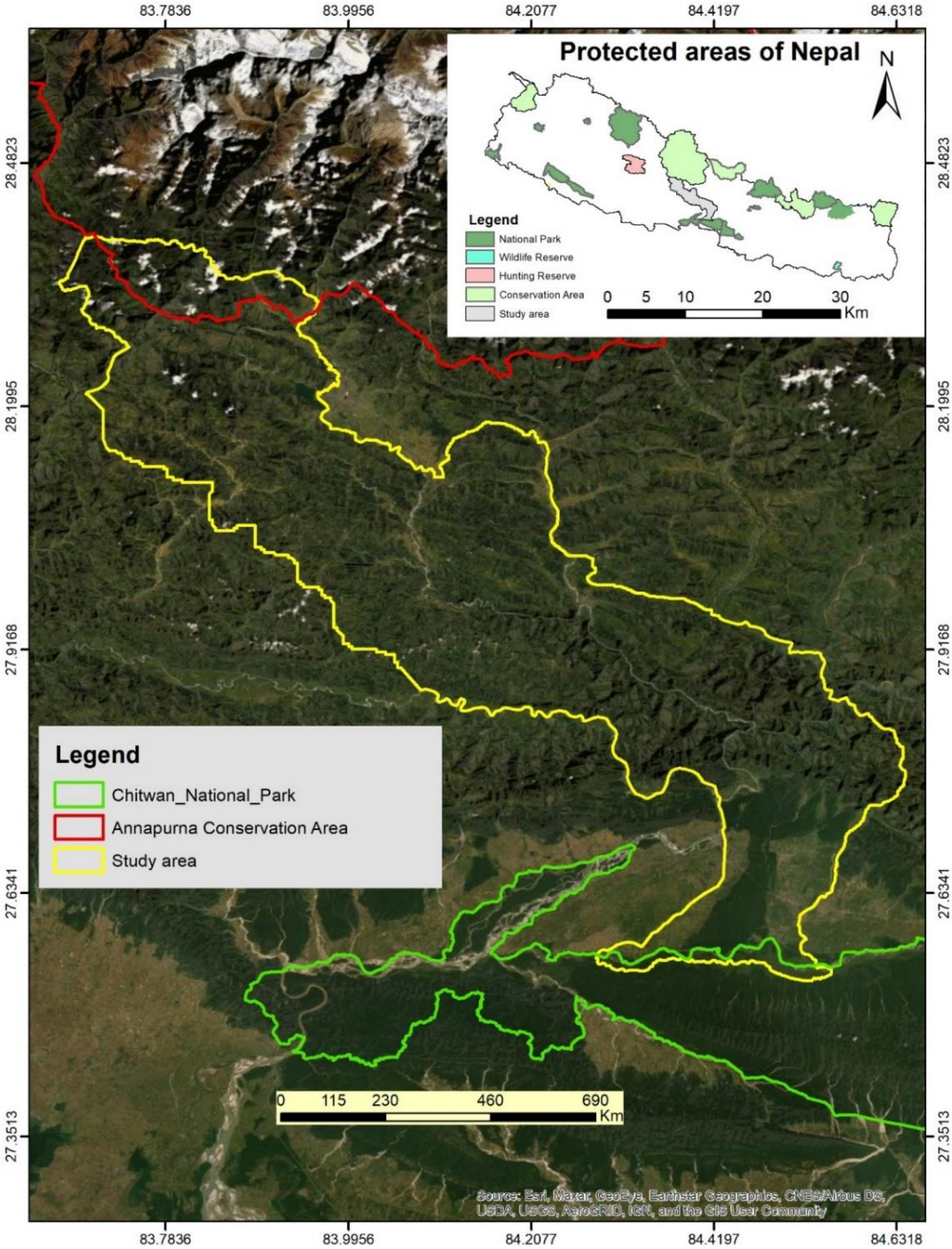


Figure 35: Map showing the intensive study areas

4.2.2. Methods

4.2.2.1. Data collection

The presence data of three carnivores (tiger, leopard and Himalayan black bear) and the prey species such as hog deer, chital, northern red muntjac, Himalayan goral, wild pig, rhesus macaque and langur, rhino were collected from 2018 to 2021 through sign survey and observation. For the data collection, the study area was divided into four study blocks (A, B, C and D). A total of 150 transects (length ranges from 1.18 km to

7.84 km) were laid in the different habitat patches (Figure 23). The large human settlement and buildup areas, inaccessible areas such as deep gorge and the steep slopes were avoided. Besides the transects, occurrence data were also collected from the other sites opportunistically (e.g., cropland, settlements, riverbanks, roads, human trails, etc.). The occurrences coordinates were collected by using the Global Positioning System (GPS) (Garmin eTrex 10).

Hog deer, rhino and tiger were excluded from further analysis due to few occurrence data (<25). The collected occurrence data were spatially filtered in 30 m by using the Spatially Rarify Occurrence Data tools of SDMtoolbox 2.0.0 in ArcGIS (Brown, 2020; Kaboodvandpour *et al.*, 2021). The filtered data were converted into .CSV format for Maxent modelling.

4.2.2.2. Environmental variables

To minimize the risk of over-fitting the model and develop the most parsimonious model, the environmental variables were selected based on field knowledge (Watts *et al.*, 2019; Rather *et al.*, 2020) of the mammals (e.g., leopard, Himalayan black bear and prey species).

The elevation, slope, and terrain ruggedness index (TRI) were extracted by using the Digital Elevation Model (DEM) in ArcGIS 10.8 (ESRI, 2019). The classified image of Landsat 8 OLI (acquisition date 2020–03–17) was used to extract the Euclidian distances to the nearest forest, grassland, water sources, buildup/settlement area and cropland. The forest layer was prepared by combining the layers of all types of the forests (e.g., riverine forest, Sal dominated forest and mixed forest). Globally, the Normalized Difference Vegetation Index (NDVI) was used to quantify the greenness of the vegetation and vegetation density and detect the changes in plant health (Yengoh *et al.*, 2015; USGS, 2022), hence selected as an environmental layer. The NDVI was calculated by using red and NIR bands. Additionally, the modified Normalized Difference Water Index (MNDWI) was calculated by using the green and short-wave infrared red (SWIR) bands as it enhances the features of open water. MNDWI also minimizes the features of build-up areas that are associated with open water in other indices (Xu, 2006). Furthermore, the Normalized Difference Built-up Index (NDBI), used as one of the environmental variables, is the ratio based on the minimize the effects of terrain brightness differences and atmospheric effects (Zha *et al.*, 2003). Two spect-

Formulae use to calculate following indexes

Normalized Difference Vegetation Index (NDVI)

$$\text{NDVI} = \frac{(\text{NIR}-\text{R})}{(\text{NIR}+\text{R})}$$

Or for Landsat 8,

$$\text{NDVI} = \frac{(\text{Band 5}-\text{Band 4})}{(\text{Band 5}+\text{Band 4})}$$

The value of NDVI ranges from -1 to 1. NDVI value -1 to 0 represents the water *sources*, -0.1 to 0.1 represents barren rocks, sands, gravels or snow, 0.2 to 0.5 indicates the shrubs, grassland or crop land and the value 0.6 to 1 indicates the dense vegetation.

The modified Normalized Difference Water Index (MNDWI)

$$\text{MNDWI} = \frac{(\text{Green}-\text{SWIR})}{(\text{Green}+\text{SWIR})}$$

Or for Landsat 8,

$$\text{MNDWI} = \frac{(\text{Band 3}-\text{Band 6})}{(\text{Band 3}+\text{Band 6})}$$

The value of MNDWI ranges from -1 to 1

The Normalized Difference Built-up Index (NDBI)

$$\text{NDBI} = \frac{(\text{SWIR}-\text{NIR})}{(\text{SWIR}+\text{NIR})}$$

Or for Landsat 8,

$$\text{NDBI} = \frac{(\text{Band 6}-\text{Band 5})}{(\text{Band 6}+\text{Band 5})}$$

The value of NDBI ranges from -1 to 1

Terrain Ruggedness Index (TRI)

$$\text{TRI} = \sqrt{\frac{1}{8}\sum(x_{ij} - x_{00})^2}$$

Where, x_{ij} = elevation of each neighborhood cell to the central cell at 0,0

x_{00}= elevation of central cell at 0,0.

TRI = terrain ruggedness index

Table 15: The environmental variables used in habitat suitability of mammals

Variable	**Distance to forest (m)**	**Distance to grassland (m)**	**Distance to water bodies (m)**	**Index of habitat heterogeneity**	**NDVI**	**MNDWI**	**Elevation (m)**	**Slope (◦)**	**TRI**	**Distance to cropland (m)**	**Distance to buildup/ settlements area (m)**	**NDBI**	**Prey species richness**
Methods	Euclidean distance to forest	Euclidean distance to grassland	Euclidean distance to water sources	Total number of habitat variables in 3×3 moving window	NIR and Red bands used to calculate NDVI	Green and SWIR bands used to calculate MNDWI	Altitude above sea level	Gradient of slope	Topographic heterogeneity	Euclidean distance to cropland	Euclidean distance to buildup/settlement area	NIR and SWIR bands are used to calculate build-up area	Habitat suitability of preys combined as the single layer
Source	Supervised classification of Landsat image 8 (OLI) of 2020			Classified image of 2020	Downloaded from https://earth explorer. usgs.gov/		Digital elevation model	Downloaded from https://earth explorer. usgs.gov/	Total number of habitat variables in 3×3 moving window	Supervised classification of Landsat image 8 (OLI) of 2020		Downloaded from https://earth explorer. usgs.gov/	Habitat suitability modelling by using Maxent
Muntjac	√	√	√	√	√	√	√	√	√	√	√	√	-
Chital	√	√	√	√	√	√	√	√	√	√	√	√	-
Sambar	√	√	√	√	√	√	√	√	-	√	-	-	-
Wild pig	√	√	√	√	√	√	√	√	√	√	√	√	-
Goral	√	√	√	√	√	√	√	√	√	√	√	√	-
Rhesus	√	√	√	√	√	-	√	√	√	√	√	-	-
Langur	√	√	√	-	√	√	√	-	-	√	√	√	-
Bear	√	√	√	√	√	√	√	√	√	√	√	√	-
Leopard	√	√	√	√	√	-	√	√	√	√	√	-	√

spectral bands NIR and SWIR were used to enhance the buildup area, thus differentiating built-up over the natural area. For leopards, prey species richness was used as a variable.

A total of 13 environmental variables were used for the modelling (Table 15). The selected variable layers were converted into ASCII format with the same resolution, extent and projection system. The spatial resolution of 30 m and UTM 45 N projected coordinate system was used for the modelling.

4.2.2.3. Occupancy modelling

Occupancy estimation for the selected large mammals was based on single species single season and spatially replicate model (MacKenzie *et al*., 2017). Single visit was carried out in this landscape; hence, spatial replicates were used rather than temporal (Srivathsa *et al.*, 2018). For occupancy, each 2 km segments of each transects were used as spatial replicate. The detection histories were constructed for each segment of each transect. The detected history was detected as binary prediction, where '1' indicated presence of animal/animal sign and '0' indicated as absent.

The data were analyzed on the basis of 'custom model' in occupancy analysis program 'PRESENCE' version 2.13.39 (MacKenzie *et al*., 2017). For greater than four spatial replicates, the presence history of animals was shortened into four to minimize the inaccuracy in the estimation of detection probability (Kroll *et al*., 2010). Simple detection probability (p) of the species was module followed by occupancy (ψ). A total of nine models were produced for nine species of mammals. For the association of different environmental variables with large mammals and habitat suitability, species distribution modeling (SDM) was used. SDM is also used as the surrogate of the occupancy that predict probability of occurrence and predict habitat suitability for species (Gavish *et al.*, 2017).

4.2.2.4. Species distribution modelling

Maxent modelling was used in the occurrence data and the environmental layers for SDM as described by Phillips *et al.* (2006). The .CSV file of the occurrence data of the all the mammals were uploaded in samples and all selected variables layers in ASCII format were uploaded in the environmental layers' menu bar. In the basic setting, the random test percentage was set to 30% for each replication. The replicates, maximum number of background points, and replicated run type, were fixed at 10, 1000 and subsample respectively. The Maxent model ran with 25 replicates with 70 % of the points used as training data and 30 % points used as validation of the model. The model performance was evaluated based on Area Under Curve (AUC) values of the Receiver Operator Characteristic (ROC) plot analysis (Phillips *et al.*, 2006; Phillips & Dudík, 2008). The AUC values range from 0 to 1. An AUC of less than 0.5 shows that the model did not outperform random, whereas values between 0.5 and 0.6 indicate no discrimination, 0.7 and 0.8 indicate discrimination, 0.8 and 0.9 suggest excellent performance, and 0.9 and 1.0 indicate outstanding performance (Phillips *et al.*, 2006; Phillips & Dudík, 2008). The model was further analyzed based on response curves, the Jackknife procedure that predicts the variable importance (Figure 36).

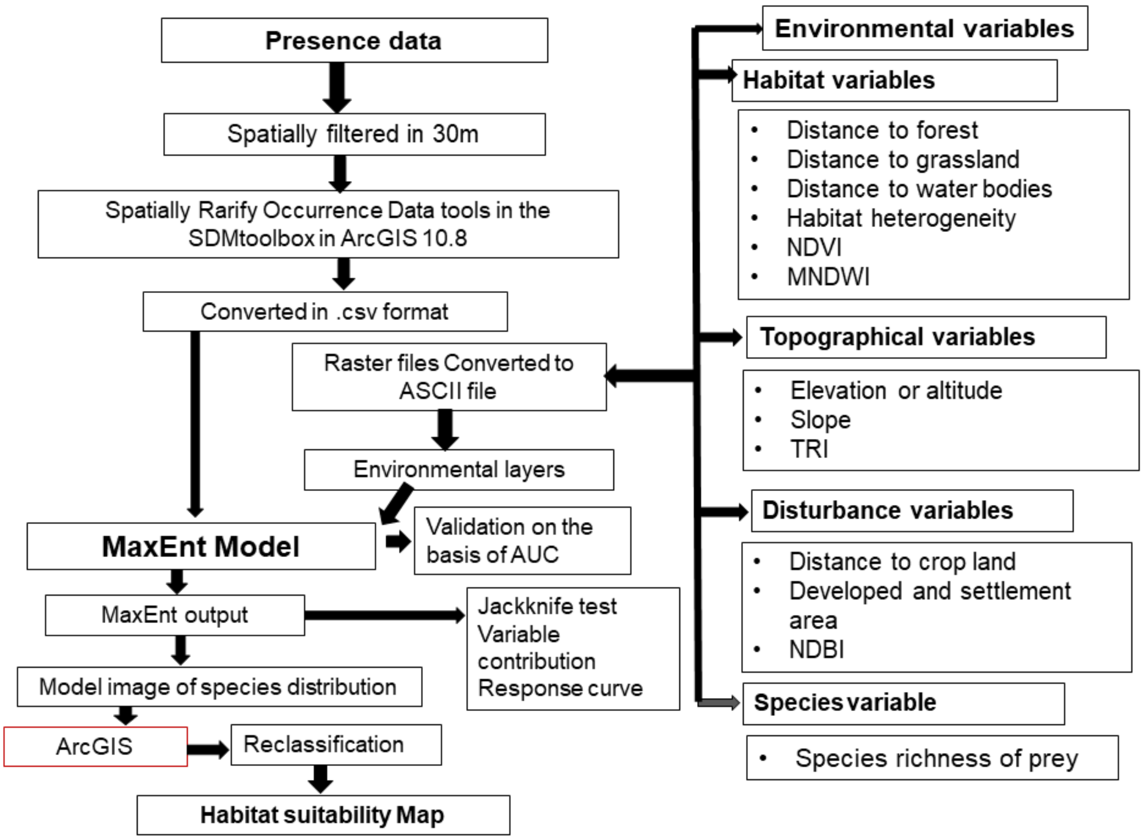


Figure 36: Flow chart of process of species distribution modelling using Maxent

The habitat suitability maps were prepared by converting the ASCII file obtained from the Maxent to raster in ArcGIS. The value of the suitability map ranges from 0 to 1. The logistic probability of suitability was further regrouped as 0 – 0.2 = unsuitable, 0.2 – 0.4 = moderately suitable, 0.4 – 0.6 = suitable and 0.6 – 1 = highly suitable following the method used by Ansari and Ghoddousi (2018) and Kogo *et al.* (2019) which was reclassified in ArcGIS to obtain the habitat suitability classes.

For the layer of prey richness of leopard, the suitability map of preys (except sambar) was calibrated as 0 for absent and 1 for the present of the species based on mean equal test sensitivity and specificity logistic threshold. Then, these layers were combined as a single layer.

4.3. Results

Of the 150 transects and opportunistic survey, signs of the leopard were detected from 289 locations whereas sign of Himalayan black bear were detected from 49 locations. Northern red muntjac among the prey were recorded from the highest locations (n = 265) among the preys (Table 16). Similarly, rhino was reported from 12 locations, hog deer from 7 locations and sign of the tiger from 23 locations. The presence location of these mammals was <25, hence, removed from SDM analysis.

Table 16: Occurrence and spatially rarefy data of the mammals

SN	Mammal	Code used	Total presence points	Points after Spatially Rarify (30 m)
1	Leopard	Leopard	289	286
2	Himalayan black bear	Black_bear	49	49
3	Himalayan goral	Goral	54	53
4	Northern red muntjac	Muntjac	265	264
5	Chital	Chital	141	137
6	Wild pig	Wildpig	124	122
7	Sambar	Sambar	26	25
8	Rhesus macaque	Rhesus	212	201
9	Langur monkey	Langur	87	87

4.3.1. Occupancy of mammals

The occupancy and detection probability varied across species: both occupancy and detection probability were high for common species and lowest for rare species. The mean detection probability of occurrence (occupancy) of leopard was the highest ($\psi = 0.944 \pm 0.048$), moderate for the rhesus macaque, langur and northern red muntjac and lower for wild pig, Himalayan black bear and lowest for the Himalayan goral ($\psi = 0.038 \pm 0.011$) (Table 17).

Table 17: Estimate occupancy of the mammals along the central part of the CHAL

SN	Mammal	Estimate ψ	SE	95% conf. interval
1	Leopard	0.944	0.048	0.743 – 0.989
2	Rhesus macaque	0.583	0.074	0.435 – 0.717
3	Langur	0.541	0.108	0.334 – 0.735
4	Northern red muntjac	0.477	0.024	0.4301 – 0.524
5	Wild pig	0.396	0.051	0.3001 – 0.499
6	Himalayan black bear	0.271	0.048	0.188 – 0.374
7	Chital	0.214	0.034	0.154 – 0.288
8	Sambar	0.201	0.064	0.137 – 0.287
9	Himalayan goral	0.038	0.011	0.022 – 0.065

The predicted species distribution model for the nine mammalian species using the Maxent program yield satisfactory statistical accuracy (AUC>0.7).

4.3.2. Northern red muntjac

The receiver operating characteristic (ROC) results revealed a mean AUC± one standard deviation of 0.737 ± 0.047 that predicted the model with satisfactory statistical accuracy (Figure 37A). Model revealed that the nearest distance to cropland was the most important variables (contribution = 59.3%) for the distribution of muntjac (Figure 36B, Table 18) followed by NDBI, NDVI, distance to buildup/settlements areas and distance to grassland (Table 18). Elevation, slope and distance to forest were less significant. Similarly, distance to water bodies, index of habitat heterogeneity and TRI were the least important in determining distribution of muntjac.

The response curves revealed that the nearest distance to cropland played positive role in the probability of occurrence of northern red muntjac (Figure 37C) but probability of occurrence was sharply decreased on increasing the NDBI (Figure 37D). Similarly, positive response was seen with NDVI (Appendix XVIII) and distance to buildup/settlement areas (Appendix XVIII). The nearest distance to grasslands was considered as more suitable for muntjac (Appendix XVIII). The distribution of muntjac ranges from 158 to 3300 m but the probability of occurrence was higher in the low elevation (up to 200 m) and mid elevation (2000 to 2500 m) (Appendix XVIII). Other variables such as slope (up to 60°), forest, proximity to water sources, habitat heterogeneity, TRI (up to 120 m), low MNDWI were suitable for this deer (Appendix XVIII).

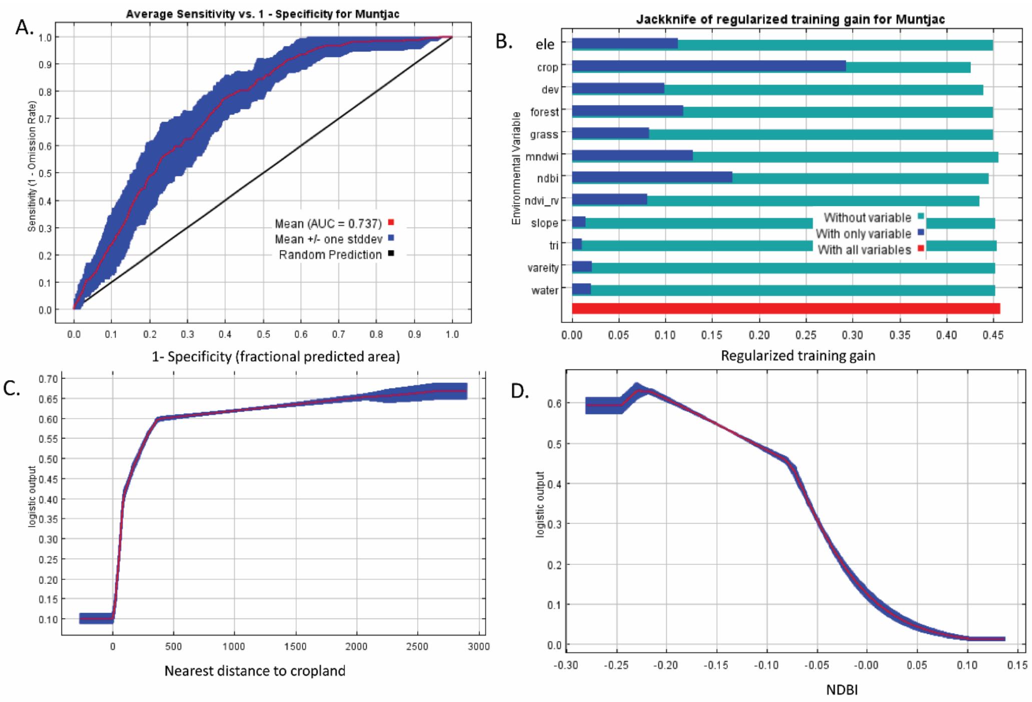


Figure 37: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of northern red muntjac, C. Relationships between nearest distance to the cropland (m) and the probability of occurrence of northern red muntjac, D. Relationship between NDBI and occurrence probability of muntjac

Table 18: Contribution values of environmental variables on habitat suitability. The bold indicates the variable with highest contribution value

Variable	**Code used**	**Variable contribution (%)**								
		Muntjac	**Chital**	**Sambar**	**Wild pig**	**Goral**	**Rhesus**	**Langur**	**Bear**	**Leopard**
Distance to cropland	Crop	**59.30**	20.40	32.40	16.50	**33.10**	2.50	**56.30**	32.60	35.10
NDBI	Ndbi	8.50	0.60	-	3.20	2.30	-	22.80	5.10	-
NDVI	Ndvi	8.10	7.50	1.30	10.50	7.40	5.90	2.00	1.40	3.70
Distance to buildup/settlements area	Dev	7.10	1.00	-	4.20	14.10	**22.90**	1.60	1.00	6.70
Distance to grassland	Grass	6.80	2.20	6.70	8.80	4.30	9.80	3.50	7.40	3.50
Elevation	Ele	2.90	**61.60**	**51.70**	**35.10**	11.70	15.70	10.10	**39.10**	1.20
Slope	Slope	2.00	1.40	1.50	5.60	0.30	4.40	-	2.90	3.20
Distance to forest	Forest	1.70	2.50	3.20	8.60	0.10	13.80	1.80	0.10	3.90
Distance to water bodies	Water	1.10	0.40	0.70	1.40	11.30	17.80	0.40	7.30	2.40
Index of habitat heterogeneity	Variety	1.10	0.60	0.80	1.50	0.20	2.90	-	0.40	1.30
TRI	Tri	1.00	1.10	-	0.40	15.10	4.20	-	0.40	1.80
MNDWI	Mndwi	0.40	0.60	1.60	4.20	0.10	-	1.50	2.30	-
Prey species richness	spp_rch	-	-	-	-	-	-	-	-	**37.20**

The response curves revealed that the nearest distance to cropland played positive role in the probability of occurrence of northern red muntjac (Figure 37C) but probability of occurrence was sharply decreased on increasing the NDBI (Figure 37D). Similarly, positive response was seen with NDVI (Appendix XVIII) and distance to buildup/settlement areas (Appendix XVIII). The nearest distance to grasslands was considered as more suitable for muntjac (Appendix XVIII). The distribution of muntjac ranges from 158 to 3300 m but the probability of occurrence was higher in the low elevation (up to 200 m) and mid elevation (2000 to 2500 m) (Appendix XVIII). Other variables such as slope (up to 60°), forest, proximity to water sources, habitat heterogeneity, TRI (up to 120 m), low MNDWI were suitable for this deer (Appendix XVIII).

Only 6.52 % of the area was highly suitable for northern red muntjac followed by 23.77 % suitable, 25.03 % moderately suitable and 44.68 % was unsuitable (Figure 38, Table 19). The habitat suitability map indicated that the BCF and nearby area, PPF and part of ACA were the most suitable habitat for northern red muntjac.

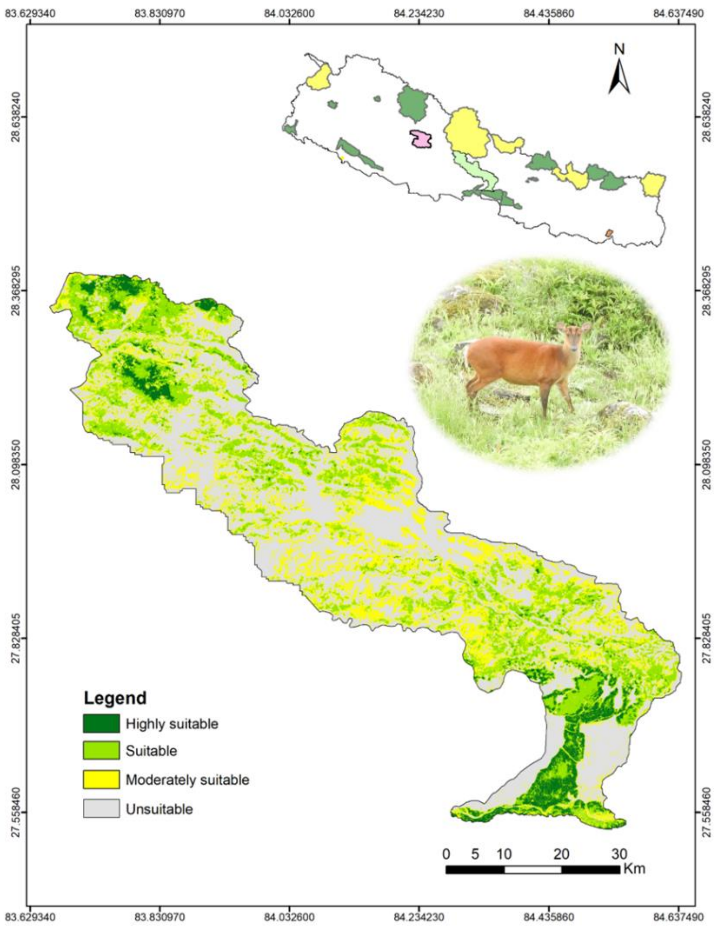


Figure 38: Predicted suitable habitats for northern red muntjac

Table 19: Predicted suitable habitat area for the mammals in CHAL, Nepal (Figures in parenthesis indicate the percentage of area)

Group	Logistic probability of suitability	Predicted area (km²)								
		Muntjac	Chital	Sambar	Wild pig	Goral	Rhesus	Langur	Black bear	Leopard
Highly suitable	0.6–1.0	179.22 (6.52)	25.76 (0.94)	18.17 (0.66)	160.81 (5.85)	128.01 (4.66)	355.48 (12.94)	223.79 (8.14)	49.77 (1.81)	213.19 (7.75)
Suitable	0.4–0.6	653.49 (23.77)	151.56 (5.51)	53.27 (1.94)	239.23 (8.7)	299.61 (10.89)	598.26 (21.76)	728.92 (26.51)	109.35 (3.98)	610.04 (22.18)
Moderately suitable	0.2–0.4	688.24 (25.03)	58.75 (2.14)	53.16 (1.93)	693.11 (25.21)	581.74 (21.16)	1050.96 (38.22)	1001.24 (36.42)	239.25 (8.7)	826.25 (35.05)
Unsuitable	0–0.2	1228.53 (44.68)	2513.41 (91.41)	2624.88 (95.47)	1656.33 (60.24)	1740.12 (63.29)	744.78 (27.08)	795.53 (28.93)	2351.11 (85.51)	1099.99 (40.00)

4.3.2. Chital

The ROC revealed that the Maxent model for chital was statistically accuracy with an AUC value of 0.905 ± 0.023 (Figure 39A). The Jackknife test results revealed that the elevation and nearest distance to cropland had significant contribution in probability of occurrence of chital (Figure 39B) but MNDWI, index of habitat heterogeneity and distance to water bodies had very low contribution (<1% each) (Table 18).

The chital has good habitat on below 400 m (Figure 39C). The proximity to croplands (<3000 m) (Figure 39D), NDVI between 0.2 to 0.8, was suitable for chital (Appendix XIX). Similarly, chital had a strong negative response with distance to the forest, distance to grassland, slope and TRI (Appendix XIX). Other variables such as distance to buildup/settlements areas, NDBI, habitat heterogeneity, MNDWI and distance to water sources also contributed to the occupancy of the chital (Appendix XIX).

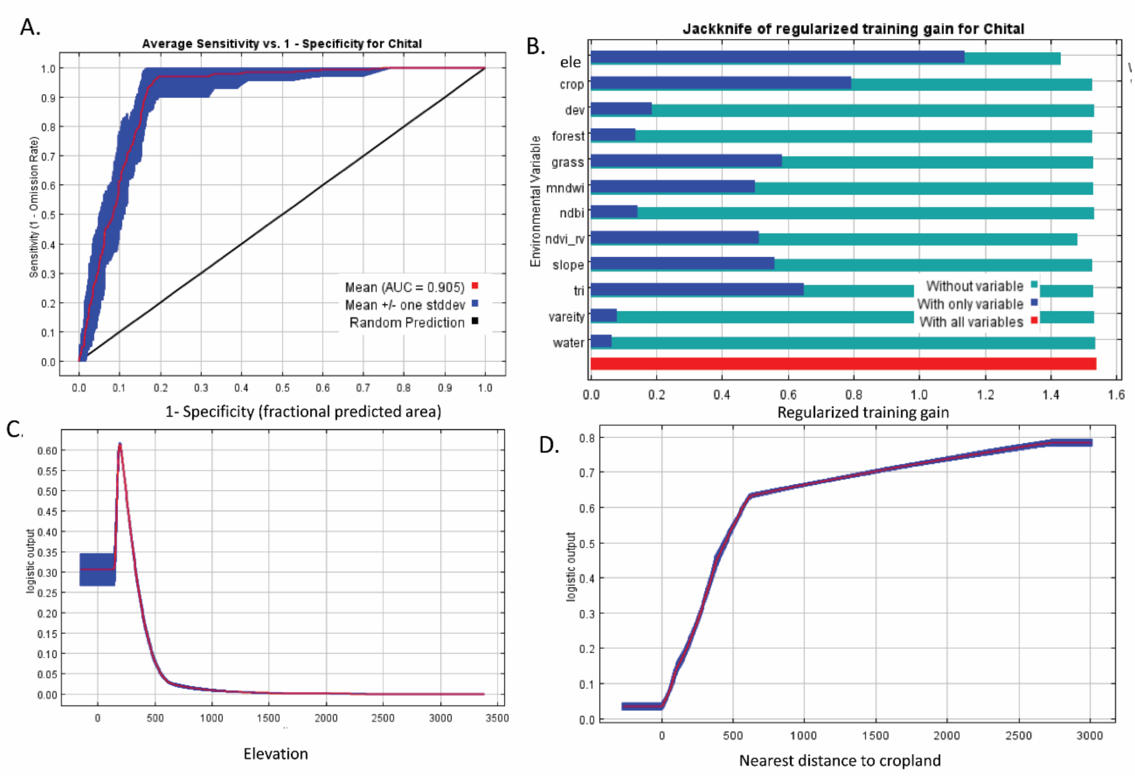


Figure 39: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of chital, C. Relationships between elevation (m) and the probability of occurrence of chital, D. Relationship between nearest distance to cropland and occurrence probability of chital

The model predicted only small fraction (0.88%) of the CHAL suitable followed by suitable (5.35 %) and moderately suitable (2.4%). More than 90% of the total area was predicted as unsuitable for chital (Table 19, Figure 40). The distribution of the chital was confined to BCF and nearby areas of Chitwan and Devghat of Tanahun.

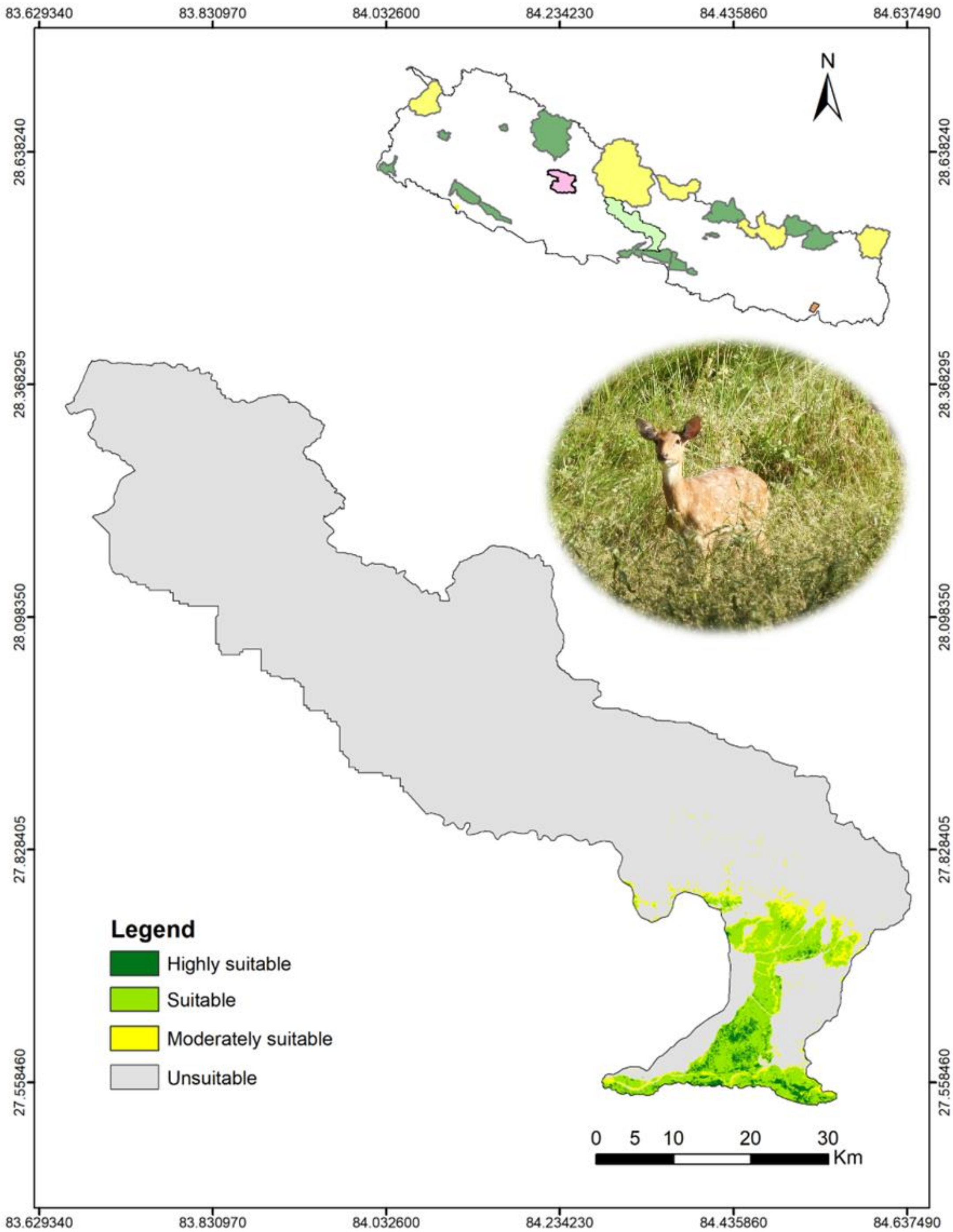


Figure 40: Predicted suitable habitats for chital

4.3.3. Sambar

The Maxent ROC for sambar was statistically accuracy with a mean AUC± one standard deviation of 0.977 ± 0.007 (Figure 41A). The Jackknife estimator revealed that elevation, distance to cropland and distance to grassland significantly contributed in selecting the habitat by sambar (Figure 41B). Other variables contributed less than 5 % to predict the distribution of sambar (Table 18).

The elevation was the determinant environmental variable for sambar. The elevation between 150 to 350 m was suitable for sambar (Figure 41C). Similarly, it showed a positive response with the distance to the cropland as they were mostly reported from the core habitat (Figure 41D). Distance to grassland less than 500 m, distance to forest below 500 m, MNDWI below 0.1, slope between 0 to 20°, NDVI ranges from 0.1 to 0.9, habitat heterogeneity between 0.5 to 7.5 (more between 5.5 to 7.5) and distance to water sources below 2000 m were suitable for the sambar (Appendix XX).

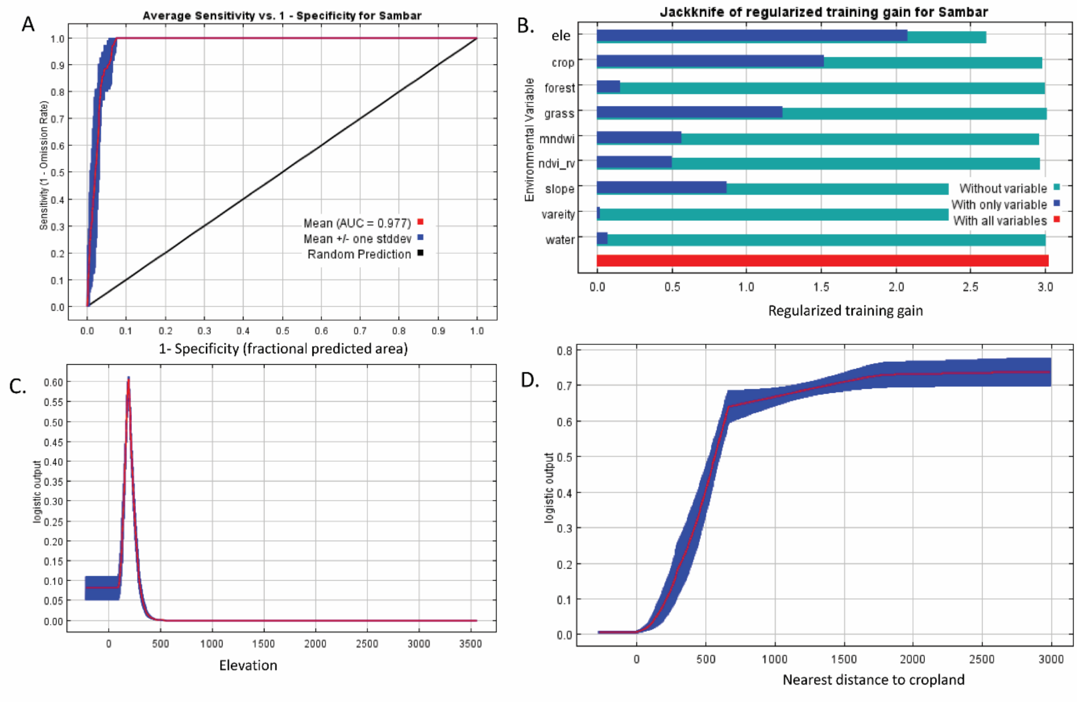


Figure 41: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of sambar, C. Relationships between elevation (m) and the probability of occurrence of occurrence of sambar, D. Relationship between nearest distance to cropland and occurrence probability of sambar

The highly suitable area for sambar was 0.66% followed by 1.94% suitable and 1.93% moderately suitable and remaining 95% area was unsuitable (Table 19). The habitat suitability map indicated that sambar was confined only in the BCF and surrounding areas (Figure 42).

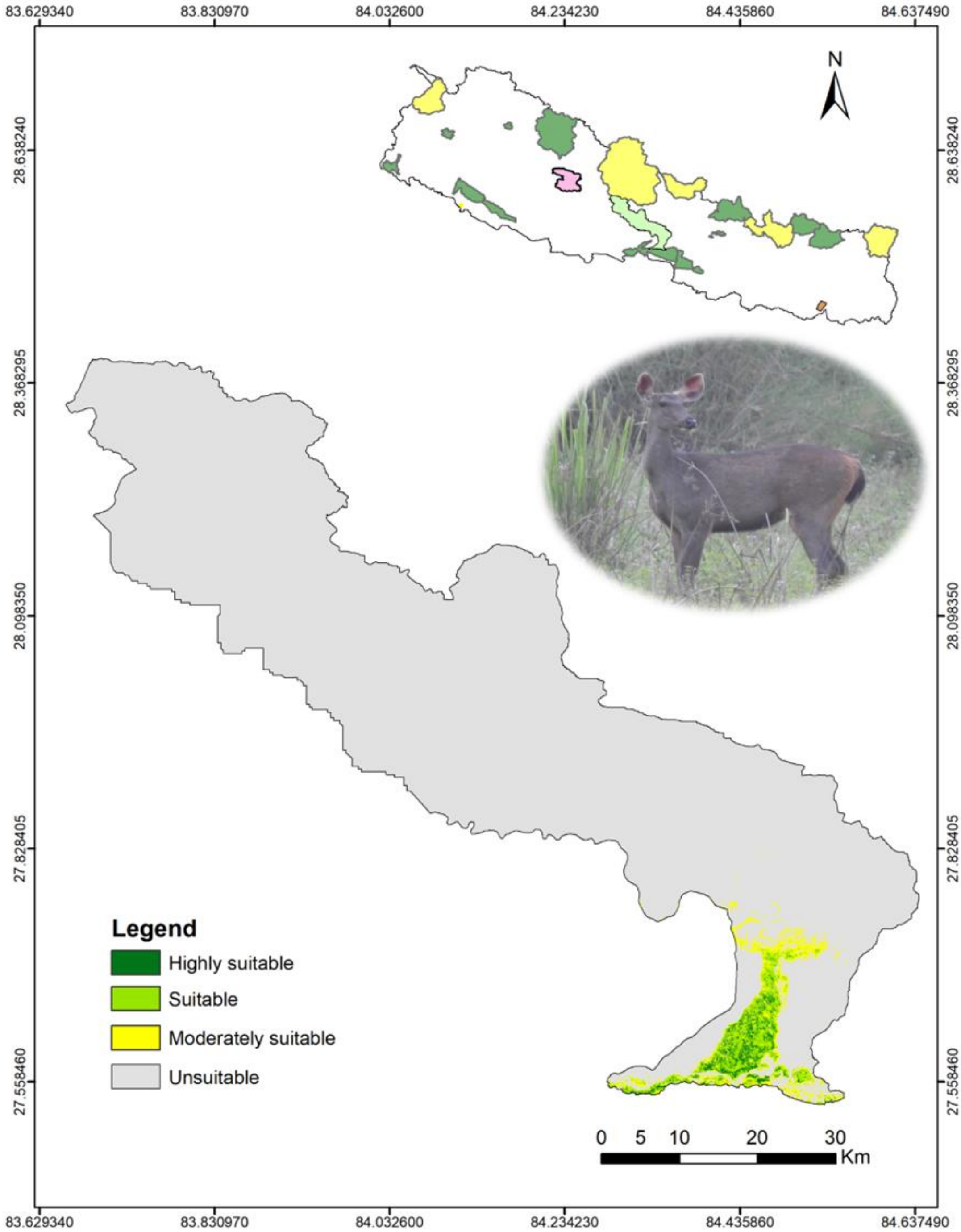


Figure 42: Predicted suitable habitats for sambar

4.3.4. Wild pig

The ROC results of the mean AUC value of 0.794 ± 0.073 indicated the habitat predictions for wild pig were acceptable (Figure 43). The analysis of regularized training gain revealed only six out of 12 variables are highly important. for wild pig (Figure 43B). The elevation has along the highest contribution (35.1%) (Table 18). Similarly, the variables such as distance to buildup/settlements area, MNDWI, NDBI, distance to water and TRI had less contributions (lower than 5% each) (Table 18, Figure 43B).

The sensitivity analysis determined the interaction of each environmental variable (n=9) on the occupancy of wild pigs (Appendix XXI). The top six variables based on contribution were elevation (Figure 43C), distance to cropland (Figure 43D), NDVI, distance to grassland, distance to forest and slope (Appendix XXI). The probability of occurrence of wild pig showed the negative association with elevation (Figure 43C). Similarly, the distance from the cropland (up to 3000 m) (Figure 43D), NDVI (up to 0.85) were suitable for wild pig (Appendix XXI). The negative response was seen with increasing the distance from grassland and distance to forest. Slope up to 30º, habitat nearer to the buildup/settlement area, MNDWI between -0.2 to 0.2, habitat with low NDBI value (below 0.05), very low and high habitat heterogeneity, nearest distance to water sources and low TRI were suitable for wild pig (Appendix XXI).

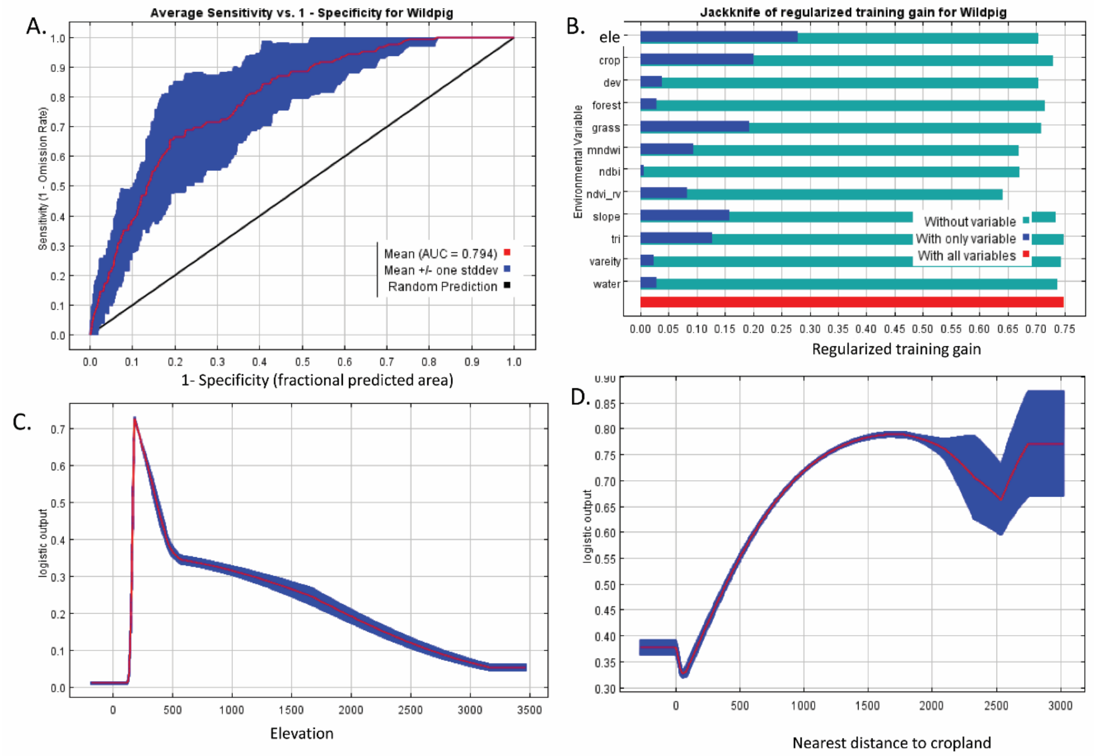


Figure 43: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of wild pig, C. Relationships between elevation (m) and the probability of occurrence of wild pig, D. Relationship nearest distance to cropland and occurrence probability of wild pig

The habitat suitability model revealed that only 5.85 % of the total area was highly suitable for wild pigs followed by 8.7 % suitable, 25.21 % moderately suitable and 60.24 % unsuitable (Table 19). The suitability map revealed that the scattered distribution of wild pigs. The BCF and nearby forest and some parts of the mid-hill landscape (Seti River basin, PPF and part of ACA) were suitable for wild pigs (Figure 44).

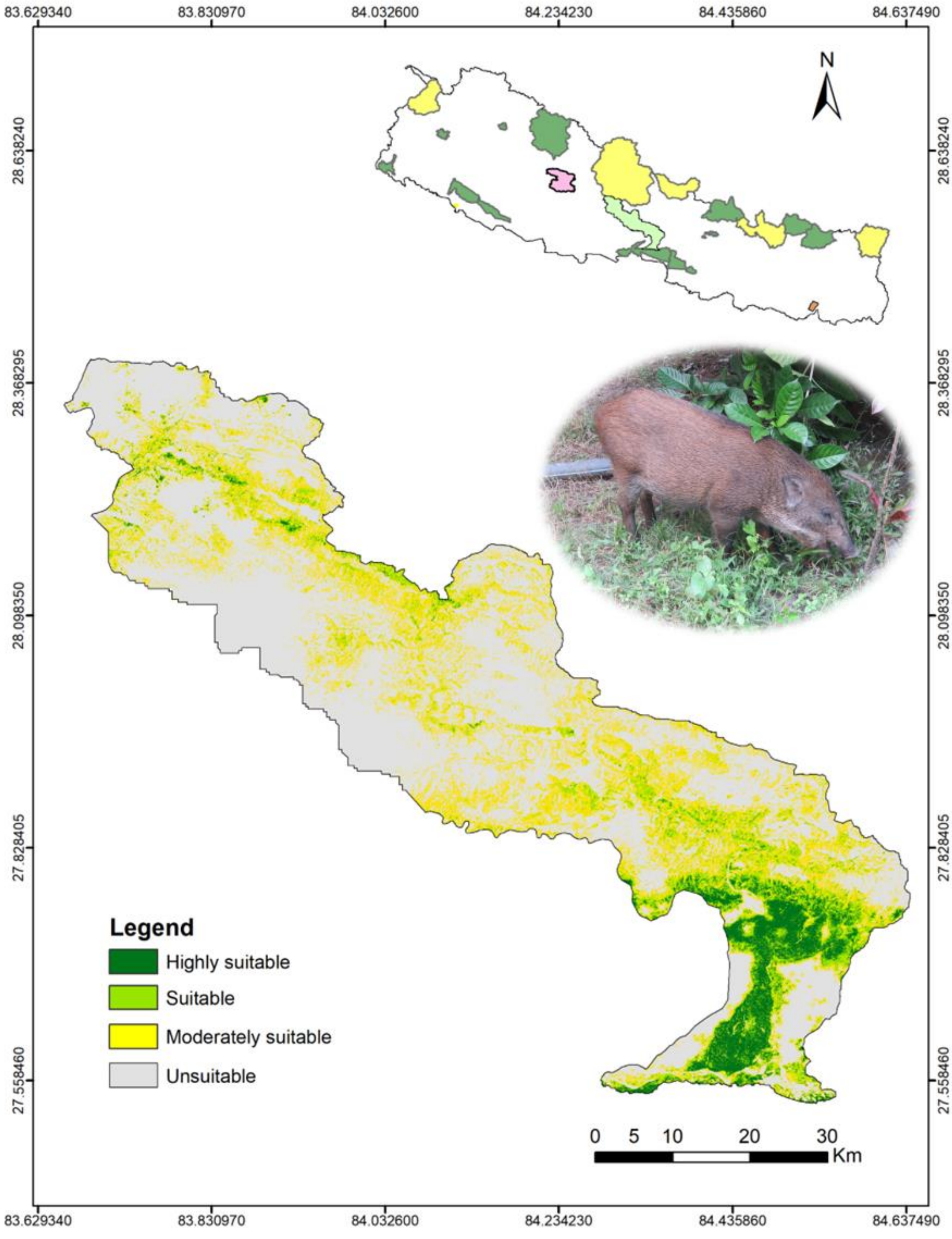


Figure 44: Predicted suitable habitats for wild pig

4.3.5. Himalayan goral

The average test AUC for 25 replicate runs in Maxent model for Himalayan goral was 0.809 with standard deviation of 0.047 (Figure 45A). The elevation and distance to cropland were very important in predicting habitat suitability of Himalayan goral

(Figure 45B). Predicted model was highly influenced by distance to cropland (33.1%) followed by TRI, distance to buildup/settlements area and elevation. Other variables such as distance to water sources and NDVI contributed moderately (7–10%) whereas distance to grassland, NDBI contributed less than 5 %. The slope and habitat heterogeneity had very low contribution (below 1 %) (Table 18).

Distribution model of Himalayan goral, the occurrence probability (>0.4) was higher between 100 to 1700 m distance to cropland (Figure 45C), 20 –100 m of TRI (Figure 45D), 300 ‐ 4500 m distance to buildup/settlement areas, 1000 – 3300 m elevation, 1000 – 5000 m distance to water sources, 0.4 to 0.8 range of NDVI (Appendix XXII). Similarly, grassland, low NDBI, higher slope (up to 70°), habitat heterogeneity index up to 4.5, MNDWI below 0.15 and core area of the forest were suitable for Himalayan gorals (Appendix XXII).

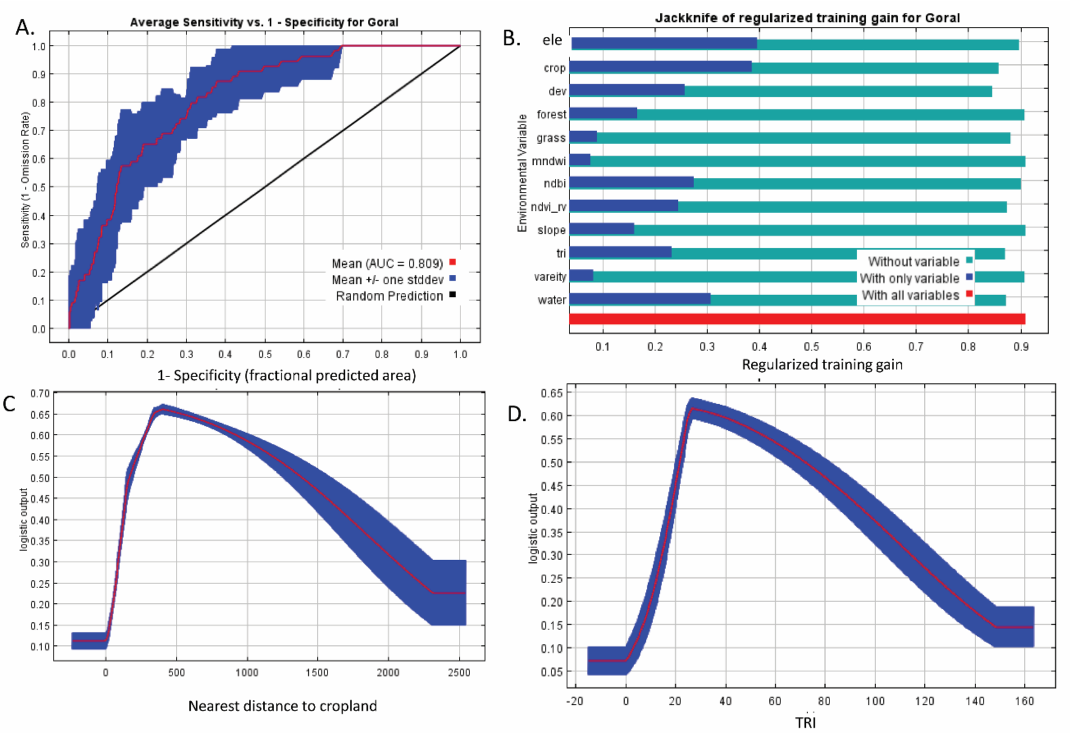


Figure 45: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of Himalayan goral, C. Relationships between nearest distance from the cropland (m) and the probability of occurrence of Himalayan goral, D. Relationship between TRI and occurrence probability of Himalayan goral

Only 4.66% of the total area was highly suitable for the goral followed by 10.89% suitable and 21.16% moderately suitable while 63.29% of the total area was unsuitable (Table 19). The PPF and part of ACA were the highly suitable habitats for Himalayan gorals (Figure 46).

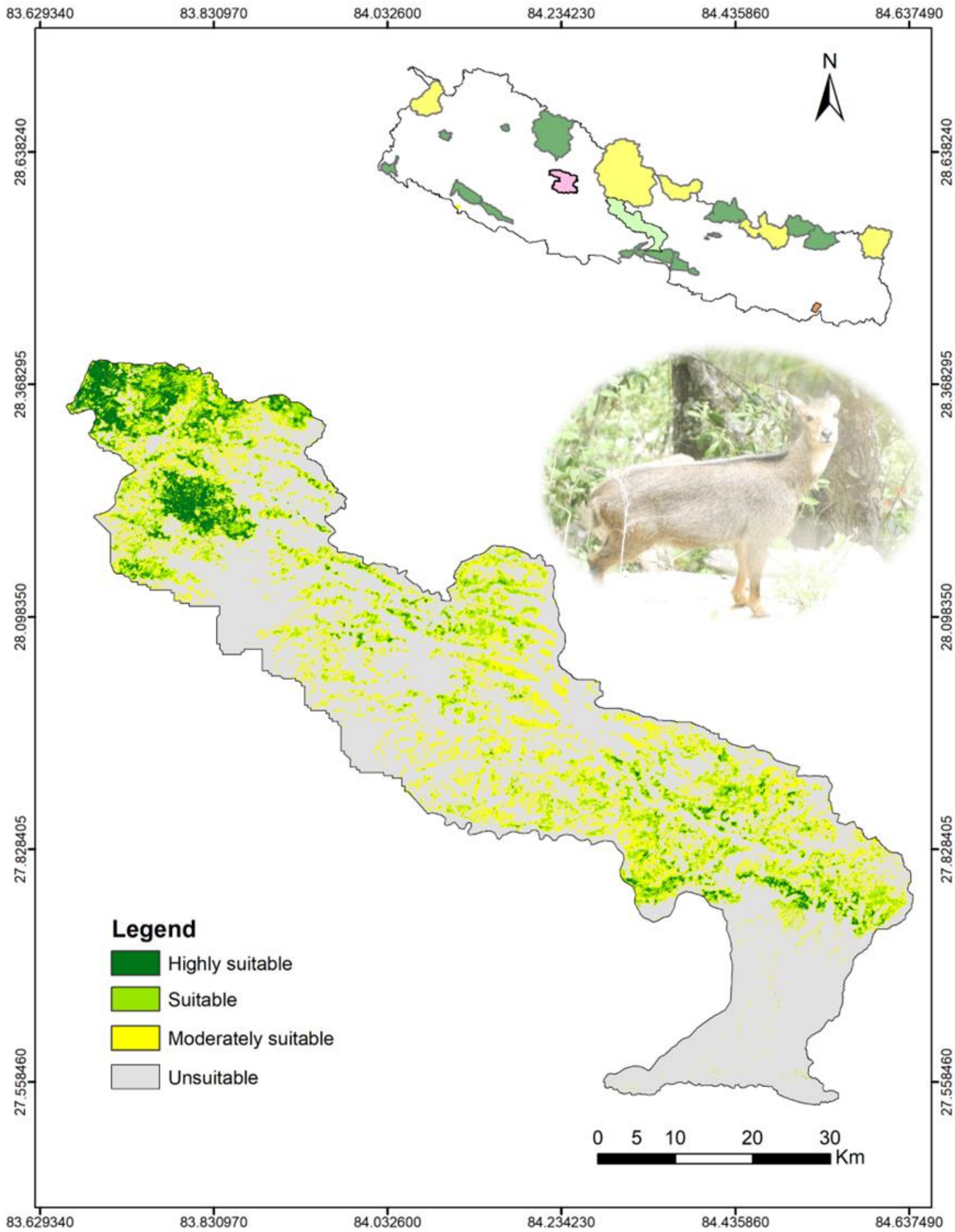


Figure 46: Predicted suitable habitats for Himalayan goral

4.3.6. Rhesus macaque

The ROC obtained from the Maxent revealed the average test AUC 0.725 with a standard deviation 0.029 (Figure 47A). The majority of the environmental variables were important in predicting occurrence of rhesus macaque (Figure 47B). Among 10 environmental variables, model prediction was highly influenced by the distance to buildup/settlements area (contribution = 22.9%) followed by distance to water sources, elevation and forest. Similarly, grassland and NDVI moderately contributed (contribution between 5–10% each) in the model but other variables such as slope, TRI, variety, and distance to croplands contributed less than 5% each (Figure 47).

Proximity to buildup/settlements area, distance to water sources ranged from 2000 to 5000 m (Figure 47C), elevation ranged from 150 – 2100 m, distance to forest ranged up to 500 m (Figure 47D), distance to grassland ranged up to 4500 m, NDVI ranged from 0.2 to 0.8, slope ranged up to 70˚, TRI ranged from 5 to 60 m, index of habitat heterogeneity ranged up to 2.5 to 6.5 and proximity of cropland (<1000 m) were suitable for rhesus macaque (Appendix XXIII).

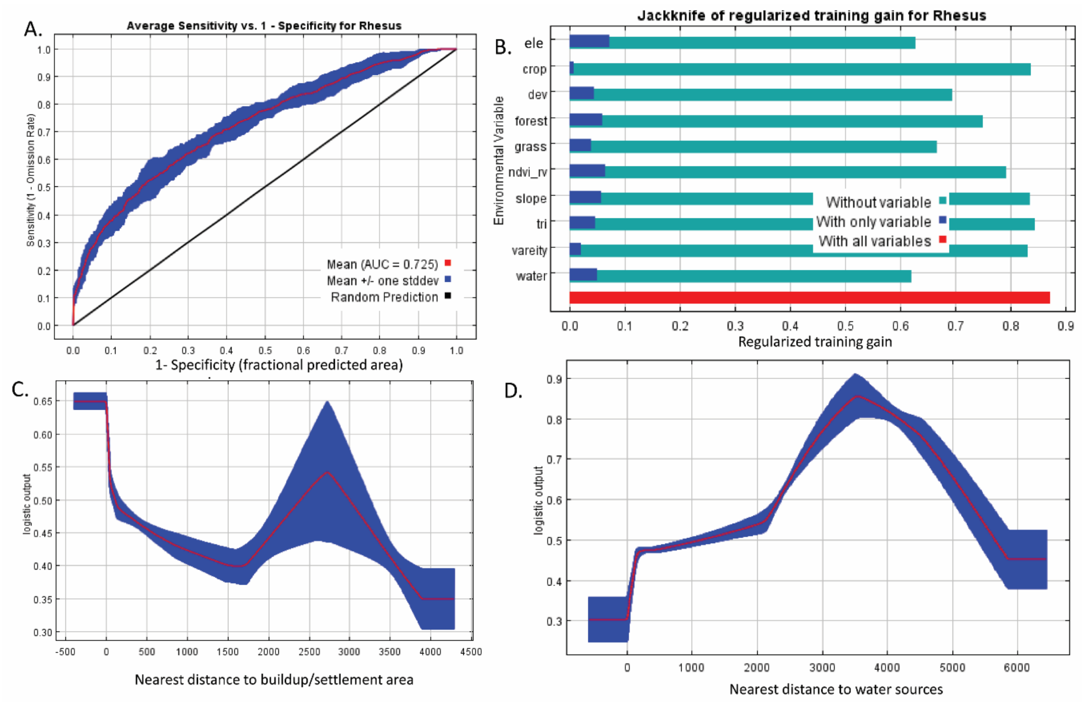


Figure 47: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of rhesus macaque, C. Relationships between nearest distance to buildup/settlement area (m) and the probability of occurrence of rhesus macaque, D. Relationship between nearest distance to water sources and occurrence probability of rhesus macaque

The predicted map showed 12.94% of the total area was highly suitable followed by 21.76% suitable and 38.22% moderately suitable for rhesus macaque (Table 19, Figure 48).

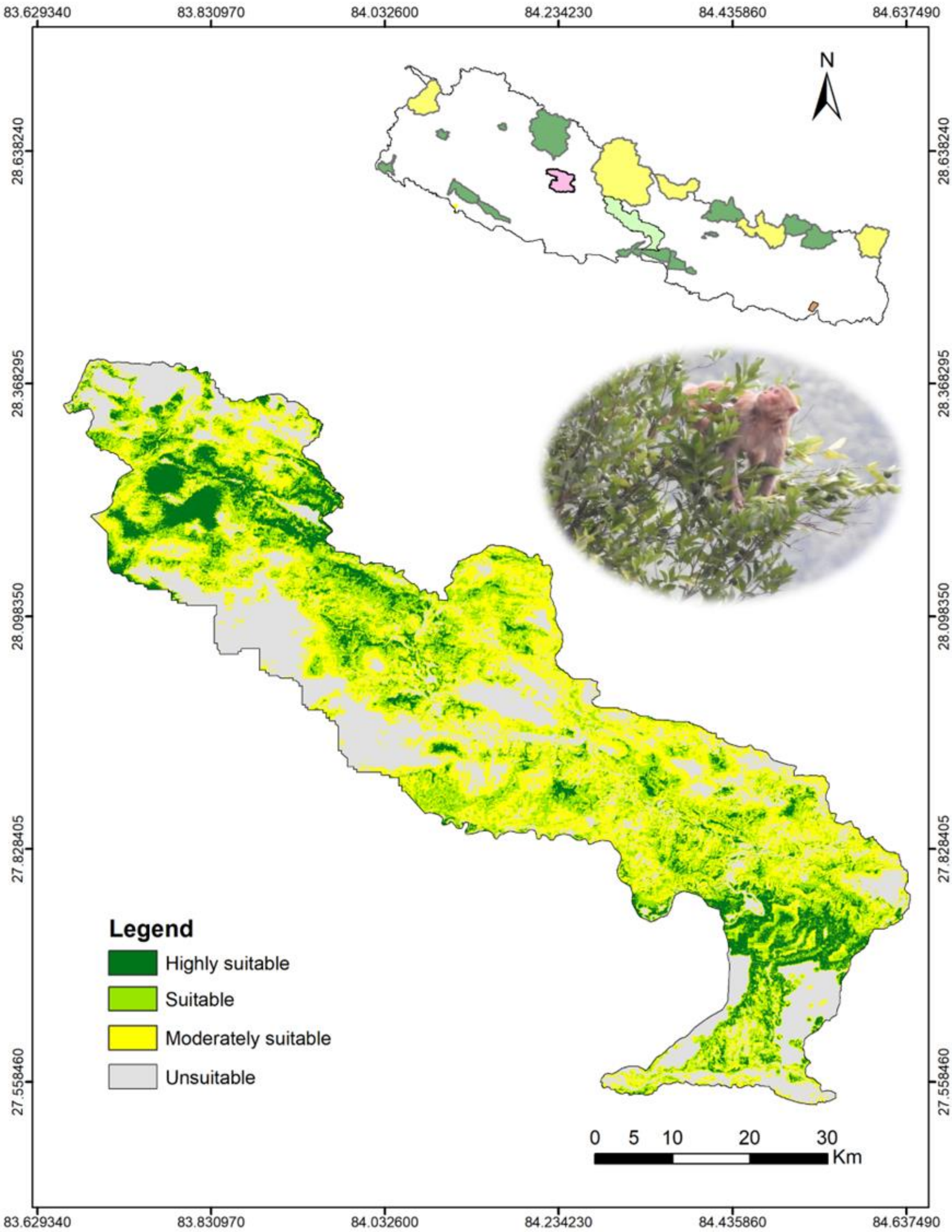


Figure 48: Predicted suitable habitats for rhesus macaque

4.3.7. Langur

The ROC results were acceptable with mean AUC 0.726 ± 0.033 for langur (Figure 49A). The internal Jackknife test revealed that variable examined did not equally contribute to the model. Among nine variables, the nearest distance to cropland, NDBI and MNDWI were the top three important variables (Figure 49B). But the proximity cropland, NDBI and elevation were the major variables had high contribution for the prediction of occurrence of langurs (Table 18). Other variables such as NDVI, the distance of forest, distance to buildup/settlements area, MNDWI and distance to water sources had less than 4% contributions (Table 18).

The response curve revealed that the probability of suitability (>0.4) for langur was ranged up to 2500 m distance from cropland (Figure 49C). Similarly, NDBI below 0.01 (Figure 49D), elevation range from 150 to 2000 m, distance to grassland up to 8000 m, NDVI up to 0.8, nearer or inside the forest area, distance to buildup/settlement area up to 4500 m, MNDWI below 0.10 and distance to water sources up to 4000 m were suitable for langur (Appendix XXIV).

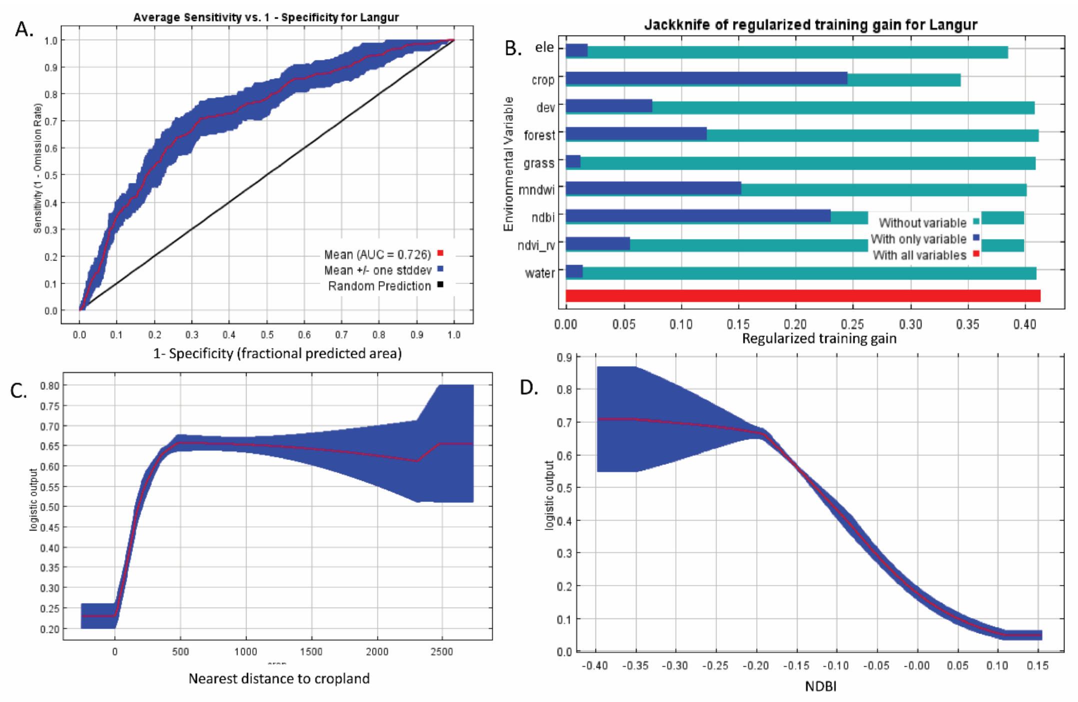


Figure 49: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of langur, C. Relationships between nearest distance from the cropland (m) and the probability of occurrence of langur, D. Relationship between NDBI and occurrence probability of langur

The habitat suitability map revealed only 8.4% area were highly suitable and 26.51% of the area were suitable for langurs (Figure 50, Table 19).

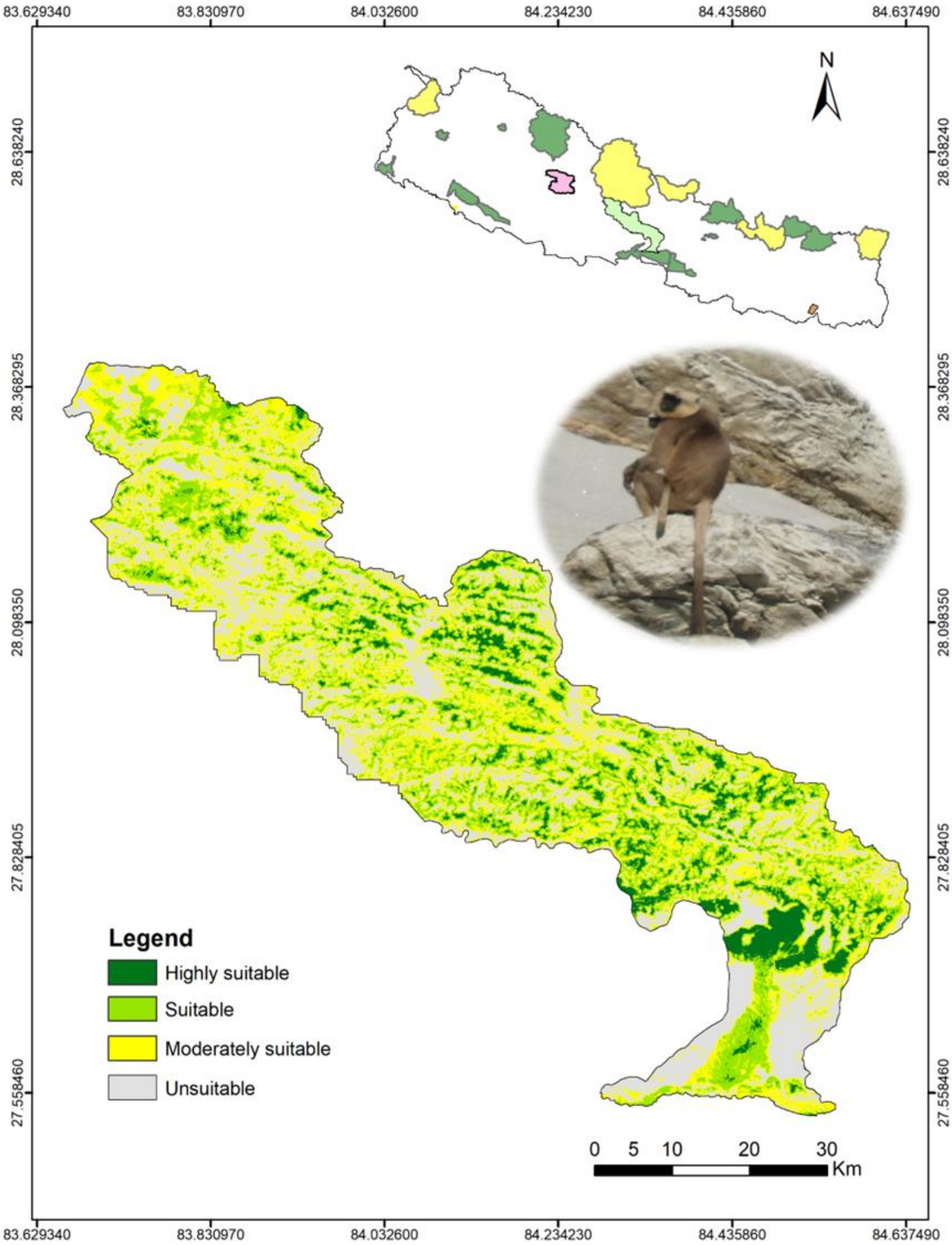


Figure 50: Predicted suitable habitats for langur

4.3.8. Himalayan black bear

The evaluation of the Maxent ROC revealed the average test AUC was 0.832 with the standard deviation 0.048. Hence the model was predicted with statistical accuracy (Figure 51A). The elevation and proximity to cropland significantly contributed to habitat suitability for the Himalayan black bear (Figure 51B). However, distance to grassland, water sources, NDBI, slope, MNDWI, NDVI, distance to buildup/settlements area had moderate contribution in the model (ranges from 1 to

7.4%) whereas variety, TRI and distance to the forest had low contribution (<1% each) (Table 18).

The response curves revealed that the elevation ranging from 1200 to 3300 m was suitable habitats (probability >0.4) for Himalayan black bear (Figure 51C). The habitat suitability was increased with increasing the distance to cropland (Figure 51D) and water sources but decreased with increasing the distance from the grassland (Appendix XXV). The acceptable range of NDBI in the suitable habitat was below -0.1, the slope ranged between 15° and 50°, MNDWI ranged between -0.25 to 0.05, NDVI above 0.4. Similarly, on increasing the distance from the buildup/settlement areas, the suitability was also increased. Habitat heterogeneity index below 4.5, TRI above 20 m and core area of the forest were important for the occurrence of the Himalayan black bear (Appendix XXV).

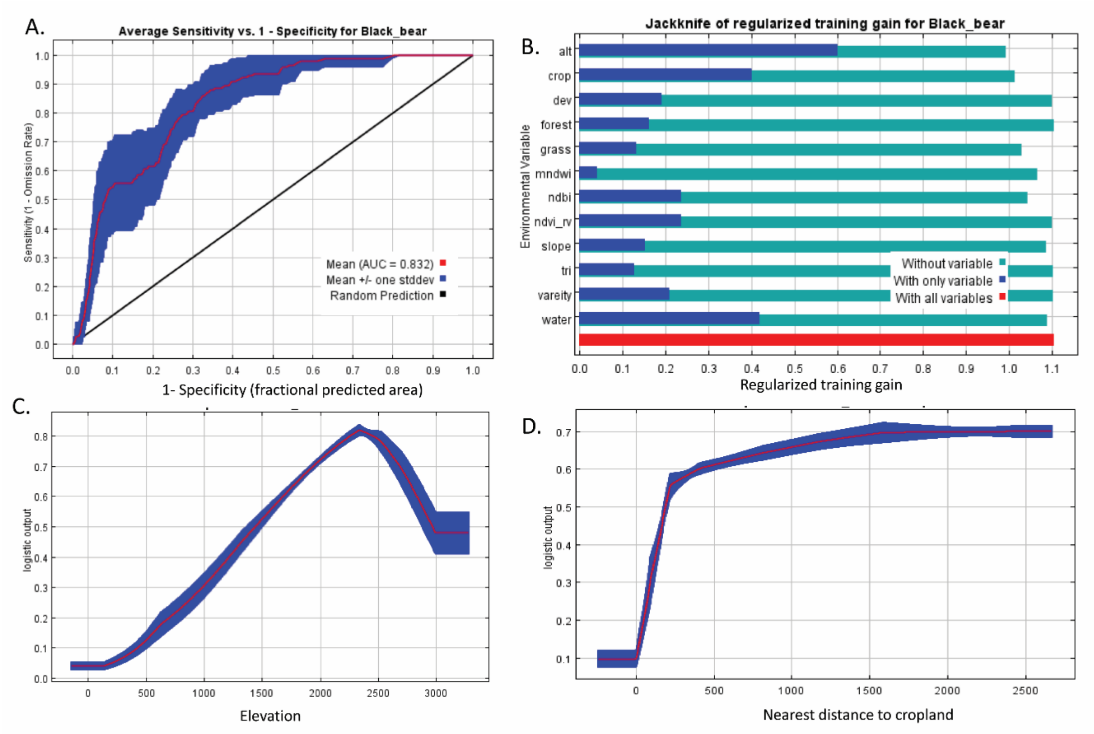


Figure 51: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of Himalayan black bear, C. Relationships between elevation (m) and the probability of occurrence of northern red muntjac, D. Relationship between nearest distance to cropland and occurrence probability of black bear

The habitat suitability map revealed that only 1.81% of total area was highly suitable, 3.98 % was suitable, 8.7 % was moderately suitable and 85.51 % was unsuitable for Himalayan black bear (Table 19). The areas under optimum protection such as PPF and part of ACA were highly suitable for Himalayan black bear (Figure 52).

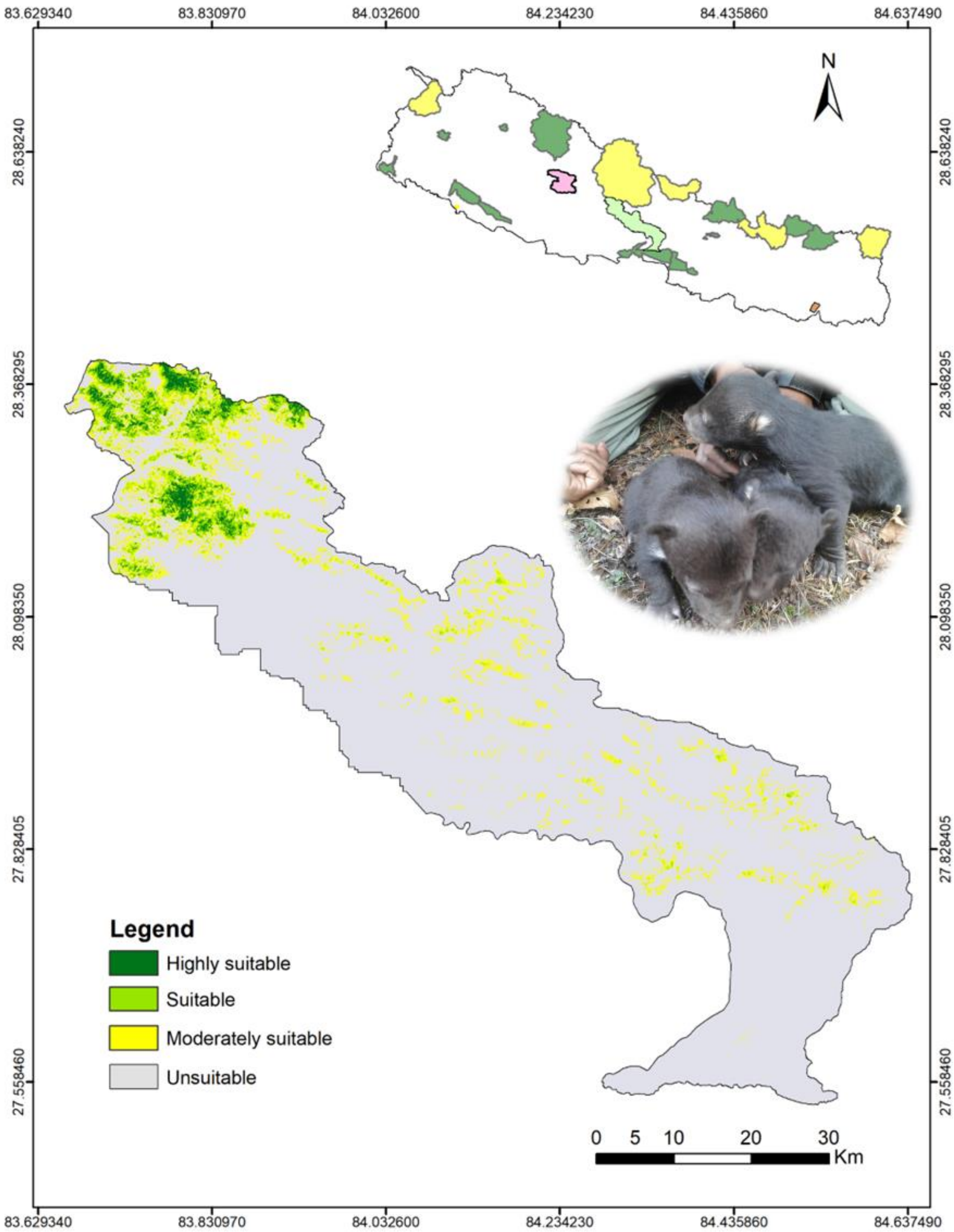


Figure 52: Predicted suitable habitats for Himalayan black bear

4.3.9. Leopard

The results obtained from the Maxent model 25-fold cross validation test revealed accuracy with a mean AUC ± one standard deviation of 0.733 ± 0.014 (Figure 53A). The leopard distribution was influenced by two main environmental variables i.e., prey species richness (contributed 37.2%) and distance to croplands (contributed 35.1%) (Figure 53B). Other variables except distance to buildup/settlements areas (6.7% contribution), contributed below 5% each (Table 18).

The prey richness had a strong positive response to the probability of the occurrence of leopard (>0.4) (Figure 53C). Similarly, distance to cropland (>150 m) (Figure 53D), proximity of settlements, core area of forest, NDVI above 0.2, up to 6000 m distance to grasslands, slope up to 60˚, distance to water sources up to 5000 m, TRI up to 150 m, index of habitat heterogeneity up to 6.5 and elevation up to 3000 m were predicted as suitable for leopard (Appendix XXVI).

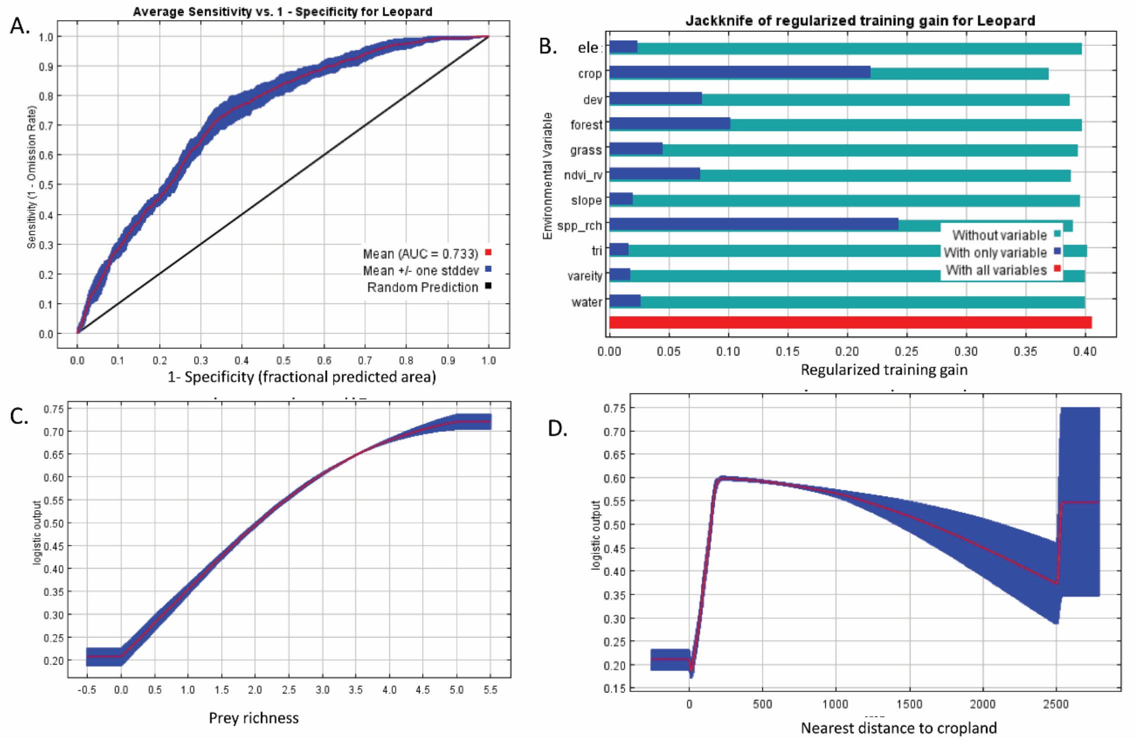


Figure 53: A. ROC curve with AUC values for Maxent model, B. Internal Jackknife test for evaluating relative importance of environmental variables for probability of occurrence of leopard, C. Relationships between prey richness and the probability of occurrence of leopard, D. Relationship between nearest distance to cropland and occurrence probability of leopard

The habitat suitability map of leopard revealed that only 6.52% of the total area was highly suitable, 23.77% was suitable, and 25.03% was moderately suitable (Table 19). The protected sites such as BCF, PPF and part of ACA were highly suitable for leopard whereas sparse distribution was observed throughout the mid-hills of Tanahun District (Figure 54).

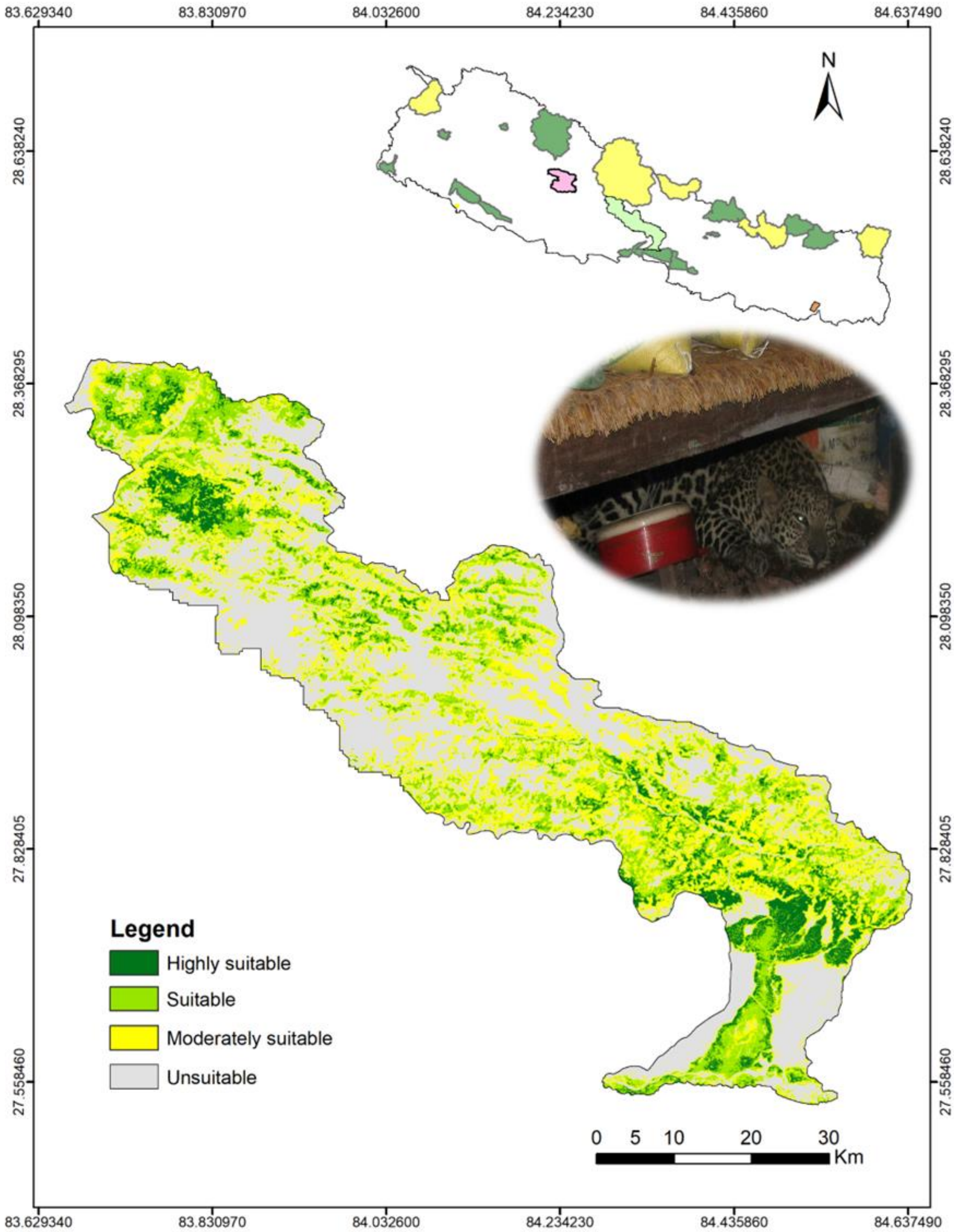


Figure 54: Predicted suitable habitats for leopard

4.4. Discussion

Occupancy modeling using PRESENCE provided the probability of occurrence (i.e., occupancy) of the large mammals separately. But the relation of probability of occurrence of the large mammals with different environmental variables were evaluated by using SDM. SDM using Maxent provided results on habitat quality of two carnivores and seven prey species in CHAL. The separate modelling of these mammals clearly revealed low, moderate and high specifications with different selected environmental parameters. The leopard among the carnivores, northern red muntjac, wild pig, langur and rhesus macaque were the most tolerant species which were reported throughout the landscape but chital and sambar were confined to the lower elevation specially BCF. Similarly, the occurrence of the Himalayan goral was confined in the mid-hill. The estimated occupancy of the leopard was the highest and Himalayan goral was the lowest as the leopard were observed from majority of the transects whereas Himalayan goral only confined in the rocky terrain of mid-hills.

The most common environmental factors that affect the occurrence probability of the large mammals in this human-dominated landscape varied according to the nature of the species. The most common variables for chital, sambar, wild pig, Himalayan black bear, northern red muntjac, Himalayan goral and langur were elevation, distance to croplands, distance to grassland and TRI, likewise, distance to buildup/settlements area, distance to forest and elevation were the most important variables for rhesus macaque. Similarly, the prey species richness and distance to cropland were the most common variables for leopard occupancy. The previous studies on habitat suitability of leopard (Thapa, 2011; Erfanian *et al.*, 2013; Ebrahimi *et al.*, 2017; Maharjan *et al.*, 2017), Himalayan black bear (Bista *et al.*, 2018; Zahoor *et al.*, 2021), mountain ungulates (Paudel *et al.*, 2015) found elevation, distance to settlements, forest, grassland, TRI, and prey richness are the important variables.

In this study, the nearest distance to cropland, NDVI and grasslands were the most important factors for northern red muntjac. The occurrence portability was higher in nearer to cropland and settlements as these are less sensitive to human disturbance (Mishra, 1982). The scattered distribution was seen in the mid-hill of Tanahun and Kaski as it is a human-dominated landscape and human settlements along with croplands are scattered. The northern red muntjac is a habitat generalist species that is recorded from low elevation to high elevation (up to 3500 m) in Nepal (Jnawali *et al.*, 2011). But in the mid-hill and the mountain area, they can't adapt to live in the open and rugged mountain slope, hence the topography limits them to the area around the croplands and human settlements nearer to the forest (Paudel *et al.*, 2012). Two protected forests (BCF and Panchase) and protected areas (part of ACA and CNP) were the major sites for their probability of occurrence. In the less protected and human dominated landscape, human settlements and disturbance limits the occurrence of this species and their movements within the small patches of the forest (Paudel *et al.*, 2012).

Chital is the principal prey species of tiger and leopard (Mishra, 1982; Grey, 2009; Bhattarai & Kindlmann, 2012c). The results showed BCF areas were the suitable habitats for chital and was recorded in high number (Adhikari *et al.*, 2021b) but the occupancy of the chital was only 0.214 ± 0.034 as it confined to the lowland area of the study landscape. Elevation was one of the major determinants for the occurrence of chital that limits their distribution (< 400 m). Studies by Pokharel and Storch (2016), Mishra (1982), also indicated that chital is restricted relatively narrow elevation range (up to 1000 m). On increasing the distance from the cropland, the occupancy of the chital increased. The grasslands scattered inside the forest of the BCF are the suitable habitats for the chital (Thapa, 2011; Adhikari *et al.*, 2021b). Likewise, the wetlands present inside the BCF and surrounding areas, well-managed forest and grassland support the abundance of the chital. A similar type of distribution patterns was also observed in Bardia National Park, Nepal and other parts of lowland Nepal (Karki *et al.*, 2016), Suklaphanta National Park (Pokheral & Wegge, 2019), and in CNP (Thapa, 2011). The habitat suitability map indicated that about 6% of the total study area was suitable for chital.

Sambar is nationally and globally vulnerable, the largest deer found in central and western Terai of Nepal (Jnawali *et al.*, 2011). Less than 3% of the total area of this landscape was suitable for the sambar as they were only confined to BCF, hence, its estimated occupancy was only 0.201 ± 0.064. The range of the sambar is estimated as 20,000 km^2 in Nepal which is about 13% of the total area of Nepal but the actual area of the occupancy is less than 2000 km^2 (1.35%) (Jnawali *et al.*, 2011; DNPWC, 2022), hence this narrow-protected forest is very important for sambar conservation. Elevation, distance to cropland, distance to grassland, and distance to forest were the major correlates that supported the higher probability of occurrence of sambar. These are confined only to low elevation up to 400 m, a similar type of the study also indicated the same altitudinal range of the sambar (Mishra, 1982). Distribution of the sambar occurs along the foothills of Chure in the southwest part of Nepal in the PAs such as Suklaphanta National Park, Bardia National Park, Banke National Park, Chitwan National Park and Parsa National Park (Jnawali *et al.*, 2011; DNPWC, 2022). They are shy in nature and live in a variety of habitats far from cropland and settlement areas and nearer to the grassland, forest along with water sources (Timmins *et al.*, 2015). Floodplains of Rapti, Khageri, Budi Rapti and other streams provide the suitable foraging ground for the many ungulates (e.g., sambar) (Thapa, 2011; Adhikari *et al.*, 2021b). Hence, BCF is an important corridor for the wildlife that provide an alternative habitat for many mammals in CHAL.

Wild pigs are adapted to a wide range of environment and commonly found in all types of habitats (Keuling & Leus, 2019) and elevations (below 4000 m) (Jnawali *et al.*, 2011; Keuling & Leus, 2019). Wild pig is widely distributed in Nepal and recorded from all PAs of Terai and in some parts of the PAs of uplands (DNPWC, 2022). Besides the PAs, it also found outside the protected area (Baral & Shah, 2008). The forest outside the PAs also played an important role in their survival as reported in our study. This study found the scattered distribution of the wild pig mainly close to the croplands.

The terrain rugged sloppy area of mid-hill of the Seti Corridor of Tanahun District, PPF and part of the ACA of this area was considered as the suitable habitat for Himalayan goral. It is adapted to a wide variety of the habitat but it mostly preferred open plant communities with grass cover (Green, 1987; Paudel *et al.*, 2015) and is preferred to adapt in the rocky and steep slope, rugged mountain terrain (Thapa *et al.*, 2011; Paudel *et al.*, 2015; Adhikari *et al.*, 2019). The suitable habitat of Himalayan goral is scattered in the mid-hill of the study area and reported 4.66% of the total area was highly suitable for goral. Goral is distributed in small, highly fragmented and patchy area of CHAL as previously reported by Paudel *et al.* (2015) from the western Nepal and found only 4% area highly suitable for goral, similarly, Hajra (2002) reported less than 1% highly suitable habitat for goral in Siwalik hills of Uttaranchal, India.

Rhesus macaque is an important prey species of leopard (Thapa, 2011; Bhattarai & Kindlmann, 2012c). Rhesus macaque can adapt to any natural habitat and man-made environment such as buildup areas, human settlements and religious sites (Jnawali *et al.*, 2011; Chalise, 2013). This result also indicated that they were found near to the buildup/settlements areas. The distribution of the rhesus macaque was common in all places and all types of habitats lower than 3000 m. But on increasing the elevation above 1700 m, the occurrence probability was sharply decreased. The previous studies also indicated the elevation range of rhesus macaque is 3000 m (Wada, 2005; Chalise, 2013). The habitat suitability map of rhesus macaque indicated that it is distributed in all parts of the study area except highly steep areas and densely populated areas. They are associated with croplands and settlements hence, human monkey interaction is the major issue in the mid-hills of Nepal (Sharma & Acharya, 2017; Adhikari *et al.*, 2018b; Koirala *et al.*, 2021).

The suitable areas for langur found that the habitat outside the protected area (central part of CHAL) was suitable for it. The ample availability of the food resources in this fragmented landscape supported the distribution of the langur. A similar type of the study of Bagaria *et al.* (2020) on Himalayan langur of western Himalayas of India and Nepal pointed out that only 15% of the total suitable habitat was supported by PAs. The suitable habitat in a territorial forest for *Semnopithecus entellus* was also found by the study of Khanal *et al.* (2018) in Nepal. A couple of studies revealed that primate species (e.g., langurs) are highly interactive with humans and lived nearer forests of the human settlements and croplands and are also involved in crop-raiding (Adhikari *et al.*, 2018b; Khanal *et al.*, 2018). The distribution of the langur is up to the elevation of 4000 m but more in the middle elevation (Singh *et al.*, 2020) as in this study. Moist deciduous forest of Siwalik and broadleaf forest of mid-hill are suitable for langurs (Jnawali *et al.*, 2011; Singh *et al.*, 2020).

This study showed the patchy distribution of black bears in the mid-hill. Major two forest patches of PPF and ACA supported were observed more suitable for black bear. The distribution of the black bears occurs within the mid-hill and Himalayan protected areas of Nepal (Jnawali *et al.*, 2011). The altitudinal range of the black bear was reported from 1600 m to 3200 m in ACA, Nepal (Bista & Aryal, 2013). Similarly, the study by Su *et al.* (2021) in Makalu Barun National Park, Nepal reported that 2000 to 3000 m was the most suitable for the black bear. Another study in the eastern Himalayas in Pakistan reported a black bear between 2500 to 3000 m (Ali *et al.*, 2017). Our study also showed that the elevation from 1700–2700 m was the most suitable for the Himalayan black bear but was reported even less than 1000 m. A similar type of observation was found in the Bardia National Park (BNP). The camera trap in BNA captured the Himalayan black bear in 2000 and 2016 at the elevation of 237 m and 327 m respectively (Yadav *et al.*, 2017). Himalayan black bear showed a positive response with the distance to cropland but the suitable distance was in between >500 m. The research of Morovati *et al.* (2020) in Iran also reported that distance from the croplands and gardens was found to be a more important variable as these areas provided the foraging grounds for the black bear. The study of Ali *et al.* (2017) in the Western Himalayas, of Pakistan found that black bears lived forests near the agricultural fields and visited frequently the agriculture fields during the crop season. This study found 159.12 km^2 of the total area was suitable as a similar type of study conducted by Bista and Aryal (2013) estimated 212 km^2 area (total study area 377 km^2) was potential for the black bear in Lamjung District, a part of ACA. But the suitability area obtained from this study was lower than in the Makalu-Barun National Park and its surrounding buffer zone (estimated area = 647 km^2) (Bista *et al.*, 2018).

The occupancy of the carnivore depends upon the prey availability and habitat quality. About 30% of the total area of this landscape was reported as suitable for leopards. The prey species richness and distance to croplands were the most important correlates for leopard. Elevation was the least important variable for the occurrence of leopards as they were reported to all types of the elevation of the study area as the study by Sarkar *et al.* (2018) in Indian part of the Kailash Sacred Landscape. The distribution ecology of the leopard also supported these results (Grassman, 1999; Dickman & Marker, 2005). The prey species richness was higher in the BCF, PPF and part of ACA, hence, the probability of occurrence of the leopard was more there. Scattered type of the distribution was found in the Seti River basin of Tanahun District (block B and C). NDVI, distance to forest and grasslands were also important for the occurrence of leopards. A similar type of results was also found in the study of Thapa (2011) in CNP; Nepal Thapa *et al.* (2014) in Bhabar of Terai Arc, Nepal, Sarkar *et al.* (2018) in Kailash Sacred Landscape, India, Jafari *et al.* (2019) in the Tang-e-Sayad protected area, Iran. The probability of occurrence of leopards was mainly found higher close to the settlements. These results indicated the increasing trends of human leopard conflicts in the mid-hills and in lowlands where there is high number of tigers in the core areas (Bhattarai & Kindlmann, 2012c; Acharya *et al.*, 2016; Adhikari *et al.*, 2018b; Lamichhane *et al.*, 2018).

4.5. Conclusions

The occupancy and species distribution modelling of the large mammals indicate that CHAL is an important area for conservation of mammals. The occupancy of leopard is comparatively higher than other species. Nearest distance to cropland and NDBI for northern red muntjac; elevation and distance to cropland for chital, sambar, wild pig and Himalayan black bear; distance to cropland and TRI for Himalayan goral; nearest distance to settlements and water sources for rhesus macaque; distance to cropland and

NDBI for langur; prey richness and nearest distance to cropland for leopard are two important environmental variables for their distribution. The total extent of suitable habitats covers 30.29% for muntjac, 14.55% for wild pig, 34.7% for rhesus macaque, 34.65% for langur and 29.93% for leopard. Similarly, chital and sambar confine in the lowland with 6.45% and 2.6% of suitable areas respectively. Likewise, 15.55% and 5.79% of mid-hill of this landscape are suitable for Himalayan goral and black bear respectively. Along with the two protected areas (CNP and ACA), the Barandabhar Corridor Forest, Panchase Protected Forest, Rumsi region, Phirphire area, Rupa area, and Bagamara area are suitable for the studied species of mammals. This study recommends that before, managing the landscape level habitat for the leopard, Himalayan black bear and prey species, the habitat suitability study of such species is essential to all the potential areas for conservation planning and strategies to improve the habitat quality and long-term viability.

CHAPTER 5

5. LANDSCAPE LEVEL HABITAT CONNECTIVITY OF LARGE MAMMALS

Abstract

The populations of many species of large mammal occur in small isolated and fragmented habitat patches in the human-dominated landscape. Maintenance of connectivity in the fragmented habitats is important for a healthy population of large mammal. This study evaluated the landscape patches using habitat suitability modelling data and their linkages between CNP and ACA by using the least-cost path approach with circuit theory and the Linkage Mapper tool in ArcGIS. A total of 15 habitat patches (average area 26.67 ± 12.70 km^2) in the landscape support more than 50% of the total large mammal species in each patch. Various level of connectivity exists between habitat patches within the CHAL; a poor connectivity for chital and sambar (Cost-weighted distance CWD: Euclidean distance EucD >100), functional connectivity (low least-cost path) for muntjac, wild pig, leopard and lower least cost path for Himalayan goral and Himalayan black bear. Furthermore, the multi-species connectivity analysis identified the potential functional and structural connectivity between the isolated populations and habitat patches. Therefore, these sites need to be prioritized for the conservation of large mammals in the landscape.

5.1. Introduction

Landscape functional connectivity is the frequency of animal movement between the isolated habitat patches along the landscape (Fahrig, 2003; Ayram *et al.*, 2016; Fletcher *et al.*, 2018). Habitat connectivity in the landscape permits the movement of the animals and maintenance of other ecological process such as gene flow, seasonal migration, prey-predator relationships (Ayram *et al.*, 2016). Poor connectivity increases the risk of extinction of species because there are high chances of inbreeding depression and no alternatives for movement during the adverse ecological conditions in their existing habitat (O'Grady *et al.*, 2006; Koen *et al.*, 2014). Hence, identification of connectivity in the landscape and improving functionality are essential for the conservation benefits (Taylor, 2006; Poor *et al.*, 2012; Koen *et al.*, 2014; Ayram *et al.*, 2016). Habitat corridors are the bands of the lands that provide the passage for the movement of animals. If the movement of animals between the isolated patches has been reported, it is regarded as functional corridor (Beier *et al.*, 2008; Howey, 2011; Sarkar *et al.*, 2018). The fragmentation, habitat loss, encroachment and increasing developmental activities (i.e., roads, hydropower, urbanization) are the major drivers of the landscape connectivity that restrict the animal movements (Fahrig, 2003; Wilson *et al.*, 2015; Fletcher *et al.*, 2018).

The general assumption is that if the scattered fragmented habitat is interconnected with each other, it will support the animal movement and ecological processes (Kindlmann & Burel, 2008). Hence, the identification of patches and corridor is essential for the conservation of biodiversity in human dominated landscape (Taylor *et al.*, 1993; Fahrig, 2003). Many studies on the landscape connectivity targeted the single species, especially, flagship species such as the tiger (Rathore *et al.*, 2012; Dutta *et al.*, 2016; Suttidate *et al.*, 2021), Asiatic elephants (Huang *et al.*, 2019; Vasudev *et al.*, 2021), leopard (Ghoddousi *et al.*, 2020; Kaboodvandpour *et al.*, 2021). Large carnivores are regarded as the habitat generalists and their movement behavior is greatly influenced by the prey availability (del Rio *et al.*, 2001; Lamichhane, 2019; Pokheral & Wegge, 2019) and human disturbance (Bhattarai & Kindlmann, 2013). Maintenance of populations of diverse prey species in fragmented landscape is important for occupancy and movement of large carnivores. Hence, identification of the habitat patches and potential corridors between them is the best option for the conservation of large carnivores and their prey species (DNPWC., 2016).

Landscape resistance is an important tool for modelling and identifying the potential connectivity along the landscape (Almasieh *et al.*, 2019; Carroll *et al.*, 2020). Two approaches have been used to estimate the resistance values- one is expert opinion (Zeller *et al.*, 2012) and field experience; and the other is habitat suitability models (Almasieh *et al.*, 2019; Ashrafzadeh *et al.*, 2020). Among these approaches, the habitat suitability model is more appropriate to evaluate resistance values and widely used to model habitat connectivity (Koen *et al.*, 2014; Brodie *et al.*, 2015; Phillips *et al.*, 2021). The linkage pathways tool (Linkage Mapper) is commonly used to identify the relation between the nearer habitat patches and develop the maps of a least-cost corridor (Cushman *et al.*, 2013; Dutta *et al.*, 2016).

Modelling connectivity between patches within a landscape have been identified using single species as well as multispecies but multi-species modelling is regarded as more effective (Brennan *et al.*, 2020). The single species connective models overlay or combine to get a single map and help to detect the hotspots and potential paths for connectivity (Wang *et al.*, 2018; Brennan *et al.*, 2020; Meyer *et al.*, 2020). Till date, few literatures have been found for modelling the species connectivity using species distribution modelling in Nepal (Shrestha & Kindlmann, 2020; Subedi *et al.*, 2021) but these are related with single species connectivity. Hence, studies related to the multi-species connectivity are still scarce. Hence, this study evaluated the potential connectivity using habitat suitability data for two carnivores (leopard and Himalayan black bear) and seven prey species (northern red muntjac, chital, sambar, wild pig, Himalayan goral, rhesus macaque and langur).

5.2. Materials and methods

5.2.1. Study area

The study area which connects CNP with ACA and covers 2749.48 km^2 in the central part of CHAL. It covers parts of the Chitwan, Tanahun, Kaski, Syanja and Parbat districts with elevation ranging from 150 m to 3300 m. The lowland of this landscape has tropical and subtropical climates, mid-hills have subtropical and temperate climate and upper part of mountain have subalpine climate (Paudel *et al.*, 2021). Rich flora and fauna are supported by topography and climate variability (DFRS, 2015) (Figure 55).

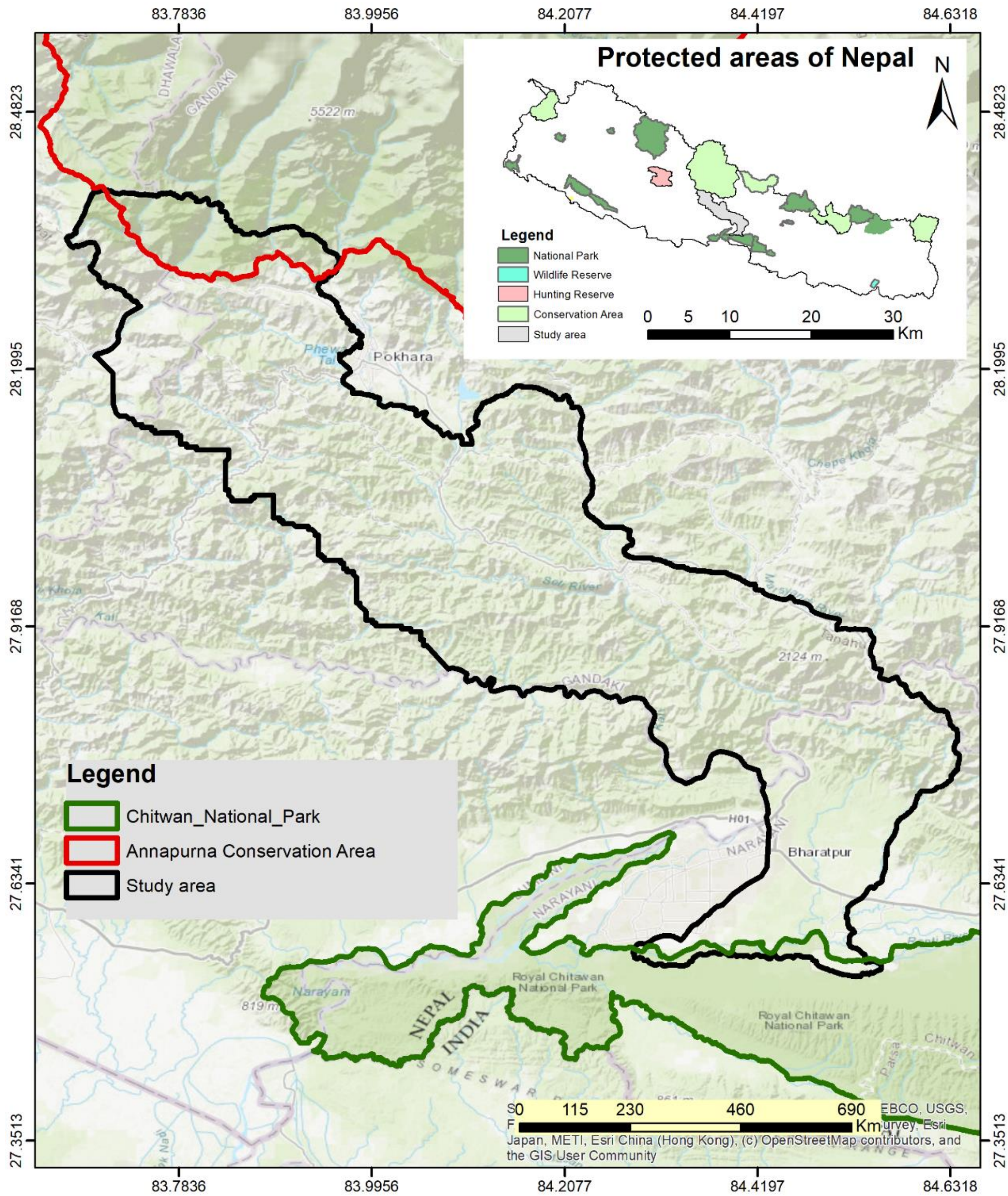


Figure 55: Intensive study area and the inset showing protected areas of Nepal along with study area

5.2.2. Methods

5.2.2.1. Habitat suitability models

The habitat suitability models prepared using the Maxent method was used for the identification of the corridors for each species. These suitability models are also useful to identify the prioritizing areas (e.g., habitat patches) for habitat and species (Rondinini *et al.*, 2011; McKerrow *et al.*, 2018). Here, the results of habitat suitability were used to prepare the habitat patch as well as resistance layers.

5.2.2.2. Landscape resistance or cost map preparation

The resistance or cost map was prepared using raster habitat suitability map (Appendix XXVII). Every cell on the map has a numeric value that indicates the cost that should be paid to pass through each cell (Bagli *et al.*, 2011; Morovati *et al.*, 2020). The cost map was developed by inverting the value of habitat suitability using the following formula (Almasieh *et al.*, 2019; Morovati *et al.*, 2020).

$$\text{Cost} = 100 \times (1 - \text{habitat suitability}) \quad (8)$$

The lower cost is assigned to highly suitable areas whereas the highest cost for the habitats with low suitability (Almasieh *et al.*, 2019; Morovati *et al.*, 2020).

5.2.2.3. Identification of habitat patch

The continuous probability of occurrence was converted to binary predictions of presence and absence based on average equal sensitivity and specificity threshold. The predicted maps of all species were combined to identify the species richness of an area. The habitat patches were defined based on the number of species present in that area. More than 50% species' present areas with 5000–pixel size was defined as the patch (Sahraoui *et al.*, 2017).

5.2.2.4. Modelling connectivity

Integrated tools of least-cost path (LCP) approaches with circuit theory were used to identify the linkage between the patches. The program Linkage Mapper 2.0.0. (McRae & Kavanagh, 2011) was used to identify the LCP for the movement of the mammals from one patch to another. The Linkage Mapper identifies the closer patch, develops the network between the patches and calculate the least-cost distance and paths (McRae & Kavanagh, 2011). The minimum cost weighted distance is regarded as the strong corridor between two patches. The least-cost path of all the species was identified and then, combined to find the multi species corridor between the patches. The Kernel density estimation method was used to identify the hotspots (Thakali *et al.*, 2015) for the connection of isolated population of the mammals in the patches.

5.3. Results

5.3.1. Habitat suitability model

SDM revealed the nearest distance to cropland, altitude, distance to grassland, forest, water sources, and settlements, as well as the Normalized Difference Built-up Index (NDBI) and the Normalized Difference Vegetation Index (NDVI), were the main factors that predict the occupancy of mammals. Suitable habitat for different species were different for example 30.29% suitable for northern red muntjac, 6.45% for chital, 2.6% for sambar, 14.55% for wild pig, 15.55% for Himalayan goral, 34.8% for rhesus macaque, 34.65% for langur, 5.79% for Himalayan black bear and 29.94% for leopard (Table 19, Figures 38, 40, 42, 44, 46, 48, 50, 52, 54).

5.3.2. Habitat patch

A total of fifteen habitat patches (mean patch size - 26.67 ± 12.70 km^2) were identified in central part of the landscape each of patch these patches supported more than 50% of the total mammal species reported (n = 9). All the patches occupied only 14.56% of the area of landscape. The patch size ranged from 4.52 km^2 in the forest in the Raipur, Phirphire area to 194.36 km^2 in BCF and surrounding (Table 20, Figure 56).

Table 20: Location and area of identified habitat patches in landscape

Patch code	Name	Area (Km^2)
1	Ghandruk ACA area	44.59
2	Forest camp, Australian camp area	24.42
3	Lumle	5.79
4	Panchase	59.89
5	Pipaltari to Ramja	6.18
6	Chilaunebas, Bhagera	8.11
7	Raipur, Phirphire area	4.52
8	Tharpek area	5.26
9	Rumsi, Keshabtar area	4.59
10	Bhirkot area	4.59
11	Bandipur area	7.37
12	Ghumaune, Chikeshowri area	5.69
13	Kota, Baidi area	15.88
14	Devghat area	8.78
15	Barandabhar and surrounding area	194.36

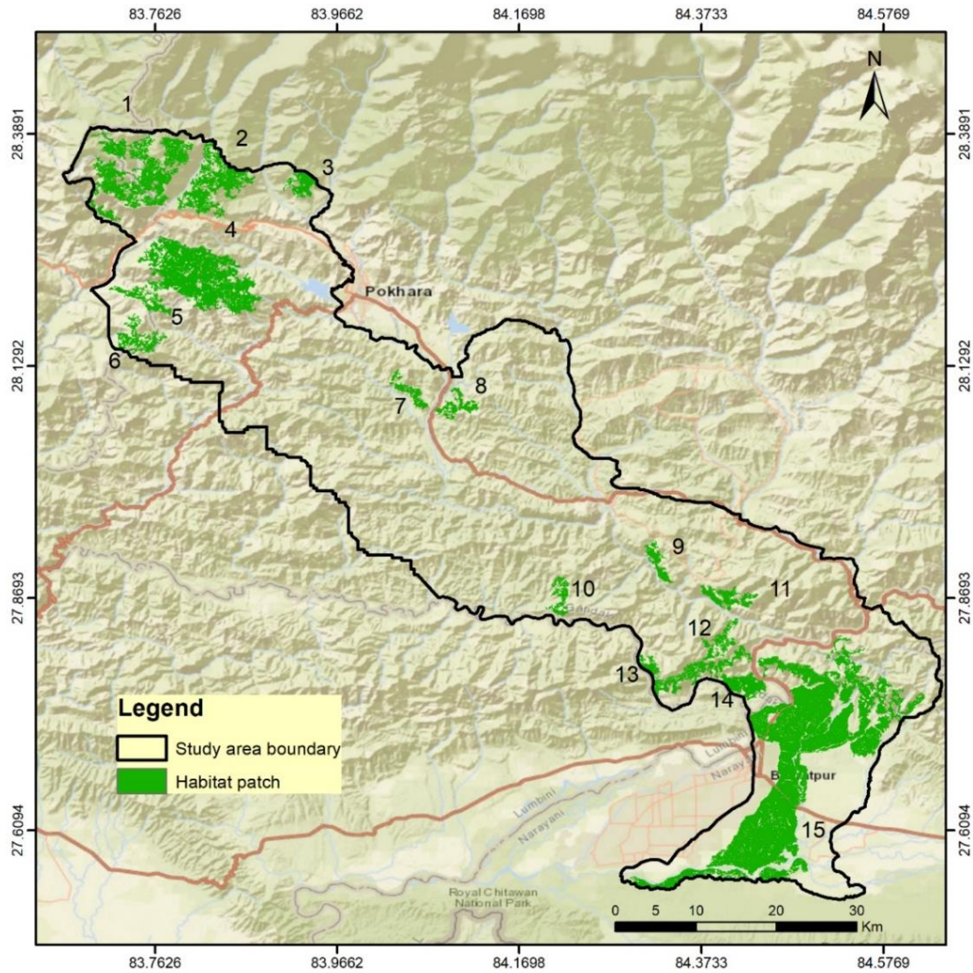


Figure 56: Major habitat patches (1–15), the number indicate the separate patches

5.3.3. Potential corridors

Low resistance areas for the movement of the specific large mammal species were scattered along the landscape. Buildup/settlement area, croplands were the major resistance in this landscape.

A total of nine LCPs were identified for nine selected mammals (two carnivores, five ungulates and two primates). A total of 31 linkages were identified between 15 habitat patches for northern red muntjac. The linkage matrix varied between patch pairs. The ratio of CWD and EucD was the lowest (CWD: EucD = 41.87) between patch two (Australian camp area) and three (Lumle area) indicated the highest quality of corridor., Similarly, the highest ratio between patch 12 and 13 (CWD: EucD = 183.47) indicated the lowest chances of connectivity (Table 21, Figure 57, Appendix XXVIII).

Table 21: Characteristics of linkages of northern red muntjac between the 15 patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	10.07	689.21	12.56	72.68	59.31
SE	2.04	143.66	2.64	3.27	1.90
Range	52.02	3660.55	60.27	121.60	51.32
Minimum	0.035	4.37	0.072	41.87	30.71
Maximum	52.05	3664.92	60.34	163.47	82.03

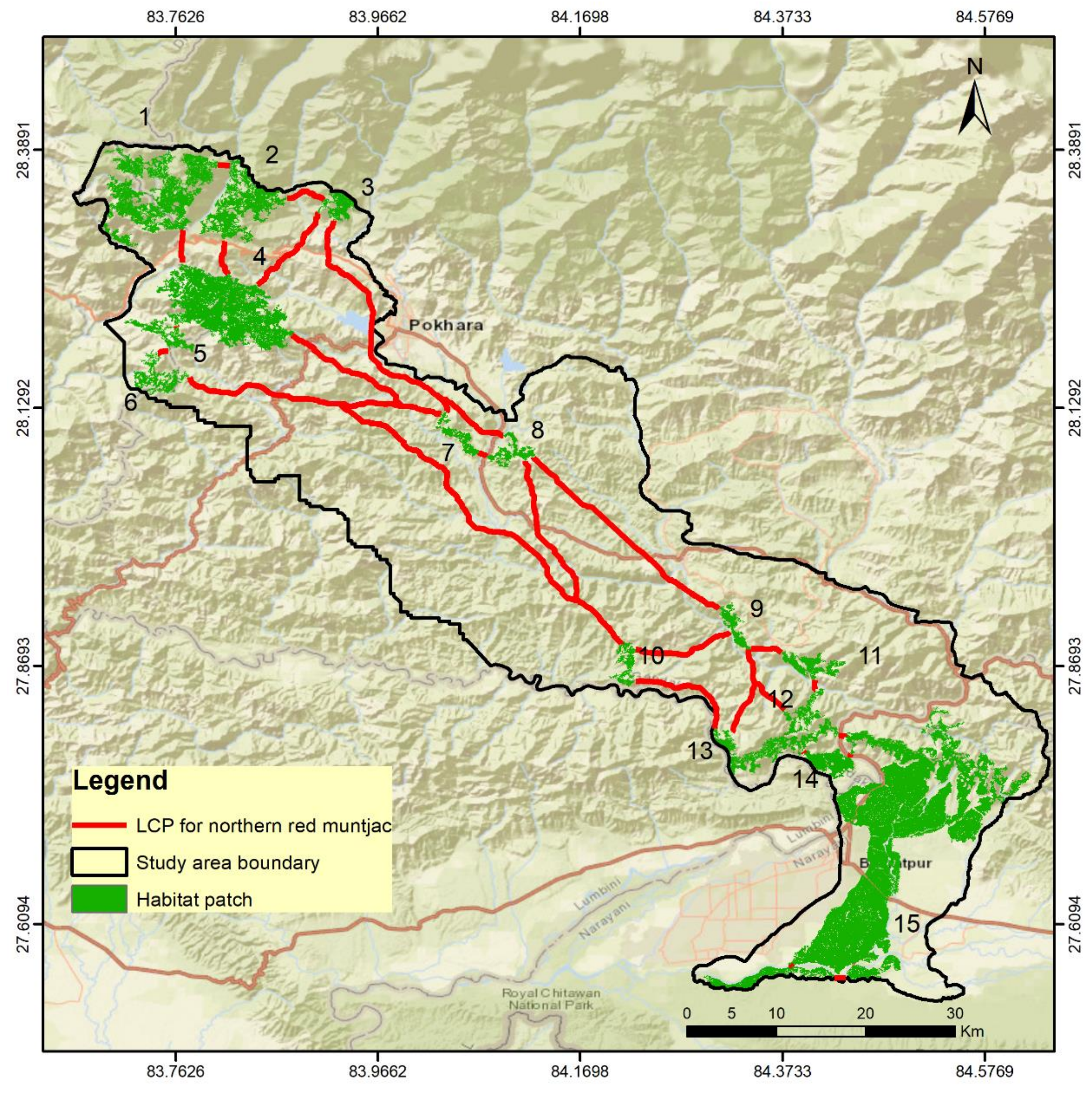


Figure 57: Least-cost path for northern red muntjac across major habitat patches in CHAL

Thirty different corridors were identified between the patches for chital. Relatively lower ratio of CWD and EucD was estimated between Devghat (14) and Barandabhar (15) (CWD:EucD = 83.74), but there was very weak relation of chital to other patches (CWD:EucD>100)(Table 22, Figure 58, Appendix XXVIII).

Table 22: Characteristics of the linkages of chital across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, weighted km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	12.27	1263.11	14.24	106.94	92.86
SE	2.88	304.09	3.56	3.59	1.83
Range	83.63	8951.72	107.64	141.59	52.33
Minimum	0.035	6.94	0.072	65.05	48.12
Maximum	83.66	8958.66	107.708	206.64	100.45

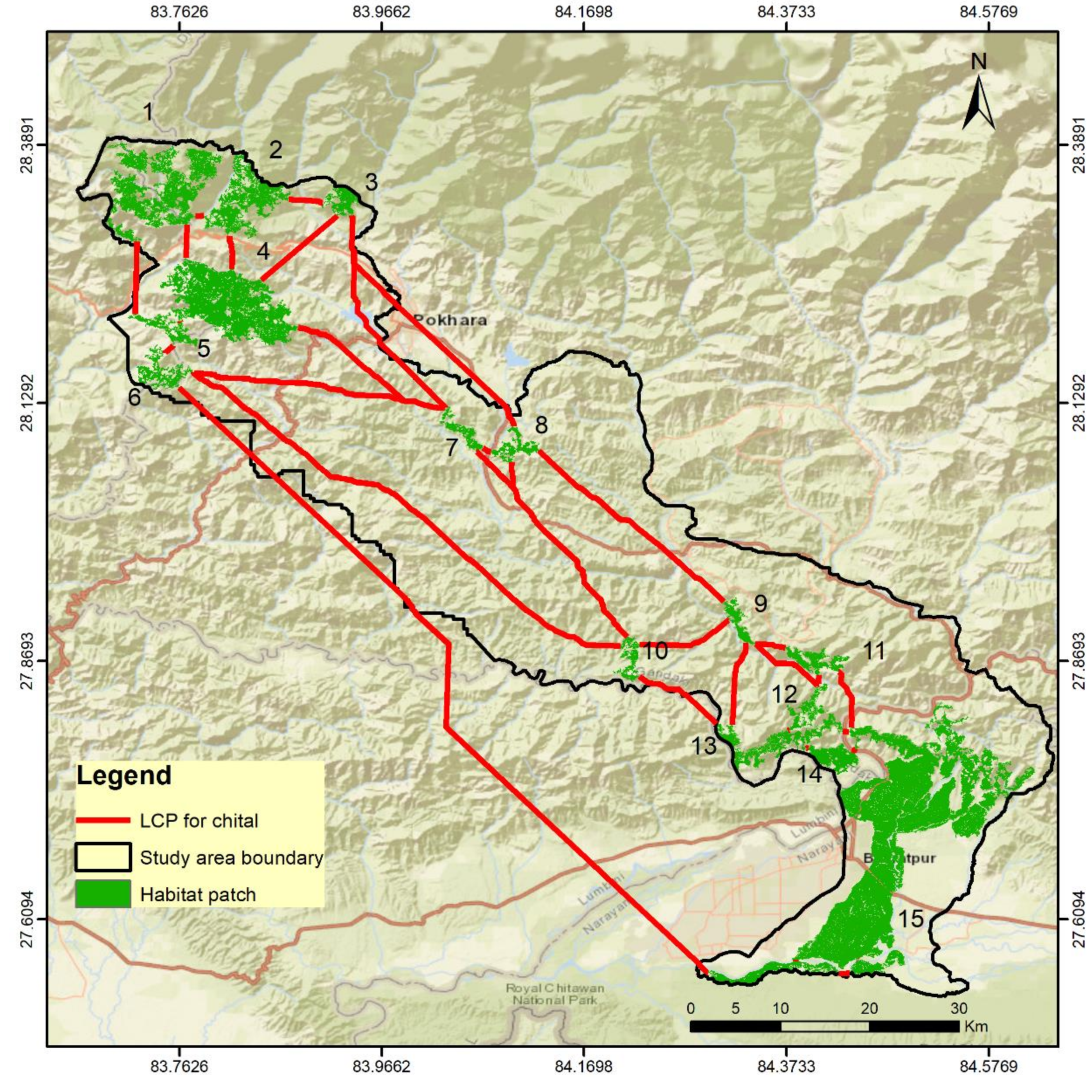


Figure 58: Least-cost path for chital across major habitat patches in CHAL

Sambar was confined to the lower parts of this study area and LCP analysis identified 32 linkages. But the analysis showed that almost all weak linkages between the patches

(CWD:EucD>100) (Table 23, Figure 59, Appendix XXVIII) and indicated the low possibility of movements between the patches along the landscape.

Table 23: Characteristics of the linkages of sambar across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	10.07	1065.84	11.43	109.89	95.87
SE	2.04	217.19	2.38	3.52	1.71
Range	52.02	5514.71	55.14	128.72	45.00
Minimum	0.035	5.80	0.072	78.21	55.59
Maximum	52.05	5520.51	55.21	206.93	100.59

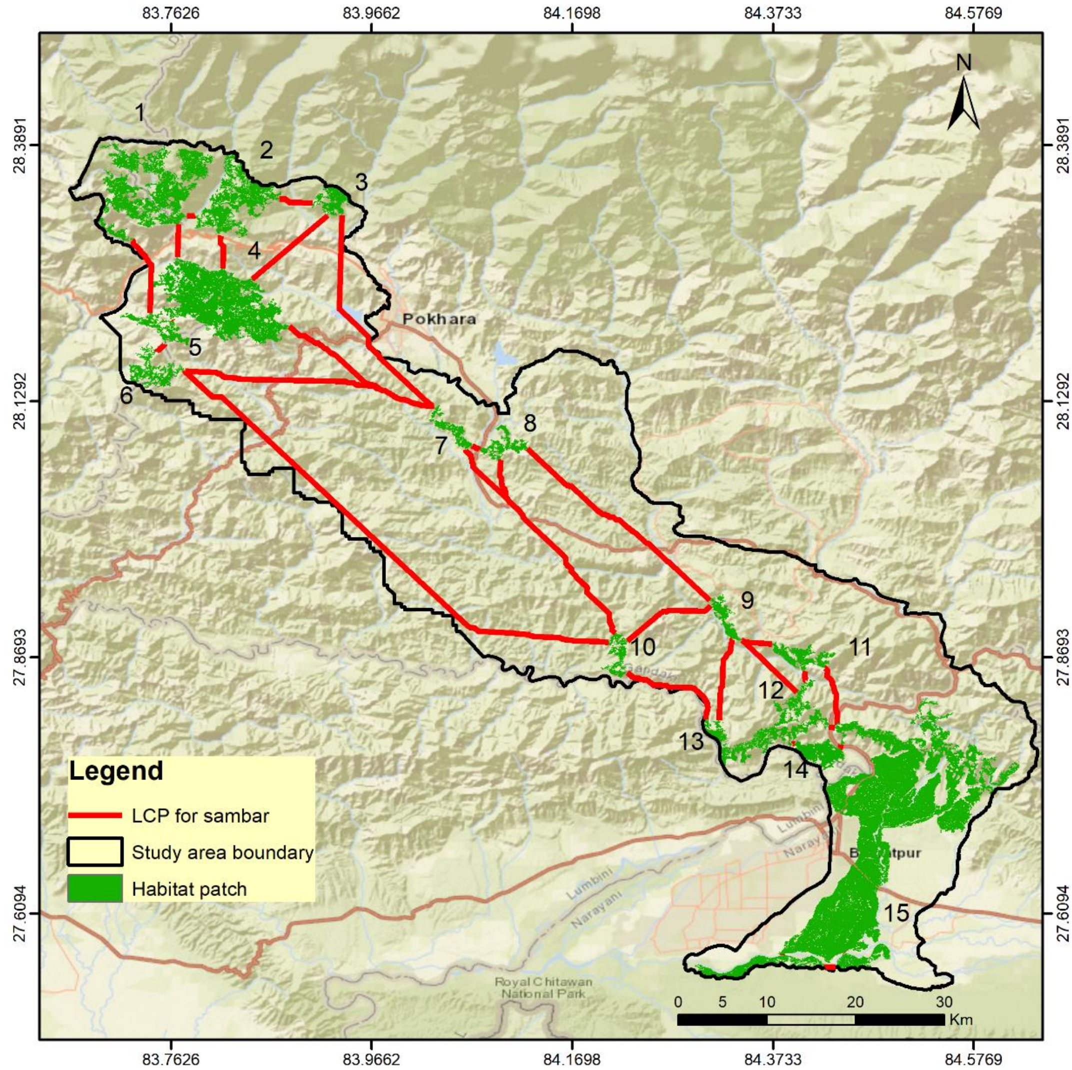


Figure 59: Least-cost path for sambar across major habitat patches in CHAL

This study identified 31 linkages between the patches for wild pigs. Among them, most of the linkages were characterized by low resistance (CWD: EucD<100) i.e., had low

LCP except Panchase to Pipaltari (CWD: EucD = 132.22) and Ghumane to Kota area (CWD: EucD = 114.11) (Table 24, Figure 60, Appendix XXVIII). But the lowest LCP length was between the patches Ghumane to Kota area (LCP = 720 m).

Table 24: Characteristics of the linkages of wild pig across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, weighted km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	12.44	940.03	15.23	74.14	60.57
SE	3.19	251.19	4.34	3.06	2.01
Range	83.63	6454.13	123.12	80.04	45.61
Minimum	0.035	3.99	0.072	52.18	37.95
Maximum	83.66	6458.12	123.19	132.22	83.56

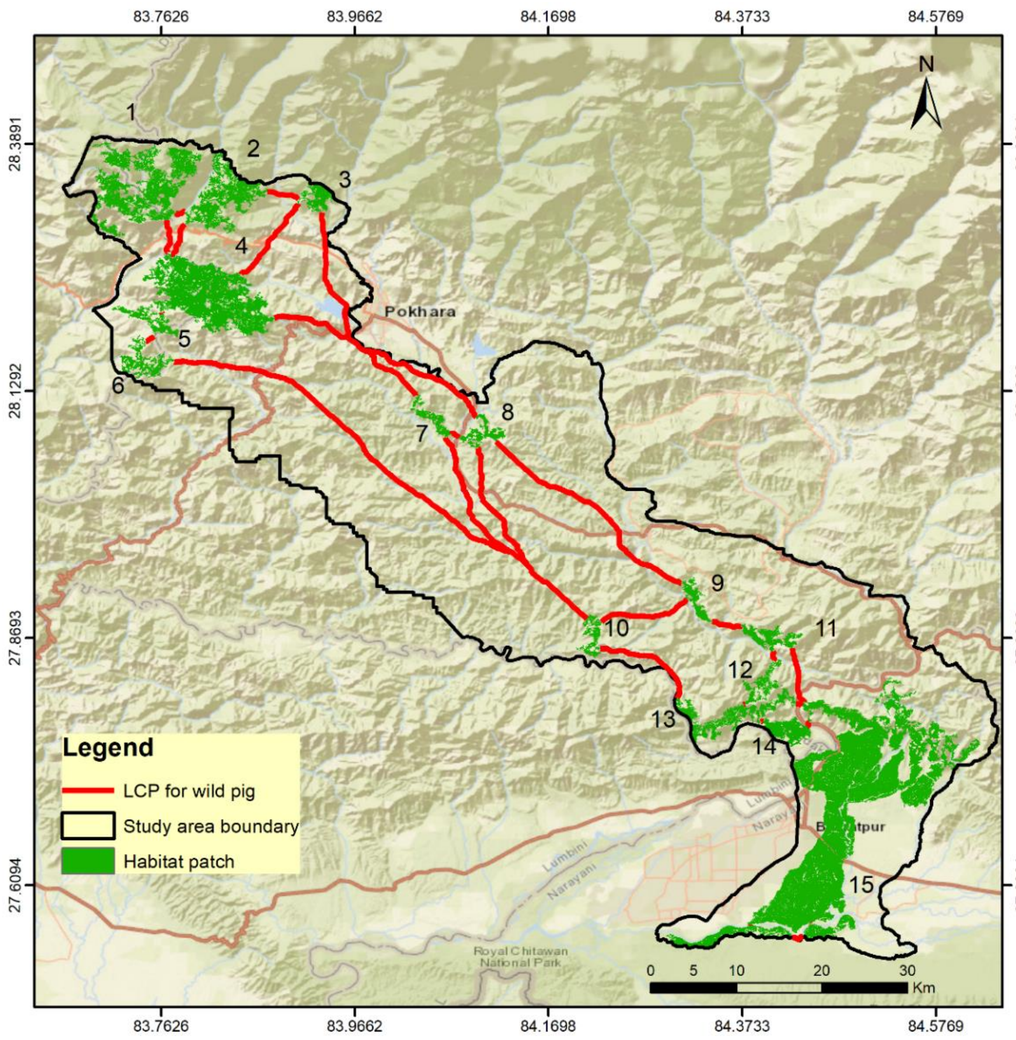


Figure 60: Least-cost path for wild pig across major habitat patches in CHAL

There are 26 linkages between the patches for Himalayan goral. CWD and EucD ratio was 45.6, 49.21 between the patches 4 to 6 and 1 to 2 respectively, hence, had low resistance and high connectivity. But high resistance was seen in the patches in the low elevations (Table 25, Figure 61, Appendix XXVIII).

Table 25: Characteristics of the mapped linkages of Himalayan goral across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	12.06	994.67	15.64	82.33	66.55
SE	2.81	250.2	3.92	3.41	2.97
Range	83.63	7584.47	120.63	87	64.26
Minimum	0.035	4.11	0.072	45.6	32.41
Maximum	83.66	7588.59	120.7	132.6	96.67

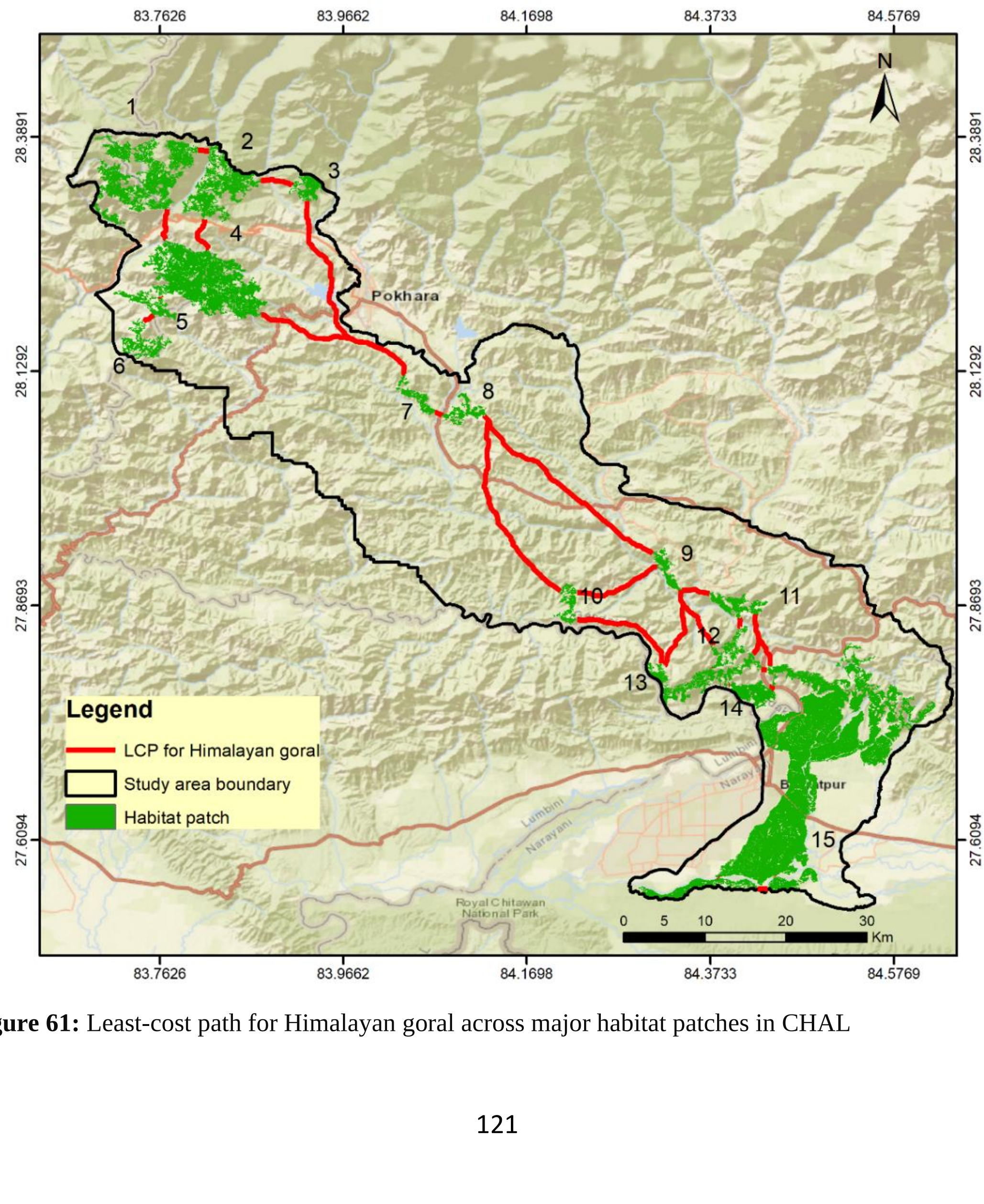


Figure 61: Least-cost path for Himalayan goral across major habitat patches in CHAL

Thirty linkages were identified for monkeys. The LCP analysis revealed that majority of the patch pairs were favorable for monkeys (CWD: EucD<100). The result revealed the rhesus macaque had low resistance in the LCP between the patches. The highest resistance for rhesus macaque was seen in patches 4 to 5 and 13 to 14 (Table 26, Figure 62, Appendix XXVIII).

Table 26: Characteristics of the linkages of rhesus macaque across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, weighted km)	Least-cost path (LCP, km)	CWD: EucD	CWD:LCP
Mean	10.07	531.946	13.52	61.285	47.35
SE	2.21	120.49	3.12	4.14	3.67
Range	52.02	2706.35	76.99	88.49	80.72
Minimum	0.35	3.47	0.72	24.62	15.11
Maximum	52.05	2709.82	77.06	113.11	95.83

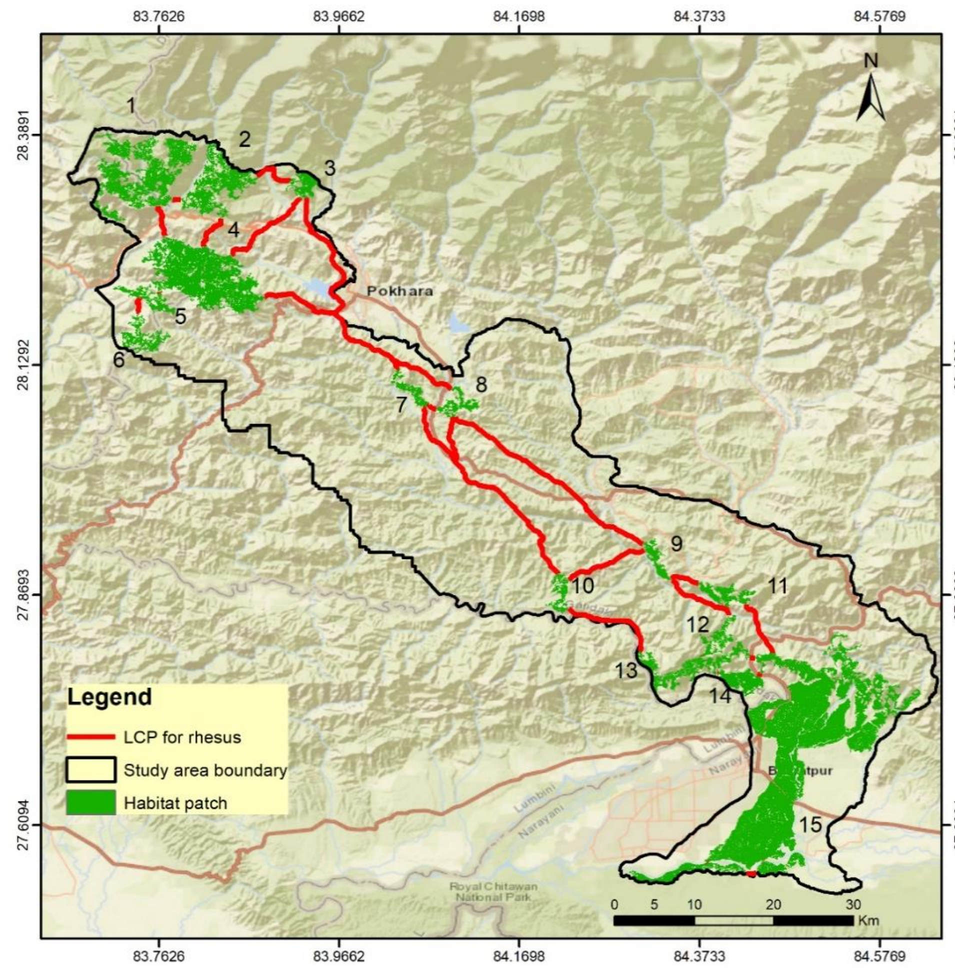


Figure 62: Least-cost path for rhesus macaque across major habitat patches in CHAL

The result found similar type of patch way langur also showed the same relation as rhesus macaque. Most of the patches were suitable for the langur and can move easily through the LCP (CWD: EucD<100), but comparatively higher resistance was seen between the patches 12 and 13 (CWD: EucD = 155.72) and patches 4 and 5 (CWD: EucD = 103.97) (Table 27, Figure 63, Appendix XXVIII).

Table 27: Characteristics of the mapped linkages of langur across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	10.24	615.03	12.56	71.75	58.91
SE	2.09	125.3	2.64	3.41	2.16
Range	52.02	3142.25	60.26	109.79	40.13
Minimum	0.035	5.45	0.072	45.93	39.48
Maximum	52.053	3147.69	60.34	155.72	79.61

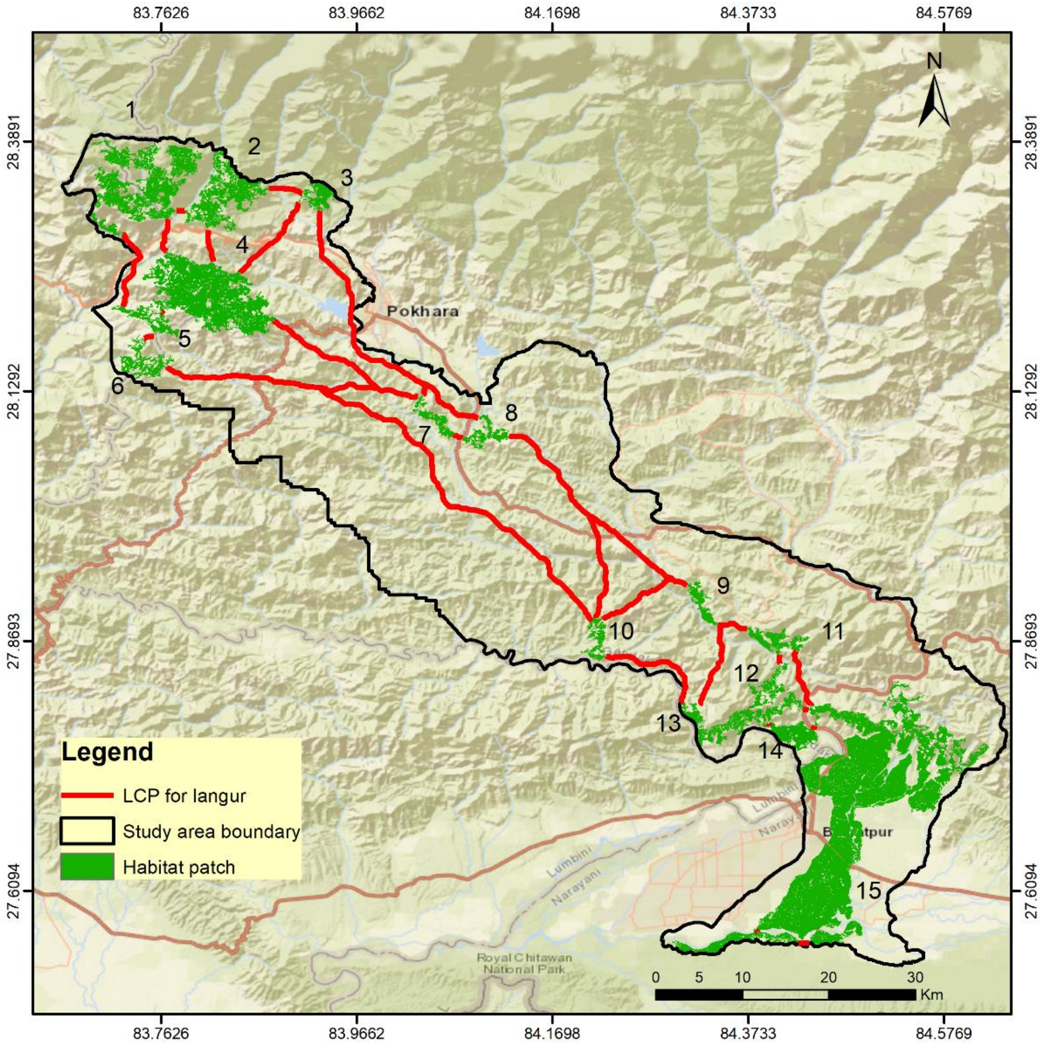


Figure 63: Least-cost path for langur across major habitat patches in CHAL

A total of 31 linkages were identified between 15 major habitat patches for the Himalayan black bear. The lowest LCP was found in between patches 1 and 2 (CWD: EucD = 48.63) indicating the strong connection between these patches (Table 28, Figure 64, Appendix XXVIII). Similarly, results showed a weak relation with the patches present in the lower elevations (CWD: EucD>100).

Table 28: Characteristics of the mapped linkages of Himalayan black bear across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	10.07	980.045	11.91	99.57	83.45
SE	2.04	208.19	2.45	3.96	2.79
Range	52.02	5013.40	60.70	138.77	75.11
Minimum	0.035	6.56	0.072	48.63	25.51
Maximum	52.053	5019.96	60.77	187.4	100.62

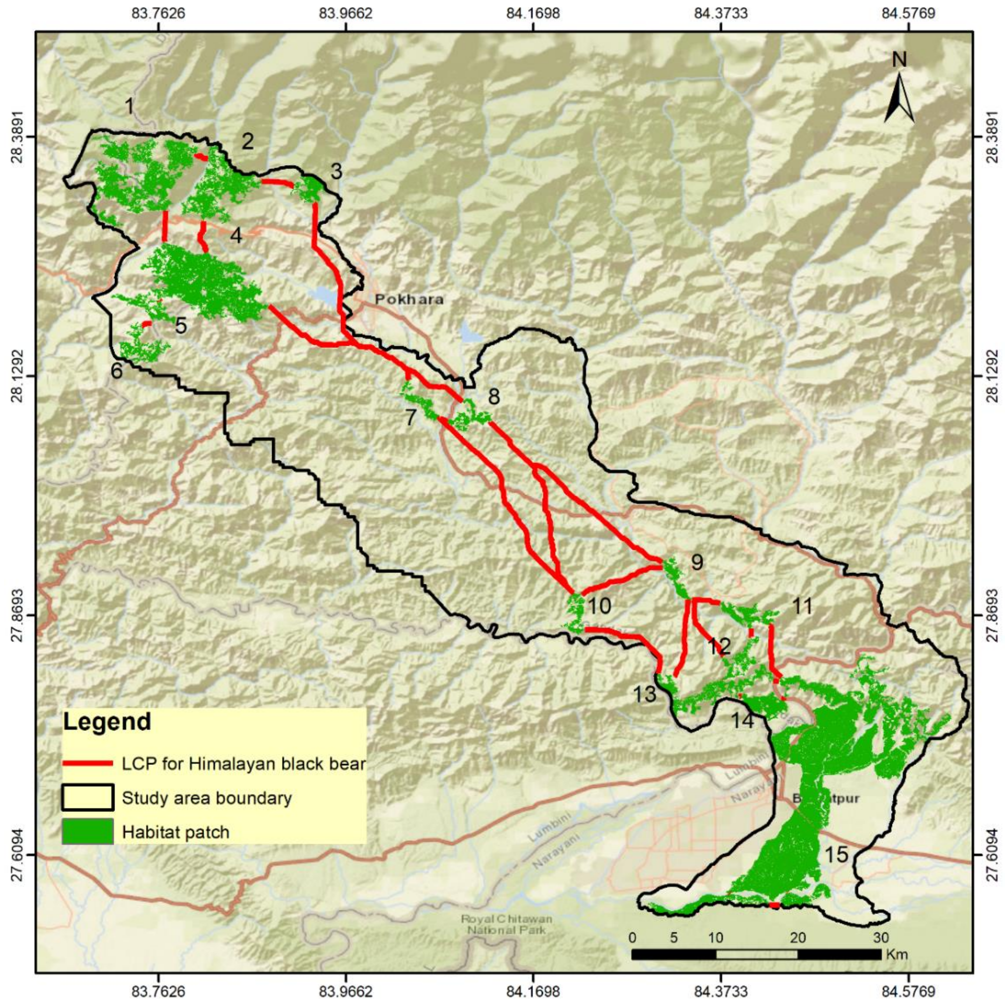


Figure 64: Least-cost path for Himalayan black bear across major habitat patches in CHAL

A total of 31 linkages were identified for leopard and the habitat patches were interlinked with low resistances. The identified habitat patches were suitable for leopard and had lower LCP (CWD: EucD>100) between patches. The range between the minimum and maximum CWD: EucD was 50.69 and 105.49 respectively (Table 29, Figure 65, Appendix XXVIII).

Table 29: Characteristics of the mapped linkages of leopard across major habitat patches in CHAL

Category	Euclidean distance (EucD, km)	Cost-weighted distance (CWD, km)	Least-cost path (LCP, km)	CWD: EucD	CWD: LCP
Mean	10.07	640.58	12.25	69.11	56.87
SE	2.04	134.55	2.54	2.44	1.94
Range	52.02	3459.51	60.55	54.80	46.31
Minimum	0.035	3.69	0.072	50.69	38.04
Maximum	52.05	3463.19	60.63	105.49	84.35

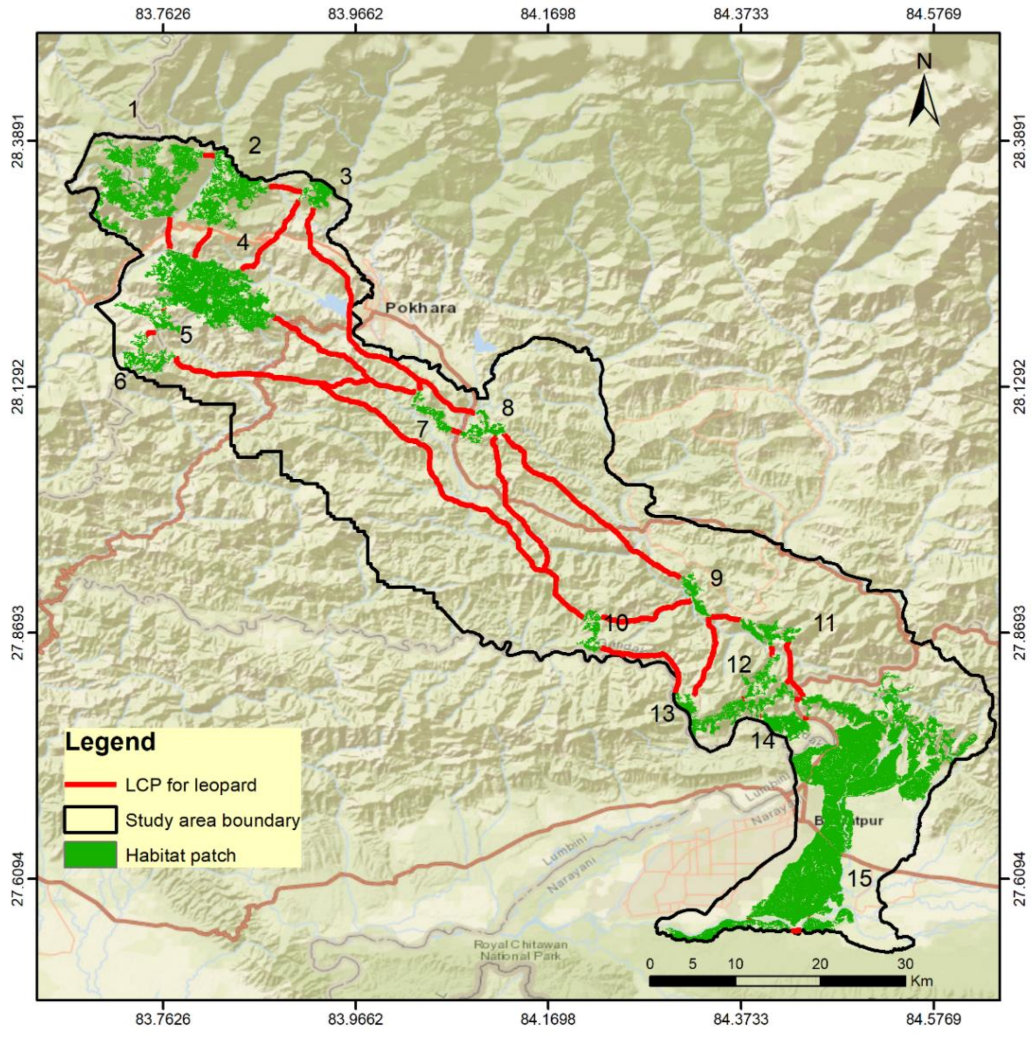


Figure 65: Least-cost path for leopard across major habitat patches in CHAL

The LCP length of the corridor for multispecies was varied from 72 m to 120.63 km. Among the species, chital and sambar had more resistance and least connected between the habitat patches. The LCP between the habitat patches were relatively more appropriate to connect populations of leopard, northern red muntjac, wild pig, rhesus macaque and langur than others, showed the high degree of functional connectivity. The scattered settlements and major cities such as Vyas, Bhimad, Shuklagandaki and Pokhara were the major resistance to mammals for the connection between patches. The patch in the Rupa, Bagmara to Bharatpokhari and Nirmalpokhari were the major least-cost path for the mammals (Figure 66). This study identified the major hotspots which had maximum occupancy of mammals and potential least cost path for the functional connectivity of the isolated populations of the mammals between the patches (Figure 67).

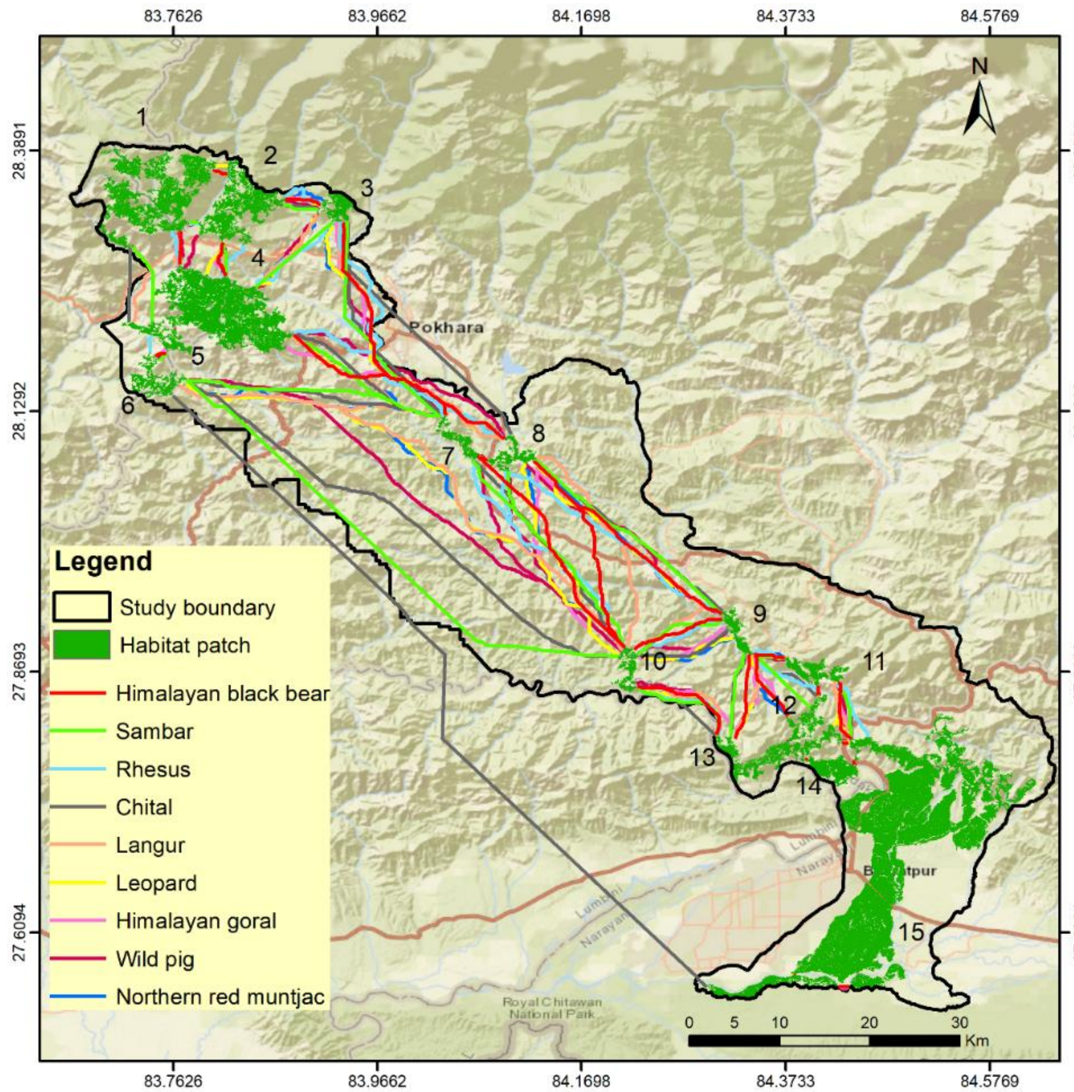


Figure 66: Multi species connectivity in identified habitat patches of CHAL

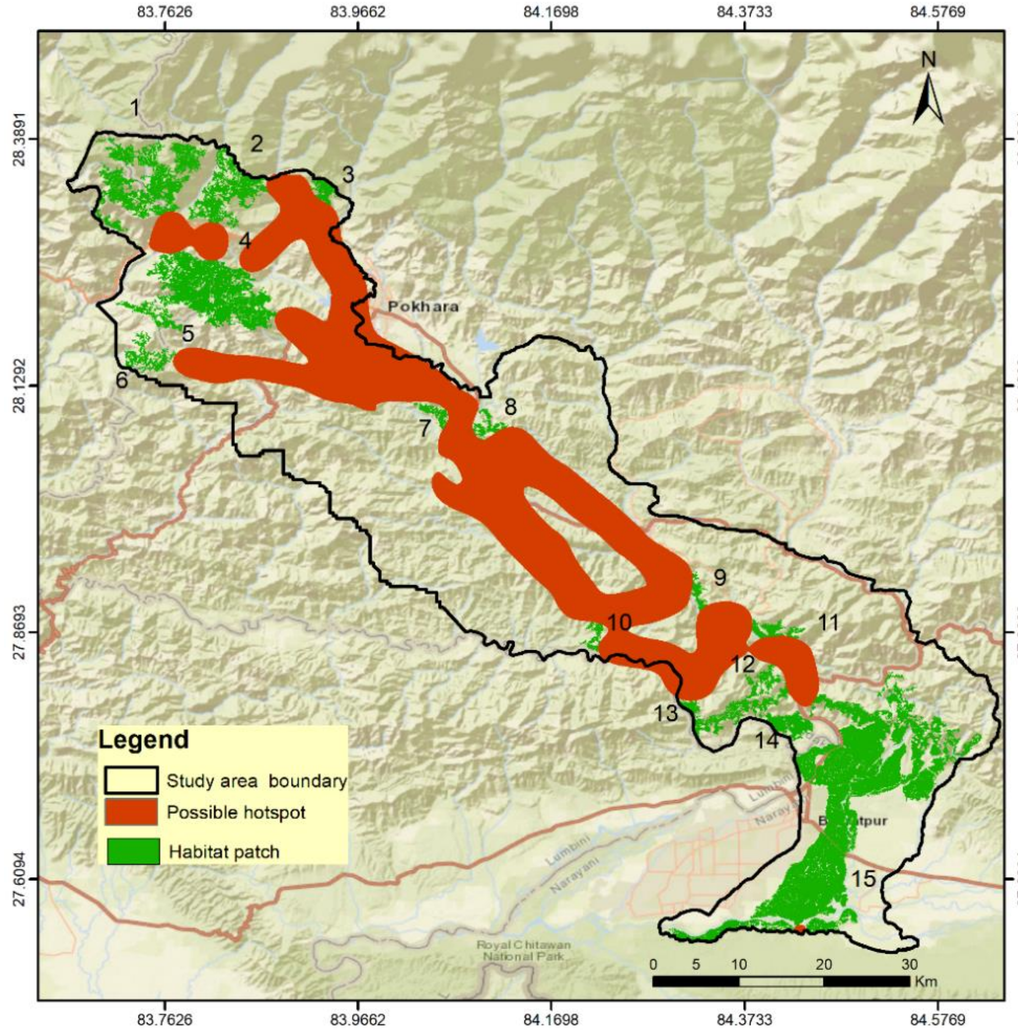


Figure 67: Potential areas (hotspot) for the movement of the mammals across major habitat patches in CHAL

5.4. Discussion

Habitat suitability models have provided the basic knowledge on needs and distribution of the species. SDM is very important to identify the potential habitat patches and potential connectivity between them (Phillips & Dudík, 2008; Koen *et al.*, 2014; Dutta *et al.*, 2016). In this study SDM was used to identify the habitat patches and investigate the connectivity between the habitat patches of two carnivores and seven prey species. Basic understanding of the environment variables and their relation with the species is essential for the conservation of the species in the landscape (Ahmadi *et al.*, 2017).

This study evaluated landscape scale single species and multispecies connectivity for the large mammals across a human-dominated landscape. The forest patches present along the Seti River basin connect CNP via BCF, Devghat and Gaighat, Shuklagandaki-

Bhimad, Panchase with ACA has been purposed structural corridor (WWF, 2013a, 2013b). Similarly, the land use and land cover analysis of 2020 also indicated that this landscape is potential structural corridor between CNP and ACA (Adhikari *et al.*, 2022a).

This study modelled the landscape-level least-cost corridor of both single and multi-species of large mammals based on species distribution modelling. For the least-cost connectivity, the species distribution model of the selected species was used in previous studies (Hanks & Hooten, 2013; Yu *et al.*, 2015; Kaboodvandpour *et al.*, 2021). The least-cost distance method is the most reliable method to model the ecological networks between the habitat patches (Bunn *et al.*, 2000; Sahraoui *et al.*, 2017). The results of the least-cost corridor are very important for delivering a clear image of the landscape and serve in the conservation of such sites. The LCP helps to mitigate the threats to connectivity or suggest restoring it (Ghoddousi *et al.*, 2020). Present study provided the landscape level multi-species connectivity map to analyze the movement of mammalian species across the human-dominated landscape and showed the dispersal strength based on the suitability index. Connectivity is a direct reaction to the extinction of species, habitat damage, and fragmentation of vegetation (Rudnick *et al*., 2012). Connectivity is a key tool for the management of habitats, biodiversity and ecosystem functions such as migration, hydrology, nutrient cycling, pollination, seed dispersal, food security, climate resilience and disease resistance (Bennett, 2003).

The forest patches connect the landscape with two protected areas (e.g., CNP and ACA), but the scattered settlements and cropland become the strong resistance for the connection of isolated populations of the mammals. These forest present in the mid-hills are fragmented and comparatively smaller in size, hence, cannot hold many species of mammals. The habitat patches are regarded as undisturbed area with high species richness (Sahraoui *et al.*, 2017). The survival of species in the fragmented landscape depends upon their movement into the different habitat patches (Noss, 1991). The connectivity between habitat patches is important for the species interaction and gene for the large mammals in the landscape (Borah *et al*., 2016; Suttidate *et al.*, 2021).

In Nepal, a few studies have been done to assess the connectivity. Most of these studies are on umbrella species e.g., tiger (Subedi *et al.*, 2021), snow leopard (Shrestha & Kindlmann, 2020), assuming that the associated species would automatically benefit while restoring corridors for these surrogate species (Koen *et al.*, 2014; Huang *et al.*, 2019; Shrestha & Kindlmann, 2020). But some range-specific surrogate species are questionable for their conservation in the corridor (Koen *et al.*, 2014). This study attempted to analyze the connectivity between population of large mammals in isolated patches. The species which have high habitat range showed good functionality than species with the narrow ranges (e.g., chital, sambar). Wide ranging species such as rhesus macaque and langur monkeys showed functional connectivity to all types of habitats patches, i.e., most of the habitat patches are suitable for monkeys and are less affected by the resistances. Likewise, leopards showed a wide range of functional connectivity. The prey availability also determines connectivity and the movement of predator (Wegge *et al.*, 2009). Leopard is the major predator occurred in this landscape and the least-cost path evaluation found that leopards used most of the identified habitat patches as it has a specific home range (6 – 90 km^2) (Norton & Henley, 1987; Odden & Wegge, 2005) and has to cover more area for prey. The Himalayan black bear is also the range-specific carnivore and is commonly found above 1000 m. But sometimes they migrate to the lower elevation even below 1000 m (Bista *et al.*, 2018). The least-cost analysis indicated its connection towards most of the habitat patches found in mid-hills and the high hill above 1000 m.

This study identified the hotspots for functional connectivity between CNP and ACA as the corridor in the other part of Nepal such as Khata Corridor (connects Bardia National Park, Nepal with Katarniaghat Wildlife Sanctuary) (Gurung *et al.*, 2018), Basanta Corridor (connects Bardia National Park and Sukhlaphata National Park, Nepal with Dudhwa National Park, India) (Gurung *et al.*, 2018), and Laljhadi Maohana Corridor (connects Suklaphanta National Park with Dudhwa National Park, India) (Thapa *et al.*, 2017). Now, these corridors become the model functional corridor in TAL for the movement of large mammals (Gurung *et al.*, 2018). The large cities such as Vyas, Bhimad, Shuklagandaki, Pokhara along with scattered settlements of the mid-hills are the major resistances to the animal movement. Hence, the forest patches nearer to such areas are very important for connection of the isolated population of mammals. For example: forests of the Rupa to Bagmara, Bharatpokhari and Nirmalpokhari areas are very important for connection of population of most of the mammals between habitat patches. Hence, these bottleneck areas must be conserved for maintaining the connectivity between CNP to ACA. Similarly, the forest of the Rumsi and Rishing areas nearer to the Vyas are important for animal movement. Bottlenecks are the cornerstones for conservation, and if not properly managed may affect the movement of the animals (Thapa *et al.*, 2018). The identified patches provide critical habitat to existing forest connectivity between CNP and ACA. If conserved well, this corridor will be the model corridor between CNP and ACA.

5.5. Conclusions

This study evaluated the structural and functional connectivity for the mammals in the central part of CHAL. This study identified 15 habitat patches with potential least-cost paths for the movement of the mammals based on the habitat suitability. The central part of CHAL is the functional corridor (i.e., least cost paths) for leopards, northern red muntjac and wild pigs. The range restricted mammals such as sambar and chital had poor functional connectivity in the landscape. Likewise, the functional connectivity for Himalayan black bear and Himalayan goral have been identified only in the mid-hills. This potential least-cost paths or functional connectivity will be the important habitat and corridor for mammals. Hence, these findings are important to judge the functional connectivity between two protected areas and will be helpful for conservation planning. These findings will be a model for other parts of Nepal and it would be a corner stone for achieving the conservation goals.

CHAPTER 6

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Quantitative analyses of land use and land cover patterns indicate that central part of CHAL has experienced the significant changes between 2000 and 2020. The land cover classes include water bodies, barren area, grassland, riverine forest, Sal dominated forest, mixed forest, croplands, and buildup/settlements areas. About 62% of the total area of the central part of CHAL was covered by forest. Land use and cover are changing rapidly in this landscape as a result of developmental activities in urban and suburban areas, similarly, emigration from rural to lowland and urban areas, is a primary driver of land cover dynamics. In the CHAL, there was a greater change in land cover between 2000 and 2010. There was an increase in mixed forest (37.46%), buildup/settlements areas (31.34%), Sal dominated forest (7.76%) but decrease in croplands, grassland, barren area and riverine forest between 2000 to 2020.

Habitat types, human disturbances, livestock grazing and IAPS cover were the major determinants of abundance and distribution of the large mammals. Abundance of the chital was higher in lowland (block A) and muntjac was higher in mid-hills (blocks B, C and D). The ungulates were mostly reported from the grasslands, open areas and forest with ample amount of understory vegetation. Presence of leopard was more in the Panchase and ACA (block D) than other parts of the mid-hill (block B and C). Crop damage, livestock depredation, human injury and death are the major issues of human-wildlife conflict which is significantly correlated with a high encounter rate of the mammals mainly close to the forest. Ungulates and monkeys are the principal crop raiders and tiger and leopard in the lowland and leopard alone in the mid-hills are the major livestock depredators. The monetary loss by crop damage and livestock depredation was US$ 86.62 per household per year in this landscape. The frequency of crop damage and livestock depredation increases as the encounter rate of the animals increases. Similarly, rhino and tiger in the lowlands and; leopard and Himalayan black bear in the mid-hills are the principal mammals causing human injury and death.

Species occupancy and species distribution modeling suggest that CHAL is a crucial location for mammal conservation. The leopard had the highest and the Himalayan goral had lowest occupancy along the landscape. Distance to cropland, NDVI, distance to grassland, forest and elevation were the major variables that affect the occupancy of two carnivores (leopard and Himalayan black bear) and six prey species (northern red muntjac, chital, sambar, wild pig, Himalayan goral, langur and rhesus macaques). Besides two protected area (CNP and ACA), Barandabhar Corridor Forest, Panchase Protected Forest, Rumsi area, Phirphire area, Rupa, Bagamara area were also the suitable habitat for studied species.

Based on habitat suitability, this study identified 15 habitat patches with potential least-cost paths for the movements of the mammals. The areas between these patches are the priority areas for the conservation of large mammals in CHAL. The whole landscape is identified as the potential functional corridor for leopard, northern red muntjac and wild pig and only the mid-hill part of this landscape provides the potential functional connectivity for Himalayan gorals and Himalayan black bear. But range restricted mammals (e.g., chital and sambar) has poor functional connectivity in the landscape. Hence, the central part of the CHAL is the potential functional corridor for large mammals that justify the functionality of the CHAL.

6.2. Recommendations

This study recommends the followings

1. Research:

- The land use and land cover (LULC) in this landscape (e.g., mid-hills) are changing. Hence, continuous research on landcover dynamics in fine scale should be done.
- This study focus on the large mammals of this landscape, hence, research on other species and habitats is needed.
- Research to investigate species movement patterns (GPS collaring for leopard, muntjac, goral, Himalayan black bear) is most needed to know patch and corridor use.

2. Management:

- Habitat management and controlling invasive and alien plant species are the major challenges for maintaining viable population of mammals. Hence, a plan to control of IAPs, restoration of grasslands and forest management throughout the landscape should prepare.

- To manage Human Wildlife Interaction, this study recommends: (i) cultivation of unpalatable crops and (ii) construction of predator-proof corals

3. Policy:

- Control internal migration and implement land management practices to control the land use and land cover dynamics.
- Developing settlement unification practice, wildlife friendly infrastructure and agricultural practice for the movement wildlife through human dominated landscape.
- This study identified the hotspots or conservation priority areas based on the most suitable habitats and connecting links. The areas such as Rumsi, Bandipur and Phirphire area of Tanahun, Bagmara, Rupa, Bharatpokhari, Nirmalpokhari area of Kaski are the major linkages to connect isolated habitat patches. These areas need more conservation efforts for long term persistence of large mammals and their habitats.

CHAPTER 7

7. SUMMARY

Protected areas play an important role in conserving large mammals and their habitat but not sufficient. The forest outside the protected areas have also played a role in conservation, but have less priority for conservation and research. The scattered settlements in the mid-hills always threats the large mammals and increases the human-wildlife conflict. Globally, there is increasing awareness that conservation planning should focus outside the protected areas with public participation. In Nepal, the forest management plan has been implemented which helps to restore the forests outside the protected areas, but not sufficient. The sustainable conservation of the large mammals in the landscape, should not only focus on the management of habitat and demography but should focus and address the socio-economic change of the local people. The mid-hill of Nepal is human-dominated and supports many wildlife species. Very few studies are in the mid-hill of Nepal. The status of biodiversity is even very little known from the mid-hill. Hence, for the sustainable management of such scattered habitat patches, the research on habitat status and distribution of animals to that area is essential. To realize this fact this study was designed in the central part of the Chitwan Annapurna Landscape (CHAL), an example of a mid-hill ecosystem. This study aimed to i) characterize the spatio-temporal pattern of land use and land cover, ii) evaluate the relative abundance of large mammals and their interaction with people, iii) examine the impacts of environmental correlates on the occupancy of large mammals and iv) identify the landscape level connectivity for the large mammals.

The CHAL in central Nepal is drained by eight major rivers and tributaries and connects six protected areas. This study chose the central part of the CHAL that connects two global biodiversity hot spots the CNP and the ACA. This intensive study area was 2749.48 km^2 which covers the part of Chitwan, Tanahun, Kaski, Syanja and Parbat districts. Barandabhar corridor forest, Gaighat forest area, forest patches along Seti River, Panchase protected forest, and lower part of ACA, are the major forest patches that make up the potential vertical corridor in this area. This area harbors many important mammal species, birds, herpetofauna, fish and other micro and macroinvertebrates.

This thesis is presented in seven chapters i.e., the introduction, four chapters related to research outputs based on objectives, conclusions and recommendations and a summary. In chapter 2, land cover and land use dynamics of the landscape was analyzed using Landsat images of 2000, 2010 and 2020. The land covers were classified into eight classes by applying supervised classification using the maximum likelihood algorithm in ERDAS imagine 9.2 and ArcGIS 10.8. According to the analysis, this landscape was composed of grassland (1.73%), barren area (1.76%), riverine forest (1.93%), water bodies (1.97%), buildup/settlements area (4.13%), Sal dominated forest (15.4%), cropland (28.13%), and mixed forest (44.95%). Land cover dynamics indicated an overall increase in Sal dominated forest (7.6%), buildup/settlements area (31.34%), mixed forest (37.46%) and decrease in riverine forest (11.29%), barren area (20.03%), croplands (29.87%) and grassland area (49.71%) within 2000 to 2020. The overall accuracy of the classified images had 81%, 81.6% and 84.77% respectively in 2000, 2010 and 2020.

Chapter 3 focuses on the relative abundance of the large mammals and their interaction with people along the landscape. The data for the abundance of large mammals along the habitat and disturbance gradients were collected by dividing the study area into four different study blocks and laying a total of 150 transects. The interaction of the mammals with people was determined using 600 semi-structured questionnaires (150 in each block). The result shows that the chital was the most abundant mammals (encounter rate of group per km (ER) = 1.49) in the block A. Similarly, muntjac was the most abundant in blocks B, C and D (ER = 0.34, 0.31, 0.79 respectively) but the relative abundance of rhesus macaque was comparatively higher in blocks B, C and D. The signs of tiger and leopard were observed in block A only (sign encounter rate (ER) = 0.44 and 0.51 respectively). But signs of leopard and Himalayan black bear were reported from B, C and D (ER of leopard and black bear in B = 0.55 and 0.05; ER in C = 0.39 and 0.08; ER in D = 0.89 and 0.27 respectively). Habitat types, human disturbances, and coverage of invasive and alien plant species (IAPs) played a vital role in the abundance of large mammals along the landscape. Similarly, an average US$ 12.02 per household from crop damage and US$ 74.60 per household from livestock depredation were lost per year in this landscape. Both crop damage and livestock depredation were higher in Panchase and part of ACA (block D). A total of 26 human attack cases (6 deaths and 20 injuries) were reported from this landscape.

Chapter 4 deals with the impacts of the different correlates for the occupancy of the mammals in the landscape. In this study, the occupancy and the suitable habitat of two carnivores – leopard and Himalayan black bear, five ungulates- northern red muntjac, chital, sambar, wild pig, Himalayan goral and two primates – rhesus macaque and langur monkeys were predicted. The occupancy of the mammals was estimated by using the presence/absence data of each 2 km segment spatial replicate of each transects (n = 150) using program PRESENCE. The SDM using Maxent was evaluated on the basis of presence points only collected from transects and opportunistic survey. The Maxent model was evaluated based on the area under the curve (AUC) value of receiver operator characteristic (ROC) and analyzed as a response curve, the relative importance of variables, Jackknife test and suitability map. Results found that estimated occupancy was of the leopard was the highest ($\psi = 0.944 \pm 0.048$) followed by rhesus macaque ($\psi = 0.583 \pm 0.074$), langur ($\psi = 0.541 \pm 0.108$), Northern red muntjac ($\psi = 0.477 \pm 0.024$) and the Himalayan goral had the least occupancy ($\psi = 0.038 \pm 0.011$). Results indicated that the models were statistically satisfactory (mean AUC>0.7). The nearest distance to cropland, elevation, distance to grassland, forest, water sources and settlements, Normalized Difference Built-up Index (NDBI) and Normalized Difference Vegetation Index (NDVI) were the major variables that predict occupancy of the mammals. The species distribution model predicated 30.29% habitat for northern red muntjac, 6.45% for chital, 2.6% for sambar, 14.55% for wild pig, 15.55% for Himalayan goral, 34.88% for rhesus macaque, 34.65% for langur, 5.79% for Himalayan black bear and 29.94% for leopard was suitable.

Identification of the habitat patches based on habitat suitability data and potential least-cost path linkage for the mammals along the landscape is discussed in Chapter 5. The least-cost path for connection of isolated population of the mammals between the habitat patches was determined by using the Linkage Mapper tool in ArcGIS. A total of 15 habitat patches of different sizes (average area 26.67±12.70 km^2) were identified in this landscape. The least-cost analysis indicated weak relation of chital and sambar between the habitat patches, hence less chance to use other habitat patches as these mammals were absent in mid-hills, but muntjac, wild pig and leopard showed the low least-cost path between the most of the patches. Likewise, Himalayan goral and Himalayan black bear have the least-path with the habitat patches located in the mid-hills. This study also identifies the major hotspots for potential connection of the isolated population of mammals between the habitat patches and this study also identifies the isolated population connectivity of multispecies between habitat patches.

This study provided detail information on the land use and landcover dynamics, relative abundance and interaction between humans and wildlife, large mammal's occupancy, habitat suitability for the large mammals and potential patches and their connectivity. The human-wildlife conflict was common issue in mid-hill Nepal and this study indicated the conflict hotspots based on monetary loss and also identifies the potential hotspots for the conservation. Hence, this study recommends lunching an effective compensation program for effective conservation, awareness campaigns to minimize the conflict and alternative options against the crop depredation. This information will be beneficial for the researchers for planning their research and planners for formulating effective conservation programs.

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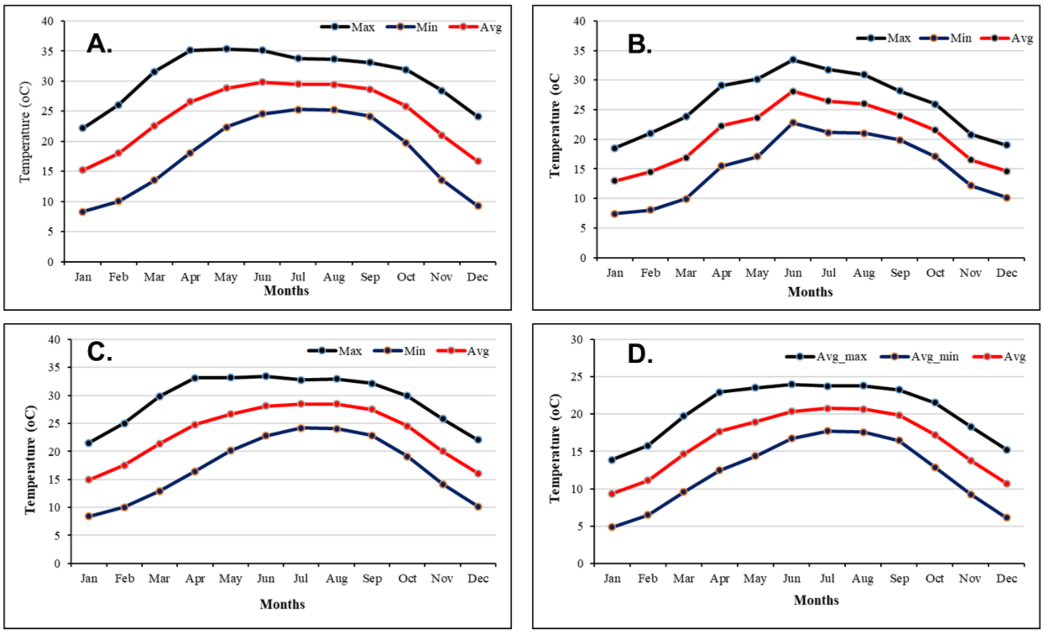
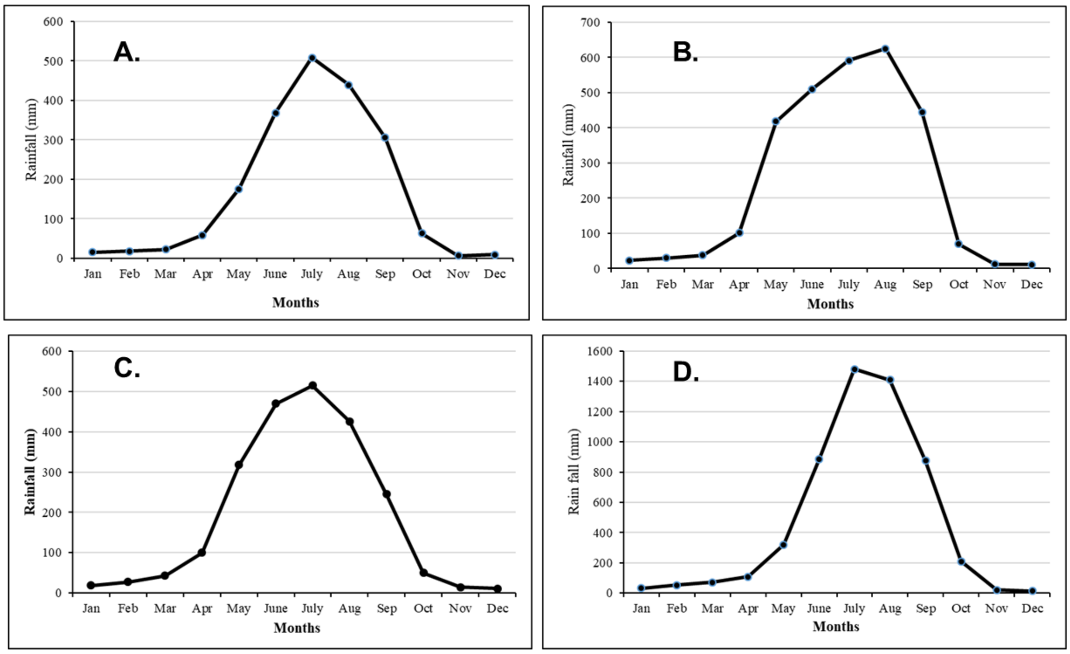
APPENDIX

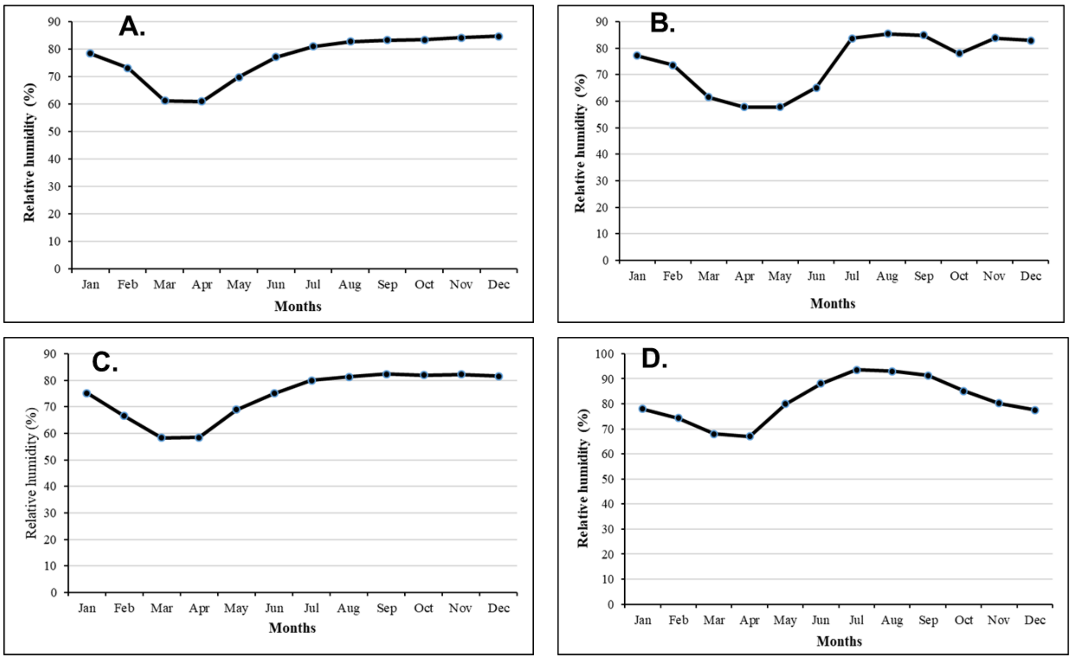
Appendix I: The mean monthly temperature (ºC) (Max= Maximum, Min=Minimum and Avg= Average temperature) of A- Block A: Chitwan valley, B- Block B: Seti River basin (Gaighat, Devghat, Bandipur to Vyas area), C- Block C: Seti River basin of Tanahun (Vyas to Khairetar, Bhimad), D. Block D: Panchase, ACA from 1989- 2018 (Source DHM (2019))



Appendix II: The Annual rainfall (mm) of A- Block A, B- Block B, C- Block C, D. Block D from 1989- 2018 (Source DHM (2019))



Appendix III: The relative humidity of A- Block A, B- Block B, C- Block C, D. Block D from 1989- 2018 (Source DHM (2019))



Appendix IV: Different bands of Landsat 5 (TM), Landsat 7 (ETM) and Landsat 8 (OLI) used for band combination

Landsat 5 TM			**Landsat 7 ETM**			**Landsat 8 OLI**		
Bands	Wave length (µm)	Resolution	Bands	Wave length (µm)	Resolution	Bands	Wave length (µm)	Resolution
Band 1-Blue	0.45-0.52	30	Band 1-Blue	0.45-0.52	30	Band 1-Coastal aerosol	0.43-0.45	30
Band 2-Green	0.52-0.60	30	Band 2-Green	0.52-0.60	30	Band 2-Blue	0.45-0.51	30
Band 3-Red	0.63-0.69	30	Band 3-Red	0.63-0.69	30	Band 3-Green	0.53-0.59	30
Band 4-Near Infrared Red (NIR)	0.77-0.90	30	Band 4-Near Infrared Red (NIR)	0.77-0.90	30	Band 4-Red	0.64-0.67	30
Band 5-SWIR1	1.55-1.75	30	Band 5-SWIR1	1.55-1.75	30	Band 5-Near Infrared Red (NIR)	0.85-0.88	30
Band 6-Thermal infrared (TIR)	10.40-12.50	120	Band 6-Thermal infrared (TIR)	10.40-12.50	30/60	Band 6-SWIR1	1.57-1.65	30
Band 7-SWIR2	2.08-2.35	30	Band 7-SWIR2	2.09-2.35	30	Band 7-SWIR2	2.11-2.29	30
			Band 8-Panchromatic (Pan)	0.52-0.90	15	Band 8-Panchromatic (Pan)	0.50-0.68	15
						Band 9-Cirrus	1.36-1.38	30
						Band 10-Thermal infrared (TIRS1)	10.6-11.19	100
						Band 11-Thermal infrared (TIRS2)	11.5-12.51	100

Appendix V: Land cover change from 2000 to 2020 in Old Padampur, New Padampur, Vyas, Panchase Protected Forest area, a part of ACA

Land cover type	Area (km^2)			Change in area					
	2000	2010	2020	2000-2010		2010-2020		2000-2020	
				Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Old Padampur area									
Water bodies	3.48	3.31	2.99	-0.17	-4.88	-0.32	-9.66	-0.49	-14.08
Barren area	3.08	1.26	0.78	-1.82	-59.09	-0.48	-38.09	-2.30	-74.67
Grassland	7.94	17.31	15.44	9.37	118.01	-1.87	-10.80	7.50	94.45
Riverine forest	7.21	11.14	13.79	3.93	54.50	2.65	23.78	6.58	91.26
Sal dominated forest	1.08	1.13	1.16	0.05	4.62	0.03	2.65	0.08	7.40
Mixed forest	0.08	0.12	0.13	0.04	50.00	0.01	8.33	0.05	62.5
Crop land	12.19	0.86	0.81	-11.33	-92.94	-0.05	-5.81	-11.38	-93.35
Buildup/settlement area	0.31	0.24	0.27	-0.07	-22.58	0.03	12.5	-0.04	-12.90
New Padampur area									
Water bodies	0.34	0.45	0.53	0.11	32.35	0.08	17.77	0.19	55.88
Barren area	0.68	0.20	0.30	-0.48	-70.58	0.10	50.00	-0.38	-55.88
Grassland	0.91	0.63	0.32	-0.28	-30.76	-0.31	-49.2	-0.59	-64.83
Riverine forest	11.86	4.53	4.60	-7.33	-61.8	0.07	1.54	-7.26	-61.21
Sal dominated forest	8.61	4.33	3.95	-4.28	-49.7	-0.38	-8.77	-4.66	-54.12
Mixed forest	1.10	0.41	1.15	-0.69	-62.72	0.74	180.48	0.05	4.54
Crop land	7.78	18.5	14.64	10.72	137.78	-3.86	-20.86	6.86	88.17
Buildup/settlement area	0.39	2.42	5.98	2.03	520.51	3.56	147.107	5.59	1433.33
V**yas area**									
Water bodies	1.11	1.37	1.35	0.26	23.42	-0.02	-1.45	0.24	21.62
Barren area	0.73	0.82	0.75	0.09	12.32	-0.07	-8.53	0.02	2.73
Grassland	0.21	0.24	0.23	0.03	14.28	-0.01	-4.16	0.02	9.52
Riverine forest	0.04	0.05	0.05	0.01	25.00	0	0	0.01	25.00
Sal dominated forest	2.41	2.51	2.61	0.10	4.14	0.1	3.98	0.20	8.29
Mixed forest	3.17	3.59	5.14	0.42	13.24	1.55	43.17	1.97	62.14
Crop land	9.96	8.79	5.89	-1.17	-11.74	-2.90	-32.99	-4.07	-40.86
Buildup/settlement area	1.86	2.12	3.47	0.26	13.97	1.35	63.67	1.61	86.55
Panchase and surroundig area									
Water bodies	2.57	2.49	2.50	-0.08	-3.11	0.01	0.401	-0.07	-2.72
Barren area	4.72	3.15	1.69	-1.57	-33.26	-1.46	-46.34	-3.03	-64.19
Grassland	5.02	3.23	2.85	-1.79	-35.65	-0.38	-11.76	-2.17	-43.22
Riverine forest	0.48	0.43	0.44	-0.05	-10.41	0.01	2.32	-0.04	-8.33
Sal dominated forest	12.75	13.63	15.72	0.88	6.9	2.09	15.33	2.97	23.29
Mixed forest	109.41	134.93	183.92	25.52	23.3	48.99	36.3	74.51	68.1
Crop land	139.15	117.21	66.89	-21.94	-15.76	-50.32	-42.93	-72.26	-51.92

Buildup/settlement area	5.22	4.25	5.31	-0.97	-18.58	1.06	24.94	0.09	1.72
A part of ACA									
Water bodies	0.29	0.28	0.27	-0.01	-3.44	-0.01	-3.57	-0.02	-6.89
Barren area	5.23	4.39	3.97	-0.84	-16.06	-0.42	-9.56	-1.26	-24.09
Grassland	18.19	15.27	14.57	-2.92	-16.05	-0.7	-4.58	-3.62	-19.9
Mixed forest	86.96	95.88	99.95	8.92	10.25	4.07	4.24	12.99	14.93
Crop land	21.28	15.84	12.56	-5.44	-25.56	-3.28	-20.7	-8.72	-40.97
Buildup/settlement area	0.54	0.83	1.17	0.29	53.7	0.34	40.96	0.63	116.66

Appendix VI: Error matrix resulting from classifying test pixels Accuracy assessment on the basis of ground-truthing points (Land cover 2000)

Land cover	Water bodies	Barren land	Grassland	Riverine forest	Sal dominated forest	Crop land	Buildup/ settlement area	Mixed forest	User's total	User's accuracy (%)
Water bodies	18	1	0	1	0	2	0	0	22	81.81
Barren area	0	11	0	0	0	0	0	4	15	73.33
Grassland	0	1	29	1	1	2	0	3	37	78.37
Riverine forest	0	0	0	27	0	1	0	3	31	87.09
Sal dominated forest	0	0	1	0	64	5	0	6	76	84.21
Crop land	0	1	4	1	8	115	3	7	139	82.73
Developed area	0	0	1	0	0	4	21	1	27	77.77
Mixed forest	2	1	1	3	7	14	5	120	153	78.43
Producer total	20	15	36	33	80	143	29	144	500	
Producer's accuracy (%)	90.00	73.33	80.50	81.80	80.00	80.41	72.41	83.30		

Appendix VII: Error matrix resulting from classifying test pixels Accuracy assessment on the basis of ground-truthing points (Land cover 2010)

Land cover	Water bodies	Barren land	Grass land	Riverine forest	Sal dominated forest	Crop land	Buidup/ settlement area	Mixed forest	User's total	User's accuracy
Water bodies	10	1	0	1	0	1	0	0	13	76.92
Barren area	0	8	0	0	0	0	0	1	10	80.00
Grassland	0	0	12	1	1	1	0	1	16	75.00
Riverine forest	0	0	0	10	0	1	0	2	13	76.92
Sal dominated forest	0	0	1	0	64	7	0	5	77	83.11
Crop land	1	1	1	1	8	135	3	12	162	83.33
Developed area	0	0	0	0	0	2	14	3	19	73.68
Mixed forest	2	1	1	1	7	15	4	160	191	83.77
Producer total	13	11	15	14	80	162	21	184	500	
Producer's accuracy	76.92	72.73	80.00	71.40	80.00	83.30	66.67	86.95		

Appendix VIII: Error matrix resulting from classifying test pixels Accuracy assessment on the basis of ground-truthing points (Land cover 2020)

Class	Water	Barren area	Grassland	Riverine forest	Sal dominated forest	Crop land	Buildup/ settlement area	Mixed forest	User total	User's accuracy (%)
Water bodies	45	2	2	1	0	0	0	0	50	90.00
Barren area	5	41	2	0	0	0	2	0	50	82.00
Grassland	2	1	51	2	1	2	0	4	63	80.95
Riverine forest	1	2	3	55	1	1	0	4	65	84.61
Sal dominated forest	0	2	2	2	117	2	1	3	129	90.69
Cropland	2	1	2	5	0	93	5	1	109	85.32
Developed area	0	2	1	0	0	5	55	2	65	84.62
Mixed forest	0	8	6	0	3	8	5	122	152	80.26
Producer total	55	59	69	65	122	111	68	136	683	
User accuracy (%)	81.18	69.49	76.11	84.61	95.90	83.78	80.88	89.70		

Appendix IX: Large mammals reported during study period in CHAL

SN	Common Name	Zoological Name	Order	Family	IUCN status	Reported from	Remarks
1	Tiger	*Panthera tigris* (Linnaeus, 1758)	Carnivora	Felidae	EN	BCF	*
2	Leopard	*Panthera pardus* (Linnaeus, 1758)	Carnivora	Felidae	VU	Along study area	**
3	Himalayan black bear	*Ursus thibetanus* G. [Baron] Cuvier, 1823	Carnivora	Ursidae	VU	Mid-hills	**
4	Golden jackal	*Canis aureus* Linnaeus, 1758	Carnivora	Canidae	LC	Along study area	R
5	Jungle cat	*Felis chaus* Schreber, 1777	Carnivora	Felidae	LC	BCF	R
6	Sloth bear	*Melursus ursinus* (Shaw, 1791)	Carnivora	Ursidae	VU	BCF	R
7	Large Indian civet	*Viverra zibetha* Linnaeus, 1758	Carnivora	Viverridae	LC	BCF	R
8	Sambar	*Rusa unicolor* (Kerr, 1792)	Cetartiodactyla	Cervidae	VU	BCF	**
9	Chital	*Axis axis* (Erxleben, 1777)	Cetartiodactyla	Cervidae	LC	BCF	**
10	Hog deer	*Axis porcinus* (Zimmermann, 1780)	Cetartiodactyla	Cervidae	EN	BCF	*
11	Northern red muntjac	*Muntiacus vaginalis* (Boddaert, 1785)	Cetartiodactyla	Cervidae	LC	Along study area	**
12	Wild pig	*Sus scrofa* Linnaeus, 1758	Cetartiodactyla	Suidae	LC	Along study area	**

13	Himalayan goral	*Naemorhedus goral* (Hardwicke, 1825)	Cetartiodactyla	Bovidae	NT	Mid-hills	**
14	Asian Elephant	*Elephas maximus* Linnaeus, 1758	Proboscidea	Elephantidae	EN	BCF	R
15	Greater one-horned rhino	*Rhinoceros unicornis* Linnaeus, 1758	Perissodactyla	Rhinocerotidae	VU	BCF	*
16	Rhesus macaque	*Macaca mulatta* (Zimmermann, 1780)	Primates	Cercopithecidae	LC	Along study area	**
17	Langur	*Semnopithecus* spp.	Primates	Cercopithecidae		Along study area	**
18	Assam macaque	*Macaca assamensis* (Hodgson, 1840)	Primates	Cercopithecidae	NT	Mid-hills	R

*: included in the other analysis but excluded for SDM (encounter > 25)

** included in all analysis including SDM (encounter <25)

R: not included in analysis as their reporting was below 5

Appendix X: Detailed information of transects

Block	**Number of Transects**	**Total length (km)**	**Average length ± SE (km)**	**Range (km)**
A	31	138.64	4.47 ± 0.29	1.72 to 7.83
B	35	103.55	2.96 ± 0.18	1.18 to 5.60
C	38	99.13	2.61 ± 0.12	1.31 to 4.39
D	46	136.37	2.96 ± 0.16	1.58 to 6.02

Appendix XI: Identification keys of the signs of carnivores

Carnivore	**Pad size (cm)**	**Width pugmark (cm)**	**Stride length (cm)**	**Scrape**	**Claw-scraping in tree**	**Scat diameter (cm)**	**References**
Tiger	9-10	12-14	>100	>35 cm long, 19 cm width	> 35 cm height, 19 cm width	>11	(Riordan, 1998; McDougal, 1999; Singh *et al.*, 2014; Lamichhane *et al.*, 2021a; Thapa *et al.*, 2021)
Leopard	<6.5	7-10	90	>25 cm long, 15 cm width	<25 cm height, 15 cm width	2-4	
Himalayan black bear	>10	>17	>100	-	>40 cm height, 20 cm width	3-5	(Shrestha & Basnet, 2005; Choudhury, 2013; Steinmetz *et al.*, 2013)

Appendix XII: Field data sheet

Date:	**Time started:**		**Time ended:**		**Starting place:** **Sampling sites:**			
Ending place:	**Block No:**		**Weather:**		**Transect No.**			
Sampling unit/point								
GPS No								
Elevation								
Area (location)								
Slope								
Forest type								
Major vegetation								
Dense/Mild dense/Barren								
Canopy cover								
Presence of IAPS								
IAPS coverage								
Distance to water sources								
Mammals reported (Prey)								
Group size								
M/F/SA/Y								
Sighting distance								
Sighting angle								
Activities								
Predator presence								
Sign type								
Pugmark No./size								
Scat								
Scrape/scent marks								
Pellets/Dung if any								
Other markings								
Human presence								
Fodder collection								

Firewood/timber								
Other forest product collection								
Fishing								
Others								
Livestock								
CF Guards								
Tourist/vechicle								
No of tourist								
Other impacts								
Time								
Notes								
Microhabitat								
Tree-1								
Tree-2								
Tree-3								
Tree-4								
Tree-5								
Tree-6								
Tree-7								
Others								
Shrubs								
Herbs								
Other minors								

Appendix XIII: Sample size calculation for questionnaires

Sample size $(n) = \frac{z^2 p\ (1-p)}{d^2}$

Here, z = 1.96 for 95% confidence limit

p = 0.5 (for unknown population and regarded as 50% of the population represents the characteristics of total population)

d = 0.04 (for tolerant margin error =4%)

Then, $n = \frac{(1.96)^2 \times 0.5\ (1-0.5)}{(0.04)^2}$

=600.25

Hence, the sample size for questionnaires = 600

Appendix XIV: Questionnaires on Human-wildlife Conflict

A. General Information

1. Date of Interview (B.S.) Name of Field Researcher:
District Name: Gaun Palika/Nagar Palika: Ward No: Village or Tole: Settlement Name:
Related forest/Community Forest: GPS location:

B. Household: General Background

Name of Respondent: Name of Head of Family:
Age: Sex(M/F/below 10 year child): Number of family members: Education status: Occupation: Residing in the area since (Year):

Land holding area of household (in katthaRopani)

Land type	**Registered land**	**Non registered land**	**Rented land(bandaki/adhiya)**	**Barren land**	**Irrigated**
Khet					
Bari					
Kharbari					
Housing plots					
Khoriya					

Agriculture

Main crops	**Area**	**Production**	**Local market rate**	**If sold (Quantity)**
Rice				
Maize				
Ginger				
Millet				
Mustard				
Wheat				
Fruits				
Vegetables				
Potato				
Broom Grass				

(Area: kattha/bigaha/Ropani, Production: kilos/quintals or muri, Fruits: number of trees)

Economic condition

Income source	Annual income	Annual expenditure	Amount	Treatment method
Service		Daily house expenses		
Business		Health		
Agriculture		Education		
Other (Specify)		Other (Specify)		

Livestock holding

Animals	Number		Feeding practice	Income	Unit price	Pasture land
	Local	Improved				
Ploughing bull						
Cow						
Buffalo						
Goats						
Pig						
other (Specify)						
Others						

Ways of feeding: Sf- stall feeding, Fg- free grazing, Fr= free ranging cattle, Income: Ploughing bull- in rent/day, Cow, buffalo= milk (mana/day), Goats- in number

Dependence on natural resources

Particular	**CF**	Colb.F	**Nat.F**	**Pvt.F**	**Khoriya (shifting cultivation)**	**Farmland**	**Grassland**
Fodder							
Firewood							
Timber							
Leaves litter							
NTFPs							
Livestock grazing							
Quantity							
Distance from village							
Time to reach							

CF- community forest, Colb.F- Collaborative Forest, Nat.F - National Forest, Pvt.F- Private Forest BZ= Buffer zone, Distance- Mile/Km. Time- Time taken to extract

C. Reasons of HWC

a. Scarcity of food b. Destruction of forest c. livestock grazing d. road construction

e. Human disturbance f. all

Natural resources collection by: a. female b. Male c. both d. child

i. Crop damage (yes/no) Time: Regular, seasonal, occasional

SN	Crop	Estimated damage area (Kattha/Ropani)	Crop damaged in Kg	By wild animal	Times	Total amount (NRs)
1	Paddy					
2	Wheat					
3	Maize					
4	Millet					
5	Potato					
6	Oat					

7	Other vegetable					
8	Mustard					
9.	Others					

Livestock depredation

Enter the number of animals lost last year to each type of mortality. If Possible, record the number of adults and young separately:

Source of Mortality	**Number lost by kind of livestock**					
	Cows	**Buffalo**	**Sheep/Goats**	**Horse**	**Duck/poultry**	**Other**
Lack of forage						
Winter snow/cold						
Disease						
Accident						
Predation						
Other						

v. Livestock depredation (yes/no)

SN	**Type of livestock killed**	**Numbers**	**Location**	**Killed by (Predator)**	**Total Monetary loss (NPR)**
1	Cow/ox				
2	Buffalo				
3	Goats				
4	Sheep				
5	Pig				
6	Horse				
7.	Poultry				
Others					

(Locations: Inside forest=1, Forest fringe area=2, settlement/home/shed=3, others=4)

vi. Human Casualty and or injuries

SN	**Name of person**	**Casualty or injuries**	**Which animal?**	**Age/sex**	**Ethnicity (Dalit, Janajati, BCH)**	**Incident Year**

D. Relevancy to address HWC

Do you get the compensation of the damage? If yes, mention source and amount.

Which of following mitigation measure you are taking for wildlife?

SN	**Animals**	**Mitigation measures**
1	Rhino	
2	Tiger	

3	Leopard	
4	Himalayan black bear	
5	Sloth bear	
6	Wild pigs	
7	Chital	
8	Muntjac	
9	Monkeys	
10		
11		

(1= Wachtower (machan), 2= noise/drumming 3= Fringe/agulto, 4= crop guarding, 5= livestock watching, 6= fencing, 7= crop diversity/unpalatable crop, 8= Killing, 9= snares 10= Guneli, Translocation to other place, 12= others)

Thank You Very Much

Appendix XV: Demographic profile of the respondents

Parameters	Category	Blocks				Total	Stasts
		A	B	C	D		
Age (Years)	20-30	4	9	6	3	22	χ^2= 15.68, p=0.407
	30-40	31	23	23	18	95	
	40-50	37	46	49	44	176	
	50-60	39	40	42	48	169	
	60-70	24	25	18	21	88	
	70 above	15	7	12	16	50	
Sex	Male	105	97	50	97	349	χ^2= 51.15, p=0.0001
	Female	45	53	100	53	251	
Education (Years of schoolings)	Illiterate	29	21	1	22	73	χ^2=43.02, p=0.0001
	Primary	53	73	91	63	280	
	Secondary	48	40	35	37	160	
	Intermediate	12	11	11	14	48	
	University	8	5	12	14	39	
Occupation	Agriculture	113	115	117	101	446	χ^2=15.04, p=0.234
	Teacher	14	11	11	14	50	
	Business	7	10	5	19	41	
	Service	8	5	9	6	28	
	Social worker	8	9	8	10	35	
Ethnicity	Braman/Chhetri	49	12	21	30	112	χ^2=87.112, p=0.0001
	Adibasi/Janajati	63	122	105	89	379	
	Dalit	21	13	22	31	87	
	Marginalized group	17	3	2	0	22	
Family size	Number	5.6±0.14	5.8±0.12	5.56±0.12	5.99±0.14	5.73±0.09	
Land	Sq m	1848±100.44	4236.08 ±255.76	5778±331.12	6961.75 ±523.06	4705.95±1104.03	
Income	US$	2103.98 ±129.45	1917.12 ±133.18	1876.801±132.78	3304.58 ±252.77	2300.7±338.37	
Livestock holding	Number	7.87±0.68	18.22±1.07	15.86±1.17	23.93±4.22	13.98±3.13	

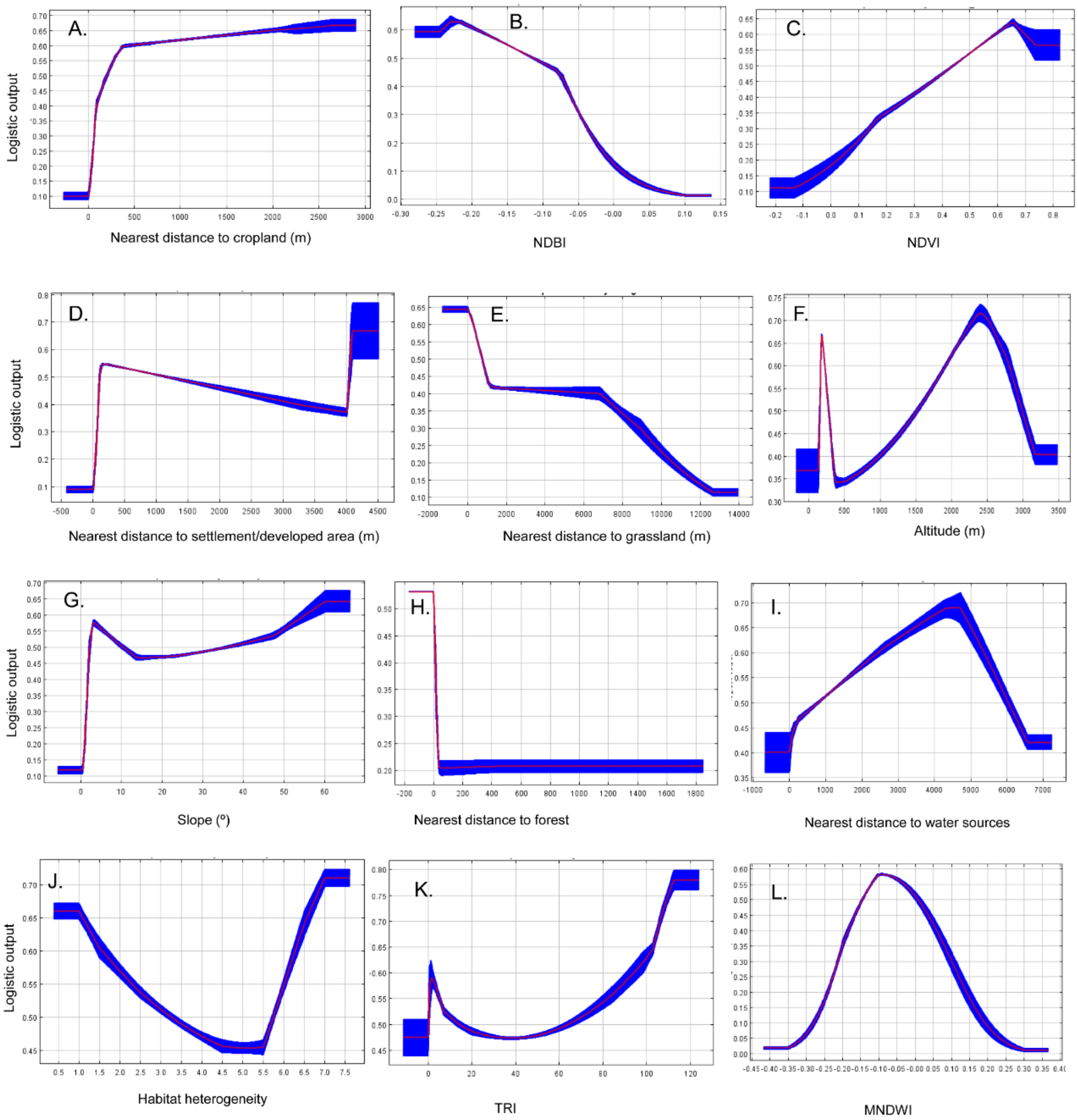
Appendix XVI: Farm get price of the crops in 2020 April

Crops	Chitwan			Tanahun			Kaski		
	Average price of Chitwan (agriculture office)	Market price	Farm get price	Average price of Tanahun (agriculture office)	Market price	Farm get price	Average price of Kaski (agriculture office)	Market price	Farm get price
Paddy	25	30	27.5	30	35	32.50	30	35	32.50
Wheat	25	27	26	25	27	26	25	35	30
Millet	30	35	32.50	30	35	32.50	30	35	32.50
Oat	0	0	0	30	38	34	30	40	35
Maize	20	35	27.50	20	25	22.50	20	30	25
Potato	25	40	32.50	25	35	30	25	45	35
Vegetable	40	60	50	40	50	45	40	65	52.50

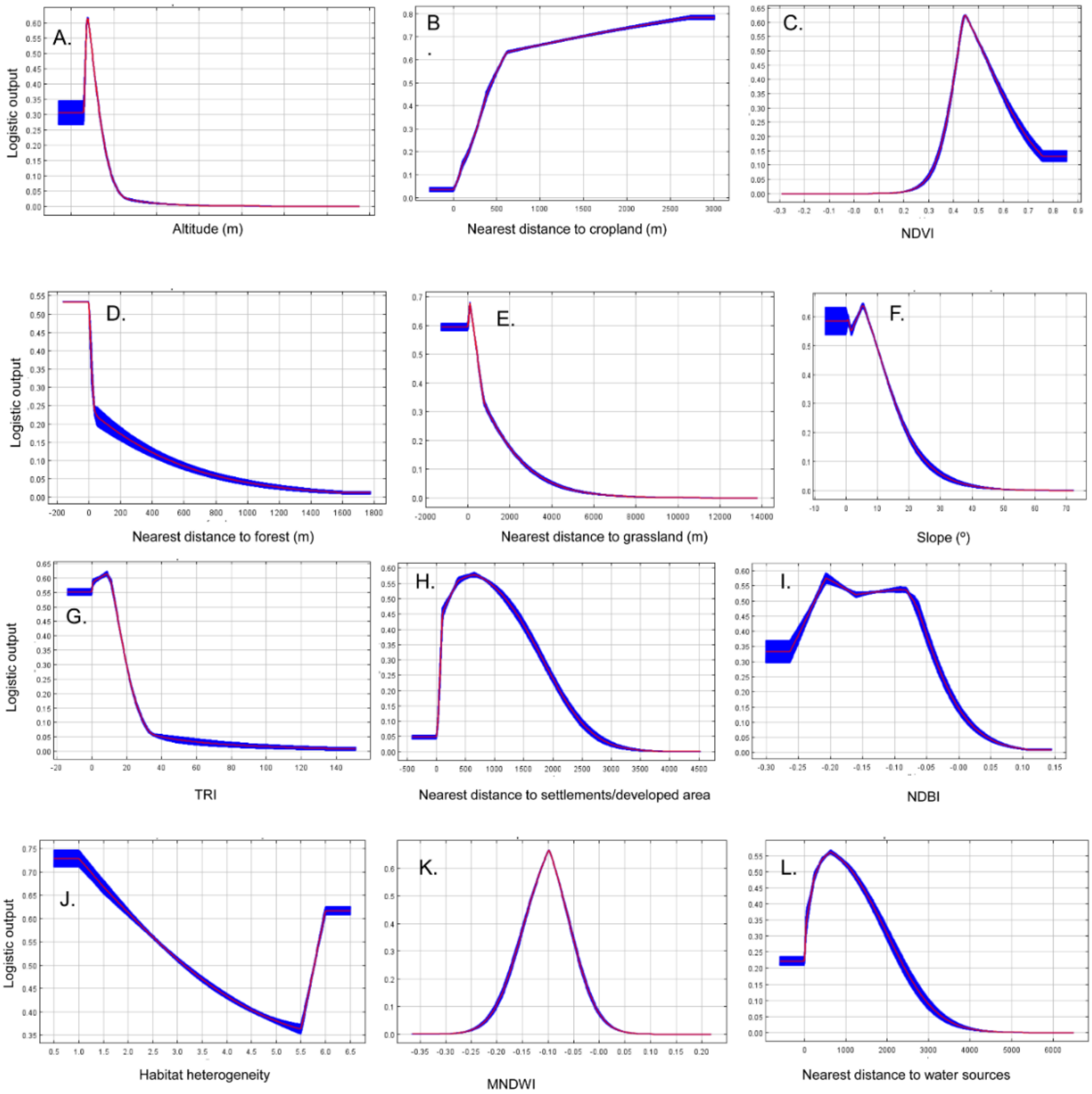
Appendix XVII: Average farm get price of livestock (April, 2020)

Livestock	Chitwan			Tanahun			Kaski		
	Veterinary office	Market price	Average farm get price (NPR)	Veterinary office	Market price	Average farm get price (NPR)	Veterinary office	Market price	Average farm get price (NPR)
Cow-milked	25000	55000	40000	15000	30000	22500	15000	25000	20000
OX	10000	20000	15000	10000	20000	15000	10000	20000	15000
Young cow	5000	5000	5000	5000	5000	5000	5000	5000	5000
Milked buffalo	70000	100000	85000	70000	100000	85000	70000	100000	85000
Male buffalo	15000	25000	20000	15000	25000	20000	15000	25000	20000
Young buffalo	10000	20000	15000	10000	20000	15000	10000	20000	15000
Goat/sheep	8000	15000	11500	8000	12000	10000	8000	15000	11500
Pig	4000	6000	5000	4000	10000	7000	4000	10000	7000
Dog	0	5000	5000	0	2000	2000	0	2000	2000

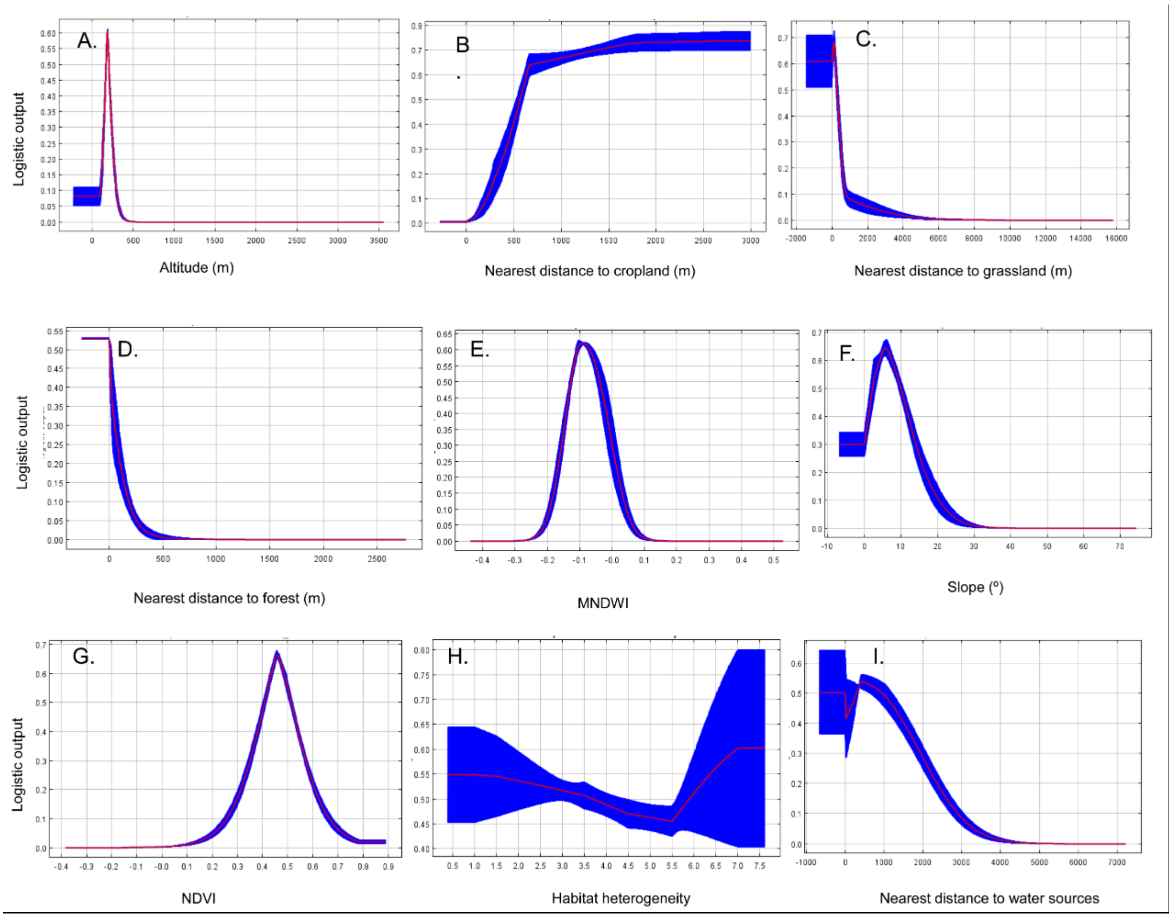
Appendix XVIII: Relationships between the environmental variables and the probability of occurrence of northern red muntjac. (Here, A. nearest distance from the cropland (m), B. NDBI, C. NDVI, D. nearest distance to buildup/settlements area (m) E. nearest distance to grassland (m), F. elevation (m), G. Slope (°), H. nearest distance to forest, I. nearest distance to water sources, J. Index of habitat heterogeneity, K. TRI-Terrain Ruggedness Index, L. MNDWI)



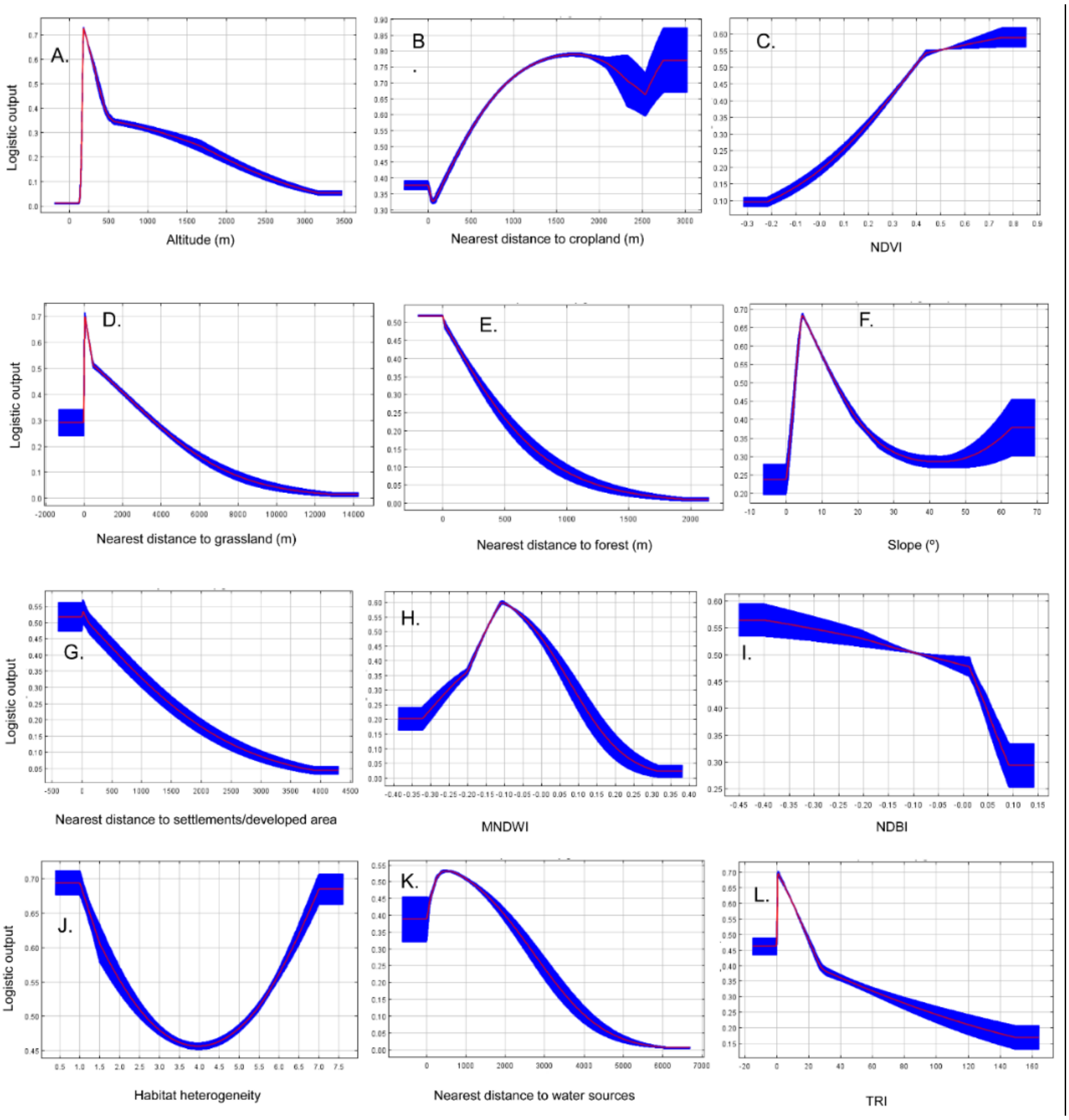
Appendix XIX: Relationships between the environmental predators and the probability of occurrence of chital; (here, A. elevation (m), B. nearest distance to cropland (m), C. NDVI, D. nearest distance to forest, E. nearest distance to grassland (m), F. Slope (º), G. TRI, H. nearest distance to buildup/settlements area (m), I. NDBI, J. Index of habitat heterogeneity, K. MNDWI, L. nearest distance to water sources)



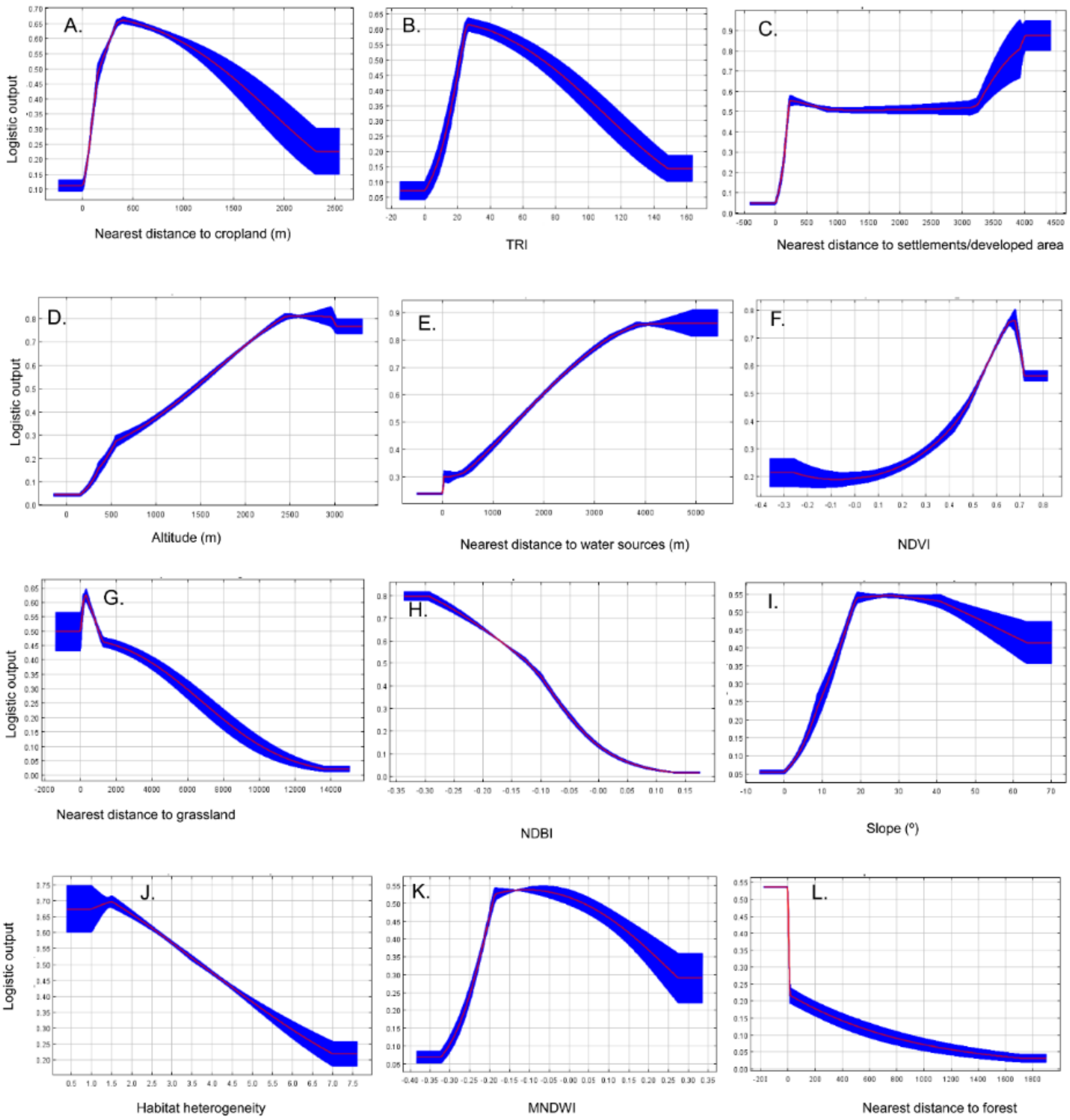
Appendix XX: Relationships between the environmental predators and the probability of occurrence of sambar. (Here, A. elevation (m), B. nearest distance from the cropland (m), C. nearest distance to grassland (m), D. nearest distance to forest, E. MNDWI, F. Slope (º), G. NDVI, H. Index of habitat heterogeneity, I. nearest distance to water sources)



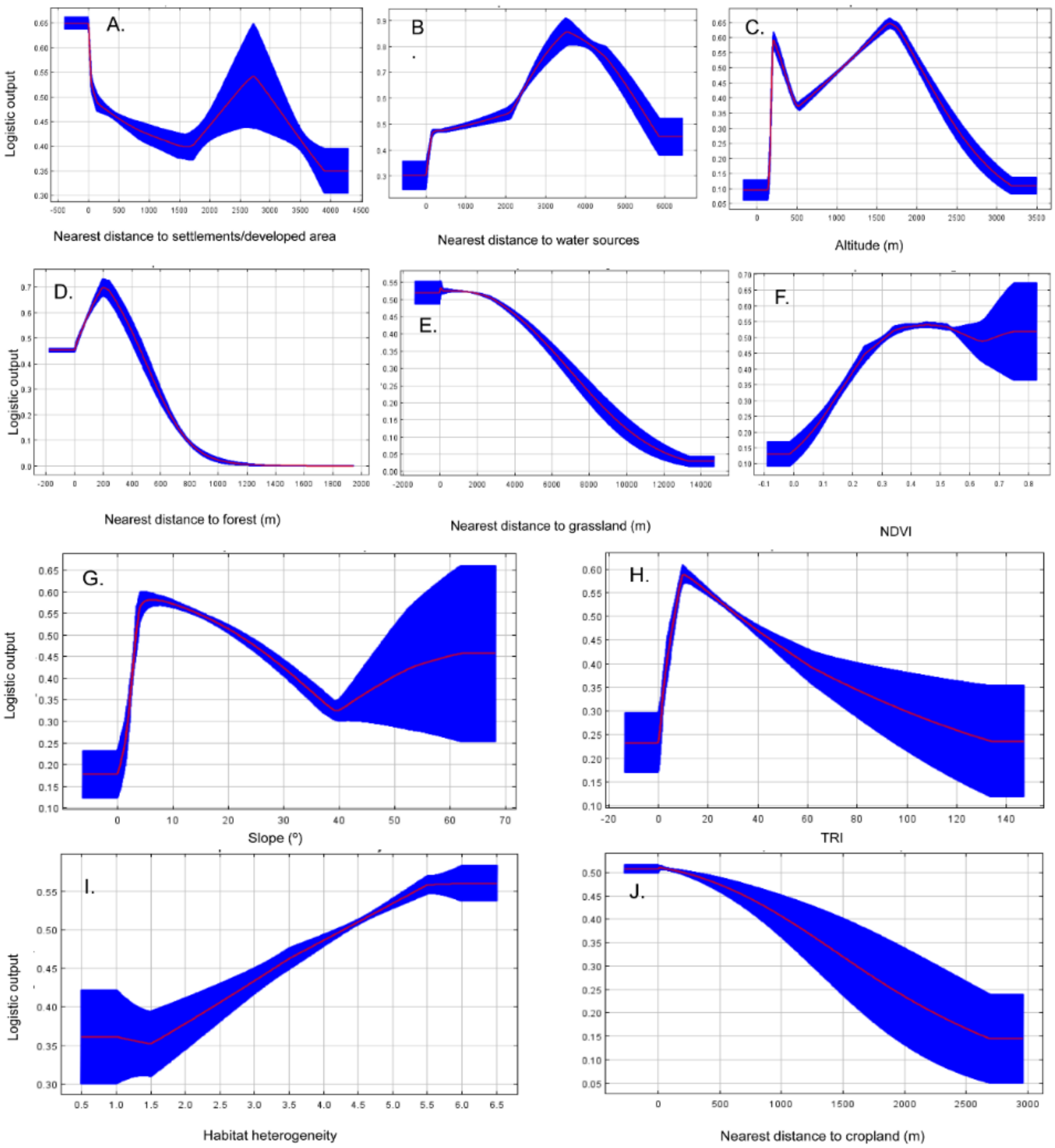
Appendix XXI: Relationships between the environmental predators and the probability of occurrence of wild pig. (Here, A. elevation (m), B. nearest distance from the cropland (m), C. NDVI, D. nearest distance to grassland (m), E. nearest distance to forest, F. Slope (°), G. nearest distance to buildup/settlements area (m), H. MNDWI, I. NDBI, J. Index of habitat heterogeneity, K. nearest distance to water sources, L. TRI)



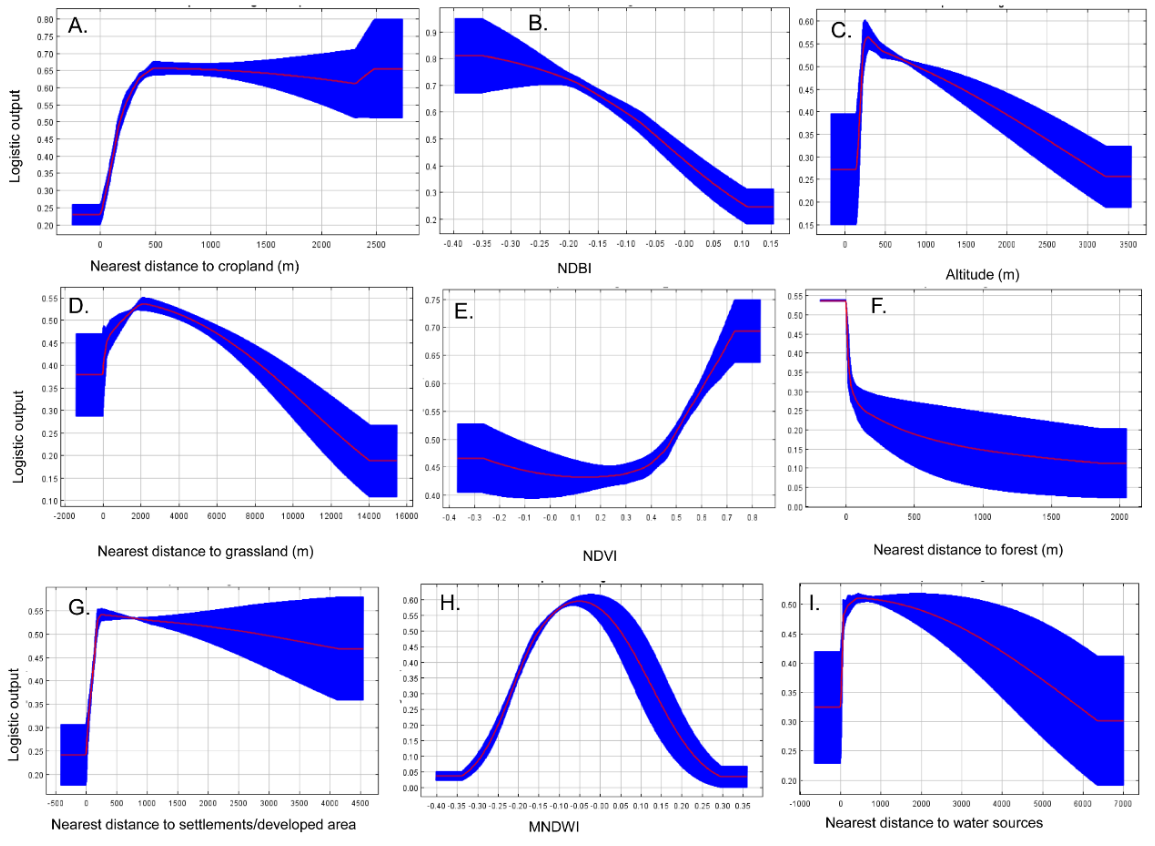
Appendix XXII: Relationships between the environmental predators and the probability of occurrence of Himalayan goral. (Here, A. nearest distance from the cropland (m), B.TRI, C. nearest distance to buildup/settlements area (m) D. elevation (m), E. nearest distance to water sources, F. NDVI, G. nearest distance to grassland (m), H. NDBI, I. Slope (º), J. Index of habitat heterogeneity, K. MNDWI, L. nearest distance to forest)



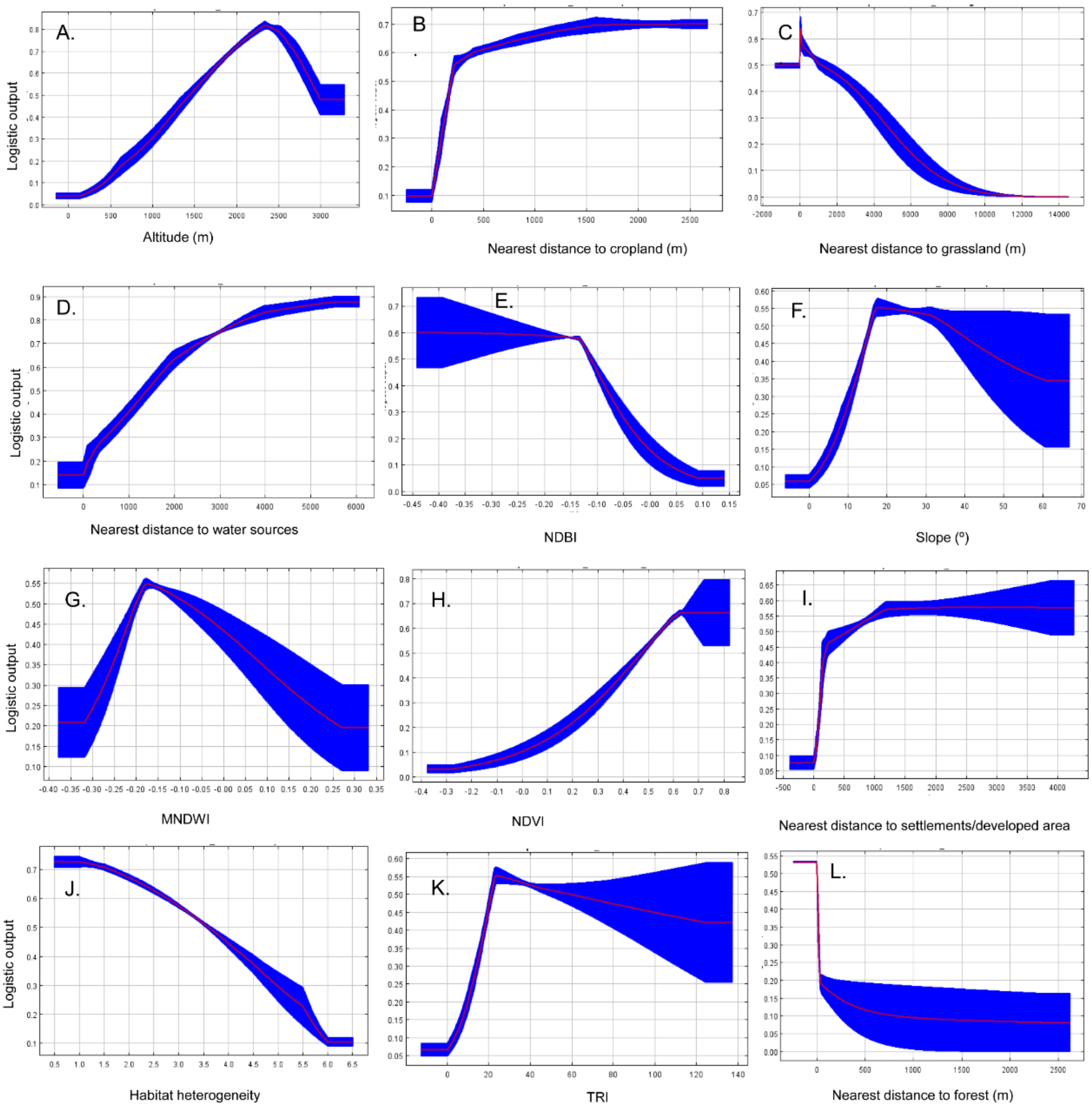
Appendix XXIII: Relationships between the environmental predators and the probability of occurrence of rhesus macaque. (Here, A. nearest distance to buildup/settlements area B. nearest distance to water sources, C. elevation (m), D. nearest distance to forest (m), E. nearest distance to grassland (m), F. NDVI, G. Slope (º), H. TRI, I. Index of habitat heterogeneity, J. nearest distance from the cropland (m))



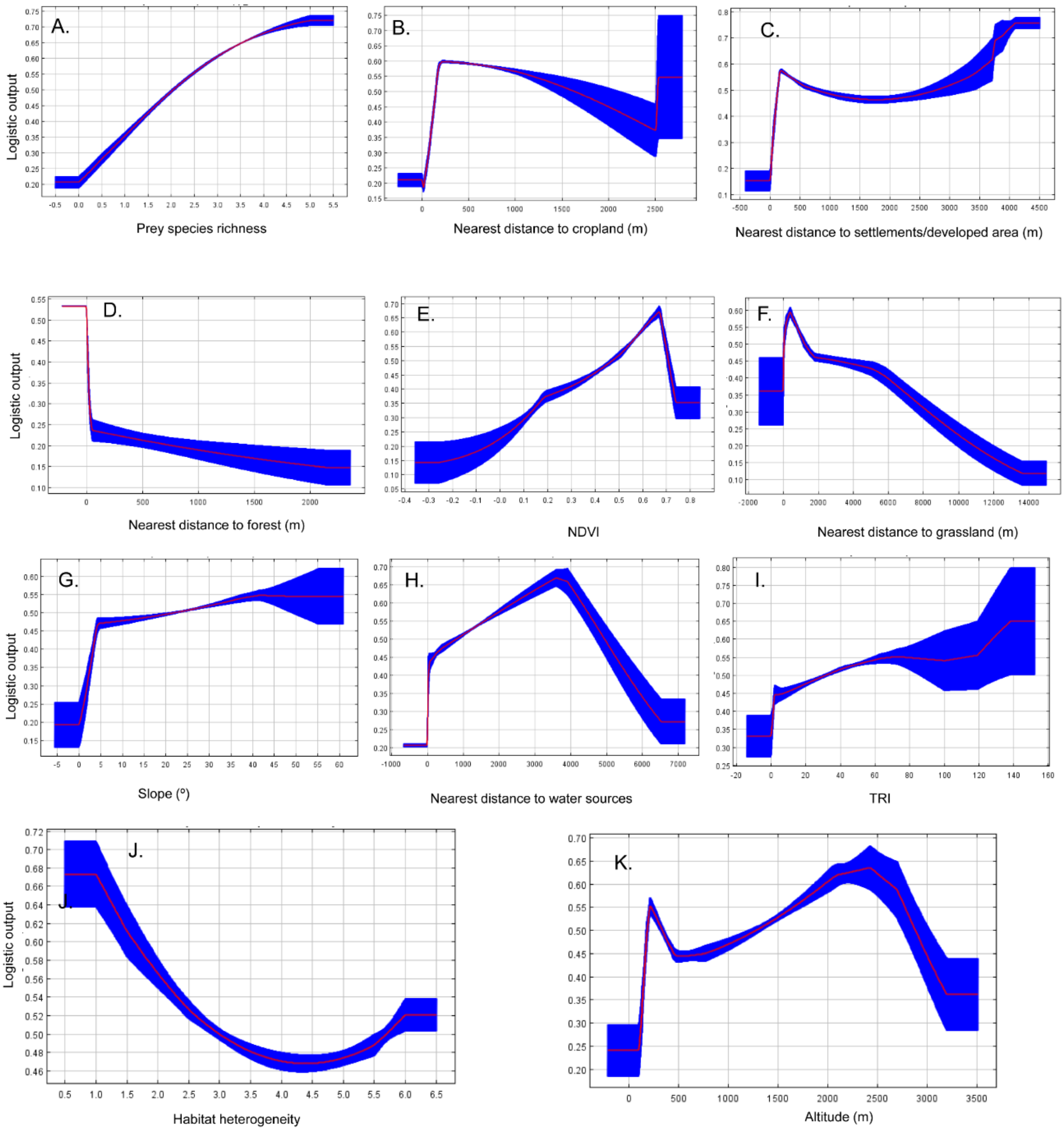
Appendix XXIV: Relationships between the environmental variables and the probability of occurrence of langur. (Here, A. nearest distance from the cropland (m), B. NDBI, C. elevation (m), D. nearest distance to grassland (m), E. NDVI, F. nearest distance to forest (m), G. Nearest distance to buildup/settlements area, H. MNDWI, I. nearest distance to water sources)



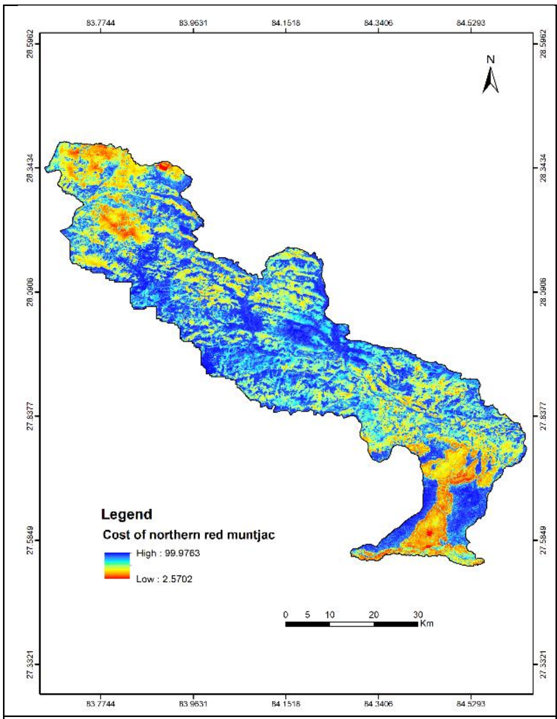
Appendix XXV: Relationships between the environmental variables and the probability of occurrence of Himalayan black bear. (Here, A. elevation (m) B. nearest distance from the cropland (m), C. nearest distance to grassland (m), D. nearest distance to water *sources*, (m) E. NDBI, F. Slope (º), G. MNDWI., H. NDVI, I. nearest distance to buildup/settlements area J. Index of habitat heterogeneity, K. TRI, L. nearest distance to forest)



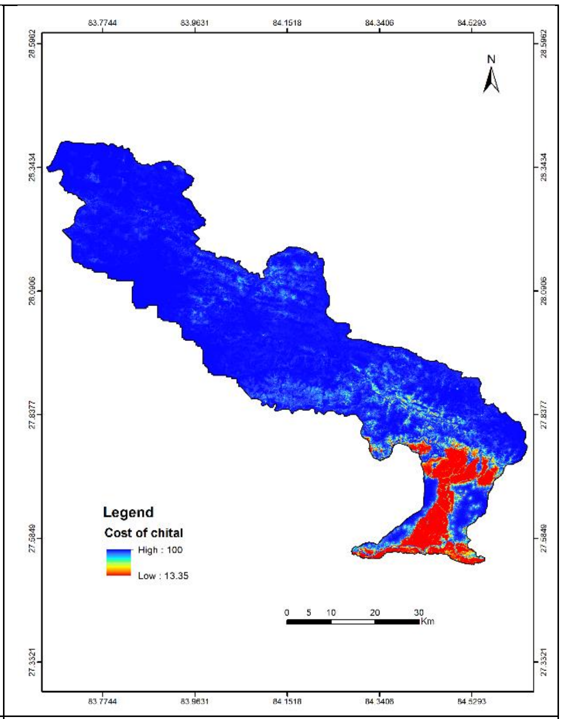
Appendix XXVI: Relationships between the environmental variables and the probability of occurrence of leopard. (Here, A. Prey species richness, B. nearest distance from the cropland (m), C. nearest distance to buildup/settlements area (m), D. nearest distance to forest, E. NDVI, F. nearest distance to grassland (m), G. Slope (º), H. nearest distance to water *sources*, I. TRI, J. Index of habitat heterogeneity, K. elevation (m))



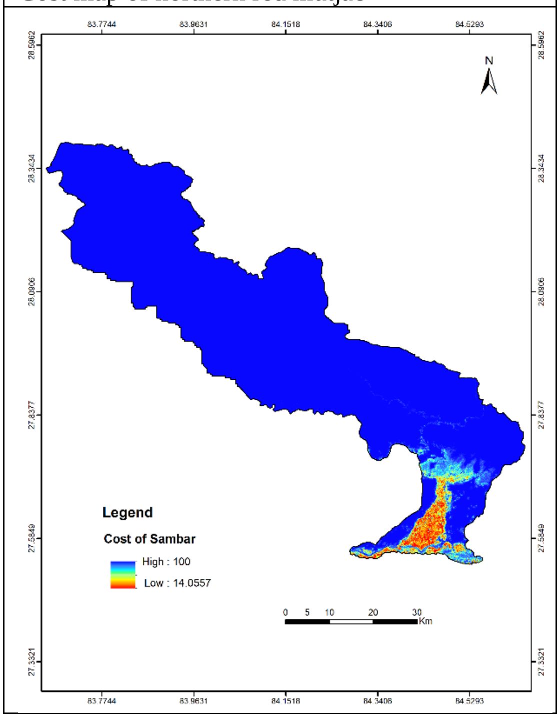
Appendix XXVII: Cost or landscape resistance for respective mammals



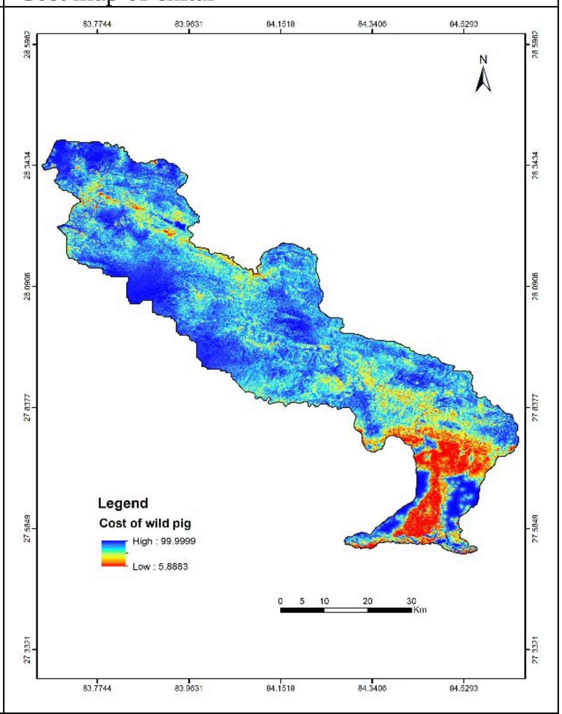
Cost map of northern red mutjac



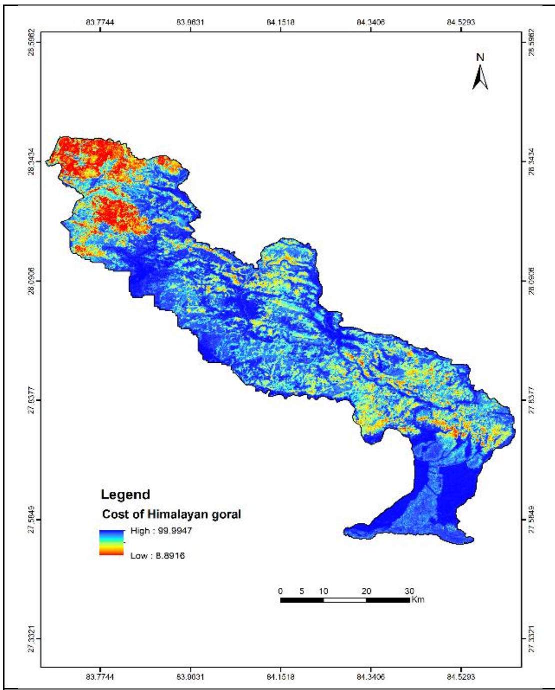
Cost map of chital



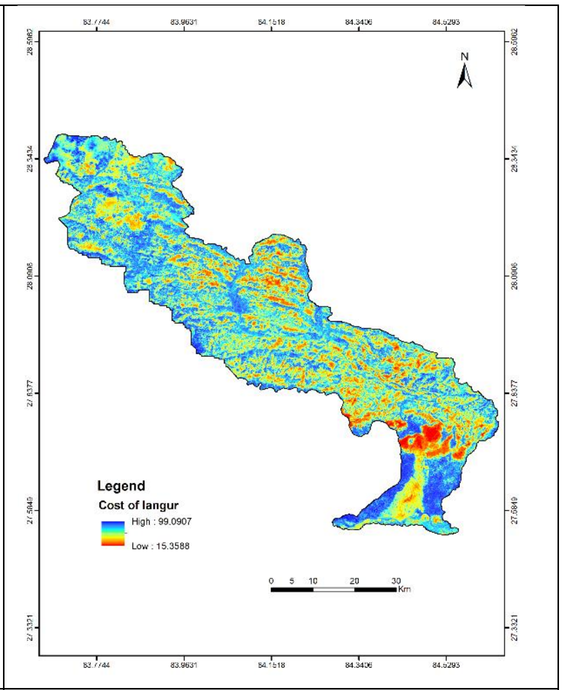
Cost map of sambar



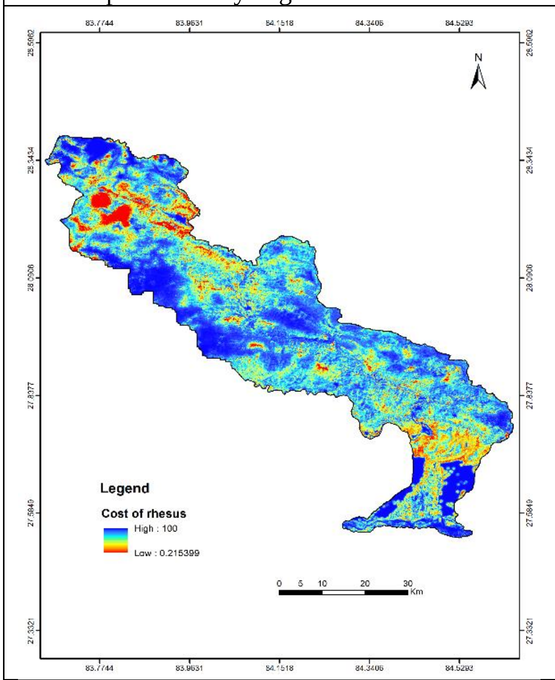
Cost map of wild pig



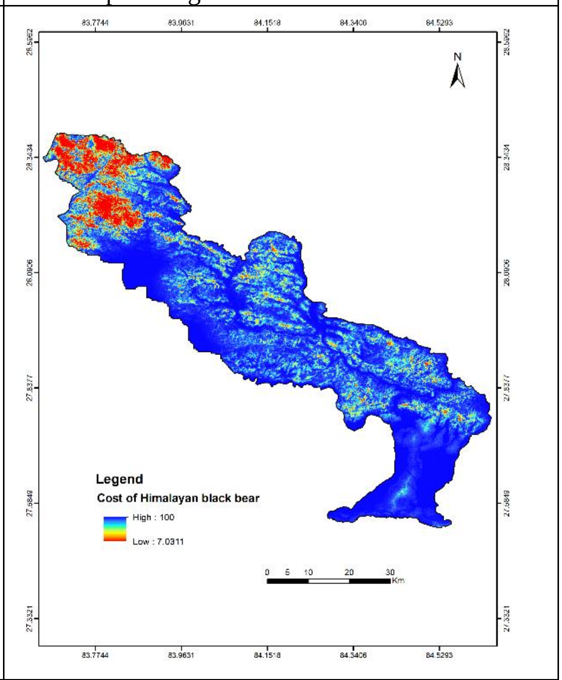
Cost map of Himalayan goral



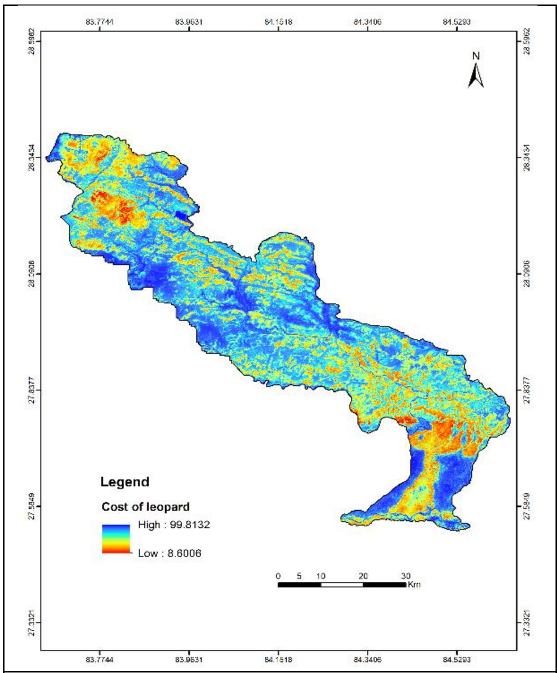
Cost map of langur



Cost map of rhesus macaque



Cost map of Himalayan black bear



Cost map of leopard

Appendix XXVIII: Characteristics of the mapped linkages between the 15 core areas for different mammals in the CHAL. Here, lcDist= Least-cost distance, lcpLength= Least-cost path length, eucDist= Euclidean distance, cwd= cost weight distance

Northern red muntjac								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:lcp*
1	1	2	1	783	49745.3	1152	63.53	43.18
2	1	4	1	3680	244219.1	3789	66.36	64.45
3	1	5	-15	8061	559286.4	10562	69.38	52.95
4	2	3	1	3300	138180.9	4500	41.87	30.71
5	2	4	1	3616	208790.1	4075	57.74	51.24
6	3	4	1	9983	719282.8	11085	72.05	64.89
7	3	7	1	23270	1682717	28809	72.31	58.41
8	3	8	1	28402	2009464	35181	70.75	57.12
9	4	5	1	91	7757.506	144	85.25	53.87
10	4	6	-15	3401	201671.8	3772	59.3	53.47
11	4	7	1	16885	1024916	18888	60.7	54.26
12	5	6	1	973	78463.3	1131	80.64	69.38
13	6	7	1	24921	1591726	27864	63.87	57.12
14	6	10	1	52053	3664921	60065	70.41	61.02
15	7	8	1	837	72216.19	929	86.28	77.74
16	7	10	-15	25444	1864858	28181	73.29	66.17
17	8	9	1	24813	1775622	26081	71.56	68.08
18	8	10	1	22373	1659908	24838	74.19	66.83
19	9	10	1	9146	572666.8	10705	62.61	53.5
20	9	11	1	2949	178521.3	3181	60.54	56.12
21	9	12	1	7500	453087	8602	60.41	52.67

22	9	13	1	9171	557745.5	10450	60.82	53.37
23	10	15	1	9293	790274.3	12284	85.04	64.33
24	10	13	-15	33159	2376085	50016	71.66	47.51
25	11	12	1	1020	89168.17	1087	87.42	82.03
26	11	15	-15	6291	443928.2	8134	70.57	54.58
27	11	13	-15	4423	293758.6	5234	66.42	56.13
28	12	15	-15	2877	170307	3300	59.2	51.61
29	12	13	1	35	5721.434	72	163.47	79.46
30	13	15	1	544	47755.43	637	87.79	74.97
31	14	15	1	372	33559.39	414	90.21	81.06
Chital								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	83271.05	834	106.35	99.84
2	1	4	1	3680	367531.7	3690	119.45	99.6
3	1	5	1	8061	889016.9	8985	110.29	98.94
4	2	3	1	3300	350801	3521	106.3	99.63
5	2	4	1	3616	382352.3	3826	105.74	99.93
6	3	4	1	9983	1032652	10352	103.44	99.75
7	3	7	1	23270	2524168	25406	108.47	99.35
8	3	8	-15	28402	3171151	32027	111.65	99.01
9	4	5	1	91	14418.01	144	158.44	100.13
10	4	6	-15	3401	359142.7	3601	105.6	99.73
11	4	7	1	16885	1782723	18248	105.58	97.69
12	5	6	1	973	103551.3	1035	106.42	100.04
13	6	7	1	24921	2602299	26339	104.42	98.8
14	6	10	1	52053	5437384	55210	104.46	98.48
15	7	8	1	837	91815.23	923	109.7	99.47
16	7	10	1	25444	2647620	26679	104.06	99.23
17	8	9	1	24813	2503366	25531	100.89	98.05
18	8	10	1	22373	2392380	24199	106.93	98.86
19	9	10	1	9146	937348.9	9942	102.49	94.28
20	9	11	1	2849	290865.2	3106	102.09	93.64
21	9	12	1	6500	719987.6	8136	110.77	88.49
22	9	14	1	8971	898017.9	9694	100.1	92.63
23	10	14	1	9293	1118833	11547	120.34	96.89
24	11	12	1	1010	101982	1087	100.97	93.82
25	11	13	1	5891	606283.1	6900	102.91	87.86
26	12	13	-15	2377	270560.8	3148	113.82	85.94
27	12	14	1	35	7232.443	72	206.64	100.45
28	13	14	1	544	58841.11	600	108.16	98.06
29	13	15	1	372	39421.8	414	105.97	95.22
30	14	15	1	110	9212.424	132	83.74	69.79
Sambar								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*

1	1	2	1	783	83485.28	834	106.62	100.1
2	1	4	1	3680	369000	3690	100.27	100
3	1	5	1	8061	898528.9	8985	111.47	100
4	2	3	1	3300	352154.3	3521	106.71	100.02
5	2	4	1	3616	382669.1	3826	105.83	100.02
6	3	4	1	9983	1035204	10352	103.7	100
7	3	7	1	23270	2540674	25406	109.18	100
8	3	8	-15	28402	3202727	32027	112.76	100
9	4	5	1	91	14485.28	144	159.18	100.59
10	4	6	-15	3401	360198.1	3601	105.91	100.03
11	4	7	1	16885	1824870	18248	108.08	100
12	5	6	1	973	103580.7	1035	106.46	100.08
13	6	7	1	24921	2633923	26339	105.69	100
14	6	10	1	52053	5520509	55210	106.06	99.99
15	7	8	1	837	92390.96	923	110.38	100.1
16	7	10	1	25444	2667547	26679	104.84	99.99
17	8	9	1	24813	2552332	25531	102.86	99.97
18	8	10	1	22373	2418407	24188	108.09	99.98
19	9	10	1	9146	989634.1	9904	108.2	99.92
20	9	11	1	2949	309340.8	3094	104.9	99.98
21	9	12	1	7500	799135.9	8006	106.55	99.82
22	9	14	1	9171	965044.1	9669	105.23	99.81
23	10	14	1	9293	1150222	11547	123.77	99.61
24	10	17	-15	33159	3654994	50247	110.23	72.74
25	11	12	1	1020	107842.3	1087	105.73	99.21
26	11	13	1	6291	659900.9	6764	104.9	97.56
27	11	14	-15	4423	471877.3	4762	106.69	99.09
28	12	13	-15	2877	293376.8	2990	101.97	98.12
29	12	14	1	35	7242.641	72	206.93	100.59
30	13	14	1	544	59574.11	600	109.51	99.29
31	13	15	1	372	39645.13	414	106.57	95.76
32	14	15	-15	17610	1790170	30406	101.6565	55.59
Wild pig								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	46780.63	1128	59.75	41.47
2	1	4	1	3680	227517.4	4137	61.83	55
3	1	5	-15	8061	584279.5	9959	72.48	58.67
4	2	3	1	3300	281729.5	3575	85.37	78.81
5	2	4	1	3616	222801.3	4206	61.62	52.97
6	3	4	1	9983	724787.3	10844	72.6	66.84
7	3	7	1	23270	1692323	26860	72.73	63.01
8	3	8	1	28402	2020895	34332	71.15	58.86
9	4	5	1	91	12032.34	144	132.22	83.56
10	4	6	-15	3401	250124.8	3935	73.54	63.56

11	4	7	1	16885	1009733	19577	59.8	51.58
12	5	6	1	973	84138.99	1070	86.47	78.63
13	6	7	-15	24921	1952614	32654	78.35	59.8
14	6	10	1	52053	4257815	56557	81.8	75.28
15	6	17	-15	83664	6458121	123195	77.19	52.42
16	7	8	1	837	61151.55	996	73.06	61.4
17	7	10	1	25444	1959046	28025	76.99	69.9
18	8	9	1	24813	2053360	27543	82.75	74.55
19	8	10	1	22373	1817154	25224	81.22	72.04
20	9	10	1	9146	615340.1	10369	67.28	59.34
21	9	11	1	2949	174645.9	3255	59.22	53.65
22	9	12	-15	7500	417026.1	8723	55.6	47.81
23	9	14	-15	9171	642640.8	11356	70.07	56.59
24	10	14	1	9293	897499.5	12097	96.58	74.19
25	11	12	1	1020	57091.16	1211	55.97	47.14
26	11	13	1	6291	383950.1	6824	61.03	56.26
27	12	13	-15	2877	158850.9	3161	55.21	50.25
28	12	14	1	35	3993.995	720	114.11	55.47
29	13	14	1	544	39699.01	686	72.98	57.87
30	13	15	1	372	28783.48	457	77.37	62.98
31	14	15	1	96	5008.929	132	52.18	37.95

Himalayan goral

Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	38531.45	1189	49.21	32.41
2	1	4	1	3680	255298.2	4062	69.37	62.85
3	1	5	-15	8061	506699.2	10926	62.86	46.38
4	2	3	1	3300	182604.5	3767	55.33	48.47
5	2	4	1	3616	204313.3	4592	56.5	44.49
6	3	4	-15	9983	732338.2	17710	73.36	41.35
7	3	7	1	23270	1846458	27701	79.35	66.66
8	3	8	-15	28402	2233098	35117	78.62	63.59
9	4	5	1	91	8603.417	144	94.54	59.75
10	4	6	-15	3401	155075.4	4071	45.6	38.09
11	4	7	1	16885	1173078	19648	69.47	59.7
12	5	6	1	973	53291.75	1330	54.77	40.07
13	6	7	-15	24921	1698124	36242	68.14	46.86
14	6	10	-15	52053	4061832	71309	78.03	56.96
15	7	8	1	837	68486.05	929	81.82	73.72
16	7	10	-15	25444	2046336	28940	80.43	70.71
17	8	9	1	24813	1828066	26566	73.67	68.81
18	8	10	1	22373	1788818	25693	79.95	69.62
19	9	10	1	9146	647761.3	10423	70.82	62.15
20	9	11	1	2949	187374.1	3193	63.54	58.68
21	9	12	1	7500	531883.9	8326	70.92	63.88

22	11	12	1	1020	105081.7	1087	103.02	96.67
23	12	14	1	35	4114.688	72	117.56	57.15
24	13	14	1	544	56023.75	600	102.98	93.37
25	13	15	1	372	39752.84	414	106.86	96.02
26	14	15	1	96	12729.55	132	132.6	96.44
Rhesus macaque								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	47873.4	919	61.14	52.09
2	1	4	1	3680	158247.8	4209	43	37.6
3	1	5	-15	8061	273200	18077	33.89	15.11
4	2	3	1	3300	218869.4	5472	66.32	40
5	2	4	1	3616	115907	4876	32.05	23.77
6	3	4	1	9983	551730.4	11970	55.27	46.09
7	3	7	1	23270	887661.4	30446	38.15	29.16
8	3	8	1	28402	1177293	37454	41.45	31.43
9	4	5	1	91	10292.98	144	113.11	71.48
10	4	6	-15	3401	142553.1	6196	41.92	23.01
11	4	7	1	16885	415718.7	21126	24.62	19.68
12	5	6	1	973	36166.2	2168	37.17	16.68
13	6	7	-15	24921	771801.7	40838	30.97	18.9
14	6	10	-15	52053	2709824	77065	52.06	35.16
15	7	8	1	837	79698.84	941	95.22	84.7
16	7	10	1	25444	1659882	29380	65.24	56.5
17	8	9	1	24813	1858745	28252	74.91	65.79
18	8	10	1	22373	1564598	26862	69.93	58.25
19	9	10	1	9146	480740.1	10291	52.56	46.71
20	9	11	1	2949	198849.1	3427	67.43	58.02
21	9	12	1	7500	459018.6	8809	61.2	52.11
22	9	14	-15	9171	580952.9	11775	63.35	49.34
23	10	14	1	9293	802913.1	11755	86.4	68.3
24	11	12	1	1020	52138.62	1156	51.12	45.1
25	11	13	1	6291	418122.4	7471	66.46	55.97
26	12	13	-15	2877	189243.3	3143	65.78	60.21
27	12	14	1	35	3465.896	72	99.03	48.14
28	13	14	1	544	57498.72	600	105.7	95.83
29	13	15	1	372	29197.78	427	78.49	68.38
30	14	15	1	96	6202.955	132	64.61	46.99
Langur								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	66392.99	834	84.79	79.61
2	1	4	1	3680	258449.4	4160	70.23	62.13
3	1	5	1	8061	569846	9943	70.69	57.31
4	2	3	1	3300	233614	3643	70.79	64.13
5	2	4	1	3616	258115.1	3878	71.38	66.56

6	3	4	1	9983	680863.2	10751	68.2	63.33
7	3	7	1	23270	1511510	27811	64.96	54.35
8	3	8	1	28402	1790663	34313	63.05	52.19
9	4	5	1	91	9460.867	144	103.97	65.7
10	4	6	-15	3401	223633.3	4088	65.76	54.7
11	4	7	1	16885	919236.2	18604	54.44	49.41
12	5	6	1	973	83049.77	1131	85.35	73.43
13	6	7	1	24921	1471913	28014	59.06	52.54
14	6	10	1	52053	3147698	60341	60.47	52.17
15	7	8	1	837	65920.62	929	78.76	70.96
16	7	10	-15	25444	1456580	32833	57.25	44.36
17	8	9	1	24813	1220034	27223	49.17	44.82
18	8	10	1	22373	1221544	26756	54.6	45.65
19	9	10	1	9146	494336.3	11010	54.05	44.9
20	9	11	1	2949	160457.6	3293	54.41	48.73
21	9	12	-15	7500	417949.9	9065	55.73	46.11
22	9	13	1	9171	421193.2	10510	45.93	40.08
23	10	13	1	9293	611438.8	12739	65.8	48
24	12	14	1	1020	83503.16	1087	81.87	76.82
25	13	15	1	6291	391163.5	7147	62.18	54.73
26	12	15	-15	2877	172626.6	3349	60	51.55
27	12	13	1	35	5450.112	72	155.72	75.7
28	11	12	1	544	46499.39	600	85.48	77.5
Himalayan black bear								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	38080.55	1493	48.63	25.51
2	1	4	1	3680	308209.9	3739	83.75	82.43
3	1	5	-15	8061	682907.8	10096	84.72	67.64
4	2	3	1	3300	217181.2	3643	65.81	59.62
5	2	4	1	3616	252185.2	4149	69.74	60.78
6	3	4	-15	9983	862029.9	16875	86.35	51.08
7	3	7	1	23270	2177344	26902	93.57	80.94
8	3	8	1	28402	2687813	33251	94.63	80.83
9	4	5	1	91	11203.06	144	123.11	77.8
10	4	6	-15	3401	223805.4	3880	65.81	57.68
11	4	7	1	16885	1454478	19472	86.14	74.7
12	5	6	1	973	86899.26	1131	89.31	76.83
13	6	7	-15	24921	2174618	31826	87.26	68.33
14	6	10	-15	52053	5019964	60778	96.44	82.6
15	7	8	1	837	90463.55	923	108.08	98.01
16	7	10	1	25444	2408867	26974	94.67	89.3
17	8	9	1	24813	2147058	26021	86.53	82.51
18	8	10	1	22373	2121844	24241	94.84	87.53
19	9	10	1	9146	856722.7	10021	93.67	85.49

20	9	11	1	2949	264811.5	3094	89.8	85.59
21	9	12	1	7500	715717.3	8101	95.43	88.35
22	9	14	1	8071	872973.1	9859	108.16	82.36
23	10	14	1	9293	1092810	11547	117.59	94.64
24	11	12	1	1020	108451	1087	106.32	99.77
25	11	13	1	6291	640380.7	6764	101.79	94.67
26	11	14	-15	4423	443295.4	4787	100.22	92.6
27	12	13	-15	2277	284716.3	3008	125.04	94.65
28	12	14	1	35	6559.071	72	187.41	91.1
29	13	14	1	544	59927.07	600	110.16	99.88
30	13	15	1	372	41445.63	414	111.41	100.11
31	14	15	1	96	13213.15	132	137.64	100.1
Leopard								
Link	Core1	Core 2	linkType	eucDist	lcDist	lcpLength	*cwd:EucD*	*cwd:LCP*
1	1	2	1	783	61030.29	1152	77.94	52.98
2	1	4	1	3680	227083.1	3888	61.71	58.41
3	1	5	-15	8061	492808.1	10372	61.13	47.51
4	2	3	1	3300	230258.1	3643	69.78	63.21
5	2	4	1	3616	211705.9	4178	58.55	50.67
6	3	4	1	9983	692847.4	11208	69.4	61.82
7	3	7	1	23270	1585873	28579	68.15	55.49
8	3	8	1	28402	1884028	35192	66.33	53.54
9	4	5	1	91	8391.948	144	92.22	58.28
10	4	6	-15	3401	186697.6	3993	54.89	46.76
11	4	7	1	16885	956745.4	19096	56.66	50.1
12	5	6	1	973	72382.9	1131	74.39	64
13	6	7	1	24921	1514266	27920	60.76	54.24
14	6	10	1	52053	3463198	60630	66.53	57.12
15	7	8	1	837	67924.85	929	81.15	73.12
16	7	10	-15	25444	1744081	28938	68.55	60.27
17	8	9	1	24813	1614928	27055	65.08	59.69
18	8	10	1	22373	1554220	25837	69.47	60.15
19	9	10	1	9146	492394.8	10965	53.84	44.91
20	9	11	1	2949	149495.3	3168	50.69	47.19
21	9	12	-15	7500	389392.8	9182	51.92	42.41
22	9	14	1	9171	482962.2	10507	52.66	45.97
23	10	14	1	9293	643004.9	12442	69.19	51.68
24	11	12	1	1020	76337.41	1099	74.84	69.46
25	11	13	1	6291	358752.7	7122	57.03	50.37
26	11	14	1	4423	245913.5	5229	55.6	47.03
27	12	13	-15	2877	147515.7	3388	51.27	43.54
28	12	14	1	35	3692.243	72	105.49	51.28
29	13	14	1	544	38833.35	637	71.38	60.96
30	13	15	1	372	31922.78	414	85.81	77.11
31	14	15	1	96	8311.631	132	86.58	62.97

Appendix XXIX: Conferences

1. Participation and paper presentation on **" International Conference on Zoology 2021: Himalayan Biodiversity in the Face of Global Change" Held** from 29 Nov -1 Dec 2021; Organized by Central Department of Zoology, TU.
2. Participation and paper presentation on **"6th Nepalese Scholars' Symposium**" organized by the Nepalese Scholars' Association (NESA) at the University of Alberta in collaboration with Nepalese Canadian Society of Edmonton (NECASE), Canada on the 5th of June 2021.
3. Participation and paper presentation on **"International Youth Conference on Science, technology and innovation**" Held in Biratnagar, Nepal on October 21-23, 2019 organized by Ministry of education, science and Technology, Nepal Academy of Science and Technology (NAST).
4. Participation and paper presentation on **"International Biodiversity Congress"** Held in Forest Research Institute (FRI), Dehradun, India from 4th - 6th October 2018; Organized by Navadhanya trust, Wildlife institute of India, Forest Research Institute (FRI), Dehradun, India.
5. Participation and paper presentation on **" National Conference on Zoology: The biodiversity conservation on changing world"** held from 28th -30th November 2020; Organized by Central Department of Zoology, TU.
6. Participation and paper presentation on **" Himalayan knowledge conclave: Sixth National Conference on Environment and Sustainable Development"** held from 5th -6th August 2020; Organized by Resources Himalaya, IOST, CDES, TU.
7. Participation and paper presentation on "**National Conference on Integrating Biological Resources for Prosperity**" Held in Biratnagar, Nepal on Magh 23-24, 2076 (February 6-7, 2020).

Appendix XXX: Publications

Adhikari, J.N., Bhattarai, B.P. Rokaya, M.B., & Thapa, T.B. (2022). Land use/ land cover changes in the central part of the Chitwan Annapurna Landscape, Nepal, *PeerJ*, **10**:e13435 https://doi.org/10.7717/peerj.13435

Adhikari, J.N., Bhattarai, B.P. Rokaya, M.B., & Thapa, T.B. (2022). Distribution of invasive plants and their impacts on wild ungulates in Barandabhar Corridor Forest, Nepal, *Folia Oecologica*, **49**(2): 182–191. https://doi.org/10.2478/foecol-2022-0021

Adhikari, J.N., Bhattarai, B.P., &Thapa, T.B. (2021). Determinants of abundance and habitat association of mammals in Barandabhar Corridor Forest, Chitwan, Nepal. *Folia Oecologica*, **48**(1): 100–109. https://doi.org/10.2478/foecol-2021-0011

Adhikari, J.N., Bhattarai, B.P., & Thapa, T.B. (2019). Determinants of distribution of large mammals in Seti River basin, Tanahun District of western Nepal. *Journal of Institute of Science and Technology*, **24**(1): 63–71. https://doi.org/10.3126/jist.v24i1.24638

Adhikari, J.N., Bhattarai, B.P., &Thapa, T.B. (2018). Human-wild mammal conflict in a human dominated midhill landscape: A case study from Panchase area in Chitwan Annapurna Landscape, Nepal. *Journal of Institute of Science and Technology*, **23**(1): 30–38. https://doi.org/10.3126/jist.v23i1.22158

Adhikari, J.N., Bhattarai, B.P., Rokaya, M.B., & Thapa, T.B. (2020). Ethno-medicinal uses of vertebrates in Chitwan-Annapurna Landscape, central Nepal. *PLoS One*, **15**(10): e0240555. https://doi.org/10.1371/journal.pone.0240555

Adhikari, J.N., Adhikari, R.B., Bhattarai, B.P., Thapa, T.B., & Ghimire, T.R. (2021). A small-scale coprological survey of the endoparasites in the Himalayan goral *Naemorhedus goral* (Hardwick, 1825) in Nepal. *Biodiversitas*, **22**(3): 1285–1290. https://doi.org/10.13057/biodiv/d2203xx

Adhikari, J.N., Bhattarai, B.P., & Thapa, T.B. (2018d). *Local people's perception on climate change, its indicators and adaptation strategies in the Chitwan-Annapurna Landscape, Nepal.* Paper presented at the International Biodiversity Congress (IBC 2018), Deharadun, India.

Manuscript submission

Adhikari, J.N., Bhattarai, B.P. Baral, S.,& Thapa, T.B. (2022). Predicting Habitat Suitability of Northern red muntjac (*Muntiacus vaginalis* (Boddaert, 1785)) in the Chitwan Annapurna Landscape, Nepal. *Heliyon*, In review

Land use/land cover changes in the central part of the Chitwan Annapurna Landscape, Nepal

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ABSTRACT

Background: Land use/land cover assessment and monitoring of the land cover dynamics are essential to know the ecological, physical and anthropogenic processes in the landscape. Previous studies have indicated changes in the landscape of mid-hills of Nepal in the past few decades. But there is a lack of study in the Chitwan Annapurna Landscape; hence, this study was carried out to fill in study gap that existed in the area.
Methods: This study evaluates land use/land cover dynamics between 2000 to 2020 in the central part of the Chitwan Annapurna Landscape, Nepal by using Landsat images. The Landsat images were classified into eight different classes using remote sensing and geographic information system (GIS). The accuracy assessment of classified images was evaluated by calculating actual accuracy, producer's accuracy, user's accuracy and kappa coefficient based on the ground-truthing points for 2020 and Google Earth and topographic maps for images of 2010 and 2000.
Results: The results of land use/land cover analysis of Landsat image 2020 showed that the study area was composed of grassland (1.73%), barren area (1.76%), riverine forest (1.93%), water body (1.97%), developed area (4.13%), Sal dominated forest (15.4%), cropland (28.13%) and mixed forest (44.95%). The results of land cover change between 2000 to 2020 indicated an overall increase in Sal dominated forest (7.6%), developed area (31.34%), mixed forest (37.46%) and decrease in riverine forest (11.29%), barren area (20.03%), croplands (29.87%) and grasslands (49.71%). The classification of the images of 2000, 2010 and 2020 had 81%, 81.6% and 84.77% overall accuracy, respectively. This finding can be used as a baseline information for the development of a proper management plan to protect wildlife habitats and forecasting possible future changes, if needed.

Subjects Conservation Biology, Ecology, Ecosystem Science, Natural Resource Management, Spatial and Geographic Information Science
Keywords Accuracy assessment, Habitat change detection, Image classification, Landsat image, Remote sensing

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Additional Information and Declarations can be found on page 18

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Distribution of invasive plants and their association with wild ungulates in Barandabhar Corridor Forest, Nepal

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Abstract

Adhikari, J.N., Bhattarai, B.P., Rokaya, M.B., Thapa, T.B., 2022. Distribution of invasive plants and their association with wild ungulates in Barandabhar Corridor Forest, Nepal. *Folia Oecologica*, 49 (2): 182–191.

Invasive and alien plant species (IAPS) are considered as major threats to native biodiversity because IAPS alter ecosystem structure and their functions. We assessed the association of four major IAPS (*Mikania micrantha*, *Chromolaena odorata*, *Lantana camara*, and *Parthenium hysterophorus*) and the abundance of wild ungulates in Barandabhar Corridor Forest (BCF), Chitwan, Nepal. We collected data on the presence of wild ungulates in IAPS invaded habitats through direct observation and sign surveys. Our study showed that the cover of *M. micrantha* was significantly high in Sal forest (Prominence value *PV* = 73.23) followed by riverine forest (*PV* = 40.5) and grassland (*PV* = 37.7) whereas *P. hysterophorus* was high in grasslands (*PV* = 22.9). Similarly, *C. odorata* was significantly high in Sal forest (*PV* =141.6%), and *L. camara* was high in mixed forest (*PV* = 22.6). It was found that there was a significant negative association of IAPS ($p = 0.002$) with wild ungulates. The abundances of deer and wild pigs were more in the buffer zone than in the non-buffer zone. The abundance of deer decreased with increasing cover of *C. odorata*, *M. micrantha*, and *P. hysterophorus* ($p = 0.002$). Similarly, the abundance of wild pigs decreased with increasing cover of *M. micrantha* and *L. camara*. IAPS were not uniformly distributed in different habitats and abundances of wild ungulates were less in IAPS invaded habitats. Hence, it is important to initiate management plans to control IAPS spread to avoid their negative impacts on wild ungulate population such as deer and wild pigs.

Keywords
biodiversity, conservation, herbivores, *Mikania micrantha*, Sal forest

Introduction

Globally, invasive and alien plant species (IAPS) are considered as major threats to biodiversity (Rai et al., 2012; Castro-la-Trellas and Garcia, 2017) as many negative impacts on ecological and socio-economic aspects are reported in various studies (Sala et al., 2000; Alee et al., 2013; Simberloff et al., 2013; Vilà and Hulme, 2017). IAPS spread rapidly to cover various habitats such as the grass lands, waste lands, forests, residential areas and the agricultural fields (Pimentel et al., 2005). Then, IAPS replace native plant species leading to the change in ecosystem processes (Gaertner, 2006; Gooden et al., 2009; Vilà et al., 2011). In addition to this, IAPS invasion alters biogeochemical cycles and decrease the productivity of the invaded areas (Mack et al., 2000; Hayes and Holzmueller, 2012; Lazzaro et al., 2017; Shrestha et al., 2019). IAPS also affect the abundance of different wild animals, including the wild ungulates (Vila and Weber, 2004; Doyle et al.,

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Determinants of abundance and habitat association of mammals in Barandabhar Corridor Forest, Chitwan, Nepal

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Abstract

Adhikari, J.N., Bhattarai, B.P., Thapa, T.B., 2021. Determinants of abundance and habitat association of mammals in Barandabhar Corridor Forest, Chitwan, Nepal. *Folia Oecologica*, 48 (1): 100–109.

Barandabhar Corridor Forest (BCF), the biologically functional corridor, is surrounded by the large human settlements that exploit the corridor where large mammals such as tigers, leopards and their prey such as ungulates, primates, and rhinoceros occur. This study aimed to evaluate major determinants that affect the distribution of large mammals in BCF, Chitwan, Nepal that connects the biologically significant Chitwan National Park with the Mahabharat range. The status and distribution of large mammals along the habitat and disturbance gradients were determined by using 29 line transects (mean length = 4.59 ± 0.38 km) that covered a linear distance of 133.13 km. The chital were the most abundant mammals (density per km^2 (D) = 8.9095 ± 1.4570 and encounter rate per km (ER) = 1.49) followed by rhesus monkey (D = 38.896 ± 16.013, ER = 0.28), wild boar (D = 14.814 ± 3.57, ER = 0.62), northern red muntjac (D = 9.6566 ± 2.9514, ER = 0.62) and sambar (D = 5.392 ± 2.319, ER = 0.38). Similarly, the sign encounter rate of tiger and leopard was 0.435 and 0.503 respectively. Habitat types, human disturbances, and coverage of invasive and alien plant species (IAPs) played a key role in the distribution of large mammals. The occurrence of mammals was low nearer to the settlements and roads and coverage of IAPs and more nearer to the water resources. However, degradation of foraging grounds such as grasslands by succession and invasion of alien plant species added more threats to the survival of large mammals. Therefore, such a situation can be improved through the scientific management of forests and grasslands.

Keywords
disturbance, habitat heterogeneity, leopard, tiger, ungulates

Introduction

The 'habitat heterogeneity hypothesis' (HHH), is one of the cornerstones of ecology, and often discussed in macroecology and biogeography. Maintaining habitat heterogeneity has been proposed as a mean of conserving species richness in habitats threatened by the human activities (Macarthur and Macarthur, 1961). In an ecosystem, when many habitats can support the large population of the species, the diversity of the species should be high because the heterogonous habitats can hold different habitat specialist animals (Tews et al., 2004). There is well-founded and widespread concern about the impact of habitat loss and fragmentation on biodiversity. Some area-sensitive species which are survived in the small habitat patches become extinct when habitat loss is going continuously (Haddad et al., 2015; Bartlett et al., 2016).

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Research Article

DETERMINANTS OF DISTRIBUTION OF LARGE MAMMALS IN SETI RIVER BASIN, TANAHUN DISTRICT OF WESTERN NEPAL

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ABSTRACT

Forest landscape in Seti River basin of Western Nepal is not conserved within the protected area network. Wildlife habitats in Seti River basin are more vulnerable due to high anthropogenic disturbance and habitat fragmentation. Present study mainly focused to evaluate the major factors that determine the distribution of large mammals in Seti River basin by walking through 34 line transects that covered a total of 59.89 km. The distribution of large mammals was greatly affected by habitat types, human disturbances, topography and altitude. Himalayan gorals were recorded in the steep grass covered areas where as Muntjacs were found in most of the habitats and slopes. There was low occurrence of all species nearer to the settlements and roads. Besides, water sources played a vital role in distribution of wildlife, as there were more occurrences of signs of large mammals nearby water resources. In the study area, community forests played a major role in the conservation of viable population of large mammals. However, habitat fragmentation due to scattered human settlements and degradation of foraging grounds such as grasslands by succession and invasion of alien plant species added more threats to the survival of large mammals. Therefore, such situation can be improved through the protection of connecting forest patches and scientific management of forests and grasslands.

Keywords: Himalayan Goral, Human disturbance, Muntjac, Sal forest, Topography.

INTRODUCTION

Nepal, a biodiversity rich Himalayan country is situated in the central part of the world's top 20 global biodiversity hotspots, the Himalayas (CI 2004) with six biomes and twelve out of 867 terrestrial eco–regions of the world (Dinerstein *et al.* 2007, Shrestha *et al.* 2010). Nepal has diverse geological and geographical structures and has thousands of rivers flowing from north to south forming gorges, river basins and valleys (Paudel *et al.* 2012). A diverse geographic structure has maximum relief, steep slope and rugged terrain (Hegan 1998). Unique geographic position and variation in the altitude and climate of Nepal supports diverse flora and fauna. The human settlements are scattered in the mid-hill of Nepal that fragments the natural forest habitats of wildlife.

Fragmentation and loss of habitat are recognized as the greatest existing threats to biodiversity (Fahrig 2003, Hilty *et al.* 2006). Cumulative researches indicate that habitat loss has consistent negative impact on biodiversity (Closset-Kopp *et al.* 2016, Shrestha 2004). Human–caused habitat fragmentation precipitates biodiversity decline because it destroys species, disrupts community interactions, and interrupts evolutionary processes (Ehrlich & Ehrlich 1981, Erb *et al.* 2012). Habitat quality in fragments may be a more important determinant of assemblages of mammals (Delciellos *et al.* 2015). Global extinction of species, driven by anthropogenic factors, is occurring at an unprecedented rate (Bloom *et al.* 2005, Bendix *et al.* 2017, Karanth & Kudalkar 2017). Among more than 83000 species evaluated, 29 % are categorized as threatened (IUCN 2019). Large terrestrial mammals are among the most threatened taxa in the world, with 25 % of species facing extinction and 50 % with declining populations (Ceballos 2007). Furthermore, mammals of South Asia such as Bengal tiger, snow leopard, greater one horned rhinoceros, Asiatic elephant are among the most endangered (Bhattarai & Kindlmann 2012, Karanth *et al.* 2010).

Twenty-five species of mammals in Nepal are globally threatened and 17 are near threatened (Amin *et al.* 2018, IUCN 2019). Similarly, 49 species were evaluated as nationally threatened (nine critically endangered species, 26 endangered species and 14 vulnerable species). Likewise, seven species were listed in near threatened and 83 species were listed in data deficient (Amin *et al.* 2018). Correspondingly, 73 mammals have been listed in the CITES Appendices (32 in Appendix I, 14 in Appendix II and 27 in Appendix III) (Jnawali *et al.* 2011, DNPWC 2018).

Conservation of biodiversity through protected areas (PAs) has been weaker on several aspects, because they are too small and isolated to maintain viable populations of many species (Naughton-Treves *et al.* 2005). Possibility study of linking habitats in human-dominated mid-hill landscape as in Tanahun district is highly applicable for habitat extension of wildlife in isolated protected areas (Cooke *et al.* 2018) such as Chitwan National Park. Hence, this study mainly focused to

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Research Article

HUMAN-WILD MAMMAL CONFLICT IN A HUMAN DOMINATED MIDHILL LANDSCAPE: A CASE STUDY FROM PANCHASE AREA IN CHITWAN ANNAPURNA LANDSCAPE, NEPAL

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ABSTRACT

Issues of human wildlife conflict (HWC) always challenges in conservation and management. Crop raiding, property damage, livestock depredation and human casualties are the most common forms of conflict. It was investigated the issues of human wild mammal conflict in and around the Panchase area in Chitwan Annapurna Landscape of Nepal from March 2017 to April 2018 using semi-structured questionnaires and focal group discussion. Wide spread human wildlife conflict was observed in Panchase area. Monkey, muntjac deer, porcupine and rabbit were the main crop raider that resulted in total economic loss of US$ 29.56 per household (HH). Overall economic loss by livestock depredation was estimated US$ 11254.54 (US$ 112.54/HH). Leopard contributed to the highest cases of livestock depredation. A total of five human attack cases were recorded including one fatal and four injuries. Himalayan black bear contributed to 80 % of the total attacks and 20 % by leopards. Present study focused on the issues and status of conflicts in the Panchase area, a representative of midhills and Chitwan Annapurana Landscape. This study suggests that future study related to mitigation and preventing methods should be conducted to minimize the issues of human wildlife conflicts.

Keywords: Human wildlife conflict, Panchase, Livestock depredation, Household, Leopard

INTRODUCTION

The history of human wildlife conflict (HWC) is as old as the existence of human beings on the earth. HWC is a common phenomenon from the past and has become a significant problem throughout the world (Redpath *et al.* 2015). Most common forms of conflicts with wildlife are crop raiding, property damage, livestock depredation and human casualties (Ogutu *et al*. 2014). Human casualties and livestock depredation are the most serious nature of conflict among all. The major governing factors of habitat loss, degradation and fragmentation through human activities are animal husbandry, agricultural expansion, exploitation of natural resources and developmental activities (Fernando *et al*. 2005). Most of the developed and developing countries are facing the issues of HWC (Ogutu *et al*. 2014). However, it is more in developing countries than developed countries as the rural population of developing countries depend upon the animal husbandry and crop for their livelihoods (Cromsigt *et al*. 2013). HWC results in negative impact on human or their resources and wildlife or their natural habitat and it carries great threats to the survival of many wildlife species (Madden & McQuinn 2014, Amaja *et al*. 2016). Crop and property damage, livestock depredation, and human injury and casualty are common effects of HWC resulting in huge economic losses that make people to migrate from wildlife-conflict areas to non-conflict areas. HWCs also bring numerous social, economic and ecological consequences (Messmer 2009). The number and type of damage caused by wildlife varies according to the species, the time of year, and the availability of natural prey and crop raiding species (Mwamidi *et al*. 2018).

In Nepal, HWC is a major problem in most of the protected areas and national forests or even in the community forest areas (Lamsal 2012). The frequency and intensity of HWC in Nepal mostly arise from crop damage, livestock depredation, human injuries and casualties caused by wildlife, illegal logging, livestock grazing, fodder collection, medicinal plant collections, poaching and poor relations between local people and protection units (Lamsal 2012, Lamichhane *et al*. 2018). The main wildlife species involve in the HWC in the lowland of central Himalaya (e.g., in the buffer zones and surrounding areas of the Chitwan National Park) are the large mammals such as Asian elephant (*Elephas maximus* Linnaeus, 1758), one-horned rhinoceros (*Rhinoceros unicornis* Linnaeus, 1758), wild boar (*Sus scrofa* Linnaeus, 1758) and Bengal tiger (*Panthera tigris* Linnaeus, 1758) (Dhungana *et al*. 2016, Lamichhane *et al*. 2018). Crop depredation by monkeys, muntjac deer, wild boar, Himalayan black bear, livestock depredation by common leopard and human injuries and casualties by leopard and Himalayan black bear is considered to be the most ubiquitous form of conflict in mid-hills of Nepal (Dhungana *et al*. 2016).

Most of the study about human wildlife conflicts was focused in and around the protected areas. The government and even the researcher give more priorities

RESEARCH ARTICLE

Ethno-medicinal uses of vertebrates in the Chitwan-Annapurna Landscape, central Nepal

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Abstract

Traditional knowledge on the use of animal products to maintain human health is important since time immemorial. Although a few studies reported food and medicinal values of different animals, a comprehensive ethno-medicinal study of vertebrates in Nepal is still lacking. Thus, present study is aimed at documenting the ethno-medicinal knowledge related to vertebrate fauna among different ethnic communities in the Chitwan-Annapurna Landscape, central Nepal. Data was collected by using semi-structured questionnaires and analyzed by using Use Value (UV), Informant Consensus Factor (ICF) and Fidelity level (FL). Results showed a total of 58 (53 wild and 5 domestic) species of vertebrate animals. They were used to treat 62 types human ailments. Four animals were also used for veterinary diseases and agriculture benefits. The most widely used species was *Felis chaus* (UV = 0.25) with 3 use-reports by 10 informants. Cardiovascular and dental problems had the highest ICF value (0.974) with cardiovascular problems having 351 use-reports for 10 animal species and dental problems having 77 use-reports for 3 animal species. The least ICF was found in ophthalmological problems (ICF = 0.833, use reports = 7 for 2 species). We concluded that the different animals were an important part of traditional medicine for the local people living in the Chitwan-Annapurna Landscape. However, the majority of animals and most likely to be threatened due to their uses. The present documented ethnozoological knowledge can be used in conservation and management of vertebrates so that they could be protected for future generations.

Introduction

Bio-resources, both flora and fauna, are integral part of the indigenous healing practices used by human beings since the prehistoric time [1–4]. The traditional knowledge on the use of bio-resources for medicine has a significant contribution in maintaining the human health [3, 5–8]. In traditional medicine, it is estimated that more than 60% of medicines is based on flora

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Short Communication: A small-scale coprological survey of the endoparasites in the Himalayan goral *Naemorhedus goral* (Hardwick, 1825) in Nepal

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Abstract. *Adhikari JN, Adhikari RB, Bhattarai BP, Thapa TB, Ghimire TR. 2021. Short Communication: A small-scale coprological survey of the endoparasites in the Himalayan goral* Naemorhedus goral *(Hardwick, 1825) in Nepal. Biodiversitas 22: 1285-1290.* This study was carried out to detect the various endoparasites in the fecal samples of the Himalayan goral *Naemorhedus goral* (Hardwicke, 1825) from a forest patch of Rumsi area, the Seti River basin, Tanahun district, Nepal. Importantly, 17 fecal samples (89.5%) were positive for different parasites. Their positive rates showed the following orders as Strongyle (73.7%), *Entamoeba* sp. (52.6%), *Strongyloides* sp. (52.6%), *Cryptosporidium* sp. (26.3%), *Cyclospora* sp. (26.3%), *Eimeria* sp. (10.5%), *Mullerius capillaris* (10.5%), and *Blastocystis* sp. (5.3%). These results showed the prevalence status of the endoparasites in the Himalayan goral. This study provides general knowledge about the parasitic community using a non-invasive method. This is the first work in Himalayan goral of Nepal, hence intensive study to the other parts of Nepal is recommended.

Keywords: Coccidia, gastrointestinal parasites, Himalayan goral, fecal pellets, strongyles

INTRODUCTION

The Himalayan goral *Naemorhedus goral* (Hardwicke, 1825) (Order: Artiodactyla; Family: Bovidae; Subfamily: Caprinae) is listed as Near Threatened on the International Union for Conservation of Nature (IUCN) Red List globally and nationally (Amin et al. 2018, IUCN 2019) and Appendix I in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) category (CITES 2020). *N. goral,* a medium-sized mammal, is endemic to the mountains of central East Asia including Nepal, Bhutan, China (south Tibet), Northern India including Sikkim, and Northern Pakistan with a normal distribution range from 900 to 4,000 m above sea level (asl) (IUCN 2019). In Nepal, Himalayan goral are widely distributed species on the forested slopes up to the timberline (Wegge and Oli 1997). The species inhabits steep mountainous areas and sometimes use evergreen forests near cliffs, but primarily stays within rugged rocky terrain. They feed on grass round in the ridges and steep rocky slopes, and hide in forest or rock crevices (Wegge and Oli 1997, Ashraf et al. 2016). In Nepal, goral occurs in nine National Parks: Khaptad, Rara, Langtang, Makalu-Barun, Bardia, Chitwan, Sagarmatha, Parsa and Shey-Phoksundo (Wegge and Oli 1997, DNPWC 2020), as well as within the Annapurna Conservation Area, Dhorpatan Hunting Reserve, Kanchenjunga Conservation Area, Gaurishankhar Conservation Area, Manaslu Conservation Area and Appi-Nampa Conservation Area (2020). Besides the national parks and conservation areas, they are also found in mountain terrains of midhill human-dominated landscape of Nepal (Adhikari et al. 2019) but there is very low exploration (Adhikari et al. 2019) and the status of Himalayan goral is even unknown.

In these regions, the mature individuals of this species are continuing to decline (IUCN 2019). Notably, in different areas, the declining factors or the threats to its survival are different, for example, hunting, overgrazing, poaching, habitat destruction, disturbance, and competition with livestock (IUCN 2019). Besides, different diseases like pneumonia, gastroenteritis, hepatitis, and parasitosis have been implicated in the deaths of *N. goral* in many areas in India (Rathore and Khera 1982). In Pakistan, overhunting, natural disasters, predators, parasites, and diseases have been indicated to be their populations' declining factors (Perveen et al. 2013). Interestingly, how microspecies like viruses, bacteria, fungi, and parasites lead to the endangerment of various macrofauna like humans and animals in the Hindu-Kush Himalayan regions has been extensively reviewed before (Ghimire et al. 2020). Among microspecies, parasites can negatively affect distribution, occupancy, body structure, pregnancy rate, offspring survival, and offspring size of wild ungulates in the mountain (Aleuy et al. 2020). We and other researchers of Nepal, already focused on the study of prevalence of gastrointestinal parasites in wild animals with the help of

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LOCAL PEOPLE'S PERCEPTION ON CLIMATE CHANGE, ITS INDICATORS AND ADAPTATION STRATEGIES IN THE CHITWAN-ANNAPURNA LANDSCAPE, NEPAL

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ABSTRACT

Climate change is regarded as one of the main obstacles of people's economy, agriculture and livelihood in under-developed countries like Nepal. These countries are more vulnerable than developed countries as the developed countries can develop problem focussed adaptive measures to cope with the climate change. Understanding people's perception and indicators of climate change are fundamental knowledge for developing various adaptation strategies.This study was based on the questionnaire survey of 204 people in the study area- Chitwan Annapurna Landscape. More than 92% of the respondents were perceived the problems of climate change such as low or unprecedented rainfall, the rate of dryness of the land, dryness of wetlands, change crop pattern and phenology.These indicators of climate change were significantly increased in the recent years. Local people have been facing impacts caused by invasive alien plant species in their farmlands and forests (87.7%) and that also replaced the pasture or grasslands (69.1%). Besides, local people have experienced the increased rate of tropical disease vectors (e.g., house flies and mosquitoes), pests on crops and livestock diseases over the last 15 years.The rain water harvesting mechanism adopted by local people is the major adaptation strategy during low rainfall and dryness of lands. Likewise, the local people use invasive alien plant species to make bio-briquettes, fodders, cattle beds, compose manures. However, the lack of sufficient knowledge and sources, people's livelihood is vulnerable under such worst situation due to climate change. Therefore, it is necessary to focus on capacity building of local people to adapt with changing climate.

INTRODUCTION

The recent researches have shown human facing the challenges for their socio-economic activities, health, livelihood, and food security due to climate change (Eriksson et al., 2009; Romieu et al., 2010; Manandhar et al., 2011; Gentle & Maraseni, 2012; Amjath-Babu et al., 2016). The climate changes seriously affect developed and undeveloped countries, poor and rich people (Ayanlade et al., 2017). Undeveloped countries are more vulnerable than developed countries as the developed countries can develop various adaptive measures to cope with the climate change (Adger, 2003). Rural people are likely to be more vulnerable to climate change, particularly because of compounding challenges of poverty, low infrastructural and technological development and high dependence on rain-fed agriculture (Eriksson et al., 2009; Chalise & Naranpanawa, 2016; Nagoda & Nightingale, 2017). More than 80% of agricultural production in Hilly region of Nepal is rain-fed (Joshi et al., 2017). The mountain and midhill regions of Nepal is greatly affected by the climate change than in Terai (Manandhar et al., 2011). The solution to cope with climate change for the marginal people of Nepal seems to develop adaptation strategies. The recent studies has been indicated that there is a large deficit of knowledge and information about the climate change and related adaptation strategies to mitigate risk of climate change (Chalise & Naranpanawa, 2016, Joshi et al., 2017). Present study highlights responses of people towards the indicators of climate change and status of public awareness in human dominated midhill landscape- Chitwan Annapurna Landscape.

MATERIALS AND METHODS

Study area

The study area encompasses landscape that connects the Chitwan National Park in lowland Terai with the Annapurna Conservation Area in the high mountain region. This region lies in the centre of the central Himalayas and represents globally outstanding biodiversity. It includes three WWF 200 global eco–regions (Terai–duar savanna and grasslands, Himalayan Sub-tropical broadleaf forests, alpine shrubs and meadows), and two Ramsar sites (Beeshazari lake, Chitwan and lake clusters in Pokhara valley) (Dinerstein et al., 2007; Ramsar, 2018). The area is key habitats for many species